Simple methods to estimate the maintenance feed requirement of small ruminants with different levels of feed restriction

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ABSTRACT
Ten Katahdin (KAT) sheep and 10 Spanish (SPA) goat wethers were used to develop a simple method to estimate dry matter intake (DMI) required for maintenance (DMIm) with feed restriction. Grass hay was fed in a 5-week maintenance phase, initially at 51 and 54 g/kg BW0.75 for KAT and SPA, respectively, and then varied by 0–5% every 2–3 days to maintain constant body weight (BW). Individual wether DMIm was the intercept of regressing DMI against BW change in 2- and 3-day periods of weeks 3 and 4. In the subsequent 8 week, wethers consumed hay at 70% or 55% of their maintenance DMIm. Restricted DMIm was average DMI in week 8 when no individual wether intercept of regressing BW against day differed from 0. Maintenance DMIm was not influenced by animal type (52.0 and 49.6 g/kg BW0.75 for KAT and SPA, respectively; SEM = 0.73). Animal type and restriction level tended (p = .084) to interact in restricted DMIm (34.1, 38.6, 30.7, and 39.0 g/kg BW0.75 for KAT-55%, KAT-70%, SPA-55%, and SPA-70%, respectively; SEM = 1.03), suggesting greater ability of Spanish sheep to less energetically use appreciable feed restriction. Correlation coefficients of 0.89, –0.06, 0.96, and 0.85 (p = .041, .927, .009, and .066, respectively) between DMIm in the two phases for KAT-55, KAT-70, SPA-55, and SPA-70, respectively, suggest preference for the 55% level for evaluating resilience to feed restriction. In conclusion, frequent determinations of BW and DMI can be used to compare DMIm of individual animals with restricted feeding.

1. Introduction
Various methods have been used to estimate quantities of nutrients and energy required for maintenance of ruminant livestock. Approaches of respiration calorimetry and comparative slaughter can be quite costly and are best suited for relatively small numbers of animals, but they do have attributes such as specificity to particular animal and dietary conditions. Meta-analyses like those addressed by Sahlu et al. (2004) also have advantages and disadvantages, including capability of addressing factors requiring large numbers of observations but necessitating broad categorization of potential sources of variation. However, none of these techniques are appropriate for use with large numbers of animals kept under standard and well-controlled conditions or by a wide range of institutions varying in available equipment and infrastructure and personnel training.

There is variability among species and breeds of ruminant livestock in the maintenance energy requirement, as well as among different ecotypes and individuals within ecotypes (NRC 2007). Hence, common nutrient requirement recommendations of various committees cannot reasonably be expected to be highly accurate in all experimental or production settings, necessitating research for adjustments to particular conditions. Diet availability is one factor that may influence not only absolute feed requirements for maintenance but also the ranking of individual animals. The importance of such factors should rise with climate change and expected increases in the length and severity of periods with low feedstuff availability and body weight (BW) loss in many areas of the world, particularly developing countries (Devendra 2012). In this regard, today genomics can be used to predict resilience to adverse environmental conditions, but with need for simple means of characterizing phenotypes of relatively large numbers of animals, optimally at multiple sites within and among different areas of the world. Relatedly, a project is currently underway in which small ruminants from different ecological zones of the USA will be evaluated for resilience to climatic stress factors at one location under standardized conditions. One such characteristic is the ability to minimize energy use with limited feed availability. Concomitant genomics analyses will occur to aid in selection of small ruminants most well suited for expected harsher environmental conditions of the future. Similar projects with small ruminants in other parts of the world would be of interest as well. Therefore, objectives of this study were to develop simple methods to determine feed requirements for maintenance by sheep and goats with different levels of feed restriction.

2. Materials and methods
2.1. Animals and forage
The protocol for the experiment was approved by the Langston University Animal Care and Use Committee. Ten Katahdin (KAT) sheep wethers and ten Spanish (SPA) goat wethers were used.
Initial BW was 30.6 (SEM = 0.40) and 21.8 kg (SEM = 0.27) for KAT and SPA, respectively. Initial age of SPA was 225 days (SEM = 2.5), as they were from a herd of the American Institute for Goat Research of Langston University. KAT sheep were purchased from a local farm, with an exact age unknown but similar to that of SPA according to information supplied by the producer. Initial body condition score (BCS), determined as described by Ngwa et al. (2007); scale of 1 to 5, with 1 very thin and 5 quite obese, was slightly greater (p < 0.01) for KAT vs. SPA (3.05 and 2.90, respectively; SEM = 0.037).

