# Breeding for sustainability: Effect of breed on cultural energy expenditure of lamb production

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**ABSTRACT**: Two-year data from terminal study conducted to evaluate post-weaning growth and carcass traits of Texel, Suffolk and Columbia sired offspring were used to evaluate the effect of breed on cultural energy expenditure of lamb production. Each year whiteface ewes ($n$ = 82) composed of primarily Polypay × Dorset ewes were exposed to Texel, Suffolk or Columbia rams for 35 days in the breeding season. The ewes were wintered outdoors on average-quality lucerne hay according to NRC (1985) requirements and were not provided any concentrate during late gestation or lactation. A total of 279 lambs were born with an average of 1.7 lambs per ewe and weaned lambs were used in the study. The lambs were weaned on average at 70 days of age and lambs from each sire breed were placed either in feedlot or on pasture. Texel and Suffolk sired lambs had higher weaning weight than Columbia sired lambs ($P$ < 0.01). Lambs in the feedlot were fed shelled maize and pelleted protein supplement. Lambs on pasture grazed for 63 days and received 455 g concentrate daily and later they were placed in the feedlot. For the cultural energy analysis, pasture establishment and maintenance, feed in feedlot and on pasture, transportation, labour, machinery, electricity and other inputs were calculated and corresponding values for each input were obtained from literature. It was assumed for the analysis that 20 percent of ewes were culled and lambs sold after weaning were included in the analysis. Texel and Columbia breeds had a higher energy input per kg live weight than Suffolk breed ($P$ < 0.04). There was no difference between breeds in terms of energy input per kg carcass ($P$ > 0.4). Suffolk breed had a lower cultural energy ratio for the protein energy output than Columbia and Texel breed ($P$ < 0.02). Energy output ratio defined as kjoule input/kjoule output was better for Suffolk breed and it was different from that of Columbia and Texel breed ($P$ < 0.03).

**Keywords**: cultural energy; sustainability; breed, sheep; Texel; Columbia; Suffolk

Due to health concerns, consumers demand leaner meat (Haley, 2001; Putnam and Allshouse, 2001), and thus meeting the consumer demand for less fat is challenging for the sheep industry. Beermann et al. (1995) reported that in the United States only less than 30% of market lambs processed into meat met requirements for leanness and muscling as specified in the "Certified Lean American Lamb" program established in 1990 by the American Sheep Industry Association. The production of leaner lambs demanded by consumers could be achieved either by introduction of new sheep breeds in terminal sire breeding programs (Latif and Owen, 1980; Croston et al., 1987; Leymaster and Jenkins, 1993; Ellis et al., 1997) or by feeding programs (Murphy et al., 1994; McClure et al., 1995). However when introducing a new breed, sustainability of the production should be considered. Sustainable agriculture defined as the management and conservation of the resource base and the orientation of technological and institutional changes in such a manner that the attainment and continued satisfaction of human needs for present and future generations will be ensured (FAO, 1991) has been a subject of great interest and ongoing debate in animal agriculture (Heitschmidt et al., 1996). Sustainability has gained a great importance due to an increase in the population and energy demand. The world population is increasing at a growth rate of 1.3% whereas the energy use is projected to increase at a rate of 2.2% from 1995 to 2015 (International Energy Annual, 1995; PRB, 2004). The application of energy output/input ratios is one of the most useful methods to examine the potential long-term sustainability of various agricultural practices and this analysis is performed to quantify the energy return from products produced relative to the cultural energy invested to produce the product (Heitschmidt et al., 1996). The objective of this study was to conduct a cultural energy analysis of Texel, Suffolk and Columbia crossbred lambs placed directly in the feedlot at weaning or left on pasture following weaning and later placed in the feedlot for finishing.

