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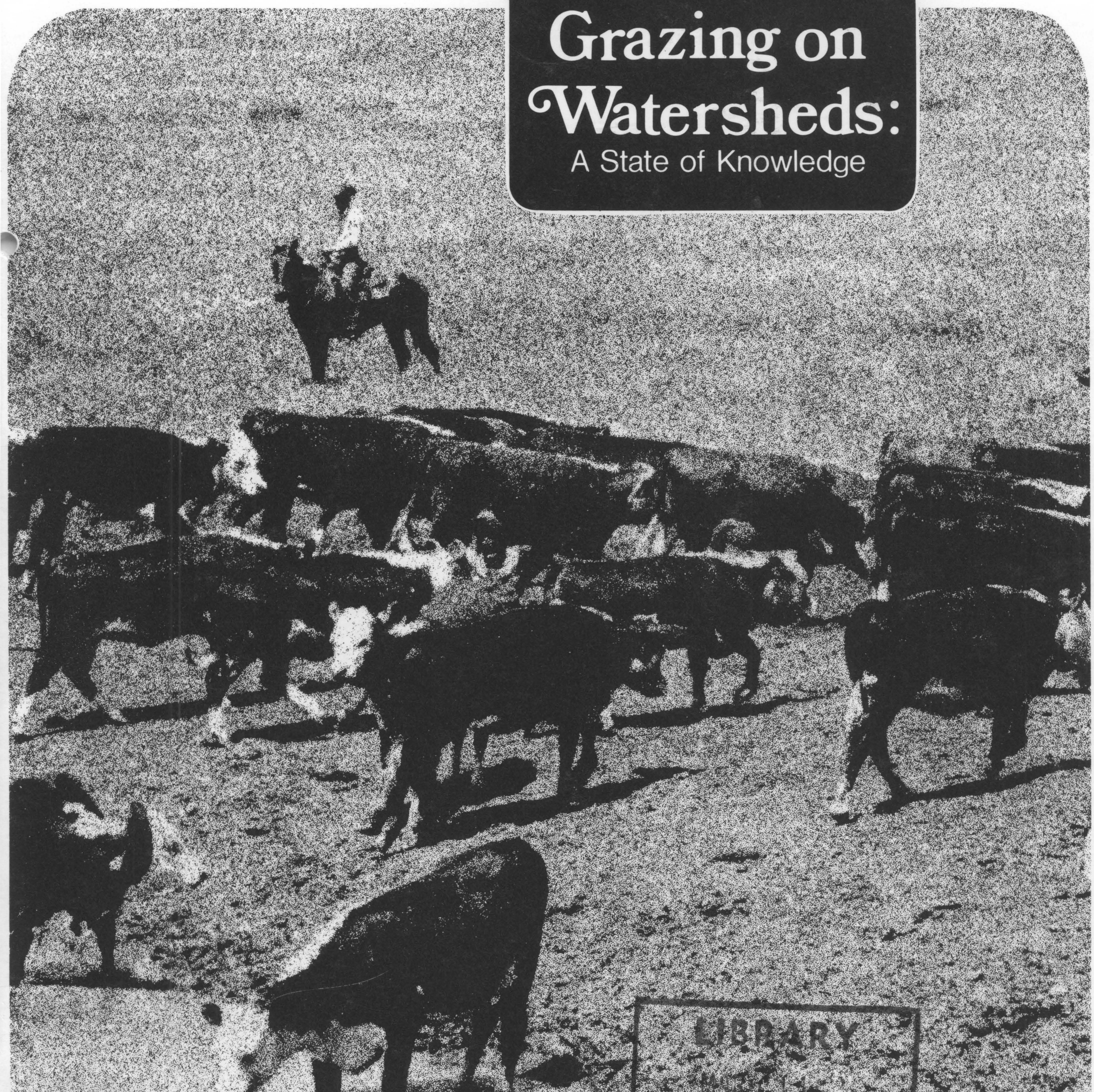
Impact of Grazing on Watersheds:
A State of Knowledge



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CONTENTS

Impacts of Grazing on Watersheds

A State of Knowledge

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SUMMARY

Livestock grazing affects watershed hydrologic properties by removing protective plant cover and by trampling. Reductions in the vegetation cover may: (a) increase the impact of raindrops, (b) decrease soil organic matter and soil aggregates, (c) increase surface crusts, (d) decrease infiltration rates, and/or increase erosion. Resultant impacts may include increased overland flow, reduced soil water content, and increased erosion. Bacteria and/or nutrients as potential pollutants from livestock grazing do not appear to be a problem on areas not included on riparian zones.

Existing studies show no hydrologic advantage to grazing a watershed lightly rather than moderately. Some studies show no difference in soil loss, infiltration capacity, or soil bulk density between light, moderate, or ungrazed pastures. Little information supports claims for specialized grazing systems. To evaluate hydrologic impacts adequately, additional studies, both intensive and extensive, should be conducted.

INTRODUCTION

Most previous watershed studies have evaluated the impact of livestock grazing on hydrologic variables after grazing treatments have been in effect for 10 to 20 years. These studies have been conducted by sundry methods, usually comparing responses of selected variables measured in areas exposed to various intensities and durations of grazing use to responses from a non-grazed area. The literature is filled with examples of the adverse impacts of heavy or abusive grazing on watersheds. However, few research projects have studied seasonal or long-term hydrologic impacts of grazing systems or proper grazing management.

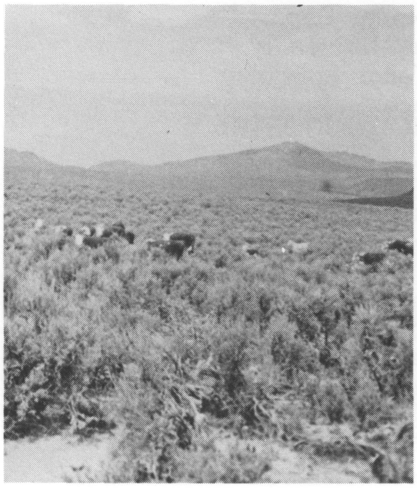
The impact of livestock grazing on watershed parameters has, in recent years, become a national resource management issue. Often the information used is based on emotion or misinterpreted data. The purpose of this paper is to review the literature by major vegetation types and assess the impacts of livestock grazing on watershed parameters.

This paper was originally presented at the National Academy of Sciences/National Research Council, Committee on Developing Strategies for Rangeland Management, Workshop on: Impacts of Grazing Intensity and Specialized Grazing Systems on Use and Value of Rangelands. El Paso, Texas, March 16-17, 1981.

VEGETATION TYPES

Sagebrush/Grass

Heavy grazing of sagebrush*/grass ranges caused total plant density to decrease and the proportion of the stand as sagebrush to increase (Pickford, 1932). These changes caused the grazing capacity of these areas to be reduced by 40 to 75 percent.



Native

At the Sheep Experiment Station near Dubois, Idaho, a pasture grazed heavily in late fall from 1924 to 1949 remained in good range condition with an open stand of sagebrush and a good understory of perennial grasses and forbs (Laycock, 1967; Pechanec and Stewart, 1949). An adjacent pasture, grazed heavily in both spring and fall, deteriorated to poor condition as grasses and forbs decreased markedly and sagebrush increased. From 1950 through 1963, heavy spring grazing only, heavy fall grazing only and protection from grazing were studied on ranges in good condition and in poor condition. Heavy spring grazing rapidly deteriorated the range originally in good condition. Heavy late-fall grazing and complete protection maintained the range in good condition. Likewise, heavy grazing in the fall only or protection improved botanical composition of the range which had been in poor condition. Laycock (1967) concluded that sagebrush/grass ranges can be improved by heavy grazing in the fall by sheep.

According to Fisser (1975) there was no significant soil movement associated with livestock grazing (no grazing intensity given) on sites in western Wyoming. Sites, however, treated with herbicides had significant soil movement, and sites treated with herbicides and grazed had even greater soil movement.

Johnson *et al.* (1980) used the Universal Soil Loss Equation to compute potential soil loss on grazed and ungrazed areas subjected to brush control and no brush control on the Reynolds Creek Watershed in southwest Idaho. There were no significant differences among four areas which were heavily grazed and one which was moderately grazed compared with ungrazed areas over the seven-year study period. Significantly less soil loss occurred from ungrazed sites than from two heavily, one severely and one moderately-grazed site. Part of the higher soil loss from grazed sites was attributed to variations in site productivity and slope.

On a portion of the Boise River watershed in Idaho, Packer (1953) studied the influence of artificial trampling on bluebunch wheatgrass and cheatgrass ranges that normally had sufficient protective cover (determined to be approximately 70 percent or more cover of plants, litter and rock) to control erosion. Following the artificial trampling, a modified type-F infiltrometer was used to evaluate runoff and erosion. Runoff and erosion remained at a safe level even under 60 percent trampling disturbance on sites with an initial ground cover of 90 to 95 percent. Trampling disturbance of 20 to 40 percent on sites with 70 to 85 percent ground cover initially resulted in overland flow and soil erosion beyond that considered a safe maximum.

Seeded

Millions of acres of depleted sagebrush range have been cleared and seeded to exotic grasses in the intermountain area since about 1940. Most studies have evaluated livestock responses and vegetation changes (Frischknecht and Harris, 1968;

*Scientific names are presented in Appendix I and follow Gould (1975).

Sharp, 1970; Robertson *et al.*, 1970) with little attention given to understanding the influence of livestock grazing on the hydrology of the watershed.

Gifford and Busby (1974) and Gifford (1981) reported on a 12-year (1968 to 1980) infiltrometer study of a plowed and seeded big sagebrush site in southern Idaho. A Rocky Mountain infiltrometer was used to evaluate grazed areas and areas protected from grazing since 1974. Cattle grazed the area each year from May through mid-September. A significant decline in infiltration rates occurred over a two- or three-year period following plowing in September of 1968 (Table 1) (Figs. 1-4). Livestock grazing, which was initiated in 1970, did not cause a further reduction in infiltration rates beyond that caused by the plowing. However, grazing appeared to eliminate seasonal trends in infiltration rates, and recovery of infiltration rates to pre-plowing rates seemed to be impossible as long as grazing was continued. The authors failed to report the intensity of livestock use, making interpretations of the results difficult. The results indicated that the area could have been severely overgrazed every year, since similar results have been reported on overgrazed pastures by Dortignac and Love (1961), Smith (1967), and Blackburn *et al.* (1980). Gifford and Busby (1974) concluded that grazing does not increase sediment production beyond that caused by plowing and seeding of this area.

Dadkhah and Gifford (1980) used a Rocky Mountain infiltrometer to evaluate the impact of selected soil surface characteristics on infiltration rates and sediment production from a loam topsoil. Plywood boxes 75 by 50 by 35 cm were uniformly filled with soil. Crested wheatgrass and intermediate wheatgrass at three levels of cover (30, 50 and 80 percent), four levels of rock cover (5, 10, 15 and 20 percent),

Table 1. INFILTRATION RATES (cm/h) AFTER 28 MINUTES FOR THE VARIOUS SAMPLING DATES AND TREATMENTS FOR A PLOWED AND SEEDED BIG SAGEBRUSH SITE IN SOUTHERN IDAHO (GIFFORD, 1981)

Date	Pretreatment	Grazed	Ungrazed
8-06-08 [1]	5.69[a]	—	—
6-04-75	—	3.01[b]	3.04[b]
8-20-75	—	3.62[b]	3.90[b]
5-16-76	—	2.38[b]	2.80[b]
9-15-76	—	2.68[b]	3.30[b]
8-09-78	—	2.86[b]	4.61[a]
9-15-80	—	3.55[b]	6.34[a]

[1] Means in the same row followed by the same letter are not significantly different at the 0.05 level of probability.

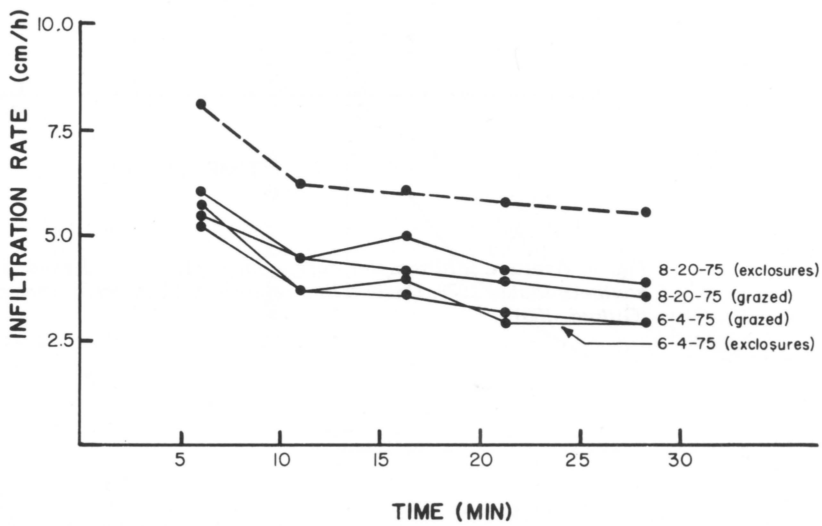


Fig. 1. Average infiltration curves for a plowed and seeded big sagebrush site in southern Idaho, 1975. Dashed line represents infiltration rates prior to plowing in 1968 (Gifford, 1981).

