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Estimation of Metabolizable Energy Requirements for Maintenance and Energetic Efficiency of Weight Gain in *Bos taurus* and *Bos indicus* Cows in Tropical Mexico

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Abstract: The aim of the present study was to estimate ME requirements for maintenance (ME_m) and Energetic Efficiency of Weight Gain (EEWG), in four Zebu (*Bos indicus*) and four Brown Swiss (*Bos taurus*) cows from cattle farms producing weaners in the tropical area of South Mexico. Cows were fed three levels of ME (low 120 kcal $kg^{-0.75}$, medium 180 kcal $kg^{-0.75}$ and *ad libitum*) during three periods of 28 days each, with an experimental ration consisting of 53% ground hay of *Pennisetum purpureum* CT-115 and 47% of a concentrate based on grains, containing 2.1 Mcal kg^{-1} DM of ME and 11.0% CP. Feed intake was measured by weighing food offered and that refused and cows were weighed at the beginning and every 14 days thereafter to assess average Changes in Live Weight (CLW). Requirement of EM_m was estimated by regressing values of CLW against ME intake (Y= B0 + B1* x). Average dry matter digestibility was 68.7±4.6 and 66.7±4.4%, whereas gross energy digestibility was 66.3±4.6 and 64.3±4.3%, for the Zebu and Brown Swiss cows, respectively. Significant differences ($p<0.05$) were found in dry matter and gross energy digestibilities due to breed of cow. No significant differences were found ($p>0.05$) for requirements of EM_m among Zebu and Brown Swiss cows (113.4±19.7 vs. 125.6±12.5 kcal/$kg^{0.75}$/d^1), although the values of EM_m of Zebu cows were 9.7% lower compared to those found for Brown Swiss. Efficiency of utilization of ME for maintenance (k_m) was similar ($p>0.05$) in both breeds of cows (0.62±0.1 and 0.74±0.1, for Zebu and Brown Swiss, respectively), although Brown Swiss cows showed a higher (19.4%) value for k_m. EEWG was similar among breeds, but Zebu cows showed greater (22.4%) values (80.2±24.6 and 65.5±4.7, for Zebu and Brown Swiss, respectively). Results from this research confirm that *Bos indicus* breeds of cattle have lower (10%) energy requirements for maintenance than *Bos taurus* breeds, an observation that may become an opportunity for beef ranching in Yucatan, for the development of cow genotypes based on crosses of *B. indicus* x *B. taurus*, which may allow an increase in energetic efficiency of beef production.

Key words: Beef, cattle breeds, energy, maintenance, energetic efficiency, Zebu cow

INTRODUCTION

Beef cattle production in the tropical areas of Mexico is carried out extensively and feeding is based on the grazing of native and introduced pastures with little or no supplementation. Cattle breeds are usually of the Zebu (*Bos indicus*) type with crosses with a variety of European (*Bos taurus*) breeds (Absalon, 2008). Crossbreeding has resulted in an improvement in growth of the offspring and reproductive performance of cows due to heterosis and complementarity; however, this strategy may induce changes in energy requirements for maintenance in cattle, particularly of the reproductive herd. Energy availability from feedstuffs is the greatest constraint to animal production and energy is obtained from the forage, which is harvested, while grazing (Rueda *et al*., 2003; Reynoso *et al*., 2004). Metabolizable Energy (ME) is an estimation of energy available to the animal and it appears as heat produced (maintenance) or retained energy in the animal as fat and protein in the carcass (Williams and Jenkins, 2003a, b).

From the total amount of energy required for beef production only 5.2-13.4% is recovered in the animals at slaughter (Ferrell and Jenkins, 1984b) and between 50-70% is employed for the maintenance component of the cow (Ferrell and Jenkins, 1985). The data suggest that energetic efficiency of beef production greatly depends of energy expenditure by the cow, due to the fact that Metabolizable Energy requirement for maintenance (ME_m) may vary between 10-30% due to genetic differences

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(Archer *et al*., 1999). Energy cost of maintenance by the cow is a factor of such a magnitude as to have substantial influence on energetic efficiency of beef production (Ferrell and Jenkins, 1985) and the knowledge of these requirements for different breeds and genotypes is of great importance to adjust maternal biological types to the environment (Johnson *et al*., 2003; Calegare *et al*., 2007).