The experiment consisted of a 2-week preliminary period for adaptation to housing conditions followed by sequential 5- and 8-week maintenance and restriction phases, respectively. Wethers were housed individually in 1.05 × 0.55 m elevated pens with a plastic-coated expanded metal floor. A moderate quality grass hay was fed, with concentrations (dry matter (DM) basis) of 10.4% CP, 64.1% NDF, 43.0% ADF, and 55.4% total digestible nutrients (TDNs) based on pre-trial samples of large round bales and analysis by the Oklahoma State University Soil and Forage Testing Laboratory (Stillwater, OK, USA). Samples of this and other available hay sources were analysed to select one of moderate quality for use. Based on visual appearance before harvest, the hay consisted primarily of equal quantities of Johnsongrass (Sorghum halepense) and bermudagrass (Cynodon dactylon) and was coarsely ground through a 3.8-cm screen. Hay was sampled daily during the 13 weeks following the preliminary period to form weekly composite samples, which were analysed for DM, ash, Kjeldahl crude protein (CP; AOAC 2006), neutral detergent fibre (NDF) with use of heat stable amylase and containing residual ash, acid detergent fibre, and acid detergent lignin (filter bag technique of ANKOM Technology Corp., Fairport, NY, USA).

2.2. Preliminary period

At the start of the preliminary period, wethers were vaccinated against clostridial organisms with Covexin 8® (Schering-Plough Animal Health Corp., Omaha, NE, USA) and orally treated for internal parasites with levamisole (Prohibit®, AgriLabs, St. Joseph, MO, USA) at 8 and 12 mg/kg for KAT and SPA, moxidectin (Cydectin®; Boehringer Ingelheim Vetmedica, Inc., St. Joseph, MO, USA) at 0.5 mg/kg, and albendazole (Valbazen®; Pfizer Animal Health, New York, NY, USA) at 10 mg/kg. Albendazole treatment was repeated 24 h later. After the experiment, animals were housed in group confinement pens approximately 2 months before being moved back to the original facility for use in a subsequent experiment. At that time, animals were treated for internal parasites as noted above. At 10 days later, the faecal egg count for all KAT was 0, but the mean for SPA was 1733 (SEM = 383.7; minimum = 200; maximum = 5350), suggestive of some level of internal parasitism of SPA during the present experiment.

Wethers were weighed at the beginning and end of the preliminary period by an animal scale with 50-g increments. The rate of feeding was 120% of an assumed metabolizable energy (ME) requirement for maintenance (ME\textsubscript{m}) without feed restriction of 51 and 54 g/kg BW\textsuperscript{0.75} for KAT and SPA, respectively, based on an assumed hay ME concentration of 8.37 MJ/kg DM estimated from the level of TDN noted earlier, the ME\textsubscript{m} requirement of growing indigenous goats of Sahlu et al. (2004) and NRC (2007), the NRC (2007) mature sheep ME\textsubscript{m} estimate without adjustment for age, and the relative difference in ME\textsubscript{m} between growing and mature goats. Hay was offered once daily at 08:00 h after refusals were collected and weighed. A small amount (8–10 g/day; as fed basis) of a mixture of 95% soybean meal and 5% of a trace mineral premix (275 mg/kg Co, 2000 mg/kg I, 43,746 mg/kg Fe, 750 mg/kg Se, 18,748 mg/kg Cu, 68,744 mg/kg Zn, and 19,998 mg/kg Mn) was top-dressed on hay. Also, each wether had free access to a small trace mineralized salt block (NaCl: 96.5–99.5%; Zn: 4000 ppm; Fe: 1600 ppm; Mn: 1200 ppm; Cu: 260–390 ppm; I: 100 ppm; and Co: 40 ppm) in the bottom of each feeder.

Wethers were moved to an adjacent room in the facility with an indirect open-circuit calorimetry system in sets of four. Heat energy (HE) and heart rate (HR) were determined as in other studies (Puchala et al. 2007, 2009) for approximately 24 h to derive the ratio of HE to HR for multiplication by HR estimated in subsequent phases to predict HE. Oxygen consumption and production of CO\textsubscript{2} and CH\textsubscript{4} were determined by an indirect open-circuit respiration calorimetry system (Sable Systems, Henderson, NV, USA) with four head boxes situated in metabolism cages in a caloriometry room. HE was based on the Brouwer (1965) equation without consideration of urinary N excretion. The ratio of HE:HR was greater (p = 0.001) for KAT vs. SPA (6.70 and 5.84 kJ/kg BW\textsuperscript{0.75} per heart beat/min; SEM = 0.161).

2.3. Maintenance phase

During this phase to estimate the DM intake (DMI) requirement for maintenance (DMI\textsubscript{m}) of each wether without feed restriction and in the subsequent phase with restriction, wethers were weighed at 13:00 h on each Monday, Wednesday, and Friday, with weeks starting on Monday. Thus, weighing intervals were 2, 2, and 3 days. The initial level of feeding was based on the assumed ME\textsubscript{m} requirement and BW at the beginning of the phase. On days after weighing, for some wethers there were small adjustments in feed offered in the one daily meal at 08:00 h. The amount of hay fed was varied by up to 5% (i.e. 10–40 g) for the 2 or 3 days after weighing beginning on the next day (i.e. with weighing on Monday, a change in offered feed may have occurred on Tuesday). The maximum total number of changes in offered feed for one animal was seven (six increases and one decrease) and the minimum was one for two animals (increases). The most that feed offered differed between the beginning and end of the phase was 100 g, and for one animal the final amount was the same as the initial, but with three increases and three decreases. The intent of changes in offered feed was so that intake would be near DMI\textsubscript{m} to maintain constant BW. Refusals when present were removed and weighed.