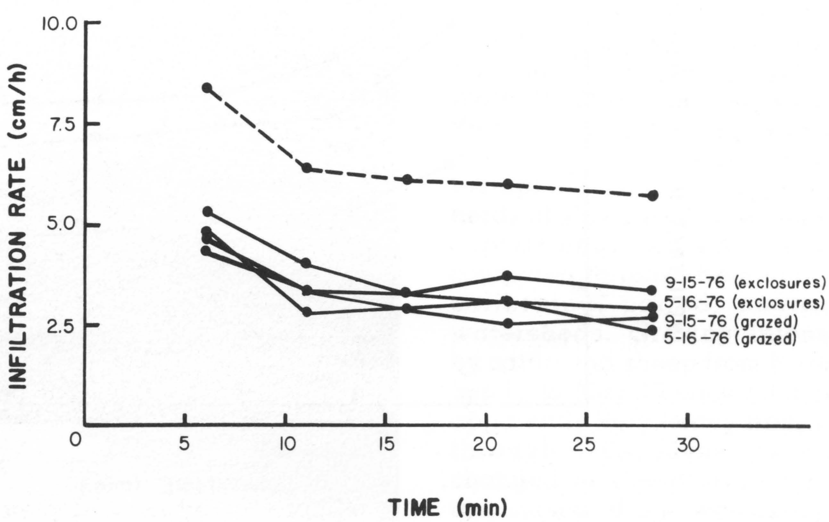


Fig. 2. Average infiltration curves for a plowed and seeded big sagebrush site in southern Idaho, 1976. Dashed line represents infiltration rates prior to plowing in 1968 (Gifford, 1981).

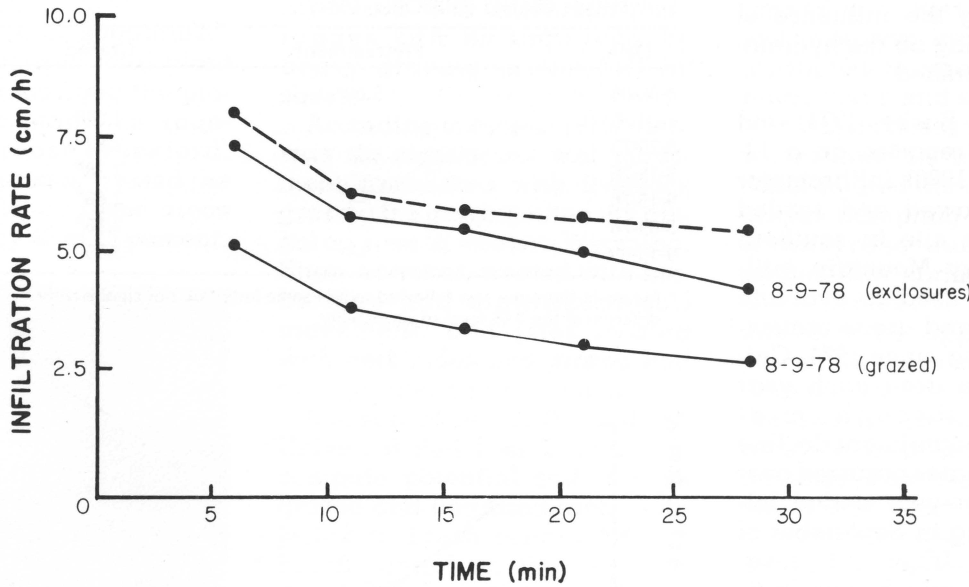


Fig. 3. Average infiltrometer curves for a plowed and seeded big sagebrush site in southern Idaho, 1978. Dashed line represents infiltration rates prior to plowing in 1968 (Gifford, 1981).

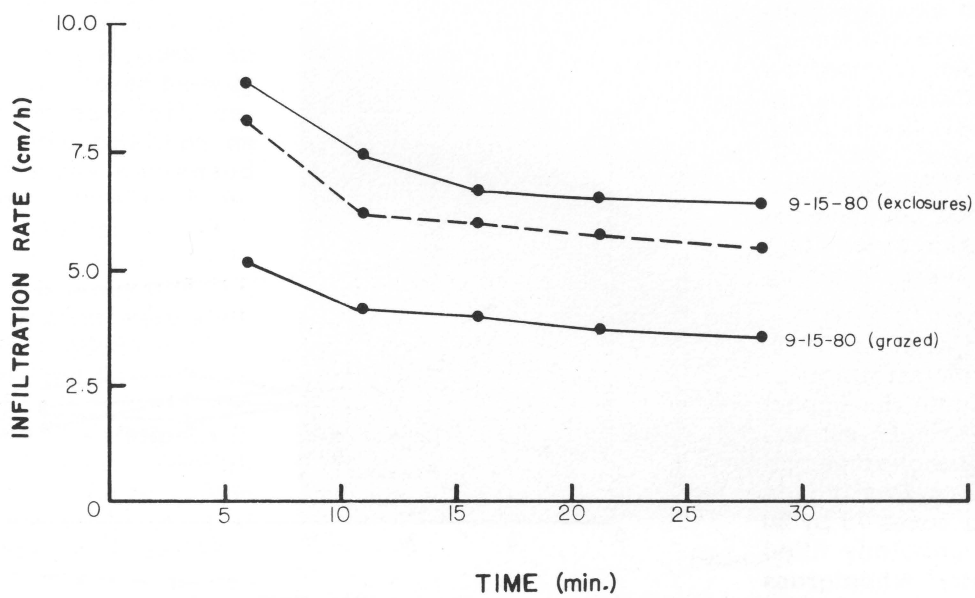


Fig. 4. Average infiltration curves for a plowed and seeded big sagebrush site in southern Idaho, 1980. Dashed line represents infiltration rates prior to plowing in 1968 (Gifford, 1981).

and six levels of simulated trampling (10 to 60 percent of the respective plot area by 10 percent increments) were studied. Infiltration rates decreased significantly with increased trampling percentages (Fig. 5) to 40 percent, after which infiltration rates were not affected. When trampling equalled or exceeded 40 percent, there were no significant differences between plots with 30 and 80 percent grass cover. As the soil was compacted, the vegetation-rock cover relationship deteriorated, and at about 20 percent cover the effects of trampling on infiltration rates disappeared completely. Regardless of trampling level, bare plots always had significantly higher sediment yield than plots with grass cover. Sediment production decreased exponentially as plant cover increased (Fig. 6). Regardless of trampling percentage, sediment yields were nearly uniform after grass cover reached approximately 50 percent. The authors concluded that watershed protection may be accomplished by maintaining 50 percent protective ground cover. This is in contrast to previous recommendations of 60 to 75 percent ground cover (Packer, 1953; Marston, 1952).

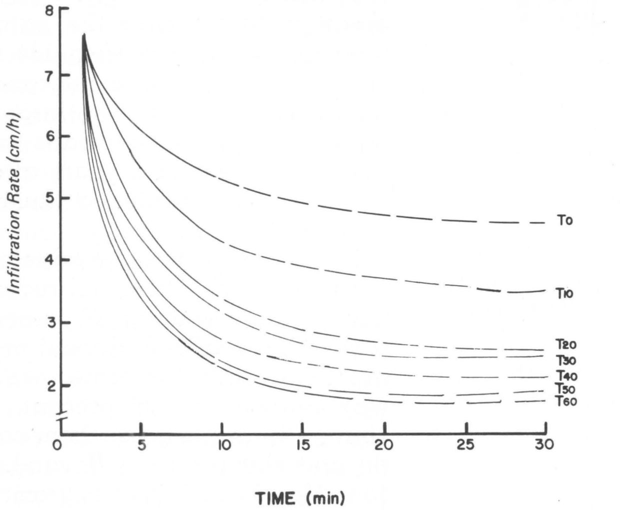


Fig. 5. Infiltration rate curves for different soil compaction treatments. Dotted portions of each curve represent time periods after 10 minutes when an interaction between rock cover and trampling existed. Data pooled over grass species, grass cover, and rock cover treatments on 75 x 50 x 35 cm plywood boxes filled with loam topsoil (Dadhkah and Gifford, 1980).

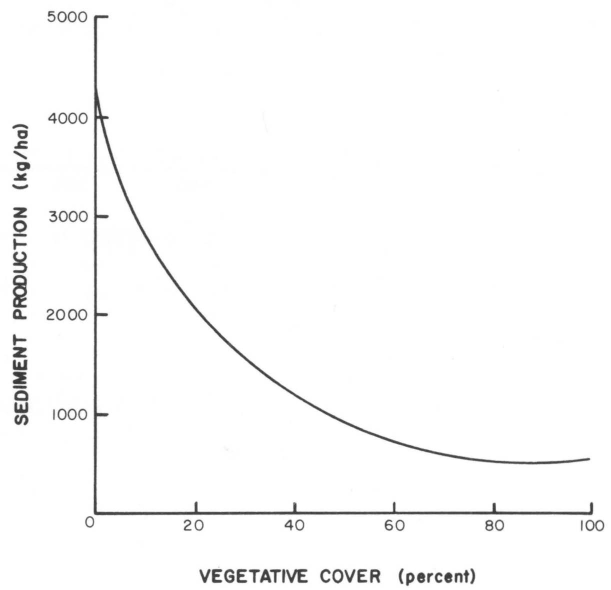


Fig. 6. Sediment production as a function of vegetation cover. All data pooled for 1980, 75 x 50 x 35 cm plywood boxes filled with loam topsoil (Dadkhah and Gifford, 1980).

Salt-desert Shrub

Salt-desert Shrub

The effects of grazing on the hydrology of salt-desert shrub rangeland has been studied for more than 20 years at Badger Wash in west central Colorado (Lusby, 1979). The effects of winter-spring grazing by mixed herds of sheep and cattle on four experimental watersheds was compared to those from four uncalibrated, paired, ungrazed watersheds. Grazing intensity by cattle and sheep from November 15 to May 15 each year was apparently very heavy from 1954 through 1965. Livestock were changed to sheep only in 1966, the season of use was changed to November 15 through February 15, and part of the watersheds were grazed every other

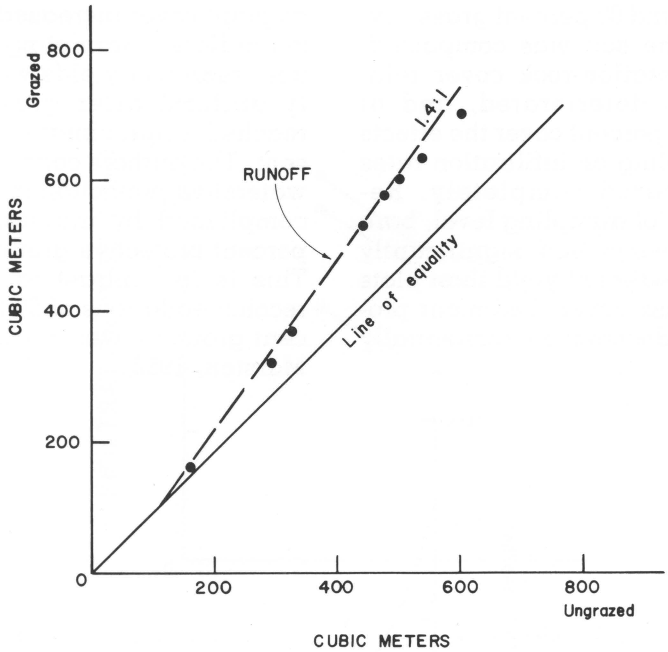


Fig. 7. Mass diagram of runoff from grazed and ungrazed watersheds (Badger Wash) in western Colorado. The data are for 13 years of measurement (Lusby, 1970) Branson et al., 1972).

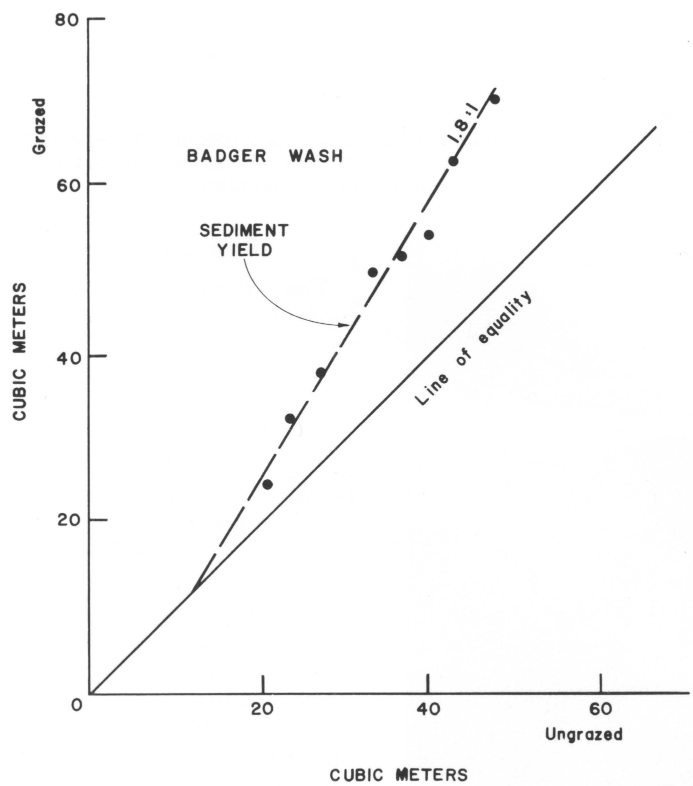


Fig. 8. Mass diagram of sediment yields from four grazed and four ungrazed watersheds (Badger Wash) in western Colorado. The data are for 13 years of measurement (Lusby, 1970; Branson et al., 1972).

year instead of each year. Runoff and sediment were measured in reservoirs at the lower end of each watershed. Runoff from grazed watersheds averaged from 131 to 140 percent of that from ungrazed watersheds from 1954 through 1966 (Fig. 7). Sediment yields during the same time period ranged from 134 to 196 percent of that from ungrazed watersheds (Fig. 8). The largest change in these relations occurred in the first 3 years after livestock were excluded (Lusby *et al.,* 1971).