In Mexico, there is no information regarding energy requirements for maintenance of the different breeds and genotypes of cattle, which are commercially exploited. In order to increase profitability of beef cattle production in tropical Mexico. It is of paramount importance to improve energetic efficiency at the farm, by employing the most efficient breeds and genotypes of cows. The aim of the resaerch hereby described, was to determine ME requirements for maintenance and energetic efficiency of weight gain in *Bos indicus* and *Bos taurus* cows in the tropical region of South Mexico.

MATERIALS AND METHODS

The experimental research was carried out at the beef cattle unit of Instituto Tecnologico de Tizimin (ITT) located in Tizimin, Yucatan, Mexico between March and July. The region is located at 17 masl, climate is AW, warm, subhumid, with an average annual temperature varying from 24.5-27.5°C, annual rainfall is 900-1100 mm, with most of the rain falling between June and October (Garcia, 1981).

Digestibility of dry matter and Gross Energy (GE) of the experimental ration was determined in two genotypes of non pregnant, non lactating cows, fed three levels of ME. Feed intake and changes of live weight were measured as well as requirements of ME for maintenance and efficiency of use of ME for maintenance and energetic efficiency of weight gain of the cows.

Animals and feeding: Four Zebu (*Bos indicus*) and fthe Brown Swiss (*Bos taurus*) cows, from commercial cattle farms in South Mexico were used. Cows had among 3-5 calvings ($\geq$7 years) and were non pregnant non lactating with at least 6 weeks of having weaned its calf were randomly assigned to individual corrals with a feeder trough, water and mineral salts. Cows were fed three levels of ME: low (120 kcal ME/kg$^{0.75}$/day), medium (180 kcal ME/kg$^{0.75}$/day) and *ad libitum*, during three consecutive periods of 28 days each, in a completely randomized design, with an experimental ration formulated to contain 11.0% crude protein and 2.0 Mcal ME kg^{-} DM (Table 1).

Table 1: Chemical composition of experimental ration for Zebu and brown Swiss cows

Ingredients	Incorporation (%)
Hay of *Pennisetum purpureum* CT-115	53.0
Ground corn	20.0
Wheat bran	20.2
Soyabean meal	6.8

Live weight changes and feed intake: Cows were adapted to corrals for 21 days prior to any measurement. Cows were weighed after 24 h water and food fast. Afterwards, each cow was weighed every 14 days in the morning after 15 h fast (water and food) to assess changes in live weight (CLW, kg day^{-1}). The amount of food offered to each cow according to feeding level was adjusted every two weeks keeping in mind the weight obtained at the last weighing and water and minerals were available at all times. Daily feed intake was measured by weighing the amount offered and that refused the next morning.

Chemical analysis of feedstuffs and feces: Daily samples of food offered and refused were obtained and stored in refrigeration for maximum periods of 7 days. A total of fthe samples of 100 g of feces per cow were obtained at each energy level. Fresh feces were taken from the floor and stored in plastic bags in the morning on days: 6, 13, 20 and 27 of each experimental period (Van Keulen and Young, 1977). Food and fecal samples were dried at 60°C for 48 h in an oven to determine dry matter content (Pichard *et al*., 1992). Once dry samples were ground to pass a 1 mm sieve and samples were taken to determine the percentage of acid-insoluble ashes in feed and feces (Thonney *et al*., 1979), as well as Crude Protein (CP), Neutral Detergent Fiber (NDF), Acid Detergent Fiber (ADF) and Gross Energy (EB, Mcal kg^{-1} DM) in the feedstuffs (Tejada, 1983).

Dry matter and gross energy digestibility: Digestibility of DM of experimental ration for each cow at each feeding level was determined, using the percentage acid-insoluble ashes in feed and feces as an internal marker, by using the following equation (Galyean, 1980):

$$\text{DMD (\%)} = 100 - 100\left(\frac{\text{AshA}}{\text{AshH}} \times \frac{\text{AshH}}{\text{AshA}}\right)$$

Gross Energy Digestibility (GED) of the ratio for each cow at each feeding level, was considered as the percent of Digestible Energy (DE) in the gross energy and was determined with the following equation:

$$Y = 0.981\ x - 1.08$$

Where:
Y = DEB
x = DMS (Minson, 1981)

Digestible Energy (DE) of the ratio was estimated with the equation:

$$DE = GE \times \left(\frac{GED}{100} \right)$$

and metabolizable energy was estimated as 82% of digestible energy (NRC, 2000).

