Manipulation of the energy metabolism of ruminants in the tropics: options for improving meat and milk production and quality

J.C. Ku Vera, E.G. Briceño, A. Ruiz, R. Mayo, A.J. Ayala, C. F. Aguilar, F.J. Solorio and L. Ramírez
Facultad de Medicina Veterinaria y Zootecnia, Universidad Autónoma de Yucatán. C.P. 97300 Mérida, Yucatán, México
Email: kvera@uady.mx

Ruminant feeding in tropical regions is characterized by grass grazing. Throughout the year, grasses show variations in their availability and quality. Therefore, modern feeding systems must consider the energy requirements of the animal and the degree in which a feed or a combination of several of them could cover the nutritional requirements of the different species and physiological conditions. The central reaction for obtaining energy is carry out in the rumen in the anaerobic fermentation of the carbohydrates present in the feed. This process is developed by the ruminal microorganisms, with the purpose of generating energy for the microbial growth and the concomitant production of volatile fatty acids, methane, carbon dioxide and fermentation heat. For improving meat and milk production and quality in tropical regions, different options have been created for manipulating the energy metabolism of ruminants. Silvopastoral systems, based on *Leucaena leucocephala* and *Panicum maximum* association, allow attaining live weight gains of 770 g/d in growing cattle. It is essential the identification of *Bos indicus* cattle breeds or crosses with lower requirements of metabolizable energy (ME) for maintenance, so as the energy efficiency of meat production could be increased. For milk, it is possible to increase the concentration of unsaturated fatty acids (CLA's) by the tannin presence in the foliages that due to its beneficial effect on human health, could supply aggregate value to the cow's milk. Feeding practices are necessary for reducing the caloric increase of the feeding and that decrease methane emissions from the rumen through the effect of some foliages and fruits that possess secondary metabolites capable of affecting ruminal fermentation.

Key words: *energy metabolism, tropical feeds, ruminants*

Introduction

Ruminant production systems in tropical regions are, in their majority, of extensive type. In them, immense land extensions are used for pasture culture. Cattle (beef and milk) and sheep feeding under these conditions are based on the grazing of native pastures species and of others introduced. The availability and quality of the pasture fluctuate throughout the year, due to the variations in rainfall (Ku-Vera *et al*. 2013). During the dry season, the dry pasture is available which contains low concentration of crude protein, high concentration of NDF, low apparent digestibility and thus, low metabolizable energy (ME) concentration. In this stage, dry matter (DM) consumption of ruminants is reduced, though their ME requirements for maintenance cannot be covered. This leads to a negative energy balance and weight losses, delaying in time (months) for the growing animals to attain the slaughter weight. This shortage also provokes low milk yields per cow.

The implementation of agroforestry type practices, as the silvopastoral, allows the integration of trees and shrubs with animal production. With this model, more rational production systems can be developed attempting less against the ecological balance of the tropical region and that, could even improve animal performance (live weight gain, milk yield), the quality of the products of animal origin (CLA's increase in meat and milk) and profitability by means of the manipulation of the ruminal fermentation.

The tree species producing foliage and fruits can be satisfactorily incorporated to ruminant feeding as fibrous, energy and protein forage, mainly in the dry seasons (Ku-Vera *et al*. 1999). In addition to their high nutritive value, these tropical resources can contain secondary metabolites that contribute to modify ruminal fermentation (Kamra *et al*. 2008 and Soliva *et al*. 2008), defaunate the rumen (Koenig *et al*. 2007) and in consequence, reduce the CH_4 emissions (Patra and Saxena 2009 and Mao *et al*. 2010).

The purpose of this paper is to review the available information on ruminal fermentation of forages and its implications on the energy metabolism. It is also intended to formulate some considerations regarding the options for increasing the efficiency of energy utilization in meat and milk producing cattle in the tropics.

Energy requirements of ruminants in cattle production systems. In modern ruminant production systems it is necessary to study the energy requirements of the animals in their different physiological states, to formulate rations, program the supply of feeds by way of the sowing and harvesting of forages, purchase of supplements and the use of by-products and culture wastes. It is important to gain knowledge on the capability of the available feeds in the ranch (ME concentration or of net energy) to cover the energy requirements of the different ruminant species (bovines, sheep, goats), for increasing animal response (live weight gain, milk yield).

Modern systems for energy feeding in ruminants (Valadares Filho *et al*. 2010) are mainly based on two components: the energy requirements of the animal and the degree in which a feed or a combination of several of them can cover these requirements. The energy requirements of ruminants have been conventionally divided into requirements for maintenance, estimated as FM/km (FM is the fast metabolism and km is the utilization efficiency of ME for maintenance), when ME consumption equals heat production, without producing gain or loss in the energy reserves and on the requirements for the production (live weight increase, milk production and wool) (CSIRO 2007). The maintenance is defined as the amount of feed (energy) resulting in a zero energy balance (figure 1). The energy requirement for maintenance represents a substantial proportion of the daily energy requirement of ruminants under production.

There are diverse criteria on the relative contribution of the different physiological functions (ion transportation [Na+, K+, Ca_2+], heart function, kidney function, respiration, protein and fat rechanging, among others) and the energy requirement for ruminant maintenance (Summers *et al* 1988). Chizzotti *et al*. (2013) emphasized on the importance of protein rechanging in the energy expense in *Bos indicus* cattle regarding the *Bos taurus*, due to the calpastatin activity in the muscular tissue, differing in each one.

Utilization of the consumed energy by ruminants. The central rumen reaction is the anaerobic fermentation of the carbohydrates of the feed. This takes place by the enzymes of the ruminal microorganisms (Krause *et al*. 2013), with the purpose of generating energy (ATP) for the microbial growth and the concomitant production of short chain fatty acids (acetic, propionic and butyric), methane, carbon dioxide and heat from the fermentation. In the ruminal environment lacking of oxygen, only generate 4-5 ATP's per mol of fermented glucose, representing from 10 to 12 % of its potential yield under aerobic conditions (36 ATP'S/mol). This thermo-dynamic limitation must be understood in the effort for synchronizing the energy availability (ATP) and the nitrogen (NH_3-N) in the rumen under practical feeding conditions, with the purpose of extracting the highest amount of useful energy of this system. The total chemical energy contained in the feeds is known as crude energy or combustion heat. This expression represents the chemical energy stored in the cellulose, hemicelluloses, starch, protein amino acids and fatty acids of the fats. The utilization efficiency of the gross energy by the ruminants is determined by complex interactions between the physical characteristics of the feed, the digestive processes occurring in the gastrointestinal tract (GIT) and the different metabolic activities associated with the maintenance and growth. Several proportions of the crude energy are lost in the processes of apprehension, digestion, absorption, transport and metabolism of nutrients.

