Analysis and Comment

Intensive silvopastoral systems with *Leucaena leucocephala* (Lam.) de Wit: productive alternative in the tropic in view of the climate change

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Abstract

This paper presents a descriptive and evaluative analysis of the productive and environmental benefits of SPSi with *Leucaena leucocephala* (Lam.) de Wit, emphasizing the nutritional quality, biomass production, voluntary intake, animal productivity and greenhouse gas emission aspects. For such purpose, a bibliographic review was made about the studies in the last 15 years, concerning animal production systems under tropical conditions, stressing the ones conducted in Colombia. It was noticed that the forage offer in SPSi with leucaena has a protein content higher than 22 % and a lower fiber content (20-30 %) with regards to most tropical pastures. Additionally, leucaena has the capacity to withstand intense browsing, and its presence increases plant and animal productivity. The animals produce at least two or three times more meat and milk ha^{-1} $year^{-1}$ as the result of a higher nutrient intake and higher forage offer, because with this legume the dry matter (DM) intake can be 1,3 times higher than the one observed in conventional systems, and the forage production can be from 5 to 18 t DM ha^{-1}. On the other hand, the inclusion of *L. leucocephala* allows to decrease the enteric emissions of CH_4 in amounts close to 20 % per kilogram of produced meat or milk and per kilogram of consumed dry matter. Compared with the traditional systems, in the ones in which *L. leucocephala* is included, the efficiency in production is increased and the negative environmental effects of animal husbandry are decreased.

Keywords: forage quality, methane, grazing system

Introduction

Leucaena leucocephala (Lam.) de Wit, commonly called leucaena, acacia forrajera or carbonero blanco, is a perennial legume, with large potential for feeding ruminants and capable of growing with companion grasses under tropical and subtropical conditions. It grows on well-drained soils, with neutral to high pH, below 1 400 meters of altitude and with acceptable fertility (Murgueitio *et al*., 2011). When managed as a shrub this species is drought-tolerant, and it is renowned for its high forage value, due to its regrowth capacity, palatability and higher nutritional characteristics, which include high crude protein and soluble carbohydrates content, in addition to a low fiber content (Cuartas *et al*., 2015a; Gaviria *et al*., 2015a).

In recent years it has been proven that there is abundant evidence about the nutritional advantages of *L. leucocephala* for ruminant feeding and its contribution to generating more productive and sustainable systems under tropical conditions (Murgueitio *et al*., 2015; Gaviria *et al*., 2015b). Due to its high forage production and nutritional quality, in the systems that include this legume it is possible to use a higher stocking rate per hectare and to obtain higher weight gains and milk productions in ruminants, with regards to those reached in other tropical forage systems (Mohammed *et al*., 2015; Gaviria *et al*., 2015b).

Hence the intensification of cattle husbandry with the use of *L. leucocephala*, mainly in intensive silvopastoral systems (SPSi), contributes to the supply of high quality forages, the rehabilitation of degraded ecosystems and the mitigation of and adaptation to the climate change (Havlík *et al*., 2013). The lower emissions of greenhouse gases (GHG) associated to this type of systems are due to the characteristics of their forages as well as to their higher productive efficiency (Molina *et al*., 2013; Rivera *et al*., 2016).

Thus, this paper makes a descriptive and evaluative analysis of the productive and environmental benefits of SPSis with *L. leucocephala*, with emphasis on the nutritional quality, biomass production, voluntary intake, animal productivity and GHG emissions.

Main grazing systems under study in the tropic

In the large and detailed bibliographic review about the studies conducted during the last 15 years concerning animal production systems under tropical conditions with emphasis on the ones conducted in Colombia, among the main grazing systems that were identified are the ones with *L. leucocephala* and the grass monocrop pasturelands.

