ELSEVIER Applied Animal Behaviour Science 51 (1997) 75–85

APPLIED ANIMAL BEHAVIOUR SCIENCE

Relationships among variables indexing selective grazing behavior of goats [1]

David Ganskopp [a,*], Ruben Cruz [b], Babajide Fajemisin [c]

[a] US Department of Agriculture-Agricultural Research Service, HC 71 4.51 Hwy. 205, Burns, OR 97720, USA
[b] Department of Rangeland Resources, Oregon State University, Corvallis, OR 97731, USA
[c] National Animal Production Research Institute, Ahmadu Bello University, Zaria, Nigeria

Accepted 29 April 1996

Abstract

Portable computers presently allow documentation of real-time grazing behavior under field conditions. Researchers are still challenged, however, with the task of selecting proper and easily recorded variables to test their hypotheses. The objective of this research was to examine relationships among variables describing grazing behavior and forage utilization by goats to identify the most easily monitored activity capable of accurately ranking their relative preferences among forages. Relationships were investigated in grassy paddocks and on native shrub/steppe rangeland. Variables recorded for each forage included: total visits, total bites, bites per visit, total grazing time, time per visit, and bite rate in both environments, and number of plants grazed, number of plants regrazed, number of regrazing events, percent utilization, grazed plant utilization, and number of plants utilized in the grassy paddocks. In grassy paddocks, with eight different forages available, total visits, total bites, total time, number of plants grazed, number of plants regrazed, and number of regrazing events were highly correlated ($r \geq 0.94$ and $P < 0.01$) during both the boot and dormant stages of phonology. Rank correlation coefficients (r_s) among forages with these variables averaged 0.96. Any of these six variables would probably give satisfactory ranking of relative preferences if the animal in question was confined to or elected to forage from a single life form (grass, forb, shrub, or tree). Utilization data were significantly ($P < 0.01$) but poorly correlated (mean $r = 0.74$) with total bites, total visits and total time. Correlations among grazing behavior variables were all statistically significant ($P < 0.01$) but much weaker in shrub/steppe vegetation where a variety of life forms were available (mean $r = 0.45$), Only total time versus total bites and bites per visit versus time per visit exhibited correlations of 0.94 or greater ($P < 0.01$). The poorer correlations obtained on rangelands were attributed to a wide array of foraging techniques used by the goats to graze the various grasses, forbs, shrubs, and trees.

* Corresponding author.
[1] Technical Paper No. 10995, Oregon Agricultural Experiment Station.

PII S0168-1591(96)01086-6

Total time was the only variable consistently correlated with total bites in both the grassy paddock and shrub/steppe pastures (mean $r = 0.94$). Monitoring of grazing time devoted to each forage could be more easily accomplished than the more attention demanding process of tallying individual bites. We suggest that adequate rankings of relative forage preference of goats could be obtained by a single observer recording grazing time expended on each forage.

Keywords: Goat; Ingestive behavior; Grazing

1. Introduction

Knowledge of large herbivore diets has long been an important determinant in management of grazing lands (Stoddart et al., 1975). Such information allows assessment of nutritional status of animals, helps develop practical forage allocation models (McInnis et al., 1983), and contributes to informed decisions regarding potential herbivore use in revegetation and pasture establishment efforts (Austin et al., 1994; Jones et al., 1994). Renewed interest in the intricacies of the plant:animal interface (Hodgson, 1985) and validation of the many offshoots of optimum foraging theory (MacArthur and Pianka, 1966) have created a need for extremely detailed records of foraging activities. While the relatively recent development of field-portable computers has provided us with the ability to record vast arrays of real-time descriptive data (Demment and Greenwood, 1987), researchers are still faced with the challenge of selecting the proper variables to test their hypotheses.

A portion of our recent research has focused on the selective foraging activities of free-ranging goats where variables of interest included the plant species being grazed and some measure of use by the animal. Our plot and field trials generated 12 and six variables, respectively (Fajemisin et al., 1996; Ganskopp et al., 1996) Trials typically involved two to four technicians involved with animal handling, recording the series of plants selected, and tallying each bite harvested. Observers were severely challenged by the demands of maintaining contact with free-ranging animals, recording each bite, and identifying species grazed, even with the aid of electronic data loggers. The objective in this investigation was to quantify relationships among our many variables and determine whether a more easily monitored activity might simplify our task. Success would facilitate more accurate data acquisition, free resources for other endeavors, or allow gathering of additional information to address other hypotheses.

