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GRAZING FREQUENCY AND ECOSYSTEM PROCESSES IN A NORTHERN MIXED PRAIRIE, USA[1]

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Abstract. The objective of this study was to evaluate for a 6-yr period the effects of a twice-over rotation grazing system (ROT) and a season-long grazing system (SL), and compare these effects with long-term grazing exclosures (NG) in terms of (1) species composition and basal cover, (2) aboveground net primary production (ANPP) and aboveground N uptake (ANPP-N), (3) rates of litter and root decomposition and N release, (4) soil N mineralization and immobilization, (5) aboveground C and N flow, and (6) grazing intensity (GI) and animal performance. The study period included the drought of 1988. No major differences were found in ANPP and ANPP-N among treatments, but there were important seasonal variations. An average of 72% of ANPP and >82% of ANPP-N occurred by mid-June. There were no differences among treatments in terms of decomposition and N release rates from litter and root biomass, or in soil N mineralization. Grazing, however, reduced the amount of C and N immobilized in standing dead and litter and the flow of C and N from standing dead to litter to soil organic matter. The NG and ROT treatment were more similar in this regard when compared to the SL treatment, and their similarities increased after the drought of 1988. There were no consistent differences in GI between the ROT and SL treatments. Before 1988 GI averaged 21% but in 1988 and 1989 GI increased to an average of 49% as a result of the drought and its aftereffects. Cumulative animal performance was similar under both grazing treatments but there were significant seasonal variations. Species composition was more responsive to grazing than were C and N flows. The differences in this case were found between the grazed and NG treatments but not between the two grazing treatments studied. There were no broad patterns of change in total plant basal cover as a result of grazing patterns or drought. Changes in species composition were highly dependent on range site. The most consistent pattern involved *Bouteloua gracilis,* which had higher relative cover in the grazed treatments than in the NG treatment.

Results from this study indicate that in the grasslands of western North Dakota (1) the recommended stocking rate may be too conservative, (2) rotation grazing may allow for higher stocking rates than season-long grazing without a major impact on animal performance, (3) rainfall is more important than grazing or grazing systems in the control of the ecosystem-level variables measured, (4) species composition is affected by drought and grazing (but not by grazing systems) but the responses are highly dependent on range site, and (5) drought and grazing tend to increase the relative composition of warm-season grasses and forbs.

Key words: above-ground C and N flows; animal performance; litter decomposition and N release; net primary production; northern mixed prairie; plant N uptake; root decomposition and N release; species composition.

INTRODUCTION

Specialized grazing systems have been the focus of research and management of rangelands since the 1950s (Holechek et al. 1989). Deferred- and rest-rotation grazing systems have been applied on the public lands in the western United States since the 1970s. Traditionally, however, range managers have maintained that stocking rate was the major factor that affected productivity (Holechek et al. 1989). In the 1970s Owen and Wiegert (1976) developed a model concerning the impact of grazing intensity on plants based upon organism-level and ecosystem-level responses. They speculated that herbivores can alter local nutrient cycling, and increase the supply of limiting resources, thus leading to increases in plant production. The theory that grazing can increase plant productivity, however, is still being intensively debated (McNaughton 1993, Painter and Belsky 1993).

Allan Savory (1988) was one of the first range managers to suggest that the distribution of animals (herding) may play a more important role in influencing range condition than stocking rate. In a review of the literature on stocking rate and grazing systems in the

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Great Plains and the western USA, VanPoollen and Lacey (1979) showed that rotation grazing systems, when implemented at moderate stocking rates, increase plant production by an average of 13% over season-long grazing. They also found, however, that a greater increase in plant production occurs (an average of 35%) when stocking rate is reduced from heavy to moderate. Milchunas and Lauenroth (1993) in a world-wide review of grazing literature, however, found that grazing has in general a negative or neutral impact on plant production.

As a result of these and other findings, the present direction in grazing management is to combine high grazing intensity for short periods of time (a form of herding) with prolonged periods of rest. Two of the most common grazing systems developed along these lines have been high-intensity, low-frequency grazing (HILF) and short-duration grazing (SDG). The HILF grazing system involves grazing periods of 15–20 d with rest periods of >60 d (Acocks 1966), while in the SDS grazing systems the periods of grazing are reduced to 5 d while the resting periods average 30 d (Savory 1988).

A review of the grazing literature in the Great Plains by Klipple and Bement (1961) concluded that most of the improvements in range conditions that can be expected from the adoption of specialized grazing management systems or changes in stocking rates occur during the first 5–7 yr with little added improvement afterward. Holechek et al. (1989) have also concluded that under conditions in which soil erosion has not been severe, recovery from severe overgrazing in the grasslands of the Great Plains should require <10 yr. The objective of this study was to evaluate for a 6-yr period the effects of a twice-over rotation grazing system (a variation of HILF) and a season-long grazing system and compare these effects with long-term grazing exclosures in terms of: (1) species composition and basal cover, (2) aboveground net primary production (ANPP) and N uptake (total and by life form), (3) rates of litter and root decomposition and N release, (4) soil N mineralization and immobilization, (5) aboveground carbon and N flow, and (6) grazing intensity (GI) and animal performance.

MATERIALS AND METHODS

Description of the study site

The study was conducted in Dunn county at the Ranch Headquarters of the North Dakota State University Dickinson Research Center. The principal natural vegetation community of the area is the mixed-grass prairie dominated by grasses of medium height such as *Agropyron smithii, Koeleria cristata, Stipa comata,* and *Stipa viridula.* Associated with these species are several shorter grasses and sedges, in particular *Bouteloua gracilis, Carex filifolia,* and *Carex heliophila.* Nomenclature follows *Flora of the Great Plains* (Great Plains Flora Association 1986).

Three major range sites are dominant in the area: sandy, shallow, and silty (USDA Soil Conservation Service 1982). The sandy range site is composed of the Veban-Parshall soil association and represents 32% of the native vegetation in Dunn county (Morken et al. 1976). The shallow range site represents 21% of the native vegetation in Dunn county and is composed of the Cabba, Cohagen, and Wayden soil series. Thirty-three percent of the native vegetation in Dunn county is on silty range sites, which are composed of the Amor, Morton, Farland, and Cherry soil series.

Climate

Dunn County is characterized by a continental climate with warm summers and very cold winters. The annual average temperature is 4.6°C. The average annual maximum and minimum temperatures are 11.4°C and −3.7°C, respectively, with a growing season that ranges from 99 to 142 d.

Average rainfall at the site (100-yr average) is 400 mm, with 80% of it taking place from April to September. Fig. 1 shows an ombrothermograph (Emberger et al. 1962) for the study site that covers the year before the layout of the experiment (1983), the study period (1984–1989), and the 100-yr average. Growing-season rainfall in 1984 (291 mm), 1985 (295 mm), and 1989 (290 mm) was below the long-term average and resulted in some water-deficient periods. Growing-season rainfall in 1983 (360 mm), 1986 (550 mm), and 1987 (354 mm) was above the long-term average, with 1986 belonging to the upper 10% quantile. Growing-season rainfall in 1988 reached only 167 mm and was the third-driest growing season on record (1936 and 1934 had growing-season precipitations of 139 mm and 154 mm, respectively).

Experimental design

Three treatments were utilized: long-term grazing enclosures (NG), twice-over rotation grazing (ROT) from June to mid-October, and season-long grazing (SL) for the same period. The NG treatment consisted of two 4-ha pastures that had a known record of at least 30 yr of protection from grazing. The proportion of range sites in these pastures was similar to that of the grazed pastures.

The grazing treatments were started in 1984, when nine 32-ha pastures were randomly allocated to the SL and ROT treatments. The pastures were fenced so as to have approximately the same proportions of the dominant range sites. This resulted in pastures with an average of 40% silty range sites, 30% sandy range sites, and 30% shallow range sites.

The SL treatment consisted of three replications, each grazed by 10 cow/calf pairs that were randomly selected and assigned to this treatment each year. The average stocking rate for these pastures for the 6-yr

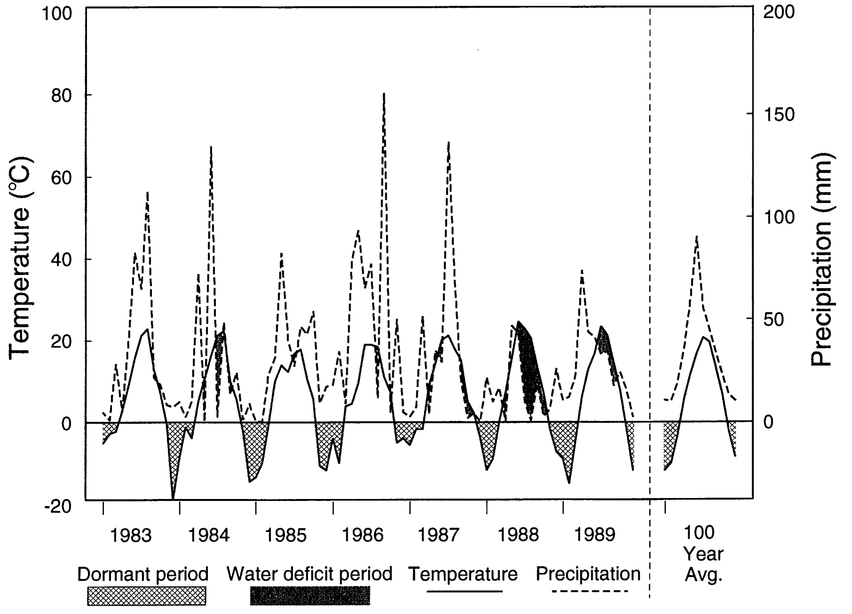

FIG. 1. Ombrothermograph for the study site from the year before the beginning of the experiment to 1989, plus the 100-yr average.

study period was 3.33 ha/AU (the Society for Range Management defines an animal unit [AU] as a mature cow of 455 kg with a calf, and stocking rate as the amount of land allocated to each AU for the entire grazable period). The grazing season in 1988 was reduced by 45 d due to the drought.

