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Tethering Meat Goats Grazing Forage of High Nutritive Value and Low to Moderate Mass

A. K. Patra, R. Puchala, G. Detweiler, L. J. Dawson[1], G. Animut, T. Sahlu and A. L. Goetsch*
E (Kika) de la Garza American Institute for Goat Research, Langston University, Langston, Oklahoma, 73050, USA

ABSTRACT : Twenty-four yearling Boer×Spanish goats were used in a crossover design experiment to determine effects of tethering on forage selection, intake and digestibility, grazing behavior and energy expenditure (EE) with forage high in nutritive value and low to moderate in mass. Objectives were to determine if tethered goats could be used as a model for study of unrestrained animals and to characterize tethering as a production practice. Four 0.72-ha pastures of wheat (*Triticum aestivum*) and berseem clover (*Trifolium alexandrium*) were grazed in December and January. Each pasture hosted six animals, three with free movement and three attached to a 4.11-m tether for access to a circular area of 53.1 m^2. Tethering areas were moved each day. One animal of each treatment and pasture was used to determine forage selection, fecal output or grazing behavior and EE; therefore, there were eight observations per treatment. Mass of forage DM before grazing in Tethered areas averaged 1,280 and 1,130 kg/ha in periods 1 and 2, respectively. The CP concentration in ingesta was greater (($p<0.05$) 239 and 209 g/kg; SE = 8.0) and the NDF level was lower ($p<0.05$) for Free vs. Tethered animals (503 and 538 g/kg; SE = 12.0); *in vitro* true DM digestion was similar between treatments (0.808 and 0.807 for Free and Tethered, respectively; SE = 0.0096). Intakes of DM (1,013 and 968 g/d; SE = 78.6), NDF (511 and 521 g/d; SE = 39.9) and ME (10.9 and 10.7 MJ/d; SE = 0.90) were similar between treatments, but CP intake was greater ($p<0.05$) for Free vs. Tethered animals (241 and 203 g/d; SE = 17.2). There were small treatment differences in *in vivo* apparent digestibility of OM (($p<0.05$) 0.780 and 0.814; SE = 0.0049), CP (($p<0.05$) 0.800 and 0.817; SE = 0.0067) and NDF (($p<0.09$) 0.777 and 0.760 for Free and Tethered, respectively; SE = 0.0078). There were no treatment effects on time spent ruminating or grazing (346 and 347 min/d for Free and Tethered, respectively; SE = 42.5), but EE was considerably greater ($p<0.05$) for Free vs. Tethered animals (571 and 489 kJ/kg $BW^{0.75}$; SE = 8.9). In conclusion, with forage of high nutritive value and low to moderate in mass, tethering can offer a production advantage over free grazing of less energy used for activity despite similar grazing time. With forage removal considerably less than that available for grazing, effects of tethering on chemical composition of selected forage were small and less than needed to markedly affect digestion. Tethering may offer a means of studying some aspects of grazing by ruminants, but would not seem suitable for energy metabolism. (**Key Words :** Goats, Tethering, Energy, Grazing)

INTRODUCTION

Many ruminants of the world graze and move freely within pastures or rangeland areas. However, a large number, particularly small ruminants, are restricted in movement often with a tether. This is common in cut-and-carry or zero-grazing production systems. Furthermore, use of tethering may rise in the future with increasing urban and peri-urban production in developing countries of the world and also to lessen damage to communal lands because of over-grazing. In addition, tethering allows farmers close control of forage resources. But, restricting the grazing area by tethering could impact plant species and part selectivity (Kim et al., 2001), thereby influencing feed intake and (or) nutritive value of the ingested diet. For example, Moniruzzaman et al. (2002) noted that feed intake and growth of Black Bengal goats grazing for an 8-h period was similar regardless of tethering. But, rumination time was longer for tethered animals, which was attributed to greater selection of forage relatively high in stems vs leaves. Another consideration for nutrient requirements is energy used for activity. Many means of predicting this cost are partially based on distance traveled (SCA, 1990; AFRC, 1993, 1998; NRC, 2000, 2001), which would be expected to be low for tethered animals. Conversely, Osuji (1974) rationalized that time spent grazing has greater effect on energy used for grazing than distance traveled, as also is

* Corresponding Author: A. L. Goetsch. Tel: +1-405-466-6164, Fax: +1-405-466-6180, E-mail: goetsch@luresext.edu
[1] College of Veterinary Medicine, Oklahoma State University, Stillwater, Oklahoma, 74078, USA.
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assumed by Sahlu et al. (2004) to predict energy use by goats in the act of grazing.

