**Factors influencing estimates of heat energy
associated with activity by grazing meat goats**

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Abstract

Ten yearling Boer goat wethers (45.4 ± 0.92 kg) grazed a 0.8-ha grass pasture or were individually confined in a crossover experiment with 3-wk periods to evaluate factors influencing heat energy (HE) associated with activity (AEC) when grazing and to evaluate different methods of estimating the AEC. Fresh forage offered to confined wethers was 15.9 and 13.4% CP and 65.0 and 67.4% NDF in periods 1 and 2, respectively. Based on forage and fecal acid detergent insoluble ash, digestibility of gross energy in forage by confined wethers averaged 67.9 and 56.5% in periods 1 and 2, respectively. From these values and fecal DM, least squares means of ME intake were 405 and 484 kJ/kg BW^{0.75} for confined and grazing wethers, respectively (SE = 15.4). HE determined from heart rate (HR) measured over 1 day and the ratio of HE to HR estimated earlier was less ($P < 0.001$) for confined than for grazing wethers (482 and 642 kJ/kg BW^{0.75}; SE = 17.2). The AEC estimated by subtraction from HE of ME required for maintenance (ME_m; 427 kJ/kg BW^{0.75}), HE expended for tissue energy gain based on recovered energy (RE) when greater than 0, an efficiency of ME use for gain (i.e., $[0.0423 \times \text{forage ME in MJ/kg DM}] + 0.006$; 0.40 ± 0.009), and the same efficiency of use for maintenance (k_m ; $[0.019 \times \text{forage ME in MJ/kg DM}] + 0.503$; 0.68 ± 0.004) of energy from forage and mobilized tissue with RE less than 0 was 39 and 213 kJ/kg BW^{0.75} for confined and grazing wethers, respectively (SE = 21.9; Partitioning approach). The AEC determined as the difference between HE by grazing and confined wethers was 165 ± 19.3 kJ/kg BW^{0.75} (Confinement approach), and that based on time spent in different activities (i.e., lying, standing, grazing, and walking) multiplied by corresponding HE and assuming that AEC resulted from HE when standing, grazing, and

walking was 46 ± 4.85 kJ/kg BW^{0.75} (Lying approach). In conclusion, method of estimation can have marked impact on the AEC, with a relatively low value for the Lying method because of lower HE while lying when confined than on pasture. Determining the AEC by the Confinement approach relies on similar conditions to minimize confounding, and the Partitioning method is influenced by specific assumptions of energy requirements and efficiencies of use for different physiological functions.

Key words: Activity, energy, goats, grazing

1. Introduction

It is commonly assumed that approximately 10% of the energy required by confined ruminants for maintenance is used for activity (AFRC, 1998; NRC, 2007). However, grazing ruminants use considerably more energy for activity, and the amount can be even as much as a confined animal requires for maintenance (Lachica and Aguilera, 2003). Therefore, accurate means of predicting this energetic expense would be very useful. But, the difficulty in determining the activity energy cost (AEC) has limited the number of estimates available and resulted in high variability.

Goetsch et al. (2010) addressed three methods of determining the AEC that have been employed recently. One used with cattle is based on differences in heat energy (HE) between times when animals are lying compared with periods while eating, standing, and walking. These differences are multiplied by the lengths of time spent in the activities (Brosh et al., 2006). Such estimates are frequently expressed as a percentage or proportion of the ME requirement for maintenance (ME_m) of animals in confinement (NRC, 2007). This may necessitate an assumption that HE while lying is

constant regardless of specific conditions, even for animals when grazing and confined. Another approach to determine the AEC is to compare HE by grazing animals with that by ones confined (Lachica and Aguilera, 2005), which requires similar conditions between the two settings to minimize confounding. A third approach is to subtract the various components of the estimate of total HE in order to derive the AEC by difference (Beker et al., 2009, 2010; Tovar-Luna et al., 2011). The accuracy of assumptions employed is very important for this method. Therefore, objectives of the present study were to evaluate factors influencing the AEC when grazing, particularly time spent in different behaviors, and compare different methods of estimation.

2. Materials and methods

2.1. Animals, phases, and experimental design

The experimental protocol was approved by the Langston University Animal Care and Use Committee. Ten yearling Boer goat wethers were used, with an average BW during the experiment of 45.4 ± 0.92 kg and age of approximately 18 months. Wethers were weighed at the beginning and end of each phase and calorimetry measurement period. The wethers were treated for internal and external parasites before the study, which consisted of a preliminary or stationary calorimetry system phase 2 wk in length followed by a crossover experiment of two 3-wk periods. Measures during the crossover occurred in a pasture and in pens and stanchions located in an alleyway adjacent to the pasture at the Langston University campus. The experiment occurred during August and September of 2013, with temperature and humidity from Weather Underground (<http://www.wunderground.com>) for the Guthrie, Oklahoma airport summarized in Table 1.