The former, which included leucaena, were intensive silvopastoral arrangements (SPSis) characterized by a high density of the cultivar Cunningham of this legume (> 20 000 shrubs ha^{-1}), associated with such grasses as *Cynodon plectostachyus* (K. Schum.) Pilg. and *Megathyrsus maximus* (Jacq.) B. K. Simon & S. W. L. Jacobs, and with other trees scattered in the enclosed pasture of different characteristics. These SPSis were managed with rotation through the use of electrical fences, with occupation periods between 12 and 24 hours and resting times close to 45 days, with *ad libitum* supply of water and salt. Likewise, they had between 5 and 20 years of establishment, under conditions of tropical dry forest (T-df) and tropical moist forest (T-mf).

Meanwhile, among the grass monocrop pasturelands, also called conventional or traditional systems, the cultivated pastures (CP) and degraded pastures (DP) stood out. The CP were generally composed by such species as *C. plectostachyus* and *M. maximus*, with some type of fertilization and sporadic irrigation, rotational management and *ad libitum* supply of water and salt. On the other hand, the DP were constituted by native grasses alone or mixed with *C. plectostachyus* and *Dichanthium aristatum* (Poir.) C.E. Hubb., with very low production of forage biomass and managed without fertilization or irrigation. In all the cases, these systems were located in lots close to the SPSis and also under T-df and/or T-rf conditions.

As important topics of these types of productive systems, the ones related to the nutritional characterization of the forage, voluntary intake by the animals, plant and animal productivity, as well as emissions of methane (CH_4) and other GHGs, mainly, will be analyzed below.

General chemical composition and nutritional considerations in SPSis with *L. leucocephala*

For determining the chemical composition and other nutritional aspects of the raw materials and diets in the different studies whose results are reviewed, conventional methods were used. In general, the following indicators were evaluated: content of dry matter (DM), neutral and acid detergent fiber (NDF and ADF, respectively), crude protein (CP), ash (Ash), calcium (Ca), phosphorus (P), lignin (Lig.), ethereal extract (EE) and crude energy (CE), besides the degradation and fermentation dynamics by the gas production technique (Mauricio *et al*., 1999). The nitrogen (N) and CP content were determined through the Kjeldahl method (ICONTEC, 1999); NDF and ADF, according to AOAC (2005); and EE by Soxhelet immersion extraction (ICONTEC, 1973). The ash content was determined by direct incineration in muffle at 500 ºC (AOAC, 2005); CA and P content, through AA and UV-VIS spectrophotometry, respectively (ICONTEC, 2013); the DM, by the forced-air stove technique; and CE, through calorimetrics (ISO, 1998).

The chemical composition, degradability and performance at rumen level of *L. leucocephala* showed its high nutritional value for grazing animals. Singh *et al*. (2014), Gaviria *et al*. (2015b) and Cuartas *et al*. (2015a) reported that the *L. leucocephala* forage has high CP levels (over 22 % of the DM), low NDF and ADF (less than 40 and 30 %, respectively) and acceptable Ca and P content. Additionally, *L. leucocephala* has moderate levels of DM degradability (> 50 %) and adequate percentages of A and B fractions, of carbohydrates (16,7 and 14,94, respectively) as well as proteins (34 and 53, respectively), for which this legume is superior from the nutritional point of view compared with the forages traditionally used in tropical and subtropical animal husbandry systems.

The association of *L. leucocephala* with grasses in SPSi contributes to increase the protein content of the diet (from 10 % to, at least, 13 %), compared with the same pastures as monocrop (Gaviria *et al*., 2015a); while the content of NDF is reduced, passing from 69,8 to 60,7 % in diets based on *C. plectostachyus* alone (Cuartas *et al*., 2013). Consequently, the diet offered in a SPSi is more adjusted to the nutritional requirements of the animals, and thus the animal husbandry efficiency increases.