## MATERIAL AND METHODS

**Feeding and Management**. Whiteface ewes composed of primarily Polypay × Dorset crosses were maintained in south central Iowa at the McNay Research Farm, in Chariton. Two to six years old ewes were used to minimize the effect of dam age. Ewes were exposed to Texel, Suffolk or Columbia rams for two 35-day breeding seasons. Ewes were all treated in the same manner both before and after breeding. The ewes were wintered outdoors on average-quality lucerne hay fed at a level to meet their NRC (1985) requirements. The ewes were not fed any concentrate during late gestation or lactation.

In early May, ewes were turned out onto grass pastures after being treated for internal and external parasites. A total of 6.07 ha of pre-dominantly cool season grass pasture was subdivided into five 1.21-ha paddocks. A two-wire electric fence was used to subdivide paddocks within an eleven-wire high tensile electrified perimeter fence. Ewes were rapidly rotated through these paddocks initially to stagger grass growth. All paddocks had their water source as fixed concrete or portable tanks with limi-

Table 1. Chemical and nutrient analysis of shelled maize and protein supplement[a]

| Nutrients | Shelled maize | | Protein supplement | |
|---|---|---|---|---|
| | As fed | Anhydrous | As fed | Anhydrous |
| DM (%) | 86 | 100 | 88.50 | 100 |
| Nitrogen (%) | 1.15 | 1.34 | 6.91 | 7.81 |
| Protein (%) | 7.18 | 8.35 | 43.20 | 48.81 |
| ADF (%) | 2.9 | 3.37 | 4.20 | 4.75 |
| Ca (%) | 0.03 | 0.03 | 4.32 | 4.88 |
| P (%) | 0.24 | 0.28 | 0.80 | 0.90 |
| K (%) | 0.33 | 0.38 | 2.04 | 2.31 |
| Mg (%) | 0.1 | 0.12 | 0.30 | 0.34 |
| S (%) | 0.08 | 0.09 | 0.47 | 0.53 |
| Na (%) | 0.01 | 0.012 | 0.10 | 0.11 |
| Zn (ppm) | 19 | 22 | 322 | 364 |
| Mn (ppm) | 6 | 7 | 234 | 264 |
| Cu (ppm) | 4 | 5 | 8 | 9 |
| Fe (ppm) | 30 | 6 | 374 | 423 |
| Co (ppm) | 1 | 1.2 | 2.0 | 2.3 |
| Al (ppm) | 1 | 1 | 50 | 56 |
| TDN (estimated) (%) | 74.86 | 87.04 | – | – |
| DP (estimated) (%) | 3.68 | 4.28 | – | – |
| ME (Kcal/kg) | 2 704 | 3 144 | – | – |
| NEm (Kcal/kg) | 1 797 | 2 092 | – | – |
| NEg (Kcal/kg) | 1 221 | 1 421 | – | – |

[a]analysis was done at Iowa Testing Laboratories, Inc., Eagle Grove, Iowa

Table 2. Composition of concentrate fed to lambs during Phase 1

| Ingredients[a] | Percentages |
|---|---|
| Maize | 73.5 |
| Soybean meal (49%) | 18.5 |
| Molasses | 5.0 |
| Limestone | 2.0 |
| Trace Mineral (TM)[b] | 0.5 |
| Ammonium sulphate | 0.5 |

[a]plus 50 g CTC, 1 000 000 IU vitamin A, 100 000 IU vitamin D, 35 000 IU vitamin E and 0.3 g Se per 0.907 metric ton of concentrate
[b]no copper in TM salt

ted protection from inclement weather provided by draws and trees. Ewes had access to magnesium-fortified blocks to reduce the risk of grass tetany. Lambing occurred from May 10 to June 15.

Human assistance at lambing was minimal and then was given only after the ewe had been in hard labour for one hour. Ewes with newborn lambs were allowed to stay in the paddock in which they lambed when the main group was rotated into the next paddock. Ewe and lambs rejoined the main group when it was rotated back into the paddock. This system, commonly referred to as drift lambing, was adopted to improve bonding between lambs and their dams. If triplets were born, one lamb was removed and reared as an orphan in the barn. Lambs were not creep-fed.