Complete grazing exclusion resulted in an additional reduction in runoff of about 20 percent from 1966 to 1973. Sediment production during this same period was reduced by 28 percent. A change in grazing use from cattle and sheep during November 15 to May 15 each year to grazing of sheep only at approximately the same utilization rate during November 15 to February 15 each year was accompanied by a reduction in runoff and sediment yield of about 29 percent. The same change in livestock use, except that grazing was allowed every other year during the sheep grazing period, resulted in a reduction in runoff and sediment yield of about 20 percent (Lusby, 1979). This research studied watershed recovery from very heavy livestock grazing by complete protection and did not evaluate the impacts of proper grazing. No causative factors for changes in the runoff and sediment yield relations were given.

Studies on causative factors do not agree with the runoff data (Lusby, 1979) collected from the watersheds. Thompson (1968) used a Rocky Mountain infiltrometer to measure infiltration rates of the extremely heavily grazed and ungrazed watersheds at Badger Wash. Average infiltration rates were lower in 1963 than in 1953 or 1958 on both grazed and ungrazed plots (Fig. 9). Results indicated that infiltration was affected less by grazing than by seasonal changes in soil-surface characteristics. Soil bulk density improved without respect to grazing treatment, and there was no significant difference in sediment production between grazed and ungrazed sites.

Bare ground on the grazed watersheds increased by 12 percent over the 10-year study period 1953-1963. No change was observed in bare ground on the ungrazed watersheds (Turner, 1971). The failure of vegetation and mulch cover to increase appreciably after 10 years of livestock exclusion was attributed to low site potential and to drought. Branson and Owen (1970) found that runoff from 17 watersheds in the Badger Wash Basin was directly related to the percentage of bare soil within the watershed (Fig. 10).

Hutchings and Stewart (1953) reported that for the desert sheep range in Utah, the great fluctuations in plant growth attributable to yearly variations in precipitation tended to overshadow the effects of grazing. Herbage production of all species tended to increase under light, moderate and heavy grazing intensities. This suggests winter utilization of 75 percent of the forage does not impair continued forage productivity.

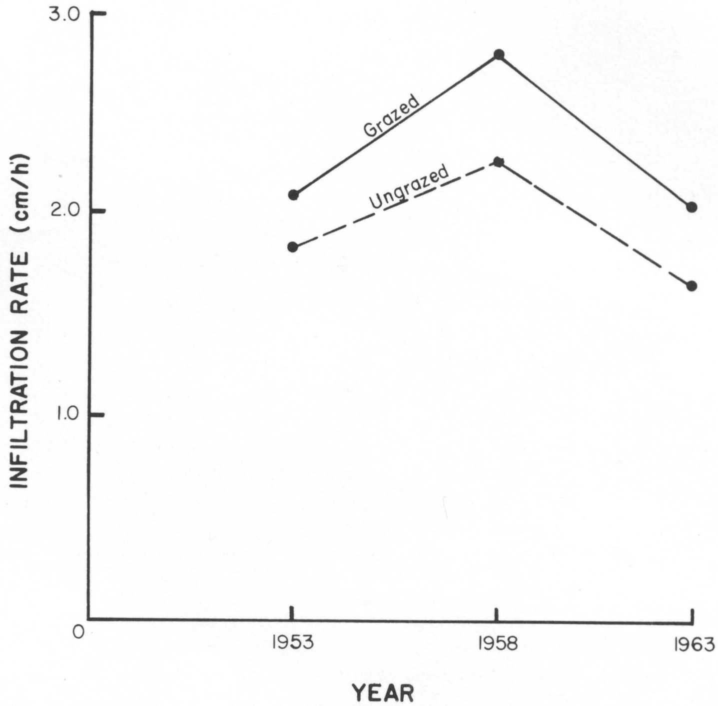


Fig. 9. Average infiltration rates and pre-runoff water absorption amounts for grazed and ungrazed plots, Badger Wash in western Colorado (Thompson, 1968).

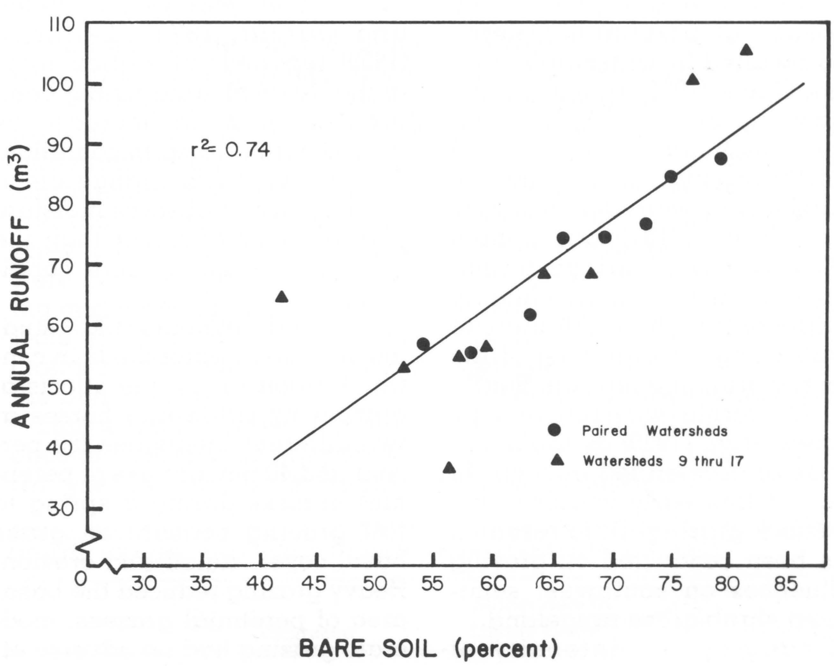


Fig. 10. Regression line for percent bare soil versus average annual runoff from 17 watersheds (Badger Wash) in western Colorado (Branson and Owen, 1970; Branson et al., 1972).

Southwest Semi-desert Shrub/Grass

Overgrazing of this vast rangeland during the early 1900s allowed brush to increase at the expense of perennial grasses and resulted in widespread erosion. Cable (1975) stated that by 1926 many areas of the chaparral type which had been covered with stirrup-high grass stands 50 years earlier were dense stands of brush. Rich (1911) and Dobbin (1933) attributed arroyo formation and increased flooding in southwestern New Mexico to overgrazing. Overgrazing of the Morena drainage basin in Southern California was reported by Barnes *et al.* (1939) as the major cause of accelerated erosion. In spite of this early concern over livestock grazing, little research has been conducted on grazing influences on southwest semi-desert shrub/grass rangeland.

Changing the intensity of grazing use of a 190 ha watershed on the Rio Puerco drainage in New Mexico from heavy continuous to moderate and with summers deferred resulted in a 71 percent decrease in sediment over a four year period (Aldon and Garcia, 1973). Leithead (1959) reported infiltration rates in the Davis Mountains-Big Bend area of Texas to decrease as ranges deteriorated in condition. He concluded that a range site in good condition absorbs moisture five to six times faster than the same range site in poor condition.

Rich and Reynolds (1963) studied chaparral watersheds in central Arizona to test the effects of grazing by cattle and horses at two different intensities (80 percent and 40 percent use of perennial grasses during a spring to fall grazing season) on grass basal cover, runoff and erosion. Heavy grazing reducéd the basal area of perennial grasses; moderate grazing had no adverse effects on basal cover. Forty percent utilization of perennial grasses in the chaparral of central Arizona had no measurable effect upon runoff or erosion.

Martin and Cable (1974) reported on a 10-year livestock grazing study designed to evaluate alternatives to moderate yearlong grazing on the Santa Rita Experimental Range in Arizona. The alternative grazing systems were (1) rest each year from November to April, and (2) rest each year May to October. Vegetation response on either six-month rest period proved superior to continuous yearlong grazing. Perennial grasses fared best on units grazed yearlong and poorest on those grazed only November to April.

Martin and Ward (1976) later compared several schedules of alternate-year grazing and rest, with continuous yearlong grazing and with winter rest every year over a seven-year period. They found no significant differences in perennial grass production among treatments.

California Grasslands

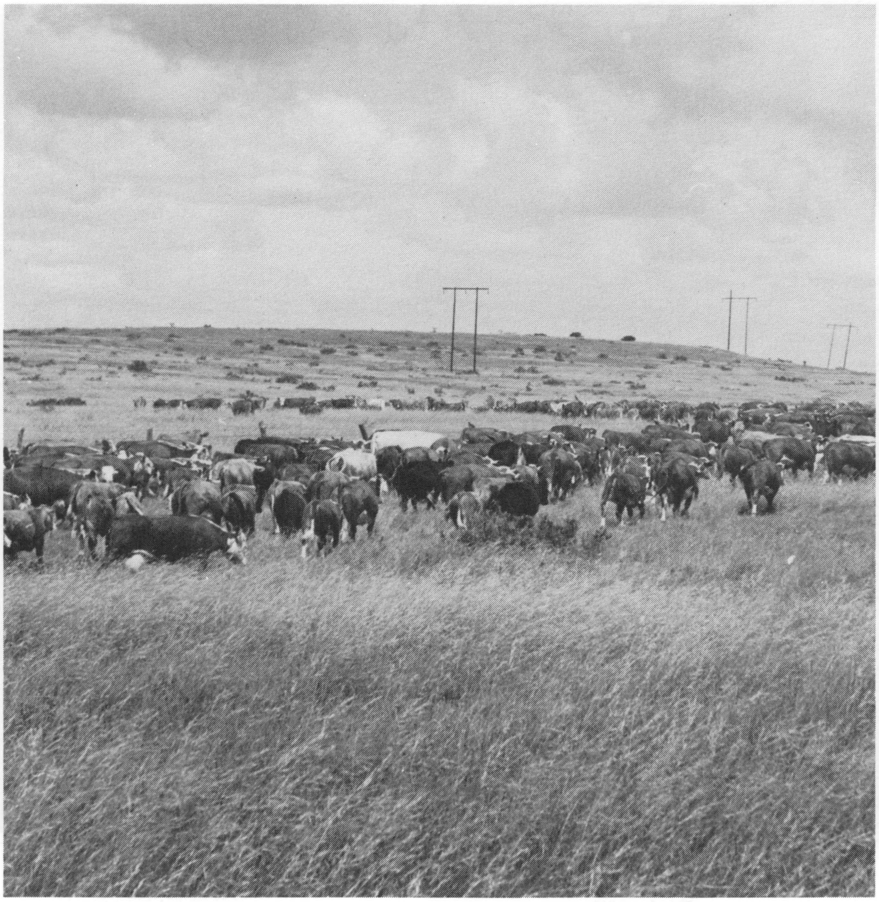
Overgrazing has altered the character of this rangeland as much as any other in the United States. Native perennial bunchgrasses were replaced in the late 1800s by annuals introduced at the Spanish missions. However, very little is known about the impacts of livestock grazing on watershed characteristics.

Talbot *et al.* (1942) reported that two seasons of grazing lightly to moderately or heavily by cattle produced no significant increase in surface runoff or erosion at the San Joaquin Experimental Range. Ratliff and Westfall (1971) found that the soil of an exclosure that had not been grazed for 34 years exhibited a lower surface bulk density than an adjacent grazed site (intensity not reported). The surface soil within the exclosure was more friable and granular in structure compared to the coarse platy structures of the grazed area. The differences in bulk density were attributed primarily to the cultivation of the soil and resultant mixing of mineral particles and organic matter by gophers. They concluded that gophers were more important than freezing and thawing, mechanical effects of plant roots or than microflora and fauna in reducing the bulk density.

Liacos (1962) studied the influence of livestock grazing on water yields and bulk density (Table 2). Heavy grazing for more than 35 years had resulted in a more dense and more shallow soil than that of ungrazed sites. Water yield was many times greater from grassland under heavy grazing than under moderate to light grazing or no grazing. He concluded that when heavy grazing is practiced for a long time, the soil-forming process is slowed down. Light to moderate or no grazing results in deeper soil with good physical properties and high soil water storage capacity.

Table 2. BULK DENSITY (g/cc) AND WATER YIELD (mm) OF UNGRAZED, MODERATELY TO LIGHTLY GRAZED, AND HEAVILY GRAZED GRASSLAND (LIACOS, 1962)

	Ungrazed	Moderately to Lightly Grazed	Heavily Grazed
Bulk Density			
0-10 cm	1.4	1.5	1.6
Water Yield	33	97	232



2. The results may be very site specific.
3. Differences between light and moderate grazing are usually very small. On some sites, there may be no significant difference between no grazing, light grazing, or moderate grazing. Gifford and Hawkins (1978) were unable to differentiate between the influence of light and moderate grazing and considered them to be identical in their infiltration model.
4. Heavy grazing almost always causes a reduction in infiltration rate.
5. Bulk densities appear to increase with grazing intensity and are higher on grazed pastures than on ungrazed pastures.

Knoll and Hopkins (1959) reported that percentage surface soil aggregate stability decreased under grazing. Aggregate stability was respectively 89, 64 and 56 percent of soils from pastures which were ungrazed, moderately grazed, and heavily grazed.

Johnson (1962) reported soil loss from fescue-dominated grassland in Alberta, grazed lightly, moderately, heavily and very heavily was, respectively, 68, 20, 20, and 1535 kg/ha/yr. Only extremely heavy grazing resulted in serious soil loss. Infiltration rates in the mixed grass prairie of the northern and central plains have been closely related to range condition (Fig. 11) (Rauzi *et al.*, 1968). Prolonged continuous heavy grazing of these rangelands results in radical changes in plant cover. The more productive tall grasses and midgrasses are selectively utilized allowing relative proportions of the short grasses to increase in the stands. This results in more bare ground, runoff and erosion. The surface (12 cm) soil structure is altered from a desirable crumbly or granular to an undesirable platy or massive structure.

