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Infiltration Rates and Sediment Production as Influenced by Grazing Systems in the Texas Rolling Plains

J.J. PLUHAR, R.W. KNIGHT, AND R.K. HEITSCHMIDT

Abstract

Research was initiated in August 1982 at the Texas Experimental Ranch to evaluate effect of selected grazing treatments on watershed condition. Two production scale grazing treatments were sampled on 4 dates over a period of 15 months. Treatments were yearlong continuous grazing stocked at a moderate rate (MC) and a 16-paddock rotational grazing treatment stocked at a heavy rate (RG). In addition, hydrologic conditions in an ungrazed exclosure (EX) and a moderately stocked 4-pasture, 3-herd deferred rotation treatment (DR) were examined during the summer of 1982. Regression analyses indicated infiltration rates increased and sediment production declined as vegetation standing crop and cover increased, soil bulk density decreased, and soil organic matter and aggregate stability increased. Averaged across the 4 sample dates, sediment production was least (33 kg/ha) and infiltration rate greatest (89 mm/hr) in the MC treatment as compared to the RG treatment (63 kg/ha and 82 mm/hr). Infiltration rates and sediment production in the RG and DR treatments before grazing were not significantly different from those in the MC treatment; however, grazing caused a significant decline in infiltration rates and a significant increase in sediment production in both treatments. Sediment production was least in the exclosure (23 kg/ha) while infiltration rates were generally greater and sediment production less in the midgrass communities as compared to the shortgrass communities. All effects were closely related to the effect of the various treatments on vegetation standing crop and cover.

Key words: range watersheds, hydrology, rotational cell grazing, continuous grazing, midgrass, shortgrass

Grazing management is defined as the manipulation of livestock grazing to accomplish a desired result (Soc. Range Manage. 1974). It is a management tool available to increase ranch income while maintaining or improving the range resource (Stoddart et al. 1975) as evidenced by more favorable plant species composition, increased plant and litter cover, and increased plant vigor. Grazing systems affect watershed condition by altering vegetation cover and standing crop, and bulk density, organic matter content, and aggregate stability of soils (Blackburn et al. 1982). Previous research has generally shown that as vegetation cover declines, water infiltration rates decrease and sediment production increases (Klemmedson 1956, Johnston 1962, Whitman et al. 1965, Smith 1967, Rauzi et al. 1968, Brown and Schuster 1969, McCalla et al. 1984). Likewise, as soil bulk density increases and organic matter content and aggregate stability decrease, rate of water infiltration decreases and sediment production increases (Klemmedson 1956, Rhoades et al. 1964, Meeuwig 1970, McGinty et al. 1978). Therefore, grazing management strategies which tend to enhance vegetation cover, reduce soil bulk density, and increase soil organic matter and aggregate stability, tend to enhance watershed condition.

The major objective of this study was to quantify the effects of a rotational grazing treatment on rangeland hydrologic properties. Specific objectives were to: (1) contrast hydrologic response across 5 grazing treatments in 2 types of plant communities, and (2) quantify the relationship between type of grazing treatment and various soil and vegetational factors as they affect water infiltration rates and sediment production. Our basic hypothesis was that watershed condition would vary among grazing treatments as a function of their effect on various soil and vegetation factors.

Materials and Methods

Study Area

The study was conducted at the 2,900-ha Texas Experimental Ranch (99° 14'W, 33° 20'N) located in the Rolling Plains natural resource area 16 km north of Throckmorton, Texas. Annual precipitation averages 680 mm and is bimodally distributed (Fig. 1).

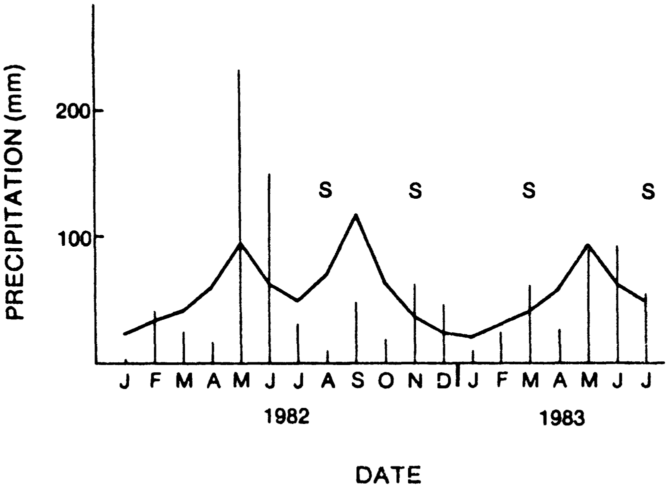

Fig. 1. *Long-term average (horizontal line) and monthly precipitation (vertical lines) received at Texas Experimental Ranch from April 1982 through August 1983. (s = sample date).*

