Energy requirements for the maintenance and growth of Dorper-Jinzhong crossbred ram lambs

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ABSTRACT
The sheep industry in China has been rapidly developing in recent years; however, the animals’ nutritional requirements under certain conditions have not been thoroughly defined. The objective of this study was to investigate the energy requirements of both the maintenance and growth of Dorper-Jinzhong crossbred ram lambs. Thirty 1/2 Dorper × 1/2 Jinzhong crossed F1 ram lambs (35 ± 0.5 kg of body weight, BW) were randomly selected and divided into five groups in a randomised design for a comparative slaughter trial. The lambs were offered one type of feed at 100%, 65% and 40% of the ad libitum intake. Another 15 lambs were used for the digestibility trial to estimate the metabolisable energy (ME) values of the diet at various feed intake levels. The net energy for maintenance (NEm) and the ME requirement for maintenance (MEm) were 286.68 kJ/kg0.75 of SBW and 437.80 kJ/kg0.75 of SBW, respectively; the energy efficiency for maintenance (kM) was 0.655. The net energy for growth (NEg) values for varying average daily gain (100–350 g) in ram lambs grown from 35 to 50 kg increased from 1.31 to 5.93 MJ/d with an energy efficiency for growth (kg) of 0.457. Our results suggest that the energy requirements of Dorper-Jinzhong crossbred ram lambs are lower than the requirements recommended by the National Research Council (NRC) and Agricultural and Food Research Council (AFRC).

Introduction
In recent years, lamb production has substantially increased in several parts of the world due to the increasing consumption of mutton (Morris 2009). The high production cost in the lamb industry warrants precise nutrient supply monitoring to measure animal energy requirements. The Dorper breed of sheep is a fast-growing meat-producing sheep originated from South Africa, and is renowned for its hardiness, early sexually maturity, lean carcass and high growth rate. The breed has been widely used as a terminal sire breed to improve the growth performance and carcass traits of lambs (Zhang et al. 2013; Xing et al. 2014). The Jinzhong breed is an indigenous sheep breed that demonstrates strong adaptability to local conditions in Shanxi province, China. Dorper sheep have recently been introduced in Shanxi to crossbreed with Jinzhong sheep, and this crossbreed is now dominant for lamb production in Shanxi. However, the production efficiency of this crossbreed is lower than those in developed countries. One of the primary causes may be a lack of precise knowledge regarding the animals’ energy and nutrient requirements, which limits the development of a more efficient feeding system.

Energy requirements and nutrient utilisation vary with age, breed, sex, physiological status, management and environmental conditions (CSIRO 2007). Moreover, energy and nutrient requirements are affected by genetic selection and crossbreeding (Fernandes et al. 2007). The most commonly used guidelines to formulate diets for lamb production are currently based on recommendations from both the NRC (2007) and AFRC (1993) and do not take into account these differences. A recent study of Dorper crossed ewe lambs suggested that both the net energy (NE) and metabolisable energy (ME) requirements are lower than those recommended by the NRC (Deng et al. 2014). Therefore, an assessment of the nutritional requirements of Dorper or Jinzhong crossed sheep is necessary to maximise lamb production efficiency in Shanxi province. The objective of this study was to investigate the energy requirements for the maintenance and growth
of Dorper-Jinzhong crossbred ram lambs using the comparative slaughter technique.