Northern Great Plains

At the Cottonwood Range Field Station, South Dakota, Hanson *et al.* (1978) studied the impact of light, moderate and heavy continuous grazing intensity on runoff from four 2-acre mixed-grass prairie watersheds from 1963 through 1967. The average seasonal runoff was respectively 2.0, 1.4 and 1.1 cm for the heavily, moderately and lightly grazed watersheds. They concluded that heavily-grazed watersheds produced runoff from short-duration, high-intensity storms as well as from storms of long duration, whereas the lightly grazed watersheds produced runoff from long-duration storms that followed periods of antecedent precipitation. If long-duration storms follow a wet period, runoff from the lightly grazed watershed may be as high as from the heavily grazed watershed.

Similar results are reported by Sharp *et al.* (1964) from the Cottonwood Range Field Station where runoff was measured from long-term grazing studies. The average runoff for the heavily, moderately and lightly grazed watersheds was respectively 4.4, 2.6, and 3.3 cm. Runoff from the heavily grazed watersheds was approximately 1.5 times greater than that from the moderately or lightly-grazed watersheds.

A number of studies in the northern Great Plains have dealt with the impact of livestock grazing on infiltration rates and/or bulk density (Tables 3 and 4). Several conclusions can be drawn from these studies:

1. The results are often confounded by range improvement activities, past grazing, and/ or climatic fluctuations.

Table 3. SUMMARY OF STUDIES OF THE INFLUENCE OF LIVESTOCK GRAZING ON INFILTRATION ON THE NORTHERN GREAT PLAINS

Study Site and Reference	*Equipment*	*Infiltration Capacity (cm/h) by Grazing Intensity*				*Remarks*
		Ungrazed	*Light*	*Moderate*	*Heavy*	
Fort Peck, Montana Nuttail saltbush and crested wheatgrass (Branson et al., 1962)	*USGS tube-type sprinkling infiltrometer*	*0.65* *3.02*	*0.45* *2.29*	— —	*0.92* *1.10*	*Unfurrowed* *Furrowed, seeded averaged over soil type and years*
Southwest Alberta Fescue grassland (Johnson, 1962)	Mobile infiltrometer	—	5.69	4.06	4.14 3.53	 Very heavy grazing
Hays, Kansas Blue grama and Buffalograss (Knoll and Hopkins, 1959)	Single-ring infiltrometer	6.55	—	5.28	4.01	Exclosure had not been grazed for 13 years
Mandan, North Dakota Mixed Prairie (Rauzi, 1963)	Mobile infiltrometer	10.84	—	6.10	3.76	Exclosure had not been grazed for 21 years
Cottonwood, South Dakota Mixed Prairie (Rauzi and Hanson, 1966)	Mobile infiltrometer	—	7.49	4.24	2.67	
Nunn, Colorado Blue grama and Buffalograss (Rauzi and Smith, 1973)	Mobile infiltrometer	— — —	1.40 4.32 5.00	1.14 5.33 5.13	1.27 2.03 2.03	Shingle sandy loam Nunn loam Ascalon sandy loam
Miles City, Montana Mixed Prairie (Reed and Peterson, 1961)	Single-ring infiltrometer	18.58 —	11.04 12.29	10.96 —	7.19 5.69	Blue grama upland Western wheatgrass bench
			17.12	—	6.74	Western wheatgrass bench
Western North Dakota Mixed Prairie (Whitman et al., 1964)	Single-ring infiltrometer	15.24	—	—	7.87	

Table 4. SUMMARY OF STUDIES OF THE INFLUENCE OF LIVESTOCK GRAZING ON SOIL BULK DENSITY ON THE NORTHERN GREAT PLAINS

Study Site and Reference	Bulk Density (g/cc) by Grazing Intensity				Remarks
	Ungrazed	Light	Moderate	Heavy	
Hays, Kansas Blue grama and Buffalograss (Knoll and Hopkins, 1959)	1.08	—	1.7	1.27	0-7.5 cm depth. Exclosure had not been grazed for 13 years
Southwestern Saskatchewan Mixed Prairie (Lodge, 1954)	1.11	1.20	1.21	1.18	0-10 cm depth
Cottonwood, South Dakota Mixed Prairie (Rauzi and Hanson, 1966)	—	1.17	1.24	1.29	0-10 cm depth
Miles City, Montana Mixed Prairie (Reed and Peterson, 1961)	— — —	1.37 1.18 1.09	1.37 — —	1.43 1.28 1.14	Blue grama upland Western wheatgrass bench Western wheatgrass bottom
Western North Dakota Mixed Prairie (Whitman et al., 1964)	1.16	—	—	1.23	0-7.5 cm depth

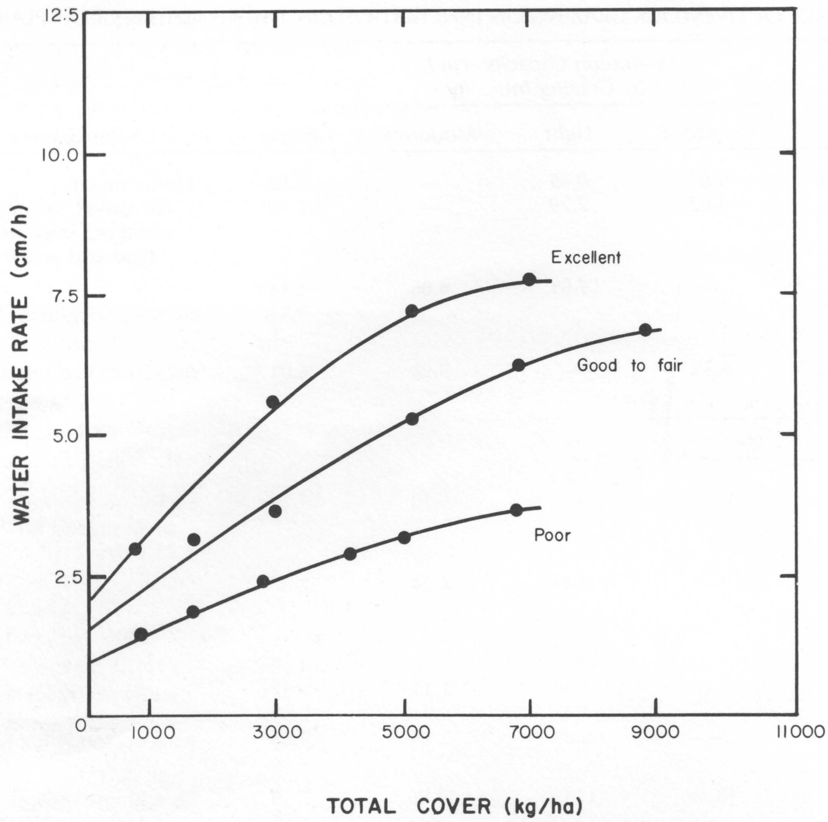


Fig. 11. Water intake rate compared to total vegetal cover and structure for the silty range-soil-group of the northern and central plains (Rauzi et al., 1968).

Southern Great Plains

Southern Great Plains

Water and ground cover relations for a Pratt loamy fine sand on the Southern Plains Experimental Range near Woodward, Oklahoma, were investigated after four levels of continuous cattle grazing had been imposed for 20 years (Rhoades *et al.*, 1964). Infiltration rates were determined with a sprinkling infiltrometer. Infiltration rates were highest on the ungrazed pastures, lowest on the heavily grazed pastures, and intermediate on the lightly and moderately grazed pastures (Table 5). Grazing had compacted the soil; however, bulk density did not differ among the different grazing intensities. Standing crop and mulch were greater on ungrazed areas than on grazed areas. The three different grazing intensities had little influence on standing crop; however, mulch production was reduced under heavy grazing. Short, sod-forming grasses dominated heavily-grazed stands and tall bunchgrasses dominated non-grazed stands. Percent bare ground on moderately or heavily grazed pastures was about twice that of the ungrazed or lightly grazed pastures. Soil loss w[illegible] negligible even on the heavily grazed sites.

Sediment discharge in runoff from grazed watersheds at the South Central Agricultural Research Station near Chickasha, Oklahoma was reported by Menzel *et al.* (1978). The study was conducted over a 10-year period (1966-76) on a watershed that was managed under a moderately-stocked rotation grazing system and a watershed that was continuously overgrazed. Runoff averaged 4.3 cm and 9.8 cm, and sediment discharge averaged 0.3 and 8.1 metric tons/ha respectively, for the rotationally and continuously-overgrazed watersheds (Fig. 12).

A rainfall simulator (Blackburn *et al.*, 1974) was used to study the impact of livestock grazing on watershed characteristics at the Texas Experimental Ranch in the

Table 5. AVERAGE INFILTRATION CAPACITY, VEGETATION, MULCH, BARE GROUND AND BULK DENSITY ON SPRINKLED INFILTRATION PLOTS IN RELATION TO PASTURE STOCKING RATES ON THE SOUTHERN PLAINS EXPERIMENTAL RANGE, OKLAHOMA (RHOADES *et al.*, 1964)

	Stocking Rate			
	Ungrazed	Light	Moderate	Heavy
Infiltration capacity (cm/h)	27[1]	11	9	6
Bulk density (g/cc)				
0-5 cm	1.44 b[2]	1.52 a	1.52 a	1.55 a
5-10 cm	1.47 b	1.68 a	1.68 a	1.73 a
Standing crop (kg/ha)	4,484[1]	1,625	1,771	1,894
Mulch (kg/ha)	9,528[1]	4,988	4,408	2,746
Bare ground (%)	8.2 b	11.9 b	20.2 a	24.2 a

[1]No significant differences given.
[2]Means in the same row followed by the same letter are not significantly different at the 0.05 level of probability.

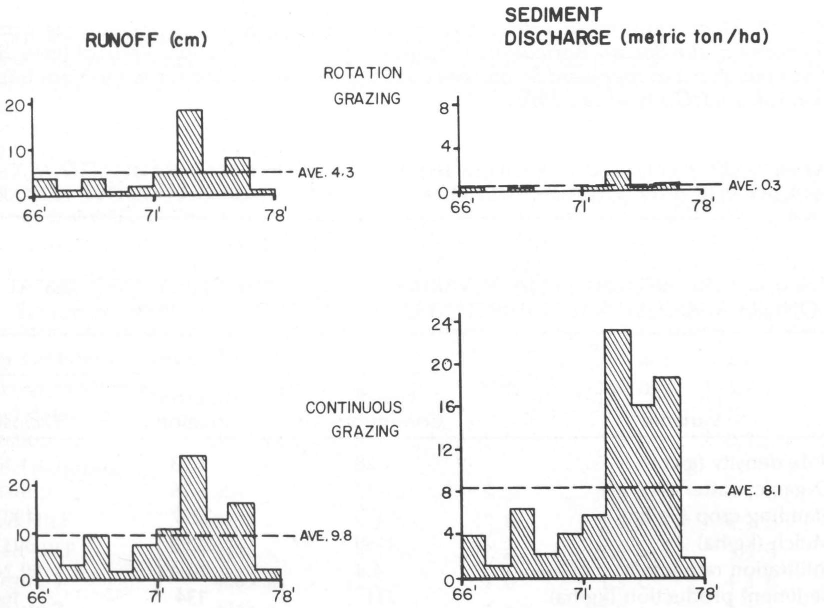


Fig. 12. Annual runoff and sediment discharges from single use watersheds (5-18 ha) near Chickasha, Oklahoma, July 1966-June 1976 (Menzel et al., 1978).

Rolling Plains and at the Sonora Agricultural Research station in the Edwards Plateau. The vegetation of these areas was characterized by short and midgrasses with varying densities of woody plants. Dominant herbaceous plants on the Throckmorton site included buffalograss, Texas wintergrass, sideoats grama, threeawns, common curly mesquite, and Japanese brome; honey mesquite and lotebush were the most commonly occurring shrubs. The dominant herbaceous plants on the Sonora study site included common curlymesquite, threeawns, sideoats grama, cane bluestem, red grama, and Texas wintergrass. Important woody plants were live oak, honey mesquite, and ashe juniper.

Pastures studied at the Texas Experimental Ranch during the summer of 1977 represented: (a) a heavily-stocked, continously-grazed pasture (4.7 ha/AU), (b) a moderately-stocked, continuously-grazed pasture (6.5 ha/AU), (c) two pastures of a Merrill 4-pasture, 3-herd deferred rotation grazing system (5.9 ha/AU), a pasture of a high-intensity, low-frequency (HILF) grazing system (119 days rest, 17 days grazed) (6.3 ha/AU), and (d) exclosures protected from grazing since 1960. Within each grazing treatment, midgrass and shortgrass-dominated interspace areas and midgrass-dominated honey mesquite canopy areas were evaluated.

Pastures evaluated in 1976 at the Sonora Research Station represented: (a) a heavily stocked, continuously grazed pasture (4.6-5.4 ha/AU), (b) one pasture of a Merrill 4-pasture, 3-herd deferred rotation grazing system (5.2 ha/AU), and (c) a livestock enclosure that had been ungrazed for 28 years. All pastures were heavily stocked, continuously grazed prior to 1948.

Terminal infiltration rates for the pasture in a 4-pasture deferred-rotation grazing system at Sonora and a 27-year exclosure were similar (Fig. 13) (McGinty *et al.*, 1978; Wood *et al.*, 1978). The heavily, continuously-grazed pasture exhibited less than one-half the infiltration rate of the deferred-rotation pasture and exclosure. Soil loss was greater from the continuously-grazed pasture (211 kg/ha) than the deferred-rotation pasture and exclosure (134 to 160 kg/ha, respectively).