Apart from interest in study of tethering as a production practice, tethered animals might serve as a model for ones with unrestricted movement. Animals must be subjected to normal grazing conditions for research to have broad applicability. But, for detailed study of grazing ruminants, measurements should not markedly alter animal behavior. These conditions have naturally restricted our understanding of the science of grazing animals, and concomitantly led to the great majority of detailed nutrition/physiology research being conducted in confinement. Hence, there is need for means of using fundamental or basic methodologies with grazing ruminants. If unrestrained grazing is adequately simulated by tethering, then with tame and appropriately trained animals there are many basic measures that could be made to fully characterize the physiology of grazing and responses of ruminants to grazing conditions. An example would be to use animals with multiple blood vessel catheters for partitioning of the grazing energy cost into that attributable to metabolism by the gastrointestinal tract and liver vs. peripheral tissues for locomotion. Therefore, objectives of this experiment were to determine how tethering of yearling meat goats influences forage selection, intake and digestibility, grazing behavior and energy expenditure with forage of high nutritive value and low to moderate mass.

MATERIALS AND METHODS

Pastures, animals and treatments

The experiment was conducted at the American Institute for Goat Research in late December and early January, and was approved by the Langston University Animal Care Committee. Four 0.72-ha pastures were used, which had been fertilized and seeded with 168 kg/ha of wheat (*Triticum aestivum*) and 22.4 kg/ha of berseem clover (*Trifolium alexandrium*) by hand-broadcasting in the fall. Twenty-four Boer×Spanish goats were used, approximately 1.3 yr of age when the experiment began. Sixteen were wethers and eight were doelings previously fitted with rumen cannulas (5.1 cm i.d.). Animals grazed an adjacent pasture with similar forage for 2 wk before the experiment began.

The experiment was a crossover, with two 2-wk periods. Four wethers and two doelings were randomly assigned to pastures, and of these, two wethers and one doeling were randomly chosen for the two treatments. Treatments were free or unrestrained movement (Free) and restraint (Tethered). Tethering involved allowing animals to move only within a circle. A chain 4.11-m long was attached to a metal ring placed around a steel post at one end and to the animal at the other. Attachment to the animal was via a collar on the neck for one wether and the doeling in each pasture. For the other wether, used for monitoring of heart rate (HR) and grazing behavior, because of the nature of the equipment attachment was to a leather collar made from belts situated around a front leg. Animals had been accustomed to tethering before the 2-wk pre-trial adaptation period.

The location of tethered animals was changed daily. They were placed in a row though not with overlapping areas of pasture access. Each morning at 07:00 h tethered goats were moved forward to the next post, and they were not allowed to graze an area that had been previously used for tethering. The area available to each Tethered animal was 53.1 m^2 (0.00531 ha), which was chosen to allow predicted removal of forage no more than 300 g/kg of that available. For example, with forage mass of 1,000 kg/ha, 35 kg BW and DMI of 30 g/kg BW, of the 5.31 kg of forage DM available daily removal would be 1.05 kg or 200 g/kg. Tethered animals had access to a small plastic hut or enclosure (0.6×1.2 m) for shelter placed at the periphery of the accessible area, which was moved each day as well. This enclosure was fitted with two containers, one on the inside for a small trace mineralized salt block and the other on the outside for a water bucket. Free animals had access to a larger enclosure in each pasture for shelter, an automatic waterer and a large trace mineralized salt block. However, Free animals generally grazed near Tethered ones and sometimes shared the small enclosures for Tethered animals. After period 1, animals grazed in the pre-trial pasture for 2 wk and returned to the same pastures when switched to the other treatment.

Measures

Goats were weighed at the beginning and end of each period. Forage mass was determined in two manners. The first was a weekly measure by clipping forage at a height of approximately 1.3 cm in four randomly placed 0.25-m^2 quadrats in each pasture. Hence, because in some cases quadrat location was in areas that had been previously grazed by Tethered animals and Free animals were not observed to spend appreciable time grazing such locations, values determined by this method should underestimate mass of forage actually being grazed. The second means of addressing forage mass was to use a disk meter (Bransby et al., 1977). The physical nature of forage did not seem to vary much during the experiment; therefore, calibration (establishment of relationship between disk height and forage mass) occurred once near the end of period 1, with 10 points. The relationship was quite strong (R^2 = 0.903). The disk meter was used daily on six mornings before moving Tethered animals on days of determining fecal output. There were five readings taken at each time in the areas to be grazed that day and(or) had been grazed in the previous 24 h. However, post-grazing measures were later omitted from analyses as they appeared influenced by movement of animals in these areas on the preceding day (i.e. trampling). The disk meter was employed for this purpose rather than the quadrat to 1) avoid removal of forage that might be consumed when determined pre-grazing, 2) minimize personnel walking in areas of Tethered animals before grazing and 3) allow the large number of determinations necessary.

