The Influence of Grazing Pressure on Rooting Dynamics of Caucasian Bluestem

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Abstract

Caucasian bluestem (*Bothriochloa caucasica* (Trin.) C.E. Hubb.) is a warm-season grass introduced from Eurasia that is currently used for reseeding farmland and depleted range in the Southern Great Plains. Although this species is thought to be grazing tolerant, little specific information is available concerning its response to grazing. Variable (put-and-take) stocking was used to maintain heavy (3 to 8 steers/ha) and light (2.5 to 4.5 steers/ha) grazing treatments during mid May to late September from 1983 to 1985. Seasonal changes in root mass and root length to a depth of 60 cm were measured the first 2 years, and end-of-season root length was measured the third year. Leaf area index (LAI) was measured during the first 2 years. Peak root mass was 27 and 46% less in heavily relative to lightly grazed swards in 1983 and 1984, respectively. Total root length for heavily grazed swards was 33 and 45% less than lengths of lightly grazed swards in 1983 and 1984, respectively. Heavy grazing resulted in a relatively larger reduction in LAI than in either root mass or length, and thus the ratio of absorbing root surface to transpiring leaf surface was greater for heavily grazed than lightly grazed plants. This increased ratio may explain our previous observation that heavy grazing resulted in an improved water status of leaf tissue. End-of-season total root length over the 3-year period (15 to 18 and 24 to 28 km/m² for heavily and lightly grazed swards, respectively) was remarkably consistent given the variable climatic conditions over the study period.

Key Words: *Bothriochloa caucasica,* defoliation tolerance, root length density

Root ecology plays a critical role in plant survival and competitive ability. However, because of the time-consuming and tedious nature of field root studies, less research effort has been devoted to this topic than studies involving aboveground plant response (Bohm 1979). Considerable emphasis has been directed to rooting dynamics in explaining plant response to defoliation (e.g., Biswell and Weaver 1933, Crider 1955). Clipping generally causes a reduction in root growth and mass (Biswell and Weaver 1933, Thaine 1954, Crider 1955, Evans 1972, Archer and Tieszen 1983, Richards 1984). An exception was the study of Chapin and Slack (1979) in which 2 years of chronic defoliation did not reduce root weight of a defoliation-tolerant arctic sedge. Cessation of root growth after defoliation has been suggested as a means of conserving plant reserves, thereby aiding in resumption of shoot growth (Evans 1972, Caldwell et al. 1981).

Although results from clipping studies suggest that continuous grazing should reduce root growth and mass, results from grazing studies are inconsistent and often confounded because grazing alters species composition of the plant community. Thus the effect of grazing on root mass will depend on rooting habits of the particular increaser and decreaser species. Weaver (1950) and Schuster (1964) reported a decline in root mass with increasing grazing intensity in tallgrass prairie and mountain grassland ecosystems, respectively. In both studies root systems of individual plants were excavated, and root mass of the dominant climax species was determined. Lorenz and Rogler (1967) and Bartos and Sims (1974) found no differences in root mass among grazing treatments in mixed and shortgrass prairie ecosystems, respectively. In contrast, Pearson (1965) and Smoliak et al. (1972) observed an increase in root biomass of grazed compared to ungrazed cold desert and mixed prairie ecosystems, respectively. In one of the few studies that examined root dynamics of a single species sward, Ruby and Young (1953) found that grazing brownseed paspalum *(Paspalum plicatulum)* over an 18-month period had little effect on root mass.

This study was part of a larger project aimed at evaluating the aboveground and belowground response to grazing of Caucasian bluestem *(Bothriochloa caucasica),* a species considered quite grazing tolerant. The specific objectives were to compare seasonal trends in rooting dynamics and root:shoot relationships of Caucasian bluestem pastures grazed continuously at heavy and light intensities.

Materials and Methods

The study was conducted at the USDA-ARS Forage and Livestock Research Laboratory near El Reno, Okla. Soils at the study site were fine-silty Pachic Haplustolls of the Dale Series. Annual precipitation averaged 80.9 cm from 1977 to 1985. During the years of the study annual precipitation was 99.0 cm (1983), 72.4 cm (1984), and 120 cm (1985). Growing season precipitation (April--September) was 54, 33, and 60 cm for 1983, 1984, and 1985, respectively.