Climate is continental and highly variable. Mean daily temperatures range from 4° C in January to 29° C in July. Average frost-free growing season is 233 days, extending from March to November.

Vegetation at the ranch is a mixture of mid- and shortgrasses. Dominant midgrasses are sideoats grama [*Bouteloua curtipendula* (Micxh.) Torr.], a warm-season perennial, and Texas wintergrass [*Stipa leucotricha* Trin. and Rupr.], a cool-season perennial. Dominant shortgrasses are buffalograss [*Buchloe dactyloides* (Nutt.) Engelm.] and common curlymesquite [*Hilaria belangeri* (Steud.) Nash], both warm-season perennials. Soils are primarily clays and clay loams. Dominant range sites are clay loam, clay flat, rocky hills, and loamy bottomland. For a more complete description of the vegetation, soils, and range sites see Heitschmidt et al. (1985).

Treatments

Grazing treatments included in the study were an ungrazed exclosure (EX), moderately stocked yearlong continuous (MC) and 4-pasture 3-herd deferred rotation (DR) treatments, and a heavily stocked 16 paddock rotational grazing (RG) treatment

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Table 1. Description of grazing treatments sampled during study.

Treatment	Date initiated	Paddock size (ha)	Number of cows	Stocking[1] rate(ha/(cow/yr)	Stocking density (au/ha)
14-paddock rotation (RG-14)	Mar. 1981	30	125	3.6	4.2
42-paddock rotation (RG-42)	Mar. 1982	10	125	3.6	12.5
4-pasture, 3-herd deferred rotation (DR)	1959	110	25	5.8	0.3
Yearlong continuous (MC)	1959	240	41	5.8	0.2
Ungrazed exclosure (EX)	1959	5	0	—	—

[1] Based on total area of all paddocks/pastures in RG and DR treatments.

(Table 1). Originally the RG treatment consisted of 14 paddocks. In 1982, one 30-ha paddock was subdivided into three 10-ha paddocks. Sample plots were subsequently located in one 30-ha paddock and one 10-ha paddock for the purpose of evaluating the effect of RG on watershed condition at 2 livestock densities. Hereafter, the RG-14 designation refers to plots in the 30-ha paddock with a livestock density equal to a 14-paddock system and RG-42 refers to plots in the 10-ha paddock which provided a livestock density equal to a 42-paddock system. Prior to this study the RG treatment was under a high intensity-low frequency system which was started in 1973. Wood and Blackburn (1981a, 1981b) reported that this grazing system had hydrologic properties similar to the MC treatment. All treatments were stocked yearlong with crossbred cows. Stocking rates in all treatments were constant. Rate of rotation of the RG herd varied seasonally and ranged from about 30 to 65 days. Length of graze ranged from 0.7 days in RG-42 during a 30-day cycle to 4 days in RG-14 during a 60-day cycle.

Sampling Scheme

Two plant communities (midgrass and shortgrass) were sampled within each treatment on a single soil series, the Nuvalde series. The Nuvalde series is a member of the fine-silty, mixed, thermic family of Typic Calciustolls. It is a deep, well-drained, moderately permeable soil located on nearly level uplands. Range site classification is clay loam. This series was selected for study because it occurred in all treatments. The midgrass communities were dominated by sideoats grama and Texas wintergrass. Buffalograss and common curly-mesquite were the dominant species in the shortgrass communities. The ungrazed exclosure contained no shortgrass community. Following the first sample date, only the midgrass plant community was sampled. The DR and RG treatment paddocks were sampled immediately prior to and after grazing. The MC and RG treatments were sampled 4 times over a 1-year period (Fig. 1). The EX and DR treatments were sampled only on the first date.