In the middle of each week, on 2 days two or three wethers of each breed × level of feed restriction treatment, described later (five KAT and five SPA each day), were fitted with HR monitoring units for approximately 24 h. As noted earlier, HR was multiplied by HE:HR to estimate daily HE.

Various methods were considered and evaluated for estimating DMI\textsubscript{m} of each wether. One procedure that was used to...
evaluate periods of time within the 5-week maintenance phase when BW was stable was segmented polynomial regression analysis. BWs were first smoothed using LOWESS, a non-parametric, polynomial regression procedure (Cleveland 1979). Smoothing data assist in estimating parameters of the segmented polynomial when data are few or ‘noisy’ (Gipson et al. 1990). Smoothed data were fitted to a segmented polynomial with the middle segment constrained to a flat line. Regression coefficients of the first and third segments and the two join points were estimated using non-linear regression. The average of the first and second join points was 16 and 28 days, respectively, indicating BW stability between these times. The method ultimately selected involved regression by the General Linear Models (GLM) procedure of SAS (2004) of DMI by individual wethers against average daily gain (ADG) in 2- and 3-day periods in different week groupings (i.e. 2–5, 3–5, 2–3, 2–4, 3–4, and 4–5). The only groupings without an intercept for a wether different from 0 \( (p > 0.10) \) were weeks 2–5 and 3–4. The weeks 3–4 grouping was chosen because of the segmented polynomial regression analysis noted earlier, desire to minimize length of the maintenance phase, and a view that 2 weeks of adaptation would be preferable to 1 week because of potential differences in previous nutritional plane. Hence, the intercept of week 3–4 regressions was used as the DMI\(_m\) estimate. Homogeneity of variance for KAT and SPA was evaluated with the BARTLETT option of SAS (2004). The ME\(_m\) requirement in kilojoules with a level of intake near the maintenance requirement was estimated assuming the hay ME concentration of 8.37 MJ/kg DM. Estimates of HE determined from HR and the HE:HR ratio for each animal in week 3 and 4 were averaged. Maintenance requirements based on the BW and HR methods were compared by the GLM procedure of SAS (2004) with a model consisting of animal type, method, and their interaction.

### 2.4. Restriction phase

Five wethers of each type had been previously randomly assigned to levels of offered feed 55% and 70% of their estimated DMI\(_m\). During this phase, hay was given in two equal-sized meals at 07:00 and 15:00 h, with the trace mineral supplement top-dressed in the afternoon. BW and HR were determined as noted before.

The overall general pattern of change in BW was somewhat unexpected based on the results of Helal et al. (2011), resulting in a slightly different method of estimating DMI\(_m\) with feed restriction than initially assumed. The method employed was similar to that in the maintenance phase, with evaluation of 1-week segments as well as longer ones. The GLM procedure

| Table 1. Composition of grass hay consumed by KAT sheep and SPA goat wethers. |
|-----------------|--------|-----|
| Item            | % DM   | SEM |
| Ash             | 8.6    | 0.05|
| CP              | 7.8    | 0.20|
| NDF             | 69.5   | 0.39|
| Acid detergent fibre | 41.5  | 0.49|
| Acid detergent lignin | 8.1  | 0.22|

Note: 15 weekly composite samples formed from samples collected daily (two preliminary period, five maintenance phase, and eight restriction phase).

Figure 1. Daily dry matter offered (DMO) and intake (DMI) by KAT sheep and SPA goat wethers during the 5-week maintenance phase to estimate the feed requirement for maintenance with feed offered near the maintenance requirement.

Figure 2. BW during the 5-week maintenance phase to determine the feed requirement for maintenance with feed offered near the maintenance requirement. Panel A: KAT sheep wethers. Panel B: SPA goat wethers.
was used to regress BW against day within week groupings. Only the week-8 grouping yielded equations for all wethers with a slope not different from 0 ($p > .10$). Thus, average DMI during week 8 served as the DMIm requirement with restricted feed intake. As in the maintenance phase, the BW and HR methods of estimating the maintenance DMIm, but here with restricted feed allowances, were compared. The GLM model consisted of level of restriction, animal type, method, and the two- and three-way interactions.

### 3. Results

#### 3.1. Hay composition

The composition of hay fed during the experiment (Table 1) was slightly different than of the sample taken before the experiment, reflecting a slightly lower quality. For example, the level of CP was 2.6 percentage units lower and that of NDF was 5.4 percentage units greater during than before the experiment. Nonetheless, the average estimates of DMIm were not greatly different than those initially assumed based on projections of TDN and ME concentrations derived from initial composition values.

#### 3.2. Maintenance phase

The amount of hay refused by KAT was small relative to SPA (Figure 1), which was caused by 2 of the 10 SPA wethers. Mean BW was relatively stable for both KAT and SPA as day of the phase advanced, with similar small changes from one day of weighing to the next for both animal types (Figure 2).