ME requirements and energetic efficiency: ME requirement for maintenance (ME_m) was considered as the amount of ME consumed by the cow, which induces zero change in live weight, expressed as kcal ME kg^{-1} metabolic body weight/day ($kcal/kg^{0.75}/day^{1}$) (Solis *et al*., 1988). Efficiency of utilization of ME for maintenance (k_m) was estimated by means of the equation $k_m = NE_m/ME_m$ (Williams and Jenkins, 2003a), where NE_m represents net energy for maintenance and it was calculated as the value that NRC (2000) recommends for the Brahman and Brown Swiss breeds.

Energetic Efficiency of Weight Gain (EEWG) for the cows, was estimated as the grams of weight gain of the cows for each Mcal of ME consumed (g $Mcal^{-1}$ ME intake) (Solis *et al*., 1988).

Statistical analysis: A simple model was used to analyze the effect of genotype of cow (Brahman, Brown Swiss) and feeding level (ME: low, medium or *ad lib*), on response variables:

$$(Y_{ijk} = \mu + G_i + N_j + e_{ijk})$$

Where:

- Y_{ijk} = Response variable (DMI, DMD, GED, DE, ME)
- μ = General mean
- G_i = Genotype
- N_j = Level of feeding
- e_{ijk} = Random error

Em_m was estimated by simple regression of CLW against ME intake ($Y = B0 + B1 \times x$). ME requirement for maintenance (EM_m), K_m and EEWG, were subjected to Analysis of Variance (ANOVA) with the General Lineal Models (GLM) of SAS and means were compared with the multiple range test (minimum significant difference).

RESULTS AND DISCUSSION

Table 2 shows chemical composition of the experimental rations fed at each level of feeding. Average values for DM, CP, NDF, ADF, Ash and gross energy were 89.0±0.9, 9.9±0.4, 56.1±1.3, 30.2±1.6, 1.9±0.3% and 3.9±0.1 Mcal kg^{-1} DM, respectively.

Results for DM and GE digestibility are given in Table 3. Averages for DMI, DMD, GED, DE and ME for the experimental ration were 8.0±1.2, 67.7±4.6, 66.3±5.1%, 2.5±0.2 Mcal kg^{-1} DM and 2.1±0.04, respectively.

Chemical composition of the experimental ration and concentrations of ME (2.1 Mcal kg^{-1} DM) and crude protein (9.9±0.4%), are within the values reported by several researchers (1.7-2.5 Mcal kg^{-1} DM; 8.5-12.0% CP), to perform experiments on the estimation of nutritional requirements, by means of intake trials (Ferrell and Jenkins, 1984b; Solis *et al*., 1988; DiCostanzo *et al*., 1990; DiConstanzo *et al*., 1991). Although, its DE and ME content correspond to rations classified as of low energy concentration (Moore *et al*., 1975).

No significant differences ($p>0.05$) were found for DMD and GED due to the effect of level of feeding. DMI was increased from the low to the medium level of feeding by 42.6%, although from the medium to the *ad libitum* levels of feeding, intake increased by only 5.7%, thus no high feed intakes were achieved, perhaps as a result of low energy concentration in the ration used in this study.

Significant differences ($p<0.05$) were found for DMD and GED by effect of breed. Zebu showed DMD and GED values higher than Brown Swiss cows by 3.2 and 3.1%, respectively. However, some researchers have suggested that there are no differences in food digestibility (DMD and GED) among *Bos indicus* and *Bos taurus* types of cattle (Howes *et al*., 1963; Kennedy, 1982), even in a situation, where DMD was higher (82.4±4.6 and 73.8±5.0% for Angus and Angus x Brahman, respectively) than those obtained in the present study (Boyles and Riley, 1991).