Surface soil bulk density from the pasture grazed heavily and continuously was similar to densities from pastures grazed on a deferred-rotation basis, but higher than density of soils from the exclosure (Table 6). Percent organic matter was relatively high on all sites, although the two grazed pastures had less organic matter than the exclosure. Standing crop and mulch were reduced aprpoximately 50 percent by heavy continuous grazing as compared to the deferred-rotation pasture or exclosure.

Wood and Blackburn (1981a) found that the infiltration rates in the midgrass interspaces of the deferred-rotation pastures at the Texas Experimental Ranch approached rates measured in two exclosures (Fig. 14), and exceeded rates in the heavily stocked, continuously grazed and ungrazed HILF pastures. Infiltration rates in the HILF pastures were similar to those of the heavily- and moderately-stocked continuously-grazed pastures.

Midgrass interspace sediment production from the heavily-stocked, continuously-grazed pastures exceeded that of the deferred-rotation treatments and exclosures (Table 7). Likewise, sediment production for the grazed HILF pasture was greater than from the rested deferred-rotation pastures and exclosures (Wood and Blackburn, 1981b).

Grass standing crop and mulch were greatest on the exclosures, lowest on the heavily-stocked continuously-grazed pastures, and intermediate on the moderately-stocked, continuously-grazed, deferred-rotation and HILF pastures (Table 7). Organic matter content of the soil in the rested deferred-rotation

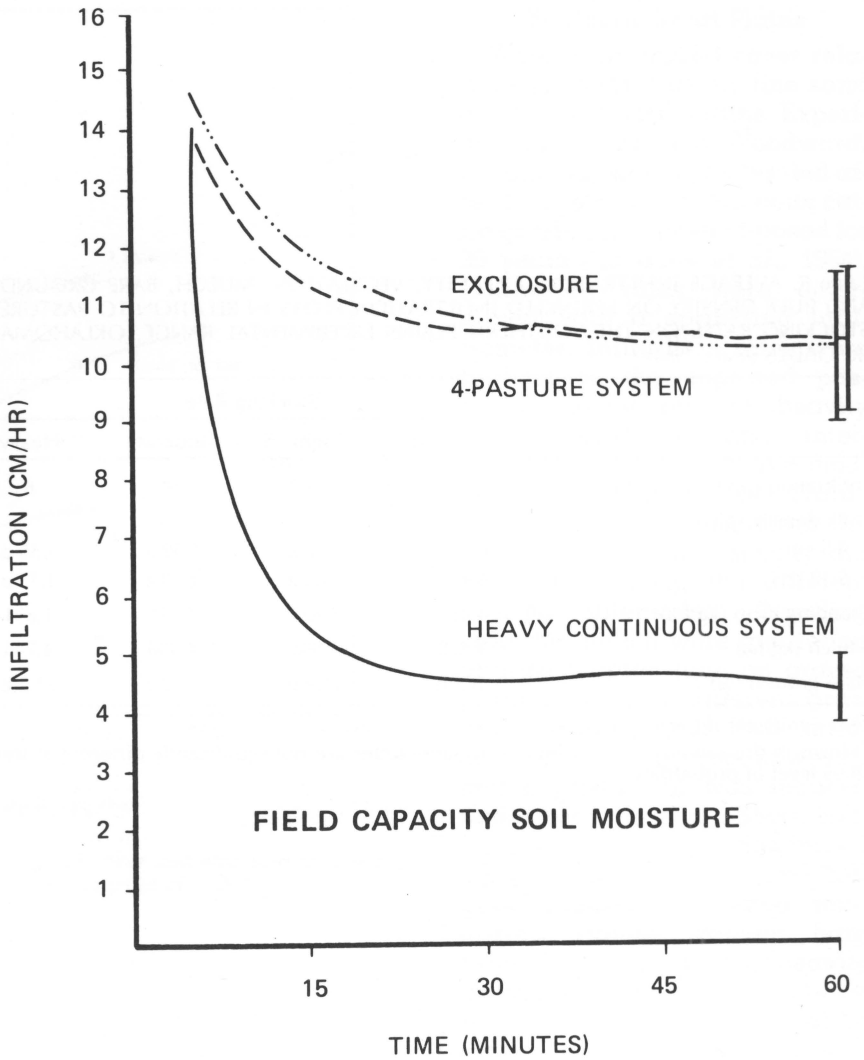


Fig. 13. Mean infiltration rates of field capacity soil moisture for various grazing practices at the Sonora Agricultural Experiment Research Station. Vertical lines at the end of each curve represent 95 percent confidence intervals for mean terminal infiltration rates (McGinty et al., 1978).

Table 6. SOIL AND VEGETATION VARIABLES FOR THREE STUDY PASTURES AT THE SONORA AGRICULTURAL RESEARCH STATION (McGINTY *et al.*, 1978)

	Pasture		
Variable	Heavy Continuous	Deferred Rotation	Exclosure
Bulk density (g/cc)	1.28	1.23	1.16
Organic matter (%)	5.32	5.26	5.76
Standing crop (kg/ha)	1270	2257	1907
Mulch (kg/ha)	1188	2758	3031
Infiltration rate (cm/h)	4.4	10.4	10.24
Sediment production (kg/ha)	211	134	160

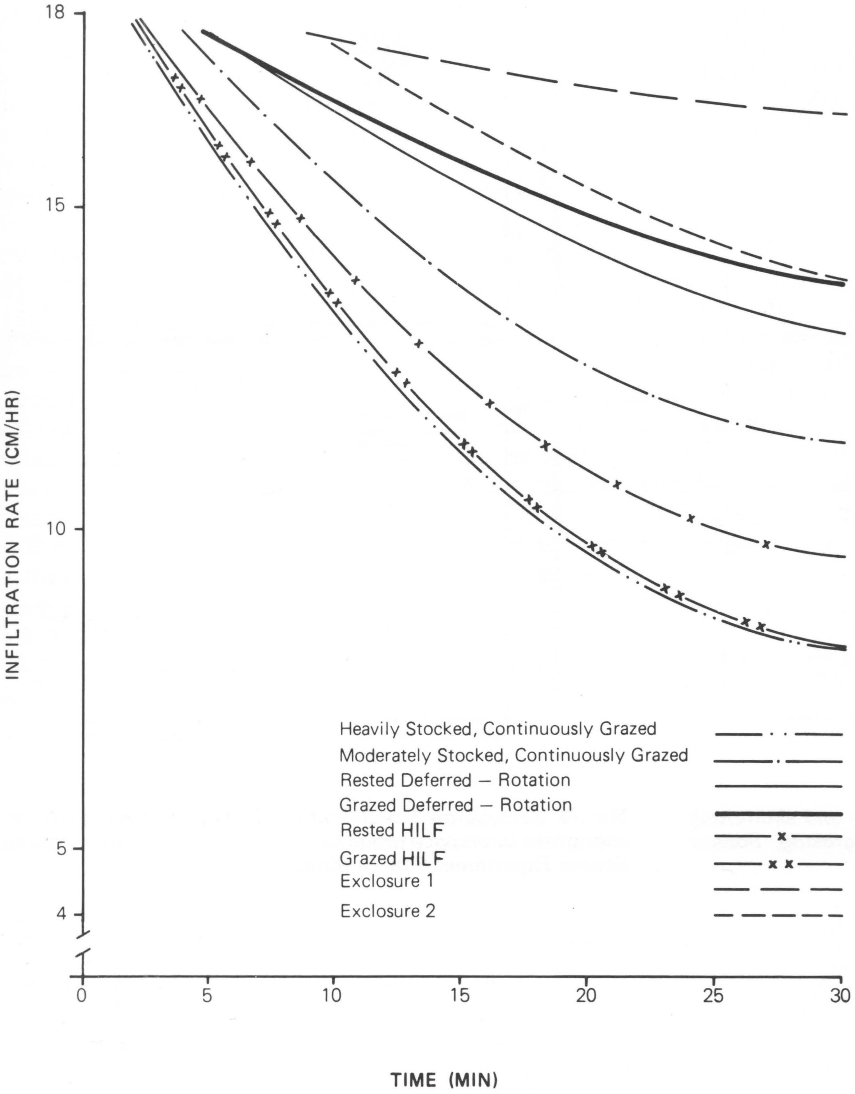


Fig. 14. Mean infiltration rates of the midgrass community for various grazing practices at the Texas Experimental Ranch. Terminal infiltration means followed by the same letter are not significantly different at the 95 percent level (Wood and Blackburn, 1981a).

pasture was significantly higher than that from the other grazing treatments. The heavily-stocked, continuously-grazed pastures and exclosure 2 were about 1 percent lower than all other treatments. Soil water stable aggregates were lowest in the heavily-stocked, continuously-grazed and grazed HILF pastures and exclosure 2, and highest in the rested HILF, deferred-rotation pastures and exclosure 1. The lowest bulk density occurred in exclosure 1 (1.3 g/cc) with all other treatments exhibiting relatively high bulk densities (1.6 to 1.9 g/cc). Percentage bare ground was low (1 to 6 percent) in the exclosures, deferred-rotation, and moderate continuously-grazed pasture when compared to the relatively high values (25 and 17 percent, respectively) in the heavy continuously-grazed and HILF pastures.

A second study at the Sonora Research Station to evaluate the influence of livestock grazing on watershed parameters included pastures grazed as follows: (a) moderate continuous (8.2 ha/AU), (b) very heavy (extreme) continuous (2.0 ha/AU), and (c) high intensity, low frequency (HILF grazing system) (119 days rest, 17 days graze) (8.2 ha/AU). The three grazing treatments were employed on a range site that had a history of moderate to light grazing by cattle, sheep and

Table 7. WATERSHED PARAMETER MEANS FOR THE MIDGRASS INTERSPACE AREAS IN EACH GRAZING TREATMENT. TEXAS EXPERIMENTAL RANCH (WOOD AND BLACKBURN, 1981a AND 1981b; WOOD, 1979; BLACKBURN *et al.*, 1980)[1]

Grazing Treatment	Grass Standing Crop (kg/ha)	Mulch (ton/ha)	Bare Ground (%)	Bulk Density (g/cc)	Organic Matter (%)	Aggregate Stability (%)	Infiltration rate after 30 min (cm/h)	Sediment Production (kg/ha)
Heavy continuous	1508 d[1]	1.2 d	25 a	1.8 a	2.6 c	35 d	8.1 c	115 a
Moderate continuous	3333 abc	4.5 bc	6 b	1.6 b	3.7 b	48 bc	11.4 bc	28 abc
Rested deferred-rotation	3865 ab	5.1 bc	1 b	1.6 b	5.5 a	57 ab	13.1 ab	10 c
Grazed deferred-rotation	2894 c	6.1 b	5 b	1.8 a	4.1 b	56 ab	13.9 ab	14 bc
Rested HILF	2437 c	3.2 cd	17 b	1.9 a	4.3 b	60 a	9.6 bc	28 abc
Grazed HILF	2414 c	4.5 bc	17 a	1.9 a	3.5 b	45 c	8.2 c	39 ab
Exclosure 1	4569 a	12.2 a	1 b	1.3 c	4.3 b	62 a	16.5 a	4 c
Exclosure 2	4243 a	11.5 a	4 b	1.8 a	2.3 c	39 cd	13.9 ab	17 bc
All treatments	2988	6.1	9	1.7	3.8	50	11.6	32

[1]Means followed by the same letter within each column are not significantly different at the .05 level of probability.

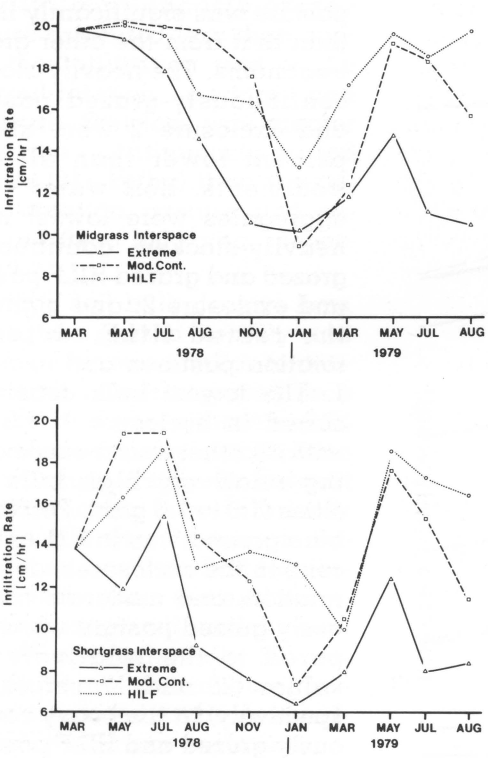


Fig. 15. Terminal infiltration rates on midgrass and shortgrass interspace areas as influenced by livestock grazing, Sonora Experiment Station (Knight, 1980).

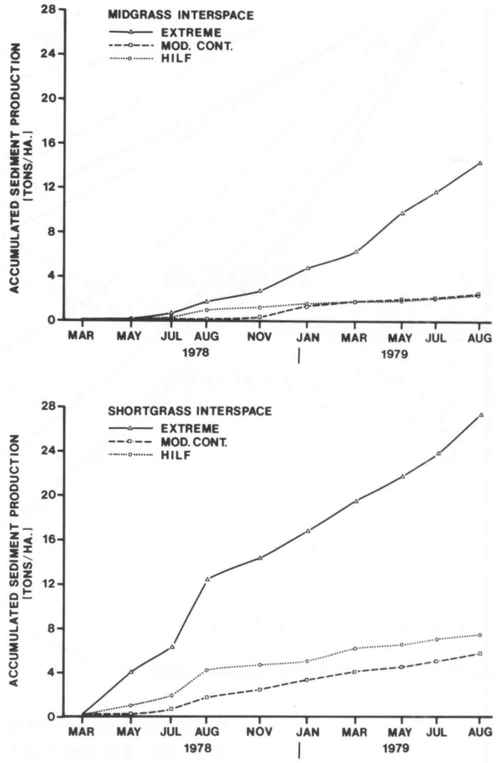


Fig. 16. Accumulated sediment production from midgrass and shortgrass interspace areas as influenced by livestock grazing, Sonora Experiment Station (Knight, 1980).