Because of the objective to develop procedures for estimation of DMIm of individual animals, it was felt desirable to present some data for individual animals in addition to treatment means and SE. In this regard, there were two SPA with a SE of the maintenance DMIm estimate considerably greater than for the others, which were the wethers refusing relatively high quantities of hay (Table 2). Variability was homogeneous between breeds ($p = .867$), although the intercept SE averaged 6.0 and 12.9 g for KAT and SPA, respectively. As expected, the DMIm estimate was the same or very similar to mean DMI of each wether in weeks 3 and 4.

Means of maintenance DM and ME intakes relative to BW$^{0.75}$ were similar between animal types and methods of determination (i.e., BW vs. HR; Table 3). The $p$ value of the interaction between animal type and method was .164, with KAT values based on BW numerically greater than those for HR (i.e. difference of 2.2 g/kg BW$^{0.75}$) compared with more similar values for SPA (i.e. 49.6 and 50.5 g/kg BW$^{0.75}$ for BW and HR methods, respectively). Estimate variation was homogenous for each animal type ($p = .190$) but not for the two methods ($p = .033$), with SE of 0.58 and 0.96 for BW and HR means, respectively.

#### 3.3. Restriction

There were considerable decreases in BW for KAT in the first week of the restriction phase, particularly for the 55% restriction

### Table 2. Equations for the linear regression of DMI against ADG of individual animals in weeks 3 and 4 of the maintenance phase with feed consumption varied near the maintenance requirement for constant BW$^a$.

| Breed  | Animal | Intercept (g/day) | Slope (g/day) | $R^2$ | Mean DMI |
|--------|--------|-------------------|---------------|-------|----------|
|        |        | Estimate          | SEM           | Estimate | SEM | $p$ value$^b$ |       |
| Katahdin | 130    | 645               | 6.0           | 0.027   | 0.022 | .293 | .217 | 643    |
| Katahdin | 131    | 599               | 5.3           | 0.020   | 0.040 | .644 | .046 | 598    |
| Katahdin | 132    | 648               | 12.7          | −0.012  | 0.057 | .842 | .009 | 649    |
| Katahdin | 133    | 615               | 5.0           | −0.002  | 0.010 | .886 | .005 | 615    |
| Katahdin | 134    | 675               | 2.3           | 0.010   | 0.011 | .414 | .137 | 675    |
| Katahdin | 135    | 666               | 3.2           | −0.017  | 0.012 | .222 | .280 | 667    |
| Katahdin | 136    | 729               | 5.9           | 0.019   | 0.025 | .475 | .106 | 728    |
| Katahdin | 138    | 646               | 5.6           | −0.008  | 0.012 | .558 | .073 | 647    |
| Katahdin | 140    | 709               | 5.4           | −0.008  | 0.016 | .636 | .048 | 709    |
| Katahdin | 141    | 654               | 2.8           | 0.005   | 0.007 | .599 | .161 | 653    |
| Spanish | 503    | 439               | 28.5          | 0.035   | 0.130 | .800 | .014 | 435    |
| Spanish | 5031   | 521               | 5.9           | 0.008   | 0.026 | .776 | .018 | 521    |
| Spanish | 5054   | 498               | 10.1          | 0.003   | 0.117 | .979 | <.001 | 498    |
| Spanish | 5056   | 480               | 29.1          | 0.124   | 0.209 | .578 | .066 | 469    |
| Spanish | 5060   | 517               | 4.3           | 0.011   | 0.016 | .540 | .079 | 516    |
| Spanish | 5065   | 499               | 3.0           | −0.004  | 0.016 | .821 | .011 | 500    |
| Spanish | 5066   | 465               | 8.7           | 0.036   | 0.043 | .443 | .122 | 463    |
| Spanish | 5068   | 468               | 9.8           | 0.075   | 0.078 | .384 | .154 | 465    |
| Spanish | 5085   | 510               | 8.9           | 0.121   | 0.067 | .130 | .396 | 508    |
| Spanish | 5091   | 480               | 8.2           | 0.005   | 0.049 | .924 | .002 | 480    |

aIntervals of 2 or 3 days in length.

b$p$ values for difference from 0.

### Table 3. Estimates of feed required for maintenance, with feed consumption varied near the maintenance requirement for constant BW based on BW and HE determined from HR and the HE:HR ratio.

| Item                  | KAT sheep | SPA goats | SEM | Breed | Method | Interaction |
|-----------------------|-----------|-----------|-----|-------|--------|-------------|
| DM intake (g/day)     | 659       | 630       | 14.4 | <.001 | .498   | .201        |
| Maintenance DM intake (g/kg BW$^{0.75}$) | 52.0 | 49.8 | 49.6 | 50.5 | 14.1 | .425 | .539 | .164 |
| Maintenance ME intake (kJ/kg BW$^{0.75}$) | 436 | 417 | 415 | 422 | 9.3 | .425 | .539 | .164 |

Note: DM – dry matter; ME – metabolizable energy.
level (Figure 3, panels A and B; Table 4). This was also true for SPA in terms of a relatively large proportion of total BW loss in week 1, but the magnitude of change was similar between 55% and 70% restriction levels (Figure 3, panels C and D). In accordance, for the repeated measures analysis of weekly average BW loss starting in week 2 relative to initial BW, p values were .089, <.001, .009, <.001, .046, <.001, and .958 for animal type, restriction level, animal type x restriction level, week, animal type x week, restriction level x week, and animal type x restriction level x week, respectively. The animal type x restriction level interaction in BW loss relative to initial BW was significant (p < .04) in each week (Table 4). In accordance with interactions noted above for the repeated measures analysis, BW loss increased more as time advanced for the 55 vs. 70% restriction level and for SPA vs. KAT, although numerically the animal type difference was due relatively more to the 70 than 55% restriction level.