The ROT treatment consisted of two replications of three pastures each. The pastures within a replication were subjected to a rotation schedule of 45 d of grazing, subdivided into a 15- and a 30-d grazing period, with 45 d of rest. The exception to this schedule was 1988, when, due to the drought, the grazing season had to be shortened to 30 d of grazing. The pasture grazed last in any year was grazed first the next year, with the other pastures shifted accordingly. Thus, after a 3-yr cycle (1984–1986 and 1987–1989), each pasture was subjected to all 15- and 30-d grazing periods. Each replication was grazed with 27 cow/calf pairs that were randomly selected every year. The average stocking rate was 3.44 ha/AU.

Plant basal cover, density, and species composition

A standard 10-point frame was used to measure plant basal cover. Ten frames (100 points) were read at 20 sampling points located within a transect. Three transects were sampled within each pasture in three randomly selected range sites (sandy, shallow, and silty) for a total of 6,000 points per pasture. All transects were sampled at peak biomass. Species composition was expressed as relative plant basal cover. Forb density was estimated with the use of 25 0.1-m^2 quadrats randomly located within the same range sites used to estimate plant basal cover (75 quadrats per pasture). All forbs rooted within the quadrat were counted. Forb density samples were also taken at peak biomass. Plant basal cover in the grazed pastures was measured for a baseline purpose at the beginning of the experiment (1984). Samples were taken again in all treatments in 1987 and 1989 (the second 3-yr cycle of the ROT treatment).

Above-ground ANPP and N uptake

ANPP was estimated with sequential sampling from 1 June to 15 October, as outlined by Redente et al. (1989). Samples within each pasture and treatment were taken six times a year, matching the movement of animals in the ROT treatment so as to estimate biomass removal. Biomass removal was used in both the ROT and SL treatments as a proxy for animal consumption.

Samples within each pasture were stratified by range site. The range sites and the samples within each range site were randomly selected at each sampling period. Ten 0.25-m^2 quadrats were clipped at each sampling period in the ROT and SL treatments, while five were clipped in the NG treatment. In the ROT and SL treatments, five of the quadrats were located within portable wire cages that excluded grazing and five were located outside. Aboveground standing live biomass, aboveground standing dead biomass, and litter were collected. All samples were oven-dried at 60°C for 48 h before weighing, and their total N content was determined with the Kjeldahl digestion method (Nelson and Sommers 1980). ANPP was calculated, using the method of Sala et al. (1981) as outlined by Redente et al. (1989). Estimates of ANPP started in 1987 at the beginning of the second 3-yr grazing cycle in the ROT

TABLE 1. Total absolute basal cover, litter cover, and percent relative basal cover for selected species and life forms in the sandy range site for the treatments NG (long-term enclosure, i.e., not grazed), ROT (rotation grazing), and SL (season-long grazing), and the regional average. Data are means ± 1 SE.

Species or life form	Regional average	NG		ROT		
		1987	1989	1984	1987	1989
Bouteloua gracilis	24 ± 2.5	4 ± 3.4	1 ± 0.5	13 ± 2.5	10 ± 2.9	10 ± 4.1
Agropyron smithii	3 ± 0.4	0	0	0.2 ± 0.1	1 ± 0.5	2 ± 1.4
Koeleria pyrimidata	22 ± 2.1	3 ± 2.8	0	4 ± 1	5 ± 2.1	1 ± 0.6
Stipa comata	8 ± 1.3	8 ± 4.9	12 ± 8.2	8 ± 2.6	9 ± 1.7	9 ± 1.9
Stipa viridula	1 ± 0.3	1 ± 0.2	1 ± 0.7	2 ± 0.8	0.1 ± 0.1	0.4 ± 0.4
Cool-season grasses	38 ± 2.8	45 ± 2.8	43 ± 5.5	30 ± 1.9	30 ± 1.5	32 ± 1.2
Total grasses	62 ± 5	49 ± 0.4	45 ± 7	44 ± 5.7	38 ± 5.1	38 ± 2.8
Carex filifolia	5 ± 1.7	6 ± 5.9	19 ± 18.4	25 ± 8.9	18 ± 7.2	24 ± 8.3
Carex heliophila	26 ± 4.7	37 ± 7.1	20 ± 1.8	26 ± 5	28 ± 5	17 ± 4.2
Total sedges	31 ± 5.8	43 ± 1.2	39 ± 16.6	51 ± 6.6	46 ± 5.5	41 ± 4.9
Forbs	7 ± 0.8	8 ± 1.6	16 ± 9.6	2 ± 0.7	17 ± 3	21 ± 2.9
Litter	76 ± 7.6	77 ± 0.8	75 ± 2.8	64 ± 3.25	67 ± 2.9	67 ± 1.7
Total absolute cover	18 ± 1	23 ± 0.8	26 ± 2.4	31 ± 2.9	25 ± 1.3	22 ± 2.7

treatment. At the beginning of the study (1984), and for comparison purposes, only peak green biomass was estimated for all the pastures that would be part of the grazing study. Aboveground N uptake (ANPP-N) was estimated as ANPP times the N content of live biomass.

Litter and root decomposition

Decomposition studies were started in 1987. In situ litter and root decomposition were evaluated, using the litter-bag technique (Santos et al. 1984). As a substrate we used the aboveground litter, and root samples (taken to a depth of 10 cm) of *Bouteloua gracilis* plants collected in 1987. Thirty litter and 30 root samples, with 15 matching blanks for each set, were located within each range site within a pasture. A fraction of the litter and root materials were analyzed before incubation for ash (to estimate the proportion of organic matter) using the proximate analysis procedure (Goering and Van Soest 1970), and for total N content using the Kjeldahl digestion method. The aboveground litter bags were anchored to the soil, while the root bags were buried 10 cm belowground. The blanks consisted of bags filled with polyethylene foam of known mass and served as controls for this experiment.

Ten litter bags and 10 root bags with their matching 5 blanks were retrieved within each range site and each pasture at the end of 4, 12, and 18 mo of incubation. The samples were weighed and analyzed for ash and total N content. Percent decomposition was calculated as:

$$\text{Percent decomposition} = \frac{[\mathrm{OM}_p \times S_p - (S_r - (C_r - C_p)) \times \mathrm{OM}_r] \times 100}{\mathrm{OM}_p \times S_p},$$

where OM_p = proportion of sample's organic matter when placed, OM_r = proportion of sample's organic matter when retrieved, C_p = mass of blanks when placed, C_r = mass of blanks when retrieved, S_p = mass of sample when placed, and S_r = mass of sample when retrieved. The percent of loss of N due to decomposition was calculated as:

$$\text{Percent loss of N} = \{[\mathrm{OM}_p \times S_p \times N_p - (S_r - (C_r - C_p)) \times \mathrm{OM}_r \times N_r] \times 100\}/(\mathrm{OM}_p \times S_p \times N_p),$$

where N_p = proportion of N in samples before incubation, and N_r = proportion of N in samples after incubation.

Soil N mineralization and immobilization

Soil N mineralization and immobilization were studied, using the buried polyethylene bag technique (Westerman and Crothers 1980). Soil samples were collected on May, June, July, and August of 1987, 1988, and 1989. At each sampling period, 10 samples were collected within each randomly selected range site per pasture with a 5 cm diameter soil core to a depth of 10 cm. Five samples were placed in plastic bags, sealed, and immediately buried 5 cm belowground. The remaining material was immediately deep-frozen for initial ammonium-N (NH_4^+-N) and nitrate-N (NO_3^--N) determinations. Ten grams of each soil sample were extracted with 50 mL of 2 mol/L KCl. The extract was filtered and analyzed for NH_4^+-N, using the ammonium indolephenol blue method (Page et al. 1982). Nitrate-N was tested, using the cadmium reduction method (Page et al. 1982). Incubated samples were retrieved at the end of May, June, July, and August. These samples were also analyzed for inorganic N (NH_4^+-N and NO_3^--N). Soil net N mineralization and immobilization rates were determined as outlined in Pastor et al. (1984).

Grazing intensity, consumption, and animal gains

Forage removal was estimated in each grazed pasture with the cage comparison method (Klingman et al.

TABLE 1. Continued.

SL		
1984	1987	1989
21 ± 6.3	5 ± 0.9	13 ± 5.6
1 ± 0.5	0.2 ± 0.2	1 ± 0.6
8 ± 2.7	8 ± 1.9	1 ± 0.3
13 ± 2	12 ± 2	11 ± 2.7
1 ± 0.4	0.1 ± 0.1	1 ± 0.3
25 ± 1.5	43 ± 1.4	28 ± 1.5
46 ± 2.7	48 ± 3.5	41 ± 4.7
35 ± 10.5	10 ± 3.1	20 ± 5.8
7 ± 2	25 ± 7.9	14 ± 4.4
42 ± 6.3	35 ± 6.1	34 ± 4.4
12 ± 2.4	16 ± 3	26 ± 4.6
55 ± 2.7	69 ± 2.3	64 ± 3.6
21 ± 2.3	28 ± 1.1	24 ± 4.6

1943). Grazing intensity (GI) was estimated following the method of McNaughton (1985) as:

$$\mathrm{GI} = \left(1 - \frac{\mathrm{FG.Biom}}{\mathrm{FP.Biom}}\right) \times 100,$$

where FG.Biom is the standing crop biomass in the unprotected, grazed vegetation at the end of the grazing season and FP.Biom is the standing crop biomass within permanent exclosures, also at the end of the grazing season. Cows and calves were weighed from June to October at 15-d intervals.