2.2. *Stationary calorimetry system phase*

Animals were adapted to housing in a room with metabolism crates (0.7×1.2 m) with plastic-coated expanded metal floors during the first week; the facility was located approximately 250 m from the pasture site. In the second week, the ratio of HE to heart rate (HR) was determined for 24 h after 1 day of adaptation to housing in an adjacent room in four metabolism crates fitted with head-boxes of an indirect, open-circuit respiration calorimetry system (Sable Systems International, Las Vegas, NV, USA). A coarsely ground moderate quality grass hay (Table 2) was fed free-choice for ad libitum consumption. The HE:HR ratio was determined as in other studies (Puchala et al., 2007, 2009). O_2 concentration was analyzed using a fuel cell FC-1B O_2 analyzer (Sable Systems International), and CH_4 and CO_2 concentrations were measured with infrared analyzers (CA-1B for CO_2 and MA-1 for CH_4 ; Sable Systems International). Prior to gas exchange measurements, analyzers were calibrated with gases of known concentrations. Ethanol combustion tests were performed to ensure complete recovery of O_2 and CO_2 produced with the same flow rates as used during measurements. HE was determined according to the Brouwer (1965) equation without consideration of urinary N.

HR was monitored generally as described by Puchala et al. (2009). Wethers were fitted with 10×10 cm electrodes prepared from stretch conductive fabric (Less EMF, Albany, NY, USA), glued to Vermed PerformancePlus ECG electrodes (Bellows Falls, VT, USA), and attached to the chest just behind and slightly below the left elbow and behind the shoulder blade on the right side. Electrodes were connected by ECG snap leads (Bioconnect, San Diego, CA, USA) to T61 coded transmitters (Polar, Lake Success, NY, USA). Human S610 HR (Polar) monitors with wireless connection to the

transmitters were used to collect HR data at a 1-min interval. HR data were analyzed using Polar Precision Performance SW software.

2.3. Crossover experiment

Five wethers grazed a 0.8-ha pasture and five were confined in period 1, and treatments were switched in period 2. The pasture consisted of Sudangrass (*Sorghum bicolor*) planted in the late spring/early summer, and grazing occurred in August and September. The pasture had not been previously grazed and, thus, available forage mass was high (i.e., > 3000 kg/ha). There was a shelter located in the pasture, and trace mineralized salt blocks and fresh water were available on pasture and in confinement. When confined, wethers resided individually in 1.2 × 1.2 m pens under a shelter. Grazing wethers were observed each morning, after which pasture forage similar to that being grazed was harvested by hand and fed at 08:00 h to confined wethers at approximately 110% of consumption on the preceding few days. The composition of forage samples collected daily in week 2 and 3 of each period is shown in Table 2.

The first week of each period was for adaptation to confinement and grazing conditions. In wk 2 of period 1 and wk 3 of period 2, canvas bags were used to collect excreted feces for 5 days. After weighing feces daily, a 10% aliquot sample was saved to form a composite that was kept frozen between and after days of sampling. Samples of the forage and feces were stored frozen at -20° C. Later, forage samples were dried by lyophilization and fecal samples at 55 °C in a forced-air oven. Samples were ground to pass a 1-mm screen and analyzed for DM, ash (AOAC, 2006), nitrogen (Leco TruMac CN, St. Joseph, MI, USA), NDF with use of heat stable amylase (Van Soest et al., 1991) and containing residual ash, ADF, acid detergent insoluble ash (ADIA; filter bag

technique of ANKOM Technology Corp., Fairport, NY), and gross energy using a bomb calorimeter (Parr 6300; Parr Instrument Co., Inc., Moline, IL, USA; AOAC, 2006). Feed intake was based on fecal output and digestibility in confined wethers that was determined from concentrations of ADIA in forage and feces. Intake of ME was determined as 82% of DE intake (NRC, 1984).