We used swards of Caucasian bluestem which had been seeded in 1979 and hayed or leniently grazed prior to initiation of this study. The pastures were burned in mid March each of the study years. Ammonium nitrate was applied at a rate of 84 kg/ha actual nitrogen in early May and again in early July of 1983 and 1985; during 1984 the second application was deleted because of dry conditions. Atrazine was applied mid March 1985 at 0.7 kg/ha to control cheatgrass (*Bromus tectorum* L.). Plant species other than Caucasian bluestem were not present during any of the sampling periods. Continuous variable (put-and-take) stocking was used to maintain high herbage mass (light grazing, 2.5 to 4.5 steers/ha) and low herbage mass (heavy grazing, 3 to 8 steers/ha) treatments on 1-ha pastures (see Wheeler et al. (1973) for discussion of variable stocking). Steers averaging about 225 kg were put on the pastures in mid-May and grazed until late September all 3 years. Growth of Caucasian bluestem is very rapid during May and June; about 3 weeks of grazing were required to achieve the desired herbage levels in the various pastures. From about the second week of June to the end of September leaf area indices (LAI's) and standing crops were <1.0 and 860 to 1,952 kg/ha, respectively, for the heavy grazing treatment and 1.4 to 4.5 and 3,180 to 10,100 kg/ha, respectively, for the light grazing treatment. A more detailed description of the study appears in Svejcar and Christiansen (1987).

During 1983 and 1984, three replicates of heavily and lightly grazed pastures were used. On 4 dates in 1983 and 3 in 1984, both aboveground and belowground plant components were sampled. Aboveground samples were removed from four 15 × 25-cm quadrats per experimental unit and returned to the lab where live leaf

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was separated from other plant parts. The leaves were measured for area with an LI-3000 area meter and LI-3050A belt conveyer (Li-Cor, Inc., Lincoln, Neb.)[1], and values converted to LAI.

Root cores from 0 to 30 and 30 to 60 cm soil depths were taken at the center of every second quadrat with a 7.6-cm diameter coring tube (Giddings Machine Co., Ft. Collins, Colo.). All root cores were washed with a hydropneumatic elutriation system (Gillison's Inc., Benzonia, Mich.). Core samples were stained with a 1% Congo Red solution for 15 minutes and rinsed with deionized water. The samples were placed in a tray of water, and debris and dead roots were manually removed. Roots which were brittle and lacked an intact stele were considered dead. The samples were scanned for length on a root-length scanner (Commonwealth Aircraft Corp., Melbourne, Australia). Percent root and percent debris were estimated from a core subsample by manually counting intersections on a grid. The scanned root-lengths were corrected for debris. The correction was necessary because even with careful hand cleaning of root samples, we found debris biased the estimate of root length by 4 to 10%. Root length density (RLD) was calculated from total root length of a sample and the volume of soil from which the roots were collected. Samples were dried at 75° C for 24 h and weighed.

One end-of-season root coring was conducted in 1985. Four paired samples were obtained along a fenceline of adjacent heavily and lightly grazed pastures; the area within 3 m of the fence was avoided. At each sampling point root cores were taken at depths of 0 to 30 and 30 to 60 cm. Cores were processed as described previously.

During 1983 and 1984 the experimental design was a randomized block with treatment, depth, and date as main effects. Analysis of LAI had treatment and date as main effects. Years were analyzed separately. Analyses were also conducted by date and depth within a year. The 1985 sampling was analyzed as a paired-t with pairing for depth and treatment. All analyses were conducted using the Statistical Analysis System (SAS).

Results

The initial sampling in 1983 was taken about 3 days prior to initiation of grazing. Thus it provided baseline data, but was not included in treatment comparisons. In 1983 there were significant ($P<.05$) treatment by date interactions for root mass and RLD; and in 1984 there were significant ($P<.05$) treatment by depth by date interactions for these 2 variables. Thus, for consistency and ease of presentation we chose to present the analyses which compare treatments at a given date and depth (see Steel and Torrie 1980, p. 399 for a comparable example). During the summer of 1983 the trend was for increasing root mass and RLD at the upper depth for both treatments, followed by a decline in early fall (Figs. 1 and 2). At the lower depth on lightly grazed pastures the trend was also for an increase during summer followed by a fall decline, but there was little seasonal variation in either root mass or RLD on heavily grazed pastures. Sampling variation was less at the lower relative to the upper depth, and treatment differences were significant ($P<.05$) at the lower depth for the last 2 sampling dates of 1983.

