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ENERGY AND NITROGEN FLOW THROUGH CATTLE ON THE SHORTGRASS PRAIRIE

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ABSTRACT

There were five major points discussed in this report: (1) Energy and nitrogen removal by cattle from the shortgrass prairie ecosystem in northern Colorado were determined. (2) Grazing intensity did not greatly affect the percentages of those nutrients that were consumed in the diet which were retained in the animals' tissues and subsequently removed. (3) The total amount of the nutrients removed from the ecosystem increased with increased grazing intensity. (4) Estimates of the percentage of the nutrients consumed that were removed were 5.5% and 6.7% for energy on heavily and lightly grazed pastures respectively, and 17.4% and 21.3% for nitrogen on heavily and lightly grazed pastures, respectively. (5) Estimates are presented for the proportions of the consumed nutrients that are partitioned to the atmosphere and soil as a result of the various digestive and physiological processes in the ruminant.

INTRODUCTION

The flow of energy and nitrogen among trophic levels has been studied in many different ecosystems (Odum 1959). However, research showing the role played by large free-ranging herbivores in the flow of nutrients between trophic levels and within the consumer trophic level is limited. The objective of this research was to partition the flow of energy and nitrogen through cattle on the shortgrass prairie with grazing at different intensities. This will provide quantitative information on each of the nutrients, indicating the amounts removed from the ecosystem and how much is returned in the various forms.

LITERATURE REVIEW

Various segments in determining the flow of these nutrients required that literature values be used. Therefore, we have presented a literature review that covers most of the aspects of energy and nitrogen partitioning with a ruminant. Gross energy (GE) intake is commonly partitioned into fecal energy (FE), urinary energy (UE), gaseous products of digestion (GPD), heat increment (HI), and net energy. In general, these terms describe the value of a particular feedstuff and reflect its ability to supply energy to animals. Fecal energy is an indirect and inverse expression of the apparent digestibility of a food. This can be affected by plane of nutrition, amount of fiber in the diet, species of animal consuming the ration, nutrient deficiencies, frequency of feeding, feed preparation, associative effect of feeds, and adaptation to the ration (Church 1969). Maynard and Loosli (1962) showed PE to be approximately 47% and 62% of the GE intake with sheep consuming soybean hay and soybean straw. Crampton and Harris (1969) stated that an average of 30% of GE intake appears as FE. Cattle fed a ration of corn and hay partitioned 41.8% of the GE intake into FE (Flatt et al. 1969).

Relatively uniform amounts of GE are partitioned to UE, although it is affected by some factors. Blaxter, Clapperton, and Martin (1966) reported that as feed intake increases for most rations, the proportion of UE decreases. It appeared that UE had no relationship to apparent digestibility. Denissov (1969) stated that UE amounted to 5.1% and 5.4% of the GE intake with green and dry roughages, respectively. Flatt et al. (1969) found that dairy cattle partitioned approximately 2.6% of the GE intake into UE. Church et al. (1971) indicated that steers channeled about 5% of the GE intake into UE on either alfalfa or concentrate diets.

A portion of the GE intake by ruminants is partitioned into GPD as a result of rumen fermentation. Although several different gases are produced, most of the energy in the GPD is in the form of methane. Flatt et al. (1969) indicated that approximately 3.3% of the GE intake of dairy cows was partitioned into methane. They also stated that as intake increased the percent of GE lost via GPD decreased. Denissov (1969) showed that methane accounted for 6.1% and 7.3% of GE intake with green and dry roughages, respectively. Cattle on maintenance diets channel at least 7% of GE intake into methane (Crampton and Harris 1969). Church et al. (1971) reported that 7% and 8% were typical GPD values for cattle on concentrate and alfalfa diets, respectively. Czerkowski, Blaxter, and Wainman (1966) showed that methane production was inversely related to the unsaturated fatty acid content of the diet. Blaxter and Clapperton (1965) have shown that the portion of GE intake comprised of methane decreased with increased levels of intake with diets varying in digestibility between 50% and 90%.

Heat increment is the energy released during digestion and metabolism of food material. Estimates of the amount of energy so produced vary greatly. Crampton and Harris (1969) reported that 3% to 20% of the GE intake appeared as HI. Church et al. (1971) stated that HI values approached those of fecal energy, amounting to 27% and 29% of the GE intake and 58% and 38% of the metabolizable energy (ME) for cattle and sheep, respectively. Armstrong and Blaxter (1957) reported that 35% to 70% of the ME was partitioned into HI in cattle. Heat increment involves many different processes and very little work has been conducted to define and quantify each process. Baldwin (1968) attempted to partition all the energy appearing as HI and was able to account for 60%. Blaxter and Graham (1955) estimated that approximately 16% of the HI is the result of mastication, fermentation, and carbohydrate digestion of dried pelleted grass. An additional 5% was channeled to HI if the ration was long-dried grass.