In the first few days of wk 3 of period 1 and of wk 2 of period 2, HR was measured for 24 h as described earlier. At the same time, wethers on pasture were fitted with GPS collars (Model 3300SL GPS unit with x-y motion sensors; Lotek Wireless, Newmarket, Ontario, Canada) and an IceTag activity monitor (IceRobotics Limited, Midlothian, Scotland, UK) on the rear left leg. The GPS collars were used to estimate horizontal distance traveled and time the head was in a 'down' position. The 'head down' determination from GPS collars arises from a motion/position sensor. The collars were scheduled to acquire a GPS fix every 5 min. Fixes were downloaded and post-differentially corrected using proprietary software (N4, Lotek Wireless) and base station files from the Perry, OK, USA continuously operating reference station (OKPR, 36°16'34.46428" N, 97°19'17.97610" W). Corrected fixes were then imported into ArcMap 9.3 (ESRI, Redlands, CA, USA). Boundaries of the pasture, including a 7-m external buffer, were constructed as shapefiles using a coordinate system of WGS 1984 UTM 14N. The x and y coordinates in meters were calculated for each fix. Only fixes within the boundary and buffer shapefiles were exported. Distance between consecutive fixes was calculated using Euclidean geometry. The area within the pasture did not markedly vary in elevation; therefore, vertical distance traveled was not computed. Time standing from IceTags encompasses both grazing/eating and non-grazing/eating periods,

and ‘active’ is walking at a relatively fast pace presumably without grazing/eating. Lying time is solely or predominantly without grazing.

Because the minimal schedulable interval between fixes for GPS collars was 5 min, data from IceTags, HR monitors, and GPS collars were averaged at 5-min intervals. During the experiment and when the IceTags and GPS collars were not used to gather experimental data, IceTags and GPS collars were deployed on a random number of wethers. They were visually observed for several hours at different times of the day for several consecutive days in order to develop prediction equations for estimating times spent in the different behaviors. The equations to predict grazing/eating, walking without grazing, resting while lying, and resting while standing were developed using a calibration study and classification tree analysis (Steinberg and Colla, 1997). CART software (Salford Systems, San Diego, CA, USA) was used to construct the classification trees using number of steps and time spent standing, lying, and active from the IceTag units and head-down, x-activity, y-activity, and horizontal distance traveled from the GPS collars as predictor variables; grazing activity was the target variable. The node classification tree developed was outputted to a SAS program, which was used to determine grazing behavior for the experimental data in 5-min intervals.

On the last 4 days of period 1 and of the second week of period 2, two additional estimates of the ratio of HE to HR were determined with a portable calorimetry system (one animal at a time) and HR monitors in stanchions situated next to the pasture and confinement pens. One estimate was for each animal when subjected to the confinement treatment and the other was for grazing. A face-mask positioned on wethers was connected to a FlowKit Mass Flow Generator and FoxBox Respirometry System of Sable

Systems International for measurement of HE from O₂ consumption and CO₂ production without consideration of CH₄ emission or urinary N (Brouwer, 1965). Measures were made with each animal for at least 5 min from 06:00 to 10:00 h, 10:00 to 14:00 h, 14:00 to 18:00, and 18:00 to 22:00 h on day 18, 19, 20, and 21 in period 1 and day 12, 13, and 14 in period 2, respectively. Measures alternated between confined and grazing wethers and the order of wethers selected within treatment was random. There was 15-min period for switching of animals and stabilization of gas exchange.

2.4. Calculations

Because of differences ($P < 0.05$) between periods in digestibilities during confinement and relatively little variability in estimates among animals within periods, period digestibility means (Table 3) were applied to both confined and grazing wethers. HE over 5-min intervals was calculated from HR and the daily averages of HE:HR determined by the first method in the stationary calorimetry system. HE values are expressed in Tables 4 and 5 relative to a 24-h period (i.e., pertinent to a wether engaged in that activity for the entire day) and the actual percentage of the day spent in the activity.

The AEC was calculated three ways. The first is similar to methods described by Beker et al. (2009, 2010) and Tovar-Luna et al. (2011), which is referred to as ‘Partitioning.’ The difference between ME intake and HE is recovered energy (RE). A ME requirement for maintenance (ME_m) of 427 kJ/kg BW^{0.75} was assumed (Sahlu et al., 2004; NRC, 2007). If RE was positive, then forage ME used for gain (ME_g) or tissue energy accretion was calculated based on the AFRC (1998) equation for the efficiency of dietary ME use for gain (k_g) of $k_g = ([0.0423 \times \text{forage ME in MJ/kg DM}] + 0.006)$. HE

used for gain (HE_g) was the difference between ME_g and RE. If RE was negative, then energy used for ME_m from mobilized tissue was assumed equal to $(-1 \times RE)$, assuming that ME from forage and tissue energy were used with the same efficiency (k_m), with k_m estimated based on the AFRC (1998) equation of $k_m = ([0.019 \times \text{forage ME in MJ/kg DM}] + 0.503)$. However, of course the sum of ME_m from the diet and mobilized tissue energy is equal to ME_m with this assumption of the same k_m . The difference between ME intake and the sum of ME_m and ME_g (or ME_m from the diet, ME_m from mobilized tissue energy, and HE_g) was the AEC. In addition, the AEC was calculated assuming a higher k_m of mobilized tissue energy of 0.80 (SCA, 1990).