As noted earlier, each of the three Free and three Tethered animals in the pastures were used for different measures. This was to minimize length of the experiment so as to incur relatively small changes in forage and other environmental conditions. Also, this averted potential effects of one measurement procedure on another. With four pastures and two periods, there were eight observations per treatment.

One set of wethers was used to determine energy expenditure (EE) by use of HR. To do so, before the pre-trial grazing adaptation period these eight wethers were placed in a head-box respiration calorimetry system (Sable Systems, Henderson, NV) while consuming *ad libitum* coarsely ground alfalfa hay for quantification of oxygen consumption and production of carbon dioxide and methane. The Brouwer (1965) equation without urinary N excretion was used to predict EE. At the same time HR was measured with a Polar S610 monitor (Polar, Woodbury, NY). The ratio of EE to HR for each animal was then used to predict EE from HR measured when grazing, which was on d 8 of each period. The use of HR to measure EE by grazing ruminants was recently reviewed by Brosh (2007). It was concluded that the effects of cold temperatures on EE:HR (comparable to oxygen pulse discussed by Brosh, 2007) is minor. This is relevant to the present grazing experiment conducted on pastures in the winter, with EE:HR determined under controlled environmental conditions in a building. Furthermore, Puchala et al. (2005, 2007) noted similar EE:HR between forage and mixed concentrate-forage diets, and Berhan et al. (2006) did not observe effects on EE:HR of various HR, comparable to ones in grazing conditions, achieved by standing and walking on a treadmill at different speeds with or without forage consumption. The animals used for HR measurement were also used to assess grazing behaviors using IGER (i.e., Institute for Grassland and Environmental Research) grazing behavior monitoring system units (Ultrasound Advice, London, UK) over a 24-h period on the same day. Measurements with IGER units are continuous, which offers accuracy benefits compared with visual observations depending on their frequency (Hirata et al., 2002; Kononoff et al., 2002).

Rumen cannulated doelings were used to assess forage selection or diet composition. Collections started at approximately 07:00, 12:00 and 16:00 h on d 12, 8, and 10, respectively. Thus, there was approximately 2 d between ingesta collections. First, digesta in the reticulo-rumen was removed and warm water was added a number of times to ensure total evacuation. Then animals were allowed to graze for 30 to 60 min, after which time ingesta was sampled and frozen. All removed digesta was then returned to the rumen. The second wether of each treatment and pasture was used to determine fecal output with fecal bags and a 5-d collection period (d 9 to 13). Daily aliquots of feces (200 g/kg) were used for form composite samples, which were stored frozen.

Laboratory analyses

Quadrat forage samples and calibration samples for the disk meter were dried in a forced-air oven at 55°C for 24 h, followed by immediate weighing. Ingesta samples were also dried at 55°C and ground to pass a 1-mm screen. A partial DM concentration in feces was assayed by drying at 55°C, followed by grinding to pass a 1-mm screen. Ground ingesta and feces were analyzed for DM (100°C), ash, Kjeldahl N (AOAC, 1990) and NDF with use of heat stable amylase and containing residual ash (filter bag technique; ANKOM Technology Corp., Fairport, NY, USA). Ingesta samples were analyzed for *in vitro* true DM digestibility ((IVTDMD) filter bag technique; ANKOM technology Corp., Fairport, NY, USA) with NDF as the end point measure. Ruminal fluid was collected from two mature Boer crossbred goats grazing a grass-based pasture and supplemented with a moderate amount of concentrate. This method is described at www.ankom.com/09_procedures/Daisy%20method.pdf and is similar, except for the end point measure, to the procedure of Tilley and Terry (1963).

Calculations and statistical analysis

Though the effect of ingesta sampling time or day was evaluated as noted below, for other purposes (e.g. calculation of DMI and digestibilities) values were averaged over time. The IVTDMD for ingesta samples was adjusted to an *in vivo* apparent total tract DM digestibility basis first by assuming metabolic fecal DM excretion of 119 g/kg DMI (Van Soest, 1994). However, this adjustment was recommended for cattle and sheep and may not have been evaluated with goats. Also, in the study on which this adjustment was based (Van Soest et al., 1966), there was considerable variability among different forages in the comparison between yield of insoluble residue obtained from the Tilley and Terry (1963) second-step acid-pepsin digestion and the neutral detergent method. The two-stage Tilley and Terry (1963) method results in microbial cell

Table 1. Mass and dry matter concentration of forage grazed by yearling Boer×Spanish goats