Maintenance nutrition is that level of feeding that provides the animal with just enough energy to satisfy its basal metabolism and activity requirements. Basal metabolism is approximately 70 kcal $bW^{.75}$ (Kleiber 1961), although it can be increased when ambient temperatures are above and below the thermal neutral zone (Whittow 1971). The maintenance requirement can be greatly affected by the level of activity. Crampton and Harris (1969) indicated the energy expenditure for activity was 0.33 × 70 kcal $bW^{.75}$. Church (1972) reported that about 2.10 Mcal of digestible energy (DE) are expended daily by a 1000-lb cow that travels 2 miles (3.2 km). Studies with sheep showed that 0.66 cal/kg/m traveled on the horizontal and 7.88 cal/kg/m traveled on the vertical were utilized during grazing (Corbett, Leng, and Young 1969). Coop and

Hill (1962) stated that grazing animals required 20% to 50% more energy for maintenance than sedentary animals. Other research indicated that the muscular energy expenditure of sheep accounted for over 40% of the maintenance energy if the animals were grazing and only 11% if they were caged (Graham 1965).

The partitioning of dietary nitrogen within ruminants is complicated and can be highly variable. Nitrogen can escape the body via feces, urine, GPD, sloughing of hair and hooves, and through insensible losses. The nature of the feedstuff appears to have a great effect on the partitioning, especially with ruminants. The apparent digestibility of nitrogen in a roughage ration generally varies from 50% to 60% while the apparent digestibility of the nitrogen of cereal grains is often 80% or more (National Research Council 1972). Nitrogen that appears in the feces is derived from undigested food material, undigested gastrointestinal microorganisms, sloughed intestinal tissues, and endogenous nitrogenous secretions. High levels of dietary fiber result in increased quantities of intestinal tissue being sloughed (Church et al. 1971). When the digestibility of protein is low, the percentage of dietary nitrogen appearing in the feces is increased (Maynard and Loosli 1969).

Most of the nitrogenous metabolites of body tissues and nitrogenous nutrients that are absorbed but not utilized are excreted in the urine (Church 1969). The amount of nitrogen excreted in the urine varies directly with the nitrogen intake. Church et al. (1971) presented figures showing that with restricted protein diets urinary nitrogen excretion is markedly less than if the animals are consuming high levels of protein.

The amount of nitrogen lost from the body via rument gases can be sizable. Church (1969) reported that cattle eructated approximately 154 l of rumen gases daily, of which about 7% is comprised of nitrogenous gases. Insensible nitrogen losses can be great in monogastrics (Albanese 1959), but estimates of the amount of these nitrogen losses apparently are not available for ruminants.

STUDY AREA AND METHODS

The field portion of this study was conducted on the shortgrass prairie of the Central Plains Experimental Range (CPER) in northeastern Colorado. The area is described in detail by Bement (1968).

Data were collected during the months of June, July, and August for 3 successive years, 1970-1972. Dry matter intake (DMI) and cattle weights were measured on two different grazing intensities twice monthly (see Table 1 for stocking rates). Food intake rates were determined according to the water intake method of Hyder (1970). Dry matter digestibility (DMD) was determined from the *in vitro* digestion of diet samples collected from esophageal fistulated cows. The *in vitro* digestion procedures used were those of Tilley and Terry (1963). The nitrogen content of the diet was estimated by analysis of vegetation samples collected during the summer months of 1972. Nitrogen content of the feces was determined by Kjeldahl procedures run on fecal grab samples which was collected monthly during 1972.

The other values needed to calculate the partitioning of energy and nitrogen were not measured so average values reported in the literature were used. Basal metabolism rates (BM) were calculated to be 70 kcal $bW^{.75}$ (Kleiber 1961). The data of Denissov (1969) for UE and GPD of 5.1% and 6.1% of the GE intake, respectively, were used to estimate these variables.

Table 1. Quantities of forage consumed (kg dry matter) by heifers grazing heavy- and light-use pastures.

Pasture	Cows (no.)	June		July		August		Total	
		Total lb	Average kg dm/ cow/day	Total lb	Average kg dm/ cow/day	Total lb	Average kg dm/ cow/day	Total lb	Average kg dm/ cow/day
Heavy-use									
1970	35	6,783	6.46	6,629	6.11	7,508	6.92	20,920	6.50
1971	30	6,228	6.92	6,743	7.25	5,701	6.13	18,672	6.77
1972	27	5,111	6.31	5,901	7.05	4,863	5.81	15,875	6.39
Total	92	18,122	6.57	19,273	6.80	18,072	6.29	55,467	6.55
Light-use									
1970	12	2,671	7.42	2,600	6.99	2,894	7.78	8,165	7.40
1971	12	2,632	7.31	2,846	7.65	2,637	7.09	8,115	7.35
1972	12	2,675	7.43	2,351	6.32	1,753	4.74	6,789	6.15
Total	36	7,978	7.39	7,797	6.99	7,294	6.54	23,069	6.97

The levels of protein and fat in the cattle tissues were estimated to be 17% and 15.5%, respectively, of the total body weight of growing heifers (M. Riley, personal communication). The amount of N eructated was calculated by assuming 154 l of GPD expelled daily by a cow and that 7% of the gas is N (Church 1969). The methods used to calculate the partitioning of energy are shown below:

(1) GE = DMI (kg) × 4.40 Mcal

(2) UE = 5.1% of GE

(3) GPD = 6.1% of GE

(4) FE = GE × (100 - DMD)

(5) BM = 70 $W^{.75}$

(6) Energy gained in animal tissues = Weight gains (kg) × 17% protein × 5.65 Mcal + weight gains × 15.5% fat × 9.40 Mcal

(7) HI = GE - UE - GPD - FE - BM - tissue energy.