When to the gross energy of a feed or ration is subtracted from that contained in the feces excreted by the ruminant, the product is denominated digestible energy. Once subtracted to this that lost in urine (urea, ammonia, uric acid, creatine, among others) and the gas erupted as methane (CH_4), the resulting product is called ME. When to this latter is subtracted the caloric increase of feeding, the product is the net energy which represents the amount of energy that is truly available for covering the maintenance requirements and the production (live weight gain, milk production). There are in world some energy systems relating the energy value to the feeds with the ruminant requirements: metabolizable energy

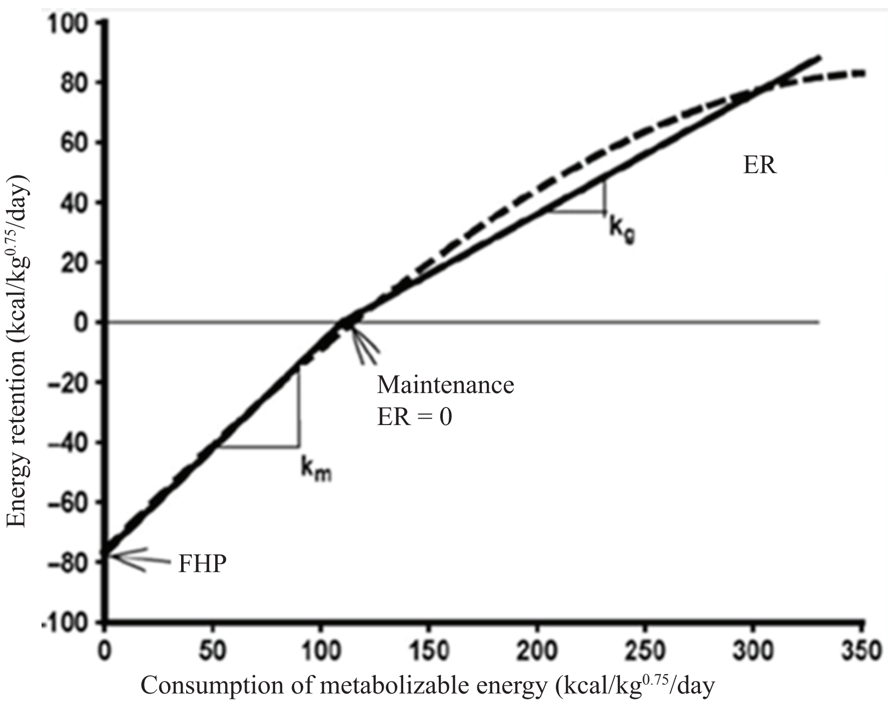

Figure 1. Relationship between ME consumption and energy retention in ruminants (FHP = fast heat production; ER = energy retention and km and kg = efficiency of ME utilization for maintenance and live weight gain, respectively (Ferrell and Oltjen 2008)

system (AFRC 1993, CSIRO 2007 and Valadares Filho *et al*. 2010) and net energy system (NRC 2007). The efficiency with which ruminants use ME, either lower (km) or higher (kf) to maintenance at this feeding level, is determined by the caloric feeding increase.

Energy efficiency in the production with ruminants. Under the conditions of tropical climate it is important to supply rations to the animals leading to low caloric increase of feeding. It is known that grains (starch) induce a low caloric increment of feeding compared to forage (cellulose). However, in areas of tropical climate it is not frequently possible to obtain grains or they are expensive for devoting them to ruminant nutrition. Under these circumstances it is convenient to supply a type of substrate with lower caloric increment. Fat is the nutrient with the highest energy density and with lowest caloric increment, representing thus an option for reducing the production of metabolic heat during the period of caloric stress under tropical conditions.

The possibility of reducing the caloric increase of the feeding in ruminants consuming typical rations of tropical regions (pastures with low concentration of crude protein, high concentration of NDF, low digestibility) could lead to the increase of the energy efficiency in production systems with ruminants. More studies are required on the energy requirements (maintenance, live weight gain, milk production) of the breeds (and crosses) of cattle (*Bos indicus* and *Bos indicus* x *Bos taurus* types) which are maintained under commercial conditions in the tropics. Researches are also needed on the utilization efficiency of ME (km; kf) under these climatic conditions (Valadares Filho *et al*. 2010, Marcondes *et al*. 2010 and Cárdenas Medina *et al*. 2010). It is also important to know the individual variation existing in the energy requirements for maintenance in the cattle breeds commercially exploited in tropical regions (Tedeschi *et al*. 2010), for identifying those making more efficient use of the absorbed ME from the GIT. This Brazilian feeding system for Zebu beef cattle incorporates some of these elements in its expressions of the ruminant energy requirements (Valadares Filho *et al*. 2010). It is important to identify the cattle breeds with lower energy requirements for their maintenance (Vercoe 1970, Frisch and Vercoe 1977, Calegare *et al*. 2007 and Calegare *et al*. 2009) and for increasing energy retention in the body of the animal (protein, fat).

Manipulation of the ruminal metabolism in the silvopastoral systems. Ruminant feeding depends on biomass production from tropical pastures. However, grasses do not contain enough crude protein for inducing rapid and consistent live weight gains throughout the year. Tropical grasses generally do not surpass 10 % of crude protein (Shelton and Dalzell 2007).

Barros *et al*. (2012) indicated that *Leucaena leucocephala* foliage contains 29 % of crude protein, which is highly digestible (63 % *in vitro*) and that its biomass yield is constant all over the year (table 1). The incorporation of tree legumes as *L. leucocephala* in the silvopastoral systems is an alternative for increasing meat and milk production of ruminants, since they supply nutrient-rich forages which are essential for the growth of animals.

Live weight gains of the cattle reported by Campos *et al*. (2011) under silvapastoral systems of Brazil were higher in the two seasons of the year (table 2). This probably indicates that the nutritive value in these systems is higher than in monocultures. Likewise, live weight gain in kg/ha was also higher, favoring the silvopastoral systems. Campos *et al*. (2011) reported that the crude protein and NDF content of *Brachiaria decumbens* were of 8.6 and 72 % in the rainy season, respectively. However, in the dry period, the crude protein concentration was of 7.3 and 71 % for NDF.

Live weight gains of the cattle reported by Campos *et al*. (2011) under silvapastoral systems of Brazil were higher in the two seasons of the year (table 2). This probably indicates that the nutritive value in these systems is higher than in monocultures. Likewise, live weight gain in kg/ha was also higher, favoring the silvopastoral systems. Campos *et al*. (2011) reported that the crude protein and NDF content of *Brachiaria decumbens* were of 8.6 and 72 % in the rainy season, respectively. However, in the dry period, the crude protein concentration was of 7.3 and 71 % for NDF.