Methods

A rainfall simulator similar to that described by Meyer and Harmon (1979) was used to measure infiltration rates in ten .71 × .71 m (0.5 m^2) randomly placed plots per treatment per sample date per vegetation type. The simulated rainfall had a drop size distribution and kinetic energy similar to natural storms of the same size. Plot areas (1 m^2) were prewet with 100 l of water using a mist-type sprinkler system to remove antecedent soil moisture differences prior to sampling. The mist-type nozzle was used to reduce possible raindrop impact. After wetting, plots were covered with plastic tarps and allowed to drain to field capacity (about 24 hours). Simulated rainfall was applied for 30 minutes at a rate of 110 mm/hour to produce runoff from all plots. Wind screens were used to minimize raindrop drift. Infiltration rates were calculated as the difference between the amount of applied rainfall and runoff over the 30-minute period. A 1-liter subsample of thoroughly mixed runoff water was collected from each sample plot to estimate sediment production. Total sediment production (kg/ha) was determined after filtering the entire subsample through a #1 Whatman filter paper and drying it at 150° C.

Percentage bareground and vegetation cover were visually estimated in each sample plot. Vegetative cover was estimated by plant species. Standing crop of grasses and forbs was determined by clipping at the soil surface. After clipping, litter biomass was collected by hand. All biomass was air dried at 60° C to a constant weight and weighed. Soil water content and bulk density were determined to a depth of 30 mm prior to each simulated rainfall event using two 60-mm diameter (Black 1965) cores. A soil sample from the top 80 mm of the soil profile was also collected from within each plot following simulated rainfall to be used for soil texture, aggregate stability, and organic matter determinations. Texture was determined by the hydrometer method (Bouyoucos 1962), aggregate stability by the wet sieve method (Kemper and Kock 1965), and organic matter by the Walkley-Black method (Walkley and Black 1934). Surface roughness was estimated for each plot using a 10-pin frame with pins placed 60 mm apart (Kincaid and Williams 1966). The frame was placed at 3 equal intervals across each plot. Standard deviations of pin heights was used as an index of surface roughness.

Statistical Analyses

Data were statistically analyzed using 2-way and 3-way analysis of variance models. Prior to analysis, all data were tested for normality using skewness and kurtosis tests. Sediment production was transformed (natural log) to fit a normal distribution. The nontransformed data will be presented in the results. Duncan's multiple range tests were utilized for mean separation. Within treatment variation (variation among subplots) was allocated to the residual for testing differences among treatments. Forward stepwise multiple regression procedures were used to generate predictive equations for infiltration rate and sediment production. All significant differences are at $P \leq 0.05$.

Results and Discussion

Rotational and Yearlong Continuous Grazing

Statistical analyses of infiltration rates indicated significant treatment, date, and treatment-by-date interaction effects. Averaged across dates, infiltration rate was greatest in the MC treatment though only significantly greater than after grazing in the RG-14 treatment (Table 2). Average infiltration rate declined in both RG treatments following grazing. The declines, however, were not statistically significant. Differences among treatments were related to differences in controlling factors particularly percentage bareground and total herbaceous standing crop (Table 2).

Infiltration rates in all treatments generally followed similar seasonal patterns (Table 3) with average infiltration rates least in spring (March 1983) and greatest in fall (November 1982). However, causal relationships were difficult to quantify because aggregate stability, surface roughness, litter cover and standing crop, and grass and total standing crop were least in March 1983 when soil bulk density, soil organic matter, and grass cover were greatest relative to the three other sample dates (Table 3). The treatment-by-date interaction effects were related to minor seasonal differences among grazing treatments (Table 4).

Statistical analyses of the sediment production data showed a significant grazing treatment effect (Table 2) but no date (Table 3) or date-by-treatment interaction effects. Sediment production increased significantly in both RG treatments following grazing but neither treatment was significantly different from the MC treatment prior to grazing. These differences emphasize the dynamic effect that the RG treatment had on watershed condition relative to sediment production. Generally, grazing in the RG treatments reduced vegetation cover and standing crop while increasing litter cover and bare ground.

Table 2. Mean values (n=40) for measured variables in 3 grazing treatments averaged across 4 dates.