2. Material and methods

The research was conducted on the Northern Great Basin Experimental Range (119°43′W, 43°29′N) 70 km west-southwest of Burns, OR. Mean annual precipitation at 1375 m elevation is 276 mm with higher monthly accumulations in November, December, January, and May (28–36 mm) and a minimum accumulation (8 mm) in July. Mean monthly maximum temperature occurs in July (28.4°C), the monthly minimum mean in January (−7.7°C) and the annual mean temperature is 7°C. Because recent work suggests goats in the region rely heavily on grasses for 66–90% of their diets (Richman et al., 1994), research paddocks were established to assess their relative acceptance of recently released grass varieties in improved pastures, and field trials were conducted to assess their preferences for and potential impact on native vegetation. A listing of the forages in our paddocks and pastures is provided in Table 1.

In paddocks the project design was a randomized complete block with three replications grazed at two stages of phonology (boot stage and dormancy) with eight varieties of grasses. Each replicate contained two paddocks, each paddock being 22.6 m × 22.6 m. Plantings of grasses were established in May 1990 from containerized stock, and grazing trials were conducted in early June and late August 1991. Each paddock supported 98 plants of each variety (total 784 plants per paddock) with each plant randomly positioned and established in a 28 × 28 matrix. Plants were arranged on 76-cm centers. Three extra paddocks of identical design and forage composition were also established and used to familiarize the goats with the grasses and sampling procedures.

Because identity of some of the grasses could not be established by casual examination, two sets of numbered cards (1–28) were placed on the ground, outside an enclosing electric fence to facilitate rapid documentation of row and column positions of plants. At each stage of phonology, three trials were conducted over 3 successive days. Seven mature, dry angora does, randomly allotted from a group of 30, were used in each trial. Sampling began with an observer equipped with a backpack-mounted platform and lap-top computer and two goats entering a paddock. One goat was selected for monitoring. For every plant grazed the observer tallied each bite on the computer by pressing the space-bar and then pressed the 'W' key when the animal left a plant. Depressions of the space-bar produced series of time entries (i.e. 07:32:27.1) in the data file, and depression of the 'W' key entered the time, prefixed by a 'W' and followed by the number of the next observation to be recorded. For instance, the entry 'W07:32:29.2 37' indicated a goat began walking at O7:32:29.2 in search of the 37th plant in the series. Two other technicians simultaneously recorded the row and column numbers of each plant that was grazed. When the first animal had foraged on 50 plants, another goat was released and followed for 50 observations. Sampling continued until a total of six goats were in the paddock and grazing activity on 250 plants had been recorded. Goats were left to forage in the paddock for the remainder of the day and penned at night to prevent possible coyote predation. The subsequent morning the previously grazed paddock was examined and an index of degree of utilization recorded for each plant ($n = 784$). Indices were: 0, no visible use; 1, 1–20% of plant weight removed; 2, 21–40% removed; 3, over 40% weight removed (Heady, 1949).

Software for acquisition and compilation of these data was written especially for these projects in QBasic by the senior author. Bite-count and coordinate data were integrated with the appropriate map of plant positions in a paddock, and an array of nine variables was compiled across the five goats for each of the grasses. Variables included the following.

1. Total visits: the total number of times goats foraged upon each species. Subsequent returns to previously grazed plants were scored as additional visits.
2. Total bites: the sum of all bites harvested from a species. A bite was recorded with any indication, either visual or audible, that material had been severed from a plant.

