Vegetation and Litter Changes of a Nebraska Sandhills Prairie Protected from Grazing

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Abstract

End of season components of biomass and litter were measured on a Nebraska Sandhills prairie site to follow vegetation changes during the first 4 years following the cessation of intense livestock grazing. The 1977-1980 mean annual end of season biomass at Arapaho Prairie, a Sandhills prairie site, was 109 g/m². Summer grazing on Arapaho Prairie was terminated in 1977, and as a result, significant increases in the biomass of the deep-rooted, palatable warm-season (C_4) grasses, sand bluestem, little bluestem and switchgrass, have occurred since then. The biomass of the shallowly rooted C_4 grama grasses for the 4-year period was significantly correlated with growing season precipitation. Significant decreases in end of season biomass of the cool-season (C_3) grasses during the same 4-year period were highly correlated with yearly decreases in May precipitation. Following the removal of grazing, litter increased from 40 to 127 g/m² from 1977 to 1980. A nonsignificant yearly increase in litter production occurred in the third year after grazing as a steady state of litter production and decomposition was approached.

The Sandhills prairie region of Nebraska is one of the largest remaining contiguous prairie areas left unplowed in the United States. Most of the 5.2 million hectares (20,000 mi²) of this unique vegetation type is privately owned and used mainly as rangeland. The Sandhills region is semiarid with a continental climate (Lawson et al. 1977) and a mean annual precipitation of 45–50 cm, 80% of which falls between April and September. Rainfall is frequently poorly distributed and drought periods are common (Weaver and Albertson 1939). This area is a "mixed" prairie with a unique assemblage of "tall" grasses, "short" grasses, and sand tolerant species. Although dominated by warm-season (C_4) grasses,several cool-season (C_3) grasses are present and locally abundant. The major objectives of this study were (1) to measure the net annual biomass production of a typical Sandhills prairie site for 4 years, (2) to quantify the vegetation changes in a Sandhills plant community during a 4-year initial period of change from a history of intense grazing by domestic cattle, and to correlate these vegetation changes with abiotic and biotic factors, and (3) to quantify litter accumulation on a Sandhills site in the 4 years following the cessation of grazing.

Study Area and Methods

Arapaho Prairie (Sections 31, 32, T18N, R39W, Arthur County, Neb.), 526 ha, is managed as an experimental ecological research site by the School of Life Sciences, University of Nebraska, Lincoln. This upland Sandhills site has had a long history of summer grazing by cattle until 1976, when cattle were removed and all grazing ceased. The topography, typical of the Sandhills, consists of vegetated dunes, flat valleys and occasional small blowouts. The topographic relief of this area is 61 m.

The vegetation at Arapaho Prairie has been divided into 3 main types based on topography and soil texture (Keeler et al. 1980, Barnes and Harrison 1982). (1) Ridge vegetation along the upper dune slopes comprises about 16% of the prairie and the dominant grasses are hairy grama *(Bouteloua hirsuta)*, prairie sandreed *(Calamovilfa longifolia)* and little bluestem *(Andropogon scoparius)* (with 20, 13, and 10% vegetative cover, respectively). (2) Valley vegetation, in between the rolling hills, is dominated by prairie sandreed, needle and thread grass *(Stipa comata)*, and blue grama *(Bouteloua gracilis)* (27, 26, and 18% vegetative cover, respectively) and comprises about 23% of the prairie. (3) The Slope vegetation type is the most common, 61% of Arapaho Prairie, with blue grama, prairie sandreed, and hairy grama (27, 22, and 13% cover, respectively) as the dominant species. Bare sand is characteristic of the steeper topographic vegetation types with 20, 5, and 0% for the Ridge, Slope, and Valley, respectively. A species checklist and a more extensive ecological description of Arapaho Prairie is presented by Keeler et al. (1980).

In September 1977, 15, 4 m² permanent plots were randomly established in vegetation on a north facing gentle slope. The soil type on this slope is Valentine fine sand. One, 1-m² quadrat was selected for clipping by species in 4 consecutive years, starting with the quadrat in the northeast corner of the plot in 1977 and proceeding clockwise in each successive year. Sampling was done during the first week of September in all years, and was considered to be representative of end of season biomass since maximum vegetative and reproductive growth of the dominant species had been achieved by this time on this warm-season grassland. Although this harvesting technique underestimates productivity of the C_3 grass species, between-year biomass comparisons are still valid with respect to long-term plant community changes following grazing release.