The silvopastoral systems come closer to the concept of sustainable cattle production models and represent an alternative for granting aggregated value to milk and beef production. It is evident that presently the cattle

Table 1. Chemical composition (g/kg DM) and edible biomass yield (kg DM/ha/paddock) of the forage components associated with the silvopastoral systems in Yucatan, Mexico (Barros *et al*. 2012)

Indicator	*Leucaena leucocephala*	*Panicum maximum*	*Cynodon nlemfuensis*
Dry matter	270	310	300
Crude protein	291	114	95
NDF	372	627	692
Grazing lands	Forage production, kg DM/ha/paddock		
	Leucaena leucocephala	Grasses	Total
35 000 leucaena plants/ha	984±47	3737±34	4721±82
55 000 leucaena plants/ha	2037±42	3050±34	5086±77

Table 2. Average daily gain (g/animal) and gain per area (kg/ha) according to the production system and year in the rainy and dry periods (Campos *et al*. 2011).

Year of the experiment	Rainy season		Dry season	
	Silvopastoral	Monoculture	Silvopastoral	Monoculture
Daily gain				
2004/2005	722	624	348	387
2005/2006	647	563	298	274
2006/2007	628	515	420	352
Mean	666	567	355	338
Live weight gain per area				
2004/2005	298	256	88	97
2005/2006	242	230	75	68
2006/2007	258	211	105	89
Mean	266	232	89	85

production systems must incorporate the local resources (Wanapat 2009) to obtain higher profitability, due to the high costs of the grain-rich feeds. Silvopastoral systems allow the improvement of live weight gain regarding those from monoculture. Ramírez *et al*. (2009) reported that live weight gains of sheep grazing from a monoculture range between 70-100 g/animal/d, depending on the pasture quality. Barros *et al*. (2012) obtained moderate live weight gains in Pelibuey sheep grazing 35 000 and 55 000 leucaena plants (table 3).

In Michoacán, Mayo-Eusebio *et al*. (2012, personal communication) in studies with cattle grazing silvapastoral systems associated with *Panicum maximum* var. Tanzania and 30 000 *Leucaena leucocephala* plants registered 770 g/d of live weight gain (figure 2). This gain is comparable to that indicated by Shelton and Dalzell (2007) in Australia, with similar production systems.

Increase of the aggregated value of the meat and milk from ruminants. Among the unsaturated fatty acids are the conjugated linoleic acid and its isomers (CLA's is the English abbreviation), whose concentration in the milk

Table 3. Live weight gains (g/d) and feed consumption of sheep in a silvopastoral system of Michoacán (Barros *et al*. 2012)

Treatments	Daily weight gain	Feed consumption (kg/d)	Feed consumption g/kg$^{0.75}$
35 000 leucaena plants/ha	106.4±12	0.968	84
55 000 leucaena plants/ha	81.3±12	0.843	72

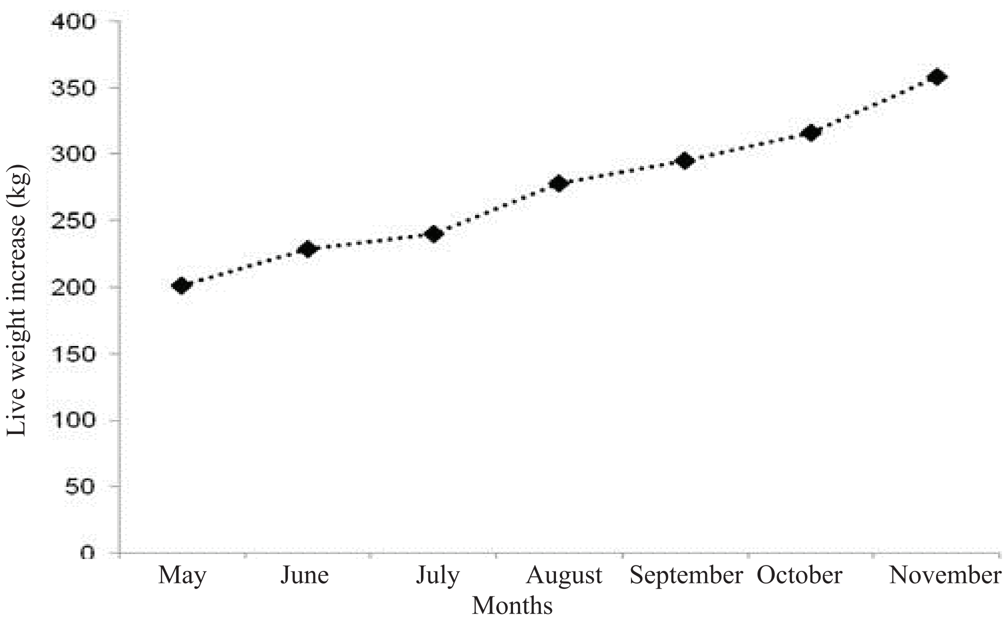

Figure 2. Live weight increase in cattle grazing in a *Panicum maximum* var. Tanzania and *Leucaena leucocephala* association in Michoacan (Mayo-Eusebio 2012, personal communication)

could be increased through the management of ruminant feeding which grants aggregate value to the cow's milk. The benefits that CLA's supplies to human health are diverse: prevention of diseases as atherosclerosis, cancer (rumenic acid), diabetes, blood pressure reduction, improves mineralization of bones, of insulin sensitivity and of immune response (Vasta *et al*. 2009 and Martínez *et al*. 2010). The CLA present in the dairy fat comes from a fraction product of the biohydrogenation of the linoleic acid in the rumen, catalized by the linoleate isomerase enzyme of the *Butirivibrio fibrosolvens* bacterium and the endogenous way taking place at the mammary gland through the Δ9-desaturase enzyme. This enzyme synthesizes the CLA from the vaccenic acid, which is another intermediary for the ruminal biohydrogenation of unsaturated fatty acids, as the linoleic and the linolenic, in the biochemical route to the conversion into stearic acid (Vasta *et al*. 2009 and Martínez *et al* 2010).

Tannins are phenological compounds interfering with the digestive processes by the union with the proteins of the diet and by the reduction of the activity of ruminal microorganisms. Vasta *et al*. (2009) stated that diets tannin-rich reduce the ruminal biohydrogenation in *in vitro* studies. There are several factors which are capable of changing the amount of vaccenic acid formed in the rumen. Among these can be mentioned the production system, the type of feeding for the cows, the breed and the use of additives in the diet, the milk production level, the lactation stage and the season of the year (Martínez *et al*. 2010).