Table 1
A listing of forages utilized by goats during grazing trials in improved paddocks and native rangeland pastures on the Northern Great Basin Experimental Range near Burns, OR

(a) Native rangeland

Growth form and scientific name	Common name
Grasses	
Agropyron desertorum (Fischer ex Link) Schultes	Crested wheatgrass
Bromus tectorum L.	Cheagrass
Festuca idahoensis Elmer	Idaho fescue
Koeleria cristata Pers.	Prairie junegrass
Leymus cinereus (Scribner & Merrill A. Löve)	Basin wildrye
Poa secunda Vasey	Sandberg bluegrass
Pseudoroegneria spicata (Pursh) A. Löve	Bluebunch wheatgrass
Stipa thurberiana Piper	Thurber's needlegrass
Forbs	
Achillea millefolium L.	Yarrow
Astragalus filipes Torr.	Basalt milk vetch
Cordylanthus ramosus Nutt.	Bushy birdbeak
Crepis accuminata Nutt.	Tapertip hawksbeard
Erigeron filifolius Nutt.	Thread-leaf
Eriogonum spherocephalum Dougl.	Round-headed eriogonum
Lepidium perfoliatum L.	Clasping pepperweed
Lithospermum ruderale Dougl.	Columbia puccoon
Lupinus caudalus Kell.	Tailcop lupine
Penstemon speciosus Dougl.	Royal penstemon
Phlox hoodii Rich.	Hood's phlox
Sisymbrium altissimum L.	Jim Hill mustard
Shrubs	
Artemisia tridentata ssp. *wyomingensis* Beetle	Wyoming big sagebrush
Chrysothamnus viscidiflorus (Hook.) Nutt	Green rabbitbrush
Tetradymia canescens DC.	Gray horse-brush
Trees	
Juniperus occidentalis Hook.	Western juniper

(b) Paddocks

Growth form and scientific name	Variety and common name
Grasses	
Agropyron desertorum (Fischer ex Link) Schultes	'Nordan' crested wheatgrass
Agropyron desertorum × *A. cristalum* (L.) Gaertn.	'CD II' crested wheatgrass
Elymus lanceolatus (Scribner & J.G. Smith) Gould	Bannock thickspike wheatgrass
Elymus laticeolatus (Scribner & J.G. Smith) Gould	'Secar' Snake River wheatgrass
Leymus cinereus (Scribner & Merr.) A. Löve	'Magnar' basin wildrye
Leymus cinereus (Scribner & Merr.) A. Löve	'Trailhead' basin wildrye
Psathyrostachys junceus (Fisch.) Nevs	'Bozoisky-Select' Russian wildrye
Pseudoroegneria spicata (Pursh) A. Löve	'Goldar' bluebunch wheatgrass

3. Mean bites per visit: the average number of bites harvested from each species per visit.
4. Total time: the accumulation of all times expended in foraging on a species, calculated as the time between the first and last bite removed from a plant. Momentary pauses (chewing, swallowing, or brief social interactions) were included in these measures. Resolution of our software was 0.1 s. When data were initially compiled, our program processed all feeding events where goats removed two or more bites from plants and derived a mean value of elapsed time per bite (2.0–2.6 s). In the final compilation 'total time' was incremented by the appropriate mean value when a single bite was harvested from a feeding station.
5. Mean time per visit: the average time expended grazing a species at each visit (s).
6. Bite rate: the number of bites occurring at each feeding station divided by the number of minutes expended at each station (bites per minute).
7. Number of plants grazed: the number of plants of a species that were actually foraged upon either one or more times. The maximum possible value was 98.
8. Number of plants regrazed: the number of plants of a species that were foraged upon two or more times.
9. Number of regrazing events: the total number of times the goats foraged on plants which had been previously grazed. This variable served as a check since the sum of the number of plants grazed (variable 7) and the number of regrazing events for a species was expected to equal 'total visits' (variable 1).

Our utilization data provided us with three variables.

10. Percent utilization: an average of the percent of plant weight removed ($n = 98$) from each species in the paddock.
11. Grazed plant utilization: an average of the percent of plant weight removed from each species and derived only from plants which had been grazed.
12. Number of plants utilized: the number of plants of each species exhibiting evidence of defoliation by the goats.

Data were summed across goats ($n = 5$) for each forage ($n = 8$) in each paddock ($n = 3$). Analyses of variance established significant ($P < 0.05$) species × phonology interactions existed for all variables, and relationships among the 12 variables at each stage of phonology were examined in a matrix of Pearson correlation coefficients (r) with the number of observations for each value being 24.