In 1984 there was generally little seasonal change in either root mass or RLD at either depth on the heavily grazed pastures (Fig. 1 and 2). The greatest seasonal change was an increase in RLD from 1.3 to 2.0 cm/cm^3 from early June to late August at the lower depth of heavily grazed pastures. Both root mass and RLD increased during the summer at upper depth of lightly grazed pastures. Treatment differences were significant ($P<.05$) for both root mass and RLD on the second two dates at the upper depth. Root mass was statistically different ($P<.01$) between treatments on the last date at the lower depth, although the magnitude of the difference was relatively small.

The root length-to-weight ratio (LWR) was not influenced by grazing level ($P>.05$), and there were no significant interactions of treatment with either depth or date in 1983 or 1984. There was a depth by date interaction ($P<.05$) in 1983, apparently a result of a fairly constant LWR at 0–30 cm and an increase over the season at 30–60 cm (Table 1). Analyses by date indicate that depths were

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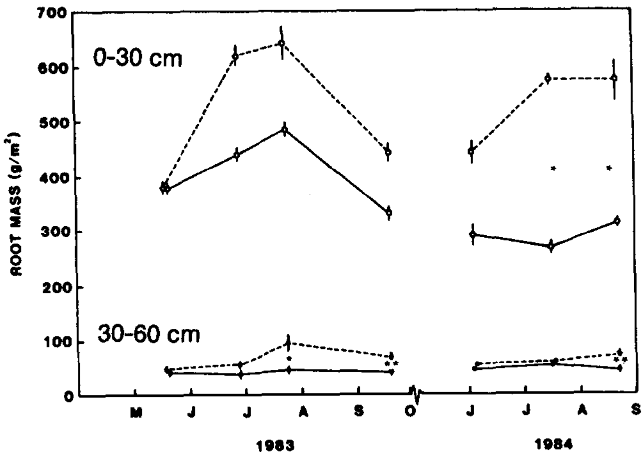

Fig. 1. *Root mass (g/m²) of lightly (dashed lines) and heavily (solid lines) grazed Caucasian bluestem at 0 to 30 cm (top of figure) and 30 to 60 cm (bottom of figure) soil depths. The first sampling (May 1983) was conducted just prior to the initiation of grazing treatments. Vertical lines are one standard error of the mean* (n = 6). *Significant treatment effects analyzed by depth and date are indicated by asterisks (* = P<.05, ** = P<.01).*

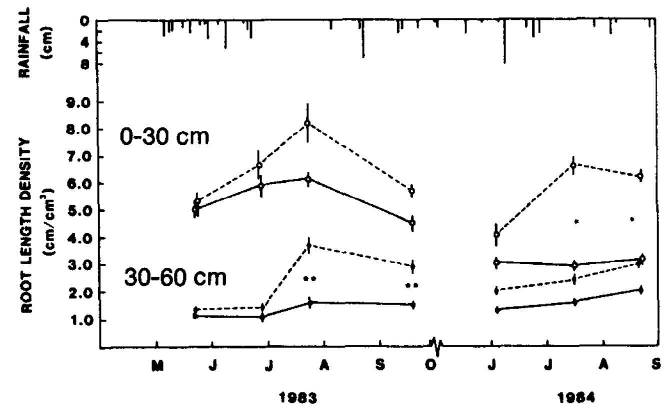

Fig. 2. *Root length density (cm/cm³) of lightly (dashed line) and heavily (solid lines) grazed Caucasian bluestem at 0 to 30 cm (top of figure) and 30 to 60 cm (bottom of figure) soil depths. The initial sampling (May 1983) was conducted just prior to imposition of grazing treatments. Vertical lines are one standard error of the mean* (n = 6). *Significant treatment effects analyzed by depth and date are indicated by asterisks (* = P<.05, ** =P<.01). Rainfall events during the two growing seasons appear at the top of the figure.*

Table 1. Length-to-weight ratio (m/g) of roots from heavily (H) and lightly (L) grazed Caucasian bluestem swards. Values are means of 6 samples.[1]

Depth and	1983				1984		
treatment	May 19	June 28	July 21	Sept. 18	June 4	July 15	Aug. 23
0–30 cm							
L	42.9	32.2	41.8	40.4	27.3	34.4	34.2
H	40.5	39.0	37.6	42.6	31.6	33.0	30.5
30–60 cm							
L	82.5	82.0	108.4	123.6	113.3	124.9	132.2
H	80.2	86.7	97.5	106.4	97.0	129.6	152.2

[1]Treatments were not significantly different ($P>.05$), however, depths were significantly different ($P<.05$).