Montero *et al*. (2011) determined the profile of fatty acids in the intramuscular fat of finishing crossbred ¾ Europpean x ¾ Zebu young bulls under grazing (*Cynodon nlemfuensis*) and in corrals (maize, soybean and tallow ration). Animals maintained in the corrals with integral diets ingested higher amount of fatty acids (palmitic, stearic, oleic and linoleic) through the ingredients of the corral diet, regarding the grazing young bulls. These latter consumed more α-linolenic acid which favors the ω6:ω3 relationship.

The feeding system modifies the profile of fatty acids in the intramuscular fat of bovines (table 4). Even though grazing animals consumed similar amounts of miristic and palmitic acids than the animals in the corrals, they deposited less amount of saturated fat and had greater deposition of stearic acid.

In spite of the fact that in this study no significant differences were found in the total CLA's content and of the isomer cis-9, trans-11 CLA between treatments, it is possible that grazing in silvopastoral systems allows the improvement of the concentration of these fatty acids, by coming directly from the rumen synthesis (Montero *et al*. 2011).

Montero *et al*. (2011) reported that the profile of fatty acids in crossbred bulls is different, due to the level of Europpean or Zebu type crossbreeding. Animals of *B. indicus* origin possess saturated fatty acids of poorer quality, on having more miristic and palmitic and less stearic. Nonetheless, in these animals the unsaturated acid contents as the linoleic and linolenic are higher than in bulls with dominance of *B. taurus* genes (table 5).

It is known that in the fatty acid composition of the meat the type of ration supplied to the animals influence

Table 4. Profile of fatty acids in the intramuscular fat of young bulls in corrals and under grazing (mg/g of fat) (Montero *et al*. 2011).

Fatty acids	Grazing	Corral
(C14:0 (miristic)	32.4	21.8
C14:1 (miristoleic)	25.2	23.8
C16:0 (palmitic)	255.4	236.5
C16:1 (palmitoleic)	32.6	30.8
C18:0 (stearic)	189.0	229.0
C18:1 (oleic)	383.9	357.4
C18:1 11-trans (vaccenic)	1.6	1.7
C18:2 (linoleic)	59.2	42.8
Total CLA	16.8	14.4
9-cis, 11-trans C18:2 (CLA)	5.8	6.1
C18:3 (linolenic)	10.9	7.7
Saturated	473.3	487.7
Monounsaturated	428.6	424.6
Polyunsaturated	81.5	93.2
Polyunsaturated:saturated	0.2	0.2
ω6:ω3 proportion	7.4	0.7

Table 5. Profile of fatty acids in the intramuscular fat of crossbred young bulls ¾ *Bos indicus* vs *Bos taurus* (mg/g of fat) (Montero *et al*. 2011)

Fatty acids	¾ *Bos indicus*	¾ *Bos taurus*
(C14:0 (miristic)	30.7	25.6
C14:1 (miristoleic)	26.5	22.5
C16:0 (palmitic)	254.6	237.3
C16:1 (palmitoleic)	33.1	30.4
C18:0 (stearic)	191.7	226.3
C18:1 (oleic)	375.2	366.1
C18:1 11-trans (vaccenic)	1.6	1.7
C18:2 (linoleic)	64.4	37.6
Total CLA	18.8	12.4
9-cis, 11-trans C18:2 (CLA)	6.3	5.6
C18:3 (linolenic)	12.5	6.1
Saturated	476.7	484.8
Monounsaturated	444.0	409.2
Polyunsaturated	90.7	84.1
Polyunsaturated:saturated	0.19	0.18
ω6:ω3 proportion	7.1	7.3

markedly. Presently, it is accepted that ruminant feeding with fresh forages propitiates greater amount of health promoters, fatty acids (polyunsaturated fatty acids [PUFA], rumenic acid and n-3 fatty acids) in the meat and low proportion of saturated fatty acids, if compared with the meat of animals consuming concentrates (Vasta *et al*. 2012).

The silvopastoral systems could allow that ruminants graze in high nutritional quality forages, resulting very convenient, since they offer aggregate value to the meat by modifying its nutritional properties.

Vasta *et al*. (2012) evaluated if the restriction of the grazing time in the morning or afternoon affects the composition of the fatty acids of the meat of sheep, compared to a traditional grazing system in which animals grazed throughout the whole day. These authors did not find significant differences in their results. The proportion of C10:0, C12:0, C14:1 cis-9, C15:0, C15:1 and C17:1 did not vary with the grazing time. However, the C14:0 proportion was higher in the meat of lambs grazing 8 h and 4 h in the morning, regarding those which did it 4 h in the evening. Also, lamb meat in the treatment of 4 h of morning grazing had greater proportion of C16:0 (8%), regarding the evening grazing of 4 h. Vasta *et al.* (2012) referred that the profile of the fatty acids of the sheep meat is affected by the hour of the day when grazing is carried out. Animals grazing in the afternoon have a meat with a profile of fatty acids with beneficial effects for human health (table 6).

Recently, Zorrilla-Ríos *et al*. (2013) concluded that carcasses from cattle fed typical rations of tropical regions of Mexico (Tabasco State) do not reach "supreme" quality, due to the poor conformation of the slaughtered animals. Delgado *et al*. (2005) and Méndez *et al*. (2009) reported similar results regarding the quality of the bovine meat produced in Mexico that manifests areas of possible improvement through the manipulation of the ruminal fermentation. Preliminary results based on the slaughtering of cattle fed under silvopastoral systems in Michoacán report yields of approximately 57% (Ayala Burgos 2012, personal communication).

The silvopastoral systems can constitute an alternative for improving live weight gains besides offering aggregate value to the meat, by improving the marbling. Shelton and Dalzell (2007) in a study realized with young bulls grazing according to different systems (150 d in buffel grass, 150 days with pasture and Leucaena, 50 d with buffel grass and 100 d with grains) reported that carcass attributes in these animals were similar to those of others fed high grain diets (table 6).

Efficiency of nitrogen utilization for milk production. According to Calsamiglia *et al*. (2010), the efficiency of the use of nitrogen in ruminants is low (-25 %). Presently, it is cause of concern the environmental effect of the excretion of nitrogenous products in urine and faces (urea, N_2O) from ruminant production (Powell *et al*. 2013). The silvopastoral systems contribute with substantial amounts of fermentable nitrogen (NH_3-N) to the ruminal environment. It is important to quantify the nitrogen dynamics and the efficiency of use of this element for milk production.

Ruiz-González (2013, personal communication) indicated that the energy of milk is increased as the level of Leucaena increases in the diet of crossbred cows. However, the efficiency of N utilization in the milk is inversely proportional to the inclusion level of Leucaena in the ration. The efficiency of use of ME for milk production, with levels of 30 and 45 % of Leucaena is of 60 % (table 7).