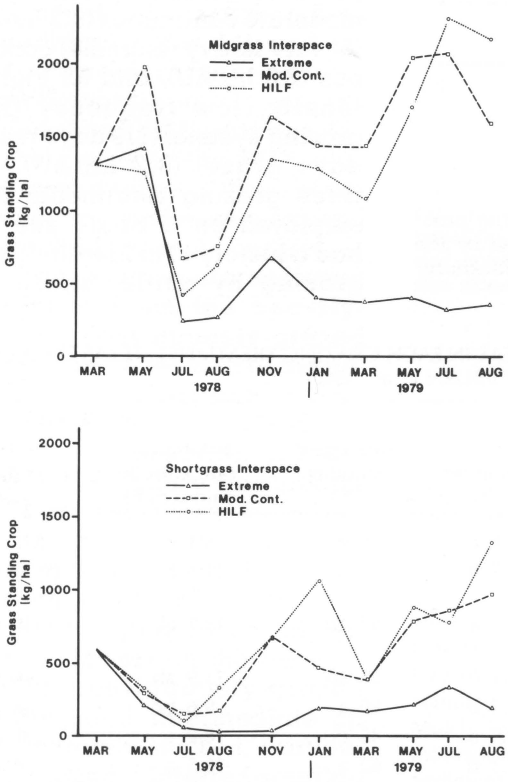


Fig. 17. Grass standing crop for midgrass and shortgrass interspace areas as influenced by livestock grazing, Sonora Experiment Station (Knight, 1980).

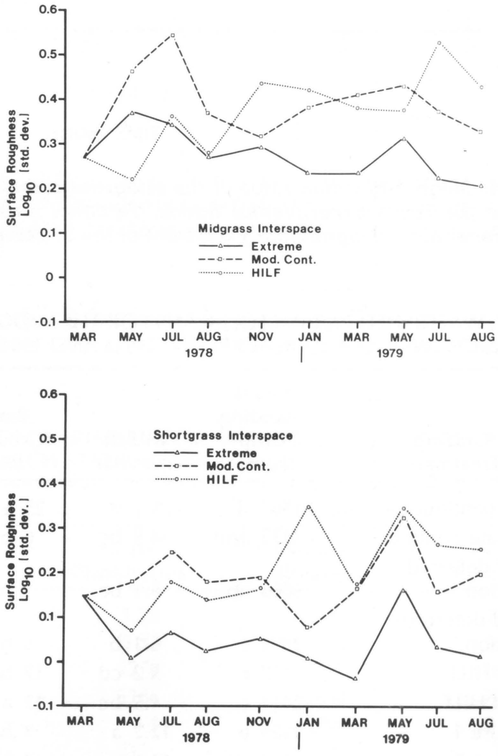


Fig. 18. Surface roughness of midgrass and shortgrass interspace areas as influenced by livestock grazing, Sonora Experiment Station (Knight, 1980).

goats. Pastures were 6 ha and were grazed by a combination of cattle, sheep and goats to approximate a 50:25:25 grazing ratio common to the Edwards Plateau. The pastures were sampled using a mobile infiltrometer at approximately 60-day intervals throughout the year (Knight, 1980; Blackburn *et al.*, 1980).

Infiltration rates corresponded closely to vegetation growth and were lowest in winter and peaked in late spring and early summer (Fig. 15). Infiltration rates, regardless of treatment, were generally higher in the midgrass interspace areas than in the shortgrass areas. Generally there was no significant difference in infiltration rate between the moderate continuous and HILF grazing treatments. Infiltration rate of the extreme continuously-grazed treatment was significantly lower than the moderate continuous or HILF treatments except for January 1979.

Sediment production was higher from the shortgrass-dominated interspace areas than from the midgrass-dominated interspace areas (Fig. 16). There was no difference between midgrass or shortgrass interspace areas in sediment production from moderate continuously grazed and HILF pastures. However, there was a large increase in sediment production from the heavy continuously-grazed pasture over moderate continuously-grazed or HILF pasture. The largest sediment increase occurred from the heavy continuously-grazed shortgrass interspace areas.

Standing crop was greater on the midgrass-dominated areas than on the shortgrass-dominated areas (Fig. 17). Similar standing crops occurred on moderate continously-grazed and HILF pastures. Standing crop from areas dominated by midgrasses and shortgrasses was similar for all grazing treatments for about four months after initiation of treatments. At this time, standing crop on the moderate continous pasture was greater than on the heavily grazed pasture. At about eight months after initiation of treatments, grass standing crop was similar on the moderate continuous and HILF pastures and higher than on the extreme continuous pasture.

Microrelief was greater for midgrass-dominated areas than in shortgrass-dominated areas, but within vegetation type, surface roughness was similar for the moderate continuous and HILF grazing treatments. Surface roughness decreased on the extreme continuously-grazed treatment (Fig. 18).

Surface soil bulk density was highly variable; only during the initial heavy stocking period (March through January, 1980) in the heavily-grazed pasture were bulk densities higher than the moderate continuous or HILF grazing treatments (Fig. 19). After stocking rates were reduced, bulk density recovered to the same level as the moderate continuously grazed and HILF pasture. No significant differences in mulch, surface soil aggregate stability or organic matter were attributed to grazing treatments after 17 months.

Brown and Schuster (1969) reported that the infiltration rate of an ungrazed butte in the southern high plains was four times that of an adjacent area that had unrestricted grazing since the 1800's. Dee *et al.* (1966) related infiltration rates to range condition in the southern high plains. They found higher infiltration rates on sites with vegetation of a higher successional stage than on deteriorated range sites.

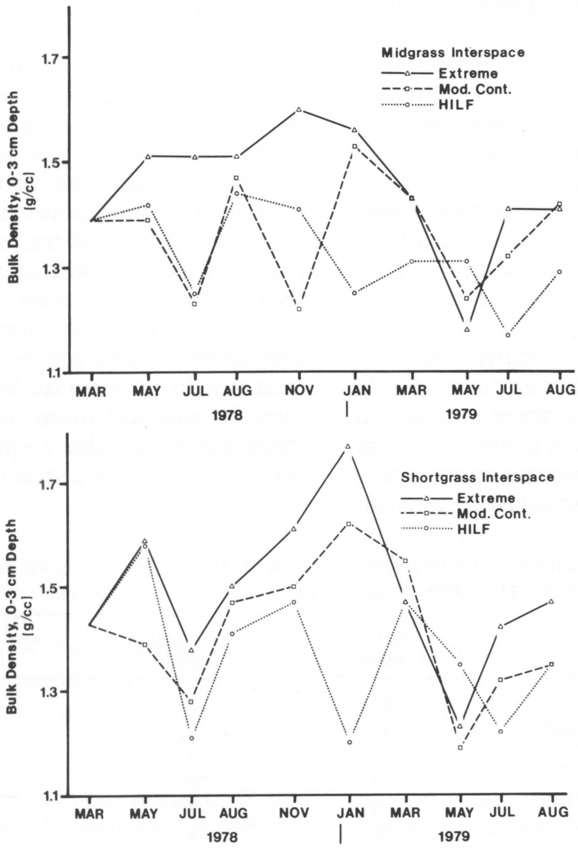


Fig. 19. Bulk densities (0-3 cm depth) of midgrass and shortgrass interspace areas as influenced by livestock grazing, Sonora Experiment Station (Knight, 1980).

Pinyon-Juniper Woodland

The pinyon-juniper woodland covers large areas in the intermountain west and southwest. The woodland has been characterized by widespread deterioration of the range resources from overgrazing and subsequent increases in tree density (Springfield, 1976). Little information is available concerning the effects of livestock grazing on watershed characteristics for this type.

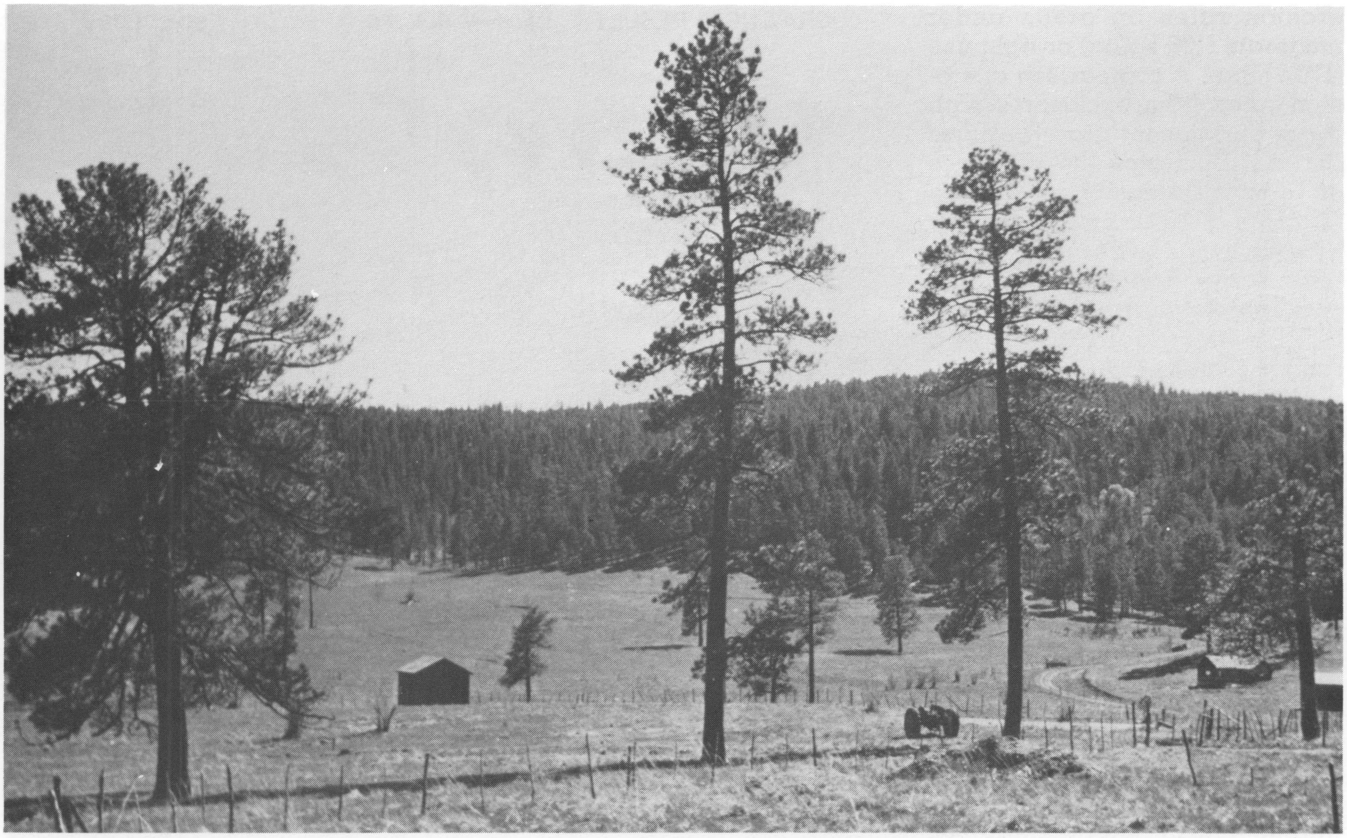
Baxter (1977) compared vegetation on a grazed area with that of an ungrazed relict mesa near Williams, Arizona. Bunchgrasses had almost disappeared under continuous grazing but were restored after 20 years of rest-rotation grazing to about half the amount on the relict mesa (Table 8). Blue grama accounted for 77 percent of the plant cover on the continuously grazed area and 35 percent of the area under rest-rotation grazing. Under continuous grazing, bare ground was eight times that of the protected mesa and three times greater under rest-rotation grazing than on the ungrazed mesa. Watershed condition was better under a rest-rotation grazing system than under continuous grazing.

Springfield (1976) states that livestock grazing in the pinyon-juniper woodland favors sodformers and annuals at the expense of bunchgrasses. Areas dominated by bunchgrasses have higher infiltration rates and lower sediment production than sodgrass-dominated areas (Blackburn *et al.*, 1980).

The impacts of cattle grazing for two weeks during June of 1974 and June of 1975 were studied in southern Utah on pinyon-juniper sites that had been converted to grass and protected from grazing for six years (Gifford *et al.*, 1976; Buckhouse and Gifford, 1976; Gifford, 1975). Infiltration rates were lower but not significantly different on grazed sites the second year than on ungrazed sites, and there were no apparent trends in sediment production. Clipping and artificial trampling did not affect infiltration rates. Researchers speculated from this limited study that one season of grazing will change infiltration rates, and protection from grazing for as long as four years may be needed even on sandy-loam soils, to fully regain maximum infiltration capacities.

Table 8. PLANT SPECIES COMPOSITION (%) OF A RELICT MESA AND SIMILAR GRAZED AREAS NEAR WILLIAMS, ARIZONA (BAXTER, 1977)

	Relict Mesa	Continuous Grazing	Rest Rotation Grazing
Mutton bluegrass	45	0	25
Bottlebrush squirreltail	15	0	10
Sideoats grama	20	3	8
Blue grama	7	77	35
Galleta	3	7	10
Ring muhly	0	8	2
Forbs	10	5	10
Bare ground	8	65	25



Ponderosa Pine/Bunchgrass

The ponderosa pine/bunchgrass ranges characterized by open grasslands interspersed within the tree community are important summer livestock-producing areas in the mountainous west. Most grazing management research for this vegetation type has been conducted at the USDA Manitou Experimental Forest, 45 km northwest of Colorado Springs, Colorado.