There were some wethers with p values of the slope of the regression of BW against day of week 8 less than .25, with a lowest value of .098 (Table 5). Many means of BW in week 8 were very similar to the regression intercept, but some were appreciably different (e.g. maximum differences of 3.7 and 3.9 kg for KAT and SPA, respectively).

Average BW in week 8 was greater for KAT vs. SPA and for the 70 than 55% restriction level (p < .02; Table 6). The animal type x restriction level interaction approached significance (p = .084), with a numerically greater difference between restriction levels for KAT than for SPA.

The DMI_m estimate in gram/day of 55.1%, 67.8%, 54.5%, and 70.9% of that during the maintenance phase for KAT-55%, KAT-70%, SPA-55%, and SPA-70%, respectively, were near targets (Table 6). For DMI_m expressed relative to BW^{0.75}, the animal type x restriction level interaction again approached significance (p = .080). That is, numerically, SPA were able to decrease the amount of feed required for maintenance (i.e. 3.4 g/kg BW^{0.75}) more than KAT with the more severe feed restriction level of 55%, and with the moderate level of 70% the extent of change was similar between animal types. Another way of viewing this is in regard to feeding rates at the start of the restriction phase of 29.2, 37.2, 27.6, and 35.9 g/kg BW^{0.75} (SEM = 0.07) for KAT-55%, KAT-70%, SPA-55%, and SPA-70%, respectively. Thus, there were differences (i.e. increases) between week-8 and initial values of 4.9, 1.4, 3.1, and 3.1 g/kg BW^{0.75} and 17, 4, 11, and 9% for KAT-55%, KAT-70%, SPA-55%, and SPA-70%, respectively (SEM = 2.5). Also, even though variation was homogenous for animal type (p = .405), restriction level (p = .892), and animal type x restriction level (p = .470), numerically the difference between highest and lowest values was greatest for KAT-70% (5.1, 8.4, 5.2, and 4.2 g/kg BW^{0.75} for KAT-55%, KAT-70%, SPA-55%, and SPA-70%, respectively).

There was a moderate correlation (p = .028) between DMI_m relative to BW^{0.75} in maintenance and restriction phases (Table 7). There was not a correlation for KAT, though a significant relationship did exist for SPA (p = .027). Similarly, there was a correlation for the 55% restriction level (p < .001) but not 70%. This was true for KAT as well, but in addition to the high correlation coefficient for SPA with the 55% restriction level, a slightly lower correlation coefficient occurred with the 70% level that tended to be significant (p = .066).

Figure 3. BW of individual wethers during the 8-week restriction phase to determine the feed requirement for maintenance with feed restriction. Panel A: KAT sheep and 55% of intake near the maintenance requirement without feed restriction. Panel B: KAT sheep and 70% of intake near the maintenance requirement without feed restriction. Panel C: SPA goats and 55% of intake near the maintenance requirement without feed restriction. Panel D: SPA goats and 70% of intake near the maintenance requirement without feed restriction.
For the analysis addressing method of estimating DMI\textsubscript{m} in gram/day during the restriction phase, there were effects (\(p < .001\)) of animal type, restriction level, and method, with a tendency for an interaction between restriction level and method (\(p = .089\); Table 8). However, for DM and ME intakes relative to BW\textsuperscript{0.75}, there were interactions between restriction level and method (\(p = .018\)). DMI\textsubscript{m} was similar between methods with the 70% restriction level but less for the BW vs. HR method (\(p < .05\)) with the 55% level.

### 4. Discussion

#### 4.1. Maintenance phase

The high SE of the DMI\textsubscript{m} estimate for the two SPA wethers with relatively high amounts of refused hay indicates an importance of minimizing orts. There may have been inadvertent inadequate attention given to this aspect in the present experiment, with perhaps excessive focus on changes in the quantity of offered feed alone based on BW. The similarity of the maintenance DMI estimate and the simple mean of daily DMI in weeks 3 and 4 suggests that either method could be used; however, the former could be preferable to reflect any non-significant trend in BW change.