Ruiz González (2013, personal communication) also evaluated the nitrogen balance in different levels of incorporation of *Leucaena leucocephala* mixed with *Pennisetum purpureum* in double-purpose cows. This researcher found a linear increment in N consumption, total N excreted (urine, feces, milk), blood and urinary

Table 6. Live weight gain and quality attributes of the carcasses of bulls fed under three different systems (Shelton and Dalzell 2007).

Attribute	Buffel grass	Leucaena-pasture	Buffel grass-grain
Initial LW (kg)	481.0	463.0	407.0
Final LW (kg)	604.0	648.0	618.0
Total LW gain (kg)	123.0	185.0	211.0
Yield (%)	55.2	54.6	56.4
Thickness of the rib fat (mm)	7.5	13.3	13.7
Area of *L. dorsi* (cm^2)	91.8	90.9	82.6
Estimated lean meat yield (points)	60.3	58.1	57.4
Fat color	6.3	6.2	7.0
Meat color	13.7	13.3	13.8
Marbling	0.2	0.3	0.3

Table 7. Energy in the milk, efficiency of N and ME utilization for milk production of crossbred cows fed different percentages of Leucaena foliage in the ration (Ruiz-González 2013, personal communication)

	Percentage of *L. leucocephala* foliage incorporation to the ration (DM basis)				ME efficiency	Contrast		
	0	15	30	45		L	C	Q
Energy in the milk, MJ/d	15.83[c]	17.71[bc]	19.55[ab]	22.10[a]	1.47	*	NS	NS
Efficiency of N utilization in milk	0.29[a]	0.22[b]	0.21[bc]	0.18[c]	0.04	*	NS	NS
Efficiency of ME utilization for milk production	0.62[a]	0.61[b]	0.60[c]	0.60[c]	0.10	*	NS	NS

Lines with different letters differ significantly at $P < 0.05$

Table 8. Nitrogen balance of the incorporation levels of *L. leucocephala* foliage mixed with *P. purpureum* pasture in double-purpose cows (Ruiz González, personal communication)

	L. leucophala foliage incorporation percentage in the ration (DM basis)				SEM	Contrast		
N g/d	0	15	30	45		L	C	Q
Consumption	90.4[c]	123.7[b]	150.7[b]	230.3[a]	13.08	*	NS	NS
Consumption, $kg^{0.75}$	0.98[c]	1.4[b]	1.6[b]	2.5[a]	0.15	*	NS	NS
N excretion, g/d								
Total urine (l)	7.7[ab]	7.9[ab]	8.2[ab]	9.7[a]	1.45	*	NS	NS
Urinary	12.8[c]	18.7[bc]	28.3[b]	47.3[a]	5.90	*	NS	NS
Fecal	42.3[c]	45.1[c]	63.7[b]	137.4[a]	8.18	*	NS	NS
Milk, g/kg	4.8[a]	4.9[a]	4.8[a]	4.4[a]	0.14	NS	NS	NS
Milk	24.8[c]	26.2[c]	31.3[b]	36.2[a]	1.93	*	NS	NS
Total excreted	85.4[c]	104.2[bc]	128.5[b]	172.2[a]	17.8	*	NS	NS
Urea								
Blood urea (mg/dl)	11.5[b]	19.6[b]	24.2[ab]	37.4[a]	4.42	*	NS	NS
Urinary urea (mg/l)	676.0[a]	774.0[a]	982.0[a]	970.0[a]	264.44	*	NS	NS
Total urinary g/d	5.0b	5.9[ab]	7.7[ab]	9.1[a]	1.80	*	NS	NS
N excreted, %								
Urinary	14.5[b]	15.6[b]	19.1[ab]	23.4[a]	2.56	*	NS	NS
Fecal	57.2[a]	47.6[a]	46.2[a]	43.8[a]	9.90	*	NS	NS
Milk	29.8[ab]	22.1[bc]	21.5[c]	18.1[c]	4.02	*	NS	NS
Total	101.6[a]	85.2[a]	86.8[a]	85.2[a]	11.01	NS	NS	NS
Retained N, g/cow/d	10.6[c]	32.2[a]	24.2[b]	9.4[c]	1.73	NS	*	NS

Lines with different letters differ significantly at $P < 0.05$

urea (table 8), as the Leucaena level increased in the ration (0, 15, 30 and 45 %).

Alternatives for the mitigation of enteric methane in the tropics. Presently, there is an increasing concern about the environmental effect of gas emissions of greenhouse effect from ruminant production systems (Bartl *et al*. 2011, Capper 2011 and Stackhouse-Lawson *et al*. 2012). Methane (CH_4) is one of gases of greenhouse effect with high potential of global warming (23 times higher than that of CO_2). According to recent reports, it is possible to mitigate the emissions of ruminal methane through the effect of the secondary metabolites, as the condensed tannins and the saponins (Mao *et al.* 2010 and Goel and Makkar 2012) present in some forage species. The effect of the secondary metabolites on the ruminal methanogenesis is today a recurrent topic of study (Morgavi *et al*. 2013). In addition, in diverse investigations are studied the available options for predicting the enteric methane emissions from ruminant species (Ramin and Huhtanen 2013 and McCartney *et al*. 2013).

In studies from Hess *et al*. (2003) it was concluded that the *E. cyclocarpum* fruits have a concentration of 19.0 mg of crude saponins/g of DM. These can contribute to the decrease of the protozoa population in the rumen (Koening *et al*. 2007) and to the modification of the flora and bacterial density (Mosoni *et al*. 2011) which has an effect on ruminal methane reduction. Mao *et al*. (2010) significantly reduced *in vivo* methane production (27 %) in sheep consuming 3 g of saponins contained in tea leaves. Rodríguez and Fondevila (2012) in *in vitro* studies with *E. cyclocarpum* foliage attained to reduce methane production through a change in the ruminal fermentation pattern (increase in the molar proportion of propionic acid in the rumen). The fruits of the tropical legume *Enterolobium cyclocarpum* have been included successfully in sheep rations, allowing acceptable dairy live weight gains (234 g/d) and feed conversion (5.2) (Briceño-Poot *et al*. 2013). This performance is possibly due to greater propionic acid production in the rumen or to the reduction in the methanogenesis (Mosoni *et al*. 2011).

It is possible that besides the condensed tannins, the nutritive value and high digestibility of the Leucaena foliage can reduce the ruminal methane production (Bonilla and Lemus 2012, Goel and Makkar 2012 and Soltan *et al*. 2013) in the silvopastoral systems. These systems also decrease the heat stress in the animals, on providing greater natural shade space to the grazing animals. Delgado *et al*. (2012) reported that the foliage of several tropical plants, as *Leucaena leucocephala*, *Samanea saman*, *Sapindus saponaria*, *Albizia lebbeck*, among others can reduce *in vitro* ruminal methane production. Also the condensed tannins can affect the ruminal biohydrogenation of unsaturated fatty acids (Vasta *et al*. 2009), on increasing the rumenic and vaccenic acids. In this way the fatty acid pattern in sheep meat is modified (Vasta *et al*. 2012) with positive effects on human health, mainly for the prevention of carcinogenic and cardiovascular diseases.