Partitioning of N flux through the cattle was calculated according to the following:

(1) N intake = DMI × % N in forage

(2) Fecal N = DMI × (100 - DMD) × % N in feces

(3) Gaseous N = 154 l × (7% N/l) × no. of days

(4) Tissue N = $\frac{\text{Animal gain (kg)} \times 17\% \text{ protein}}{6.25}$

(5) Urinary N = N intake - fecal N - gaseous N - tissue N

Some N is partitioned into hair and hooves and N is also lost via insensible channels, none of which were estimated nor appear in the urinary nitrogen.

RESULTS

Dry matter intake, DMD, forage nitrogen content, fecal nitrogen content, and weight gains of the cattle are variables that were measured. All other values used to calculate the energy and nitrogen partitioning are representative values taken from the literature.

The number of cattle grazing the heavy-use pasture varied each year (Table 1), depending on herbage production. The stocking rate in this pasture was such that the total herbage on the ground was never less than approximately 115 kg/ha. Twelve cattle grazed the light-use in each year of the study.

The total DM intake (GE intake) was greatest from the heavy-use pasture (Tables 1 and 2) although intake per animal was greatest for those individuals using the light-use pasture. The average intake for the cattle on the light-use pasture was 0.42 kg dm or 1.85 Mcal of energy greater than for those on the heavy-use pasture. All cattle grazing in the heavy-use pasture consumed a total of 32,398 kg or 142,551 Mcal more than the all cattle using the light-use pasture. Intake per heifer on the heavy-use pasture was greatest during the month of July with June being greater than August. Heifers on the light-use pasture consumed the greatest amount during June and the least during August.

Estimates of energy excreted in the feces are based on DMD values from 1970, thus the percentage of GE appearing in feces is the same for all years (Table 3). As the grazing season progressed, the amount of fecal energy increased with heifers on the heavy-use pasture. There was 8.3% more energy appearing in the feces in August than in June for this herd. Fecal energy for the heifers on the light-use pasture was

Table 2. Gross energy (Mcal) consumed by heifers on heavy- and light-use pastures.

Pasture	Cows (no.)	June		July		August		Total	
		Mcal/cow/day[a/]	Mcal/period	Mcal/cow/day[a/]	Mcal/period	Mcal/cow/day[a/]	Mcal/period	Mcal/cow/day[a/]	Mcal/period
Heavy-use									
1970	35	28.42	29,845.2	26.88	29,167.6	30.45	33,035.2	28.60	92,048.0
1971	30	30.45	27,403.2	31.90	29,669.2	26.97	25,084.4	29.79	82,156.8
1972	27	27.76	22,488.4	31.02	25,964.4	25.56	21,397.2	28.12	69,850.0
Total	92	28.88	79,736.8	29.93	84,801.2	27.66	79,516.8	28.84	244,054.8
Light-use									
1970	12	32.65	11,752.4	30.76	11,440.0	34.23	12,733.6	32.56	35,926.0
1971	12	32.16	11,580.8	33.66	12,522.4	31.20	11,602.8	32.34	35,706.0
1972	12	32.69	11,770.0	27.81	10,344.4	20.86	7,757.2	27.06	29,871.6
Total	36	32.52	35,103.2	30.72	34,306.8	28.76	32,093.6	30.65	101,503.6

[a/] Average of Mcal/cow/day given, rather than total.

Table 3. Total energy (Mcal) and percentage of GE intake in feces of heifers grazing under heavy- and light-use regimes.

Pasture	June		July		August		Total	
	Total (Mcal)	GE intake (%)[a/]	Total (Mcal)	GE intake (%)[a/]	Total (Mcal)	GE intake (%)[a/]	Total (Mcal)	GE intake (%)[a/]
Heavy-use								
1970	11,311	37.9	12,980	44.5	15,262	46.2	39,553	42.8
1971[b/]	10,386	37.9	13,203	44.5	11,589	46.2	35,178	42.8
1972[b/]	8,523	37.9	11,554	44.5	9,886	46.2	29,963	42.8
Total	30,220	37.9	37,737	44.5	36,737	46.2	104,694	42.8
Light-use								
1970	4,842	41.2	4,359	38.1	5,093	40.0	14,294	39.8
1971[b/]	4,771	41.2	4,771	38.1	4,641	40.0	14,183	39.8
1972[b/]	4,849	41.2	3,941	38.1	3,103	40.0	11,893	39.8
Total	14,462	41.2	13,071	38.1	12,837	40.0	40,370	39.8

[a/] Percentage of GE intake given, rather than total.

[b/] Estimates based on *in vitro* DMD of 1970.

much more uniform between months and only varied 3.1%. Cattle on the heavy-use pasture partitioned 3.0% more of the GE into fecal energy than did the animals on the light-use pasture over the entire study.

Both GPD and UE were calculated as percentages of the GE intake and do not reflect on differences between grazing intensities other than those already demonstrated in GE intake. More total energy, approximately 8,695 and 7,210 Mcal, was calculated as GPD and UE, respectively, in the heavy-use pasture than in the light-use pasture (Tables 4 and 5).

The amount of GE consumed during the summers and retained in the body tissues of the heifers is shown in Table 6. The heifers grazing the light-use pasture retained 1.26% more of the GE energy intake than did those on the heavy-use pasture. The percentage retained decreased progressively with the advancement of the summer for the heifers on the heavy-use pasture, while the heifers on the light-use pasture retained more in August than in June. Energy deposited in animal tissues is the only energy that is actually removed from the ecosystem. Energy removed in this form constituted 5.46% and 6.72% of the GE intake.