L. leucocephala intake by grazing cattle

For the quantification of voluntary intake, in some studies the n-alkanes technique was used (Mayes *et al*., 1986), with grazing steers from 250 to 350 kg of live weight, under T-df conditions (Gaviria-Uribe *et al*., 2015c); while in other studies it

Table 1. Chemical composition of *L. leucocephala* in different studies conducted in Colombia

DM	NDF	ADF	Lig.	CP	EE	Ca	P	Ash	CE	Source
Percentage of the DM									Mcal kg-1	
25,2	36,8	22,1	-	29,4	2,74	1,2	0,25	7,83	4 676	Gaviria *et al.* (2015b)
-	32,5	29,3	-	27,6	2,95	1,23	0,25	8,4	4 652	Gaviria *et al.* (2015a)
-	33,6	28,3	-	26,1	2,92	1,34	0,23	8,59	4 640	Gaviria *et al.* (2015c)
-	32,4	13,8	-	27,6	2,21	1,42	0,21	6,92	-	Cuartas *et al.* (2015b)
21,9	33,4	22,2	7,7	26,8	2,31	1,43	0,22	6,95	4 170	Cuartas *et al.* (2014)
27,7	34	30,9	-	27,2	1,82	0,88	0,24	7,1	4 375	Molina *et al.* (2016)
24,5	27,7	23,6	7,9	28,2	3,28	1,19	0,19	8,15	4 720	Molina *et al.* (2013)
21,2	33,9	12,5	-	28,2	-	0,96	0,21	8,04	3 854	Cuartas *et al.* (2015a)

was done through the quantification of the offer and refuse in confined animals (Molina *et al*., 2016).

The voluntary intake, chemical composition of the feedstuffs and their degradability are essential to determine the quantity of available nutrients (Sossa *et al*., 2015). Higher intake implies that more nutrients can be utilized by the animals, with which they can improve their productive performance.

The animals that grazed in SPSis with presence of *L. leucocephala* had DM intakes up to 1,3 times higher than those which grazed in conventional grazing systems (table 2). In SPSis, the leucaena intake can represent between 25 and 30 % of the total ingested DM (Cuartas *et al*., 2015b; Gaviria-Uribe *et al*., 2015c).

This could be due to the following factors:

The higher forage offer in SPSis with *L. leucocephala*, which can be up to 230 % higher than that of conventional systems such as CP and DP only based on tropical grasses, allows higher availability and selectivity for the animals (Broom *et al*., 2013; Gaviria-Uribe *et al*., 2015c).

According to Gaviria-Uribe *et al.* (2015c) and Cuartas *et al.* (2015a), the NDF in diets of *M. maximus* and *C. plectostachyus* can decrease in 15 % when 25 % of *L. leucocephala* is included, while the ADF content can be reduced in 20 %. On the other hand, the low fiber content in the diet improves intake, by allowing higher passage rates (Boval and Dixon, 2012). In addition, the legume particles

Table 2. Daily intake of DM and nutrients per animal in SPSi and MP systems, Colombia

Fraction	SPSi with *L. leucocephala*♦	SSPi with *L. leucocephala*♦♦	Monocrop with *M. maximus*♦
Crude protein (kg)	0,95	1,24	0,5
NDF (kg)	3,34	5,81	3,46
ADF (kg)	1,72	3,01	1,88
Lignin (kg)	0,4	-	0,34
Cellulose (kg)	1,32	-	1,54
Hemicellulose (kg)	1,62	-	1,58
Calcium (g)	62,1	69,9	36,2
Phosphorus (g)	10,1	20,1	9,6
Ethereal extract (g)	94,2	160	69,6
Ash (k)g	0,52	1,12	0,59
Organic matter (kg)	5,47	-	5,8
Dry matter (kg)	5,99	9,45	5,29
Dry matter (% of live weight)	2,42	2,46	2,13

♦Cuartas *et al.* (2015b): Zebu steers with live weight of 248 ± 23,1 kg; ♦♦Gaviria *et al.* (2015c): Zebu steers with live weight of 381 ± 12 kg. The total intakes in SPSi differ, probably due to the weight of the animals.

are cubic, while the grass particles are long and thin, which implies higher passage rates in such species as *L. leucocephala* (Barahona-Rosales and Sánchez, 2005).

