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Performance and forage selectivity of sheep and goats co-grazing grass/forb pastures at three stocking rates☆

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Abstract

Differences among ruminant species in forage selectivity offer potential for efficient utilization of pastures with diverse arrays of plant species. One common management strategy that may influence forage selectivity is stocking rate (SR). Therefore, this experiment was conducted to determine effects of SR on performance and forage selectivity of growing sheep and goat wethers co-grazing grass/forb pastures. Grazing was for 16 weeks in 2002 and 2003. Pastures consisted of various grasses, primarily bermudagrass (*Cynodon dactylon*) and johnsongrass (*Sorghum halepense*), and forbs (e.g., ragweed; *Ambrosia* spp.). Sheep (Khatadin) and goats (75% Boer) averaged 21 ± 0.7 and 21 ± 0.5 kg initial BW, respectively, and were 4–5 months of age when grazing began. Stocking rates were four (SR4), six (SR6), and eight (SR8) animals per 0.4-ha pasture, with equal numbers of sheep and goats. The nine pastures (three/treatment) were divided into four paddocks for rotational grazing in 2-week periods. Forage mass (pre- and post-grazed) and composition of grass versus forbs were determined by quadrat samples and transect analysis, respectively. BW was measured every 4 weeks and preference values for grass, forbs, and ragweed (10: highest possible preference; 0: consumption in proportion to availability; −10: no consumption) were determined from fecal microhistology and transect measures. There was a year × SR interaction ($P < 0.05$) in herbage DM mass before grazing (year 1: 2937, 3298, and 3351 kg/ha; year 2: 3033, 2928, and 2752 kg/ha for SR4, SR6, and SR8, respectively (S.E. = 174.4)). Post-grazed forage mass decreased linearly ($P < 0.05$) as SR increased (2279, 1693, and 1288 kg/ha for SR4, SR6, and SR8, respectively (S.E. = 102.6)). In vitro true DM digestibility of pre-grazed forage samples was similar among SR, but SR × year interacted ($P < 0.05$) for post-grazed samples (year 1: 57.0, 54.4, and 53.5; year 2: 56.8, 49.0, and 48.3 for SR4, SR6, and SR8, respectively (S.E. = 2.16).

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Year and SR interacted ($P < 0.05$) in the percentage of grass in pastures post-grazing determined by transect (year 1: 64, 69, and 74%; year 2: 50, 66, and 73% for SR4, SR6, and SR8, respectively (S.E. = 8.4)). The preference for grasses was higher and that for total forbs lower for sheep than for goats ($P < 0.05$). The preference value for ragweed, measured in year 2, was lower ($P < 0.05$) for sheep than for goats (−1.6 versus 0.2) and increased linearly with increasing SR. Average daily gain tended ($P < 0.10$) to decrease linearly as SR increased (61, 51, and 47 g/day), and total BW gain per hectare increased linearly ($P < 0.05$; 610, 759, and 933 g/day for SR4, SR6, and SR8, respectively). In conclusion, post-grazing herbage mass >1000 kg/ha at most measurement times suggests that decreasing forage availability with increasing SR may not have been primarily or solely responsible for the effect on ADG by limiting DM intake. Rather, the effect of SR on available forage mass could have limited the ability of both sheep and goats to compensate for the effect of SR on forage nutritive value.

Keywords: Goat; Sheep; Co-grazing; Stocking rate; Mixed pastures

1. Introduction

Cattle, sheep, and goats differ physiologically in many known ways (Van Soest, 1994; Gordon et al., 1996) that, along with less well-understood unique characteristics, affect plant species selectivity. In general, goats prefer and spend more time than sheep consuming browse plants (Rodriguez Iglesias and Kothmann, 1998; Ngwa et al., 2000). Bartolome et al. (1998) also noted differences in dietary preferences between sheep and goats grazing rangeland, with sheep selecting primarily grasses throughout the year; goats, however, selected against grasses and preferred certain trees. But, plant species preferences by sheep and goats are influenced by specific plants available. For example, Penning et al. (1997) noted that, with availability of only white clover (*Trifolium repens*) and ryegrass (*Lolium repens*), sheep showed greater preference for clover than did goats.

Because of differences in factors, such as herbage preferences and selectivity by cattle, sheep, and goats, multiple species or co-grazing has favorably affected pasture or rangeland conditions and animal performance. For example, grazing sheep and cattle together on pastures containing 29% Kentucky bluegrass, 11% white clover, and 60% weeds (broad leaf and other grass species) improved animal performance, botanical composition, and soil characteristics compared with grazing cattle or sheep alone (Abaye et al., 1994, 1997). Relatedly, del Pozo et al. (1996) observed enhanced lamb growth rates with grass/clover swards previously grazed by goats compared with ones grazed only by sheep. However, effects of multiple compared with mono-species grazing are affected by conditions influencing the extent to which potential differences in herbage selectivity are expressed (Dumont, 1997; Kitessa and Nicol, 2001). A primary management decision affecting such forage conditions is stocking rate (SR).

SR is well known to impact animal performance and forage conditions (Huston et al., 1993; Davies and Southey, 2001). High SR restricts forage mass and limit potential forage selectivity (Wilson and Macleod, 1991; Davies and Southey, 2001) and, due to the general preference of animals for highest quality plants and plant parts, lead to a reduction in quality of available forage (Senft, 1989; Chong et al., 1997). For mono-species grazing, increasing SR decreases level of production per animal, although up to a certain SR production per unit land area increases (Sahlu et al., 1989; Aiken et al., 1991b; Huston et al., 1993; Davies and Southey, 2001). However, the nature of these changes depends on preferences of the one ruminant species present for different plants present in the sward, as well as effects of SR on available plant species. With co-grazing and the associated greater diversity in forage preferences compared with grazing by one species, it seems likely that effects of SR cannot be directly extrapolated from findings with mono-species grazing. Relatedly, with co-grazing species are exposed daily to the same forage conditions, which is not the case with mono-species grazing. Furthermore, because perhaps of an accompanying lesser degree of change in availability of particular plant species with the large number being consumed throughout the grazing season with co- versus mono-species grazing, less adverse effect of high SR with co-grazing on performance of individual animals and, therefore, a more positive effect on productivity per unit land area seems likely. In this regard, in a study reviewed by Brand (2000), without browse plant species present, dietary preferences of co-grazing Dorper sheep and Boer goats in the Valley Bushveld of South Africa were not influenced by SR (i.e., 6 goats and 6 lambs versus 42 goats and 59 lambs per 21 ha).

