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Project Summary

Rangeland Watershed Water Budget and Grazing Cattle Waste Nutrient Cycling

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This research project was designed to determine baseline data concerning the source, movement, concentration and factors affecting nonpoint pollutants in runoff from a representative tallgrass prairie watershed grazed by cattle in North Central Oklahoma. A 60-hectare (ha), tallgrass prairie watershed moderately grazed yearlong by beef cows and calves was instrumented to determine precipitation and runoff amounts and concentrations of sediment, nitrogen, phosphorus, potassium, BOD, COD, and TOC. Soil types, range sites and topography were surveyed, mapped and described. Soil water content, live and standing dead vegetation biomass, dung pat density, ground cover and herbage utilization were determined at 25 locations on the watershed periodically from April 1976 through October 1978. Concentrations of N, P, K, Ca, and structural carbohydrates were determined in live and standing dead vegetation and dung collected periodically from different locations on the watershed. Stocking density and grazing pressure were calculated. Independent site factors were used in regression equations to predict plant species abundance, live and standing dead vegetation biomass, utilization and dung pat density and biomass. Changes in dung chemical composition over time were determined for dung deposited during different seasons and in place for different periods of time.

The amount of nonpoint source pollution contributed to receiving waters by runoff from the watershed was comparable to that from tallgrass prairie watersheds in other parts of the United States and was minimal when compared to other nonpoint sources of pollution such as cropland and fertilized pastures. Significant runoff occurred in every season, but spring was the season with the greatest runoff and pollution potential because precipitation and soil water content were greatest and ground cover was lowest at this time. Sediment was the most significant pollutant and was contributed primarily from the sides of drainageway channels. Direct overland movement of dung into stream channels was minimal because standing vegetation and ground litter on the lower slope positions acted as a filter.

Plant transpiration rapidly depleted soil water content between mid-May and mid-July, especially in the upper 35-cm of the soil profile. This drawdown reduced the probability of runoff from all precipitation events except intense thunderstorms during the summer and fall. Tallgrasses, standing vegetation and ground cover were much greater on loamy prairie range sites on lower slope positions, whereas dung density and biomass were greater on the upland, more xeric shallow prairie sites. Areas selected by cattle for bedgrounds and resting areas had a much greater influence on dung distribution than did areas selected for grazing. Nutrient concentrations in dung decreased to a steady state level in less than six months regardless of the season of deposition.

This Project Summary was developed by EPA's Robert S. Kerr Environmental Research Laboratory, Ada, OK, to an-

nounce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

As the demands on rangelands for meat, water and other products and uses become more intense, the need to understand the fundamental relationships in rangeland ecosystems becomes more critical. Grazing by herbivores and water production have historically coexisted on rangelands. They will continue to coexist as long as we choose to utilize meat from grazing animals and water from runoff and as long as rangeland managers have and use the knowledge necessary to make grazing and water production compatible.

Relatively little research has been or is being conducted on potential water pollution from rangeland watersheds grazed by livestock. The need for research on water budgets and nutrient inventories and cycling on rangeland is critical and immediate. Rangelands and forest-ranges could provide either a large area for animal waste disposal or be a potentially significant source of water pollution. The realization of a beneficial and safe land use instead of a detrimental consequence of natural herbivore grazing depends largely on the capacity of different rangelands to receive and hold animal wastes without exceeding the acceptable level of pollutants in water runoff.

Because of the greater demands on rangeland to produce red meat while maintaining production of water of acceptable quality (P.L. 92-500) and the limited amount of information concerning potential water pollution from rangeland watersheds grazed by cattle, this study was designed to determine on a North Central Oklahoma rangeland watershed grazed by beef cattle 1) the source, transfer and transformation of potential pollutants, 2) the hydrologic and meteorologic parameters necessary to establish the water budget and movement of selected nutrients, 3) effects of environmental conditions on the rate of degradation of grazing cattle dung, and 4) effects of cattle waste concentration, chemical composition and distribution on levels of nutrients in soils.

Conclusions

The amount of nonpoint source pollution contributed to receiving waters by runoff from this watershed, representative of tallgrass prairie watersheds grazed by cattle in North Central Oklahoma, is comparable to that from tallgrass prairie watersheds in other parts of the United States and is minimal when compared to other nonpoint sources of pollution, such as cropland and fertilized pastures. Significant runoff can occur in any season, but spring has the greatest runoff and pollution potential when precipitation is greatest and ground cover is at the lowest level.