Energy is returned to the environment as heat from HI, energy used for activity, and basal metabolism. The amount of GE that fell into this category was a very large portion of the GE intake (Table 7). The percentage of GE returned to the environment as heat was very similar for both herds of cattle, with 1.8% more for the heifers on the light-use pasture.

The total nitrogen intake is a reflection of the nitrogen content of the forage and the amount of food consumed. There was no difference in

Table 4. Total energy (Mcal) eructated with rumen gases from heifers grazing heavy- and light-use pastures.[a]

Pasture	Total energy (Mcal) June	July	August	Total (Mcal)
Heavy-use				
1970	1,821	1,779	2,015	5,615
1971	1,672	1,810	1,530	5,012
1972	1,372	1,584	1,305	4,261
Total	4,865	5,173	4,850	14,888
Light-use				
1970	717	698	777	2,192
1971	706	764	708	2,178
1972	718	631	473	1,822
Total	2,141	2,093	1,958	6,192

[a] All values are calculated to be 6.1% of GE.

Table 5. Total energy (Mcal) appearing in the urine from heifers grazing heavy- and light-use pastures.[a]

Pasture	Total energy (Mcal)			Total (Mcal)
	June	July	August	
Heavy-use				
1970	1,522	1,488	1,685	4,695
1971	1,398	1,513	1,279	4,190
1972	1,147	1,324	1,091	3,562
Total	4,067	4,325	4,055	12,447
Light-use				
1970	599	583	649	1,831
1971	591	639	592	1,822
1972	600	528	396	1,524
Total	1,790	1,750	1,637	5,177

[a] All values are calculated to be 5.1% of GE intake.

Table 6. Energy (Mcal) assimilated into tissues from ingested foods by heifers on heavy- and light-use pastures.

	Weight gains and energy retained in animal tissues.											
	June			July			August			Total		
Pastures	Gain (kg)	Total (Mcal)	GE[a/] (%)	Gain (kg)	Total (Mcal)	GE[a/] (%)	Gain (kg)	Total (Mcal)	GE[a/] (%)	Gain (kg)	Total (Mcal)	GE[a/] (%)
Heavy-use												
1970	789.4	1,908.4	6.39	437.2	1,056.9	3.62	515.6	1,246.4	3.77	1,742.2	4,211.7	4.59
1971	879.0	2,125.0	7.75	486.5	1,176.1	3.96	523.2	1,264.8	8.38	1,888.7	4,565.9	6.70
1972	1,054.8	2,549.9	11.34	591.5	1,429.9	5.51	231.0	558.4	2.61	1,877.3	4,538.2	6.49
Total	2,723.2	6,583.3	8.49	1,515.2	3,662.9	4.36	1,269.8	3,069.6	4.92	5,508.2	13,315.8	5.93
Light-use												
1970	240.2	575.7	4.90	471.9	1,140.9	9.97	494.7	1,195.9	9.39	1,206.8	2,912.5	8.09
1971	184.9	447.0	3.86	281.0	679.3	5.42	292.7	707.6	6.10	758.6	1,833.9	5.13
1972	317.2	766.9	6.52	300.6	726.7	7.03	237.5	574.1	7.40	855.3	2,067.7	6.98
Total	742.3	1,789.6	5.09	1,053.5	2,546.9	7.47	1,024.9	2,477.6	7.63	2,820.7	6,814.1	6.73

a/ Percentage of GE given, rather than a total given.

Table 7. Energy (Mcal) appearing as heat from heifers on heavy- and light-use pastures.[a/]

Pastures	June		July		August		Total	
	Total (Mcal)	GE (%)[b/]	Total (Mcal)	GE (%)[b/]	Total (Mcal)	GE (%)[b/]	Total (Mcal)	GE (%)[b/]
Heavy-use								
1970	13,281.1	44.5	11,871.2	40.7	12,817.7	38.8	37,970.0	41.3
1971	11,810.8	43.1	11,956.7	40.3	8,578.9	34.2	32,346.4	39.2
1972	8,905.4	39.6	10,074.2	38.8	8,558.9	40.0	27,538.5	39.5
Total	33,997.3	42.4	33,902.1	39.9	29,955.5	37.7	97,854.9	40.0
Light-use								
1970	5,018.3	42.7	4,656.1	40.7	4,889.7	38.4	14,564.1	40.6
1971	5,060.5	43.7	5,672.6	45.3	4,838.4	41.7	15,571.5	43.6
1972	4,837.5	41.1	4,520.5	43.7	3,133.9	40.4	12,491.9	41.7
Total	14,916.3	42.5	14,849.2	43.2	12,862.0	40.2	42,627.5	42.0

a/ Includes HI, BM, and activity.

b/ Percentage GE given, rather than a total given.

the amount of nitrogen in the forage between the heavy- and light-use pastures (Table 8). The nitrogen content in the forage decreased with the advancement of plant maturity. Heifers on the heavy-use pasture consumed 502.15 kg more nitrogen than did the cattle on the light-use pastures.

The amount of nitrogen excreted in the feces is a reflection of the quantity of nitrogen consumed and the digestibility of the forage. The percentage of nitrogen in the feces of both herds of cattle decreased as the summer progressed (Table 9). The percentage of fecal nitrogen from the heifers on heavy-use pasture was greater than that of the light-use herd during each month of the summer. Approximately 260.7 kg more of nitrogen was returned to the soil via feces by the heifers grazing the heavy-use pastures than by the heifers on the light-use pastures.

