The effect of initial fattening weight on sustainability of beef cattle production in feedlots

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Abstract

The aim of this study was to conduct cultural energy (CE) analyses of beef cattle animals with different initial weights. Data were obtained by a questionnaire administered to 100 beef farms selected by stratified random sampling. The beef farms were divided into three groups based on initial animal weights and were analyzed. Initial weights were assigned as light (<226 kg, 37 farms), medium (226-276 kg, 31 farms) and high (>276 kg, 32 farms). Cultural energy used for feed for the treatments was derived from their lot feed consumption and values from the literature. Transportation energy was included in the analysis. As the objective of the study was to evaluate CE analysis of the feeding systems, energy that the calves had deposited in muscle and fat tissue, when they were purchased was deducted from carcass energy. Total expended CE was highest for the lighter animals (P < 0.05). Feed energy was more than half of total CE and again was highest for the lighter animals (P < 0.05). Energy expended kg⁻¹ live weight did not differ among the three initial weight groups (P > 0.05). Cultural energy Mcal⁻¹ of protein energy decreased as initial body weight increased (P < 0.05). Efficiency, defined as Mcal input Mcal⁻¹ output, was best in heavier cattle and was worst for lighter animals (P < 0.05). The medium weight animals did not differ from the other groups (P > 0.05). The results showed that efficiency became better as initial body weight increased and that to be more sustainable the initial animal weight should be taken into account.

Additional key words: cultural energy, efficiency, energy conversion.

Resumen

Efecto del peso inicial en el desarrollo sostenible de la producción de ganado vacuno en engorde intensivo a corral

El propósito de este estudio fue realizar análisis de la energía para el engorde (CE) de ganado vacuno con diferentes pesos iniciales. Los datos se obtuvieron mediante un cuestionario dirigido a 100 granjas de vacuno seleccionadas por un método de muestreo estratificado y al azar. Las granjas fueron clasificadas en tres grupos, de acuerdo a los pesos iniciales, y analizadas. De acuerdo al peso inicial fueron agrupadas como ligeras (<226 kg, 37 granjas), intermedias (226-276 kg, 31 granjas) y pesadas (>276 kg, 32 granjas). La energía utilizada para la alimentación en los tratamientos se obtuvo de los consumos correspondientes de cada uno de los lotes y de los valores de la bibliografía. La energía de transporte también se incluyó en el análisis. Puesto que el objetivo del estudio fue evaluar el análisis de CE de los sistemas de engorde, la energía que los terneros habían depositados en músculo y en tejido graso cuando fueron comprados se descontó de la energía de la canal. La CE total gastada fue superior para los más ligeros (P < 0.05). La energía de alimentación constituyó más de la mitad del total de CE y fue superior en el ganado más ligero (P < 0.05). La energía gastada por kg de peso vivo no fue diferente entre los grupos por peso inicial (P > 0.05). La energía por Mcal de energía proteica disminuyó cuando el peso inicial aumentó (P < 0.05). La eficacia definida como Mcal entrada Mcal⁻¹ salida fue mejor para el ganado más pesado y peor para el más ligero (P < 0.05), quedando el ganado de peso intermedio con un valor medio, aunque no diferente de los otros grupos (P > 0.05). Los resultados mostraron que la eficacia es mejor cuando el peso inicial aumenta y para que sea más sostenible, el peso inicial del ganado debe ser tenido en cuenta.

Palabras clave adicionales: conversión de la energía, eficacia, energía para el engorde.

^{*} Corresponding author: vecdem@ziraat.sdu.edu.tr Received: 14-03-07; Accepted: 15-11-07.

Introduction¹

As forecast energy use between years 1995 to 2015 will increase by 2.2% in the world and world population is increasing at a rate of 1.3%, there will be increased energy deficits in the future (IEA, 1995; PRB, 2004). Thus as world population and energy use increase, animal production systems that are more sustainable, consume less energy and use less cereal are needed. Sustainable agriculture, defined as the management and conservation of the resource base and the orientation of technological and institutional changes in such a way as to ensure the attainment and continued satisfaction of human needs for present and future generations (FAO, 1991), has been a subject of great interest and ongoing debate in animal production (Heitschmidt *et al.*, 1996).