Item	Period 1		Period 2	
	Mean	SE	Mean	SE
Forage mass, quadrat (kg/ha)				
Beginning of measurements	558	65.1	574	61.7
End of measurements	504	50.3	496	67.2
Forage mass, disk meter (kg/ha)	1,280	48.5	1,130	27.0
Average forage DM (g/kg)	301	5.0	386	4.7

Table 2. Effects of tethering on composition of forage selected by yearling Boer×Spanish goats

Item	Treatment		Period		SE	Collection time (h)			SE	Significance		
	Free	Tethered	1	2		07:00	12:00	17:00		Treatment	Period	Time
OM (g/kg DM)	871	856	880	847	7.2	857	866	868	8.5		*	
CP (g/kg DM)	239	209	226	222	8.0	228	228	217	8.6	*		
NDF (g/kg DM)	503	538	502	539	12.0	531	508	523	13.4	*	*	
In vitro true DM digestibility	0.808	0.807	0.824	0.791	0.0096	0.796	0.804	0.823	0.0107		*	

debris that as a proportion of initial substrate is similar to metabolic fecal DM *in vivo*, therefore not requiring an adjustment (Minson, 1990; Van Soest, 1994). However, the initial adjustment of Van Soest (1994) resulted in low retained or recovered energy (RE) compared with observed changes in BW (e.g. negative RE for Free animals despite no observed decrease in BW). Though BW change with such short periods can be appreciably influenced by changes in gut digesta fill not necessarily in accordance with empty body gain or loss, in a subsequent experiment with similar methodologies (Patra et al., 2006) the 119 g/kg adjustment likewise resulted in much lower RE than expected based on ADG (i.e. negative RE for both Free and Tethered animals despite no change in BW). Hence, a second method of adjustment was employed, which is of importance only for absolute magnitudes of MEI and RE and does not impact relative differences between treatments or periods. Metabolic fecal CP was assumed to be 26.7 g/kg DMI (Moore et al., 2004). Because most metabolic fecal CP in ruminants appears to be of microbial origin (Van Soest, 1994), this value was divided by a bacterial CP concentration of 485.6 g/kg (Ørskov, 1992), resulting in an adjustment of 55 g/kg to convert *in vitro* true DM digestion to an *in vivo* apparent total tract DM digestion basis. Values averaged over pasture were applied to fecal output estimates for the corresponding treatment and period to estimate DMI. Digestibilities of OM, CP and NDF were determined based on DMI, fecal DM and concentrations of these constituents in ingesta and feces. Metabolizable energy intake was estimated assuming 19.33 kJ/g digestible OM intake (NRC, 1981) and 0.82 kJ/kJ DE (Garrett et al., 1959). Metabolizable energy intake relative to $BW^{0.75}$ of fecal output animals for the four treatment-period combinations was applied to animals used for EE, with RE determined as the difference between MEI and EE.

Data were analyzed by SAS (1990) using mixed model methodology (Littell et al., 1996). Most data were analyzed with a model consisting of animal (used for the different measures), period of the crossover and treatment, with a repeated measure of period and random effect of animal. To evaluate temporal patterns of behavior measures and EE, values were averaged for the 24 1-h periods. These data were also analyzed as a mixed model with random effects of animal and animal within treatment×period and a repeated measure of period×hour. Diet composition data were analyzed in a similar manner, considering time of ingesta collection.

RESULTS

Forage mass and DM concentration

Neither the estimate of forage mass measured by quadrat nor that with the disk meter markedly differed between periods (Table 1). Values by the latter method were about twice as great as the former. Based on forage mass by disk meter, Tethered animals had 6.8 and 6.0 kg of forage DM available for grazing. Forage DM concentration was slightly less in period 1 vs. 2.

Ingesta composition

Forage OM concentration was similar between treatments, whereas the level of CP was greater and that of NDF was slightly lower for Free vs. Tethered animals ($p<0.05$; Table 2). However, *in vitro* true DM digestion was similar between treatments, which corresponds to apparent total tract DM digestibility of about 0.75.

The level of ash was greater ($p<0.05$) in forage of period 2 vs. 1, CP concentration was similar between periods and the concentration of NDF was less ($p<0.05$) in period 1 (Table 2). In agreement with differences in ash and NDF concentrations, *in vitro* true DM digestion was greater ($p<0.05$) in period 1 than 2.