All lambs had been vaccinated against enterotoxaemia prior to weaning. After weaning lambs were allocated within sire groups to one of the two finishing programs. The finishing programs were direct to feedlot (FP1), and backgrounding on pasture followed by feedlot (FP2). The lambs were given an 8–9-day post-weaning adaptation period to adjust to their finishing program prior to the start of the experiment. Lambs in FP1 were grouped in different pens in the barn and fed a high concentrate ration consisting of shelled maize and pelleted protein supplement (Table 1). Lambs in FP2 were backgrounded on pasture (Phase 1) for 63 and 56 days during the first and second year, respectively. They were raised as a single group on pasture and supplemented with 455 g/h of concentrate daily. The composition of concentrates fed to lambs in Phase 1 in FP2 is given in Table 2. During the last weigh period of Phase 1 in FP2, lambs were gradually brought up to the same high concentrate diet as was fed to lambs in FP1. Upon entering Phase 2 lambs were moved to the barn and penned in groups and continued on the same diet until slaughter.

After lambs were initially weighed on test, they were weighed at approximately 21-day intervals. Weights were obtained as a single weighing starting at about 8.00, which was before feeding concentrates. Overall post-weaning average daily gains were calculated using initial and final weights of lambs during the experiments. However, to main-

Table 3. Energy inputs per hectare for sheep on smooth bromegrasss in Iowa

| Inputs for pasture establishment | Quantity/ha | MJ/ha |
|---|---|---|
| (a) Labour (h) | 8.00 | 18.20 |
| (b) Machinery (kg) | 5.80 | 626.64 |
| (c) Diesel fuel (l) | 65.00 | 3 104.15 |
| (d) Nitrogen (kg) | 56.15 | 3 453.47 |
| (e) Seed (kg) | 8.60 | 431.79 |
| (f) Fencing (km) | 0.60 | 1 110.52 |
| Total | | 8 744.77 |
| Energy input per year prorated over 20-year life of stand (A) | | 437.23 |
| Inputs for annual maintenance | | |
| (a) Labour (h) | 1.00 | 2.26 |
| (b) Machinery (kg) | 3.50 | 378.15 |
| (c) Diesel fuel (l) | 4.00 | 191.04 |
| (d) Nitrogen (kg) | 56.15 | 3 453.47 |
| Total (B) | | 4 024.92 |
| Total energy input per ha/year (A + B) | | 4 462.15 |

Table 4. Cultural energy for various inputs

| Inputs for feed | MJ/units | Reference |
|---|---|---|
| Maize (kg) | 7.91 | Gee (1980) |
| Hay (kg) | 2.68 | Gee (1980) |
| Soybean meal (kg) | 12.05 | Gee (1980) |
| Molasses (kg) | 5.82 | Sainz (2003) |
| Ammonium sulphate (kg) | 69.99 | Cervinka (1980) |
| Limestone (kg) | 1.34 | Terhune (1980) |
| Mineral and vitamin (kg) | 0.38 | Sainz (2003) |
| Input for transportation (km/kg) | 0.054 | Cook et al. (1976) |

tain uniformity in all lamb groups, ADG during intermediate weigh periods (WP) were calculated and reported only for the first through the fifth WP. Daily DMI of concentrates were measured and feed efficiencies (FE; kilograms of DMI per kilograms of gain) were calculated on a pen basis.

When lambs in each finishing program reached market weights of 58.5 ± 7.2 kg, they were shipped to a commercial slaughter facility for processing and collection of carcass data. Carcass weight (CW) was taken 24 hours after slaughtering the lambs. Dressing percentage (DP) was calculated by dividing carcass weight, including kidney fat, by final live weight of the lamb.