Estimations of ruminal methane production by stoichiometric techniques. Stoichiometric models have been proposed for estimating the partition of the rumen fermentable carbohydrates toward volatile fatty acid (VFA's), CH_4 and fermentation heat (Wolin 1960, Ørskov *et al*. 1968 and Morvay *et al*. 2011). These models could be useful for comparing the CH_4 production rates in ruminants fed rations of poor nutritive value based on tropical grasses and in grain-rich diets (Kurihara *et al*. 1999). The amount of soluble sugars in the forage can also have some relationships with the methane emissions (Ellis *et al*. 2012).

Valdivia-Salgado *et al*. (2013) concluded through the stoichiometric technique that supplementation with *Brosimum alicastrum* foliage to a ration based on poor quality guinea grass (*Panicum maximum*) hay did not had effects on ruminal methane emissions in sheep (table 9). However, it is possible that the greater increase in the energy loss as methane occurs due to the greater DM consumption (Shibata and Terada 2010). Briceño-Poot *et al*. (2012) also indicated greater CH_4 production in sheep fed tropical legume fruits (table 10). Solís Pérez (2012) reported that methane emission of grazing cows in a silvopastoral system is slightly higher to that registered in a monoculture system, which according to this author is due to greater DM consumption by the cows in the silvopastoral system.

Table 9. DM consumption, apparent DM digestibility, molar VFA's proportion and prediction of energy loss as CH_4 in hair sheep, fed poor quality *P. maximum* with supplementation of *B. alicastrum* forage (Valdivia-Salgado *et al*. 2013)

Indicators	level of *Brosimum alicastrum* in the ration (% DM)				EEM	Answer
	0	15	30	45		
DM consumption (g/d)	511.0	848.0	1106.0	1315.0	106.0	L **
NFD consumption (g/d)	364.0	522.0	675.0	711.0	55.0	L **
Digestible carbohydrate consumption (g/d)	101.6	194.5	265.5	294.5	-	-
DM Digestibility (kg/kg MS)	0.36	0.45	0.47	0.50	1.7	L**
NFD Digestibility (kg/kg MS)	0.33	0.44	0.46	0.48	3.1	L*
Acetic acid (mmol/100 mmol)	74.8	73.1	73.4	72.2	1.4	n.s.
Propionic acid (mmol/100 mmol)	16.4	17.7	16.6	17.3	0.5	n.s.
Butirico acid (mmol/100 mmol)	7.0	7.4	7.9	8.6	0.6	n.s.
Conversion efficiency of hexose into VFA´s	0.72	0.72	0.72	0.72	-	-
Heat of fermentation (kj)	0.064	0.064	0.064	0.064	-	-
Energy loss as CH_4 (kJ/mol)	387.4	719.2	998.3	1085.2	-	-

Table 10 DM consumption, apparent DM digestibility and prediction of energy loss as methane in hair sheep fed tropical legume fruits (Briceño-Poot *et al*. 2012)

Variables	Control	*A. pennatula*	*E. cyclocarpum*	EEM
DM consumption (g/d)	933.0[b]	1155.0[a]	1123.0[ab]	108.4
Digestible carbohydrate consumption (g/d)	448.0	479.0	474.0	48.5
Digestibilidad de la MS (kg/kg DM)	838.0[a]	668.0[b]	723.0[b]	32.8
Conversion efficiency of hexose into VFA´s	0.79	0.76	0.77	
Heat of fermentation (kj)	0.064	0.064	0.064	
Energy loss as CH_4 (kJ/mol)	196.0	237.0	219.0	22.5

Conclusions

The extensive tropical cattle production systems have low productivity and competitiveness since, among other factors, to the seasonal nature of pasture production and to their relatively low quality. In this sense, silvopastoral systems can contribute to maintain stable and sustainable cattle productivity throughout the year. Also, they can help to improve the quality of the products (meat and milk) bringing to them greater aggregate value, mainly by means of the increase of the unsaturated fatty acid concentration (CLA's), whose consumption has been demonstrated to have beneficial effects for human health. It is necessary to identify the breeds or cattle crosses with lower ME requirement for the maintenance for increasing in this way the energetic efficiency of meat production. Similarly, it is essential to realize feeding practices aimed at reducing the caloric increment of the feeding. The silvopastoral systems reduce the effect of heat stress and supply greater comfort to the animal, on reducing the energy losses from the increasing respiratory rate (gasping) of the animals in warm environments, which increases the ME requirement for maintenance.

The silvopastoral systems could also contribute to reduce the methane emissions from the rumen through the effect of some foliages and fruits possessing secondary metabolites, capable of affecting ruminal fermentation. For example, fruits and foliage of *E. cyclocarpum* contain saponins (terpenic compounds) that reduce the protozoa population in the rumen (affecting the methanogenic archaea) and consequently decrease the CH_4 emission to the environment.

The cattle producer and the technician must evaluate the availability and cost of the feeding options herein presented to decide their use and, in this way, manipulate the energy and protein metabolism of ruminants, with the objective of attaining greater economical profitability and greater sustainability of the meat and milk productions in tropical regions.

References

AFRC. 1993. Energy and Protein Requirements of Ruminants. CAB International. Wallingford, UK. 159 pp.

Barros, R.M., Solorio, S.J., Ku, V.J., Ayala, B.A., Sandoval, C.C. & Solís, P.G. 2012. Productive performance and urinary excretion of mimosine metabolites by hair sheep grazing in a silvopastoral system with high densities of *Leucaena leucocephala*. Tropical Animal Health and Production 44: 1873

Bartl, K., Gómez, C.A. & Nemecek, T. 2011. Life cycle assessment of milk produced in two smallholder dairy systems in the highlands and the coast of Peru. J. Cleaner Prod. 19:1494

Bonilla, C.J. & Lemus, F.C. 2012. Emisión de metano entérico por rumiantes y su contribución al calentamiento global y al cambio climático. Rev. Mexicana de Ciencias Pecuarias 3: 215

Briceño-Poot, E.G., Ruiz-González, A., Chay-Canul, A.J., Ayala-Burgos, A.J., Aguilar-Pérez, C.F., Solorio-Sánchez, F.J. & Ku-Vera, J.C. 2012. Voluntary intake, apparent digestibility and prediction of methane production by rumen stoichiometry in sheep fed pods of tropical legumes. Animal Feed Sci. and Technol. 176:117

Briceño-Poot, E.G., Soto-Aguilar, A., Ruiz-González, A., Espinoza-Hernández, J.C., Arjona-Alcocer, V.A., Ayala-Burgos, A.J., Aguilar-Pérez, C.F. & Ku-Vera, J.C. 2013. Productive performance and carcass yield of hair sheep fed ground pods of tropical trees as a replacement for grains. Small Ruminant Res.