All plant species were clipped at ground level, dried at 70° C for 48 h and weighed for above-ground biomass determinations. 'Recent dead' material which died during the current growing season was also collected by species and considered as annual above-ground biomass. The biomass values for all species present in the quadrat were summed and the mean values calculated. Student's t-test (Steel and Torrie 1960) was used to compare yearly mean biomass values.

The permanent clip quadrats were purposely located in an intermediate productivity "slope" vegetation site which is typical of 61% of the prairie. To compare 1980 biomass and litter values from the permanent clipped quadrats with those of other topographic sites in Arapaho Prairie, nine 0.1-m² clipped quadrats were located on each of 4 different topographic sites in mid-August, 1980. Stand sample areas were based on the topographic designations of

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Keeler et al. (1980).

Results

The mean annual end of season biomass on the study site was 109 g/m^2. Due to the rolling topography, this estimate is representative of 61% of the prairie. Other topographic sites have greater (valley) and lesser (ridge) standing biomass (Table 1).

Table 1. Biomass and litter accumulation (g/m^3 ± 2 S.E.) in August, 1980, at four topographic sites at Arapaho Prairie compared to the Permanent Clip Plot Site.

Site	Biomass	Litter
Ridge	85±16	55±16
(*Bouteloua hirsuta* dominated 'Choppy Sands' site)[2]		
Slope	260±49	464±97
(*Calamovilfa dominated 'Sands' site)*[2]		
Swale	241±40	478±76
(Agropyron spp. dominated site)[3]		
Valley[4]	111±60	90±24
(*Stipa-Bouteloua* dominated 'Sandy' site)		
Permanent Clip Plots		
Slope	126±8	127±12
(mixed species 'Sands' site)[2]		

[1]Topographic designations from Keeler et al. (1980).
[2]Equivalent Nebraska Sandhills Range Sites (USDA 1981)
[3]No equivalent Sandhills Range Site
[4]This is an atypical Valley site dominated exclusively by *Stipa comata* and *Bouteloua gracilis,* due to peculiar edaphic characteristics.

During the 4 years that data were collected, values of net annual biomass showed no significant overall increase or decrease (Fig. 1). However, in 1978 (the second year following grazing cessation) there was a significant decrease in season's end biomass ($P<.05$) which occurred in the year which had the lowest growing season precipitation (April–August) (Table 2). This decrease in total biomass was clearly due to the relative absence of the short-lived perennial forb western sagebrush *(Artemisia campestris),* which was notably abundant in the previous year. This is an opportunistic native composite which tends to increase on overgrazed rangelands in years of favorable precipitation similar to

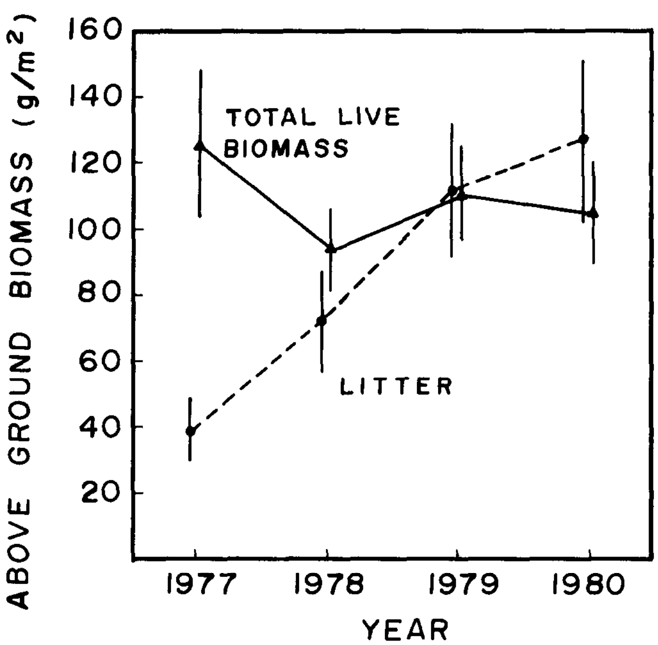

Fig. 1. *Above ground biomass and litter trends for the four year sampling period. The solid line represents total live biomass and the dashed line represents litter. Vertical bars represent ± 2 S.E.*

Table 2. Rainfall (mm) Arthur Station, 1977-1980, Arthur Co., Nebraska.