**Cultural energy analysis**. Cultural energy used for pasture establishment and maintenance was calculated using the actual inputs and their corresponding energy values from literature (Hoveland, 1980; Table 3). Hoveland (1980) reported only the values of energy input for pasture establishment but did not have the values for fencing. Energy used for fencing was derived from Gee (1980) and the actual fencing length used was multiplied with this value to obtain total energy expended for fencing. When calculating energy input per year for pasture establishment it was assumed that the cool season grass stand would have 20-year life. Total energy input for pasture establishment and maintenance was divided into total number of grazing by ewes and lambs and total days they grazed and thus energy expended for grazing and pasture establishment per ewe and lamb was calculated. Since ewes were fed hay for wintering, this was also included in cultural energy invested in ewes. Total energy expended on ewe included cultural energy expended on pasture, hay fed in winter, labour, water pond established, and other miscellaneous cultural energy expenditures (Gee, 1980). Cultural energy used for feed for treatments was derived from their corresponding feed consumption and corresponding values for each feed ingredient from literature (Davulis and Frick, 1977; Cook et al., 1980), Table 4. Cultural energy expended on transportation included lamb and culled ewe transportation energy. In the experiment, 52, 54 and 58 ewes were bred with Texel, Suffolk and Columbia breed rams, respectively. Since the whole system cultural energy input and output was calculated in order not to be biased, when calculating the number of ewes used, 52 ewes were used as base number. Thus using survival rates of weaned lambs, new numbers of weaned lambs for Suffolk, Texel Columbia sire breeds were calculated. Not all lambs were used in the study and some lambs were sold after weaning. Energy output from lambs sold after weaning was included in the calculation by using average weaning weight and dressing percentage for weaned lambs. It was assumed that weaned lambs would have 17.1% protein and 18.8% fat. When calculating energy deposited in the carcass of finished lambs, it was assumed that carcass content would have 16.2% protein and 23.4% fat. Energy values of 1 g of protein and fat were taken as 23.85 kjoule and 39.33 kjoule, respectively. Total energy deposited in carcass was calculated as carcass energy, MJ = (carcass weight × carcass protein ratio × unit protein energy) + (carcass weight × carcass fat ratio × unit fat energy). Total cultural energy expended for FP1 was formulated as cultural energy expended for ewe, feed and transportation whereas for FP2 was cultural energy for grazing supplement on pasture and cultural energy expended for pasture for lamb in addition to those in FP1. Efficiency defined as cultural energy input per energy output was calculated by dividing total cultural energy expended by energy deposited in carcass. Energy required to produce unit protein was calculated by dividing total cultural energy expended by carcass protein energy content.

**Statistical analysis**. The data were analyzed using the General Linear Model procedure of SAS (1999) by using sire breed in the model and PDIFF statement was used to compare sire breed means for dependent variables.

## RESULTS AND DISCUSSION

Cultural energy input and output are presented in Table 5. Cultural energy expended on feed was lowest for Texel sired lambs ($P < 0.02$), Suffolk and Columbia sired lambs had similar CE for feed. Cultural energy expended on feed included cultural energy for feed offered in the feedlot and supplement given on pasture. Dry matter intake (DMI) of Suffolk sired lambs was highest and was followed by Columbia and Texel sired lambs and each breed differed from each other ($P < 0.01$; Table 6). Since lambs of different sires had different DMIs, this was reflected in their cultural energy expenditure on feed (Table 5). Cultural energy expended on feed comprised around 58% of the total cultural energy expended. These values were higher than those of range sheep production in the Intermountain Great Basin (Utah, Nevada and Southern Idaho) where sheep graze desert ranges during the winter from about November 1 until April 1, after which they are trailed onto foothill ranges where they lamb on crested wheatgrass and/or native grass-sagebrush types and subsequently into higher mountain zones (Cook, 1976). The reason for the range sheep production system to have lower cultural feed energy is that these sheep consumed less feed and thus had lower cultural energy on feed. When Koknaroglu (unpublished data) compared cultural energy expenditure of intensive program in which sheep and lambs were maintained in the feedlot to sheep grazed on pasture and lambs initially grazed and later finished in feedlot, he found that the intensive program had higher CE expenditure on feed.