Sediment is the most significant pollutant and is contributed primarily by the sides of drainageway channels. The potential danger of pollution from chemical leaching from watershed vegetation is very low compared to the potential pollution of sediment and dung movement into drainageways. Direct overland movement of dung into stream channels is minimal because standing vegetation and ground litter on the deeper soils of the lower slope positions adjacent to stream channels act as retardants and filters. Utilization of standing vegetation is also relatively light in areas adjacent to stream channels.

Soil water drawdown and recharge cycle were much more consistent all three years of the study than were precipitation amounts and distribution. Soil water content decreases from maximum to minimum within about 60 days (i.e., mid-May to mid-July) primarily due to transpiration of actively growing vegetation. Soil water content in the lower part of the soil profile is much more consistent than that in the upper part of the soil profile. Soil water content is greater in ungrazed areas where standing vegetation and plant ground litter are greater than in grazed areas. Soil water use rates are closely related to soil water availability and the amount of growing vegetation. As vegetation matures in late summer, soil water recharge is greater than evapotranspiration use.

Peak vegetation production varied each year and occurred earliest (June) during the driest year. Accumulative production of the different plant species classes amounted to 25 to 30% more production than peak standing crop. Therefore, accumulative production of rangeland vegetation should be used as a measure of total production rather than peak standing crop. Productivity of grazed vegetation is about as high as that of ungrazed vegetation. Abundance of different plant species is closely related to slope position, aspect, soil types, range sites, A horizon and total water content and grazing pressure. From 80 to 90% of the variation in live and standing dead vegetation at different watershed locations can be accounted for with regression equations and independent site factors. Large differences in plant species composition and biomass, ground cover, herbage utilization and dung distribution can be expected on the basis of range sites.

The average effective duration of dung biomass is about two years since the average dung biomass on the watershed is about twice that deposited annually by grazing cattle. Chemical concentrations of N, P, K, and Ca in fresh dung decrease with time and appear to reach a steady state in about six to eight months. Dung decomposition is apparently affected more by fragmentation and decomposer activity than by leaching or chemical transformation. Decomposition appears to be slower on the more xeric, shallow prairie range sites than on loamy prairie sites. Cattle site preference for bedgrounds and resting areas has a greater influence on dung distribution and potential pollution sources than does site preference for grazing. The effect of urine on potential pollution is insignificant because of rapid movement into the soil or volatilization of N-compounds into the air and the absence of perennial streams on the watershed.

Study Area

The study area watershed is located at latitude 33°N, longitude 97°W about 16 km northwest of Stillwater, Oklahoma. The watershed has been grazed with cows and calves for many years prior to the study. Grazing continued during the study as before. The area is generally not grazed during the last two weeks of April and during the 75 days between August 1 and October 15. The average grazing use for the watershed during the study period was 70 to 80 animal-unit-days/ha.

The watershed is part of a prairie-woodland complex on undulating terrain. The elevation varies from 290 m at the main runoff-measuring weir to 318 m at the upper end. The weighted average slope for the entire watershed is 5.7%. Topography and drainage patterns are shown in Figure 1. In addition to the contours, the map also shows the location of all permanent reference points for soil water and vegetation sampling, fenced exclosures, locations of rain gages, runoff measuring stations, and access roads.

The watershed is composed of two principal drainageways. Drainage density is 8.9 km/km^2. The south drainageway is 715 m in length, has a channel gradient of 2.0% and drains 51% of the watershed. The north branch is 493 m in length, has a slightly flatter gradient, 1.5%, and drains 42% of the watershed. The remaining 7% of the watershed drains directly into the