Although energy consumption for improving productivity of Turkish agriculture has been increasing at a steady rate (MENR, 2001), efficiency of energy use has consistently declined (Ozkan *et al.*, 2004). Further, to sustain agricultural production, effective energy use in agriculture is required, since it gives financial savings, preserves fossil fuel resources and reduces air pollution (Pimentel, 1980; Pervanchon *et al.*, 2002).

Energy output/CE input ratio is of considerable value because it gives an estimate of the level of dependence on exogenous energy to meet established production goals (Heitschmidt *et al.*, 1996). Further, this ratio is one of the most useful methods to examine potential long term sustainability of various agricultural practices and the analysis can quantify the energy return from a product relative to the CE invested in the product (Heitschmidt *et al.*, 1996).

To increase profit, time of marketing and production efficiency should be considered. Initial weight is one of the most important factors affecting efficiency and profitability in beef cattle production (Koknaroglu *et al.*, 2005a). Young, lighter cattle have better feed conversion efficiency and have higher protein and lower fat deposition than heavier animals. As fat deposition is more expensive than protein deposition the initial weight of cattle should be considered when starting on feed (Ralston *et al.*, 1970).

Studies have examined the profitability and performance of cattle by initial weight (Gaili and Osman, 1979; Koknaroglu *et al.*, 2005a,b). However, to the author's knowledge, no study has examined the CE analysis of beef cattle animals by their initial weight. Thus the objective of this study was to analyze CE use of initial weight of beef cattle and to incorporate it into a sustainability model.

Material and Methods

Data were primary information obtained by a questionnaire from beef farmers in Afyon province, Turkey. With the data obtained from the questionnaires, similar studies, conducted by other institutions and researchers, were also utilized. The data were information from the year 2005.

The region was selected for the study because beef cattle production in Afyon is an important branch of agriculture and it is third in beef cattle production in Turkey. According to 2002 data red meat production in Afyon was 19,118 Mg and 96% of this meat was beef. The total number of cattle in Afyon is 210,043 head and 76% of these are European breeds (DIE, 2002). Afyon is located at the intersections of adjacent provinces' roads and markets beef products to these provinces. Thus the beef production industry is well established and developed in Afyon (DPT, 1996).

Based on personal interviews with staff of the Ministry of Agriculture branch in Afyon, 23 villages in Afyon province, Bolvadin, fiuhut, Çay, Dinar, Sinanpasa and İhsaniye districts that were involved in intensive beef farming were selected to answer the questionnaire. Beef farms in these villages that met the research criteria were the population sample. Districts chosen for the research were 81.7% of the beef cattle population in Afyon province (MARA, 2004) and thus the sample size represents the population size. The Neyman method of stratified random sampling was used to select beef farms for the questionnaire (Yamane, 1967). The Neyman method is used to determine the number of samples depending on population size. According to the method after determining the sample size, sample size is stratified into groups and the sample size studied. In this study values required to obtain the sample size are given in Table 1. Using Table 1 values, the sample size (n) was determined by Equation [1]:

¹ Abbreviations used: ADG (average daily gain), CE (cultural energy), DMI (dry matter intake), GLM (general linear model), SAS (statistical analysis systems).

Number of cattle for farm groups	\overline{X}	N_h	S_h	$N_h * S_h$	S_h^2	$N_h * S_h^2$	Number of farms (n _h)	Spare questionnaires	Total number of farms
5-10	6.9	647	1.70	1,099.90	2.89	1,869.83	30	3	33
11-25	15.5	324	4.14	1,341.36	17.14	5,553.36	37	4	41
26+	36.2	93	9.59	891.87	91.97	8,553.21	24	2	26
Total		1,064		3,333.13		15,976.40	91	9	100
Average	11.97			_	_			_	

Table 1. Distribution of farms by farm groups and the number of farms in each group

 \overline{X} : mean of each group. N_h : number of population of each group. S_h : standard deviation of each group. S_h^2 : variance of each group. n_h : sample size of each group.