	1977	1978	1979	1980	$\bar{X}$ (30 yr)
May	102	71	68	52	77
April–June	302	153	207	180	208
April–August	447	232	395	275	324
August–October	100	88	97	97	116
Yearly total	544	411	542	402	442

other western plains perennial species of western sagebrush (Redmann 1975). Massive vegetative growth and flowering of this species in 1977 accounted for an estimated 75% of the C_3 forb biomass. A similar increase in western sagebrush has not been observed since grazing cessation in 1977. Similarly, above-average precipitation in April–August (38%) has not occurred since 1977. The appearance of the shallow rooted annual six-week fescue *(Festuca octoflora)* only in 1977 is also attributed to the above average spring precipitation.

Cool-season (C_3) and warm-season (C_4) grasses comprised most (about 90%) of the total above-ground biomass (Figure 2, Table 3). A remarkable and significant increase (59%, $P<.01$) in the C_4 grasses and decrease (51%, $P<.05$) in the C_3 grasses occurred during the 4-year period while the total grass biomass (C_3 + C_4) remained constant.

Highly significant ($P<.01$) biomass increases in the larger, grazing-sensitive C_4 grasses, sand bluestem, little bluestem and switchgrass *(Panicum virgatum),* were found by the fourth year. The increases in these 3 species occurred despite below-average growing season (April–June and April–August) precipitation in 1978 and 1980. There was no correlation between the productivity of these 3 species and monthly or current growing season precipitation (April–August, May–July etc.) or with precipitation occurring in the previous fall (August, September, and October). Notably, no

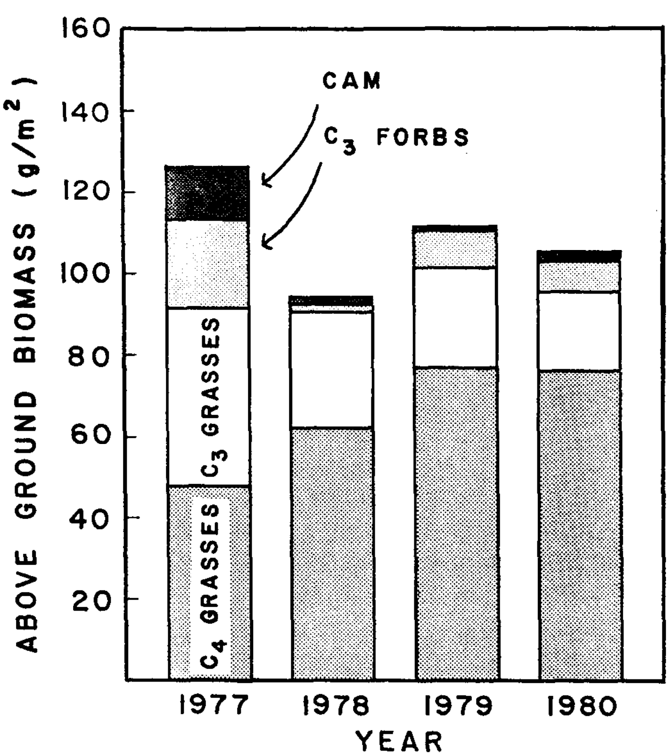

Fig. 2. *Four year trends in C_4 grass, C_3 grass, C_3 forb, and CAM components of total above ground biomass.*

Table 3. End of season biomass and litter dynamics (g/m² ± S.E.) of the major species of Arapaho Prairie vegetation.