Estimates of the quantity of nitrogen eructated with rumen gases merely reflect the number of cattle using the pastures since all animals were considered to eructate equal amounts of gas with no seasonal or grazing intensity effects. The estimated amounts of nitrogen eructated are shown in Table 10.

The weight gains and estimates of the composition of body weight gain on the heifers indicate the amount of nitrogen retained in the body tissues. Cattle on the heavy-use pasture retained more nitrogen early in the summer than in August (Table 11). The heifers on the light-use pasture retained more nitrogen during July and August than during June. The total for the three summers indicate that the cattle under the heavy grazing intensity removed 73.08 kg more nitrogen from the ecosystem than did the cattle on the light-use pasture.

Table 8. Percentage of nitrogen in forage and nitrogen intake (kg) by heifers grazing on heavy- and light-use pasture.

Pasture	June		July		August		Total	
	N forage (%)	N intake (kg)	N forage (%)	N intake (kg)	N forage (%)	N intake (kg)	N forage (%)	N intake (kg)
Heavy-use								
1970[a]	1.81	122.77	1.50	99.44	1.36	102.11	1.56	324.32
1971[a]	1.81	112.73	1.50	101.15	1.36	77.53	1.56	291.41
1972	1.81	92.51	1.50	88.52	1.36	66.14	1.56	247.17
Total		328.01		289.11		245.78		862.90
Light-use								
1970[a]	1.73	46.21	1.50	39.00	1.45	41.96	1.56	127.17
1971[a]	1.73	45.53	1.50	42.69	1.45	38.24	1.56	126.46
1972	1.73	46.28	1.50	35.27	1.45	25.56	1.56	107.11
Total		138.02		116.96		105.76		360.74

[a] Nitrogen values for 1972 are also used for the years 1970 and 1971.

Table 9. Percentage of nitrogen in feces and total nitrogen (kg) excreted in feces by heifers grazing on heavy- and light-use pastures.[a]

Pasture	June		July		August		Total	
	Fecal N (%)	N excreted (kg)	Fecal N (%)	N excreted (kg)	Fecal N (%)	N excreted (kg)	Fecal N (%)	N excreted (kg)
Heavy-use								
1970[a]	1.87	48.07	1.74	51.33	1.54	53.42	1.72	152.82
1971[a]	1.87	44.14	1.74	52.21	1.54	40.56	1.72	136.91
1972	1.87	36.22	1.74	45.69	1.54	34.60	1.72	116.51
Total		128.43		149.23		128.58		406.24
Light-use								
1970[a]	1.74	19.15	1.59	15.75	1.41	16.32	1.58	51.22
1971[a]	1.74	18.87	1.59	17.24	1.41	14.87	1.58	50.98
1972	1.74	19.18	1.59	14.24	1.41	9.94	1.58	43.36
Total		57.20		47.23		41.13		145.56

[a] Values from 1972 are used to calculate 1970 and 1971 values.

Table 10. Liters of rumen gases eructated and amounts of nitrogen (kg) in gases from heifers grazing heavy- and light-use pastures.

	June		July		August		Total
Pasture	GPD	N (kg)	GPD	N (kg)	GPD	N (kg)	N(kg)
Heavy-use							
1970	161,700	13.10	167,090	13.53	167,090	13.53	40.16
1971	138,600	11.23	143,220	11.60	143,220	11.60	34.43
1972	124,740	10.10	128,890	10.44	128,890	10.44	30.98
Total	425,040	34.43	439,200	35.57	439,200	35.57	105.57
Light-use							
1970	55,440	4.49	57,288	4.64	57,288	4.64	13.77
1971	55,440	4.49	57,288	4.64	57,288	4.64	13.77
1972	55,440	4.49	57,288	4.64	57,288	4.64	13.77
Total	166,320	13.47	171,864	13.92	171,864	13.92	41.31

Table 11. The amount (kg) of nitrogen retained in body tissues of heifers grazing heavy- and light-use pastures.

Pasture	June	July	August	Total
Heavy-use				
1970	21.47	11.89	14.02	47.38
1971	23.91	13.23	14.23	51.37
1972	28.67	16.09	6.28	51.04
Total	74.05	41.21	34.53	149.79
Light-use				
1970	6.53	12.84	13.46	32.83
1971	5.03	7.64	7.96	20.63
1972	8.63	8.18	6.46	23.27
Total	20.19	28.66	27.88	76.73

The amount of urinary nitrogen was assumed to be the difference between the amount of dietary nitrogen and sum of the nitrogen appearing in the feces, eructated gases, and body tissues. Approximately 104 kg more nitrogen were returned to the soil via urine by heifers on the heavy-use pasture than by the cattle on the light-use pasture (Table 12). In both pastures the amount of nitrogen appearing in the urine decreased as the summer progressed.

The partitioning of dietary nitrogen is shown in Table 13. Fecal nitrogen comprised the greatest percentage of the dietary nitrogen under both grazing regimes, although the value for the heifers on the heavy-use were about 7% higher than the value for the light-use pasture. Approximately 25% of the dietary nitrogen appeared in the urine for both herds of cattle, although the heifers on the light-use pasture channeled more through this route than did those on the heavy-use pasture. Nearly 12% of the nitrogen consumed was eructated into the atmosphere with rumen gases. The difference between the two grazing intensities was small. Cattle on the light-use pasture retained 21.3% of the dietary nitrogen in their tissues compared to 17.4% for heifers on the heavy-use pasture.