On the other hand, there is evidence which demonstrates that *Bos indicus* breeds of cattle utilize low quality forage rations more efficiently than *Bos taurus* breeds (Ferrell *et al*., 2005), which agree with the results of the present study, where the ration was based on forrage. With rations based on forages (11.0% CP, 2.4 Mcal DE kg^{-1} DM), Moore *et al*. (1975), found differences ($p<0.05$) among *B. indicus* and *B taurus* types of cattle in dry matter digestibility (61.7 vs. 55.6% DMD) and gross energy digestibility (60.0 vs. 53.5% DEB). Moore *et al*. (1975) observed a higher ($p<0.05$) disappearance of dry matter *in vitro* in Brahman compared to Hereford (71.0 vs. 67.4%) steers and this was believed to be a result of the higher rate of fermentation of feedstuffs in *Bos indicus* type of cattle, due to the different rates at which rumen microorganisms attack cellulose.

Thus, the use of *B. indicus* and its crosses with *B. taurus* in cow-calf systems for meat production in the Mexican tropics may contribute to improve energetic efficiency of meat production by means of an increase in the supply of ED as it has been suggested under tropical conditions by Solis *et al*. (1988) and Tedeschi *et al*. (2002).

Table 2: Chemical composition of experimental rations fed to Zebu and brown Swiss cows

Energy level	DM (%)	CP (%)	NDF (%)	ADF (%)	Ash (%)	GE ($Mcal\ kg^{-1}$ DM)
120 kcal ME/kg$^{0.75}$/day						
Mean	89.2	9.6	56.3	30.7	1.8	3.88
CV	0.7	3.3	2.9	4.4	10.7	0.6
180 kcal ME/kg$^{0.75}$/day						
Mean	89.9	10.1	55.8	31.2	1.9	3.83
CV	1.8	1.5	1.7	6.4	2.7	2.8
Ad libitum						
Mean	86.6	10.4	55.9	28.4	2.3	3.8
CV	1.8	2.2	2.6	1.8	7.0	0.7

DM = Dry Matter; CP = Crude Protein, NDF = Neutral Detergent Fiber; ADF = Acid Detergent Fiber; Ash = Acid-insoluble Ashes; GE = Gross Energy; Mcal = Megacalories; kg = kilogram; CV = Coefficient of Variation

Table 3: DM intake, DM and GE digestibility, digestible and metabolizable energy of the experimental ration in relation to breed and Feeding level

Ingredients	DMI (kg day^{-1})	DMD (%)	GED (%)	DE $Mcal\ kg^{-1}$ DM	ME $Mcal\ kg^{-1}$ DM
Breed					
Zebu	8.1±0.1	68.7±0.6^a	66.3±0.6^a	2.6±0.02	2.1±0.02
Brown Swiss	7.9±0.1	66.6±0.6^b	64.3±0.6^b	2.5±0.02	2.1±0.02
Energy level					
120 kcal ME/kg$^{0.75}$/day	6.1±0.1^c	68.6±0.8	66.3±0.8	2.6±0.03^a	2.1±0.03
180 kcal ME/kg$^{0.75}$/day	8.7±0.1^b	68.2±0.8	65.8±0.8	2.6±0.03^a	2.1±0.03
Ad libitum	9.2±0.1^a	66.2±0.8	63.9±0.8	2.4±0.03^b	2.0±0.03^{abc}

Different letters inside a column, in the same factor are statistically different ($p<0.05$). DMI = Dry Matter Intake; DMD = Dry Matter Digestibility; GED = Gross Energy Digestibility; DE = Digestible Energy; ME = Metabolizable Energy; SE = Standard Error; Values are shown as mean±SE

Table 4: Means and standard deviations for metabolic weight, ME intake and live weight changes of *B. indicus* and *B. taurus* cows fed three levels of feeding in tropical Mexico

			ME Intake (MEI)		
Genotype of cow	Energy level	Mean metabolic weight (kg$^{0.75}$)	Mcal day^{-1}	kcal/kg$^{0.75}$/day	LWC (kg day^{-1})
Zebu	120 kcal ME/kg$^{0.75}$/day	93.0±9.5	12.8±1.2	138.4±4.6	0.2±0.4
	180 kcal ME/kg$^{0.75}$/day	93.0±11.9	17.3±2.4	186.2±3.7	1.5±0.9
	Ad libitum	96.6±11.6	19.0±2.9	197.4±26.4	0.8±1.3
Brown Swiss	120 kcal ME/kg$^{0.75}$/day	85.5±3.9	11.2±0.004	132.5±6.5	0.6 ±0.2
	180 kcal ME/kg$^{0.75}$/day	88.0±3.8	12.4±0.03	144.7±6.2	0.9±0.1
	Ad libitum	92.1±4.2	17.9±0.01	204.0±8.8	1.5±0.3