The second approach of estimating the AEC for grazing ruminants was that of Brosh et al. (2006), referred to as ‘Lying.’ The method is based on time spent in different activities (i.e., lying, standing, grazing, and walking) multiplied by their corresponding HE values and assuming that the AEC resulted from HE when standing, grazing, and walking. Hence, the AEC is based on the degrees to which HE values when standing, grazing, and walking are greater than HE when lying and the lengths of time spent in the activities.

The third AEC method, described by Lachica and Aguilera (2003, 2005), Lachica et al. (2007), and Shinde et al. (1998), is termed ‘Confinement.’ HE by animals when confined is subtracted from values when grazing, preferably with the same animals used in both scenarios as in the present experiment though naturally at different times. The estimates of AEC are expressed relative to different bases, which were total HE while confined for the ‘Confinement’ method, total HE if lying the entire day for ‘Lying’, and the assumed ME_m requirement for ‘Partitioning.’

2.5. *Statistical analyses*

Data were analyzed with mixed effects models using PROC MIXED of SAS (SAS Inst. Inc., Cary, NC, USA; Littell et al., 1996). The three estimates of the ratio of HE:HR (stationary calorimetry system and the portable calorimetry system with wethers grazing and in confinement) were compared, without considering time of measurement, with a model consisting of the fixed effect of method and random effect of animal within method. The model for evaluating effects of time of the day on the ratio of HE:HR measured with the portable calorimetry system contained fixed effects of treatment (grazing and confinement), period, time, and treatment $\times$ time, with a repeated measure of period $\times$ time and random effects of animal and animal within treatment $\times$ period.

Comparisons of activities for wethers when confined (lying vs. standing) and grazing (grazing, lying, standing, and walking) were made with a model consisting of activity and the random effect of animal within activity. Effects of hour of the day on time spent grazing, lying, standing, and walking and time lying and standing and HE by wethers when confined were determined with a model consisting of the repeated measure of time and random effect of animal. Moreover, HE at all hours of the day by wethers when grazing and confined was analyzed with a model including treatment, period, hour, and treatment $\times$ hour, with the repeated measure of period $\times$ hour and random effect of animal within treatment $\times$ period.

Energy variables for the 'Partitioning' method were analyzed with a model containing fixed effects of treatment (confinement and grazing) and period, with period as a repeated measure and random effect of animal within treatment $\times$ period. The three methods of estimating the AEC of wethers while grazing were evaluated with a model

containing method and random effect of animal within method. Because of a significant ($P = 0.001$) Bartlett test for both expressions of the AEC ($\text{kJ/kg BW}^{0.75}$ and % of base values), individual SE are presented. Also, the effect of treatment (confinement vs. grazing) on HE when lying was determined with a model consisting of treatment, the repeated effect of period, and random effect of animal within period $\times$ treatment.

3. Results

3.1. Method of determining HE:HR

There was an effect of time ($P = 0.028$) on the HE:HR ratio determined with the portable calorimetry system but no effects of treatment ($P = 0.173$), period ($P = 0.843$), or treatment $\times$ time ($P = 0.127$). The HE:HR ratio was greatest among periods of time ($P < 0.05$) for 14:00-18:00 h (6.21, 6.28, 6.76, and 6.28 $\text{kJ/kg BW}^{0.75}$ and day per heart beat/min for 06:00-10:00, 10:00-14:00, 14:00-18:00, and 18:00-22:00 h, respectively; SE = 0.196). The average daily ratio of HE:HR was similar ($P = 0.486$) among the three methods of determination, with least square means of 6.41, 6.54, and 6.23 $\text{kJ/kg BW}^{0.75}$ and day per heart beat/min for the stationary calorimetry system, portable system with confined wethers, and portable system with grazing wethers, respectively (SE = 0.180).

3.2. Forage composition and digestibility

Based on composition of forage samples in the two periods (Table 2), lower intake and(or) digestibilities were anticipated in period 2 vs. 1. The differences noted in Table 3 were slightly greater than expected, although measures such as the concentration of ADL and in vitro digestibility would have been useful for most accurate prediction of conditions in vivo.

3.3. *Behavior*

Confined wethers spent 6.5 more hours each day lying than standing ($P < 0.001$; Table 4). On a per unit of time basis, in this case 1 day, standing required more energy than did lying ($P < 0.001$), with a difference of $82 \text{ kJ/kg BW}^{0.75}$ per day. However, the magnitude of difference was greater in the length of time spent lying and standing than in HE per unit of time, such that the daily quantity of energy expended was $94 \text{ kJ/kg BW}^{0.75}$ greater ($P < 0.001$) for lying than standing, which equated to approximately 20% of total HE.