Table 3. Effects of tethering on forage intake and digestion by Boer×Spanish goats

Item	Treatment		Period		SE	Significance	
	Free	Tethered	1	2		Treatment	Period
BW (kg)	41.7	40.5	39.5	42.7	1.43	*	*
Intake							
DM (g/d)	1,013	968	908	1,073	78.6		*
OM (g/d)	881	825	799	907	68.9		*
CP (g/d)	241	203	205	239	17.2	*	*
NDF (g/d)	511	521	466	575	39.9		*
ME							
MJ/d	10.90	10.67	10.09	11.49	0.898		*
kJ/kg $BW^{0.75}$	660	665	639	686	48.9		
Digestibility (g/kg)							
OM	780	814	795	799	4.9	*	
CP	800	817	793	824	6.7	*	*
NDF	777	760	793	744	7.8		*

Table 4. Effects of tethering on grazing behavior, heart rate, energy expenditure and recovered energy in Boer×Spanish goats

Item	Treatment		Period		SE	Significance	
	Free	Tethered	1	2		Treatment	Period
BW (kg)	37.8	36.6	35.7	38.7	1.22	*	*
Grazing behavior (min/d)							
Ruminating	331	360	334	357	27.4		
Eating	346	347	333	360	42.5		
Idle	763	733	773	723	42.8		
Heart rate (beats/min)	87	74	82	79	2.9	*	
Energy expenditure							
MJ/d	8.70	7.26	7.88	8.09	0.27	*	
kJ/kg $BW^{0.75}$	571	489	539	521	8.9	*	
ME intake (MJ/d)	10.07	9.89	9.31	10.65	0.288		*
Recovered energy							
MJ/d	1.37	2.62	1.43	2.55	0.240	*	*
kJ/kg $BW^{0.75}$	88	177	100	165	16.5	*	*

Ingesta collection time did not influence composition, and the interaction between treatment and time was not significant (Table 2). Although, numerically *in vitro* true DM digestion was highest among times for the late afternoon collection, which is in accordance with differences noted between hay harvested in the afternoon vs. morning (Fisher et al., 1999; Burns et al., 2005). Such findings have been attributed to level of nonstructural carbohydrates, which were not directly assayed in the present experiment. However, a crude estimate can be derived by assuming an ether extract level of 40 g/kg (Preston, 2005), ignoring ash in NDF and calculating the difference between 1,000 and the sum of concentrations of ash, CP, NDF, and ether extract (58, 90 and 88 g/kg for 07:00, 12:00 and 17:00 h, respectively).

Forage intake and digestion

Intakes of DM, OM and NDF were similar between Free and Tethered animals (Table 3). However, because of the difference in ingesta concentration, CP intake was greater ($p<0.05$) for Free than for Tethered animals. Digestibilities of OM and CP were greater ($p<0.05$) for Tethered than for Free animals, though NDF digestibility tended ($p<0.09$) to be greater for Free. But, magnitudes of difference were not great. As a result of numerically greater OM intake for Free vs. Tethered animals and greater OM digestibility for Tethered, MEI was similar between treatments.

Intakes of DM, OM, CP and NDF were greater ($p<0.05$) in period 2 than 1 (Table 3). Organic matter digestibility was similar between periods, as a result of opposite differences ($p<0.05$) in CP and NDF digestibilities (CP: period 2>1; NDF: period 1>2). Because of greater forage intake in period 2 vs. 1, MEI was considerably greater ($p<0.05$) in period 2 as well.

Grazing behavior and EE

Times spent ruminating, grazing and idle were similar between treatments (Table 4). Heart rate and EE in MJ/day and kJ/kg $BW^{0.75}$ were considerably greater ($p<0.05$) for Free vs. Tethered animals. As a consequence of similar MEI and greater EE for Free than for Tethered animals, RE was less ($p<0.05$) for Free vs. Tethered. Despite greater MEI in period 2 vs. 1, grazing behavior and EE were similar

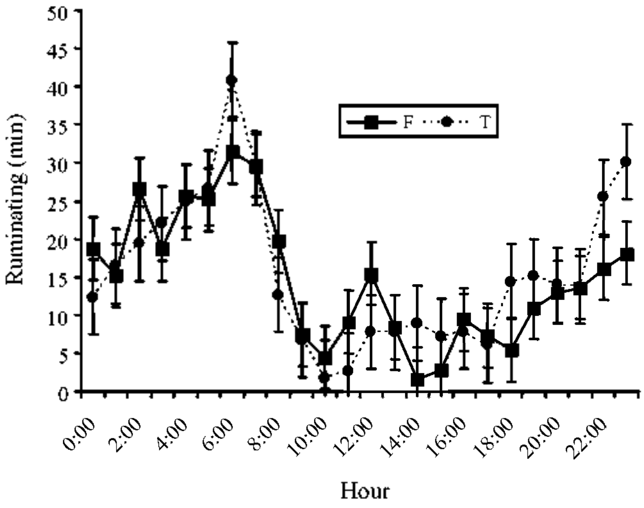

Figure 1. Effects of tethering (T) compared with unrestrained or free movement (F) on the hourly pattern of time spent ruminating by Boer×Spanish goats.