Our 1993 field trials employed eight Spanish goats grazing native rangeland. Pasture vegetation was characterized by an overstory of western juniper (*Juniperus occidentalis* Hook.), a shrub layer dominated by Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis* Beetle), and a herbaceous layer where Idaho fescue (*Festuca idahoensis* Elmer) and bluebunch wheatgrass (*Pseudoroegneria spicata* (Pursh) A. Löve) were most prevalent. Two 4-day trials were conducted. The first occurred when the major grasses were in the anthesis (flowering) stage of phonology and the second after grasses had cured and entered dormancy. Project design was again a randomized complete block with eight goats as blocks and two stages of phonology. Days ($n = 4$) were repeated measures, and the 25 species foraged upon were classed as treatment effects.

Two technicians accompanied goats as they were successively released in a pasture. One recorded grazing activity on a lap-top computer, as described previously, and the second recorded the identity of each plant as it was grazed. Again each goat was observed as it foraged at 50 separate feeding stations. Sampling typically involved an entire morning, and goats were left to forage for the remainder of the day in the pasture. They were penned each evening to prevent predation.

Because we could not track repeat visits to individual plants and did not estimate levels of utilization on forages, only six variables were derived from these data. These included: total visits, total bites, mean bites per visit, total time, mean time per visit, and bite rate. Data were summed for each replication ($n = 8$) on each day ($n = 4$) for 25 species of forages at each of two stages of phonology. Again, relationships among the six variables at each stage of phonology were examined in a matrix of Pearson correlation coefficients (r).

Among the several techniques used to quantify diet composition of free-ranging herbivores, esophageal-fistula methods are typically ranked as most accurate (McInnis et al., 1983; Forbes and Beattie, 1987; Jones and Lascano, 1992). Short of this invasive technique, bite-count techniques have been judged quite acceptable in most instances (Ortega et al., 1995); and we assumed 'total bites' was our best index for ranking the relative preferences of goats in these trials. In our regression analyses, variables consistently yielding correlation coefficients of 0.94 or greater were considered possible alternatives for ranking forages because they could account for 90% or more of the variation (r^2) exhibited in total bites. Agreement in the ranking of forages by these variables was tested with Spearman's rank correlation coefficient (r_s).

3. Results and discussion

Many of the variables from the trials in the grassy paddocks were highly correlated (Table 2). Across forages and stages of phonology correlation coefficients averaged 0.68 and ranged between 0.04 and 0.99. Out of 66 possible combinations at each stage of phonology, 54 exhibited statistically significant ($P < 0.01$) associations during the boot stage of phonology and 47 when the grasses were dormant. Given that large herbivores are more selective when herbage is green than when phonology is more advanced (Stuth, 1991), one would expect more significant associations at the boot stage of growth than during dormancy.

At both stages of phonology 13 correlation coefficients equalled or exceeded 0.94 (Table 2). Twelve of these values involved comparisons among total visits, total bites, total time, number of plants grazed, number of plants regrazed, and number of regrazing events. Variables which did not exhibit any strong correlations included: bites per visit, time per visit, bite rate, percent utilization, grazed plant utilization, and number of plants utilized.

Because expressions of percent utilization and grazed plant utilization actually index the proportion of plant weight removed by the goats, they are perhaps better indicators of grazing impact on the various forages than measures of dietary intake. If the relative contributions of the forages to the total herbage mass are known, these values can be weighted by the corresponding utilization estimates to derive expressions of dietary intake. Because these integrations involve two variables, however, we are also introduc-

Table 2
Pearson correlation coefficients (r) among 12 variables describing grazing behavior of angora goats foraging among eight varieties of grasses during the boot (above the diagonal) and dormant (below the diagonal) stages of phenology on the Northern Great Basin Experimental Range. Underlined coefficients indicate statistically significant correlations at $P < 0.01$. Italic coefficients equal or exceed 0.94. For each value, $N = 24$