$$n = \frac{\left(\sum N_h S_h\right)^2}{N^2 * D^2 + \sum N_h S_h^2} =$$

$$= \frac{(3,333.13)^2}{1,132,096 * 0.0932 + 15,976.40} = 91$$
[1]

where N_h : number of farms in h^{th} group; S_h : standard deviation of h^{th} group; S_h^2 , variance of h^{th} group; N: population size (1,064); $D^2 = (d/z)^2$, where *d* is deviation (5%) from mean ($\overline{X} = 11.97$), being \overline{X} the average number of animals/farm in population and *z* is standard normal distribution value (1.9) that corresponds to 95% probability (Equation [2]):

$$D^{2} = \left(\frac{d}{z}\right)^{2} = \left(\frac{\overline{X} * 0.05}{1.96}\right)^{2} = \left(\frac{11.97 * 0.05}{1.96}\right)^{2} = 0.0932 \ [2]$$

Values for D^2 in Equation [2] are used in Equation [1] to find the sample size. Using Equation [1], the sample size that would represent the population was found to be 91. However, as some questionnaires would not qualify for analysis, 104 beef farms were chosen, at random, to complete the questionnaire. Of the 104 farms 4 did not qualify for analyses, thus 100 farms were used for study. Farms that answered the questionnaire were randomly chosen. Since there were differences in cattle population among the farms the establishment of groups was decided on to homogenize the population. Considering the farm animal population and frequency distribution, farms were divided into three groups. For distributing farms into groups Equation [3] was used (Yamane, 1967):

$$n_h = \frac{N_h S_h}{\sum N_h S_h} * n$$
[3]

where n_h is sample size for each group. The distribution of population by groups and the number of farms by groups are shown in Table 1.

Among farms based on size, farms were divided into three groups: Group I, farms that had 5-10 animals (33 farms); Group II, farms that had 11-25 animals (41 farms) and Group III, farms that had more than 25 animals (26 farms).

Questions answered by the producers gave the following information: the number of cattle fed, their initial, final and carcass weight, feed intake, days on feed, distance to the slaughter house, distance to the cattle market where the animals were bought, distance the feed was bought. Generally cattle were fed *ad lib* and water was provided at all time. Housing was open lot and confinement buildings. Veterinary services were provided when needed.

Cultural energy analysis

For feedlot operations, the CE expended for feedlot operations for Kansas feedlots was used (Lipper *et al.*, 1976). The cultural energy for feedlot operations included the energy expended for receiving cattle, preparing feed, feeding, inspection, veterinary care, waste removal, loading out and overheads (Cook *et al.*, 1980).

Feed CE was calculated for feed used for the treatments and was obtained from feedlot consumption and from values for each feed ingredient in the literature (Table 2).

Transport energy was included in the analysis and shipping of calves to the farms, shipping yearlings to a slaughterhouse and shipping feed to the farms accounted for transport energy. In calculating transport

Feed inputs	Mcal unit ⁻¹	Reference
Concentrate mixture, kg	1.13	Calculated
Barley, kg	0.73	Cook <i>et al.</i> (1980)
Wheat, kg	0.73	Cook et al. (1980)
Cotton seed meal, kg	0.31	Sainz (2003)
Sunflower meal, kg	0.31	Sainz (2003)
Dried sugar beet pulp, kg	2.90	Sainz (2003)
Sugar beet, kg	0.77	Pimentel and Pimentel (1996)
Potato, kg	0.73	Haj Seyed Hadi (2006)
Straw, kg	0.33	Calculated
Alfalfa, kg	0.38	Sainz (2003)
Corn, kg	1.89	Gee (1980)
Corn gluten meal, kg	2.98	Sainz (2003)
Grass hay, kg	0.64	Gee (1980)
Soybean meal, kg	1.34	Sainz (2003)
Salt, kg	0.09	Sainz (2003)
Silage, kg	0.56	Sainz (2003)
Wheat bran, kg	0.08	Sainz (2003)
Mineral, kg	0.09	Sainz (2003)
Vitamin, kg	9.89	Calculated
Input for feedlot operations,		
Mcal head ⁻¹ d ⁻¹	1.20	Lipper et al. (1976)
Input for transport, km kg ⁻¹	0.0013	Cook et al. (1976)