Materials and methods

Comparative slaughter trial

All animal procedures were approved by the Shanxi Agricultural University Animal Care and Ethics Committee. A total of 30 1/2 Dorper × 1/2 Jinzhong crossed ram lambs (35 ± 0.5 kg) were randomly selected. The lambs were placed in individual stalls (3.0 m × 0.8 m) equipped with feeders and a water source and were injected with ivermectin at a dosage of 0.2 mg/kg of body weight (BW) to eliminate parasites. Prior to the experiment, the ram lambs were fasted for 16 h, and their shrunk body weight (SBW) was recorded immediately after the fast. After being anesthetised via CO2 inhalation, the animals were exsanguinated, and the weights of the blood, carcass, head, feet, hide, wool, viscera and adipose tissue (removed from internal organs) were recorded. The gastrointestinal tract, including the oesophagus, rumen, reticulum, omasum, abomasum and small and large intestine, was weighed prior to and after the removal of the contents. The carcass and head were split longitudinally into two identical halves; the right half of the carcass, head, and anterior and posterior feet were dissected into muscle, bone, and fat. Each part was fully ground with a bone grinder, and a 500-g sample was stored at −20°C for further analysis. Wool samples were taken.

Digestibility trial

A total of 15 crossed lambs were assigned to three groups in a randomised design according to the same DMI as the comparative slaughter trial to measure the digestibility of the energy. All lambs were housed in individual metabolism cages, and deworming and feeding management were the same as those in the slaughter trial. The digestibility trial began when the BW of 15 lambs reached 43 kg and lasted for 20 days, including 10 days of adaptation and 10 days for data and sample collection.

The offered feed, remaining feed and faeces were collected, weighed, homogenised and sampled (10% of total weight) each day in the morning. All samples were oven-dried at 65°C for at least 72 h, ground to pass through a 1-mm screen and stored at −20°C for further use. The urine was collected daily in buckets containing 100 mL of 7.2 N H2SO4 for urinary N analysis. After collection, the total volume was measured and diluted to 5 L (the sample was not diluted if the volume was over 5 L); the liquid was sampled (20 mL)
and stored at −20 °C for further analysis. Finally, all samples were pooled to form a composite sample for each animal.

CH4 production was measured using an open-circuit respirometry system (Sable Systems International, Las Vegas, NV). Prior to the experiment, the animals were trained for confinement in head boxes attached to the metabolism cages. The lambs from the digestibility assays were moved to the metabolism cages equipped with head boxes for the CH4 output assessments. Prior to the measurements, the animals underwent 24 h of adaptation. The CH4 analyser was calibrated with nitrogen gas (99.999%, Beijing APBAIF Gases Industry Co. Ltd., Beijing, China) and a reference gas mixture (0.3% CH4 in nitrogen gas, Beijing APBAIF Gases Industry Co. Ltd., Beijing, China). The CH4 measurements were performed as previously described (Tovar-Luna et al. 2007) with minor modifications: a 2-min analysis of ambient air as a reference and a 2-min re-calibration to the head box air, followed by an 8-min analysis of the head box air, a 2-min re-calibration to ambient air, and, finally, a 2-min analysis of the ambient air as a reference. The measurements were performed over a total of 24 h. The CH4, O2 and CO2 concentrations, temperature, humidity, dew point and air flow rate through the head boxes were recorded and processed using software from Sable Systems for the CH4 production calculations. The energy of CH4 production was calculated by multiplying the CH4 volume by 39.54 kJ/L.

Sample analysis

The feed, orts and faeces were dried at 105 °C at least 8 h for dry mass (DM) analysis using the procedure described by AOAC (1990). Ash was obtained via complete combustion in a muffle furnace at 600 °C for 6 h. The total nitrogen (N) was measured using the Kjeldahl method, and the ether extract (EE) was determined via extraction in petroleum ether in a Soxhlet apparatus for 6 h. Neutral detergent fibre (NDF) was analysed according to a previously described method (Van Soest et al. 1991). The gross energy (GE) was measured using a bomb calorimeter (C200, IKA Works Inc., Staufen, Germany); the urine total N levels were determined using the Kjeldahl method. For the urine GE measurement, 10 mL of the urine sample was absorbed using filter paper, oven-dried at 55 °C, and then measured in a bomb calorimeter. Additionally, the GE of the filter paper was also determined. The urinary GE was calculated by subtracting the value of the absorbed filter paper from that of the original filter paper.