Considerable grazing land in Oklahoma as well as in other areas of the U.S. and the world do not receive intensive management practices such as use of herbicides or fertilizer and, thus, host a variety of grasses and forbs. Means to achieve optimal utilization of such pastures are not well understood. However, because of the diverse arrays of plant species available, co-grazing would seem a logical, preferred practice. Relatively little research with such conditions has been conducted compared with intensively managed pastures. Therefore, objectives of this experiment were to evaluate effects of SR on performance and forage selection by sheep and goats co-grazing pastures containing various grasses and forbs.

2. Materials and methods

2.1. Treatments

This experiment was conducted at the E (Kika) de la Garza American Institute for Goat Research of Langston University, Langston, Oklahoma, and was approved by the Langston University Animal Care Committee. There were two consecutive years (2002 and 2003) of grazing with each experiment lasting 16 weeks from May to September. Nine 0.4-ha (1 acre) pastures were used for the experiment. Pastures were randomly assigned to three SR with three pastures per SR. SR were four (SR4, low), six (SR6, moderate), and eight (SR8, high) animals per pasture, with equal numbers of sheep and goats. Pastures were divided into four paddocks, which were sequentially grazed in 2-week periods for two 8-week grazing cycles (2 weeks of grazing and 6 weeks of regrowth). The pastures contained a complex mixture of grasses, predominantly bermudagrass (*Cynodon dactylon*) and johnsongrass (*Sorghum halepense*), and various forbs, primarily ragweed (*Ambrosia* artemisiifolia) but also included others such as *Lespedeza cuneata* and nightshade (*Solanum* spp.) (Table 1). The pastures were constructed in one large pasture, and because of the time taken to construct fences for these pastures and to establish tree legumes in others in the same area, the pastures were not grazed in the preceding year. The 16-week experimental period encompassed most of a typical grazing season for such warm season herbage-based pastures depending on SR and weather conditions. Animals were grouped for similar mean BW and variation in BW and randomly assigned to pastures in accordance with SR.

Table 1
Plants encountered in pastures co-grazed by goats and sheep

Latin name	Common name
Grasses	
Cynodon dactylon	Bermudagrass
Sorghum halepense	Johnsongrass
Bromus tectorum	Cheat grass
Tridens flavus	Purpletop
Dichanthelium oligosanthes	Scribner's panicum
Forbs	
Ambrosia artemisiifolia	Common ragweed
Cirsium carolinianum	Purple thistle
Cirsium spp.	Thistle
Solanum elaeagnifolium	Silverleaf nightshade
Solanum carolinense	Carolina horsenettle
Trifolium campestre	Plains clover
Trifolium spp.	Clover
Vicia sativa	Narrow leaved vetch
Medicago sativa	Alfalfa
Medicago spp.	
Lespedeza cuneata	
Rudbeckia hirta	Blackeyed susan
Oenothera laciniata	Cutleaf evening primrose
Baptisia australis	Blue wild indigo
Plantago aristata	Bracted plantain
Melilotus officinalis	Yellow sweet clover
Rumex crispus	Curly dock
Castilleja indivisa	Indian paintbrush
Achillea millefolium	Common yarrow
Lactuca canadensis	Wild lettuce
Conza canadensis	Marestail
Asclepias syriaca	Milkweed
Schrankia uncinata	Sensitive brier

2.2. Animals and location

In each year, 27 goat and 27 sheep wethers were used. Sheep (Khatadin) and goats (≥75% Boer) averaged 21 ± 0.7 and 21 ± 0.5 kg initial BW (mean ± S.E.), respectively, and were 4–5 months of age when grazing began. Animals were obtained from commercial producers. Most sheep were from the same source in the 2 years (south-central Oklahoma). Goats were, however, from two different sources but both were located near Sonora, Texas. Upon arrival, wethers were quarantined for 3 weeks, vaccinated with Covexin 8 (Schering-Plough, Kinilworth, NJ), and treated for internal parasites (Ivomec® orally; Merck Ag Vet Division, Rahway, NJ) before the experiment. Fecal egg counts by the modified McMaster method (Stafford et al., 1994) were made from two goats and two sheep per pasture every 28 days during the grazing period to ascertain need for re-treatment.

2.3. Measurements

Forage measures were performed at the beginning and end of each grazing period. Pre- and post-grazed herbage mass was assessed by clipping herbage at a height of 2.5 cm in four randomly placed 0.25 m^2 quadrats. Mass of DM was determined by drying for 72 h in a forced-air oven at 55 °C. The four samples from each paddock were then mixed and ground to pass a 1-mm screen for laboratory analysis.

Pre- and post-grazed forage cover of the sward were determined using two 91-m randomly placed transects, with readings made at 0.9-m intervals. Plants that lied on the top of the point were recorded. When bare ground, litter, or rock was encountered, no reading was made. In the first year, readings were for grasses and forbs, whereas in the second year forbs were classed as ragweed or others.

Unshrunk BW was measured at the beginning of the experiment and at 28-day intervals to determine ADG per animal and total gain per pasture or hectare. Rectal grab fecal samples were collected from individual animals on weigh days for estimating diet botanical composition by microhistological analysis of plant fragments (Sparks and Malechek, 1968). Fecal samples were dried at 55 °C, ground in a Willey mill to pass a 1-mm screen, and used to prepare three slides per sample. Twenty randomly chosen points from each slide were read for the presence and absence of grasses, ragweed, and other forbs with expression as a percentage of the total. Before slides were read, reference slides were prepared by mixing different proportions of grasses and forbs present in the pastures and used for training in recognition. Preference ratings or selectivity ratios of dietary components were developed as described by Durham and Kothmann (1977). Preference values were calculated as: ((% diet − % available)/(% diet + % available)) × 10, using percentages in the diet obtained from microhistological analysis and available forage from transect measures. A preference value of +10 indicates the highest possible preference, −10 reflects no consumption, and 0 infers consumption in proportion to availability.