Calegare, L., Alencar, M.M., Packer, I.U., Ferrell, C.L. & Lanna, D.P.D. 2009. Cow/calf preweaning efficiency of Nellore and *Bos taurus* x *Bos indicus* crosses. J. Animal Sci. 87:740

Calegare, L., Alencar, M.M., Packer, I.U. & Lanna, D.P.D. 2007. Energy requirements and cow/calf efficiency of Nellore and Continental and British *Bos taurus* x Nellore crosses. J. Animal Sci. 85:2413

Calsamiglia, S., Ferret, A., Reynolds, C., Kristensen, N. & van Vuren, A. 2010. Strategies for optimizing nitrogen use by ruminants. Animal. 4:1184

Campos, P.D., Tavares, C.C., Miranda, G.C., Martins, M.R., Ávila, P.M., Dias, M.M. & Ferreira, X.D. 2011. Performance of dairy heifers in a silvopastoral system. Livestock Sci. 141:166

Capper, J.L. 2011. The environmental impact of beef production in the United States: 1977 compared with 2007. J. Animal Sci. 89:4249

Cárdenas-Medina, J.V. Ku-Vera, J.C. & Magaña-Monforte, J.G. 2010. Estimation of metabolizable energy requirements for maintenance and energetic efficiency of weight gain in *Bos taurus* and *Bos indicus* cows in tropical Mexico. J. Animal and Veterinary Advances 9:421

CSIRO 2007. Nutrient Requirements of Domesticated

Ruminants. Collingwood, Australia. 270 pp.

Chizzotti, M.L., Valente, E.E., Busato, K.C., Ladeira, M.M. & Gomes, R.A. 2013. Energetic efficiency of Zebu cattle. XL Reunión de la Asociación Mexicana para la Producción Animal y la Seguridad Alimentaria (AMPA). Villahermosa, Tabasco. Pp. 213-225

Delgado, D.C., Galindo, J., González, R., González, N., Scull, I., Dihigo, L. Cairo, J., Aldama A.I. & Moreira, O. 2012. Feeding of tropical trees and shrubs foliages as a strategy to reduce ruminal methanogenesis: studies conducted in Cuba. Tropical Animal Health and Production. 44:1097

Delgado, E.J., Rubio, M.S., Iturbe, F.A., Méndez, R.D., Cassís, L & Rosiles, R. 2005. Composition and quality of Mexican and imported retail beef in Mexico. Meat Sci. 69:465

Ellis, J., Dijkstra, J., France, J., Parsons, A.J., Edwards, G.R., Rasmussen, S., Kebreab, E. & Bannink, A. 2012. Effect of high-sugar grasses on methane emissions simulated using a dynamic model. J. Dairy Sci. 95:272

Ferrell, C.L. & Oltjen, J.W. 2008. Net energy systems for beef cattle- Concepts, application, and future models. J. Animal Sci. 86:2779

Frisch, J.E. & Vercoe, J.E. 1977. Food intake, eating rate, weight gains, metabolic rate and efficiency of feed utilization in *Bos taurus* and *Bos indicus* crossbred cattle. Animal Production. 25:343

Goel, G. & Makkar, H.P. 2012. Methane mitigation from ruminants using tannins and saponins. Trop. Animal Health and Production. 44:729

Hess, H.D., Kreuzer, M., Díaz, T.E., Lascano, C.E., Carulla, J.E., Soliva, C.R. & Machmuller, A. 2003. Saponin rich tropical fruits affect fermentation and methanogenesis in faunated and defaunated rumen fluid. Animal Feed Sci. and Technol. 109:79

Kamra, D. N., Patra, A. K., Chatterjee, P. N. & Kumar, R. 2008. Effect of plant extracts on methanogenesis and microbial profile of the rumen of buffalo: a brief overview. Australian J. Experimental Agric. 48:175

Koenig, K.M., Ivan, M., Teferedegne, B.T., Mogavi, D.P., Rode, L.M., Ibrahim, I.M. & Newbold, C.J. 2007. Effect of dietary *Enterolobium cyclocarpum* on microbial protein flow and nutrient digestibility in sheep maintained fauna-free, with total mixed fauna or with *Entodinium caudatum* monofauna. British J. Nut. 98:504

Krause, D.O., Nagaraja, T.G., Wright, A.D.G. & Callaway, T.R. 2013. Rumen microbiology: leading the way in microbial ecology. J. Animal Sci. 91:331

Kurihara, M., Magner, T., Hunter, R.A. & Mc Crabb, G.J. 1999. Methane production and energy partition of cattle in the tropics. British J. Nutrition 81:227

Ku-Vera, J.C., Ayala-Burgos, A.J., Solorio-Sánchez, F.J., Briceño-Poot, E.G., Ruiz-González, A., Piñeiro-Vázquez, A.T., Barros-Rodríguez, M., Soto-Aguilar, A., Espinoza-Hernández, J.C., Albores-Moreno, S., Chay-Canul, A.J., Aguilar-Pérez, C.F. & Ramírez-Avilés, L. 2013. Tropical tree foliages and shrubs as feed additives in ruminant rations. In: Nutritional Strategies of Animal Feed Additives. Nova Sci. Publishers. New York. USA. Pp. 59-76

Ku Vera, J.C., Ramírez Avilés, L., Jiménez Ferrer, G., Alayón, J.A. & Ramírez Cancino, L. 1999. "Árboles y arbustos para la producción animal en el trópico mexicano". In: Agroforestería para la Producción Animal en América Latina. FAO. Roma, Italia. Pp. 231-250

Mao, L.H., Wang, J.K., Zhou, Y.Y. & Liu, X.J. 2010. Effects of addition of tea saponins and soybean oil on methane production, fermentation and microbial population in the rumen of growing lambs. Livestock Sci. 129:56

Marcondes, M.I., Tedeschi, L.O., Valadares Filho, S.C., Gionbelli, M.P. & Chizzotti, M.L. 2010. Prediction of partial efficiency of use of metabolizable energy to net energy for gain and maintenance. En: Energy and Protein Metabolism and Nutrition. G. Matteo Crovetto (Ed.) EAAP Publication No. 127. Wageningen Academic Publishers. The Netherlands. Pp. 543-544

Martínez, B.A., Moya, C.S., González, R.H., Hernández, J. & Pinelli, S.A. 2010. Contenido de ácido linoleico conjugado (CLA) en leche de ganado lechero Holstein estabulado en el noreste de México. Rev. Mexicana Cienc. Pecuarias. 1: 221