	1977	1978	1979	1980
C_4 Grasses + Graminoids				
Andropogon hallii	1.6± .8	5.6±1.3*[1]	7.0±1.2**[3]	10.1±3.0**[4]
Andropogon scoparius	5.1±1.5	8.2±3.0	14.2±4.1	20.2±7.4**[4]
Bouteloua spp. (*B. gracilis* + *B. hirsuta*)	21.9±3.4	18.6±2.0	26.6±5.6	22.0±1.6
Calamovilfa longifolia	13.3±3.4	24.4±4.4	23.5±4.3	14.4±3.4
Cyperus schwinitzii	—	—	.1± .1	.1± .1
Muhlenbergia pungens	—	.3± .3	.6± .6	.4± .4
Panicum virgatum	3.4± .9	5.2±1.7	6.5±1.6	10.3±1.9**[4]
Sporobolus cryptandrus	2.8±1.6	2.6± .9	1.9±1.4	2.1±1.1
Total C_4 biomass	48.1±3.0	64.3±4.1**[1]	76.8±6.1***[3]	76.2±9.8**[4]
C_3 Grasses + Graminoids				
Carex heliophila	.7± .3	3.0±1.6	1.0± .3	.7± .2
Festuca octoflora	2.1± .6	—	—	—
Koeleria pyramidata	13.4±2.2	19.0±3.3[6]	6.1±1.3	7.2±1.7
Stipa comata	22.2±6.5	4.4±1.6[6]	17.6±2.9	11.4±3.1
Total C_3 grass biomass	38.2±7.2	26.4±3.0	24.7±2.7	19.6±2.4*[4]
Total C_3 forb biomass	27.0±1.7	1.6± .5**[1]	8.9±2.1**[2],*[3]	7.3±3.6*[4]
Total CAM[5] biomass	12.7±6.5	1.7± .3	2.1± .9	2.3±1.0
Total biomass	126.0±11.3	94.2±6.3*[1]	111.2±7.1	105.3±7.8
Litter	39.8±14.6	72.3±7.6*[1]	112.4±10.2***[2,3]	127.8±12.4***[4]

*,**,***Significant at the .05, .01 and .005 level, respectively.
[1]test of significance between 1977-78. Student's t test
[2]test of significance between 1978-79
[3]test of significance between 1977-79
[4]test of significance between 1977-80
[5]CAM = *Opuntia* and other cacti species
[6]*Stipa* and *Koeleria* are difficult to distinguish vegetatively and were confused during 1978. *Stipa* generally has greater relative biomass as in other years.

significant increases in biomass were found during the 4-year period in prairie sandreed or the smaller grama grasses which are important co-dominants. The productivity of the shallow rooted grama grasses was positively correlated with total growing season precipitation (April–August, R^2=.99, P<.01) over the 4-year period. Similar correlations with the other deep rooted C_4 co-dominants sand bluestem, little bluestem, prairie sandreed, and switchgrass were not significant.

Although the collective decline in C_3 grass biomass over the 4-year period was significant (P<.05), no significant decreases for individual species were found. A regression of precipitation during the months of April, May, June, and April–June with current season's C_3 grass biomass indicates that May precipitation alone explains most of the yearly variation in the C_3 grass biomass (R^2=.998, P=.001). This highly significant positive correlation indicates that May is a critical time for growth of these C_3 species in the Sandhills. Correlations of C_3 biomass with April, June and April--June precipitation were positive but not significant. Collectively, productivities of the cool-season (C_3) grasses, needle and thread grass and june grass, which make up 93% of the C_3 grass biomass, are also highly correlated with May precipitation (R^2=.99, P<.01) for the 4-year period. These significant positive correlations suggest that the steady decrease in cool-season (C_3) grasses over the 4 years was related to differences in early growing season (May) precipitation.

During the first 3 years after grazing, there were significant yearly increases in litter accumulation (Fig. 1). In the fourth year, the yearly increase in accumulated litter was not significant. The increase in accumulated litter is a direct result of the cessation of grazing. It appears that yearly litter accumulation has approached a constant value (120 g/m² to 130 g/m²) as a constant turnover rate is approached.

Discussion

Grazing Response

Hover and Bragg (1981) have shown that summer removal of above-ground C_4 biomass can reduce C_4 productivity and it is known that many years of intensive grazing during the active growing period (June, July, and August) for the palatable C_4 grasses causes a decrease in their abundance and vigor. With the removal of grazing, increases in the biomass of the C_4 species is expected (Weaver 1954, Dyksterhuis 1949, USDA 1981).