Less variability in the DMI\textsubscript{m} estimate based on the BW than HR method probably involves factors such as more frequent measurement of BW, the regression approach for the BW method vs. the simple mean of DMI during weeks 3 and 4 for HR, and employment of individual wether HE:HR determined in the preliminary period with the HR method, and suggests preference for (or an advantage of) the estimate based on BW. However, HR is a more appropriate indicator of ME\textsubscript{m} during relatively short periods or at specific points in time particularly when BW is changing, albeit with a need to estimate ME intake to establish its similarity to HE (Brosh 2007). The ME intake requirement for maintenance in kJ/kg BW\textsuperscript{0.75} is presented only to establish similarity to common recommendations, such as of NRC (2007). For use of ME rather than DM intake, it would be necessary to estimate metabolizability, preferably with the same individual animals, that would also be required at different levels of feed restriction and with consideration of the length of time of intake restriction. Conversely, interest in developing a simple model or method of determination with intake both near maintenance and restricted was for comparing phenotypes of large numbers of animals, with a desirability of including impact on DMI\textsubscript{m} estimates of individual animal variability in both efficiency of ME usage and metabolizability. Thus, absolute values in kJ of ME were not viewed.

### Table 4. BW loss by KAT sheep and SPA goat wethers in different weeks of the feed restriction phase\textsuperscript{a} as a percentage of initial BW.

| Week\textsuperscript{b} | 55% | 70% | 55% | 70% | Breed | Restriction | Interaction |
|--------------------------|-----|-----|-----|-----|-------|------------|-------------|
| 2                        | 13.2\textsuperscript{a} | 7.0\textsuperscript{a} | 7.6\textsuperscript{a} | 7.4\textsuperscript{a} | .97 | .016 | .005 | .007 |
| 3                        | 13.4\textsuperscript{a} | 6.5\textsuperscript{a} | 7.8\textsuperscript{a} | 7.5\textsuperscript{a} | 1.07 | .048 | .004 | .008 |
| 4                        | 13.4\textsuperscript{a} | 6.3\textsuperscript{a} | 8.2\textsuperscript{a} | 7.4\textsuperscript{a} | 1.03 | .064 | .001 | .007 |
| 5                        | 15.3\textsuperscript{a} | 6.6\textsuperscript{a} | 9.9\textsuperscript{a} | 8.1\textsuperscript{a} | 1.18 | .119 | .005 | .010 |
| 6                        | 15.6\textsuperscript{a} | 7.1\textsuperscript{a} | 11.3\textsuperscript{a} | 8.8\textsuperscript{a} | 1.14 | .287 | <.001 | .019 |
| 7                        | 16.8\textsuperscript{a} | 8.3\textsuperscript{a} | 12.3\textsuperscript{a} | 9.4\textsuperscript{a} | 1.24 | .128 | <.001 | .038 |
| 8                        | 18.4\textsuperscript{a} | 8.7\textsuperscript{a} | 13.4\textsuperscript{a} | 10.6\textsuperscript{a} | 1.34 | .267 | <.001 | .022 |

\textsuperscript{a}Feeding levels were 55% and 70% of feed required for maintenance of each wether based on frequent small changes in feeding levels for constant BW in an earlier phase.

\textsuperscript{b}Average BW was determined on day 0, 2, 4, and 7 of each week.

\textsuperscript{c,d,e}Means in a row without a common superscript letter differ (\(p < .05\)).

### Table 5. Equations for the linear regression of BW (kg) against day of week 8 of the feed restriction period\textsuperscript{a}.

| Animal type | Restriction\textsuperscript{b} | Animal | Intercept (kg) | Slope (kg) | p value\textsuperscript{c} | R\textsuperscript{2} | Mean BW |
|-------------|-------------------------------|--------|----------------|------------|---------------------------|----------------|---------|
| Katahdin    | 70                            | 130    | 29.0           | 1.59       | -.056                     | .0033          | .208    |
|             | 70                            | 131    | 24.0           | 1.28       | -.014                     | .0244          | .635    |
|             | 55                            | 132    | 27.0           | 3.50       | -.071                     | .0670          | .398    |
|             | 55                            | 133    | 23.9           | 3.25       | -.007                     | .0621          | .926    |
|             | 70                            | 134    | 29.8           | 3.66       | -.049                     | .0699          | .587    |
|             | 55                            | 135    | 25.9           | 1.28       | -.030                     | .0245          | .341    |
|             | 55                            | 136    | 22.6           | 1.37       | .049                      | .0262          | .205    |
|             | 70                            | 138    | 27.0           | 1.34       | -.013                     | .0254          | .656    |
|             | 70                            | 140    | 29.8           | 0.74       | -.042                     | .0141          | .098    |
|             | 55                            | 141    | 23.7           | 2.61       | -.043                     | .0500          | .484    |
|             | 55                            | 503    | 16.2           | 1.35       | .025                      | .0257          | .430    |
|             | 55                            | 5031   | 16.1           | 2.95       | .075                      | .0564          | .316    |
|             | 5054                          | 18.8   | 0.46           | .018       | .0088                     | .179           | .675    |
|             | 5056                          | 20.1   | 2.55           | -.036      | .0487                     | .534           | .219    |
|             | 5060                          | 17.8   | 2.07           | .021       | .0396                     | .655           | .119    |
|             | 5065                          | 16.4   | 1.28           | .014       | .0244                     | .635           | .133    |
|             | 5066                          | 20.5   | 1.98           | -.064      | .0379                     | .236           | .584    |
|             | 5068                          | 16.5   | 3.68           | .018       | .0703                     | .824           | .031    |
|             | 5085                          | 17.7   | 1.48           | -.013      | .0282                     | .699           | .091    |
|             | 5091                          | 17.8   | 1.13           | -.002      | .0216                     | .939           | .004    |

\textsuperscript{a}Intervals of 2 or 3 days in length.