The DM content of each body component, with the exception of the wool, was obtained by lyophilising 100 g of each initial sample for 72 h. Afterward, the ash, N and GE levels of these components were determined as described above. For the EE content, each body component sample was extracted in petroleum ether for at least 24 h, and the EE was determined as described above. The DM, ash, N, EE and GE levels of the wool were also analysed as above.

Data calculation

The energy value of the diet was calculated based on data from the digestibility trial. The digestible energy (DE) was calculated by subtracting the faecal energy from the GE intake. The ME of the diet was calculated by subtracting the urinary energy and CH4 energy from the DE. Energy of body components was calculated by multiplying weight of samples (muscle, fat, skeleton, blood + viscera, fur skin and hair) with individual energy unit, which was determined by oxygen bomb calorimeter. Body energy (BE) content was calculated as a sum of joule value of all body components. The initial BE of baseline animals was the BE of lambs ad libitum in group A.

For intermediate and final slaughter groups, initial BE was calculated through regression equation developed between BE content and empty body weight (EBW) of baseline animals. The initial EBWs of intermediate and final slaughter groups were calculated according the regression equation between EBW and BW (Equation is shown in Table 2). Retained energy (RE) was calculated as a difference between the final and initial BE contents.

Heat production (HP, kJ/kg0.75 of SBW) was calculated as the difference between the ME intake (MEI, kJ/kg0.75 of SBW) and the RE (kJ/kg0.75 of SBW). The NE requirement for maintenance (NEm, kJ/kg0.75 of SBW) was estimated using the antilog of the linear regression intercept for the log HP and MEI (Lofgreen & Garrett 1968).

Table 2. Predicted equations for the EBW and initial BE.

| Equations | r² | RMSE | p |
|-----------|----|------|---|
| EBW, kg = 0.781(±0.0032) x BW, kg | 0.99 | 0.1031 | <0.01 |
| SBW, kg = −11.761(±2.324) + [1.2964(±0.0664) x BW, kg] | 0.99 | 0.0449 | <0.01 |
| log IE, MJ = 1.677(±0.0039) x log EBW, kg | 0.99 | 0.0051 | <0.01 |

EBW: empty body weight; BW: body weight; SBW: shrunk body weight; IE: initial body energy.
The ME requirement for maintenance (ME$_{r_m}$, kJ/kg$^{0.75}$ of SBW) was calculated using an iteration of the semi-log linear regression equation until the HP was equal to the MEI (Galvani et al. 2008). The efficiency of ME utilisation for maintenance ($k_m$) was computed as NE$_{r_m}$/ME$_{r_m}$. The BE of different BWs was estimated from linear regression between the log of BE and the log of EBW$^{0.75}$ in *ad libitum* group A, B, C. Requirements for NE for growth (NE$_g$) were calculated as the difference between energy content of the empty body at different intervals of EBW. The slope of the regression of RE for the MEI above maintenance (MEIg) was assumed to be the partial efficiency of energy utilisation for growth ($k_g$), and the ME requirement for growth (ME$_g$, kJ/kg$^{0.75}$ of BW) was computed as NE$_g$/k$_g$.

**Statistical analysis**

The statistical analysis was performed using SAS 9.0 (SAS Institute Inc., Cary, NC). Each animal was considered an experimental unit, and the data were expressed as the means ± SEM. The food intake, energy content, body composition, growth rate and organ weight were analysed using PROC ANOVA and the model was $y_{ij} = \mu + a_i + e_{ij}$, where $y_{ij}$ is the observed value, $\mu$ is the overall constant value, $a_i$ is fixed effect of treatment and $e_{ij}$ is random error. Tukey's honestly significant difference was used for the post hoc analyses. Linear regressions were performed using PROC REG. Observations with a studentised residual $>2.5$ or $<-2.5$ were considered to be outliers. The assumptions of the models, in terms of homoscedasticity, independency, and normality of the errors, were examined by plotting residuals against predicted values. $p < 0.05$ was considered to be statistically significant in all data.