Significant (P<.01) inceases during the 4 years in the biomass of 3 of the palatable C_4 grasses (sand bluestem, little bluestem, and switchgrass) at Arapaho Prairie occurred after grazing removal despite below-average growing season precipitation in 1978 and 1980. These increases are not correlated with precipitation from the current growing season or that of the previous fall. The increased productivity of these species over the 4-year period is attributed to the release from grazing pressure.

Precipitation Response

The bluestem grasses and switchgrass are deeply rooted (Weaver 1919) and rely on stored soil moisture throughout the growing season; these larger species may therefore derive little benefit from small summer rainfall events due to surface interception, storage and consumption by the more shallowly rooted species (Barnes and Harrison 1982). Indeed, Barnes and Harrison (1982) found stomatal conductances in deep rooted C_4 grasses to be rather insensitive to growing season precipitation events. Similarly, Gilbert et al. (1979) found individual shoot productivity of switchgrass and sand bluestem rather insensitive to current year dryness on a Sandhills prairie similar to Arapaho.

The productivity of 3 of the 4 co-dominant C_3 and C_4 grasses which do not show an increase in biomass with grazing removal showed significant (P<.05) positive correlations with precipitation. These species (needle and thread grass, june grass, and the grama grasses), have shallow, fibrous root systems (Weaver 1919) and use shallowly stored soil moisture from unpredictable summer showers (Brown and Trlica 1977, Detling 1979). On Arapaho Prairie, the biomass of the C_3 species (needle and thread grass and june grass) increased in years of increased early growing season precipitation (May). Boutton et al. (1980) have shown that April, May, and June are the months when the C_3 grasses are physiologically the most productive due to cooler temperatures for optimal photosynthesis. In contrast, the biomass of the C_4 grama grasses was correlated with total growing season (April–August) precipitation. Similarly, Cable (1975) found that current and previous summer's rainfall determined grass productivity in an Arizona semidesert where three species of *Bouteloua* were among the dominants.

It is likely that for these shallow rooted C_3 and C_4 grasses, the sensitivity to current growing season precipitation would mask any grazing release response. Another possible explanation is that the early growing season activity period of the C_3 species makes them less impacted by summer grazing.

It is unknown why prairie sandreed, the fourth co-dominant, deep rooted C_4 species showed no increase in biomass following grazing cessation. Although it is reported to be less palatable than the other C_4 grasses (Vallentine 1976), it is unlikely that it escaped severe grazing pressure.

Litter Accumulation

Many land managers and ranchers in the Nebraska Sandhills assume that litter, if allowed to accumulate, could increase the potential for large-scale range fires. Litter increased three-fold to 127 g/m^2 on this typical 'Slope' or 'Sands' range site (USDA 1981) (which comprises 61% of Arapaho Prairie) from 1977 to 1980 due to the removal of domestic cattle grazing. However, the rate of increasing litter production in the Sandhills has declined sharply within 3 years after grazing, rather than continuously increasing, and now appears to be approaching a steady state.

The amount of litter at Arapaho Prairie on this upland site after 4 years without grazing is similar to or less than that on an ungrazed short grass prairie in Eastern Colorado (216 g/m^2), and ungrazed bunch grass or mixed grass (216 g/m^2) prairies from Kansas to North Dakota (range = 216 to 713 g/m^2; Sims et al. 1978) where range fires are not especially serious. After 4 years without grazing, the more productive lower slopes, swales, and valley bottoms have litter accumulation values comparable to those of mixed and tall grass prairies (416 g/m^2 to 583 g/m^2)(Sims et al. 1978). Separate management guidelines should be proposed for these lower valley bottom areas which comprise only 23% of Arapaho Prairie. These may include prescribed periodic burning, haying, or grazing.

Although the results of this study indicate that the productivity of the large palatable C_4 grasses in the Sandhills can increase from 2-4 fold in 3 years and 3-6 fold in 4 years following the complete removal of intense summer grazing, further studies are needed to determine how long these increases could be sustained once grazing was re-established and if similar increases would occur with periodic shifts to a winter grazing schedule.

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