Mcal day^{-1} = Megacalories per day; kcal/kg$^{0.75}$/day = kilocalories per metabolic body weight per day; LWC = Live Weight Change; kg = kilogram

Table 5: Regression equations for the estimation of energy requirements for maintenance, efficiency of utilization of ME for maintenance (k_m) and Energetic Efficiency of Weight Gain (EEWG) in *B. indicus* and *B. taurus* cows in the tropics

Genotype of cow	Regression equation	R	SE	Me_m (kcal/kg$^{0.75}$/day)	k_m	EEWG (g $Mcal^{-1}$ MEI)
Zebu	Y = 118.197 + 41.6859 x LWC	0.84±0.03	9.1	113.4±19.7	0.62±0.1	80.2±24.6
Brown Swiss	Y = 132.053 + 38.2976 x LWC	0.75±0.2	7.9	125.6±12.5	0.74±0.1	65.5±4.7

R = Correlation coefficient; SE = Standard Error; kcal = kilocalorie; ME_m = ME requirement for maintenance; km = Efficiency of utilization of ME for maintenance; EEWG = Energetic Efficiency of Weight Gain; g = Grams; Mcal = Megacalorie; MEI = ME intake, LWC = Live Weight Change. a, b = Literals within the same column are statistically significant ($p<0.05$)

Table 4 gives results for metabolic body weight, ME intake and live weight changes of cows in relation to genotype and level of feeding. No significant differences ($p>0.05$) were found in metabolic body weight among genotypes, although Zebu (94.2±10.9 kg$^{0.75}$) was 6.4% heavier than Brown Swiss cows (88.5±4.0 kg$^{0.75}$). ME intake (Mcal day^{-1}; kcal/kg$^{0.75}$/day^{1}) increased linearly, in response to the increase in level of feeding.

Table 5 shows results for regressions performed to estimate requirements for ME_m, k_m and EEWG for Zebu and Brown Swiss cows. No significant differences were found ($p>0.05$) for ME_m requirements, k_m and EEWG among Zebu and Brown Swiss cows. Results for ME_m for Zebu cows (113.4±19.7 kcal/kg$^{0.75}$/day^{1}) are within the range of values for *B. indicus* breeds; Solis *et al*. (1988) estimated 98 kcal $kg^{-0.75}$ (SE = 4.8) as the requirement of ME_m for Brahman cows, for Nellore cows, Calegare *et al.* (2007) estimated 141 kcal $kg^{-0.75}$ for Me_m and Chizzotti *et al.* (2008) reported 109, 108 and 110 kcal $kg^{-0.75}$ for ME_m for bulls, heifers and young bulls, respectively. ME_m requirements estimated for Brown Swiss cows (125.6±12.5 kcal/kg$^{0.75}$/day) are similar to those reported for that type of cattle.

Ferrell and Jenkins (1984b) observed that *Bos taurus* cows of medium size and medium to high milk yield, Me_m requirements of 130-145 kcal $kg^{-0.75}$, Solis *et al.* (1988) for Holstein cows, estimated 119 kcal $kg^{-0.75}$ as ME_m (SE = 4.8). Zebu cows gave 9.7% lower ME_m requirement than Brown Swiss cows, which agrees with 10% lower ME_m requirement *Bos indicus* breeds compared to animals of the *Bos taurus* type (NRC, 2000).

Differences observed among Zebu and Brown Swiss cows for ME_m requirements may be attributed to biological factors such as body composition and genetic potential for milk production, which together determine basal energy expenditure due to the mass and activity of the metabolically active organs such as the liver and the intestines (Jenkins *et al*., 1986; Montaño *et al*., 1990; DiCostanzo *et al*., 1990; Ferrell and Jenkins, 1998b).

Brown Swiss is considered a breed of high potential for growth and milk production, thus the cows may present heavier metabolically active organs and a high energy cost for maintenance compared to Zebu type cows (Jenkins *et al*., 1986; Archer *et al*., 1999).

In the present experiment, body composition of the cows was not measured; however, it is possible that differences did exist in distribution of body fat between the two breeds evaluated. Distribution of body fat is a factor, which in part determine energy expenditure for maintenance in the cows and it has been demonstrated that breeds with higher potential for growth and milk production deposit more intramuscular fat and around the organs, which involves a greater energy expenditure for maintenance, while meat breeds accumulate subcutaneous fat instead (Ferrell and Jenkins, 1998a, b).