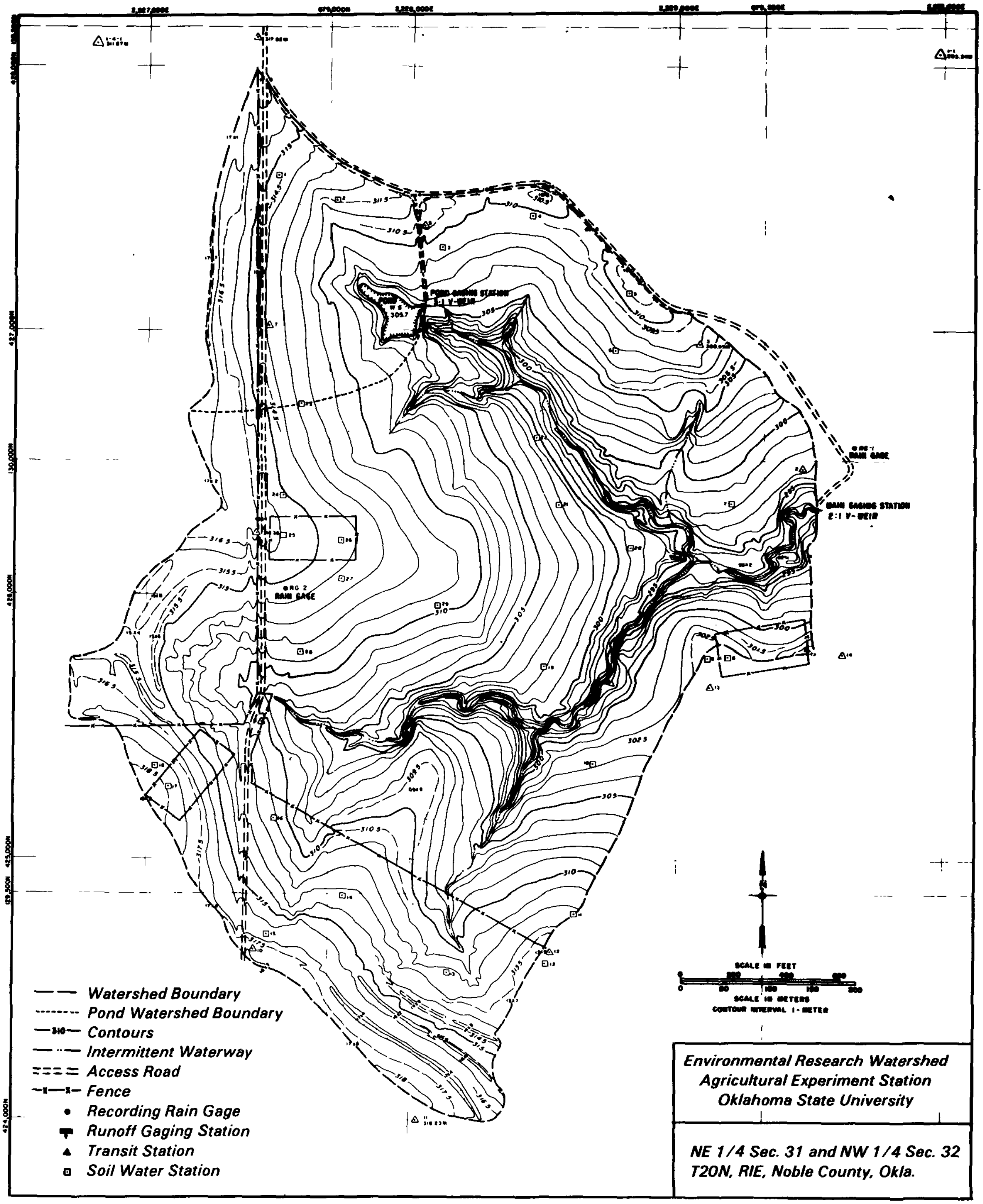

Figure 1. Topographic map of experimental research watershed in North Central Oklahoma.

main drainageway, which has a 1.0% slope.

Total drainage area of the watershed is 57.7 ha. Land use includes 53.8 ha rangeland, 3.6 ha cultivated land planted each year to winter wheat, and a 0.3 ha stock water pond located at the upper end of the north drainageway. The pond has a drainage area of 6.9 ha, approximately 13% of the total watershed area. In general soils of very-fine or fine-loamy, mixed thermic Vertic Haplustalfs occupy 70% of the watershed. The proportion of soil orders is 78% Alfisols, 16% Mollisols and 6% Inceptisols. Loamy soils developed under tallgrass prairie vegetation are most common. Soil fertility in the A horizon is high. A B_2 horizon is generally present. Soil water-holding capacity is good except on the limited area of coarse-textured soils.

Shrubs and trees are common along drainageways and on shallow, coarse-textured soils overlying fractured sandstone. Range sites include Loamy Prairie, Claypan Prairie, Shallow Prairie, Shallow Savannah and Sandy Savannah.

Results

Precipitation and runoff data per 10-day period from April 1976 through December 1978 are shown in Figure 2. The limited number of runoff events is readily apparent. None occurred during the first 13 months of the study. The first runoff event produced the greatest amount of runoff. In that 10-day period about 25% of the 160+ mm precipitation moved off the watershed. Although runoff events were infrequent, runoff occurred at least once during all seasons.