In SPSis with *L. leucocephala*, higher thermal comfort is achieved for the animals and they dedicate more time to browsing and grazing, because they have possibilities of ingesting a higher biomass quantity (Broom *et al*., 2013). Molina *et al.* (2016) reported that when including *L. leucocephala* in 24 % in the diet of growing heifers, the DM intake went from 2,02 to 2,47 % of the animal live weight ($p = 0{,}01$).

Plant and animal productivity

For the quantification of available DM in monocrop grasslands, Cajas-Girón *et al.* (2011) and Gaviria *et al*. (2015b) used the gauge technique with double sampling, according to the method described by Haydock and Shaw (1975); while for the biomass from the leucaena shrubs they used a modification of this same method, with a scale of five strata in segments of one linear meter, representative of different growth levels. In these segments the plant material consumed by the animals (leaves and fine stems) was harvested and weighed, and with the above-referred scale at least 50 observations were made to estimate the forage availability of each strip.

On the other hand, the estimation of the animal productivity, according to the studies conducted by Gaviria *et al.* (2012), Cuartas *et al.* (2013), Rivera *et al.* (2013) and Mohammed *et al.* (2015), was conducted by periodically weighing the animals and the produced milk in double purpose and specialized milk production systems; while the production per hectare was estimated from the individual productions in each system and the stocking rate, which in turn was determined taking into consideration the DM offer (gauges) and demand (requirements).

Because of the improvement of the nutritional quality and the higher nutrient intake, in the systems that include *L. leucocephala* more meat and milk is produced than in conventional ones (Cuartas *et al*., 2014). In addition, the animal husbandry based on these systems is more profitable (González, 2013).

With regards to plant productivity, in SPSis with leucaena the biomass offer can be higher than 16 t DM ha^{-1} year^{-1}, with fewer fluctuations in the dry season and without applying fertilizers (Gaviria *et al*., 2012; Gaviria *et al*., 2015b). This offer is similar to the one reported by Naranjo *et al.* (2012) for grass systems with irrigation and high dependence on external inputs (table 3), and much higher than the available 7 t ha^{-1} year^{-1} of DM which are indicated for DP that cover a good part of the country (Cajas-Girón *et al*., 2011).

According to Gaviria *et al.* (2015a) and Cuartas *et al.* (2015b), the contribution of *L. leucocephala*, can be around 4,3 t ha^{-1} year^{-1} DM. The higher biomass production in SPSi with regards to conventional systems can be due to the presence of aerial strata that allow higher capture of sunlight and deeper root systems which absorb nutrients and humidity more efficiently (Murgueitio *et al*., 2011; Broom *et al*., 2013), and to the capacity of this legume to fix atmospheric nitrogen and contribute it to the companion grasses.

Regarding milk production, in the Colombian dry Caribbean region Rivera *et al*. (2015b) reported 5 551 L ha^{-1} year^{-1} in a SPSi with L. leucocephala (10 000 shrubs ha^{-1}), *C. plectostachyus* and *M. maximus*; and 1 150 L ha^{-1} year^{-1} in a conventional grazing system without trees. Likewise, in the SPSi the content of protein, fat and total solids in the milk was significantly higher ($p < 0{,}05$). The productions of total solids, fat and protein per animal day^{-1} were 0,59 *vs.* 0,51; 0,22 *vs.* 0,17 and 0,15 *vs.* 0,13 kg for the SPSi and DP, respectively. On the other hand, Paciullo *et al.* (2014) reported that in Brazil the association of leucaena with pasturelands of *Urochloa decumbens* (Stapf) R. D. Webster (= *Brachiaria decumbens* Stapf.) allows to increase milk production from 9,5 to 10,4 liters cow day^{-1} ($p < 0{,}05$).

Table 3. Plant and animal productivity in systems aimed at milk production in different regions of Colombia.