	Grazing treatment[1]				
	RG-14		RG-42		
Variable	Before	After	Before	After	MC
Vegetation					
Bareground (%)	20b[2]	26b	12c	23ab	9c
Grass cover (%)	47b	50c	64a	50c	60ab
Forb cover (%)	3ab	1b	2b	1b	4a
Litter cover (%)	20c	23bc	22bc	26ab	28a
Total vegetation cover (%)[3]	80b	74c	88a	77bc	92a
Grass standing crop (kg/ha)	2244b	2188b	2644a	2010b	2198b
Forb standing crop (kg/ha)	70a	27a	108a	17a	144a
Litter standing crop (kg/ha)	1241b	1329b	1400b	1541b	2842a
Total standing crop (kg/ha)[3]	3555b	3544b	4152b	3568b	5184a
Soil					
Bulk density (g/cm^3)	1.2a	1.1a	1.2a	1.2a	1.1a
Organic matter (%)	6.3ab	4.4c	6.7a	5.7b	6.5a
Aggregate stability (%)	68a	65a	68a	70a	72a
Surface roughness (mm)	6.2a	6.2a	6.4a	6.4a	7.4a
Infiltration rate (mm/hr)	87ab	77b	85ab	78ab	89a
Total Sediment production (kg/ha)	52b	85a	29b	85a	33b

[1] See Table 1 for treatment identification.
[2] Means in a row followed by same letter are not significantly different at $P \leq 0.05$.
[3] Grass + forb + litter.

Table 3. Mean values (n = 50) for measured variables on 4 sample dates averaged across RG-14, RG-42, and MC grazing treatments.

	Date			
Variable	Aug. 1982	Nov. 1982	Mar. 1983	July 1983
Vegetation				
Bareground (%)	17a[1]	19a	17a	18a
Grass cover (%)	55bc	56b	63a	50c
Forb cover (%)	3a	2a	2a	3a
Litter cover (%)	25b	23b	18c	29a
Total vegetation cover (%)[2]	83a	81a	83a	82a
Grass standing crop (kg/ha)	2473a	2301a	1826b	2392a
Forb standing crop (kg/ha)	89a	15a	29a	162a
Litter standing crop (kg/ha)	1722a	1721a	1625a	1652a
Total standing crop (kg/ha)	4284a	4039ab	3480b	4206a
Soil				
Bulk density (g/cm^3)	1.1b	1.1b	1.2a	1.1b
Organic matter (%)	5.2c	5.7bc	6.7a	6.2ab
Aggregate stability (%)	71b	69b	51c	81a
Surface roughness (mm)	6.0b	7.1a	5.9b	7.0a
Infiltration rate (mm/hr)	83b	92a	74c	83b
Total sediment production (kg/ha)	54a	55a	73a	57a

[1] Means within a row followed by same letter are not significantly differet at $P \leq 0.05$.
[2] Grass + forb + litter.

Type of Plant Community

Water infiltration rates were significantly greater in midgrass (84 mm/hr) than shortgrass communities (75 mm/hr) when averaged across grazing treatments (Table 5). These findings agree with the findings of Wood and Blackburn (1981a). Although the effect of type of plant community on sediment production (Table 5) was not as clearly discernible in this study as in the study conducted by Wood and Blackburn (1981b) at the Texas Experimental Ranch, differences were significant when averaged across grazing treatment. Sediment production in our study averaged 49 and 55 kg/ha in the midgrass and shortgrass communities, respectively, as compared to 39 and 95 kg/ha, respectively, in their study. We attribute these differences primarily to climatic differences among years. For example, in 1982 growing conditions were extremely favorable (Fig. 1) relative to the growth of warm-season grasses. As a result there were fewer differences between plant communities in amount of bareground and vegetation cover in this study than in their study.

Table 4. Infiltration rates (mm/hr) for 3 grazing treatments on 4 dates.

	Date			
Treatment[1]	Aug. 1982	Nov. 1982	Mar. 1983	July 1983
RG-14				
Before	95a(x)[2]	96ab	84a(y)	72b(z)
After	64b(z)	87bc(x)	72a(y)	82ab(x)
RG-42				
Before	81a(y)	95ab(x)	69a(z)	94a(x)
After	85a(x)	101a(x)	59a(y)	68b(xy)
MC	90a(x)	83c(y)	84a(y)	99a(x)

[1] See Table 1 for treatment identification
[2] Means in a row or within a column followed by same letter within parentheses.