\textsuperscript{b}Feeding levels were 55% and 70% of feed required for maintenance of each wether based on frequent small changes in feeding levels for constant BW in an earlier phase.

\textsuperscript{c}p values for difference from 0.
as highly important. Moreover, a moderate quality grass hay diet, rather than one higher in quality such as containing considerable concentrate feedstuffs, was used to best simulate most common conditions under which reproducing female small ruminants are raised around the world. Although, this approach could incur some differences among batches of forage in quality greater than with common concentrate feedstuffs, but that could be partially addressed to avoid confounding by including one or more animals of all types in sets undergoing measurements at the same time. Moreover, determining ME concentration of different forage batches under standard conditions would be useful for comparing animals of different sets on a ME basis.

### 4.2. Restriction phase

A pattern of decrease in BW fairly similar to that reported by Helal et al. (2011) was expected, which entailed a gradual rather than a marked decrease in BW in the first few weeks of restriction and a lesser rate of decline as time advanced until stabilization in the last segment of the phase. Exactly why patterns in the present experiment were somewhat disparate is unclear but presumably involves differences in conditions such as animal age, level of feeding before restriction, initial body condition, etc.

It would be preferable to base the restriction phase estimate of DMIm on a period longer than 1 week. This is exemplified by a few p values for the slope of the regression of BW against day of week 8 less than .25 though greater than .05 and some wethers with mean BW values fairly different than the regression intercept. Relately, extending the restriction phase longer than 8 weeks was considered, but stable BW during that week and a desire to avoid individual wether BW loss greater than 20–25% of initial BW were precluding factors. However, with the relationship between BW change and BCS noted by Ngwa et al. (2007), it would not appear that BCS of many if any of the wethers would have declined more than approximately 1 unit or were less than a score of 2 on a 1–5 scale.

### Table 6. BW and DMI required for maintenance (DMIm) in week 8 of the feed restriction phasea for treatments and individual KAT sheep and SPA goats.

| Item | Animala | KAT sheep | SPA goats | p values |
|------|----------|-----------|-----------|---------|
| BW (kg) | Mean  | 23.5  | 26.2  | 17.5  | 18.4  | 0.60  | <.001 | .014 | .884 |
| 131, 130, 503, 503 | 23.3 | 26.1 | 17.5 | 20.1 |
| 132, 133, 5056, 5054 | 23.3 | 23.6 | 18.2 | 19.8 |
| 135, 134, 5060, 5065 | 24.3 | 27.5 | 18.9 | 17.1 |
| 136, 138, 5068, 5066 | 25.1 | 26.3 | 17.5 | 17.2 |
| 141, 140, 5085, 5091 | 21.4 | 27.7 | 17.0 | 17.2 |
| DMI (g/kg BW0.75) | Mean | 32.4 | 39.7 | 38.8 | 41.5 | 0.92 | 39.0 | 37.2 | 0.65 | <.001 | <.001 | .381 |
| 131, 130, 503, 503 | 32.6 | 43.5 | 32.6 | 31.1 | 0.80 | <.001 | <.001 | .487 | .425 | .089 | .590 |
| 132, 133, 5056, 5054 | 33.2 | 38.8 | 34.7 | 34.7 | 0.92 | 39.0 | 37.2 | 0.65 | <.001 | <.001 | .381 |
| 135, 134, 5060, 5065 | 37.7 | 32.6 | 31.1 | 5.4 | <.001 | <.001 | .228 | .715 | .018 | .381 |
| 136, 138, 5068, 5066 | 31.7 | 32.6 | 31.1 | 5.4 | <.001 | <.001 | .228 | .715 | .018 | .381 |
| 141, 140, 5085, 5091 | 21.6 | 27.7 | 17.0 | 17.2 | <.001 | <.001 | .381 |
| DMI (g/day) | Mean | 315 | 385 | 396 | 426 | 11.3 | 435 | 326 | 8.0 | <.001 | <.001 | .381 |
| 131, 130, 503, 503 | 313 | 385 | 396 | 426 | 11.3 | 435 | 326 | 8.0 | <.001 | <.001 | .381 |
| 132, 133, 5056, 5054 | 324 | 39.7 | 38.8 | 41.5 | 0.92 | 39.0 | 37.2 | 0.65 | <.001 | <.001 | .381 |
| 135, 134, 5060, 5065 | 37.7 | 32.6 | 31.1 | 5.4 | <.001 | <.001 | .228 | .715 | .018 | .381 |
| 136, 138, 5068, 5066 | 31.7 | 32.6 | 31.1 | 5.4 | <.001 | <.001 | .228 | .715 | .018 | .381 |
| 141, 140, 5085, 5091 | 21.6 | 27.7 | 17.0 | 17.2 | <.001 | <.001 | .381 |

*aFeeding levels were 55% and 70% of feed required for maintenance of each wether based on frequent small changes in feeding levels for constant BW in an earlier phase.