Table 2. Cultural energy inputs for feed, feedlot operations and transport

energy, weight of animals and feed, distance between farms, the animal market, the slaughter house and the feed seller were considered. Total energy expended was the sum of feed energy, feedlot operations energy and transport energy. When calculating energy in the carcass, it was assumed that the carcass would be 18% protein and 35% fat. The energy value of a g of protein and fat were taken as 5.7 and 9.4 kcal, respectively (Cook, 1976). Total energy deposited in the carcass was calculated as carcass energy, Mcal = (carcass weight × carcass protein ratio \times unit protein energy) + (carcass weight \times carcass fat ratio×unit fat energy). Carcass energy in autumn born calves at the start of the study was assumed to be 280 Mcal (Heitschmidt et al., 1996). Spring-born calves were heavier and their energy content was calculated using cattle weight and cattle energy content (Heitschmidt et al., 1996). Energy deposited in the carcass during the experiment was calculated as total carcass energy minus the carcass energy when the calves were put onto the experiment. Efficiency defined as CE input/energy output was calculated by dividing total CE expended by energy deposited in carcasses. The energy required to produce a unit of protein was calculated by dividing total CE expended by the carcass protein energy content.

Statistical analyses

To determine the effect of initial animal weight on CE use, farms were assessed for initial weight. For this cattle weighing < 226 kg, 226 to 276 kg and > 276 kg were allocated to light, medium and heavy weight groups. The number of farms in the light, medium and heavy groups were 37, 31 and 32, respectively

Data were analyzed using the General Linear Model (GLM) procedure of SAS (1999) and PDIFF statements were used to compare weight groups.

Results

Performance and carcass characteristics of cattle by initial weight are given in Table 3. Initial and final weight differed among initial weight groups (P < 0.05). The heavier weight group had a higher average daily gain, carcass weight and dressing percentage than the light weight group (P < 0.05). The medium weight group was intermediate and did not differ from the light and heavy weight group in average daily gain, carcass weight and dressing percentage than the light differ from the light and heavy weight group in average daily gain, carcass weight and dressing percentage (P > 0.05).

Dry matter intake (DMI) by initial weight group is presented in Table 4. The light weight group had a

	Light weight	Medium weight	Heavy weight
Number of cattle fed (head)	$14.64 \pm 2.24^{\#}$	22.39 ± 2.45	20.41 ± 2.41
Days on feed (d)	231 ± 11.01	196 ± 12.03	177 ± 11.84
Initial weight (kg)	$180.54^{a} \pm 32.71$	$256.29^{b} \pm 35.74$	329.3° ± 35.17
Finishing weight (kg)	$450.97^{a} \pm 66.33$	$500.98^{b} \pm 72.46$	$556.15^{\circ} \pm 71.32$
Weight gain during feeding period (kg)	270.43 ± 36.47	244.69 ± 39.85	226.85 ± 39.22
Average daily gain (kg d ⁻¹)	$1.17^{\mathrm{a}}\pm0.18$	$1.25^{ab}\pm0.20$	$1.28^{b} \pm 0.19$
Feed efficiency	8.39 ± 0.45	8.92 ± 0.49	8.28 ± 0.48
Carcass weight (kg)	$250.71^{a} \pm 40.11$	$285.28^{ab} \pm 43.82$	$328.93^{b} \pm 43.13$
Dressing percentage (%)	$55.59^{\mathrm{a}}\pm0.55$	$56.94^{\mathtt{ab}}\pm0.60$	$59.14^{\mathrm{b}}\pm0.59$

Table 3. Performance and carcass characteristics of cattle by initial weight group

^{abc} Means with a different superscript in the same row differ (P < 0.05). [#] Standard error.

lower DMI than the medium and heavy weight groups (P < 0.05). The heavy and medium weight groups had similar DMIs (P > 0.05). The heavy weight group consumed more concentrates than the light weight group (P < 0.05). The medium weight group was intermediate in terms of concentrate consumption and did not differ from the other groups (P > 0.05).