DISCUSSION

The purpose of this paper was to ascertain what effects cattle have in energy flow and nitrogen cycling in the shortgrass prairie ecosystem. In order to complete the picture of nutrient cycling, many assumptions had to be made and some error accepted. It is not intended that the figures presented in this paper be interpreted other than approximations of the nutrient partitioning within the animals.

Table 12. The amount (kg) nitrogen excreted in the urine of heifers grazing heavy- and light-use pastures.

Pasture	June	July	August	Total
Heavy-use				
1970	40.13	22.69	21.14	83.96
1971	33.45	24.11	11.14	68.70
1972	17.52	16.30	14.82	48.64
Total	91.10	63.10	47.10	201.30
Light-use				
1970	16.04	5.77	7.54	29.35
1971	17.14	13.17	10.77	41.08
1972	13.98	8.21	4.52	26.71
Total	47.16	27.15	22.83	97.14

Table 13. The percentages of dietary nitrogen partitioned by grazing cattle.

Dietary nitrogen	Heavy-use pasture 1970	1971	1972	Average	Light-use pasture 1970	1971	1972	Average
				June				
Fecal	39.2	39.2	39.2	39.2	41.4	41.4	41.4	41.4
Urine	32.6	29.6	19.8	27.3	34.8	37.7	30.3	34.2
GPD	10.7	10.0	10.9	10.5	9.7	9.9	9.7	9.8
Tissue	17.5	21.2	30.1	22.9	14.1	11.0	18.6	14.6
				July				
Fecal	51.6	51.6	51.6	51.6	40.3	40.3	40.3	40.3
Urine	22.9	23.8	18.4	21.7	14.9	30.2	28.2	24.4
GPD	13.6	11.5	11.8	12.3	11.9	10.9	13.2	12.0
Tissue	11.9	13.1	18.2	14.4	32.9	18.6	18.3	23.3
				August				
Fecal	52.3	52.3	52.3	52.3	38.9	38.9	38.9	38.9
Urine	20.7	14.3	22.4	19.1	17.9	28.2	17.6	21.2
GPD	13.3	15.0	15.8	14.7	11.1	12.1	18.2	13.8
Tissue	13.7	18.4	9.5	13.9	32.1	20.8	25.3	26.1
				Average				
Fecal	47.7	47.7	47.7	47.7	40.2	40.2	40.2	40.2
Urine	25.4	22.7	20.2	22.7	22.5	32.0	25.4	26.6
GPD	12.5	12.7	12.8	12.5	10.9	11.0	13.7	11.9
Tissue	14.4	17.6	19.3	17.1	26.7	16.8	20.7	21.3

The variables having the greatest effect on the flow of energy through cattle appear to be DM intake and DMD. The heavier stocking rate resulted in a greater intake and more of the available energy in the forage being cycled through the cattle. Also, the level of intake has been shown to affect the partitioning of energy within a cow. Work has shown that the level of intake affects FE (Church 1969, Blaxter, Kielanowski, and Thorbek 1969), UE (Denissov 1969, Flatt et al. 1969), and GPD (Church 1969, Flatt et al. 1969, Blaxter and Clapperton 1965). Our data showed a slight difference in the intake $\cdot$ animal^{-1} $\cdot$ day^{-1}, probably reflecting differences in forage availability between the heavy- and light-use pastures. The DMD also affects the amount of energy cycled through cattle as well as the partitioning of energy within the cow. Feeds with low DMD can reduce intake (Church 1969) and also can cause more of the energy consumed to appear in the fecal material. The heifers on the light-use pasture digested more of the forage eaten than the heifers on heavy-use pasture. This probably reflects a higher quality of forage in the light-use pasture. However, *in vitro* digestibility studies of diets collected with fistulated cattle on the study site have varied between 30% and 75% (Rice, unpublished data), which demonstrates the tremendous variation that can exist in dry matter digestibility.

Much of the energy ingested (GE intake) was returned to the ecosystem as organic matter in the form of fecal material and urine. Fecal energy constitutes the largest proportion of the energy channeled to the soil and is greatly affected by DMI and DMD, as mentioned previously. Most of the energy found in the feces is in the form of undigested plant tissues. The remainder is in the form of endogenous secretions, undigested intestinal microbes and sloughed tissues from the digestive tract. The remainder of the energy channeled to the soil is in the urine. Flatt et al. (1969) reported that the amount of energy in the urine is relatively uniform. Most of the UE is in nitrogenous compounds such as ammonia, amino acids, urea, creatine, creatinine, and others. Reducing sugars may also be found in the urine (Church 1969).

Energy, contained in an organic form, is channeled into the atmosphere via GPD as methane. The amount of GE appearing as methane is relatively uniform when there are not large differences in diet quality or quantity, as in this study.

A very large proportion of the GE intake is returned to the atmosphere in the form of heat. Energy in this form results from HI, basal metabolism, and activity. Estimates of heat production vary greatly as pointed out in the literature review. Heat production varied between the cattle grazing under the different intensities. This is probably related to the higher DMD of the cattle on the light-use pasture. As the amount of food digested increases, HI also increases.