	Boot stage of phenology											
	Total visits	Total bites	Bites per visit	Total time	Time per visit	Bite rate	No. of plants grazed	No. of plants regrazed	No. of regrazing events	Percent utilization	Grazed plant utilization	No. of plants utilized
Total visits		*0.98*	0.64	*0.96*	0.65	−0.20	*0.99*	*0.98*	*0.99*	0.90	0.68	0.82
Total bites	*0.98*		0.68	*0.99*	0.71	−0.34	*0.96*	0.93	*0.97*	0.88	0.67	0.79
Bites per visit	0.65	0.75		0.69	0.91	−0.09	0.65	0.57	0.61	0.67	0.71	0.49
Total time	*0.94*	*0.97*	0.77		0.73	−0.26	*0.95*	0.91	*0.95*	0.87	0.67	0.77
Time per visit	0.54	0.62	0.91	0.73		−0.36	0.67	0.59	0.62	0.67	0.71	0.52
Bite rate	−0.27	−0.28	−0.32	−0.39	−0.60		−0.20	−0.19	−0.20	−0.19	−0.25	−0.23
No. of plants grazed	*0.98*	*0.94*	0.61	0.89	0.48	−0.23		*0.97*	*0.96*	0.92	0.69	0.85
No. of plants regrazed	*0.99*	*0.98*	0.63	*0.95*	0.53	−0.28	*0.97*		*0.97*	0.85	0.65	0.79
No. of regrazing events	*0.97*	*0.97*	0.66	*0.97*	0.59	−0.30	0.91	*0.97*		0.86	0.66	0.79
Percent utilization	0.87	0.83	0.66	0.81	0.56	−0.30	0.89	0.83	0.88		0.86	0.89
Grazed plant utilization	0.48	0.44	0.35	0.42	0.29	−0.04	0.52	0.45	0.41	0.73		0.69
No. of plants utilized	0.86	0.83	0.66	0.81	0.54	−0.23	0.87	0.82	0.80	0.91	0.72	
	Dormant stage of phenology											

Table 3
Pearson correlation coefficients (r) among six variables describing grazing behavior of Spanish goats foraging in sagebrush/steppe vegetation during two stages of phonology (anthesis above the diagonal and dormancy below the diagonal) on the Northern Great Basin Experimental Range. All coefficients are significant at $P<0.01$ ($n=800$ for each value). Italic coefficients equal or exceed 0.94

	Anthesis stage of phenology					
	Total visits	Total bites	Bites per visit	Total time	Time per visit	Bite rate
Total visits		0.88	0.29	0.81	0.19	0.24
Total bites	0.88		0.47	*0.95*	0.38	0.18
Bites per visit	0.31	0.52		0.54	*0.97*	0.18
Total time	0.71	0.86	0.55		0.50	0.13
Time per visit	0.19	0.39	0.83	0.68		0.08
Bite rate	0.27	0.20	0.26	0.13	0.10	
	Dormant stage of phenology					

ing two possible sources of error. We concur that utilization estimates are typically poor measures of dietary intake; and more direct methods provide greater accuracy, especially in pastures with a diverse flora (Laycock et al., 1972; McInnis et al., 1983).

In our rangeland trials the goats foraged on 25 species. Given our large number of observations ($n=800$), all of the correlations (Table 3) among the six variables describing their activities were statistically significant ($P<0.01$) but weaker than those exhibited in the paddocks. Across stages of phonology, correlation coefficients (r) averaged 0.45 and ranged from 0.08 to 0.97. Correlation coefficients (r) exceeded 0.94 in only two instances involving total time paired with total bites and bites per visit with time per visit when grasses were at the anthesis stage of phonology. During dormancy the two strongest correlations included total bites versus total visits ($r=0.88$) and total time versus total bites ($r=0.86$).