2.4. Laboratory analysis

Samples of forage were ground to pass a 1-mm screen and analyzed for DM (100 °C), Kjeldahl N (AOAC, 1990), and NDF (filter bag technique; ANKOM Technology Corp., Fairport, NY). Forage samples were also analyzed for in vitro true DM digestibility (IVDMD; filter bag technique; Ankom Technology Corp.) with NDF as the end-point measure. Ruminal fluid for IVDMD was collected from three mature Boer crossbred goats grazing native grass pasture and supplemented with a moderate amount of concentrate.

2.5. Statistical analyses

Data were analyzed using mixed model procedures of SAS (Littell et al., 1996). For forage measures, average values for the first and second 8-week grazing cycles or periods of the 16-week experimental period were calculated. Hence, the model consisted of SR, year, period (i.e., 8-week), and their interactions. For performance and forage selectivity measures the model consisted of SR, species, year, and their interactions. The random effect and repeated measure for forage measurements were animal group (SR) and year × period, respectively. For performance and forage selectivity measures, random effects were animal group (SR) and species (group × SR) and the repeated measure was year of grazing. Orthogonal contrasts were performed for linear and quadratic effects of SR. SR × year, SR × period, and SR × species interactions and main effects of year, species, and period are reported when effects were significant ($P < 0.05$).

3. Results and discussion

3.1. Forage mass

SR × year, SR × period, and year × period interactions were noted ($P < 0.05$) in forage mass before graz-

Table 2
Means of pre-grazed and post-grazed forage mass (DM) for mixed grass/forb pastures as influenced by different stocking rates (SR) of co-grazing goats and sheep

Item	Year	Period[1]	SR[2]			S.E.	Effect[3]		Period		S.E.
			SR4	SR6	SR8		L	Q	1	2	
Pre-grazed forage mass (kg/ha)	1	Mean	2937	3298	3351	174.4	0.12	0.48			
	2	Mean	3033	2928	2752		0.27	0.87			
	Mean	1	2983	3302	3342	174.4	0.17	0.53			
	Mean	2	2986	2925	2761		0.38	0.82			
	1								3172b	3219b	116.3
	2								3245b	2562a	
Post-grazed forage mass (kg/ha)	Mean	Mean	2279	1693	1288	102.6	0.01	0.50			
	1								2096d	1919c	70.8
	2								1773b	1225a	
Pre- minus post-grazed forage mass (kg/(ha day))	1	Mean	29	101	124	7.5	0.01	0.02			
	2	Mean	72	101	128		0.01	0.86			
	Mean	1	36	105	132	7.5	0.01	0.05			
	Mean	2	65	98	120		0.01	0.52			

(a–d) Means within year × period groupings without a common letter differ ($P < 0.05$).
[1] First and second halves of the 16-week experiment.
[2] SR4: two goats and two sheep per 0.4-ha grass/forb pasture; SR6: three goats and three sheep per 0.4-ha grass/forb pasture; SR8: four goats and four sheep per 0.4-ha grass/forb pasture.
[3] L and Q: observed significance levels for linear and quadratic effects of SR, respectively.

ing (Table 2). Pre-grazing forage mass for moderate and high SR was less in period 2 versus 1 and year 2 versus 1 ($P < 0.05$), but values were similar ($P > 0.10$) between years and periods for the low SR. SR had relatively little effect on pre-grazed forage mass. For year 1, this may be explained by similar SR among pastures in years before this experiment was conducted and these pastures were constructed, with the area as one large pasture, and no grazing in the preceding year.

There were significant SR effect and a year × period interactions in post-grazed forage mass ($P < 0.05$; Table 2). Post-grazed forage mass decreased linearly as SR increased ($P < 0.01$). This is in line with the report of Aiken et al. (1991a) with beef steers grazing subtropical grass–legume pastures at three SR (2.0, 3.5, and 5.0 steers/ha in 1987 and 3.0, 5.3, and 7.5 steers/ha in 1988) and that of Davies and Southey (2001) with lambs grazing subterranean clover-based pastures at SR of 4.9, 6.7, and 8.6 lambs/ha. Post-grazed forage mass was less in the second versus first half of the grazing period, but the difference was much greater in year 2 than 1. Likewise, the difference between years was greater in the second period than in the first. As noted for pre-grazed forage mass, this may be partially a function of no grazing in the season before year 1 compared with grazing before year 2. Forage mass was quite low after grazing in week 14 (453 kg/ha) and 16 (428 kg/ha) of year 2 for the high SR treatment that may be below levels that may limit feed intake and performance by other ruminant species; however, values at other times were above 1000 kg/ha.

Pre- minus post-grazed forage mass, or change in forage mass, was affected by SR × year and SR × period ($P < 0.05$) interactions (Table 2). Although the difference in forage mass before and after grazing periods is impacted by forage growth within the grazing period, it would be largely influenced by consumption by the grazing animals. SR linearly increased change in forage mass in both years and periods. However, magnitudes of change were greater in year 1 versus 2 and period 1 versus 2, primarily because of relatively low removal in year 1 and period 1 as reflected by a quadratic effect ($P < 0.05$). There was a tendency ($P < 0.06$) for a year × period interaction in change in forage mass (year 1: 77 and 93 kg/(ha day); year 2: 105 and 96 kg/(ha day) for period 1 and 2, respectively

(S.E. = 6.1)). Factors responsible for this trend include differences in forage growing conditions such as due to precipitation and temperature. Relatively low values in year 1 reflect high forage growth compared with consumption as well as variability in measurement of forage mass.