The percentage of the day spent by grazing wethers in different activities ranked ($P < 0.05$) lying > grazing > standing > walking (Table 5). Time spent lying by grazing wethers tended to be lower ($P = 0.071$) than that by confined goats. Numerically, lying by grazing goats required less energy per unit of time than did grazing, standing, or walking, for which values were quite similar. As a result of marked differences among activities in the percentage of the day they occupied and only a tendency for the lowest expenditure of energy per unit of time for lying, percentages of total HE attributable to the four activities were not greatly different than percentages of the day. Lying accounted for approximately 10% less of HE by grazing than confined wethers ($P = 0.083$).

The period when a relatively large majority of time was spent grazing was in the late afternoon and early evening at 17:00 through 19:00 h, with moderate percentages of time grazing at 07:00 through 15:00 h (Figure 1). Even though the study was conducted in the mid- to late summer, there was not a noticeable mid-day period when grazing wethers rested most of the time. Based on time standing by wethers when confined

(Figure 2), it would not appear that time eating was much, if any, greater in the 17:00 to 19:00 h period than during the mid-day.

3.3. *Treatment effects on HE origins*

The difference in ME intake between confined and grazing wethers ($P < 0.001$) was greater than that in HE ($P < 0.001$), resulting in lower RE for grazing vs. confined wethers ($P = 0.011$; Table 6). ME and HE for tissue energy gain were similar between treatments ($P = 0.242$), whereas ME_m from mobilized tissue was greater and that from the diet was less ($P = 0.012$) for grazing vs. confined wethers. Consequently, the AEC was greater for wethers when grazing than confined ($P < 0.001$), with the value for confined wethers not different from 0 ($P = 0.113$). As an example of the impact of one of the assumptions, with use of the k_m for mobilized tissue energy of 0.80 HE for maintenance from the diet was 312 and 233 kJ/kg $BW^{0.75}$ ($SE = 20.1$) and HE from mobilized tissue energy use was 90 and 160 kJ/kg $BW^{0.75}$ ($P = 0.012$; $SE = 19.0$) for confined and grazing wethers, respectively. This resulted in greater AEC than noted above of 57 and 241 kJ/kg $BW^{0.75}$ for confined and grazing wethers ($P < 0.001$; $SE = 23.9$), with the confinement value different from 0 at a P of 0.046.

3.4. *AEC method*

The AEC in kJ/kg $BW^{0.75}$ ranked ($P < 0.05$) ‘Lying’ < ‘Confinement’ < ‘Partitioning’ (Table 7). The ranking relative to the different bases was the same, although the magnitude of difference between ‘Confinement’ and ‘Partitioning’ methods was greater than when expressed as kJ/kg $BW^{0.75}$. HE was greater by wethers when grazing than confined at all times of the day ($P < 0.001$; Figure 3), although the treatment $\times$ hour interaction was significant ($P < 0.001$).

4. Discussion

4.1. Method of determining HE:HR

The similar HE:HR ratio among the three determinations agrees well with previous findings. Puchala et al. (2007, 2009) did not find large effects of the nature of the diet or level of intake on the ratio of HE:HR. A similar ratio for three of the four measurement times with the portable calorimetry system also is in accordance with earlier studies, which indicated advantages from determining the HE:HR ratio over at least 1 day. However, short measurement periods can be used as well if there are multiple determinations to capture potential diurnal changes.

4.2. Forage composition and digestibility

The method of applying averages of energy digestibility for confined wethers to ones while grazing was chosen primarily because of the lack of an adequate method of determining the concentration of the internal marker in DM ingested by wethers when grazing. That is, in some cases grazing ruminants ingest soil high in ADIA that impairs its use as an internal marker (Cochran et al., 1987). Furthermore, it was felt that this method was advantageous to the common approach of using in vitro digestion as a measure of digestion in vivo as well as coupling with an estimate of fecal DM to predict feed intake and digestible nutrient and energy intakes (Weiss, 1994).