Cultural energy input and output/head are given in Table 5. Light weight cattle had a higher CE expended on feed than the medium and heavy weight cattle (P < 0.05). The CE expended for feed was similar for the medium and heavy cattle (P > 0.05).

Cultural energy expended for feedlot operations was also higher for lighter cattle and this differed from both medium and heavy cattle (P < 0.05; Table 5). The heavy and medium weight cattle had a similar CE expended for feedlot operations (P > 0.05). Medium weight cattle had higher transport energy expenditure than the other two weight groups (P < 0.05; Table 5).

Total CE expenditure was similar for the medium and heavy cattle (P>0.05; Table 5). The light cattle had the highest total CE expenditure. When CE expended for feed is divided into days spent on the feedlot, feed energy d^{-1} is obtained. This ratio was highest in the heavy cattle and differed significantly from the other groups (P < 0.05; Table 5). The light and medium weight cattle used similar feed energy d^{-1} (P > 0.05).

Even though the CE expended kg⁻¹ live weight gain defined as total CE expended divided by kg of liveweight gain, was similar for all groups (P > 0.05; Table 5), there was a trend for it to increase as initial weight increased. Carcass energy content is shown in Table 5. This value was low, average and high for light, medium and heavy weight cattle, respectively (P < 0.05; Table 5).

When total CE expended is divided by the hot carcass weight, the CE kg⁻¹ of carcass is obtained. The CE kg⁻¹ of carcass decreased as initial weight increased (P < 0.05; Table 5). The CE Mcal⁻¹ for protein energy is given in Table 5. This decreased as initial weight increased (P < 0.05).

Efficiency, defined as the total CE expenditure divided by energy deposited in the carcass during feeding is given in Table 5. It was highest in light cattle and lowest in heavy cattle (P < 0.05). The medium cattle were average and did not differ from the other two groups (P > 0.05).

Discussion

The purpose of this study was to conduct CE analyses for beef cattle with different initial body weights. Thus

Га	bl	e	4.	Dry	matter	intak	e by	initial	weight	group
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Feed ingredient	Light weig	ht	Medium wei	ght	Heavy weight	
	(kg head ⁻¹ d ⁻¹)	(%)	(kg head ⁻¹ d ⁻¹)	(%)	(kg head ⁻¹ d ⁻¹)	(%)
Concentrate	$5.68^{a}\pm0.27^{\#}$	60.49	$5.92^{ab}\pm0.29$	55.64	$6.48^{\text{b}}\pm0.29$	61.54
Roughage	3.31 ± 0.24	35.25	3.87 ± 0.27	36.37	3.73 ± 0.26	35.42
Green chopped forage	0.40 ± 0.22	4.26	0.85 ± 0.24	7.99	0.32 ± 0.23	3.04
Total	$9.39^{\mathtt{a}}\pm0.27$	100.00	$10.64^{\text{b}}\pm0.29$	100.00	$10.53^{\text{b}}\pm0.29$	100.00

 ab Means with a different superscript in the same row differ (P $\!<\! 0.05$). $^{\#}$ Standard error.