3.2. Sward composition

Contributions of grass and forbs to the sward in years 1 and 2 and that of ragweed to total forbs in year 2 are shown in Table 3. The pre-grazed contribution of grass differed between years, being 7 percentage units less in year 2 compared with year 1, and a SR × period interaction occurred also ($P < 0.05$). The difference between years may relate to pasture management before the experiment compared with grazing in two sequential seasons during the trial. SR did not significantly affect the pre-grazed contribution of grass to the sward. SR and year interacted ($P < 0.05$) in the contribution of grass to the post-grazed sward, with a tendency for a linear effect of SR in year 2 ($P < 0.07$). The contribution of grasses to the sward post-grazing was lower ($P < 0.05$) in year 2 versus 1 for the low SR but was similar between years for the medium and high SR. This may have been due to limited defoliation of ragweed that resulted in a higher proportion of ragweed at the end of the grazing cycle in pastures stocked with four animals. The pre-grazed forb contribution of ragweed in year 2 was only influenced by period ($P < 0.05$). However, there was a trend ($P < 0.08$) for a linear decrease in the contribution of ragweed to forbs in pre-grazed samples. The post-grazed ragweed percentage, similar to that pre-grazed, tended ($P < 0.08$) to linearly decrease as SR increased.

Sheep and goats consume more forbs than cattle (Rodriguez Iglesias and Kothmann, 1998). Diets of goats likewise often consist more of forbs compared with sheep diets, although there is a relatively greater difference in preference for browse (Bartolome et al., 1998; Rodriguez Iglesias and Kothmann, 1998). Results of this experiment depict how SR can affect botanical composition of available forage, although the effect of SR on the percentage of grass in the sward was only significant after 2 and not 1 year of grazing. With the low SR, on a percentage of the sward basis, there appeared relatively greater removal of grasses than forbs, which resulted in a greater grass level in the pre- and post-grazed sward in year 2 versus 1. This is in contrast with similar levels between years for moderate and high SR.

For goats, ragweed, the primary forb in pastures of this experiment, is not highly preferred (Bauni, 1993). Although impacted also by consumption by sheep, these results suggest that with low and moderate SR, animals consumed relatively more forbs other than rag-

Table 3
Means of pre-grazed and post-grazed contributions of grass to the sward and the contribution of ragweed (*Ambrosia aratemisiifolia*) to forbs as influenced by different stocking rates (SR) of co-grazing goats and sheep

Item	Year	Period[1]	SR[2]			S.E.	Effect[3]		Year		Period		S.E.
			SR4	SR6	SR8		L	Q	1	2	1	2	
Pre-grazed grass composition (%)	Mean	1	53	55	54	7.0	0.89	0.89					
	Mean	2	54	66	69		0.16	0.60					
		Mean							62b	55a			4.0
Post-grazed grass composition (%)	1	Mean	64	69	74	8.4	0.42	0.96					
	2	Mean	50	66	73		0.07	0.62					
Pre-grazed ragweed composition (% total forbs)	2	Mean	74	57	48	8.5	0.08	0.70			48a	72b	5.3
Post-grazed ragweed composition (% total forbs)	2	Mean	88	82	49	12.6	0.08	0.41					

(a and b) Means within year and period groupings without a common letter differ ($P < 0.05$).
[1] First and second halves of the 16-week experiment.
[2] SR4: two goats and two sheep per 0.4-ha grass/forb pasture; SR6: three goats and three sheep per 0.4-ha grass/forb pasture; SR8: four goats and four sheep per 0.4-ha grass/forb pasture.
[3] L and Q: observed significance levels for linear and quadratic effects of SR, respectively.

weed compared with ragweed. But with the highest SR, grazing pressure was high enough and forage availability adequately limited to lessen forb selectivity against ragweed to a point at which the contribution to forbs in the sward pre- and post-grazing was similar for ragweed and other forbs.

3.3. Nutrient composition of the sward

Pre- and post-grazed N concentrations in forage were affected by a year × period interaction ($P < 0.05$; Table 4). Pre-grazed N concentration was not affected by SR ($P > 0.05$), whereas, post-grazed N concentration in forage linearly decreased ($P < 0.05$) with increasing SR. Analysis by week within year (data not shown) indicated influence of SR on the pre-grazed forage N concentration only in the very latter part of the grazing season, with slightly more frequent impact on the post-grazed level. Hence, these findings, along with the relatively low N concentration in post-grazed forage compared with requirements for growth of sheep and goats (NRC, 1975; AFRC, 1998), suggest an increasing potential for impact and a magnitude of effect of N intake at performance with increasing SR. Changing forage N concentration with advancing time would, in addition to preferential selection by sheep and goats for relatively high nutritive value forage, involve increasing stage of maturity of the various plant species.

Pre- and post-grazed NDF concentrations were affected by year × period interactions ($P < 0.05$; Table 4). SR did not affect ($P > 0.10$) pre- or post-grazed NDF concentration, although numerically ($P < 0.11$) NDF concentration in post-grazed samples increased linearly as SR increased. Overall, forage

Table 4
Means of pre-grazed and post-grazed forage nutrient composition for mixed grass/forb pastures as influenced by different stocking rates (SR) of co-grazing goats and sheep

Item	Year	Period[1]	SR[2]			S.E.	Effect[3]		Period		S.E.
			SR4	SR6	SR8		L	Q	1	2	
Pre-grazed N (% DM)	Mean	Mean	1.30	1.15	1.22	0.058	0.38	0.16			
	1								1.45c	0.92a	0.054
	2								1.25b	1.28b	
Post-grazed N (% DM)	Mean	Mean	1.20	0.98	0.99	0.060	0.05	0.16			
	1								1.12b	0.83a	0.043
	2								1.04b	1.23c	
Pre-grazed NDF (% DM)	Mean	Mean	59.7	64.6	63.7	2.13	0.23	0.31			
	1								59.4a	66.4b	1.65
	2								62.8ab	62.0a	
Post-grazed NDF (% DM)	Mean	Mean	61.7	66.8	68.9	2.69	0.11	0.66			
	1								64.9a	68.8b	1.76
	2								65.0a	64.5a	
Pre-grazed IVDMD (% DM)[4]	Mean	Mean	60.0	54.9	56.6	1.50	0.16	0.12			
	1								64.2c	53.7a	1.29
	2								57.8b	53.0a	
Post-grazed IVDMD (% DM)	1	Mean	57.0	54.4	53.5	2.16	0.27	0.75			
	2	Mean	56.8	49.0	48.3		0.02	0.20			
	1								59.0b	50.9a	1.38
	2								52.0a	50.8a	