Rotational, Yearlong Continuous, and Deferred Rotation Grazing

The effect of livestock grazing in the RG and DR treatments was generally reflected by a reduction in total vegetation cover and total standing crop and an increase in amount of bareground regardless of type of plant community. The resultant effect was rate of water infiltration generally declined and sediment production generally increased in both types of plant communities following grazing (Table 5). There were no significant differences among treatments in infiltration rate when the MC, before-grazing RG and DR treatments, and EX were compared. The EX and MC treatment had the lowest sediment production, while generally the after grazing treatments had the highest. Wood and Blackburn, (1981a, 1981b) working at the same location, reported similar results when comparing infiltration rate and sediment production on a Leeray clay in the MC, DR, and EX treatments.

Table 5. Mean (m = 10) infiltration rates (mm/hr) and sediment produc tion (kg/ha) for 2 types of plant communities in 5 grazing treatments.

	Infiltration rate		Sediment production	
Treatment	Midgrass	Shortgrass	Midgrass	Shortgrass
RG-14				
Before grazing	95a[2]	75a	37bc	63ab
After grazing	64b	55b	105a	105a
RG-42				
Before grazing	81ab	86a	41bc	61ab
After grazing	85a	79a	75ab	53ab
DR				
Before grazing	86a	80a	28c	45b
After grazing	81ab	68ab	71ab	54b
MC	89a	85a	35c	30b
EX	88a	—[3]	23c	—
Mean	84	75	49	55

[1] See Table 1 for treatment identification.
[2] Means in a column followed by same letter are not significantly different at $P \leq 0.05$.
[3] The shortgrass plant community did not occur in the exclosure.

Predictive Models

The two predictive models from the pooled data developed were:

$$Y_1 = 77.32 - 0.46X_1 + 0.004\,X_2 \quad R^2 = 0.16 \quad df = 339$$
$$Y_1 = 14.7 + 0.18X_1 - 0.0044X_2 \quad R^2 = 0.20 \quad df = 284$$

Where Y_1 = rate of water infiltration (mm/hr)

Y_2 = total sediment production (kg/ha)
X_1 = percentage bareground (%)
X_2 = total vegetation standing crop (kg/ha)

Amount of bareground was the first variable selected in both models, accounting for 12% of the variation in the infiltration model and 16% in the sediment production model. The 2 models substantiate that as bareground increased in this study, infiltration rates decreased and sediment production increased. Likewise, as amount of vegetation standing crop increased, infiltration rates increased and sediment production declined. The addition of percentage sand content in the soil and aggregate stability to the infiltration model increased the R^2 to 0.20 while the addition of aggregate stability and surface roughness to the sediment production model increased the R^2 to 0.24.

Although our final R^2 values are less than those reported by Wood and Blackburn (1981a, 1981b), both models were highly significant ($P<0.0001$). The R^2 values, even though they were low, still helped to explain the factors affecting infiltration rates and sediment production. We chose not to develop our models as a function of type of grazing treatment, plant community, or season of year because our basic objective was to identify the most important factors contributing to differences in watershed condition regardless of grazing treatment, type of vegetation, or season of year. Both models clearly indicate amount of bareground and vegetation standing crop were the 2 major variables affecting watershed condition in this study.

Conclusions

Basing our conclusions on the results of this study, we accept our basic hypothesis that watershed condition will vary among grazing treatments as a function of their effect on various soil and vegetative factors. We further conclude that differences among grazing treatments are directly related to their effect on amount of bare ground. Grazing treatments which cause a reduction in vegetative cover and standing crop, with a corresponding increase in bare ground, tend to reduce water infiltration rates and concurrently enhance sediment production. This may be realized over the long-term by inducing a change in plant species composition from midgrass to shortgrass dominated communities or over the short-term by consuming and/or trampling the available vegetation standing crop. Further, we find no evidence from the results of this study that would suggest any association exists between watershed condition in a rational grazing treatment and number of paddocks. There were no benefits of RG compared to MC grazing when considering the measured hydrologic parameters.

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