4.3. Behavior

The significant difference in daily HE of 82 kJ/kg BW^{0.75} between lying and standing positions for confined wethers presumably reflects that standing encompasses time spent in other activities, namely eating. Likewise, there was a similar difference in daily HE (i.e., 98 kJ/kg BW^{0.75}) between lying and the average of values for grazing,

standing, and walking of grazing wethers. As might be expected, these differences were slightly greater than a daily standing cost of $54 \text{ kJ/kg BW}^{0.75}$ (i.e., 14.4% greater standing than lying) found by Susenbeth et al. (2004) for steers without feed access. Moreover, Susenbeth et al. (2004) reported an average cost for ingestion by cattle of $20 \text{ J/(min per kg BW)}$. Application of this value to findings with grazing wethers yields a daily cost of $25.3 \text{ kJ/kg BW}^{0.75}$, which is intermediate to values of 36.8 and $11.2 \text{ kJ/kg BW}^{0.75}$ derived from differences between grazing vs. lying and standing values, respectively. The former relatively large difference is probably because the estimate of Susenbeth et al. (2004) is attributable only to ingestion, without influence of nutrient absorption, in contrast to grazing in the present experiment. Similarly, the small latter difference could relate to activities goats were engaged in when standing with relatively high HE, such as ones social in nature.

The very substantial amount of time spent lying reflects the considerable importance of HE per unit of time for that activity to total daily HE. Conversely, Brosh et al. (2006) reported much lower lying times of 4.5-8.3 h/day by beef cows in different reproductive states grazing Mediterranean foothill rangeland at two stocking rates in four seasons. Lying times of 5.4-7.1 h were also noted in a later study with similar forage conditions for beef cows in three seasons (Brosh et al., 2010). However, longer periods of time lying of 7.4-10.3 h by beef cattle in the same pasture area were observed by Aharoni et al. (2009, 2013). In most cases lying time for goats while grazing in other studies has been relatively high compared with these cattle estimates, with values of 10.1-10.2 (Animut et al., 2005), 10.1-12.4 h (Tovar-Luna et al., 2011), 7.5-14.7 h (Beker et al., 2009), 7.1-9.3 (Askar et al., 2013), and 10.4-11.8 h (Askar et al., 2015). Although,

Berhan et al. (2005) reported lying times of 8.3, 8.3, and 6.7 h/day for growing Boer × Spanish wethers grazing cool-season forages with 4, 8, and 24 h/day of pasture access, respectively. The relatively large portion of the day spent lying by wethers in the present experiment probably relates to their high stage of maturity and the fairly high nutritive value of the forage.

4.4. Treatment effects on HE origins

With the assumption that the ME_m requirement employed includes an AEC of about 10% of the true requirement, it is not surprising that the AEC for confined wethers was near 0 with k_m set equal for dietary ME and mobilized tissue energy. However, that the value numerically differed from 0 at a P value of 0.113 and was different with the mobilized tissue energy k_m of 0.80 displays how the ‘Partitioning’ method is subject to influences of the specific assumptions employed. Although, this limitation would seem of somewhat lesser concern for comparisons of treatments such as different stocking rates, forage types and stages of maturity, etc. But, appreciable caution may be warranted for treatments affecting energy requirements, an example being different physiological states of the animal.

4.5. AEC method

The primary reason for the relatively low AEC for grazing wethers with the ‘Lying’ method is the lower (P < 0.001) HE while lying per unit of time while confined than when grazing (450 vs. 598 kJ/kg BW^{0.75} per day, SE = 18.1). This is in accordance with postulates of Goetsch and Gipson (2014) based primarily on studies of Patra et al. (2008a,b) in which HE was greater for goats allowed free movement in a pasture compared with ones tethered throughout all periods of the day regardless of activities

animals were engaged in. This is in agreement with differences in HE between grazing and confined wethers during each hour of the day in the present experiment. Thus, it would appear that grazing conditions can influence the AEC by affecting the length of time spent in different activities, primarily lying vs. others, and basal metabolic rate. Nonetheless, the ‘Lying’ method is useful for comparisons of various treatments such as stocking rates (i.e., Brosh et al., 2006), and it has an attribute of not necessitating estimates with confined animals or relying on applications of assumptions of averages and ignoring animal to animal variability. Furthermore, if there is an intent is to express the AEC relative to an estimate of ME_m of animals in confinement that encompasses a relatively low AEC (i.e., NRC, 2007), then the degree to which HE while lying is greater than the assumed ME_m could need to be considered, with the difference perhaps added to the ‘Lying’ AEC estimate.

Factors responsible for the greater AEC estimate with the ‘Partitioning’ than ‘Confinement’ approach cannot be conclusively discerned, but there are a number of probable contributing factors. First, if the ‘Partitioning’ AEC estimate of confined wethers is subtracted from the value for grazing wethers, the product is very similar to the ‘Confinement’ AEC value (i.e., 178 vs. 165 kJ/kg $BW^{0.75}$). The ‘Confinement’ AEC of 39 kJ/kg $BW^{0.75}$, though not different from 0, suggests that one or more of the assumptions used for the ‘Partitioning’ method was not highly accurate or possibly length of adaptation before measurements was not of sufficient length. Relatedly and as alluded to below, perhaps the individual housing of confined wethers in relatively small pens caused a relatively low basal metabolic rate, resulting in a ME_m requirement less than assumed.