Suffolk sired lambs had higher cultural energy expended on transportation than Texel and Columbia sired lambs ($P < 0.003$; Table 5). Suffolk sired lambs had higher transportation energy due to their heavier final weights (Table 6). Despite having the same initial weights, Suffolk sired lambs were nearly 9 and 6 kg heavier than Texel and Columbia sired lambs, respectively ($P < 0.01$; Table 6). Texel sired lambs were equal in final weights to Columbia sired lambs. These results are in agreement with Simm (1987) and Leymaster and Jenkins (1993). Leymaster and Jenkins (1993) reported that the Suffolk breed had a greater potential for growth than the Texel breed, and the weight of purebred Suffolk and Texel ewes averaged 94.5 and 74.5 kg, respectively.

Transportation energy was the third highest CE contributing to total cultural energy expended. This result may not apply to other experiments because a slaughterhouse in Iowa was chosen as packing plant for this research and the distance between slaughterhouse and research farm was 483 km. Cultural energy expended for ewe maintenance was the second highest contributor to total CE expended. Ewes stayed on pasture and were fed hay in winter, thus CE for ewe maintenance includes CE for wintering,

Table 5. Cultural energy (CE) input and output for treatments

| Items | Texel | Suffolk | Columbia | $P$-values |
|---|---|---|---|---|
| CE expended for feed (MJ) | 122 752.66[a] | 135 746.99[b] | 131 323.92[b] | 0.02 |
| CE for transportation (MJ) | 37 464.54[a] | 41 996.90[b] | 38 645.47[a] | 0.003 |
| CE for lambs on pasture (MJ) | 500.41 | 800.65 | 750.61 | |
| CE for ewe maintenance (MJ) | 51 222.03 | 51 222.03 | 51 222.03 | NA |
| Total CE expended (MJ) | 211 939.64[a] | 229 766.58[b] | 221 942.03[c] | 0.04 |
| Total carcass energy (MJ) | 28 449.61[a] | 32 667.08[b] | 29 252.14[a] | 0.001 |
| CE (MJ/kg live weight) | 52.72[a] | 51.92[b] | 53.81[a] | 0.04 |
| Carcass CE (MJ/kg) | 101.55 | 99.16 | 103.01 | |
| Protein efficiency (MJ) input/MJ protein energy output | 25.10[a] | 23.63[b] | 25.61[a] | 0.02 |
| Efficiency (MJ) input/MJ output | 7.48[a] | 7.08[b] | 7.62[a] | 0.03 |

[abc]means within a row with different superscripts differ respective to their $P$-values

Table 6. Growth traits of lambs sired by Texel, Suffolk or Columbia rams[a]

| Growth traits | Sire breeds | | |
|---|---|---|---|
| | Texel | Suffolk | Columbia |
| Number of lambs | 50 | 55 | 58 |
| Initial weight (kg) | 23.9 ± 0.7[b] | 25.1 ± 0.6[b] | 23.7 ± 0.6[b] |
| Final weight (kg) | 54.9 ± 1.0[b] | 63.0 ± 1.0[c] | 57.0 ± 0.9[b] |
| Post-weaning ADG (g) | | | |
| Phase 1 | 247 ± 7[b] | 299 ± 7[c] | 256 ± 6[b] |
| Phase 2 | 266 ± 7[e] | 326 ± 7[f] | 309 ± 6[g] |
| Overall | 262 ± 5[b] | 318 ± 5[c] | 286 ± 5[d] |
| Dry matter intake (kg/day)[h] | 1.39 ± 0.08[b] | 1.64 ± 0.07[c] | 1.53 ± 0.07[d] |
| Feed efficiency (kg feed/kg gain)[i] | 4.81 ± 0.07[b] | 4.73 ± 0.06[b] | 4.74 ± 0.06[b] |
| Carcass weight (kg) | 28.9 ± 0.7[b] | 33.7 ± 0.8[c] | 30.3 ± 0.7[b] |
| Dressing (%) | 52.0 ± 0.3[b] | 52.7 ± 0.4[b] | 52.2 ± 0.3[b] |