Dunford (1954) used 0.004-ha runoff plots to evaluate impacts of heavy and moderate cattle grazing and no grazing on runoff and erosion. Pretreatment calibration estimated plot runoff to be essentially the same, 6 to 6.8 mm, during the summer rainfall period. After 12 years of grazing, heavy grazing removed two-thirds of the herbage, and runoff from heavily grazed plots averaged 8.6 mm per season. Moderate grazing removed one-third of the herbage, and runoff from moderately-grazed plots averaged 5.6 mm per season. The ungrazed plots averaged 0.28 mm of runoff per season (Fig. 20). Erosion occurred almost exclusively during July and August. Average erosion for the summer calibration period averaged 134 to 183 kg/ha. Annual soil loss from heavily-grazed plots averaged 354 kg/ha, 162 kg/ha from moderately grazed plots and 150 kg/ha from ungrazed plots. Dunford (1954) concluded that influences of heavy grazing exceeded the limits allowable in good watershed management practices. Erosion has accelerated beyond a normal rate and surface runoff has increased, thus allowing less water to enter the soil profile where it could be available for plant growth or subsurface flow. Erosion does not appear to be substantially increased as a result of moderate grazing, despite some additions to surface flow. Currie and Gray (1978) reported that 35 years of livestock grazing in the ponderosa pine type was not unduly detrimental to soil surface features.

Based on simulated rainfall studies at Manitou Experimental Forest (Dortignac and Love, 1961; Smith, 1967), infiltration rates in 1952 were about the same as in 1941 for the various grazing treatments. Infiltration rates in pastures under light or moderate grazing remained high (4.8 and 5.3 cm/h, respectively) while pastures under heavy grazing remained low (4.1 cm/h). Infiltrometer measurements inside livestock exclosures increased from 4.5 cm/h in 1941 to 7.2 cm/h in 1954 as a result of protection from grazing. In contrast, infiltration rates on continuously grazed ranges were about the same at the beginning and end of the study. Thus, cattle grazing prevented an increase or recovery in infiltration rates.

Erosion rates on areas subjected to heavy grazing, as determined by simulated rainfall, were nearly double (283 kg/ha)

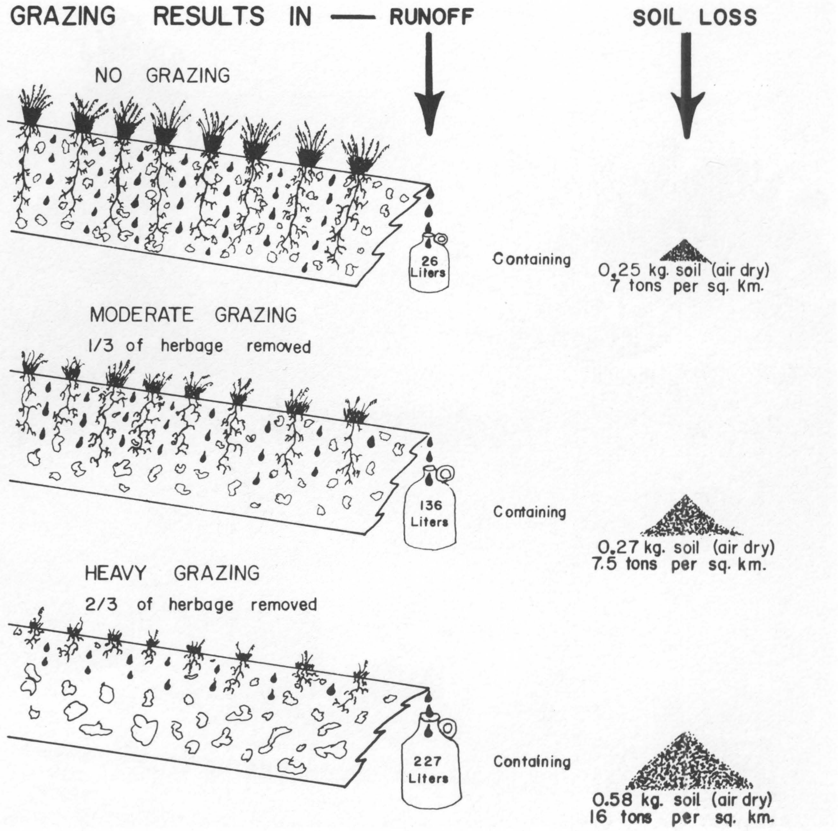


Fig. 20. The degree of grazing use substantially affects surface runoff and soil loss when more than half of the herbage is removed, Manitou Experimental Forest, Colorado (Dunford, 1954; Currie, 1975).

Table 9. AVERAGE EROSION RATES (kg/m^2) OF SURFACE RUNOFF FOR PLOTS INSIDE AND OUTSIDE EXCLOSURES (OPEN TIMBER AND GRASSLAND COMBINED), MANITOU EXPERIMENTAL FOREST, COLORADO. UNGRAZED PLOTS COMPARED TO PAIRED GRAZED PLOTS (SMITH, 1967)

	Light Grazing	Moderate Grazing	Heavy Grazing
Ungrazed Range [1]	1	6	7
Grazed Range	12	16	46

[1]Livestock grazing had been excluded for 12 years.

erosion rates on areas under moderate (136 kg/ha) or light use (170 kg/ha). A comparison of erosion rates from exclosures with those of adjacent grazed ranges in 1954 illustrates the influence of grazing intensity on erosion (Table 9). Erosion on the heavily-grazed range was eight times that in the exclosures and approximately four times that on lightly or moderately grazed ranges (Smith, 1967).

Skovlin *et al.* (1976) studied three stocking rates, (1) continuous grazing season-long, (2) a deferred-rotation grazing system, and (3) no grazing, in the Blue Mountains of the Pacific Northwest. Skovlin found no significant differences in herbage production attributable to grazing intensity or grazing system. However, grassland soil surface characteristics related to watershed protection were influenced. Amount of bare area increased and litter decreased as stocking rate increased. Both the area occupied by rocks, and the area of total vegetation tended to increase with the level of grazing. Neither rates of stocking nor system of grazing produced significant differences in bulk density of the primary grassland or forest soils. Results of a survey of sediment-collecting basins showed no differences attributable to grazing treatment. Skovlin concluded the following: (a) heavy stocking lowered grazing capacity and depleted ground cover, (b) moderate stocking maintained grazing capacity, (c) light stocking provided a substantial increase in potential capacity, (d) protection from cattle use slightly improved the composition of high quality forage species and produced little change in potential grazing capacity, and (e) deferred-rotation grazing was superior for improving forage and for restoring mountain watersheds.

Currie (1976) studied protection from grazing, alternate rest, spring grazing and fall grazing at Manitou Experimental Forest. He concluded that season and system of grazing management did not influence herbage yields, basal areas, or plant densities during the five year study. No season or system of grazing was more efficient than any other, including complete protection in promoting recovery of ponderosa pine/bunchgrass range which had been grazed heavily for 23 years. Thus, instituting a rotation management system is a questionable management practice for promoting improvement or recovery of pine/bunchgrass ranges.

A Beaver Creek watershed in central Arizona which has been grazed after converting to a grass cover, resulted in only an 8 percent increase in runoff due to 60 percent utilization of perennial grasses. This increase was not statistically significant. No difference in suspended sediment was observed on the moderately grazed watershed (Brown *et al.*, 1974).

U.S. Forest Service

High Elevation Rangelands

Unregulated and excessive grazing of these rangelands in the early 1900's increased flooding, channel cutting,and sediment production. This abusive grazing caused an early concern for proper grazing of these mountain watersheds (Copeland, 1963; Croft and Ellison, 1960; Marston, 1958; Croft *et al.*, 1943; Chapline, 1929; Forsling, 1931; Lull, 1949; Sampson and Weyl, 1918). However, relatively little research has been conducted on the influence of livestock grazing on these rangelands. According to Frank *et al.* (1975), the Black Mesa watershed in Colorado, subjected to different intensities of cattle grazing, did not significantly change the runoff or sediment production; 99 percent of total yearly runoff and 89 percent of suspended sediment were produced during spring snow melt. Sediment yields were small, and apparently came from a few local areas such as stream channels and other sites with little protective cover. Soil recently deposited on the ground surface by pocket gophers probably contributed to sediment movement. There was a general increase in vegetation cover on all watersheds, regardless of treatment.

Leaf (1975), in his report on the state-of-the-art, concluded that moderate intensities of cattle grazing do not affect water runoff on high elevation rangelands with extensive grassland parks. Branson and Lommasson (1958) reported on the effects of 23 years of moderate stocking of an allotment in Montana which had previously been overgrazed. Improved management practices resulted in increased forage production on most of the study area.

An overgrazed watershed in central Utah did not respond appreciably to grazing exclusion and produced surface runoff during the more intense summer storms (Meeuwig, 1960). Heavy grazing changed an adjacent, fairly stable watershed into a serious flood-source area. Erosion that occurred because of plant cover depletion reduced productivity of some parts of the watershed so that they will no longer support as much plant cover as they did before depletion. Meeuwig (1965) reported that moderate grazing for four years significantly lowered the protective cover.

Bulk density and organic matter content of the surface soil in grazed areas was similar to that of ungrazed areas. Average runoff and sediment production was significantly greater from grazed areas than from protected areas. Meeuwig (1965) concluded that even moderate grazing can have pronounced residual effects on infiltration capacity and soil stability. Laycock and Conrad (1967) found that soil bulk density in moderately-grazed plots was similar to that of ungrazed exclosures, both in early summer before grazing and in late summer after grazing.

Marston (1952) recommended 65 percent ground cover for protection of high elevation watersheds in northern Utah. Results of Packer's (1963) study of the Gallatin Elk winter range in Montana suggest that at least 70 percent plant and litter cover is necessary to prevent excessive erosion. He recommended that openings between plants not be any larger than four inches in diameter on wheatgrass ranges, and no larger than two inches in diameter on cheatgrass ranges. These conditions were generally found on sites having 35 to 45 percent plant cover.

Eastern Hardwood or Pine Forest

The long history of woodland overgrazing and studies poorly designed to evaluate proper livestock management has given the grazing animal a bad image in eastern forestry (Lee, 1980; Johnson, 1952; Adams, 1975). Most of the studies conducted in eastern forests have evaluated the impacts of heavy, continuous grazing. Dissmeyer (1976), using his First Approximation of Suspended Sediment (FASS) method to evaluate soil loss in the southeast stated that, in some areas, overgrazing of woodland is clearly the major source of sediment production.

Heavy livestock grazing has been reported to increase soil bulk density and lower infiltration rates (Table 10). Stoeckeler (1959) reported infiltration rates of ungrazed oak woods to be 150 times greater than adjacent heavily-grazed woods. Duvall and Linnartz (1967) reported that infiltration rates of heavily-grazed, moderately-grazed and ungrazed longleaf pine/bluestem range were respectively 2.0, 3.0, and 4.7 cm/h (Fig. 21). They also stated that compaction by livestock consistently reached the 40 cm depth. These findings, probably reflecting soil texture interactions, are contrary to other studies that found grazing impacts restricted to the surface 15 cm. Alderfer and Robinson (1947) found soil compaction by cattle was limited to the surface 2.5 cm. Lull (1959) reviewed soil compaction on forests and concluded that trampling by livestock may compact the upper 15 cm of the soil, exert pressure equivalent at least to that of heavy tractors, and reduce infiltration as much as logging equipment.

Abusive livestock grazing caused devastating effects on a hardwood watershed at the Coweeta Hydrologic Laboratory (Johnson 1952). Livestock browsing and trampling influenced the rate of runoff and quality of water. Storm water flowed to streams over the land surface rather than subsurface. Turbidity was 30.5 ppm from the control watershed and 107.5 ppm from the grazed watershed. Grazing decreased soil porosity and infiltration rates (Table 11).

Table 10. INFLUENCE OF LIVESTOCK GRAZING AND NO GRAZING ON SELECTED WATERSHED PARAMETERS OF THE EASTERN HARDWOOD AND PINE FORESTS

Parameter	Ungrazed	Light Grazing	Moderate Grazing	Heavy Grazing	Location	Reference
Bulk Density (g/cc)	1.09	1.51	—[1]	1.54 to 1.91	Pennsylvania	Alderfer and Robinson, 1947
	0.92	—	—	1.15	New York	Chandler, 1940
	0.51	—	0.92	—	Allegheny River Watershed	Trimble *et al.*, 1951
	1.01	—	—	1.22	South Dakota	Read, 1957
	1.32	—	1.39	1.41	Louisiana	Linnartz *et al.*, 1966
Infiltration (cm/h)	18.9	—	—	0.1	Oak Woods Wisconsin	Stoeckeler, 1959
	28.0	—	—	3.1	Scotch Pine Plantation Wisconsin	Stoeckeler, 1959
	4.7	—	3.0	2.0	Louisiana	Linnartz *et al.* 1966

[1]Data not reported.