Aboveground C and N flow

We estimated C and N flow through standing dead, litter, and decomposition using the mass flow approach suggested by Golley (1965) and used in a similar grassland in western North Dakota by Abouguendia and Whitman (1979). Biomass C was estimated by dividing dry biomass by 2.5 (atomic mass: CH_2O/C) (Sauer 1976).

Annual inputs into standing dead C (SD-C) and N (SD-N) were the annual ANPP-C (ANPP × 0.4) and ANPP-N minus animal consumption when it applied. Annual outputs from SD-C and SD-N in year i were calculated as:

$$\text{SD-C-OUT}_i = (\text{ANPP-C}_i - \text{AC-C}_i) + \text{SD-C-Spring}_i - \text{SD-C-Spring}_{i+1}$$

$$\text{SD-N-OUT}_i = (\text{ANPP-N}_i - \text{AC-N}_i) + \text{SD-N-Spring}_i - \text{SD-N-Spring}_{i+1},$$

where AC-C_i and AC-N_i represent animal consumption in year i; SD-C-Spring_i and SD-N-Spring_i represent the amount of C and N measured in standing dead biomass in 1 June of year i.

Annual inputs to the litter C (L-C) and N (L-N) in year i were the SD-C-OUT_i and SD-N-OUT_i for the same year. Annual outputs from L-C and L-N were equated with decomposition (De-C and De-N) and estimated as:

$$\text{De-C}_i = \text{SD-C-OUT}_i + \text{L-C-Spring}_i - \text{L-C-Spring}_{i+1}$$

$$\text{De-N}_i = \text{SD-N-OUT}_i + \text{L-N-Spring}_i - \text{L-N-Spring}_{i+1}$$

where L-C-Spring_i and L-N-Spring_i are the amount of litter C and N, respectively, present in the 1 June sample of year i. For comparison purposes we also calculated De-C and De-N for the 1987–1988 period using the 12-mo decomposition constants generated by the litter-bag techniques.

Statistical analysis

The data on annual ANPP, N uptake, plant basal cover, plant density, and species composition were analyzed within years and range sites using one-way ANOVA. The data for ANPP by date within a growing season, litter and root decomposition, and soil mineralization/immobilization were analyzed with the use of a repeated-observation ANOVA model to incorporate the sequential sampling nature of the experiments. A similar approach was used for all the data when comparisons were made among years. Treatment effects were separated using preplanned orthogonal comparison (Snedecor and Cochran 1967). Results were considered statistically different when $P < 0.05$. All data that involved percentages were transformed before analysis with the use of an angular transformation (Bonham 1989). Plant density and all other data that involved counts were subjected to the square-root transformation (Bonham 1989).

RESULTS

Plant basal cover and species composition

Tables 1–3 show the data on total plant basal cover and species composition as estimated by relative basal cover. For comparison purposes we show data from a 1975 survey of 34 sandy range sites, 27 shallow range sites, and 34 silty range sites (denoted as regional average) conducted in Dunn County (Morken et al. 1976). Morken et al. (1976) estimated the range condition for the region to be Good for the silty and sandy range sites and Low–Good for the shallow range site.

There were, in general, no differences found in total plant basal cover among the NG, ROT, and SL treatments in both 1987 and 1989 (Tables 1–3), the only exception being the NG treatment within the silty range site in 1989, which had a higher ($P < 0.05$) plant basal cover than the grazed treatments (41% vs. an average of 26% for the grazed treatments). Also, there were, in general, no measurable changes in plant basal cover as a result of the drought of 1988, since the average for all treatments and range sites ranged from 27% in 1987 to 26% in 1989.

While plant basal cover did not, in general, respond to grazing treatments, species composition did. The relative cover of *Bouteloua gracilis* was lower ($P <$

TABLE 2. Total absolute basal cover, litter cover, and percent relative basal cover for selected species and life forms in the shallow range site. Treatment abbreviations as in Table 1. Data are means ± 1 SE.

Species or life form	Regional average	NG		ROT		
		1987	1989	1984	1987	1989
Bouteloua gracilis	9 ± 4	6 ± 2.9	11 ± 0.1	40 ± 4.1	36 ± 3.9	29 ± 4.6
Agropyron smithii	0	0	0.3 ± 0.3	0.2 ± 0.1	0.1 ± 0.1	0
Stipa comata	4 ± 0.8	21 ± 5.4	17 ± 6	17 ± 3	10 ± 2.1	15 ± 2
Cool-season grasses	15 ± 2.6	30 ± 3.9	20 ± 3.5	30 ± 2.1	28 ± 1.6	20 ± 1.4
Total grasses	62 ± 7.5	36 ± 5.9	21 ± 8	69 ± 4.8	64 ± 6.2	48 ± 4.4
Carex filifolia	21 ± 6.9	33 ± 3.7	49 ± 9.1	18 ± 4.4	15 ± 4.4	28 ± 4.2
Carex heliophila	14 ± 3.2	7 ± 0.8	1 ± 0.8	3 ± 1.5	6 ± 2.2	3 ± 1.5
Total sedges	35 ± 7.4	40 ± 4.5	50 ± 8.3	21 ± 3.7	21 ± 4.1	31 ± 4.4
Forbs	3 ± 1.9	25 ± 10.4	30 ± 16.3	4 ± 0.4	15 ± 3.3	21 ± 1.3
Litter	75 ± 6	72 ± 1.3	72 ± 5.1	60 ± 1.8	59 ± 3.6	65 ± 1
Total absolute cover	18 ± 1.2	25 ± 1.5	21 ± 1	35 ± 2.4	27 ± 1	24 ± 2.5

0.05) in the NG treatment when compared with the grazed treatments (Tables 1–3). This result is consistent with the characterization of *Bouteloua gracilis* as an increaser species (sensu Dyksterhuis 1958) by the Soil Conservation Service (SCS) for the range sites within the Missouri slope vegetation zone (USDA Soil Conservation Service 1984). No general trend on the relative cover of *Bouteloua gracilis* was detected on the grazed treatments that can be related to the drought of 1988. In the case of the NG treatment, however, there was a sharp decline in *Bouteloua gracilis* relative cover between 1987 and 1989 in the shallow and silty range sites ($P < 0.05$).

The dominant cool-season grasses found in the experimental pastures as well as in the 1975 regional survey were *Agropyron smithii, Koeleria pyrimidata, Stipa comata,* and *Stipa viridula* (Tables 1–3). The aggregate relative cover of cool-season grasses ranged from a low of 20% to a high of 69%, but no consistent pattern was found that can be related to the drought of 1988. Within the sandy range site the NG pastures had in general higher aggregate relative cover of cool-season grasses ($P < 0.05$) than the grazed treatments. No differences in the aggregate relative cover of cool-season grasses were found among all treatments in both the shallow and silty range sites (Tables 2–3).

The aggregate relative cover for all grasses ranged from 21 to 76% with significant changes observed in the shallow and silty range site from 1987 (before the drought) to 1989 (after the drought) primarily due to changes in the NG treatment (Tables 2–3). The aggregate relative cover of grasses in the sandy range site averaged 43%. In the shallow range site, the aggregate relative cover of grasses of both grazed treatments was higher ($P < 0.05$) than the one measured in the NG treatment in 1987 (57% vs. 36%), but in 1989 this difference only held true for the ROT treatment (48% vs. 21% in the NG treatment). There was, however, a decline ($P < 0.05$) in all treatments from 1987 to 1989 (50% vs. 30%), which in all likelihood was related to the 1988 drought (Table 2). In the silty range site no differences were found among the treatments before the drought of 1988, but in 1989 the grazed treatments had higher ($P < 0.05$) aggregate relative cover of grasses than the NG treatment (51% vs. 25%; Table 3).

The two dominant sedges observed both in this study

TABLE 3. Total absolute basal cover, litter cover, and percent relative basal cover for selected species and life forms in the silty range site. Treatment abbreviations as in Table 1. Data are means ± 1 SE.

Species or life form	Regional average	NG		ROT		
		1987	1989	1984	1987	1989
Bouteloua gracilis	20 ± 1.4	11 ± 2.2	3 ± 2.6	41 ± 10	32 ± 6.3	53 ± 6.7
Agropyron smithii	12 ± 5	0	5 ± 2.1	9 ± 1.7	5 ± 1.2	6 ± 1.3
Koeleria pyrimidata	12 ± 3.3	3 ± 0.3	0.4 ± 0.4	4 ± 1.7	12 ± 4.1	1 ± 0.7
Stipa comata	6 ± 1	17 ± 3.3	8 ± 0.7	12 ± 4.4	5 ± 1.3	14 ± 2.8
Stipa viridula	2 ± 1	0.2 ± 0.2	9 ± 3.1	12 ± 5.2	5 ± 3.6	7 ± 5.9
Cool-season grasses	41 ± 2.4	36 ± 2.2	23 ± 1.7	37 ± 3.2	30 ± 2.6	28 ± 3
Total grasses	62 ± 2.1	47 ± 8.6	25 ± 1.1	76 ± 5.5	62 ± 3.9	53 ± 6
Carex filifolia	4 ± 7.6	10 ± 6.9	32 ± 8.2	7 ± 2.7	12 ± 13	22 ± 4.5
Carex heliophila	28 ± 2.7	33 ± 2.7	14 ± 5.3	3 ± 1.7	6 ± 2.7	1 ± 0.2
Total sedges	32 ± 1.1	43 ± 4.2	46 ± 2.9	10 ± 2.6	18 ± 4.2	23 ± 4.6
Forbs	7 ± 1.4	10 ± 4.4	29 ± 1.9	8 ± 2.3	20 ± 2.2	25 ± 6.1
Litter	70 ± 7	74 ± 1.7	55 ± 1	57 ± 4.9	63 ± 3.2	62 ± 4.4
Total absolute cover	21 ± 2.3	26 ± 1.4	41 ± 4.4	39 ± 2.9	28 ± 2.6	25 ± 1.9

TABLE 2. Continued.