Table 2. Leaf area index (LAI), root length (km) to a depth of 60 cm per m² of ground area, root area:leaf area ratio, and distribution of root mass and root length for heavily (H) and lightly (L) grazed Caucasian bluestem pastures.[1]

	1983								1984						1985	
	May 19		June 28		July 21		Sept. 18		June 4		July 15		Aug. 23		Oct. 2	
Variable	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L
LAI	2.4	2.9	0.7	3.2	0.7	1.4	1.0	1.9	2.0	3.0	0.8	4.5	0.4	1.4	—	—
Root length (km) per m²[2]	18.9	20.4	21.0	24.6	23.4	35.2	18.0	25.8	12.9	18.3	13.8	27.0	15.3	27.9	17.4	24.0
Root area:leaf area ratio[2]	6.2	5.7	24.6	6.1	26.7	19.4	14.1	10.6	5.1	4.8	13.7	4.8	32.4	15.4	—	—
Root mass in upper profile (%)[3]	90	90	92	92	91	87	89	87	87	90	83	91	89	89	88	90
Root length in upper profile (%)[4]	81	81	84	83	80	73	75	66	70	67	65	73	61	67	74	81

[1]Both LAI and root area:leaf area ratio are unitless, however, they can be visualized as m² of leaf area per m² of ground area and m² of root surface per m² of leaf surface, respectively.
[2]Root surface area was calculated using an average root diameter of 0.25 mm.
[3]Percentage of total root mass to a depth of 60 cm which occurred in the top 30 cm.
[4]Percentage of total root length to a depth of 60 cm which occurred in the top 30 cm.

significantly different ($P<.05$) on all dates. There was not a significant depth by date interaction ($P>.05$) in 1984, and the main effect of depth was significant ($P<.05$).

In 1983 LAI was significantly greater ($P<.05$) for the lightly compared to heavily compared grazed pastures (the 19 May sampling was excluded for the analysis) (Table 2). In 1984 there was a treatment by time interaction ($P<.05$). In the by date analysis there was no significant difference ($P>.05$) in LAI between lightly and heavily grazed pastures on 4 June, which was about two and a half weeks after initiation of grazing; however, grazing treatments were significantly different ($P<.05$) on 15 July and 23 August in 1984. Root length per m² of ground area was calculated from root length densities for the 0 to 60 cm depth. Total root length at the end of the growing season was remarkably consistent over the 3-year period, with values of 15.3 to 18.0 km/m² and 24.0 to 27.9 km/m² for the heavy and light grazing treatments, respectively (Table 2). Although the last sampling date in 1984 was earlier than the other 2 years, the lightly grazed plants had senesced and changes in root length during September would probably have been minimal. The heavily grazed plants were active during the late summer period and changes in root length may have occurred.

Using values of total root lengths, and assuming a root diameter of 0.25 mm, total root surface areas were calculated. Under a dissecting scope we estimated 0.25 mm to be the median root diameter class over the 0–60 cm sampling depth for 1985 samples. More rigorous measurement of root diameter would be necessary to obtain precise root surface estimates, however, a median value should suffice for illustrative purposes. These root surface values were divided by leaf area to provide a ratio of absorbing surface of root to transpiring surface or leaf. With the exception of 4 June 1984, when the leaf area of heavily grazed pastures was still fairly high, there was at at least a 38% increase in the ratio of root surface area to leaf area under heavy grazing. During July and August of 1984 these ratios were more than twice as high for the heavily compared to lightly grazed treatment. Location of roots in the soil profile will influence root surface estimates because deep roots are thinner (Table 1); however, proportions of roots in the upper depth were generally similar between treatments (Table 2). And regardless of the relationship between treatments in root distribution, the heavily grazed pastures had higher ratios of root to leaf surface than those lightly grazed.