For beef production in the tropics it is important to use cows of breeds or genotypes with low requirements of Me_m. *B. indicus* and its crosses with *B. taurus* are characterized by low requirements of ME_m and deposit subcutaneous fat (Ferrell and Jenkins, 1984a, b), which represents an advantage under tropical conditions, since reserves of adipose tissue may be utilized with a high energetic efficiency (k_f = 0.80) for maintenance and lactation (AFRC, 1993).

Estimates of k_m for Zebu cows (k_m = 0.62) were 16.2% lower than for Brown Swiss cows (k_m = 0.74), but they are within the range (0.60-0.77) for more conventional cattle rations (Webster, 1976). Tedeschi *et al*. (2002) estimated a value for k_m of 0.66 and 0.69 for bulls and steers, respectively and Ferrell and Jenkins (1998a, b) estimated similar values for k_m ($p>0.05$) in the range 0.65-0.69 for various breeds of *B. taurus* and its crosses with *B. indicus*. In the experiment hereby described, results suggest that the use of ME for maintenance was higher for Brown Swiss cows, which reflects the greater potential for production of this breed. Archer *et al*. (1999) reported that there is evidence among cattle breeds that there are differences in efficiency of utilization of ME for maintenance and those differences are highly correlated with the productive potential of each breed.

EEWG estimated for Zebu and Brown Swiss cows in the present research were within the range found by Solis *et al*. (1988) for meat and milk cows (58-151 g $Mcal^{-1}$ of MEI); EEWG was 22.4% greater for Zebu (80.2±24.6 g $Mcal^{-1}$ of MEI) compared to Brown Swiss cows (65.5±4.7 g $Mcal^{-1}$ of MEI).

Results obtained for Zebu cows suggest an apparent greater efficiency for this breed for the use of ME for weight gain, which may be the result of differences among breeds in deposition and distribution of tissues in the body and higher metabolic activity as were pointed out by several researchers (Solis *et al*., 1988; Owens *et al*., 1995).

This situation is of great importance in production systems, where food is not completely available during the whole year as in the tropics. Working in Israel, Aharoni *et al*. (2009) estimated that under situations of harsh environmental conditions, small size mature cows (Baladi breed; 268 kg Live Weight) expended less energy in locomotion and had a greater digestible intake per unit of metabolic body weight than large size cows (Beefmaster x Simford; 581 kg Live Weight). It is then likely, that small size breeds of cows may have an implication in the search for increasing energetic efficiency of beef production in the tropics.

Energetic efficiency of beef production is the result of the interplay of the cow-calf system before and after weaning thus, the efforts must be directed towards increasing the amount of meat produced by the progeny as a percentage of the reproductive herd (Archer *et al*., 1999; Calegare *et al*., 2009). Under tropical conditions, it is important to produce meat at the least possible cost as far as feeding costs are concerned, in order to increase energetic efficiency of the complete cycle of beef production.

Therefore, the best strategy to increase energetic efficiency of meat production in adverse nutritional environments in cattle production systems, is to have cows with low energy requirements for maintenance (Montaño *et al*., 1990; Montaño and Nielsen, 1990a, b; Green *et al*., 1991a, b; Fox *et al*., 2002).

CONCLUSION

Zebu cows showed a higher digestibility ($p<0.05$) of DM and gross energy than Brown Swiss cows. There were no significant differences ($p>0.05$) for ME_m requirements among Zebu and Brown Swiss cows, although values of ME_m for Zebu cows were 9.7% lower. Efficiency of utilization of ME for maintenance (k_m) was similar ($p>0.05$) for both breeds, but Brown Swiss had a

19.4% higher k_m value. Energetic efficiency of weight gain was similar for both breeds, but Zebu cows showed a 22.4% higher value than that for the Brown Swiss breed.

Beef cattle production in the tropical areas of Mexico may be benefited by using breeds or genotypes of cows with moderate potential for milk production, without the disadvantages involved in using cows with high energy requirements for maintenance. This could represent an opportunity to realize significant increases in weaning weight, higher post-weaning weight gains of the progeny and higher energetic efficiency of beef production in nutritionally restricted environments such as those in the tropics.

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