SL		
1984	1987	1989
42 ± 9	22 ± 4.1	4 ± 1
2 ± 1	0.3 ± 0.2	0
8 ± 1.3	13 ± 2.2	12 ± 2.5
25 ± 1.8	29 ± 1.6	16 ± 2
67 ± 10	50 ± 6	21 ± 4.7
8 ± 1.2	22 ± 3.4	45 ± 8.3
14 ± 8	3 ± 1.7	5 ± 3
22 ± 2.1	25 ± 2.4	50 ± 5.7
11 ± 1.4	25 ± 4.1	30 ± 3.8
56 ± 2.7	63 ± 1.7	60 ± 7.7
29 ± 2.6	29 ± 2	22 ± 2.9

and in the 1975 regional survey were *Carex filifolia* and *Carex heliophila* (Tables 1–3). No differences in the combined relative basal cover of either sedge was found within the sandy range site among the treatments or as a result of the 1988 drought. In the shallow range site the grazed treatments had a lower relative cover of sedges than the NG treatment only in 1987 (23% vs. 39%), but the statistical difference between the NG and ROT was no longer present in 1989 (Table 2). In the silty range site the NG treatment had a consistently higher relative cover of sedges than the grazed treatments in both 1987 and 1989 (an average of 45% vs. 17%). There was however, no discernable effect that can be attributed to the 1988 drought (Table 3).

The dominant forbs measured in the experimental pastures were *Artemisia ludoviciana, Chenopodium album,* and *Helianthus rigidus.* In 1987, the NG treatment had a lower ($P < 0.05$) relative cover of forbs than the grazed treatments in both the sandy (8% vs. 16% average for the grazed treatments) and the silty (10% vs. 24%) range sites. These differences were no longer present after the drought of 1988 because of a significant ($P < 0.05$) increase in the relative cover of forbs in the NG treatment in 1989. The silty range site was the only one where consistent differences in plant density were found among treatments as a result of the 1988 drought. In 1987 the grazed treatments had higher ($P < 0.05$) forb density than the NG treatment (an average of 92 vs. 49 plants/m^2) but in 1989 the reverse was true (an average of 34 plants/m^2 for the grazed treatments vs. 64 plants/m^2 for the NG treatment) a pattern that is consistent with the changes in relative forb basal cover described above.

TABLE 3. Continued.

SL		
1984	1987	1989
32 ± 9	26 ± 6.6	25 ± 7.6
4 ± 1.4	5 ± 2.4	6 ± 1.2
10 ± 2.8	12 ± 2.4	2 ± 0.9
6 ± 1.3	8 ± 1.6	14 ± 4
1 ± 0.7	4 ± 1.1	2 ± 1.6
22 ± 1.5	31 ± 1.7	24 ± 2.3
54 ± 6.4	57 ± 9.4	48 ± 6.2
22 ± 11	6 ± 3.2	7 ± 3.9
5 ± 1.9	10 ± 6.3	5 ± 1.6
27 ± 8	16 ± 5.8	12 ± 4.5
19 ± 2.9	28 ± 5.8	28 ± 4.3
57 ± 2.3	69 ± 2.4	68 ± 4.7
29 ± 2.6	31 ± 2	28 ± 4.3

TABLE 4. Average peak biomass by range sites (g/m^2) for the grazing treatment pastures at the beginning of the experiment, the 1975 regional survey of Dunn County (Morken et al. 1976), and the expected production under "climax" conditions as estimated by the Soil Conservation Service (95% CI in parentheses).

	Sandy range site	Shallow range site	Silty range site
Climax	224 (34)	157 (78)	218 (33)
Regional survey (1975)	236	147	256
Experimental pastures (1984)	190 (20)	122 (9)	221 (19)

Above-ground net primary production

Table 4 shows the average peak aboveground green biomass for the nine pastures used for the grazed treatments at the beginning of the experiment (1984). For comparison purposes we also show data from the regional survey of Dunn County conducted in 1975 (Morken et al. 1976) and production at "climax" conditions as estimated by the USDA Soil Conservation Service (1982).

Fig. 2 shows that, with the exception of the silty range site in 1988 (the year of the drought), there were no differences among the treatments in terms of ANPP. As a result of the 1988 drought, however, there was an average decline in ANPP of 46% ($P < 0.05$) within the shallow and silty range sites that persisted into 1989. Interestingly enough, the drought did not in general reduce ANPP in the sandy range site (the only exception being the SL treatment in 1988), even though total rainfall in 1988 was 44% lower than in 1987. An average of 72% of total ANPP took place by mid-June, with the majority taking place in April and May. From June to September the NG treatment tended to have a higher average ANPP than the grazed treatments, but the differences were not large enough to affect annual ANPP.

Aboveground nitrogen uptake

Fig. 3 shows the uptake of N by aboveground biomass for the 1987–1989 period. The NG treatment had higher ($P < 0.05$) N uptake during the drought of 1988 in the sandy and silty range sites. In these same range sites a significant decline ($P < 0.05$) in N uptake due to the 1988 drought was observed in the grazed treatments, from an average of 2.4 g/m^2 in 1987 to 1.6 g/

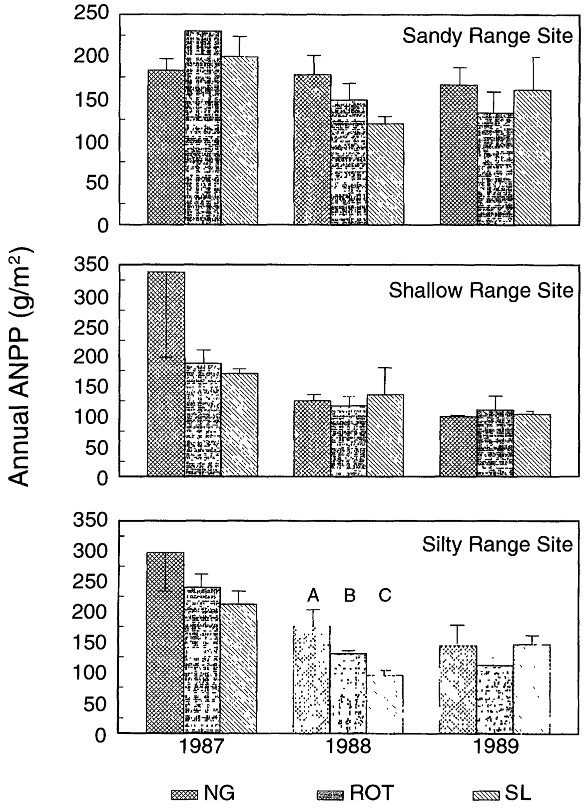

FIG. 2. Annual aboveground net primary production (ANPP, g/m²) by year, treatment, and range site. Vertical lines represent the 95% CI, while treatments within a year and range site with different letters are statistically different at the $P <$ 0.05 level. Treatment abbreviations: NG = long-term exclosure (i.e., not grazed), ROT = rotation grazing, and SL = season-long grazing.

m² in 1988 for the sandy range treatment, and 3.2 g/m² in 1987 to 1.3 g/m² in 1988 for the silty range site. Most of the N uptake took place before mid-June, with the majority having taken place during the April–May period: an average of 82% in 1987 and 1988, and 92% in 1989.

Litter and root decomposition and nitrogen release

Litter decomposition after an 18-mo incubation period averaged 47% across all range sites and treatments while N release averaged 30% (Fig. 4). The only difference ($P < 0.05$) among treatments at the end of 18 months of incubation involved N release from litter in the shallow range site where the NG treatment had lower N release than the grazed treatments (22% vs. 34%). More than 70% of both decomposition and N release, however, took place in the first growing season of the incubation period (May–August). In the second growing season (12–18 mo of the incubation period), the pattern for litter decomposition (for the sandy and shallow range sites) and litter N release (shallow and silty range sites) tended to be lower ($P < 0.05$) in the NG treatment than in the grazed treatments (Fig. 4).

The cumulative (18-mo) decomposition and N release across range sites for roots averaged 36% and 23%, respectively, with no differences among treatments (Fig. 5). Root decomposition and N release for the first 4 mo of incubation within the shallow range site was higher in the grazed treatments than in the NG treatment (36% in the grazed treatments vs. 11% in the NG treatment for decomposition, and 23% vs. 5% for N release). There was net N release by roots from the fall to the second growing season of incubation (4–12 and 12–18 mo periods) only 6 out of the 18 times it was measured.

Soil nitrogen mineralization and immobilization

There was no clear pattern for soil N mineralization or immobilization as a result of treatment effect because of the large standard error encountered (Fig. 6). For all range sites and treatment combinations, measurements of cumulative net soil N mineralization from May to August dropped from 8 out of 9 cases in 1987 to 4 out of 9 cases in 1988 and 1989, indicating a possible lingering effect of the drought of 1988. Soil

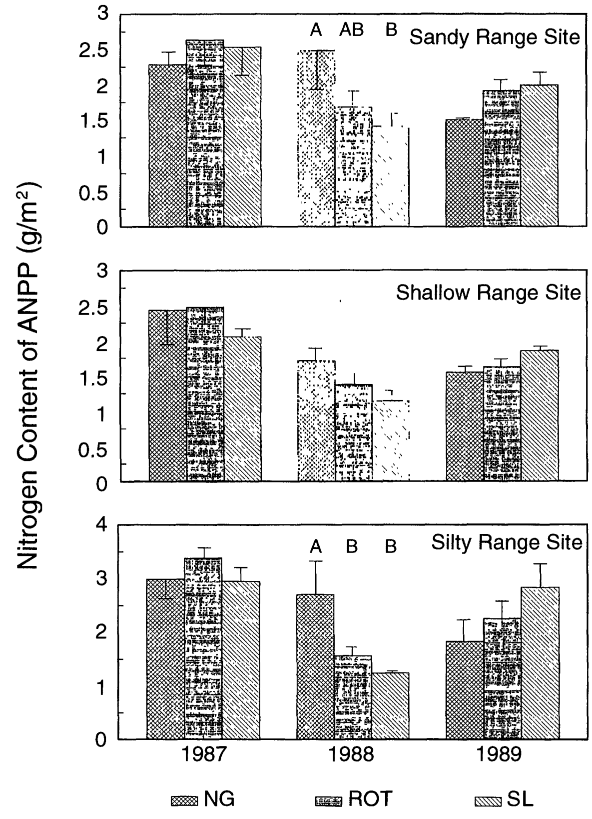

FIG. 3. Annual aboveground N uptake (ANPP-N, g/m²) by year, treatment, and range site. Vertical lines represent the 95% CI, while treatments within a year and range site with different letters are statistically different at the $P < 0.05$ level.