As discussed by Goetsch et al. (2010), the greatest challenge in using the ‘Confinement’ method to estimate AEC would be to minimize confounding in conditions such as the composition and level of forage consumed, environmental factors of temperature, humidity, sun exposure, and wind, nutrient requirements as affected by stage of production, etc. Moreover, with measures made on the same animals, more labor, expense, and time would be required compared with the ‘Partitioning’ method. However, based on results of this experiment, it would seem quite beneficial to at least include some ‘Confinement’ determinations to validate reasonableness of assumptions used for the ‘Partitioning’ approach.

5. Conclusions

Averages of short measurements of the HE:HR ratio at different times of the day with a portable calorimetry system near the experimentation site for both confined and grazing wethers were similar to that determined earlier at a different location with a stationary system. HE while lying accounted for 60% of total HE of confined goats because of a difference in the percentage of the day spent lying vs. standing greater than that in HE associated with the activities per unit of time. HE while lying accounted for less HE of grazing than confined wethers (50 vs. 60%) primarily because of the larger percentage of time spent in other activities of grazing, standing, and walking. Estimation of the AEC based on the ‘Lying’ method resulted in lower values compared with the other approaches because of lower HE per unit of time while lying when confined than grazing. Estimates of the AEC with the ‘Confinement’ and ‘Partitioning’ methods were 165 and 217 kJ/kg BW^{0.75}, respectively. Most important factors influencing estimates with the ‘Confinement’ and ‘Partitioning’ methods would be minimization of

438 confounding conditions between confinement and grazing settings and the accuracy of
439 assumptions employed, respectively.

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Table 1

Temperature and humidity during the experimental period

Month	Item	Mean	SE	Minimum	Maximum
August	Mean daily temperature (° C)	27.2	0.45	21.8	31.3
	Minimum daily temperature (° C)	21.7	0.38	17.8	25.8
	Maximum daily temperature (° C)	33.1	0.51	28.3	38.9
	Daily relative humidity (%)	64.9	1.51	47.7	84.1
September	Mean temperature (° C)	24.6	0.60	17.7	28.7
	Minimum temperature (° C)	18.6	0.72	9.4	23.3
	Maximum temperature (° C)	31.3	0.66	22.2	36.1
	Relative humidity (%)	58.8	1.52	43.0	77.4

Table 2

Composition of forage consumed by yearling Boer goat wethers

Item	Fresh forage ¹		Grass hay ²
	Period 1	Period 2	
Ash (% dry matter)	7.8	7.4	6.6
Crude protein (% dry matter)	15.9	13.4	11.0
Neutral detergent fiber (% dry matter)	65.0	67.4	72.5
Acid detergent fiber (% dry matter)	38.0	40.3	34.6
Energy (MJ/kg dry matter)	17.61	18.08	18.38

¹Sudangrass harvested daily consumed by confined wethers.²Grass hay consumed by wethers immediately before the study in the stationary calorimetry system.

Table 3

Feed intake and digestion in confined yearling Boer goat wethers

Item	Period 1		Period 2	
	Mean	SE	Mean	SE
Dry matter				
Intake (g/day)	760	22.3	680	47.8
Intake (g/kg BW ^{0.75})	44.4	1.28	38.3	2.13
Digestion (%)	66.6	1.08	59.5	1.33
Digestion (g/day)	506	17.3	404	25.5
Organic matter				
Intake (g/day)	701	20.6	630	44.3
Digestion (%)	69.3	1.09	61.7	1.36
Digestion (g/day)	486	16.6	387	24.2
Nitrogen				
Intake (g/day)	19.3	0.57	14.6	1.03
Digestion (%)	78.9	0.50	65.9	1.82
Digestion (g/day)	15.3	0.462	9.6	0.69
Neutral detergent fiber				
Intake (g/day)	494	14.5	458	32.2
Digestion (%)	62.4	2.19	53.9	3.47
Digestion (g/day)	308	13.58	245	14.7
Acid detergent fiber				
Intake (g/day)	289	8.5	274	19.3
Digestion (%)	50.4	1.82	41.9	2.54
Digestion (g/day)	145	6.2	115	10.5
Energy				
Intake (MJ/day)	13.96	0.410	12.30	0.865
Intake (kJ/kg BW ^{0.75})	816	23.5	693	38.6
Digestion (%)	67.9	0.95	56.5	1.39
Digestion (MJ/day)	9.49	0.337	6.93	0.442
Digestion (kJ/kg BW ^{0.75})	555	20.1	391	20.4

Table 4

Least squares means for time spent in and heat energy (HE) associated with different positions for confined yearling Boer goat wethers

Item	P value	Position		SE
		Lying	Standing	
% of day	< 0.001	63.5 ^b	36.5 ^a	3.84
HE (kJ/kg BW ^{0.75} on a daily basis) ¹	< 0.001	450 ^a	532 ^b	15.5
Daily HE (kJ/kg BW ^{0.75}) ²	< 0.001	287 ^b	193 ^a	18.9
HE (% of total daily HE)	< 0.001	59.8 ^b	40.2 ^a	3.99

¹HE per unit of time (i.e., if animals spent the entire day in the activity).