Productive response	DP♦♦♦	SPSi Tolima♦ (Piedras)	SPSi Cesar♦♦ (Codazzi)	SPSi Valle♦ (Cerrito)	SPSi Valle♦ (Bugalagrande)
Plant productivity (t DM ha^{-1} year^{-1})	7,0	15,4	13,9	12,4	17,9
Stocking rate LAU ha^{-1} (1 LAU = 450 kg)	0,80	2,90	3,30	3,34	3,80
Production per animal (L day^{-1})	3,3	11,6	3,9	11,4	11,8
Animal productivity (L ha^{-1} year^{-1})	1 150	13 462	5 551	15 725	18 412

DM: dry matter, LAU: large animal unit, DP: traditional grassland with native and degraded pastures, SPSi: intensive silvopastoral system with leucaena densities higher than 10 000 trees ha^{-1} and *C. plectostachyus*; ♦ unpublished data; ♦♦ Rivera *et al.* (2009); ♦♦♦ Cajas *et al.* (2011).

The characteristics of the milk produced in SPSis allow to increase the yield of dairy products and the efficiency in the transformation into cheese in the dry season, with regards to the milk produced by animals supplemented with sorghum. In spite of using lower supplementation, the SPSi did not differ from the conventional system regarding production, according to Mohammed *et al.* (2015), who also indicated higher economic profitability in the system with leucaena. On the other hand, González (2013) estimated internal return rates (IRR) of 13 % in systems with leucaena and of only 0,7 % in conventional systems, in Mexico.

With regards to meat productivity, when analyzing in Colombia two SPSis with leucaena, Gaviria *et al.* (2012) observed that the individual weight gains were 45 and 70 % higher, compared with CP and DP. In addition, the productivity per hectare was much higher in the SPSis, due to the higher stocking rate (2,34 *vs.* 4 LAU) and animal weight gain (830 kg ha^{-1} $year^{-1}$); while in the country the production average in beef production systems is close to 120 kg ha^{-1} $year^{-1}$.

Finally, with regards to meat quality, Montoya *et al.* (2015) found that animals from leucaena systems produced tenderer meat, with better pH and color, and they also reached higher weights at slaughter, hot carcass weight and yield percentage, than the animals from traditional grazing systems. It was also observed that the diet of the SPSi can improve the profile of fatty acids, by increasing the percentage of unsaturated fatty acids, which generates the possibility of entering special markets with higher commercial value. Table 5 shows some results obtained by the above-cited authors regarding the quantity of fatty acids in 100 g of meat.

Emissions of methane (CH_4) and other GHGs

The measurements of CH_4 emitted by enteric fermentation were conducted by Molina *et al.* (2016), through the polytunnel technique, in heifers of 218-280 kg of live weight, under T-df conditions. In turn, to determine the CH_4, N_2O and CO_2 flows from pasturelands, Rivera *et al.* (2015) used the static closed chamber technique. Meanwhile, to estimate the carbon footprint Rivera *et al.* (2016) used the ISO 14044 methodology to calculate emissions inside and out (input elaboration and transportation) of the farm.

Table 4. Productive response in traditional systems and systems with leucaena for meat production

Productive response	TP♦	CP♦	SPSi 1♦♦	SPSi 2♦♦	SPSi 3♦♦♦
Plant productivity (t DM ha^{-1} $year^{-1}$)	7	19,2	19,2	15,6	15,4
Stocking rate LAU ha^{-1} (1 LAU = 450 kg)	0,85	2,34	4	2,71	3,5
Gain per animal (kg day^{-1})	0,25	0,4	0,42	0,84	0,69
Animal productivity (kg meat ha^{-1} $year^{-1}$)	77,6	341,6	609	827	864

TP: traditional pastureland with native and degraded pastures, CP: cultivated or introduced pasture based on *C. plectostachyus* and *M. maximus,* SPSi: intensive silvopastoral system with leucaena densities higher than 10 000 shrubs ha^{-1} and *C. plectostachyus*, LAU: Large Animal Unit; ♦Cajas-Girón *et al.* (2011), ♦♦ Gaviria *et al.* (2012), ♦♦♦ Mahecha *et al.* (2012).