Table 1 is a summary of the number and magnitude of rainfall events and related runoff events for each calendar year of the study. There was a total of 274 rainfall events, of which 42 resulted in runoff. In 1976 only one of 20 rainfall events resulted in runoff. At that, the runoff was almost insignificant. In 1977 and 1978 there was an average of one runoff event for every nine rainfall events. However, the total observed runoff was five times greater in 1977 than in 1978. During 1979 when rainfall was higher than normal there was a runoff event for each 3.3 rainfall events.

Table 2 shows sediment loss rates for the 12 runoff events in terms of watershed area and amount of runoff. As expected, the larger runoff events produced the greatest sediment losses per hectare. However, when expressed in terms of kilograms per hectare per milli-

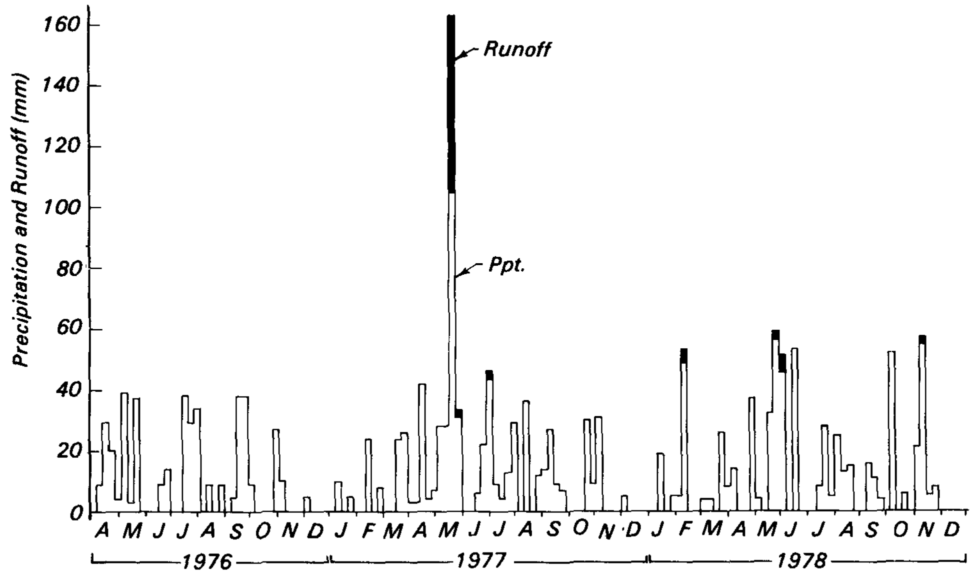

Figure 2. *Precipitation and runoff for 10-day periods during study period.*

Table 1. *Summary of Rainfall and Runoff Events (April 1976 - December 1979) Environmental Research Watershed, Oklahoma State University*

	Precipitation				Runoff		
Year	No. of Events	Largest Event (mm)	Observed Total (mm)	Percent of Long-Term Average	No. of Events	Largest Event (mm)	Observed Total (mm)
1976*	40	39.5	420.4	59	2	0.97	1.96
1977	77	101.6	722.2	87	9	44.27	62.18
1978	84	51.3	676.6	82	9	5.82	12.44
1979	73	75.0	886.0	107	22	23.60	101.73

**Period includes April - December only.*

Table 2. *Summary of Sediment Loss by Runoff Environmental Research Watershed, Oklahoma State University*

Runoff Date	Rainfall (mm)	Runoff (mm)	Sediment Loss (kg/ha)	Sed/Runoff Ratio (kg/ha/mm)
20 May 77	101.55	44.27	687.6	15.53
23 May 77	38.61	13.56	193.7	14.28
27 May 77	22.35	1.85	6.9	3.75
1 July 77	45.72	1.72	32.1	18.68
14 Nov 78	47.75	0.94	6.8	7.30
18 March 79	20.32	0.56	11.8	21.21
22 March 79	55.37	16.43	411.3	25.03
10 April 79	26.92	1.85	34.7	18.70
2 May 79	99.31	32.03	294.7	10.55
9 June 79	75.95	8.76	126.0	14.39
5 July 79	52.07	2.36	25.9	10.98
17 July 79	82.55	23.47	737.6	31.43
TOTAL	668.47	147.80	2569.1	

Weighted Average Sediment/Runoff Ratio = 17.38 kg/ha/mm meter (kg/ha/mm) of runoff, the sediment loss rates were quite similar for most of the events. Very little of the sediment loss from the environmental watershed was caused by raindrop impact on bare areas. Inspection of the watershed during rainfall leads us to believe bank erosion was largely responsible for the sediment load that was collected at the lower end of the watershed.