Discussion

The study of belowground structures has generally been neglected (Risser et al. 1981), thus our understanding of root:shoot relationships is somewhat limited. Kummerow (1980) concluded that the ratio of absorbing root surface to photosynthetically active leaf area is functionally more relevant than ratios of root to shoot biomass. Although Kummerow presented surface ratio values for shrubs, little information is available for grassland species, and no studies document the effect of grazing on this ratio. McNaughton (1983) hypothesized that "herbivory may improve the water relations in remaining tissue and tissue newly synthesized following tissue removal due to a greater ratio of root absorbing surface to remaining tissue". The results presented in this and a previous paper (Svejcar and Christiansen 1987) support McNaughton's hypothesis that at least for some grazing tolerant grasses an improved absorbing root surface to transpiring leaf surface ratio can improve the water status of leaf tissue. Although heavy grazing reduced both root mass and length (Figs. 1 and 2), the reduction in leaf area was relatively greater, thus increasing the root surface to leaf surface ratio relative to light grazing (Table 2). In another portion of this study, xylem water potentials were measured weekly from 16 June to 9 September 1984 on plants from the heavily and lightly grazed treatments. When averaged over the season, heavily grazed plants had xylem potentials 28% less negative and total leaf conductances 76% higher than lightly grazed plants (Svejcar and Christiansen 1987). Although there was an increase in leaf conductance, heavily grazed swards had only one-third to one-fifth the leaf area of lightly grazed swards during mid to late summer of 1984. Thus, water use should have been less for heavily grazed swards; soil moisture measurements support this conclusion (Svejcar and Christiansen 1987). However, because only active leaves in the upper canopy were measured in the lightly grazed swards, average canopy conductance may have been lower than our measurements would indicate when LAI was high.

Information on rooting patterns is important in predicting both plant response to grazing and general plant response to climatic and edaphic factors. On rangeland, as well as in other systems, water and nutrient extraction by plants are the primary factors controlling plant growth. Taylor and Klepper (1978) concluded that many of the conceptual models developed to describe water uptake by plants assume that uptake rate is a function of: (1) transpiration rate, (2) root length, (3) water uptake per unit root length, and (4) the water potential difference between some point in the soil and some point in the plant or atmosphere. However, most of the rooting information currently available on grassland species involves root mass rather than length. In the present study, root mass tended to be more concentrated in the upper horizon than did root length (Table 2). This can be accounted for by the root length to weight ratios (Table 1), which showed that the deep roots had considerably more length per unit weight than upper horizon roots. Similar results have been found with annual cereals (Derera et al. 1969) and annual clovers (Pearson and Jacobs 1985). Thus, some species may be able to explore more soil at the lower depths than would be expected from root mass values alone. In the present study the proportion of root mass in the upper profile was remarkably constant among treatments and over time but there was a good deal of variation over time in proportion of root length in the upper profile (Table 2). In both 1983 and 1984, as the season advanced and the profile became drier, roots at the lower depth developed higher LWR (Table 1). Roots had less length per unit weight at the lower depth in 1983 compared to 1984, which might be related to lower precipitation in 1984, causing more extensive exploration by roots. Many questions concerning the functional aspects of rooting dynamics remain unanswered. There is little empirical information currently available concerning the rooting density required to dry a soil profile to a given level, especially for perennial species. Caldwell (1976) suggests that the energetic costs of perennial root systems are difficult to justify if roots are viewed strictly as organs of water absorption. In the present study, the reduction in root length and leaf area with heavy grazing was sufficient to delay drying of the soil profile relative to light grazing; however, regardless of treatment most of the available soil moisture was extracted (Svejcar and Christiansen 1987).

Our observation that root mass and length tend to be concentrated in the upper portion of the soil profile is consistent with studies from other grassland systems (Weaver 1950, Ruby and Young 1953, Smoliak et al. 1972, Bartos and Sims 1974). Again, the functional aspects of this phenomena are not clearly understood, but 2 possibilities have been suggested. Species adapted to regions where small rainfall events constitute the majority of summer precipitation may benefit by extracting a maximum of surface moisture before it is lost to evaporation (e.g., Sala and Lauenroth 1982). Another possible explanation is that roots are concentrated at the soil surface because that is where a majority of the plant nutrients are located (Williams 1969). In the present study, the distribution of root length in the soil profile varied over time, and to some extent between treatments (Table 2). However, the importance of these variations in distribution will be difficult to interpret until we gain a better understanding of the tradeoff between energy required to grow roots at a given soil depth and the resultant increase in water and nutrient uptake.

Summary and Conclusions

Continuous heavy grazing reduced root mass and length relative to light grazing on Caucasian bluestem pastures. However, the relative reduction in root length was less than the reduction in leaf area for heavily compared to lightly grazed pastures. The result was an improvement in root surface area to leaf area ratio, and thus improved water status for heavily grazed pastures. This response, in concert with Caucasian bluestem's profuse tillering habit and maintenance of stable carbon pools (Christiansen and Svejcar 1987) helps explain this species' ability to tolerate heavy grazing. However, we caution that many questions concerning the functional aspects of root response remain unanswered.

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