We attribute the lower correlations in our rangeland trials to the diversity of forages and the various grazing techniques employed to harvest plants or plant parts. In our paddocks where the goats foraged solely on grasses, several techniques were used to remove herbage from the selections. The two crested wheatgrasses and two basin wildryes were larger in stature than the remaining varieties. During the boot stage of phonology the goats foraged on the smaller grasses by removing entire tillers or stems supporting three to five leaves. Among the four larger varieties they selected and removed individual leaves from the stems. After grasses were dormant, even more variation was exhibited. The goats still harvested entire stems and leaves from the smaller grasses, selected individual leaves from the two basin wildryes, and removed seed heads from the two crested wheatgrasses. Bite rate in the paddocks averaged 30.3 bites min^{-1} and ranged from 22 to 48 bites min^{-1} among species. Despite these differences in grazing technique, correlations among many of the variables remained quite high (Table 2).

On native range, with four growth forms (grasses, forbs, shrubs and trees) distributed among 25 species (Table 1), even more variation in grazing technique was evident. Bite

Table 4
Spearman's rank correlation coefficients (r_s) relating relative rankings among eight grasses foraged by goats during two stages of phenology and scored by six highly correlated ($r > 0.94$) variables. All values are statistically significant ($P < 0.004$)

	Anthesis stage of phenology					
	Total visits	Total bites	Total time	No. of plants grazed	No. of plants regrazed	No. of regrazing events
Total visits		0.90	0.90	1.00	1.00	0.98
Total bites	0.98		1.00	0.90	0.90	0.88
Total time	0.95	0.98		0.90	0.90	0.88
No. of plants grazed	0.98	0.95	0.93		1.00	0.98
No. of plants regrazed	0.98	1.00	0.98	0.95		0.98
No. of regrazing events	0.98	1.00	0.98	0.95	1.00	
	Dormant stage of phenology					

rate averaged 10.1 bites min^{-1} and ranged from 2.8 to 44 bites min^{-1} among species. Among forbs several foraging techniques were employed. These included: cropping entire plants in a single bite (royal penstemon), harvesting individual leaves (yarrow) or individual flowers (tapertip hawksbeard), removing individual seed pods (basalt milk-vetch), or cropping portions of stems with several leaves (Columbia puccoon) in a single bite. Among the shrubs and trees, bites ranged from individual leaves (big sagebrush) to strips of bark 0.5 m in length (sagebrush and juniper). We speculate the variability in foraging rates and returns per bite in these instances contributed to lower correlations than in pasture environments. Several plant and animal attributes affect bite rate (Erlinger et al., 1990; Laca et al., 1994) and given the great variation among our forages in morphology and relative biomass, it is beyond the scope of this project to fully address them.

Among our variables 'total time' was highly and consistently correlated with 'total bites' (Tables 2 and 3), and rankings of forage acceptability with these two variables were quite similar in both paddock and pasture environments. With our highly correlated variables, rank correlation coefficients ranged between 0.98 and 1.00 (Tables 4 and 5). Where the goats were confined to a single life form, i.e. grasses in the paddocks, total visits, total bites, and total time all proved to be highly correlated and acceptable

Table 5
Spearman's rank correlation coefficients (r_s) relating rankings among 25 rangeland forages grazed by goats during the anthesis stage of phenology as scored by four highly correlated ($r \geq 0.94$) variables. All values are statistically significant ($P < 0.000$)

	Total time	Bites per visit	Time per visit
Total bites	0.98	0.95	0.92
Total time		0.96	0.95
Bites per visit			0.97

agreements in the ranking of species were also obtained (Tables 2 and 4). In instances where the herbivore in question is more limited in its selection of life forms, probably any of these variables could be used to index dietary intake and subsequently rank forage acceptability. Examples might be cattle or horses which typically focus on grasses.

With computer assistance, one can easily monitor frequency of visits to species or the start and stop times of foraging activities. Tracking the numbers of plants actually grazed or regrazed in field situations would require either additional assistance or video equipment, and quantifying these variables is probably an unrealistic endeavor in rangeland settings. Utilization data were poorly correlated with our real-time variables, and we acknowledge that variables derived from this source are poor indicators of dietary intake. Among all of our choices, the variable most consistently correlated with total bites in plot and field environments was total time. We feel that with some training on a lap-top computer, one could easily record both the species foraged upon and grazing time, and these data would accurately depict the relative rankings and relative amounts of each forage in the animals diet.