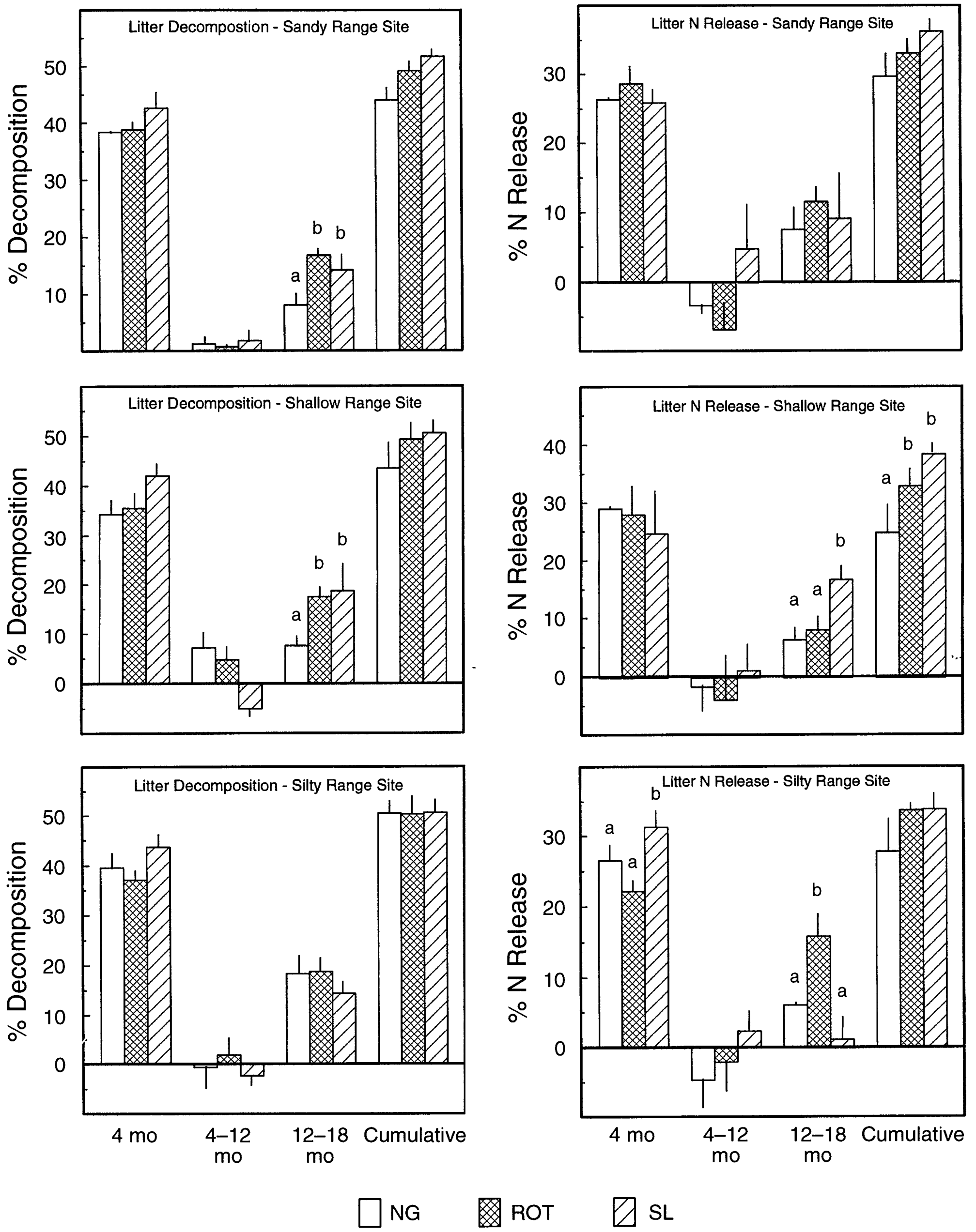

FIG. 4. Percent litter decomposition and N release through litter decomposition from 1987 to 1988 by range site, treatment, and incubation period. Vertical lines represent the 95% CI, while treatments within a decomposition period and range site with different letters are statistically different at the $P < 0.05$ level.

net N release to a depth of 10 cm at the pasture level increased from 1.56 g/m^2 in 1987 to 7.25 g/m^2 in 1989 ($P < 0.05$) in the ROT treatment. No trend was found for the NG and SL treatments, which averaged 2.4 g/m^2.

Grazing intensity and animal performance

Fig. 7 shows the data on grazing intensity (GI) from 1987 to 1989. There were in general no consistent differences in the grazing intensity patterns between the ROT and SL grazing treatments, the only exception being the shallow range site in 1987, where the GI in the ROT treatment was higher ($P < 0.05$) than the one in the SL treatment. The drought of 1988, however, significantly increased ($P < 0.05$) the GI in the SL treatment across all range sites from an average of 21% in 1987 to 57% in 1989, even though the grazing season was shorter (see *Methods*).

There were no differences in calf mass gains between treatments and among years (Fig. 8). The data for 1988

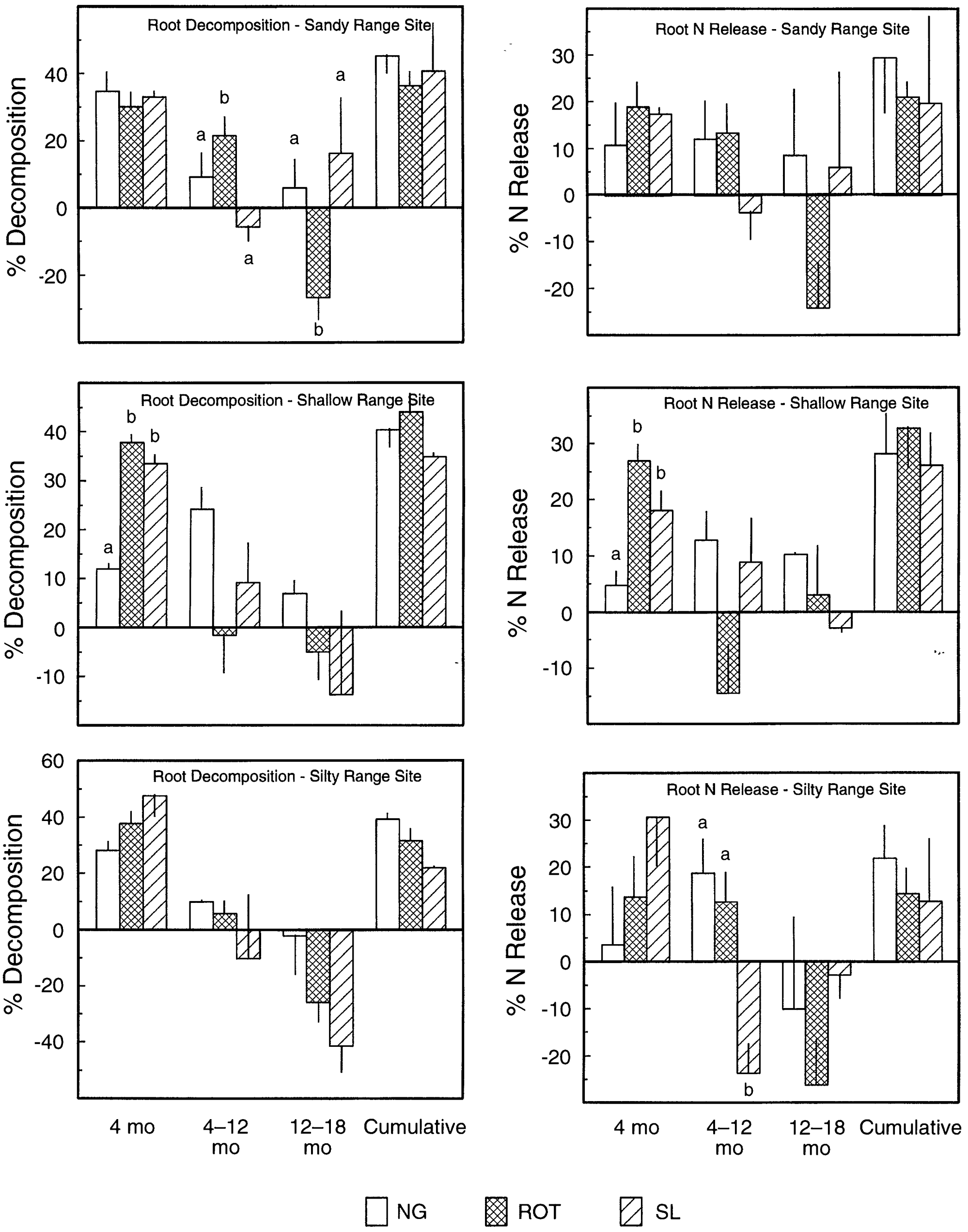

FIG. 5. Percent root decomposition and N release through root decomposition from 1987 to 1988 by range site, treatment, and incubation period. Vertical lines represent the 95% CI, while treatments within a decomposition period and range site with different letters are statistically different at the $P < 0.05$ level.

are not reported because the drought shortened the grazing season in such a way as to make the data noncomparable. Average daily gains (ADG) for calves showed two distinct patterns. From June to the early part of July ADG were higher ($P < 0.05$) in the SL treatment when compared with the ROT treatment: 1.2 kg/d vs. 1 kg/d. During August and September, however, calves in the ROT treatment showed higher ADG than in the SL treatment: 1.15 kg/d vs. 0.9 kg/d.