(a–c) Means within year × period groupings without a common letter differ ($P < 0.05$).
[1] First and second halves of the 16-week experiment.
[2] SR4: two goats and two sheep per 0.4-ha grass/forb pasture; SR6: three goats and three sheep per 0.4-ha grass/forb pasture; SR8: four goats and four sheep per 0.4-ha grass/forb pasture.
[3] L and Q: observed significance levels for linear and quadratic effects of SR, respectively.
[4] %; filter bag technique with NDF as the end point measure.

NDF concentrations are in accordance with levels of N; however, there appeared relatively greater differences in the level of NDF versus N between moderate and high SR.

Pre-grazed forage IVDMD (Table 4) was affected by a year × period interaction ($P < 0.05$), but SR had no effect ($P > 0.05$). SR × year and year × period interactions were noted ($P < 0.05$) in post-grazed forage IVDMD. Regarding the former interaction, SR did not have effect ($P > 0.10$) in year 1, whereas in year 2 IVDMD decreased linearly with increasing SR ($P < 0.05$). Forage IVDMD are in general agreement with concentrations of N and NDF, although the linear effect of SR on post-grazed forage IVDMD suggests more impact on forage nutritive value in year 2 than 1.

3.4. Grass and forb composition of the diet

The percentage of grass in the diet determined from fecal microhistological analysis was influenced by species and SR × year ($P < 0.05$; Table 5). Factors responsible for an overall similar percentage of grasses in the diet between years for the low and high SR but a slightly greater level of grasses for the moderate SR in year 2 versus 1 are unclear. Despite differences in vegetation, the magnitude of difference in the level of grasses in the diet between goats and sheep was similar to results of Bartolome et al. (1998) in Mediterranean heath woodland range, but greater compared with results of Pfister and Malechek (1986) in a deciduous woodland area of Brazil. In slight contrast, with grass/clover pasture Angora goats selected more grass

Table 5
Means of dietary contributions of grass, forb, and ragweed consumed and forage preference of goats and sheep co-grazing mixed grass/forb pastures at different stocking rates (SR)

Item	Year	Species	SR[1]			S.E.	Effect[2]		Species		S.E.
			SR4	SR6	SR8		L	Q	Goat	Sheep	
Dietary contribution											
Grass (%)	1	Mean	62.5	59.5	62.6	1.94	0.98	0.24			
	2	Mean	56.4	62.3	55.1		0.64	0.02			
	Mean								51.4a	68.1b	1.12
Ragweed (%)	1	Mean	17.1	18.4	16.7	1.16	0.81	0.33			
	2	Mean	18.6	14.7	24.1		0.01	0.01			
	Mean								21.1b	15.4a	0.67
Other forbs (%)	Mean	Mean	22.7	22.6	20.8	0.73	0.12	0.41			
	1								28.6c	13.5a	0.78
	2								26.6c	19.4b	
Preference value											
Grass	1	Mean	0.3	0.1	0.4	0.38	0.86	0.58			
	2	Mean	1.2	0.6	0.5		0.19	0.66			
	Mean								0.0a	1.0b	0.22
Forbs[3]	1	Mean	−0.3	0.3	−0.4	0.61	0.92	0.37			
	2	Mean	−1.5	−1.0	−0.3		0.19	0.88			
	Mean								0.5b	−1.6a	0.35
Ragweed[4]	2	Mean	−3.3	−0.7	1.9	0.97	0.01	0.95	0.2b	−1.6a	0.57
Other forbs[5]	2	Mean	3.6	2.1	1.2	0.89	0.10	0.78	3.1b	1.5a	0.52

(a–c) Means within year × period groupings without a common letter differ ($P < 0.05$).
[1] SR4: two goats and two sheep per 0.4-ha grass/forb pasture; SR6: three goats and three sheep per 0.4-ha grass/forb pasture; SR8: four goats and four sheep per 0.4-ha grass/forb pasture.
[2] L and Q: observed significance levels for linear and quadratic effects of SR, respectively.
[3] Forb preference value: total forb.
[4] Ragweed preference value: year 2.
[5] Other forbs: forbs other than ragweed in year 2.

and less clover than did Merino sheep (Gurung et al., 1994), similar to findings of Penning et al. (1997). In the present experiment, the size of the difference between species in dietary level of grasses was fairly consistent throughout the grazing season of both years 1 and 2 (data not shown), which is in line with results of Pfister and Malechek (1986) for 2 years of grazing deciduous woodland.

The dietary proportion of ragweed was affected by species and SR × year ($P < 0.05$; Table 5). SR did not influence the dietary percentage of ragweed in year 1, although the percentage decreased and then increased as SR increased in year 2 (linear and quadratic changes; $P < 0.05$). Values averaged over SR were greater ($P < 0.05$) for goats versus sheep. Factors responsible for the quadratic effect of SR on the dietary proportion of ragweed in year 2 are unclear. The species difference reflects a greater preference for, or perhaps less aversion to, ragweed by goats than sheep. Though growth stage of ragweed was not monitored, no consistent change in the dietary percentage of ragweed with advancing time (data not shown) and values for each year not markedly different suggest fairly steady plant characteristics that influence consumption.