**Results**

**Growth, slaughter performance and internal organ development according to energy level in lambs**

As shown in Table 3, the initial BWs of the three groups were the same ($p = 0.68$), whereas the final BW was significantly decreased by feed restriction (*ad libitum* $>65\% >40\%$). The net weight gain in the *ad libitum* group was higher than the other two groups ($p = 0.015$). The lambs fed *ad libitum* exhibited greater daily gains ($p < 0.05$) than those fed with both restricted diets, and the lambs fed with the 65% restricted diet had a greater average daily gain (ADG) than those in the 40% restricted feed intake group.

| Table 3. Effect of various feeding levels on the growth, slaughter performance, and internal organ weight of Dorper-Jinzhong crossed ram lambs. |
|---------------------------------|---------|---------|---------|---------|---------|
| Item                           | AL     | 65%     | 40%     | SEM     | p       |
| No. of lambs                   | 6      | 6       | 6       | –       | –       |
| Initial BW, kg                 | 35.31  | 35.06   | 34.94   | 0.12    | 0.68    |
| Final BW, kg                   | 50.64$^a$ | 43.00$^b$ | 36.03$^c$ | 0.55    | <0.01   |
| Net gain, kg                   | 15.33$^a$ | 7.94$^b$   | 1.29$^c$  | 0.51    | 0.02    |
| Average daily gain, g          | 338.20$^a$ | 169.10$^b$ | 28.99$^c$  | 18.86   | 0.02    |
| Dry matter intake, g/d         | 1,892.00$^a$ | 1,193.00$^b$ | 790.80$^c$  | 31.13   | <0.01   |
| Feed: gain, g/g                | 7.55$^a$  | 7.20$^b$   | 24.40$^c$  | 2.11    | <0.01   |
| SBW, kg                        | 47.42$^a$  | 41.06$^b$   | 34.52$^c$  | 0.63    | <0.01   |
| EBW, kg                        | 41.23$^a$  | 34.28$^b$   | 29.36$^c$  | 0.54    | <0.01   |
| Carcass, kg                    | 23.38$^a$  | 19.79$^b$   | 17.21$^c$  | 0.41    | <0.01   |
| Dressing percentage, %         | 49.30   | 48.23   | 49.85   | 0.66    | 0.04    |
| Meat weight, kg                | 19.98$^a$  | 16.73$^b$   | 14.45$^c$  | 0.44    | <0.01   |
| Meat percentage, %             | 42.12   | 40.76   | 41.82   | 0.74    | 0.41    |
| Ratio of bone to meat, g/g      | 0.18    | 0.19    | 0.20    | 0.10    | 0.43    |
| Visceral fat weight, g          | 1,423.00$^{a,b}$ | 1,047.00$^{a,b}$ | 876.70$^b$  | 133.49   | 0.03    |
| Visceral fat percentage, %     | 6.07    | 5.23    | 5.07    | 0.60    | 0.47    |
| Heart, g                       | 198.42$^a$  | 156.63$^b$   | 151.65$^c$  | 6.56    | <0.01   |
| Liver, g                       | 774.23$^a$  | 507.14$^b$   | 429.67$^c$  | 15.71   | <0.01   |
| Kidney, g                      | 115.72$^a$  | 96.06$^b$   | 78.14$^c$  | 3.83    | <0.01   |
| Lung and weasand, g            | 528.53$^a$  | 451.91$^b$   | 393.28$^c$  | 11.83   | <0.01   |
| Spleen, g                      | 89.59$^a$  | 78.59$^b$   | 49.99$^b$  | 9.40    | 0.03    |
| Gastrointestinal tract, g      | 2,957.00$^a$ | 2,280.00$^b$ | 1,925.00$^c$  | 58.66   | <0.01   |
| Oesophagus, g                  | 116.00$^a$  | 92.68$^b$   | 77.33$^c$  | 5.53    | <0.01   |
| Rumen, g                       | 927.00$^a$  | 660.72$^b$   | 525.37$^c$  | 36.13   | <0.01   |
| Reticulum, g                   | 139.91$^a$  | 119.54$^b$   | 102.48$^c$  | 5.32    | <0.01   |
| Omasum, g                      | 125.74$^a$  | 115.29$^b$   | 85.37$^c$  | 6.81    | <0.01   |
| Abomasum, g                    | 207.23$^a$  | 152.36$^b$   | 141.02$^b$  | 11.93   | <0.01   |
| Small intestine, g             | 834.23$^a$  | 672.44$^b$   | 537.95$^c$  | 25.82   | <0.01   |
| Large intestine, g             | 607.41$^a$  | 466.38$^b$   | 455.94$^a$  | 21.09   | <0.01   |