Cow mass gains were also mostly unaffected by grazing treatment (Fig. 8). As in the case of calves, there were distinct seasonal differences. From June to the end of July the ADG of cows in the SL treatment was higher ($P < 0.05$) than in the ROT treatment: an average ADG across all years of 0.67 kg/d for the SL treatment vs. 0.45 kg/d in the ROT treatment. That pattern was reversed during the months of August and September, where the average ADG was 0.3 kg/d for the ROT treatment vs. 0.02 kg/d for the SL treatment. These patterns may result from differences in selective grazing, since the crude protein content of the clipped biomass for the major plant life forms from May to October was found to be similar for both treatments.

Aboveground C and N flows

Figs. 9–11 show the weighted average for the aboveground C and N flows at the pasture level for the 1987 to 1989 period. There were significant effects both due to treatments and as a result of the drought of 1988.

The NG treatment (Fig. 9) had consistently higher ($P < 0.05$) standing dead C (SD-C) and standing dead N (SD-N) than the ROT (Fig. 10) and SL (Fig. 11) treatments in all years. There was, however, a >60% decline in SD-C and >40% decline in SD-N from 1987 to 1988: 50 g C/m^2 and 1.21 g N/m^2 in 1987 to 20 g C/m^2 and 0.58 g N/m^2 in 1989 in the NG treatment, and an average 17 g C/m^2 and 0.44 g N/m^2 in 1987 to 6 g C/m^2 and 0.2 g N/m^2 in 1989 for the grazed treatments.

A slightly different pattern was found for litter carbon (L-C) and litter N (L-N). L-C and L-N declined by >50% from 1987 to 1989 in the NG and ROT treatments, with the majority of the decline taking place between 1988 and 1989. In the case of the SL treatment, however, the majority of the decline took place between 1987 and 1988. L-C and L-N were higher ($P < 0.05$) in the NG treatment than in the grazed treatments in 1987 (254 g C/m^2 and 6.6 g N/m^2 vs. an average of 123 g C/m^2 and 3.25 g N/m^2 for the grazed treatments). In 1988 the NG and ROT treatments were similar but they had higher L-C and L-N than the SL treatment (an average of 161 g C/m^2 and 4 g N/m^2 for the NG and ROT treatment vs. 66 g C/m^2 and 1.84 g N/m^2 for the SL treatment). By 1989 no differences in L-C were detected among treatments.

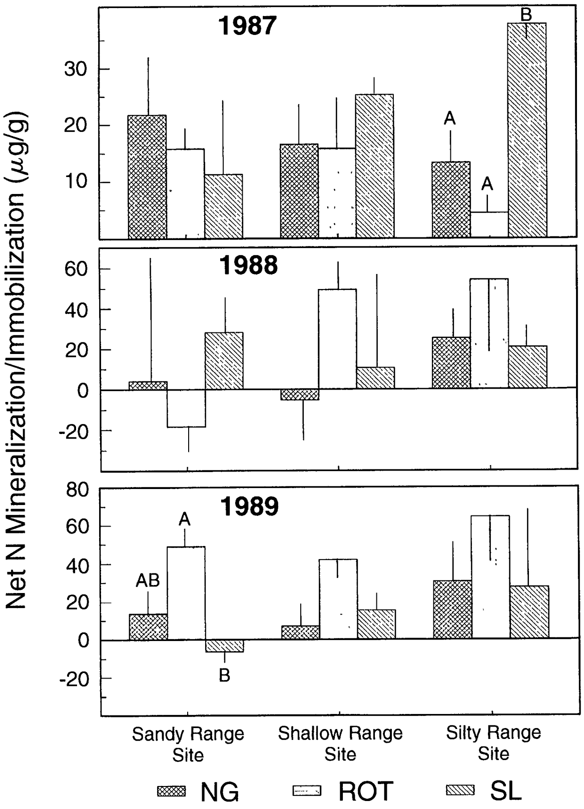

FIG. 6. Cumulative growing season (May–August) soil N mineralization/immobilization (µg/g) for 1987–1989 by range site. Vertical lines represent the 95% CI, while treatments within a range site with different letters are statistically different at the $P < 0.05$ level.

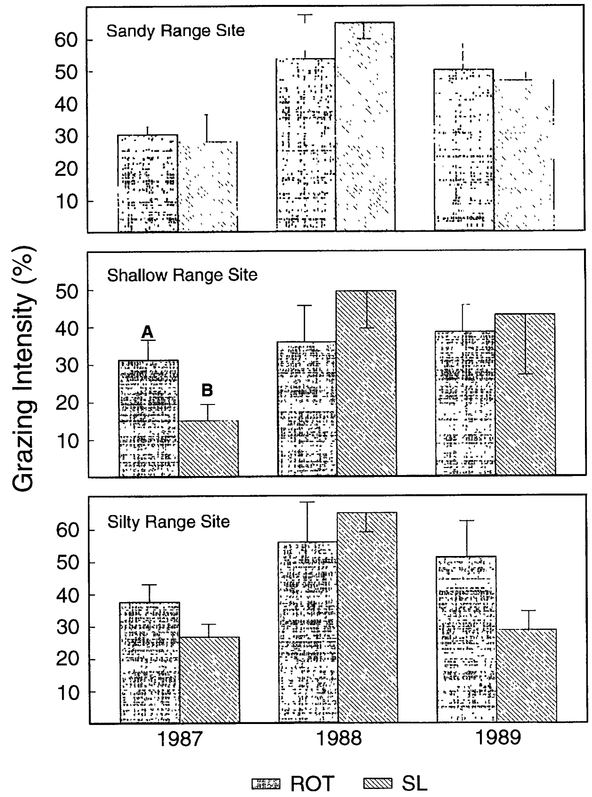

FIG. 7. Grazing intensity as a function of treatment, range site, and year. Vertical lines represent the 95% CI, while treatments within a year and range site with different letters are statistically different at the $P < 0.05$ level.

In conjunction with declines in SD-C there was also a >40% decline in the C flow from standing dead to litter (SD-C-to-L-C) as a result of the drought of 1988, with the largest one taking place in the NG treatments (111 g C/m^2 in 1987 to 59 g C/m^2 in 1989). There was, however, no change from 1987 to 1989 in the flow of N from standing dead to litter (SD-N-to-L-N) for either the NG or ROT treatment (2.76 g N/m^2 in 1987 to 1.94 g N/m^2 for the NG treatment and 1.84 g N/m^2 to 1.29 g N/m^2 for the ROT treatment). The SD-N-to-L-N flow in the SL treatment declined by 63% (1.56 vs. 0.57 g N/m^2) during the drought of 1988.

Estimations of C losses via decomposition (De-C) from 1987 to 1988 using the mass flow method (see *Methods*) and the decomposition rates estimated with the litter-bag technique were statistically similar (Figs.

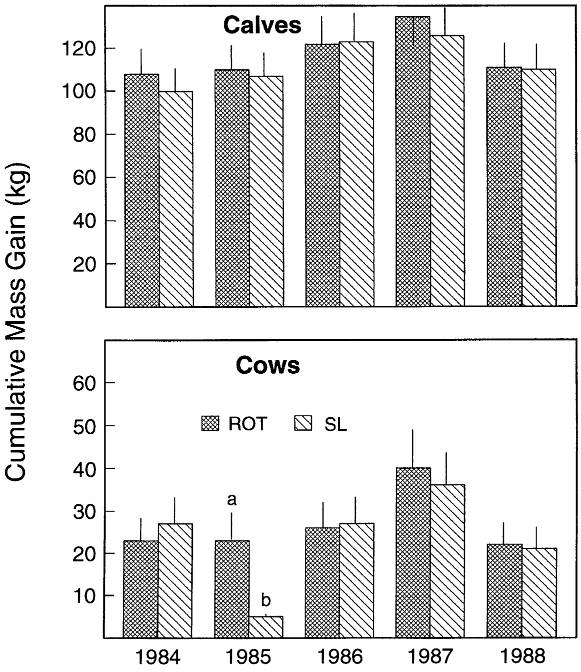

FIG. 8. Cumulative mass gains for calves and cows in grazed treatments from 1984 to 1989 (1988 data are not shown because the drought reduced the grazing season by 45 d). Vertical lines represent the 95% CI, while treatments within a year and range site with different letters are statistically different at the $P < 0.05$ level.

9–11). N losses via decomposition (De-N) estimated with mass flow, however, were higher ($P < 0.05$) than those estimated with the litter-bag technique (Figs. 9–11). No differences in De-C and De-N were found in the NG treatment between the 1987–1988 and 1988–1989 periods, which averaged 177 g C/m^2 and 4.5 g N/m^2 (Fig. 9). The ROT treatment had an increase ($P < 0.05$) in De-C for the same period (60 vs. 114 g C/m^2), but no change in De-N, which averaged 2.3 g N/m^2 (Fig. 10). The SL treatment, however, had a drastic decline ($P < 0.05$) in De-C and De-N, with N actually being immobilized in the 1988–1989 period (86 vs. 15 g C/m^2 for De-C, and 2.62 vs. −0.27 g N/m^2 for De-N; Fig. 11). On average the NG treatment had higher N release via decomposition than the ROT treatment, which in turn had higher De-N than the SL treatment.