SR did not impact the dietary percentage of other forbs ($P > 0.05$; Table 5). The dietary percentage of forbs other than ragweed consumed was affected by a species × year interaction ($P < 0.05$). Because other forbs made up a higher percentage of the diet of goats than sheep in both years, although goats consumed diets with a higher level of ragweed than did sheep, this might be thought of as a greater preference for forbs versus grasses rather than one for ragweed. As was the case for ragweed, the dietary level of other forbs did not markedly vary among times of sampling within or between years (data not shown). Therefore, as suggested for ragweed, plant characteristics of other forbs affecting dietary preference may not have markedly changed with advancing week of the experiment or greatly differed between years.

3.5. Forage preference values

The preference value for grasses was affected by species and a SR × year interaction ($P < 0.05$; Table 5). The overall preference value for grass was lower for goats compared with sheep, with means for goats at the individual sampling times (data not shown) ranging from −1.0 to 1.5 and sheep means of 0.5–2.3. Hence, goats were not highly selective for or against grasses and sheep only slightly preferred grasses. There were no SR effects ($P > 0.05$) in both years, with only a numerical decline as SR increased in year 2. This may in part relate to relatively low forage mass especially towards the end of the grazing period in year 2 versus 1 and a decreasing forage nutritive value and an increasing percentage of grass in the sward as SR increased.

The preference value for total forbs was greater ($P < 0.05$) for goats than for sheep (Table 5). Although SR did not have significant linear or quadratic effects in year 1 or 2, there was a SR × year interaction ($P < 0.05$). In year 1 for both species and in year 2 for goats, the forb preference value appeared to increase as the grazing period advanced (data not shown). This might in part involve lesser change with advancing maturity in nutritive value of forbs versus grasses (Long et al., 1999). Ragweed preference values do not indicate that this change with time was solely due to ragweed. There appeared relatively larger differences among preference values for forbs versus grasses, perhaps reflecting the greater number of forbs than grasses in the pastures whose availabilities during the grazing season changed more with time than of the few species of grasses present.

The preference value for ragweed in year 2 was affected by species and SR ($P < 0.05$; Table 5). The preference value for ragweed was lower ($P < 0.05$) for sheep versus goats and increased linearly ($P < 0.05$) with increasing SR. The preference value for forbs other than ragweed was lower for sheep than for goats ($P < 0.05$) and tended ($P < 0.10$) to decline linearly as SR increased. Overall, it does not appear that ragweed was a forb highly preferred or averted compared with others available in these pastures, and neither goats nor sheep displayed a clear pattern of change in preference for ragweed or other forbs as the grazing period advanced. Results of this experiment suggest that preference for ragweed is somewhat more subject to modification by SR than that of other forbs both by goats and sheep. Hence, although goats consumed more ragweed than sheep, management factors such as SR should affect ragweed consumption by sheep and goats in a similar manner.

Table 6
Means of initial and final BW and ADG of goats and sheep as influenced by different stocking rates (SR) of goats and sheep co-grazing mixed grass/forb pastures

Item	Species	SR[1]			S.E.	Effect[2]		Species		S.E.	Year[3]		S.E.
		SR4	SR6	SR8		L	Q	Goat	Sheep		1	2	
Initial BW (kg)	Goat	20.1	21.6	20.6	1.07								
	Sheep	21.2	21.3	21.5									
	Mean	20.6	21.5	21.0	0.76	0.72	0.51	20.7	21.3	0.62	20.8	21.3	0.62
Final BW (kg)	Goat	25.0	25.2	24.3	0.94								
	Sheep	29.9	29.1	28.2									
	Mean	27.5	27.1	26.3	0.66	0.25	0.93	24.8a	29.1b	0.55	26.5	27.3	0.55
ADG (g/day)													
0–28 day	Goat	96	40	93	27.9								
	Sheep	157	147	143									
	Mean	127	94	118	21.4	0.78	0.31	76a	149b	16.1	84a	142b	13.9
29–56 day	Goat	79	73	57	20.6								
	Sheep	114	81	88									
	Mean	96	77	73	18.5	0.40	0.74	70	94	11.9	69a	95b	11.7
57–84 day	Goat	17	27	33	10.4								
	Sheep	49	59	31									
	Mean	33	43	32	7.3	0.96	0.29	26	46	6.0	57b	15a	6.0
85–112 day	Goat	−15	−13	−51	17.9								
	Sheep	−8	−9	−22									
	Mean	−12	−11	−36	15.5	0.31	0.51	−26	−13	10.4	−5b	−34a	10.4
Overall	Goat	44	32	33	6.3								
	Sheep	78	69	60									
	Mean	61	51	47	5.1	0.10	0.62	36a	69b	3.7	51	54	3.7
Total gain (g/(ha day))	Goat	440	476	664	94.6								
	Sheep	780	1041	1203									
	Mean	610	759	933	70.6	0.02	0.88	527a	1008b	55.0	746	789	53.8

(a and b) Means within species and year groupings without a common letter differ ($P < 0.05$).
[1] SR4: two goats and two sheep per 0.4-ha grass/forb pasture; SR6: three goats and three sheep per 0.4-ha grass/forb pasture; SR8: four goats and four sheep per 0.4-ha grass/forb pasture.
[2] L and Q: observed significance levels for linear and quadratic effects of SR, respectively.
[3] Year: comparison of the 2 years of grazing.

3.6. Average daily gain

Initial BW was similar among SR, and between species and years ($P > 0.10$; Table 6). Final BW was not influenced by SR or year ($P > 0.10$), but was greater ($P < 0.05$) for sheep versus goats. In both years ADG decreased as the grazing season progressed, but was greater in year 2 versus 1 in the first two 28-day segments and lower in the second. A number of factors probably contributed to overall ADG by sheep nearly twice as great ($P < 0.05$) as that by goats. First, growth rate is typically greater for sheep than for goats because of factors such as different selection histories. Although, Boer goats were developed for attributes including large size, muscularity, and rapid growth. Another factor that may have had influence is previous nutritional plane. Since animals were purchased and it was only possible to obtain them after weaning near when grazing in the experiment was to begin, previous nutritional plane may have differed. In fact, over 50% of the difference in overall ADG was attributable to the first 28 days of grazing. Furthermore, ADG was greater ($P < 0.05$) for sheep versus goats in the first two 28-day segments of grazing but was similar between species in the last two segments. This suggests differences in compensatory growth potential, for which exhibition may have been feasible in the first part of the grazing season when forage availability and quality were highest. But, no species difference in ADG late in the grazing season when forage quality and availability were lowest could relate to suggestions that performance by goats is less adversely affected by low nutritional planes compared with other ruminant species (Silanikove, 2000).