Total soil water in the soil profile during the 32-month sampling period varied from a low of about 90 mm in August of each year to a high of 200 mm in late May of 1977 and 1978. The soil water storage capacity of the watershed soil was about or slightly greater than 110 mm. The soil water depletion and recharge patterns were relatively consistent each of the three years. Soil water depletion was very rapid in late spring during the period of most rapid plant growth. Most of the soil water depletion was due to transpiration rather han evaporation. Recharge occurred after he low point in August regardless of the amount of precipitation received. In genaral maximum depletion occurred in about a three-month period. The average soil water contents at all depths in the soil profile were consistently greater where grazing was excluded than where grazing was allowed. Although soil characteristics e.g., texture) for the paired soil water sampling locations differed slightly, the differences in soil water content appear to be due primarily to vegetation cover. The average standing, aboveground vegetation kg DM/ha) for ungrazed and grazed areas were 3160 and 1730, respectively.

The rate of soil water use or loss from he soil due to evapotranspiration is shown n Figure 3. Soil water use rates were calculated as (precipitation - runoff - difference in total soil water in succeeding sampling dates) divided by the number of days between sampling dates. The rate of soil water use was related to soil water availability and vegetation growth. In general the soil water use rates shown in Figure 3 appear to be more realistic measures of evapotranspiration than pan evaporation or any other parameter that does not consider temperature, available soil water or water use by the actively growing plants present at a particular time in the year.

Ground litter values were most variable, both within a single sampling date and between sampling dates. Although runoff hrough the weir was not frequent, intense rainstorms of short duration often moved recently deposited ground litter on steep slopes and ridgetops down to lower slopes

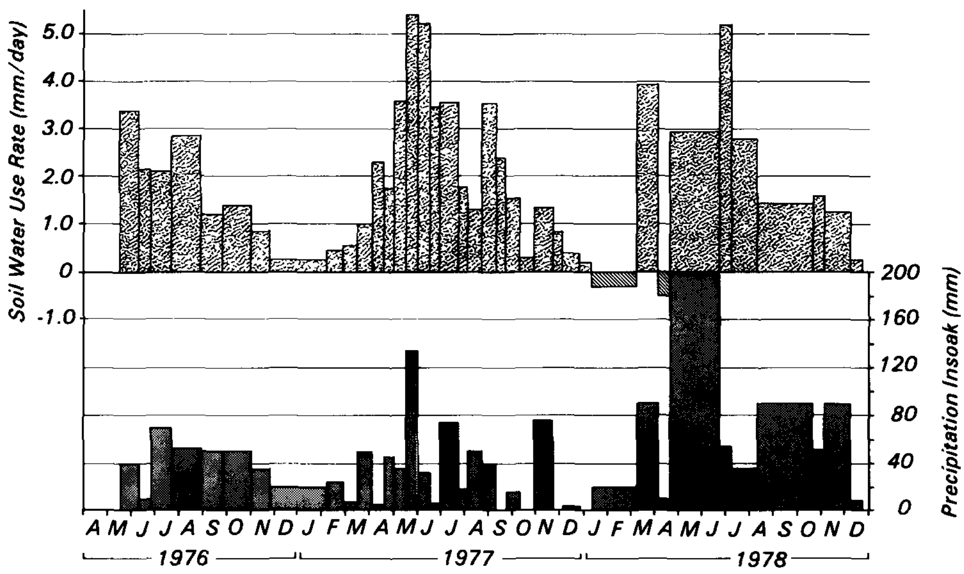

Figure 3. Soil water use rate (mm/day) in relation to precipitation and insoak (mm).

where it was accumulated. Greater amounts of standing vegetation on the lower slopes acted as a barrier to overland flow of runoff water and ground litter. Ground litter was generally least in early spring after winter decomposition.