AL: *ad libitum*; 65%: 65% of the *ad libitum* feed intake; 40%: 40% of the *ad libitum* feed intake; BW: body weight; SBW: shrunk body weight; EBW: empty body weight.

$^{a,b,c}$The values within a row with different superscripts are significantly different.
The DM intake was decreased with a decreasing feed intake. The lambs in the 40% feed intake group had a higher \((p < 0.05)\) ratio of food intake to weight gain than the other groups.

The slaughter performances were calculated based on the comparative slaughter trial. The data in Table 3 show that the slaughter body weight, EBW, carcass weight and meat weight in the three groups exhibited the same pattern of changes \((ad \text{ libitum} > 65\% > 40\%, p < 0.0001)\). The lambs fed \(ad \text{ libitum}\) deposited more visceral fat than the other groups \((p < 0.05)\). There were no differences in the dressing percentage, net meat percentage, ratio of bone to meat or visceral fat percentage between the three groups \((p > 0.05)\).

The internal organs were weighed after slaughter. The weights of the liver, kidney, lung, weasand, rumen and small intestine were significantly decreased in the lambs in the restricted feed groups \((p < 0.0001)\). The weights of the heart, oesophagus, abomasum, large intestine and reticulum in the \(ad \text{ libitum}\) group were significantly higher than those in the other groups. The weights of the spleen and omasum were decreased in the 40% feed restricted group compared with the other groups. The relative weight of each internal organ (ratio of the organ weight to the EBW, data not shown) was also calculated; the relative weights of the rumen and liver were decreased when the animals were fed a restricted diet compared with the \(ad \text{ libitum}\) group (no difference between the restricted groups). The relative weights of the other organs were not influenced by feed intake.

**Digestibility and metabolisability of dietary energy**

As shown in Table 4, the GE, faecal energy, methane energy, DE and ME varied according to feed intake and linearly declined with a reduction in feed intake \((p < 0.0001)\). However, there were no differences between the groups regarding urinary energy. The digestibility \((\text{DE}/\text{GE})\) tended to decrease with feed restriction \((P = 0.065)\), and the metabolisability \((\text{ME}/\text{GE})\) value of the diet was not affected by feed intake.

**Energy requirements for maintenance**

The relationship between HP and MEI is shown in Figure 1: \(\log (\text{HP}) = 2.4574(\pm 0.0187) + [0.00042(\pm 0.000025) \times \text{MEI}]\), \(R^2 = 0.9283, p < 0.001\). The antilog of the intercept of this regression was the \(\text{NE}_m\) value for the lambs, which was 286.68 kJ/kg\(^{0.75}\) of SBW. The \(\text{ME}_m\) was also calculated based on the above regression equation, and the value was 437.80 kJ/kg\(^{0.75}\) of SBW. The \(k_m\) \((\text{NE}_m/\text{ME}_m)\) was calculated as 0.655.