SR did not influence ADG in any 4-week period ($P > 0.10$; Table 6). However, ADG in the entire 16-week experiment tended to decrease linearly ($P < 0.10$) as SR increased, with the difference numerically greater between low versus moderate and high SR than between moderate and high SR. This is in accordance with differences among SR in forage quality indices such as the concentration of N and IVDMD. Similarly, a linear decrease in ADG with increasing SR was reported for beef steers grazing a mixture of tropical legumes and bahiagrass (*Paspalum notatum* Flugge; Aiken et al., 1991b). Also, for sheep grazing smooth bromegrass pasture at SR of 15 or 30 lambs/ha (Sahlu et al., 1989) and light and heavy beef calves grazing Plains Old World bluestem at three SR (Ackerman et al., 2001), ADG linearly decreased with increasing SR.

The lack of interaction between SR and species presumably indicates that, overall, availabilities of the various grass and forb species with all SR were relatively greater than differences in preferences for, or aversions to, particular plant species. Forage preference values were not greatly different from 0 and, thus, limited availability of a particular preferred plant should have simply resulted in increased consumption of a slightly lesser preferred or more averted one.

The most obvious factors potentially responsible for the decrease in ADG by both sheep and goats with increasing SR are decreasing forage mass and nutritive value. Although, there are certainly other factors that may have had influence, such as differences in energy expenditure due to grazing that would impact energy available for growth (Animut et al., 2005). Though it is not possible to conclusively discern the relative importance of these factors from measures reported here, forage nutritive value may deserve greatest attention. Pre-grazed forage mass in all instances, and post-grazed forage mass in nearly all cases, was greater than 1000 kg/ha, which suggest that forage mass did not markedly restrict DM intake. However, decreasing forage mass with increasing SR could have accentuated potential impact of decreasing forage nutritive value on digestible nutrient consumption. As forage mass declines, biting rate and grazing time increase, although these changes are many times not completely compensatory for the decrease in bite size (Stobbs, 1973; Jamieson and Hodgson, 1979; Burns and Sollenberger, 2002). Furthermore, the degree to which plants and plant parts highest in nutritive value can be selected declines with increased rate of biting, apart from the decrease in nutritive value of forage available as SR increased in this experiment. In this regard, these results suggest that goats were no more able to cope with the challenge of selecting and ingesting a sufficient quantity and nutritive value of forage under these conditions to attain a moderate to high level of growth than were sheep.

Total BW gain per hectare increased linearly ($P < 0.05$) with increasing SR (Table 6). Hence, the magnitude of change in ADG per animal with increasing SR was much less than differences in SR. Similar findings were noted by Ackerman et al. (2001) with beef steers grazing Plains Old World bluestem at three SR. Phillips and Coleman (1995), comparing three grazing systems, also noted increased gain per ha with greater SR despite lower ADG. Conversely, with very high SR that severely limit forage mass, thereby markedly reducing ADG, increased BW gain per unit land area can be minimal or even absent. For example, with a simulation model Seman et al. (1991) proposed that gain/ha increased to about 200 kg/ha with a SR of 22 steers per hectare and then declined.

4. Conclusions

Overall, increasing SR influenced forage mass after grazing (decrease), percentage of grass in the sward (increase), and nutritive value of available forage (decrease), although effects varied with year and time within year. Goats exhibited a greater preference for or less aversion to ragweed than sheep. It did not appear that ragweed was a forb highly preferred or averted compared with others available, and preference for ragweed by both sheep and goats was affected more (increased) by SR than for other forbs. ADG decreased slightly as SR increased regardless of species, and was greater for sheep than for goats. In conclusion, post-grazing herbage mass greater than 1000 kg/ha at most times suggests that decreasing forage availability may not have been primarily responsible for the effect of increasing SR on ADG by limiting DM intake, although the SR effect on available forage mass could have limited the ability of both sheep and goats to compensate for the effect of SR on forage nutritive value.

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References

Abaye, A.O., Allen, V.G., Fontenot, J.P., 1994. Influence of grazing cattle and sheep together and separately on animal performance and forage quality. J. Anim. Sci. 72, 1013–1022.

Abaye, A.O., Allen, V.G., Fontenot, J.P., 1997. Grazing sheep and cattle together or separately: effect on soils and plants. Agron. J. 89, 380–386.

Ackerman, C.J., Purvis II, H.T., Horn, G.W., Paisley, S.I., Reuter, R.R., Bodine, T.N., 2001. Performance of light vs. heavy steers grazing Plains Old World bluestem at three stocking rates. J. Anim. Sci. 79, 493–499.

AFRC, 1998. The Nutrition of Goats. CAB International, New York, NY.

Aiken, G.E., Pitman, W.D., Chambliss, C.G., Portier, K.M., 1991a. Plant responses to stocking rate in a subtropical grass–legume pasture. Agron. J. 83, 124–129.

Aiken, G.E., Pitman, W.D., Chambliss, C.G., Portier, K.M., 1991b. Responses of yearling steers to different stocking rates on a subtropical grass–legume pasture. J. Anim. Sci. 69, 3348–3356.

Animut, G., Goetsch, A.L., Aiken, G.E., Puchala, R., Detweiler, G., Krehbiel, C.R., Merkel, R.C., Sahlu, T., Dawson, L.J., Johnson, Z.B., Gipson, T.A., 2005. Grazing behavior and energy expenditure by sheep and goats co-grazing grass/forb pastures at three stocking rates. Small Rum. Res. 59, 191–201.