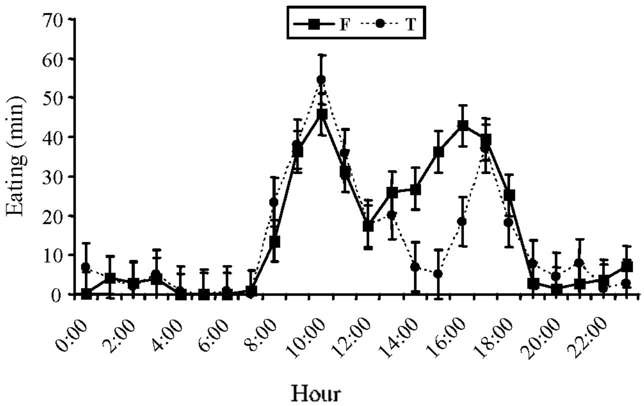

Figure 2. Effects of tethering (T) compared with unrestrained or free movement (F) on the hourly pattern of time spent grazing by Boer×Spanish goats.

between periods. In accordance, RE was greater ($p<0.05$) in period 2 than 1.

Rumination was influenced only by time or hour, without a significant treatment×time interaction (Figure 1). For time spent grazing, there was an effect of time ($p<0.05$) and a tendency for an interaction between treatment and time ($p<0.06$; Figure 2). Grazing began for each treatment when Tethered goats were moved to the next grazing site. The peak in time spent grazing in the morning at 11:00 h was slightly greater for Tethered vs. Free animals. In the afternoon from 14:00 to 17:00 h, time of each hour spent grazing was greater for Free vs. Tethered animals. Energy expenditure was influenced by treatment and time ($p<0.05$), without a significant treatment×time interaction. Nonetheless, differences between treatments were less during some (09:00 to 13:00 h) than other hours of the day, which encompassed the morning peak in grazing time.

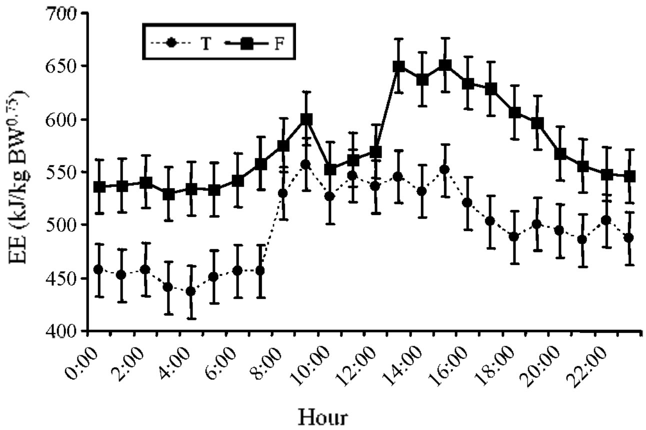

Figure 3. Effects of tethering (T) compared with unrestrained or free movement (F) on the hourly pattern of energy expenditure (EE) by Boer×Spanish goats.

Differences in EE among hours were much less than in grazing time.

DISCUSSION

Forage mass

The intent of the experiment was to address grazing of high nutritive value forage with low to moderate mass. It is important to characterize forage conditions since they may influence effects of tethering compared with free movement. Hence, other research of tethering with varied forage conditions (e.g., Patra et al., 2006) is warranted. Though there was a greater than anticipated difference in forage mass between quadrat and disk meter estimates, they do reflect that desired conditions were achieved. Based on cattle studies of Redmon et al. (1995) and Lippke et al. (2000), mass of wheat forage in this range could restrict growth by young ruminants. But, AFRC (1998) discussed a limited number of reports available for goats suggesting that forage mass in the range of that in this experiment with a forage of high nutritive value should have been adequate for at least maintenance of yearling meat goats. Hence, as was observed, it was felt that the yearling goats of this experiment should not have incurred large decreases in body energy status. The AFRC (1998) also summarized some studies in which increasing forage mass or allowance increased level of milk production. However, for mature animals not having high nutrient requirements, such responses are not likely and would presumably be limited to fat accretion, which would decrease in magnitude with advancing time. In support, in 9-mo experiments over a 2-yr period, ADG by Landim goats grazing natural pasture for 7 h daily, with mass of low quality forage of 210 to 670 and 650 to 2,410 kg/ha in yr 1 and 2, respectively, was 26 to 27 g when unrestrained and 5 to 10 g when tethered (Muir and Massaete, 1996).