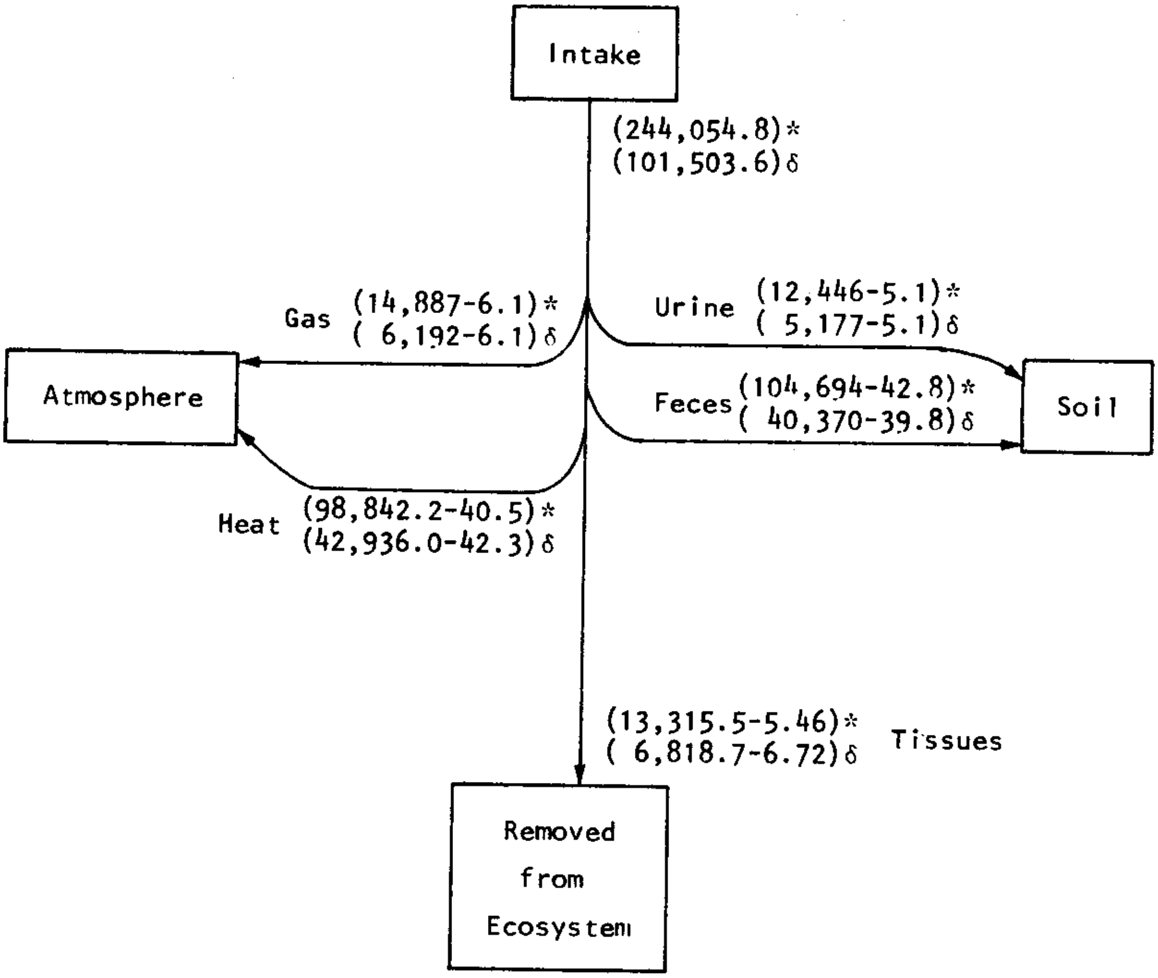
Heifers on the heavy-use pasture partitioned much more total GE into animal tissues than did the cattle on the light-use pastures, although a greater percentage of GE was channeled to tissues with the heifers on the light-use pasture. The figures determined in this study for the amount of GE partitioned into animal products (5.46% and 6.72% for heavy- and lightuse pastures, respectively) compare favorable with the value (6.0%) presented by Petrides and Swank (1965) for cattle and the value (4%) reported by Maynard (1954) for steers and lambs. Cook (1970) showed that cattle partitioned 5.45% of the GE intake into gains while grazing during the summer. A limited amount of work which allows for a comparison between species of animals indicates that beef cattle are more efficient in converting GE into edible products than are small ruminants. Davis and Golley (1963) indicated that white-tailed deer (*Odocoileus virginianus*) partitioned only 1.2% of food into growth. However, dairy cattle and monogastric animals channeled considerably more of the GE intake into edible products than beef cattle and deer (Maynard 1954). Approximately 20% of the GE intake by pigs is channeled to animal tissues and about 15% of the GE intake by dairy cattle appears in edible products.

Fig. 1 is a model representing the flow of energy through heifers on the shortgrass prairie. The diagram illustrates that most of the energy passing through the cattle is returned to the ecosystem. However, the amount of energy that is returned in a usable form is considerably less. It is very unlikely that energy returned to the ecosystem as heat or GPD will be utilized within the ecosystem.

In general, it appears that the stocking rate does not greatly affect the partitioning of energy within the ecosystem; however, the stocking rate greatly affects the total amount of energy flowing through the ecosystem.