DISCUSSION

Results from the study indicate that in western North Dakota rotation and season-long grazing at moderate stocking rates do not differ substantially in terms of plant species composition, production, or N uptake. There were, however, differences between grazing vs. long-term exclosure from grazing in terms of species composition and aboveground C and N flow, in particular the immobilization of C and N in dead biomass.

No major differences were found in ANPP among treatments but there were important seasonal variations. Most aboveground growth took place by mid-June. Since one of the main objectives of rotation grazing is to prevent early grazing of regrowth, the seasonal distribution of ANPP observed in this study and the fact that grazing always began on 1 June may explain the similar results observed under rotation and season-long grazing.

The ANPP results in this study were similar to the ones found by Lauenroth and Whitman (1977) in the same area. Our results, however, do not fit the grazing optimization hypothesis (Georgiadis et al. 1989, Jefferies 1989), model results for the short-grass prairie (Holland et al. 1992), or empirical results for tropical savannas (Pandey and Singh 1992). Our results are also inconclusive regarding the dispute about compensatory growth. In terms of total ANPP and ANPP by life form, the impact of grazing was neutral, thus rejecting, at least in this setting, the proposition that grazing may lead to higher photosynthesis and ANPP (Georgiadis et al. 1989, McNaughton 1983). Our results are more consistent with the findings of Trlica and Rittenhouse (1993), Noy-Meir (1993), and Risser (1993), which suggest that the effects of grazing are dependent on post-harvest conditions, environment, leaf area, stored nutrients, frequency of harvest, and production. It also tends to agree with the Milchunas and Lauenroth (1993) analysis of 236 sites located world-wide. Their results indicate that grazing has in general a negative or neutral impact on ANPP, with only 17% of the sites showing increases in ANPP.

Another difference between our results and others found in the literature involves the combined effects of drought and grazing on ANPP. Georgiadis et al. (1989) found in a greenhouse experiment that infrequent watering and long periods between clipping tended to stimulate production, while Oesterheld and McNaughton (1991) in a similar setting also found overcompensation on plants that were grown under stress and low growth conditions. In our study, most of the statistical differences in ANPP occurred during the drought of 1988, but the results were the opposite of those reported above: higher ANPP in the long-term exclosure treatment than in the grazed treatments.

A possible explanation for the divergence between our results and the ones outlined above may result from the fact that most of the data on the subject have been derived from greenhouse experiments, modeling, or natural systems where ANPP and herbivory fluctuate widely (Sinclair 1975, Walker et al. 1987). Results from grazing experiments where stocking rates and rotation patterns have been controlled show a different picture. Hart et al. (1993) showed that under grazing intensities of 39–44%, grazing strategies did not affect standing crop biomass (a proxy for ANPP). Similar results have been observed by Taylor et al. (1993) and Olson et al. (1993). Heitschmidt et al. (1987) also did not find differences in ANPP as a result of rotation grazing. In an analysis of their results, Heitschmidt et al. (1987) point

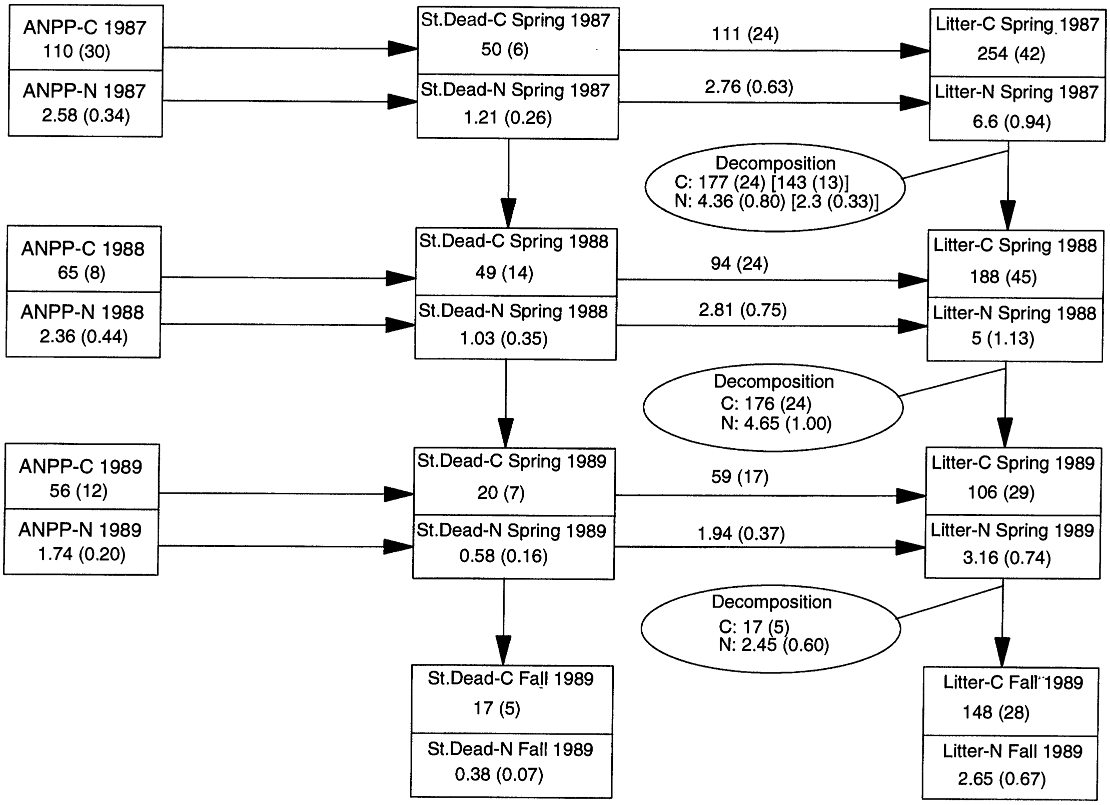

FIG. 9. Aboveground C and N flow (in g/m^2) for the long-term exclosure treatment (NG), calculated as a weighted average across all range sites. Numbers in parentheses represent the 95% CI. Numbers in brackets for the 1987–1988 C and N flow-through decomposition represent estimates using the rates from the decomposition experiment.

out that the conflict between the biologic theory of rotation grazing (Voisen 1959, Acocks 1966, Gammon 1978) and experimental results is primarily due to the theoretical assumptions that the relative growth of the vegetation complex is either constant or that there is high potential for regrowth. As our results and others (Hart et al. 1993) have shown, this is not the case in the northern Great Plains.

We did not find a consistent and significant impact of grazing on aboveground N uptake (ANPP-N). Our results are in conflict with data from Coppock et al. (1983) and McNaughton et al. (1988) and model results for the Serengeti grasslands (Seagle et al. 1992) and the short-grass prairie (Holland et al. 1992). McNaughton et al. (1988) hypothesized that lack of grazing should reduce ANPP-N because of higher immobilization in dead material, reduced decomposition rates, and reduced soil N mineralization. McNaughton et al. (1988) showed results of $\leq$63% decrease in net soil N mineralization as a result of grazing exclusion. Decreases in soil N mineralization as a result of grazing protection have also been reported by Ruess (1984) and Ruess and McNaughton (1987). Holland and Detling (1990) have shown that net soil N mineralization in prairie dog towns was on average higher than in adjacent lightly grazed areas. Our data show, however, that while total N immobilized in standing dead biomass and litter was indeed higher in the long-term exclosure treatment than in the grazed ones, there were no significant differences among treatments in terms of decomposition and N release rates from litter and root biomass, or in soil N mineralization. In fact, the long-term exclosure treatment had higher total N release from litter than did the grazed treatments, but that was a mere reflection of higher litter biomass. The lack of ANPP-N response to grazing may be in part explained by the fact that >80% of the aboveground N uptake took place by mid-June, before any substantial impact of grazing had taken place.

Aboveground decomposition rates measured in this study were higher than those reported by Abouguendia and Whitman (1979) (38% vs. 20%), but lower than the 50% reported by Lauenroth and Whitman (1977) for western North Dakota. Root decomposition rates were substantially higher than the 18% reported by Sims and Coupland (1979) and the 8% reported by Dormaar and Willms (1993), but lower than the 57% reported by Lauenroth and Whitman (1977).