**Energy requirements for growth**

As shown in Table 5, allometric equations including the EBW and body components were constructed to predict the water, protein, fat and energy retained in

| Table 4. Energy metabolism and energy balance of the animals on the \(ad \text{ libitum}\) or 65% or 40% of the \(ad \text{ libitum}\) intake diets in the digestibility trial. |
|---------------------|----------|----------|----------|--------|----------|
| Item                | Level of intake | AL       | 65%      | 40%      | SEM     | \(p\)     |
| GE intake, kJ/kg BW\(^{0.75}\)\/d | 1726.43\(a\) | 1242.74\(a\) | 782.48\(a\)  | 27.05  | <0.01   |
| Faecal energy, kJ/kg BW\(^{0.75}\)\/d | 813.72\(a\)  | 530.36\(b\)  | 313.33\(b\)  | 25.28  | <0.01   |
| Urinary energy, kJ/kg BW\(^{0.75}\)\/d | 28.42   | 32.37   | 31.08   | 2.66    | 0.55      |
| Methane energy, kJ/kg BW\(^{0.75}\)\/d | 128.36\(a\) | 87.14\(b\) | 62.91\(b\) | 2.76    | <0.01   |
| DE, MJ/kg DM         | 9.64    | 10.43   | 10.91   | 0.46    | 0.07      |
| ME, MJ/kg DM         | 7.98    | 8.68    | 8.72    | 0.47    | 0.27      |
| DE/GE, %             | 52.96   | 57.31   | 59.92   | 1.49    | 0.07      |
| ME/GE, %             | 43.85   | 47.68   | 47.91   | 1.51    | 0.27      |
| ME/DE, %             | 82.82   | 83.14   | 79.83   | 0.70    | 0.21      |

**AL:** \(ad \text{ libitum}\); 65%: 65% of the \(ad \text{ libitum}\) feed intake; 40%: 40% of the \(ad \text{ libitum}\) feed intake; GE: gross energy; BW: body weight; DE: digestible energy; ME: metabolisable energy.

\(a,b\): The values within a row with different superscripts are significantly different.
EBW: empty body weight; BW: body weight; SBW: shrunk body weight; BP: body protein; BE: body energy.

Table 5. Regression equations used to estimate the body composition and RE in Dorper-Jinzhong crossed ram lambs.

| Equation | \( r^2 \) | RMSE | \( p \) |
|----------|----------|------|-------|
| \( EBW, kg = -3.049(±1.717) + [0.8788(±0.03955)\times BW, kg] \) | 0.9686 | 1.075 | <0.01 |
| \( EBW, kg = -5.592(±1.354) + [0.9902(±0.03296)\times SBW, kg] \) | 0.9826 | 0.8008 | <0.01 |
| Log water, g = 3.0465(±0.1043) + [0.8154(±0.06791)\times log EBW, kg] | 0.9001 | 0.0212 | <0.01 |
| Log BP, g = 2.7660(±0.06299) + [0.6647(±0.04101)\times log EBW, kg] | 0.9426 | 0.0128 | <0.01 |
| Log fat, g = 0.5628(±0.2610) + [0.1307(±0.1680)\times log EW, kg] | 0.9253 | 0.0429 | <0.01 |
| Log BE, MJ/\( kg = 1.66(±0.0007) - \log EBW, kg \) | 0.99 | 0.044 | <0.01 |

EBW: empty body weight; BW: body weight; SBW: shrunk body weight; BP: body protein; BE: body energy.

Table 6. Body composition of the Dorper-Jinzhong crossed ram lambs from 35 to 50 kg.

| BW (kg) | 35 | 40 | 45 | 50 |
|---------|----|----|----|----|
| BW, kg | 27.71 | 32.10 | 36.50 | 40.89 |
| Water, g/EBW | 601.58 | 585.45 | 571.75 | 559.88 |
| Body protein, g/EBW | 191.55 | 182.33 | 174.65 | 168.12 |
| Body fat, g/EBW | 156.31 | 184.61 | 213.43 | 242.70 |
| Body energy, MJ/EBW | 8.96 | 9.87 | 10.74 | 11.58 |

BW: body weight; EBW: empty body weight.