AOAC, 1990. Official Methods of Analysis, 15th ed. Association of Official Analytical Chemists, Washington, DC.

Bartolome, J., Franch, J., Plaixats, J., Seligman, N.J., 1998. Diet selection between sheep and goats on Mediterranean heath-woodland range. J. Range Manage. 51, 383–391.

Bauni, S.M., 1993. Utilization of cross timbers rangelands by Angora Goats. Ph.D. Dissertation. Oklahoma State University, Stillwater, OK.

Brand, T.S., 2000. Grazing behaviour and diet selection by Dorper sheep. Small Rum. Res. 36, 147–158.

Burns, J.C., Sollenberger, L.E., 2002. Grazing behavior of ruminants and daily performance from warm-season grasses. Crop Sci. 42, 873–881.

Chong, D.T., Stur, W.W., Shelton, H.M., Tajuddin, I., Samat, M.S., 1997. Stocking rate effect on sheep and forage productivity under rubber in Malasia. J. Agric. Sci. 128, 339–346.

Davies, H.L., Southey, I.N., 2001. Effects of grazing management and stocking rate on pasture production, ewe live weight, ewe fertility and lamb growth on subterranean clover-based pasture in Western Australia. Aust. J. Exp. Agric. 41, 161–168.

del Pozo, M., Wright, I.A., Whyte, T.K., Colgrove, P.M., 1996. Effects of grazing by sheep or goats on sward composition in ryegrass/white clover pasture and on subsequent performance of weaned lambs. Grass Forage Sci. 51, 142–154.

Dumont, B., 1997. Diet preference of herbivores at pasture. Ann. Zootech. 46, 105–116.

Durham Jr., A.J., Kothmann, M.M., 1977. Forage availability and cattle diets on the Texas Coastal Prairie. J. Range Manage. 30, 103–106.

Gordon, I.J., Illius, A.W., Milne, J.D., 1996. Sources of variation in the foraging efficiency of grazing ruminants. Funct. Ecol. 10, 219–226.

Gurung, N.K., Jalow, O.A., McGregor, B.A., Watson, M.J., McIlroy, B.K.M.H., Holmes, H.G., 1994. Complementary selection and intake of annual pastures by sheep and goats. Small Rum. Res. 14, 185–192.

Jamieson, W.S., Hodgson, J., 1979. The effects of variation in sward characteristics upon the ingestive behaviour and herbage intake of calves and lambs under a continuous stocking management. Grass Forage Sci. 34, 273–282.

Huston, J.E., Thompson, P.V., Taylor Jr., C.A., 1993. Combined effects of stocking rate and supplemental feeding level on adult beef cows grazing native rangeland in Texas. J. Anim. Sci. 71, 3458–3465.

Kitessa, S.M., Nicol, A.M., 2001. The effects of continuous stocking on the intake and live-weight gain of cattle co-grazed with sheep on temperate pastures. Anim. Sci. 72, 199–208.

Littell, R.C., Milliken, G.A., Stroup, W.W., Wolfinger, R.D., 1996. SAS® Systems for Mixed Models. SAS Inst. Inc., Cary, NC.

Long, R.J., Apori, S.O., Castro, F.B., Ørskov, E.R., 1999. Feed value of native forages of the Tibetan Plateau of China. Anim. Feed Sci. Technol. 80, 101–113.

Ngwa, A.T., Pone, D.K., Mafeni, J.M., 2000. Feed selection and dietary preferences of forage by small ruminants grazing natural pastures in the Sahalian zone of Cameroon. Anim. Feed Sci. Technol. 88, 253–266.

NRC, 1975. Nutrient Requirements of Sheep, fifth ed. National Academy Press, Washington, DC.

Penning, P.D., Newman, J.A., Harvey, A., Orr, R.J., 1997. Diet preference of adult sheep and goats grazing ryegrass and white clover. Small Rum. Res. 24, 175–184.

Pfister, J.A., Malechek, J.C., 1986. Dietary selection by goats and sheep in a deciduous woodland of Northeastern Brazil. J. Range Manage. 39, 24–28.

Phillips, W.A., Coleman, S.W., 1995. Productivity and economic return of three warm season grass stocker systems for the southern great plains. J. Prod. Agric. 8, 334–339.

Rodriguez Iglesias, R.M., Kothmann, M.M., 1998. Best linear unbiased prediction of herbivore preferences. J. Range Manage. 51, 19–28.

Sahlu, T., Jung, H.G., Morris, J.G., 1989. Influence of grazing pressure on energy cost of grazing by sheep on smooth Bromegrass. J. Anim. Sci. 67, 2098–2105.

Seman, D.H., Freer, M.H., Stuedemann, J.A., Wilkinson, S.R., 1991. Simulating the influence of stocking rate, sward height and density on steer productivity and grazing behavior. Agric. Syst. 37, 165–181.

Senft, R.L., 1989. Hierarchical foraging models: effects of stocking and landscape composition on simulated resource use by cattle. Ecol. Model. 46, 283–303.

Silanikove, N., 2000. The physiological basis of adaptation in goats to harsh environments. Small Rum. Res. 35, 181–193.

Sparks, D.R., Malechek, J.C., 1968. Estimating percentage dry weight in diets using a microscopic technique. J. Range Manage. 21, 264–265.

Stafford, K.J., West, D.M., Pomroy, W.E., 1994. Nematode worm egg output by ewes. N.Z. Vet. J. 42, 30–32.

Stobbs, T.H., 1973. The effects of plant structure on the intake of tropical pastures. 1. Variations in the bite size of grazing cattle. Aust. J. Agric. Res. 24, 809–819.

Van Soest, P.J., 1994. Nutritional Ecology of Ruminants, second ed. Comstock Publishing, Ithaca, NY.

Wilson, A.D., Macleod, N.D., 1991. Overgrazing: present or absent? J. Range Manage. 44, 475–482.