McCartney, C.A., Bull, I.D., Yan, T. and Dewhurst, R.J. 2013. Assessment of archaeol as a molecular proxy for methane production in cattle. J. Dairy Sci. 96:1211

Méndez, R.D., Meza, C.O., Berruecos, J.M., Garcés, P., Delgado, E.J. & Rubio, M.S. 2009. A survey of beef carcass quality and quantity attributes in Mexico. J. Animal Sci. 87:3782

Montero, L.M., Juárez, L.F. & García, G.H. 2011. Perfil de ácidos grasos en carne de toretes Europeo x Cebú finalizados en pastoreo y en corral. Rev. Mexicana de Ciencias Pecuarias. 2:137

Morgavi, D.P., Martin, C. & Boudra, H. 2013. Fungal secondary metabolites from Monascus spp. reduce rumen methane production *in vitro* and *in vivo*. J. Animal Sci. 91:848

Morvay, Y., Bannink, A., France, J., Kebreab, E. & Dijkstra, J. 2011. Evaluation of models to predict stoichiometry of volatile fatty acid profiles in rumen fluid of lactating Holstein cows. J. Dairy Sci. 94:3063

Mosoni, P., Martin, C., Forano, E. & Morgavi, D.P. 2011. Long-term defaunation increases the abundance of cellulolytic ruminococci and methanogens but does not affect the bacterial and methanogen diversity in the rumen of sheep. J. Animal Sci. 89:783

NRC. 2007. Nutrient Requirements of Small Ruminants. Sheep, Goats, Cervids and New World Camelids. National Academy Press. Washington, D.C. USA. 362 pp.

Ørskov, E.R., Flatt, W.P. & Moe, P.W. 1968. Fermentation balance approach to estimate extent of fermentation and efficiency of volatile fatty acid formation in ruminants. J. Dairy Sci. 51:1429

Patra, A. K. & Saxena, J. 2009. Dietary phytochemicals as rumen modifiers: a review of the effects on microbial populations. Antonie van Leeuwenhoek. 96: 363

Powell, J.M., MacLeod, M., Vellinga, T.V., Opio, C., Falcucci, A., Tempio, G., Steinfeld, H. & Gerber, P. 2013. Feed-milk-manure nitrogen relationships in global dairy production systems. Livestock Sci. 152:261

Ramin, M. & Huhtanen, P. 2013. Development of equations for predicting methane emissions from ruminants. J. Dairy Sci. 96:2476

Ramírez, A.L., Petit, A.J. & Ku, V.J. 2009. Producción ovina en sistemas agroforestales en el trópico. XIV Congreso Latinoamericano de Buiatría. Lima, Perú

Rodríguez, R. & Fondevila, M. 2012. Effect of saponins from *Enterolobium cyclocarpum* on *in vitro* microbial fermentation of the tropical grass *Pennisetum purpureum*. J. Animal Physiology and Animal Nut. 96:762

Shelton, M. & Dalzell, S. 2007. Production, economic and environmental benefits of leucaena pastures. Tropical Grasslands. 41:174

Shibata, M. & Terada, F. 2010. Factors affecting methane production and mitigation in ruminants. J. Anim. Sci. 81:2

Solís Pérez, G. 2012. Consumo voluntario y composición-químico nutricional como indicadores en la producción de metano en vaquillas pastoreando en un sistema silvopastoril del trópico michoacano. Master Thesis. Universidad Autónoma de Yucatán. Mérida, México.

Soliva, C. R., Zeleke, A. B., Clément, C., Hess, H. D., Fievez, V. & Kreuzer, M. 2008. *In vitro* screening of various tropical foliages, seeds, fruits and medicinal plants for low methane and high ammonia generating potentials in the rumen. Animal Feed Sci. Technol. 147:53

Soltan, Y.A., Morsy, A.S., Sallam, S.M.A., Lucas, R.C., Louvandini, H., Kreuzer, M. & Abdalla, A.L. 2013. Contribution of condensed tanins and mimosine to the methane mitigation caused by feeding *Leucaena leucocephala*. Archives of Animal Nut. 67:169

Stackhouse-Lawson, K.R., Rotz, C.A., Oltjen, J.W. & Mitloehner, F.M. 2012. Carbon footprint and ammonia emissions of California beef production systems. J. Animal Sci. 90:4641

Summers, M., McBride, B.W. & Milligan, L.P. 1988. Components of basal energy expenditure. In: Aspects of Digestive Physiology in Ruminants. A. Dobson and M.J: Dobson (Eds.). Cornell University Press. Ithaca, USA. Pp. 257-285

Tedeschi, L.O., Fox, D.G., Carstens, G.E. & Ferrell, C.L. 2010. The partial efficiency of use of metabolisable energy for growth in ruminants. In: Energy and Protein Metabolism and Nutrition. G. Matteo Crovetto (Ed.). EAAP Publication No. 127. Wageningen Academic Publishers. The Netherlands. Pp. 519-529

Valadares Filho, S.C., Marcondes, M.I., Chizzotti, M.L. & Rodrigues Paulino, P.V. 2010. Nutrient Requirements of Zebu Beef Cattle BR-Corte. 2nd Ed. Federal University of Vicosa, Department of Animal Sci. Brazil. 185 pp.

Valdivia-Salgado, V. Briceño-Poot, E.G., Ramírez-Avilés, L. & Ku-Vera, J.C. 2013. Prediction of methane production in the rumen by stoichiometric techniques in hair sheep fed low quality tropical grass supplemented with foliage of *Brosimum alicastrum*. Proc. Conference on Greenhouse Gases in Animal Agric. Dublin, Ireland. Wageningen Academic Publishers. In press.

Vasta, V., Makkar, H., Mele, M. & Priolo, A. 2009. Ruminal biohydrogenation as affected by tannins *in vitro*. British J. Nut. 102:82

Vasta, V., Pagano, R. I., Luciano. G., Scerra, M., Caparra, P., Foti, F., Cilione, C., Biondi, L., Priolo, A. & Avondo, M. 2012. Effect of morning vs. afternoon grazing on intramuscular fatty acid composition in lamb. Meat Sci. 90:93

Vercoe, J.E. 1970. The fasting metabolism of Brahman, Africander and Hereford x Shorthorn cattle. British J. Nutrition 24:599

Wanapat, M. 2009. Potential uses of local feed resources for ruminants. Tropical Animal Health and Production. 41:1035

Wolin, MJ. 1960. A theoretical rumen fermentation balance. J. Dairy Sci. 43:1452

Zorrilla-Ríos, J.M., Lancaster, P.A., Goad, C.L., Horn, G.W., Hilton, G.G. & Galindo, J.G. 2013. Quality evaluation of beef carcasses produced under tropical conditions of Mexico. J. Animal Sci. 91:477

Received: September 2013