Table 7. NE and ME requirements for growth in Dorper-Jinzhong crossed ram lambs.

| ADG (g) | 35 | 40 | 45 | 50 |
|---------|----|----|----|----|
| NE\(_g\) | 100 | 1.31 | 1.44 | 1.57 | 1.69 |
| 200 | 2.62 | 2.88 | 3.14 | 3.38 |
| 300 | 3.93 | 4.33 | 4.71 | 5.08 |
| 350 | 4.59 | 5.06 | 5.50 | 5.93 |
| ME\(_g\) | 100 | 2.86 | 3.15 | 3.43 | 3.70 |
| 200 | 5.73 | 6.31 | 6.87 | 7.40 |
| 300 | 8.60 | 9.48 | 10.31 | 11.11 |
| 350 | 10.04 | 11.06 | 12.04 | 12.97 |

ADG: average daily gain; BW: body weight; NE\(_g\): net energy requirement for growth; ME\(_g\): metabolisable energy requirement for growth.

Discussion

Efficient lamb production depends on precise knowledge of their energy and nutrient requirements. The guidelines of the NRC (2007) and AFRC (1993) are usually used to formulate the diets of lambs and to evaluate feeding programs under different conditions. Lambs grow and mature at different rates (Malhado et al. 2009), thus, the current criteria likely either under- or overestimate the energy requirements of Dorper-Jinzhong crossbreeds. According to previous reports, the energy requirements recommended by different nutritional systems are not always consistent (Dawson & Steen 1998; Galvani et al. 2008). In the current study, we determined the energy requirements of Dorper-Jinzhong crossbred ram lambs to provide recommendations for lamb production in China.

The diet of the current study was formulated according to the NRC’s (2007) recommendations, and the ADG in the ad libitum group was 338 g/d, which exceeded our expected ADG (300 g/d). The ADG in the 40% restricted group was also higher than expected. These discrepancies may also suggest that the current recommended nutritional requirements slightly overestimates the energy requirements of Dorper-Jinzhong crossbred lambs in Shanxi province.

Although the SBW, EBW, visceral fat, carcass weight and meat weight were decreased with reduced feed intake, the dressing percentage, meat percentage and visceral fat rate did not change, suggesting that lamb production performance was constant over a particular range of body weights. Additionally, the ratio of bone to meat increased in the feed-restricted groups, which
may be due to a higher priority of increasing bone density than skeletal muscle during growth (Sayer & Cooper 2005). The lambs’ organ weights were compared after slaughter. As expected, the restricted feed intake diet decreased the weights of all of the organs. The relative organ weights (organ weight/EBW) were also compared. Interestingly, only the relative weights of the rumen and liver were influenced by feed restriction, which may be due to the important role of the rumen in feed fermentation and the liver in metabolism. Therefore, higher feed intake could more effectively stimulate the development of rumen and liver compared with lower feed intake.

According to a previous study, methane was produced from both the sheep rumen and hind gut, and 89% of the methane produced by the hind gut was absorbed into the blood and excreted through the lungs (Murray et al. 1976), indicating that nearly all of the total methane emissions can be measured using head boxes. Our study utilised head boxes; methane emissions were significantly decreased by feed restriction, which agreed with a previous report (Deng et al. 2012). Methane energy accounted for 7.4% of the GE in our study, which was greater than that in a previous study (Deng et al. 2012). The MEm value in our study was 22% lower than the value (560 kJ/kg0.75 of SBW) recommended by NRC (2007), and this recommended value from NRC is out of our confidence interval (278.1 kJ/kg0.75 of BW to 282.1 kJ/kg0.75 of BW).