Standing dead biomass was more consistent than ground litter both within a single sampling date and between sampling dates. Standing dead biomass was least in early spring and greatest in early winter. Standing dead biomass was less in 1977 and 1978 because of reduced live plant biomass in 1976 and 1977, respectively. Live plant biomass was less in 1976 and 1977 than in 1978. Peak production was 1420 kg/ha in mid-June 1976, 1440 kg/ha in early June 1977 and 1630 kg/ha in mid-August 1978. Summer rains in 1977 caused a second peak production in early September. Summer rains in 1978 maintained peak production from late June through mid-August. In this study, the accumulative or sum-of-the-peaks production was 24%, 14%, and 17% greater than the greatest single peak production estimate in 1976, 1977, and 1978, respectively.

The watershed occupies portions of two pastures. About 80% of the watershed is in one pasture and 20% is in another pasture. Stocking density, grazing pressure and herbage utilization were calculated for each portion of the watershed in separate pastures and then adjusted to show average stocking density (animal units/hectare [a.u./ha]), grazing pressure (animal units/1000 kg of standing herbage) and utilization (kg herbage/hectar; %) for the watershed. The stocking density on the watershed for the study period, ranged from a low of 0.14 a.u./ha to a high of 0.38 a.u./ha when the watershed was grazed. The yearlong average stocking rate was 0.20 a.u./ha in 1976, 0.34 a.u./ha in 1977 and 0.28 a.u./ha in 1978. In general grazing pressure was less variable than stocking density. However, the potentially high pollution period in late winter is shown more clearly. During this period standing herbage biomass is relatively low because of winter grazing and pressure from snow and freezing rain.

Utilization by cattle of the live vegetation, by species class, and of the standing dead vegetation was used to determine vegetation removed or trampled and various factors related to forage value, diet composition, selectivity and temporary changes in herbage composition due to grazing. Utilization values were determined by averaging caged and grazing residue species class biomass values separately for all samples. All other utilization-related factors were determined from these averages.

The average, total live and standing dead herbage utilized between April 12, 1976 and October 9, 1978 was 950 kg/ha or about 32% of the herbage available. The exclosure study showed the average total live vegetation in the exclosures was about 42% greater than that outside the exclosures. Even with relatively heavy winter grazing on the upper slopes, exclosures had only 50% more standing litter than adjacent grazed areas. The proportion of live vegetation utilized (31.2%) was about the same as the proportion of standing dead utilized (32.5%).

Within the live vegetation about 30% of the grass biomass and 34% of the forb biomass was utilized. Utilization values for tall and midgrasses were lower than those for forb species class and lower than those for shortgrasses, cool season grasses (primarily *Bromus japonicus*) and *Schizachyrium scoparium* (SCSC, little bluestem). The utilization figures are the result of site selection as well as species selection. In addition, these values include utilization data from two winter grazing periods. Results from small, uniform watersheds may be misleading if extrapolated to large, diverse rangeland watersheds.

Based on utilization (%) and available herbage composition (%), grasses were twice as important for forage as were forbs. Of all species classes, SCSC had the highest forage value index and was about three times more important as forage than were tallgrasses. Grasses were estimated to contribute about 64% of the diet; forbs contributed the remaining 36% during the growing season.

Compared with chemical analyses of tallgrass prairie vegetation in this area by other scientists, the average nitrogen and calcium contents in live vegetation was much higher than usual, especially in summer and fall. Potassium content was about average. Phosphorus content was about average in the spring, lower during June and July and average or above average in August and September. The generally higher than reported nutrient content in our samples was because of a lower percentage of tallgrasses with corresponding higher percentage mid- and shortgrasses and forbs, lower rainfall and reduced production, and recycling of nutrients through grazing animals.

Nitrogen, phosphorus and potassium contents in live vegetation decreased from a high in early spring to a low in summer at a rate closely resembling the decrease in soil water content. Changes in standing dead composition were uniformly cyclic with seasons and generally reflected the effects of drought and plant maturity on different species classes. Changes in chemical composition of dung reflected the effects of nutrient availability in forage and supplemental feed.

Chemical yields from all plant materials (biomass X chemical composition) were 50 kg N/ha, 25 kg Ca/ha, 16 kg K/ha and 3 kg P/ha on the watershed. Ground litter, usually because of its greater biomass, produced half or more of the total nutrient yields for N, P, and Ca, but only 5 kg/ha of the 16 kg K/ha. Total yields were relatively low for all nutrients as compared to those from highly fertilized pastures and croplands. Total digestible dry matter (DDM) yield in standing vegetation ranged from a low of about 200 to 300 kg DDM/ha in late winter to a high of 1220 kg DDM/ha in mid-summer of 1978. Live DDM yields varied relatively more than those in standing dead vegetation.