²Actual HE for that portion of the day spent in the activity.

Table 5

Least squares means for time spent in and heat energy (HE) associated with different activities for yearling Boer goat wethers while grazing used in estimating the activity energy cost from HE above that when lying

Item	P value	Activity				SE
		Grazing	Lying	Standing	Walking	
% of day	< 0.001	33.8 ^c	53.9 ^d	11.4 ^b	0.9 ^a	2.44
HE (kJ/kg BW ^{0.75} on a daily basis) ¹	0.099	707	598	674	707	23.5
Daily HE (kJ/kg BW ^{0.75}) ²	< 0.001	241 ^c	322 ^d	75 ^b	6 ^a	17.9
HE (% of total daily HE)	<0.001	36.9 ^c	50.1 ^d	12.1 ^b	0.9 ^a	2.56

¹HE per unit of time (i.e., if animals spent the entire day in the activity).

²Actual HE for that portion of the day spent in the activity.

^{a,b,c,d}Means in a row without a common superscript letter differ (P < 0.05).

Table 6

Least squares means of energy measures for confined and grazing yearling Boer goat wethers used in estimating the activity energy cost by subtraction of other sources of heat energy

Item (kJ/kg BW ^{0.75}) ¹	P value	Housing		SE
		Confinement	Grazing	
ME intake	< 0.001	405	484	15.4
HE	< 0.001	482	642	17.2
Recovered energy ²	0.011	-77	-158	21.9
ME for gain ³	0.242	30	3	15.1
HE for gain ³	0.242	16	2	8.3
ME _m from mobilized tissue ⁴	0.012	90	160	19.3
ME _m from the diet ⁴	0.012	337	268	19.3
Activity energy cost ⁵	< 0.001	39	213	21.7

¹HE = heat energy; ME_m = ME used for maintenance.

²Recovered energy = difference between ME intake and HE.

³Based on recovered energy when positive and an efficiency of use of ME for tissue energy gain of $([0.0423 \times \text{forage ME in MJ/kg DM}] + 0.006)$.

⁴Assumed that mobilized tissue energy was used for ME_m (427 kJ/kg BW^{0.75}) with the same efficiency as dietary ME $([0.019 \times \text{forage ME in MJ/kg DM}] + 0.503)$.

⁵Based on the difference between HE and the sum of the ME requirement for maintenance (ME_m) and HE associated with tissue energy gain (with negative recovered energy, the sum of ME from the diet and mobilized tissue equals ME_m).

Table 7

Effects of method of estimating the activity energy cost (AEC) of yearling Boer goat wethers while grazing

AEC expression	P value	Method ¹					
		Confinement		Lying		Partitioning	
		Mean	SE	Mean	SE	Mean	SE
kJ/kg BW ^{0.75}	< 0.001	165 ^b	19.3	46 ^a	4.9	217 ^c	19.7
% of base ²	< 0.001	35.0 ^b	4.8	7.9 ^a	0.98	50.9 ^c	4.6

¹Confinement = the difference in heat energy (HE) of individual animals when grazing and confined; Lying = based on time spent in different activities (i.e., lying, standing, grazing, and walking) multiplied by corresponding HE and assuming that the AEC resulted from HE when standing, grazing, and walking; Partitioning = based on the difference between HE and the sum of the ME requirement for maintenance (ME_m) and HE associated with tissue energy gain (with negative recovered energy, the sum of ME from the diet and mobilized tissue equals ME_m).

²The base was total HE while confined for the Confinement method, total HE if lying 24/day for the Lying method, and the assumed ME_m requirement for the Partitioning method.

^{a,b,c}Means in a row without a common superscript letter differ (P < 0.05).

Figure 1. Effects of hour of the day on time spent grazing, lying, standing, and walking by yearling Boer goat wethers.

Figure 2. Effects of time of the day on time spent lying and standing by confined yearling Boer goat wethers.

Figure 3. Effects of time of the day on heat energy by yearling Boer goat wethers when grazing and confined.