Nitrogen flux through the heifers responded to stocking in the same manner as energy flow, i.e., the number of cattle grazing the pasture greatly affected the quantity of nitrogen passing through the animals, but did not affect greatly the partitioning of nitrogen within an animal. The largest difference attributable to stocking rates was in the percentage of dietary nitrogen channeled into feces. Although the data presented in this study do not explain this difference, it is very probable that the difference is a reflection of a poorer quality diet being consumed by the animals on the heavy-use pasture. Very little can be said about the quantities of nitrogen partitioned into urine and GPD

Figure 1. A model of the energy flow through cattle on the shortgrass prairie.[a]



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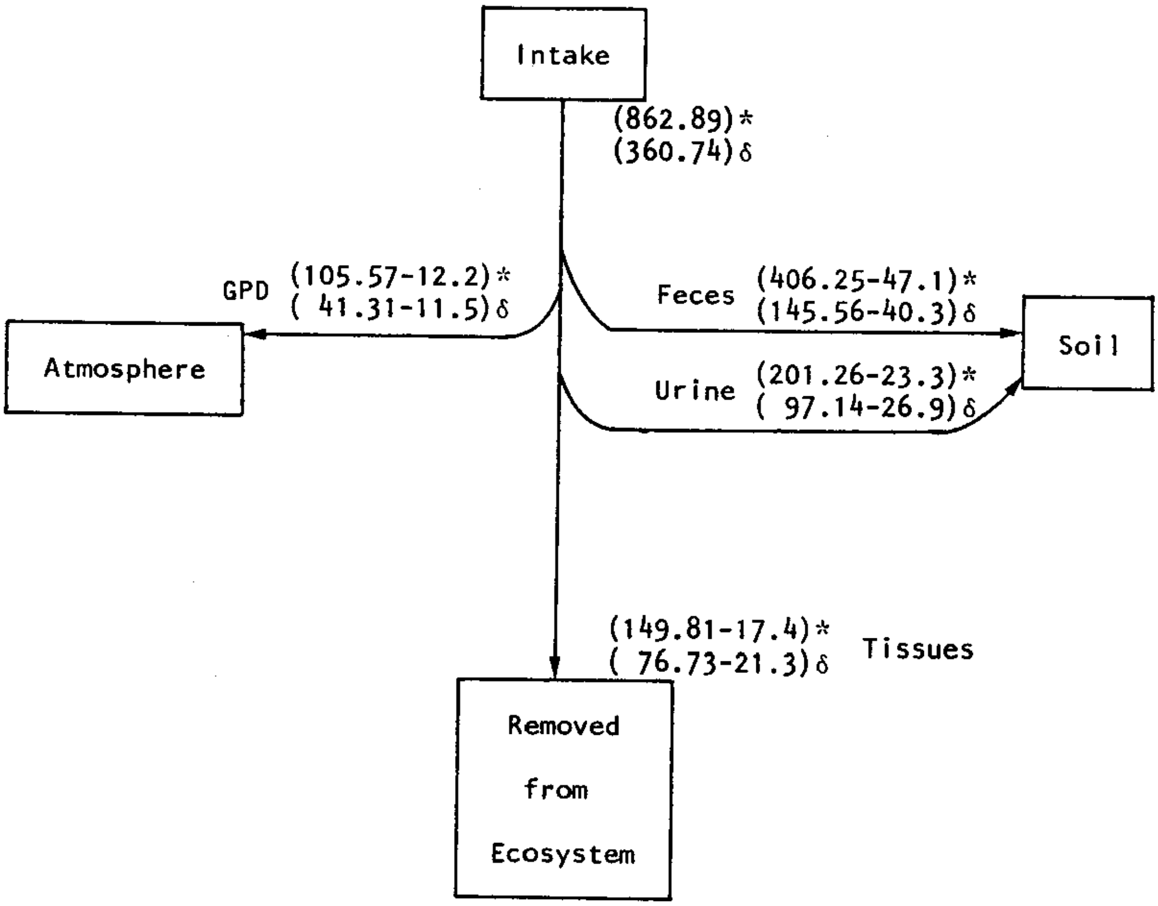
[a]Figures in parenthesis with * represent the total energy (Mcal) flow and the percentage of GE, respectively, that was partitioned to the various areas by heifers on the heavy-use pasture. Figures with δ represent the same, except they refer to heifers using the light-use pasture.

since neither was measured directly. Both do appear to account for a sizable percentage of the nitrogen intake, especially the urinary nitrogen. Approximately 4% more of the dietary nitrogen appeared in the tissues of the cattle using the light-use pasture than for those grazing the heavy-use pasture. This is also a reflection of diet quality, and perhaps quantity, that allowed for more growth by the heifers on the light-use pasture.

A model of the nitrogen flow through the heifers is presented in Fig. 2. A greater percentage of dietary nitrogen than dietary energy is removed from the ecosystem. Approximately one-fifth of the nitrogen consumed was retained by the animals. However, if the amount of nitrogen and energy partitioned to the atmosphere is considered lost from the ecosystem, then a smaller percentage of nitrogen than energy is lost from the ecosystem. Approximately 12% of the dietary nitrogen was eructated.

Figure 2. A model of the nitrogen flow through cattle on the shortgrass prairie.[a]



[a]Figures in parenthesis with * represent the total nitrogen (kg) flow and the percentage of dietary nitrogen, respectively, partitioned to the various areas by heifers on the heavy-use pasture. Figures with δ represent the same except they refer to heifers using the light-use pasture.

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