The MEm was 437.8 kJ/kg0.75 of SBW, which was 14.9% and 8.9% greater than the results from the Texel (381 kJ/kg0.75 of SBW) and Dorper crossbred lambs (402 kJ/kg0.75 of SBW), respectively (Galvani et al. 2008; Deng et al. 2012). The MEm value in our study was 22% lower than the value (560 kJ/kg0.75 of SBW) recommended by NRC (2007), and this recommended value from NRC is out of our confidence interval (426.4 kJ/kg0.75 of SBW to 444.9 kJ/kg0.75 of SBW). The variability of MEm was mainly due to genotype, age, physiological state and environmental conditions (CSIRO 2007). The partial efficiency of use of MEm for NEm (kEm NEm/MEm) was 0.655 in the present study, which was lower than the values reported for Dorper crossbred lambs and Santa Ines lambs (Deng et al. 2012; Regadas Filho et al. 2013; Silva et al. 2003) and higher than those reported for tropical lambs and Texel crossbred lambs (Galvani et al. 2008). This kEm value is higher than the constant value (0.644) recommended by the NRC (2007). AFRC (1993) proposed an equation for kEm calculation: kEm = 0.35 × qm + 0.503, where qm is the diet metabolisability (ME/GE). Based on this equation, the kEm value would be 0.666, which was higher than our kEm. The kEm values from both NRC and AFRC are out of our 95% confidence interval (0.644–0.666).

The allometric equations assessing the EBW and body components revealed that the water content decreased and the energy and fat contents increased as the lambs grew from 35 to 50 kg SBW, which is in agreement with previous observations in both sheep and goats (Galvani et al. 2008; Regadas Filho et al. 2013; Deng et al. 2014). This result may indicate that the increased BE of lambs in the 35–50 kg SBW stage is primarily due to fat deposits.

NEg is affected by both growth rates and energy contents of weight gain. AFRC (1993) proposes two equations to calculate NEg for male lambs: NEg (MJ/d) = ADG, kg × EVg (energy value for gain), and EVg (MJ/kg) = 2.5 + 0.35 BW. Based on the above two equations, NEg for male lambs of 35 kg gaining varying ADG (100–350 g) in our study are 1.48, 2.95, 4.43 and 5.08 MJ/d, respectively; these values are about 13% higher than the equivalent values (1.31, 2.62, 3.93 and 4.59 MJ/d) obtained in our study, and are out of our
confidence intervals (1.31–1.32 for 100 g, 2.62–2.65 for 200 g, 3.93–3.98 for 300 g and 4.59–4.95 for 350 g).

Moreover, NEg values in our study are about 25% less than the NRC recommendations for early maturing lambs. Therefore, the NEg requirements estimated for the varying ADGs are lower than the corresponding values predicted by both the AFRC (1993) and the NRC (2007) in our study. The $k_g$ indicates the efficiency of utilisation of ME above maintenance for growth. Both AFRC (1993) and NRC (2007) proposed equations (AFRC, $k_g = 0.78q_m + 0.006$ and NRC, $k_g = (1.42 \times ME - 0.147 \times ME^2 + 0.0122 \times ME^3 - 1.65)$ to predict $k_g$. Using the above two equations, the $k_g$ values would estimate to be 0.36 and 0.3, which are 78.8% and 65.6% of that value in our study, and these values are out of 95% confidence interval of our $k_g$ (0.451–0.461).

Conclusions

In summary, we determined the energy requirements of Dorper-Jinzhong crossbred ram lambs using the comparative slaughter technique, and our data indicated that energy requirements were lower than those recommended by both the NRC and AFRC. The NEm requirement was 286.68 kJ/kg0.75 of SBW, and the MEM requirement was 437.8 kJ/kg0.75 of SBW. The NEg values for ADG from 100 to 350 g ranged from 1.31 to 5.93 MJ/d, respectively. Our data may facilitate the formulation of appropriate diets in the lamb production industry.

Disclosure statement

The authors declare no conflicts of interest.

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