Forage selection

The obvious factor responsible for the higher concentration of CP and lower level of NDF in ingesta of Free vs. Tethered animals is the greater area available for Free animals to graze. Thus, tethering can alter chemical composition of grazed forage, even with forage of very high nutritive value such as vegetative wheat and berseem clover. But, perhaps because of the vegetative growth stage of the forage, IVTDMD (Table 2) and *in vitro* NDF digestibility (calculated from NDF concentration and IVTDMD; 0.62 and 0.64 for Free and Tethered, respectively) were similar between Free and Tethered animals, although *in vivo* NDF digestibility did tend to be greater for Free vs. Tethered. A factor that most likely limited differences in forage selectivity between Free and Tethered animals is the proportion of available forage mass removed, which averaged only 150 g/kg.

Intake and digestion

Greater intake of CP by Free than Tethered animals was primarily the result of the difference in ingesta CP concentration. One factor that could have contributed to the lower CP digestibility for Free vs. Tethered animals despite greater CP intake (Asplund, 1994) is the tendency for greater DMI by Free animals, which would suggest greater metabolic fecal CP excretion. Assuming metabolic fecal CP to be 26.7 g/kg DMI (Moore et al., 2004), this difference accounted for approximately 5 g/kg or about 0.3 of the difference in CP digestibility between Free and Tethered animals.

Apparent total tract OM digestiblities were greater than a TDN listing for fresh wheat pasture of 700 g/kg (Preston, 2005). However, Hart et al. (1993) reported an *in vitro* OM digestibility of 0.78 for wheat pasture and Montossi and Hodgson (1997) noted *in vitro* OM digestibility of 0.80 to 0.81 for ryegrass selected by lambs. It is unclear why *in vivo* NDF digestibilities in the present experiment were slightly greater than *in vitro*, though more thorough particle disintegration, disruption of forage tissue associations and increased available surface area for microbial attachment and degradation with mastication than grinding in a laboratory mill may have been involved (Moore et al., 1996). The tendency for greater NDF digestibility in Free vs. Tethered animals also is not in harmony with *in vitro* findings. It is possible that an ingesta collection time very early in the morning before Tethered animals were moved would have resulted in a greater overall difference between treatments in ingesta NDF concentration since prior removal by Tethered animals of forage of highest nutritive value would be expected. Although, from visual observations as well as grazing time measures with IGER units, Tethered animals did not graze appreciably early in the morning before being moved.

Reasons for substantially greater forage intake in period 2 than 1 are unknown. Weather data were not recorded and different climatic conditions could have had impact. But, collections did not occur with extreme conditions, as is supported by grazing behavior measures similar between periods. Another consideration is that animals were more accustomed to the groups in period 2 vs. 1 and even more adjusted to the experimental procedures in period 2. Lower NDF digestibility in period 2 than 1 probably reflects prior selection in period 1 by Free animals of forage of relatively high nutritive value, resulting in forage of lower quality available in period 2.

Grazing behavior and EE

With similar MEI, it may not be surprising that there were no differences in daily grazing behaviors, the most important being grazing time because of its influence on and(or) close relationship with EE (Osuji, 1974). It should be noted, however, that grazing time was not particularly high (Dulphy et al., 1980), less than 6 h. Hence, animals appeared to have opportunity to graze longer to achieve greater MEI. In this regard, EE was 0.2 greater for Free than for Tethered animals, resulting in greater energy gain by Tethered than Free animals. In addition to potential for longer grazing, a higher rate of MEI is a consideration, which was 0.77 kJ/(min×kg BW) for Free animals. Berhan et al. (2005) reported a value of 1.17 kJ/(min×kg BW) by growing meat goats grazing a mixture of cool season annual grasses at the same time of the year, although these animals only had 4 h/day of pasture access with a grazing time of 3.8 h. Rates of MEI of 0.87 and 0.81 kJ/(min×kg BW) were noted for animals with 8 and 24 h of pasture access and 6.3 and 7.3 h of grazing time, respectively.

Another factor that may have influenced behavior, MEI and RE is the social nature of the animals. As noted before, Free animals were in close proximity to Tethered ones at most times, which may have promoted similar grazing behaviors. Free and Tethered animals were in the same pastures, however, primarily to maintain similar nutritive value of forage available for consumption, which could not have been achieved otherwise.

Overall, these results indicate that short-term RE can have little impact on grazing behaviors. Had the grazing periods been considerably extended, perhaps grazing behavior of Free goats would have differed from Tethered animals to increase RE, such as through increased grazing time or a greater rate of energy intake. Alternatively, with presumably primarily fat accretion by these yearling animals, as body fat would increase with advancing time, an earlier and probably more drastic decrease in MEI would be expected for Tethered vs. Free animals.