[a]least square means ± SE
[b,c,d]means within a row with different superscripts differ ($P < 0.01$)
[e,f,g]means within a row with different superscripts differ ($P < 0.06$)
[h]dry matter intake of lambs in drylot
[i]feed efficiency of lambs in drylot

labour, CE expended for pasture, etc. Since ewes were treated alike, their CE for maintenance was the same, thus, they cannot be compared. Total CE expenditure of Suffolk sired lambs was higher than that of Texel and Columbia sired lambs and each breed had different total CE expenditure ($P < 0.04$; Table 5).

Energy deposited in the carcass during the experiment was calculated as total carcass energy of lambs subtracted by carcass energy deposited in the carcass when lambs were put on experiment and carcass energy from culled ewes. Total carcass energy of Suffolk breed was higher than that of Texel and Columbia breed ($P < 0.001$; Table 5) due to their higher carcass weights ($P < 0.01$; Table 6). As mentioned previously in the Materials and Methods part, total carcass energy is a function of carcass weight. Therefore as dressing percentage increases carcass weight increases thus increasing carcass energy. Carcass weights were greater for lambs sired by Suffolk rams than for lambs sired by Texel or Columbia rams ($P < 0.01$; Table 6), but sire breeds did not affect dressing percentage. Ellis et al. (1997) also did not find any differences in dressing percentage between Texel and Suffolk sired lambs (45.2 vs. 44.4%, respectively). Another reason for Suffolk sired lambs to have higher total deposited carcass energy is that since Suffolk sired lambs had higher survival rates, they had higher numbers of lambs sold after weaning (Table 7) and thus the energy of these lambs was included in the analysis. Prolificacy of ewes bred to Texel, Suffolk or Columbia rams was similar (1.71, 1.65 and 1.74, respectively). This further demonstrated that the distribution of Polypay × Dorset crossbred ewes in this experiment was uniform in terms of prolificacy. It is necessary that there should be no confounding of prolificacy (litter size) and sire breeds, when the performance of progeny from terminal sire breeds is compared. Differences in the prolificacy of ewes bred to Texel, Suffolk or Columbia rams will cause a bias in results, because according to Peeters et al. (1996) litter size has an effect on postnatal growth of lambs. More O'Ferrall (1974), Leymaster and Smith (1981) and Leymaster and Jenkins (1993) reported results similar to our findings regarding prolificacy. Survival rate of lambs was not affected by sire breed, although Suffolk sired lambs had a higher survival rate than lambs sired by Texel or Columbia rams (80.3, 68.2 and 67.2%, respectively). Texel sired offspring did not excel in livability as reported by Leymaster and Jenkins (1993). They found that Texel progeny, as compared to Suffolk progeny, had 9% higher ($P = 0.06$) survival rate to weaning. In our study lambing occurred on pasture, whereas in Leymaster and Jenkins (1993) experiments lambing occurred in drylots. However, our results are similar to More O'Ferrall (1974)

Table 7. Productivity performance of ewes and growth parameters of lambs sired by Texel, Suffolk or Columbia rams[a]

| Sire breeds (A) | Prolificacy (B) | Number of lambs born (A × B) | BW[b] (kg) | WW (kg) | Adj-WW (kg) | ADG (g) | SR (%) |
|---|---|---|---|---|---|---|---|
| Texel ($n$ = 52) | 1.71 ± 0.08 | 89 | 5.3 ± 0.13[c] | 24.5 ± 0.8[e] | 18.4 ± 0.5[c] | 238 ± 8[e] | 68.2 |
| Suffolk ($n$ = 54) | 1.65 ± 0.08 | 89 | 5.4 ± 0.13[c] | 24.7 ± 0.6[e] | 18.4 ± 0.4[c] | 237 ± 6[e] | 80.3 |
| Columbia ($n$ = 58) | 1.74 ± 0.08 | 101 | 4.7 ± 0.15[d] | 22.0 ± 0.9[f] | 16.2 ± 0.6[d] | 209 ± 9[f] | 67.2 |