While no consistent differences were found among the treatments in terms of ANPP, ANPP-N, litter and root decomposition, N release rates, and soil N mineralization, the same cannot be said of species com-

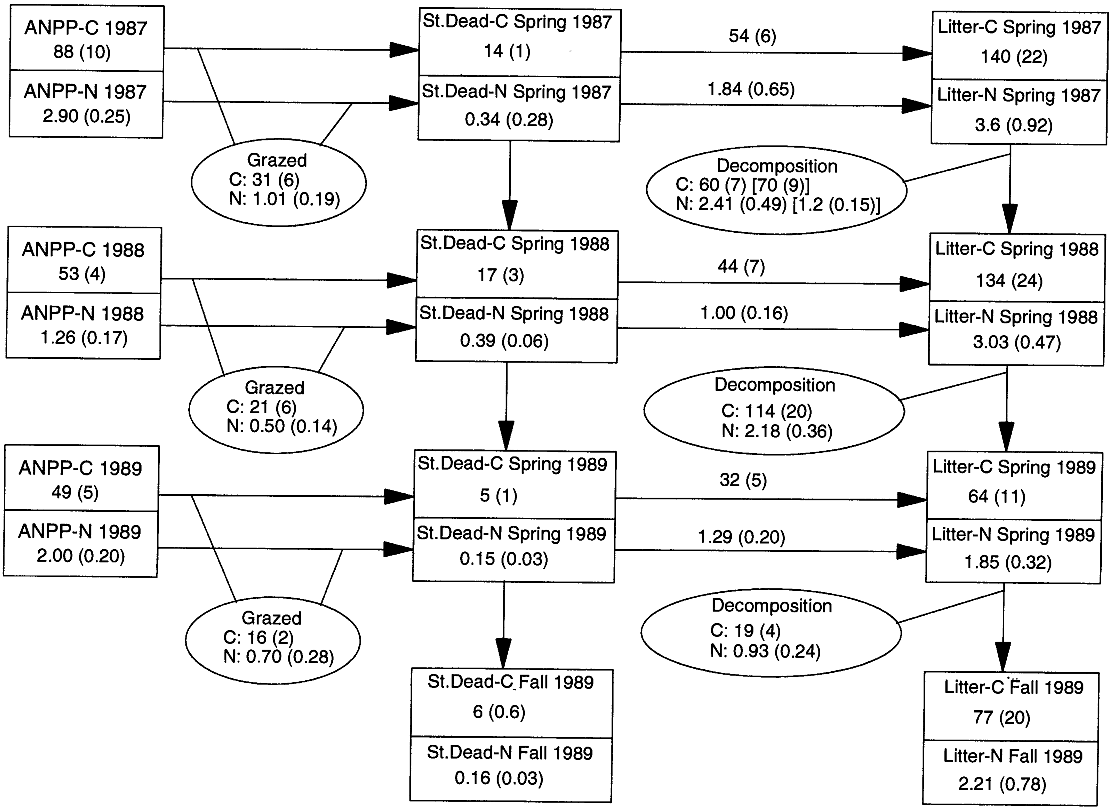

FIG. 10. Aboveground C and N flow (g/m²) for the rotation grazing treatment (ROT), calculated as a weighted average across all range sites. Numbers in parentheses represent the 95% CI. Numbers in brackets for the 1987–1988 C and N flow-through decomposition represent estimates using the rates from the decomposition experiment.

position. The relative basal cover of *Bouteloua gracilis* increased significantly as a result of grazing but was unaffected by grazing frequency. Relative composition of *Bouteloua gracilis, Carex* spp., *Stipa viridula, Stipa commata,* and forbs recorded in the grazed treatments of this study were similar to the ones reported by Hofmann et al. (1993) further east. The lack of response of species composition as a result of grazing frequency is consistent with the extensive literature in grazing studies in the Great Plains (Sarvis 1941, Denny et al. 1977, Denny and Barnes 1977, Denny and Steyn 1977, Gammon and Roberts 1978, Heitschmidt et al. 1985, 1987, Pitts and Bryant 1987, Hart et al. 1988, Bryant et al. 1989, Taylor 1989, Gillen et al. 1990, Hart et al. 1993, Olson et al. 1993, Taylor et al. 1993). Our data and the cited literature contradict to a certain extent the extensive analysis of a world-wide review of the grazing literature in a variety of ecosystems by Milchunas and Lauenroth (1993). This difference may be related to the fact that grazing intensity in our study as well as most of the grazing studies cited was seldom >50% and in most cases <40%. Our results, however, are in agreement with the Milchunas and Lauenroth (1993) findings of increases in dominant species under conditions of low consumption and short evolutionary history.

This study confirms a well-established observation, that at least in the Great Plains, individual livestock performance tends to be as good or higher under continuous, season-long grazing than under rotation grazing (Fisher and Marion 1951, Hubbard 1951, McIlvain and Savage 1951, Rogler 1951, Smoliak 1960, Kothmann et al. 1971, Mathis and Kothmann 1971, Owensby et al. 1973, Currie 1978, Heitschmidt et al. 1982, Heitschmidt 1986, Reece 1986, Heitschmidt and Taylor 1991). Experiments conducted at the Central Grassland Research Center in north-central North Dakota for eight consecutive years have also shown similar patterns with average daily gains (ADG) for cows and calves, respectively, of 0.4 kg/d and 1.1 kg/d in the continuous, season-long grazing treatment and 0.36 kg/d and 1.09 kg/d in the twice-over rotation grazing treatment (Barker 1993). These results are generally attributed to higher selectivity of plant species and a reduction of livestock stress than can result from pasture movement and changes in forage quality that accompany changes in pastures (Holechek et al. 1989). In our study, however, ADG for both calves and cows during August and September tended to be higher in the ROT treatment than in the SL treatment. This result seems to suggest that a twice-over rotation grazing system may allow

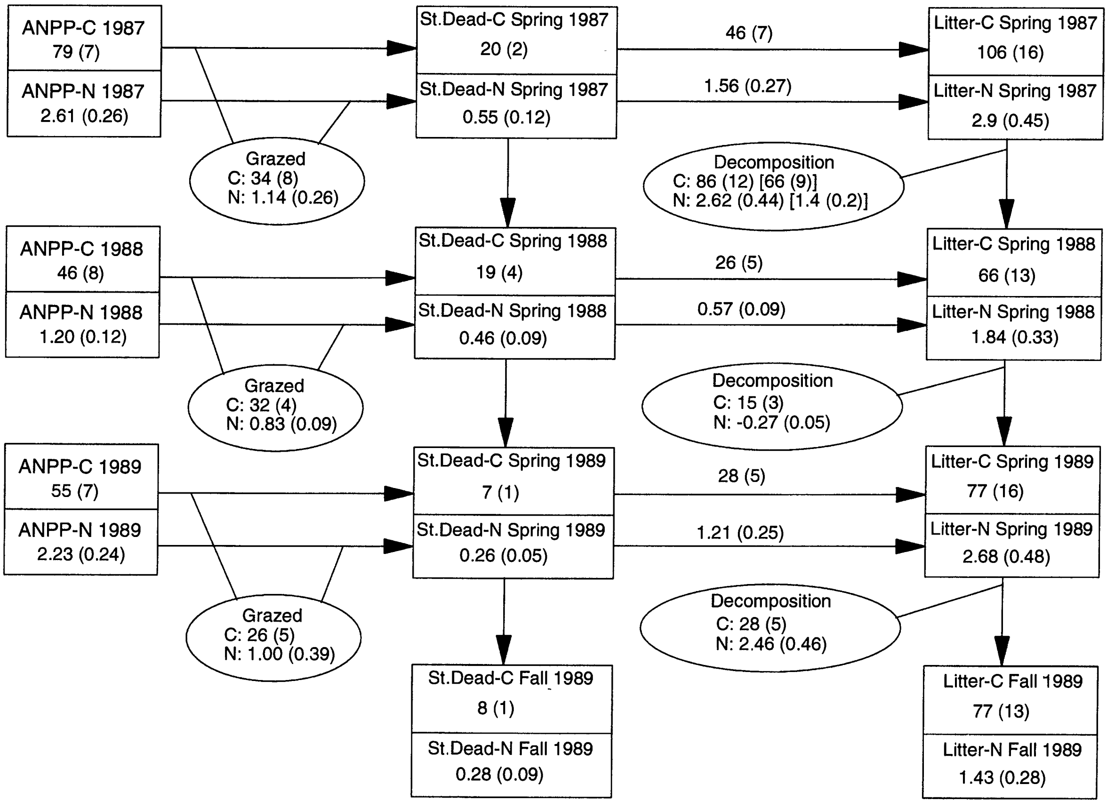

FIG. 11. Aboveground C and N flow (g/m^2) for the season-long grazing treatment (SL), calculated as a weighted average across all range sites. Numbers in parentheses represent the 95% CI. Numbers in brackets for the 1987–1988 C and N flow-through decomposition represent estimates using the rates from the decomposition experiment.

for higher animal selective grazing late in the growing season than a continuous, season-long grazing.

CONCLUSIONS

The broad conclusions and recommendations from this study are:

1) There were no differences in grazing intensity between the ROT and SL treatments. Before the drought of 1988 GI averaged 21%, while after the drought it increased to an average of 49% (50% is considered moderate grazing [Holechek et al. 1989]). These results indicate that the stocking rate recommended for the area (3.33 ha/AU) may be too conservative and could be increased (at least in average rainfall years).

2) Cumulative animal performance was not affected by grazing treatment, but the ROT treatment had higher ADG than the SL treatment late in the growing season. These results suggest that rotation grazing may allow for higher stocking rates than season-long grazing without a major impact in animal performance.

3) Neither grazing nor grazing treatments had a consistent impact on ANPP, ANPP-N, rates of litter and root decomposition and N release, or soil N mineralization. There were, however, large reductions of ANPP and ANPP-N as a result of the drought of 1988.

4) Grazing reduced the amount of C and N immobilized in standing dead and litter and the flow of C and N from standing dead to litter to soil organic matter. The NG and ROT treatments, however, were more similar in this regard when compared to the SL treatment, and the degree of similarity between them was increased by the drought of 1988.

5) Our results clearly indicate that in the grasslands of western North Dakota, rainfall is more important than grazing or grazing systems in the control of the ecosystem-level variables measured. The detection of some similarities in aboveground C and N flows between the NG and the ROT treatments, however, suggests that there may be potential beneficial effects in the use of rotation grazing that lie beyond the scope and time frame of our study.

6) At the floristic level our data suggest that in western North Dakota grasslands (a) total plant basal cover under moderate grazing tends to be stable and relatively unresponsive to grazing, grazing systems, or drought; (b) species composition is clearly affected by grazing (but not grazing systems) and drought but the responses are highly dependent on range site; (c) *Bouteloua gracilis* is a good indicator of grazing intensity; (d) the aggregate species composition of cool-season grasses and sedges is reduced by grazing, while the aggregate

composition of warm-season grasses is increased by grazing; and (e) grazing and drought increase the aggregate composition of forbs.

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