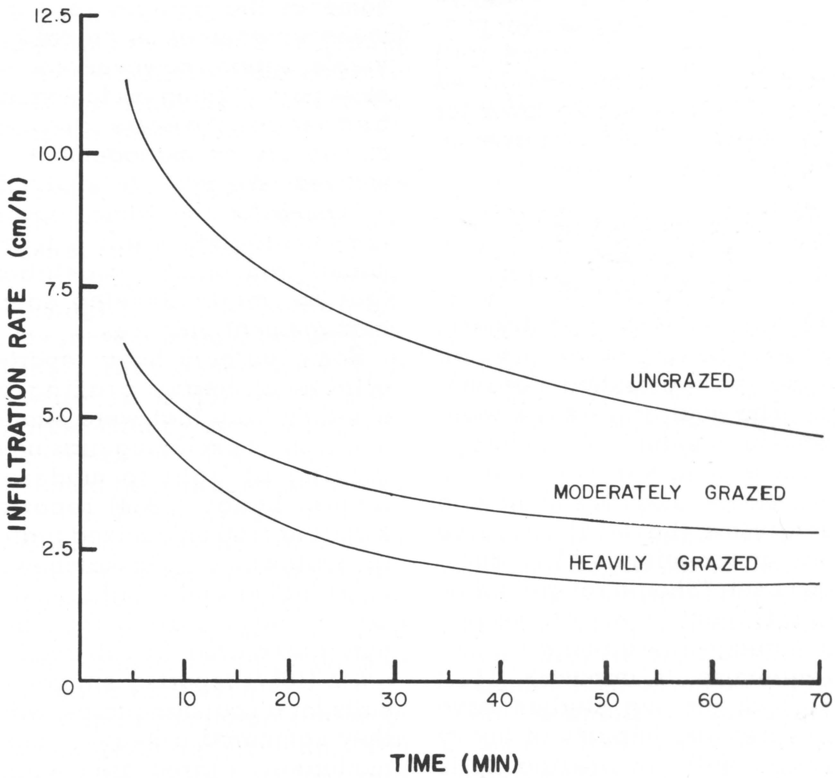


Fig. 21. Infiltration rates of three grazing intensities, longleaf pine/bluestem range, Louisiana (Linnartz et al., 1966).

Johnson reports the utilization of understory trees 4.6 m tall or less was so complete that in this size class practically all yellow-poplar, ash, blacklocust, oak, dogwood, sweet birch and sassafras have disappeared. Trees up to 6.5 cm in diameter were ridden down and tops eaten. Forage was so scarce that cattle required supplemental feeding to generate enough strength to range the area. The author contends that the grazing intensity was typical of grazed farm woodlands. The results of this study and other similar ones should not be used to evaluate the impact of proper livestock grazing in eastern forests.

Table 11. CHANGES IN TOTAL POROSITY AND INFILTRATION RATES OF THE SOIL CAUSED BY SOIL TRAMPLING EXPRESSED AS A PERCENT OF THE CONTROL FENCED PLOT, COWEETA HYDROLOGIC LABORATORY (JOHNSON, 1952)

	Cove Hardwood	Oak Hickory on Slopes	Pine-Oak on Ridges
Total Porosity			
0-5 cm	42[1]	15	6
5-10 cm	56[1]	12	4
Infiltration	91[1]	67[1]	—

[1]Statistically significant from control.

SUMMARY AND CONCLUSIONS

Hydrologic impacts of livestock grazing result primarily from the interactions of climate, vegetation, soil, and intensity and duration of livestock use. Thus, grazing impacts will vary naturally from area to area due to the normal variability of these factors. Few studies have attempted to account for these natural variations. Documentation of the intensity and duration of livestock grazing has been poor or completely ignored in most studies. Likewise, what is described as moderate grazing intensity in one study may be the same as heavy grazing in another study. Only for the ponderosa pine/bunchgrass and Great Plains rangelands do we have a sufficient data base for evaluation of the impacts of proper livestock grazing.

Heavy Grazing and Exclusion From Grazing

Grazing, whether by arthropods or ungulates, has an impact on watershed parameters. The goal of livestock management is to harvest the forage resource in such a manner as to keep the impacts consistent with sustaining the total resource base of rangelands. The question is not, "Should rangeland be grazed?", but "How can we better manage the grazing animal to minimize its impacts?" Most livestock grazing studies have compared the impacts of heavy grazing with no grazing. It is easy to get the impression from the literature that heavy grazing is a viable management objective or that livestock grazing is universally equivalent to heavy grazing; however, no such oversimplification is justified.

It has been recognized for 70 years that heavy continuous grazing accelerates erosion and runoff (Rich, 1911; Duce, 1918; Sampson and Weyl, 1918). The literature is filled with examples of the adverse impacts of overgrazing on watersheds (Crouch, 1979; Dregne, 1978; Smeins, 1975; Ellison, 1960; Dunford and Weitzman, 1955; Harper, 1953; Lull, 1949; Olson, 1949; Woods and Woolley, 1933; Cottam and Evans, 1945; Cottam and Stewart, 1940; USDA, Forest Service, 1940; Bennett, 1934; Chapman, 1933; Woolley, 1933; Kotok, 1932; Kotok, 1931; Stewart and Forsling, 1931; Forsling, 1928). In 1958 Love wrote, "There is a large body of information leading to the conclusion that heavy grazing has had bad hydrologic consequences. It is doubtful that more investigations are needed to emphasize this conclusion."

The exclusion of livestock from some of the nation's arid and steep rangelands is probably a viable option; however, for the most part, grazing exclusion and heavy continuous grazing should not be management objectives. We need to study the extremes for the same reasons that ecologists study successional and climax vegetation, that we might develop sound management practices.

Some authors have reported effects of heavy grazing on standing crop that were similar to effects of excluding grazing or grazing at light to moderate levels. Lodge (1954) reported standing crop on a mixed prairie in southwestern Saskatchewan to be higher under light, moderate or heavy grazing than in a non-grazed area. Duvall and Linnartz (1967) reported similar results for a Louisiana forest when they compared a heavily and a moderately grazed area with a non-grazed area. Hazell (1967) in Oklahoma, Clary (1979) in Louisiana, and Branson *et al.* (1962) in Montana found similar standing crops under heavy grazing as compared to moderate or light grazing. Hyder *et al.* (1975) reported heavy grazing of shortgrass ranges in Colorado for short periods increased plant production. McNaughton (1979) in the African Serengeti found that moderate grazing resulted in above ground primary production up to twice the level of ungrazed plots. Productivity was similar to ungrazed areas even under very intensive grazing. In spite of these reported vegetation increases under heavy grazing, those authors who studied watershed impacts did not recommend continuous heavy grazing (Johnson, 1962; Duvall and Linnartz, 1967).

Light or Moderate Grazing Intensity

We have very little information on the hydrologic impacts of light or moderate grazing intensity. The available data strongly suggest that hydrologic differences between pastures continuously grazed lightly or moderately are not significant. There appears to be no hydrologic advantage to grazing a watershed lightly rather than moderately. Some studies have failed to show a difference in soil loss, infiltration capacity, or soil bulk density among light, moderate, and ungrazed pastures.

Grazing Systems

Much interest has been generated by specialized grazing systems and their potentials (Savory, 1978). Little information is available, however, to support many of the claims concerning specialized grazing systems. Gifford and Hawkins (1976) found no published evidence to show that any single grazing system consistently or significantly increased plant and litter cover on watersheds. Other reviews (Beck, 1980; Van Poolen and Lacey, 1979) of the impacts of grazing systems on range vegetation support Gifford and Hawkins' conclusion.

Most of the information on the impacts of specialized grazing systems on watershed characteristics comes from studies conducted in the Rolling Plains and Edwards Plateau of Texas (McGinty *et al.*, 1978; Wood and Blackburn, 1981a, 1981b; Blackburn *et al.*, 1980). The results of these studies indicate that pastures grazed under a 4-pasture deferred-rotation system are hydrologically similar to those of livestock exclosures. Conversely, the HILF grazing systems were either similar hydrologically to heavy continuous grazing in the Rolling Plains or to moderate continuous grazing in the Edwards Plateau.

Water Quality

The major pollutant from rangeland watersheds is sediment. Moderate continuous grazing or specialized grazing systems should reduce sediment losses to a minimum from most watersheds. However, it should be recognized that if watersheds have been severely overgrazed, instituting a moderate continuous or specialized grazing system may not reduce sediment losses. Bacteria or nutrients as potential pollutants from livestock grazing do not appear to be a problem on areas not included in riparian zones (Doran and Linn, 1979; Buckhouse and Gifford, 1976; Gifford *et al.*, 1976).

Research Needs

To plan effective management programs, the rangeland manager needs to understand the hydrologic impacts of livestock grazing. Unfortunately, few research data relative to these impacts exist for western rangelands. Hydrologic responses often occur much more slowly and subtly than do vegetation changes. To evaluate hydrologic changes adequately, studies should be conducted for more than five years.

The research emphasis should be on the "best" known grazing management practices. Nongrazed areas or abusive continuous grazing treatments should be included to ensure characterization of the extremes. It is imperative that the stocking rates, frequencies, and durations of grazing be reported. The literature is full of examples where this information has not been reported (Lusby, 1979; Gifford, 1981) making research results highly questionable and difficult to interpret. Likewise, it is important that the intended livestock use of the study areas be achieved, which may require the use of relatively small pastures (10 to 50 ha). Such studies should be designed to account for the interactions of climate, vegetation, soil, intensity, and duration of livestock use.

Because of the relatively small quantity but high variability of precipitation on western rangelands, watershed data obtained with simulated rainfall are probably the most reliable. This does not preclude the use of natural runoff plots or small watersheds if local hydrologic conditions are favorable and funds are available for such studies.

Ideally, these studies should be both intensive and extensive in design. An example of such a project is presented here.

Intensive Study. This study should be conducted using small runoff plots (2 by 22 m). Plot size should be large enough to include the variability present in an area, particularly that associated with vegetation patterns (i.e., brush-canopy areas and interspace areas). The runoff plots should be instrumented with a 15 cm H-flume and a 20 cm Coshocton wheel sampler or similar water measuring and sampling devices. These runoff plots would measure and sample natural and simulated rainfall events.

A rainfall simulator (similar to that of Meyer and Harman, 1979) should be placed in line and used at selected times during the year to apply rainfall to the runoff plots. The rainfall application rate should exceed infiltration rates, and raindrop size and terminal velocities should approximate a natural storm of the intensity simulated.

A minimum of three runoff plots should be used per grazing treatment and vegetation-soil unit sampled. From these runoff plots the following information should be collected at predetermined intervals thrughout the year:

- Infiltration rate
- Sediment production
- Additional water-quality parameters
- Vegetational cover by species
- Bare ground cover
- Shrub-canopy area and interspace area
- Microtopography
- Vesicular crust cover and hardness

From shrub-canopy and interspace areas adjacent to the runoff plots, the following information should be collected at the same predetermined intervals:

- Soil bulk density
- Soil organic matter
- Soil aggregate stability
- Grass standing crop

Extensive Study. This study should use a small portable rainfall simulator (Meyer and Harman, 1979) and variable runoff plots that will allow separate evaluation of shrub-canopy areas and interspace areas. Runoff plots should be 0.5 to 1 m^2 in size. Simulated rainfall rates should exceed infiltration rates, and raindrop size and terminal velocities should be similar to those of a natural storm. These plots should be relocated at selected intervals on a similar site before the next simulated rainfall is applied. A minimum of six runoff plots should be used per grazing treatment and vegetation-soil unit sampled. The following data should be collected from each runoff plot:

- Infiltration rate
- Sediment production
- Vegetational cover by species
- Bare ground cover
- Microtopography
- Soil bulk density
- Soil organic matter
- Soil aggregate stability

- Grass standing crop
- Vesicular crust cover and hardness

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APPENDIX I:

Common and Scientific Names of Plants Mentioned

Common Name	Scientific Name
Ash	*Fraxinus* spp.
Ashe juniper	*Juniper ashi*
Black locust	*Robinia pseudoacacia*
Bluebunch wheatgrass	*Agropyron spicatum*
Blue grama	*Bouteloua gracilis*
Bluestem	*Andropogon* spp.
Bottlebrush squirreltail	*Sitanion hystrix*
Buffalograss	*Buchloe dactyloides*
Cane bluestem	*Bothriochloa barbinodis*
Cheatgrass	*Bromus* spp.
Common curlymesquite	*Hilaria belangeri*
Crested wheatgrass	*Agropyron desertorum*
Dogwood	*Cornus* spp.
Fescue	*Festuca* spp.
Galleta	*Hilaria jamesii*
Honey mesquite	*Prosopis glandulosa*
Intermediate wheatgrass	*Agropyron intermedium*
Japanese brome	*Bromus japonicus*
Juniper	*Juniperus* spp.
Live oak	*Quercus virginiana*
Longleaf pine	*Pinus palustris*
Lotebush	*Ziziphus obtusifolia*
Mutton bluegrass	*Poa fendleriana*
Nuttail saltbush	*Atriplex nuttallii*
Oak	*Quercus* spp.
Pinyon	*Pinyon* spp.
Ponderosa pine	*Pinus ponderosa*
Red grama	*Bouteloua trifida*
Ring muhly	*Muhlenbergia torreyi*
Sagebrush	*Artemesia* spp.
Sassafras	*Sassafras* spp.
Scotch pine	*Pinus sylvestris*
Sideoats grama	*Bouteloua curtipendula*
Sweet birch	*Betula lenta*
Texas wintergrass	*Stipa leucotricha*
Threeawns	*Aristida* spp.
Western wheatgrass	*Agropyron smithii*
Wheatgrass	*Agropyron* spp.
Yellow poplar	*Liriodendron tulipifera*

APPENDIX II:
Abbreviations and Definition of Symbols Used

Symbol	Definition
cm	Centimeter
cm/h or cm/hr	Centimeter per hour
g/cc	Gram per cubic centimeter
ha	Hectare
ha/AU	Hectare per animal unit
kg	Kilogram
kg/ha	Kilogram per hectare
kg/ha/yr	Kilogram per hectare per year
kg/m^2	Kilogram per square meter
km	Kilometer
mm	Millimeter
m	Meter
m^2	Square meter
m^3	Cubic meter
min	Minute
ppm	Parts per million
ton/ha	Ton per hectare
sq km	Square kilometer

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