[a]least squares means ± SE
[b]BW = birth weight, WW = weaning weight, Adj-WW = 60-d adjusted weaning weight, ADG = pre-weaning average daily gain, SR = survival rate
[c,d]means within a column with different superscripts differ ($P < 0.01$)
[e,f]means within a column with different superscripts differ ($P < 0.05$)

and Latif and Owen (1979). More O'Ferrall (1974) reported nonsignificant differences for the perinatal survival of 91.6 and 90.1% for Suffolk and Texel sired lambs, respectively, and Latif and Owen (1979) reported the survival of 89.6% for Suffolk and 90.4% for Texel crossbred progeny. Vesley et al. (1966) reported equal survival rates for purebred Suffolk and Columbia progeny (85.3 and 89.5%, respectively).

Cultural energy expended for kg liveweight gain defined as total cultural energy expended divided by kg liveweight gain was lower for Suffolk sired lambs and this was different from that of Texel and Columbia sired lambs ($P < 0.04$; Table 5). Since Suffolk sired lambs had higher post-weaning ADG than Texel and Columbia sired lambs ($P < 0.01$; Table 6) and numerically better feed efficiency in drylot, this might have an impact on CE for kg of liveweight gain.

Cultural energy expended for 1 kg of carcass for Suffolk, Texel and Columbia sired lambs was similar ($P > 0.4$; Table 5). Even though Suffolk sired lambs had higher carcass weight than Texel and Columbia sired lambs, they had similar CE energy input for kg of carcass due to their higher total CE expenditure stemming from higher CE on feed and transportation.

Cultural energy expended for 1 MJ protein energy is given in Table 5. Suffolk sired lambs had lower CE expenditure required to produce 1 MJ of protein energy output than Texel and Columbia sired lambs ($P < 0.02$; Table 5). Texel and Columbia sired lambs had similar CE expenditure requirement for producing 1 MJ of protein energy output ($P > 0.4$). Pimentel (2004) reported that kjoule of fossil energy required to produce 1 kjoule of animal protein was 40 kjoule input/ kjoule protein for lambs fed a grain and forage mixture. Our result for CE expenditure requirement for producing 1 MJ of protein energy was lower than that found by Pimentel (2004) and a reason for this could be the integration of grazing and finishing of lambs in feedlot. Koknaroglu et al. (2005) reported that the inclusion of pasture into cattle feeding decreased CE expenditure and thus CE required to produce protein energy.

Efficiency defined as total cultural energy expenditure divided by energy deposited in carcass during feeding is presented in Table 5. This shows the kjoule of cultural energy expended for kjoule of food energy. Suffolk sired lambs had better efficiency than Texel and Columbia sired lambs ($P < 0.03$). Texel and Columbia sired lambs had similar efficiencies and did not differ from each other ($P > 0.4$). Efficiency is a measure that shows the effectiveness of a system and in this study it shows the effectiveness of Suffolk sired lambs depositing more energy for unit of energy invested.

## CONCLUSIONS

This study shows that Suffolk sired lambs had lower cultural energy expended for kg of liveweight, and for MJ of protein energy output than Texel and Columbia sired lambs. Since Suffolk sired lambs had higher growth rate, thus higher carcass weight and survival rate, they had better efficiency than Texel and Columbia sired lambs. In general cultural energy expended for MJ of protein energy output was lower than that reported in literature and the reason for this could be the integration of grazing and finishing of lambs in feedlot. Results show that when introducing a new breed, sustainability of the production should be considered and Suffolk sired lambs were found to be more efficient in converting CE to carcass energy than Texel and Columbia sired lambs.

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