	Light weight	Medium weight	Heavy weight
CE expended for feed, Mcal	$1,569.13^{a} \pm 20.52^{\#}$	1,443.21 ^b ±22.42	$1,439.29^{b} \pm 22.06$
CE feedlot operations, Mcal	$275.84^{a} \pm 13.22$	$235.74^{b} \pm 14.44$	$212.63^{b} \pm 14.21$
CE for transport, Mcal	$466.09^{\mathtt{a}} \pm 3.20$	$503.24^{\mathrm{b}}\pm3.50$	$469.10^{\mathrm{a}}\pm3.44$
Total CE expended, Mcal	$2,311.06^{a} \pm 26.81$	$2,182.19^{b} \pm 29.29$	$2,121.02^{b} \pm 28.83$
CE for feed, Mcal d ⁻¹	$6.79^{\mathtt{a}}\pm0.33$	$7.36^{\rm a}\pm0.37$	$8.13^{\text{b}}\pm0.36$
CE, Mcal kg-1 gain	8.55 ± 0.56	8.92 ± 0.62	9.35 ± 0.61
Weaning carcass energy, Mcal	$292.34^{\mathrm{a}}\pm15.98$	$435.28^{b} \pm 17.11$	$573.05^{\circ} \pm 17.08$
Total carcass energy, Mcal	$993.46^{\mathtt{a}}\pm37.26$	$1,130.45^{b} \pm 40.71$	$1,303.42^{\circ} \pm 40.07$
Energy deposited in carcass during feeding, Mcal	701.12 ± 37.22	695.17 ± 40.67	730.37 ± 40.03
Carcass CE, Mcal kg ⁻¹	$9.22^{\mathrm{a}}\pm0.35$	$7.65^{\text{b}}\pm0.38$	$6.45^{\circ}\pm0.38$
Protein efficiency, Mcal input Mcal ⁻¹ protein energy output	$13.71^{\mathrm{a}} \pm 0.52$	$11.37^{\text{b}}\pm0.57$	$9.59^{\circ} \pm 0.56$
Efficiency, Mcal input Mcal ⁻¹ output	$3.30^{\mathrm{a}}\pm0.19$	$3.14^{ab}\pm0.21$	$2.90^{\text{b}}\pm0.21$

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

^{abc} Means with a different superscript in the same row differ (P < 0.05). # Standard error.

CE analyses of different body weights were compared. Cultural energy expended on feed was the highest contributor to total CE expended. Light weight cattle had a higher CE expended on feed than medium and heavy cattle (P < 0.05; Table 5). Even though the light cattle had a lower DMI (P < 0.05; Table 4) they had a higher CE expended on feed due to their longer fattening period on the feedlot (Table 3). Research has shown that heavier cattle consume more feed than lighter cattle (Ralston et al., 1970; Gaili and Osman, 1979; Schoonmaker et al., 2002; Koknaroglu et al., 2005a,b, 2006). The reason for heavy cattle to have a higher DMI is related to their body size. Thornton et al. (1985) found that DMI increased by 0.68 kg for each 45.4 kg increase in initial weight. These results agree with NRC (1996). Their prediction equation for DMI (kg d⁻¹) was:

DMI = 4.54 + 0.0125 * Initial body weight.

The relationship shows that DMI increases linearly as initial body weight increases. The CE expended on feed on all farms was 67.2% of total CE. This is in agreement with Koknaroglu *et al.* (2007) who found that CE expended on feed for fattening cattle fed in a feedlot throughout the feeding period was 61.9% of total CE expenditure. However, this was lower than reported by Cook (1976) who found that CE expended on feed for a 15,000 head feedlot operation was 84.6% of total CE expenditure.

In our feedlot operations the CE used in feedlot operations in Kansas feedlots $(1.20 \text{ Mcal } d^{-1})$ was used (Lipper *et al.*, 1976). As the CE for feedlot operations is a function of time spent on the feedlot, this was shown in the CE values for feedlot operations (Table 5). Light cattle spent longer on the feedlot because they

were lighter when they started fattening on the feed and required more time to reach market weight. They also had a lower ADG.

The medium weight group cattle had higher transport energy expenditure than the two other weight groups (P < 0.05; Table 5) and this could be due to their higher DMI. Transport energy was the second highest CE contributing to total CE expended. Cultural energy for the transport of 0.454 kg of live cattle for 1.609 km requires 4 kcal (Cook, 1976) and thus distance becomes more important for slaughterhouse since the cattle marketed are heavier than cattle started on feed.

The total CE expended is the sum of CE expended on feed, on feedlot operations and on transport. The light cattle had a higher total CE expenditure than the medium and heavy cattle (P < 0.05; Table 5). Total CE expenditure was similar for the medium and heavy cattle (P > 0.05; Table 5). The light cattle had a higher total CE expenditure due to higher CE expenditure on feed and feedlot operations.