The average effective duration of dung biomass on the watershed is estimated to be about two years. Based on the weight of dung collected from 30-m diameter areas around each of 25 locations on April 1, 1977 dung biomass on the watershed averaged 900 kg/ha and ranged from 60 kg/ha to 2900 kg/ha. The average daily dung deposition rate was about 5.0 kg/day/a.u., and the annual dung deposition was 460 kg/ha/yr (0.25 a.u./ha X 5.0 kg/day/a.u. X 365 days/yr). Since the average dung biomass on the watershed was 900 kg/ha and the annual deposition rate was 460 kg/ha, the average weight loss of dung biomass is about 50% per year.

The locations with the greatest dung biomass were all along the upper slopes of the watershed. Five of the six locations with the greatest dung biomass were on soils with a sandy loam surface horizon. Since cattle usually defecate after rising from their bedground, these areas may be preferred bedgrounds and resting areas. Cattle may prefer sandy soils for bedgrounds in the winter since sandy soils are drier and warmer than are fine-textured soils with a higher soil water-holding capacity. Another factor affecting dung distribution may be a slower rate of decomposition on sandy soils. Drier soils with lower soil fertility, lower soil water content and less standing vegetation and ground litter would be expected to have lower levels of metabolic activity of decomposer microorganisms.

The simple linear correlation coefficient between dung biomass per location and dung pat density per location was +0.93. The regression coefficient of +0.33 indicates the average dung pat weighed about 0.33 kg (SE=0.03 kg).

Small differences in dung density and biomass due to range site and plots of accumulative dung density over time per location indicated similarities in dung deposition pre- and post-removal due to range site, but differences in deposition distribution patterns within range sites. Dung deposition was much greater on shallow prairie range sites than on loamy prairie range sites.

Regression equations developed to predict pre-removal dung density and biomass and post-removal dung density accounted for about 80 to 90% of the variation. A horizon soil water and sodium contents and moisture economy index were inversely related to dung density and biomass, whereas A horizon potassium content was directly related to dung density and biomass in both equations. In general dung density and biomass were greater on the warmer and more xeric sites.

Dung deposition measures were not highly correlated with herbage utilization measures. The magnitude of the correlation coefficients between dung deposition and utilization of standing dead were, however, about twice the magnitude of correlation coefficients between dung deposition and utilization of live vegetation. Therefore, cattle apparently spent more time grazing in the areas of greatest dung deposition in the winter than during the growing season. Standing dead utilization was influenced primarily by abiotic site factors, whereas live vegetation utilization was influenced to a high degree by live production and species composition which were significant only during the growing season.

The highest dung deposition values were for those locations used as bedgrounds and resting areas and where the dung decomposition rates would be lowest. These locations coincided with the locations with a high degree of standing dead utilization, primarily on the relatively high, wide and flat ridgetop in the west central portion of the watershed. Both live and dead utilization were relatively low on the lower slope positions along drainageways; however, live utilization was frequently much higher than dead utilization in these areas. Cattle apparently prefer to graze green tallgrass material during the growing season, but not dead tallgrass material in any season.

Changes in N, P, K, and Ca concentrations in dung in place on the watershed for various periods of time were not consistent with respect to nutrient or season of deposition. Averaged over all deposition seasons, there was only a slight decrease in N content over time. Essentially, those factors influencing the N content of dung at the time of deposition strongly outweighed environmental factors influencing loss of N after deposition. The phosphorus content in dung also varied due to season of deposition and period of time subject to degradation. In general P concentrations increased during the first 30 to 90 days after deposition and decreased after about 90 days in place. The change in potassium contents over time was much more consistent than those of N and P contents. K content decreased rapidly in the first 15 to 30 days in place, then stabilized over the remainder of the period. Changes in calcium content in dung over time were similar to those of K content. However, the relative loss of Ca over time was not as great as that of K. Changes in concentrations of structural fiber components (i.e., ADF, ADL and CEL) were determined over a 240-day degradation period for dung deposited in July 1976. ADF and ADL increased over time, whereas CEL decreased over time.

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The complete report, entitled "Rangeland Watershed Water Budget and Grazing Cattle Waste Nutrient Cycling," (Order No. PB 83-180 844; Cost: $26.50, subject to change) will be available only from:

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