A suggested format for such data would include an 'alpha' key, linked with a time entry when grazing began, followed by a simple time entry when the animal abandoned a feeding station. The alpha codes would furnish identities of the forages selected. From these one could derive the number of visits to a species, the total time devoted to each, the time per visit for each species, and the sequence in which forages were selected. Because the data sequence remains intact, a transition matrix describing how often the animal shifted from one forage to another could also be generated. In field environments the most challenging aspect of this design would be obtaining a complete listing of forages and assigning each its own alpha code. Inevitably there are omissions, and some means of recording the unexpected should be included in the programming protocol. Whatever the design, a number of practice sessions are advised before resources are committed to actual trials.

References

Austin, D.D., Stevens, R., Jorgensen, K.R. and Urness, R.J., 1994. Preferences of mule deer for 16 grasses found on Intermountain winter ranges. J. Range Manage., 47: 308–311.

Demment, M.W. and Greenwood, G.B., 1987. The use of a portable computer for real-time recording of observations of grazing behavior in the field. J. Range Manage., 40: 284–285.

Erlinger, L.L., Tolleson, D.R. and Brown, C.J., 1990. Comparison of bite size, biting rate and grazing time of beef heifers from herds distinguished by mature size and rate of maturity. J. Anim. Sci., 68: 3578–3587.

Fajemisin, B., Ganskopp, D., Cruz, R. and Vavra, M., 1996. Potential for woody plant control by Spanish goats in the sagebrush steppe. Small Rumin. Res., 20: 99–107.

Forbes, T.D.A. and Beattie, M.M., 1987. Comparative studies of ingestive behaviour and diet composition in oesophageal-fistulated and non fistulated cows and sheep. Grass Forage Sci., 42: 79–84.

Ganskopp, D., Richman, L., Johnson, D., Angell, R. and Cruz, R., 1996. Preferences of Angora goats for eight selections of grasses used for reclamation of Great Basin rangelands. Small Rumin. Res., 19: 103–112.

Heady, H.F., 1949. Methods of determining utilization of range forage. J. Range Manage., 2: 53–63.

Hodgson, J., 1985. The control of herbage intake in the grazing ruminant. Proc. Nutr. Soc., 44: 339–346.

Jones, R.J. and Lascano, C.E., 1992. Oesophageal fistulated cattle can give unreliable estimates of the proportion of legume in the diets of resident animals grazing tropical pastures. Grass Forage Sci., 47: 128–132.

Jones, T.A., Ralphs, M.H. and Nielson, D.C., 1994. Cattle preference for 4 wheatgrass taxa. J. Range Manage., 47: 119–122.

Laca, E.A., Ungar, E.D. and Demment, M.W., 1994. Mechanism of handling time and intake rate of a large mammalian grazer. Appl. Anim. Behav. Sci., 39: 3–19.

Laycock, W.A., Buchanan, H. and Kruger, W.C., 1972. Three methods of determining diet, utilization, and trampling damage on sheep range. J. Range Manage., 25: 352–356.

MacArthur, R.H. and Pianka, E.R., 1966. On optimal use of a patchy environment. Am. Nat., 100: 603–609.

McInnis, M.L., Vavra, M. and Krueger, W.C., 1983. A comparison of four methods used to determine the diets of large herbivores. J. Range Manage., 36: 302–306.

Ortega, I.M., Bryant, F.C. and Drawe, D.L., 1995. Contrasts of esophageal-fistula versus bite-count techniques to determine cattle diets. J. Range. Manage., 48: 498–502.

Richman, L.M., Johnson, D.E. and Angell, R.F., 1994. Evaluation of a positive conditioning technique for influencing big sagebrush (*Artemisia tridentatta* sspp. *wyomingensis*) consumption by goats. Appl. Anim. Behav. Sci., 40: 229–240.

Stoddart, L.A., Smith, A.D. and Box, T.W., 1975. Range Management. McGraw-Hill, New York, 532 pp.

Stuth, J.W., 1991. Foraging behavior. In: R.K. Heitschmidt and J.W. Stuth (Editors), Grazing Management: An Ecological Perspective. Timber Press, Portland, OR, pp. 65–83.