A factor that might have contributed to greater EE by Free than Tethered animals is greater distance traveled, since measured daily grazing behaviors were similar. Although neither distance traveled nor number of steps was assessed in this experiment, with some assumptions distance traveled can be addressed. Berhan et al. (2006) determined EE by goats while walking on a treadmill at different speeds. The average cost of movement for the six walking treatments without forage ingestion was 3.82 J/(kg BW×m). By applying this value to the average BW of Free animals and to the difference in EE between Free and Tethered animals, predicted distance traveled is 10 km. Given the small size of these pastures and the high nutritive value of the forage, it is highly unlikely that distance traveled was this great. This suggests that free movement as compared with tethering impacted more than simply distance traveled, although other factors influenced are unclear. One possibility is a greater effect of forage ingestion on EE when walking by Free animals than standing by ones tethered. In this regard, Berhan et al. (2006) noted a greater effect of consumption of alfalfa hay on the subsequent maximum or plateau EE by Alpine does when walking vs. standing, and the effect on EE in the hour after the plateau tended to be greater for walking as well. Moreover, the effect of walking on EE was less pronounced when consuming forage than before. Hence, in the present experiment EE by Free animals could have been relatively greater than by Tethered animals because of more time spent grazing and walking simultaneously and also walking without grazing.

An additional consideration for the difference between Free and Tethered animals in EE is the temporal pattern of grazing behaviors. It is notable that EE by Free animals was numerically highest among times at 14:00 to 16:00 h when grazing time was low compared with earlier and later times. This may relate to findings of Berhan et al. (2006) concerning the carryover effect of forage consumption at one time on subsequent EE. That EE was greater for Free vs Tethered animals in most hours of the day, with in fact greater differences when ruminating vs. grazing, indicates that free movement influenced basal metabolic rate irrespective of activity displayed at any one given time. This implies that distance traveled, most likely greater for Free vs. Tethered animals, was not responsible for a large portion of the difference between treatments in EE.

Energetic cost of grazing activities

It can be difficult to partition quantities or proportions of energy used for different functions because of the many assumptions required. Nonetheless, results of this experiment may allow assessment of the energy used in movement by Free animals with minimal assumptions. First, EE attributable to energy accretion can be estimated assuming energy in tissue accreted was in fat and an efficiency of 0.75 (SCA, 1990). These values can be subtracted from total EE to project the ME requirement for maintenance (ME_m) plus activity. The difference in this quantity between Free and Tethered animals would be the energetic cost of free movement, 1.86 MJ/day, 111 kJ/kg $BW^{0.75}$ and 0.26 of ME_m plus activity cost of Tethered animals (based on kJ/kg $BW^{0.75}$). It is more subjective to project the activity cost of Tethered animals. Nonetheless, based on findings of Luo et al. (2004) and Sahlu et al. (2004), a ME_m plus confinement activity cost of 423 kJ/kg $BW^{0.75}$ can be assumed using mature animal values. Thus, EE by Tethered animals was only 0.02 greater. If assumed that the confinement activity energy cost is 0.1 of the true ME_m requirement (AFRC, 1998), then the 423 kJ/kg $BW^{0.75}$ value can be partitioned into 384.5 kJ/kg $BW^{0.75}$ for true ME_m and 38.5 kJ/kg $BW^{0.75}$ for confinement activity. The total activity cost of Tethered animals then becomes 45.8 kJ/kg $BW^{0.75}$ (7.3+38.5 kJ/kg $BW^{0.75}$), or 0.12 of true ME_m. This would be the cost of forage ingestion and minimal movement. The activity cost for Free animals, likewise, is 0.41 of true ME_m, of which 0.71 is due to movement and 0.29 is attributable to grazing and minimal movement. These calculations reflect an activity energy cost for Tethered animals similar to that of animals in confinement and that free movement has a substantial impact on energy used for activity.

CONCLUSIONS

With forage of high nutritive value and low to moderate in mass, it appears that effects of tethering, with forage removal considerably less than that available for grazing, on chemical composition of forage selected by yearling meat goats are relatively small and less than needed to markedly affect digestion. Likewise, tethering did not influence DMI or grazing behaviors such as grazing time. But, freely moving animals had considerably greater EE, suggesting an energy cost of free movement of 111 kJ/kg $BW^{0.75}$. Hence, for production purposes tethering would seem to offer an advantage over free grazing of less energy used for activity, which in this instance allowed increased RE. These results indicate that tethered ruminants would not be a perfect model for ones with free movement for all areas of investigation. Nonetheless, it may be acceptable for specific studies and purposes when appropriately considering potential unique features of tethered animals, such as a lower activity energy cost.

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