*bThe order of animals is that listed for breed × restriction level means.

*cInitial DMI relative to BW at the start of the restriction phase was 29.2, 37.2, 27.6, and 35.9 g/kg BW0.75 for KAT-55%, KAT-70%, SPA-55%, and SPA-70%, respectively (SEM = .072).

### Table 7. Correlation between DMI required for maintenance relative to BW0.75 during maintenance and restriction phases based on the BW method.

| Observations | n | Correlation coefficient | p value |
|--------------|---|------------------------|---------|
| All          | 20 | .49                    | .028    |
| KAT sheep    | 10 | .21                    | .565    |
| SPA goats    | 10 | .69                    | .027    |
| 55% restriction level | 10 | .95                    | <.001   |
| 70% restriction level | 10 | .16                    | .669    |
| KAT sheep, 55% restriction level | 5 | .89                    | .041    |
| KAT sheep, 70% restriction level | 5 | .06                    | .927    |
| SPA goats, 55% restriction level | 5 | .96                    | .009    |
| SPA goats, 70% restriction level | 5 | .85                    | .066    |

Note: Feeding levels were 55% and 70% of feed required for maintenance of each wether based on frequent small changes in feeding levels for constant BW in an earlier phase.

4.2. Restriction phase

A pattern of decrease in BW fairly similar to that reported by Helal et al. (2011) was expected, which entailed a gradual rather than a marked decrease in BW in the first few weeks of restriction and a lesser rate of decline as time advanced until stabilization in the last segment of the phase. Exactly why patterns in the present experiment were somewhat disparate is unclear but presumably involves differences in conditions such as animal age, level of feeding before restriction, initial body condition, etc.

It would be preferable to base the restriction phase estimate of DMIm on a period longer than 1 week. This is exemplified by a few p values for the slope of the regression of BW against day of week 8 less than .25 though greater than .05 and some wethers with mean BW values fairly different than the regression intercept. Relately, extending the restriction phase longer than 8 weeks was considered, but stable BW during that week and a desire to avoid individual wether BW loss greater than 20–25% of initial BW were precluding factors. However, with the relationship between BW change and BCS noted by Ngwa et al. (2007), it would not appear that BCS of many if any of the wethers would have declined more than approximately 1 unit or were less than a score of 2 on a 1–5 scale.
The relationships between DMI_{m} relative to BW^{0.75} in maintenance and restriction phases for different groupings of observations support a benefit from use of a greater level of restriction such as 55% compared with 70%. A greater magnitude of change in HE arising from metabolism of all tissues, more consistent change in HE among tissues making major contributions to the total, or a greater number of tissues incurring change in metabolism with the 55% than 70% restriction level may have been factors responsible for the former difference. Furthermore, the animal type difference in the relationship could relate to the tendency for a greater difference in DMI_{m} between 55% than 70% restriction levels for SPA compared with KAT.

Although a primary interest of this experiment was not to compare the two animal types, other than in regard to potential use of the same study model, it would appear that with an appreciable feed restriction level such as 55%, SPA have an ability to incur less BW loss and, thus, decrease energy used for maintenance to a greater extent than KAT. This agrees with findings of Asmare et al. (2011, 2012) that suggested less ability of Rambouillet sheep wethers to decrease extra-splanchnic tissue energy use than Boer or SPA goat wethers.

It would seem reasonable to expect that the presumed greater level of internal parasitism in SPA than KAT influenced DMI_{m} during both maintenance and restriction phases, though possibly to a greater extent during the latter phase assuming impact of feed restriction on the immune response. However, that DMI_{m} of the maintenance phase was slightly greater for KAT and lower for SPA than initially assumed does not imply a substantial effect, such as considerable in HE arising from metabolism of all tissues, more consistent change in HE among tissues making major contributions to the total, or a greater number of tissues incurring change in metabolism with the 55% than 70% restriction level may have been factors responsible for the former difference. Furthermore, the animal type difference in the relationship could relate to the tendency for a greater difference in DMI_{m} between 55% than 70% restriction levels for SPA compared with KAT.

5. Conclusion

The methods addressing feed requirements for maintenance based on BW and DMI seem preferable to use of HR under these conditions, particularly with the greatest level of feed restriction. In this regard, after 2 weeks of adaptation, frequent weighing and change in offered feed for 2 weeks may offer a relatively simple means of estimating maintenance feed needs of small ruminants. Likewise, average feed intake during part of a restriction phase when BW is stable provides a method for assessing the ability of individual animals to decrease energy used for maintenance that could be widely used. The relevant segment of time in the restriction phase of this experiment was week 8, although a longer period such as 2 weeks would be preferable. Based on the tendency for a greater amount of feed used for maintenance of KAT with the 55% vs. 70% level of restriction and similar values for SPA, the 55% level would seem most appropriate for evaluating differences among individual animals as well as various animal types.

Disclosure statement

No potential conflict of interest was reported by the authors.

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