Light and medium weight cattle used similar feed energy d^{-1} (P>0.05; Table 5). Heavy cattle used a higher feed energy d^{-1} because they stayed on the feedlot for less time.

Cultural energy expended kg⁻¹ of live weight increased as initial weight increased. A similar ratio was found by Koknaroglu *et al.* (2007) and a higher ratio was found by Cook (1976). Light cattle tended to have a lower CE expended kg⁻¹ of live weight gain because even though they had a higher total CE expenditure they had relatively higher weight gain during feeding period due to their longer stay on the feedlot.

As this study examines the CE expended and deposited during feedlot feeding, to avoid bias, energy deposited in the cattle before feeding on the feedlot weaning carcass energy was calculated. Weaning carcass energy increased as initial weight increased (P < 0.05; Table 5). This was because the initial weight of the cattle differed at the start of feeding.

Carcass energy content was low, average and high for light, medium and heavy cattle, respectively (P < 0.05; Table 5). As there were differences in cattle finishing weights due to their initial weight, differences could be expected at slaughter (Table 3). Another reason for this is that the dressing percentage increased with initial weight increase yielding heavier carcasses. When the cattle were sold, the light cattle weighted less and were supposed to be younger, thus they would be forming the skeleton and organs and developing muscle and depositing fat, whereas heavier cattle would have well developed muscles. Thus heavy cattle had a higher dressing percentage than light cattle (P < 0.05).

Cultural energy kg⁻¹ of carcass decreased as initial weight increased (P < 0.05; Table 5). This was lower than reported by Koknaroglu *et al.* (2007) who found that CE expended for 1 kg of carcass was 10.03-11.86 Mcal.

The CE Mcal⁻¹ for protein energy decreased as initial weight increased (P < 0.05; Table 5). Pimentel *et al.* (1975) found that energy use estimates for protein production was 10 Mcal Mcal⁻¹ protein for range beef and 78 Mcal for feedlot beef, whereas it was 2 to 4 Mcal of CE Mcal⁻¹ of protein from various plants. Pimentel (2004) reported that kcal of fossil energy required to produce 1 kcal of animal protein was either 40 or 20 kcal input kcal⁻¹ protein for beef cattle fed on a grain and forage mixture and for beef cattle fed only on forage, respectively. Koknaroglu et al. (2007) found that the CE expended Mcal⁻¹ protein energy was highest for cattle fed on a feedlot throughout the feeding period and was lowest for cattle grazed on pasture for a longer time and then finished on a feedlot. In this study the CE Mcal⁻¹ protein energy was lower than that reported in literature because the concentrate level was lower than reported in the literature but cattle performance was comparable. Ward et al. (1977) reported that least energy-intensive management systems required 16 Mcal of energy to produce 1 Mcal carcass beef protein while most energy-intensive system required 36 Mcal. Koknaroglu et al. (2007) fed cattle with 82% concentrate whereas in this work the cattle were fed a lower ratio of concentrate (Table 4).

Efficiency, defined as total CE expenditure divided by energy deposited in carcass during feeding shows Mcal of CE expended Mcal⁻¹ of food energy. This was highest for the light cattle and was lowest for the heavy cattle (P < 0.05). The medium cattle did not differ from the other two groups (P > 0.05; Table 5). These results are comparable to those of Cook (1976) who found that forage fed steers and grain fed steers had efficiencies of 3.47 and 5.18, respectively. Koknaroglu *et al.* (2007) found efficiency ranged from 3.26 to 4.07 for cattle fed for different periods on pasture and then finished on a feedlot.

This study showed that light cattle had higher CE expended on feed and feedlot operations than medium and heavy cattle. Light cattle had a higher total CE expenditure than medium and heavy weight cattle. The results show that, as initial weight increased, CE expended for a kg of live weight tended to increase. The CE expended for a Mcal of protein energy output decreased as initial weight increased. The efficiency of heavier cattle was better than that of lighter cattle and shows that to be more sustainable, cattle initial weight should be considered when starting cattle on feed.

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