Table 5. Quantity of fatty acids in 100 grams of meat in animals fattened in SPSis and in cultivated pastures, in two regions of Colombia

Quantity of fatty acids (g 100 g^{-1} of meat)	SPSi 1	SPSi 2	CP	TS	p < 0,05
Total fatty acids	$0,87^{ab}$	$1,26^{a}$	$0,66^{b}$	$1,15^{a}$	0,0124
Myristic (C 14)	$0,03^{ab}$	$0,04^{a}$	$0,02^{b}$	$0,04^{a}$	0,0057
Palmitic (C 16)	$0,28^{ab}$	$0,37^{a}$	$0,19^{b}$	$0,38^{a}$	0,008
Stearic (C 18:0)	$0,20^{ab}$	$0,29^{a}$	$0,16^{b}$	$0,25^{ab}$	0,0335
Oleic (C 18:1)	$0,32^{ab}$	$0,46^{a}$	$0,23^{b}$	$0,40^{a}$	0,011
Linoleic (C 18:2)	$0,04^{b}$	$0,08^{a}$	$0,05^{ab}$	$0,06^{ab}$	0,0294
Linolenic (C 18: 3)	$0,01^{b}$	$0,02^{a}$	$0,02^{ab}$	$0,01^{b}$	0,007

SPSi 1: intensive silvopastoral system based on *L. leucocephala*, *M. maximus* and *C. plectostachyus;* SPSi 2: intensive silvopastoral system based on *L. leucocephala, M. maximus* and *G. sepium;* CP: cultivated pastures of *C. plectostachyus,* TS: traditional system based on *Dichanthium aristatum*.

In different studies, the capacity of the systems with *L. leucocephala* to reduce the GHG emissions in cattle has been proven. These determinations include the *in vivo* as well as *in vitro* CH_4 production by enteric fermentation, determination of the carbon footprint and GHG balance, and measurement of the gas flows from the pasturelands and cattle excretions (Harrison *et al*., 2015; Rivera, 2015; Molina *et al*., 2016).

Concerning the enteric emissions of CH_4, Molina *et al*. (2016) reported that with diets based on *C. plectostachyus* and inclusion of approximately 25 % of *L. leucocephala*, supplied to heifers, these emissions can decrease in 15 % per kilogram of consumed dry matter (CDM), because they decreased from 43,6 to 37,7 L of CH_4 kg^{-1} of CDM (table 6). In addition, there was lower energy loss per production of CH_4 in the diets with *L. leucocephala*. Molina *et al*. (2015) found similar results when evaluating the enteric emissions of methane in response to an inclusion of 24 % *L. leucocephala* in diets based on *C. plectostachyus* and *M. maximus*.

In both evaluations, although the animals in the systems with leucaena consumed from 15 to 20 % more of DM, the total emissions per animal were increased in only 3 % as average, without significant differences. This is due to the fact that with the inclusion of leucaena the total NDF values decrease, and this reduces the methane emissions (Archimède *et al*., 2011). Another element that contributes to the decrease of CH_4 emissions when leucaena is offered is the presence of condensed tannins (Barahona-Rosales *et al*., 2000). These components possibly inhibit the growth of *Archaea* in the rumen, and their effect depends on the chemical structure and their quantity (Archimède *et al*., 2011; Huang *et al*., 2011).

In an *in vitro* study conducted by Rivera *et al.* (2015) in Colombia, it was found that with the inclusion of 25 % of leucaena in diets with *C. plectostachyus* CH_4 was decreased in 8 % per kilogram of potentially consumed DM ($p = 0{,}0029$) and in 13 % per kilogram of degraded DM ($p = 0{,}0016$).

On the other hand, the inclusion of *L. leucocephala* results in a lower carbon footprint in the meat and milk produced in a SPSi. Rivera *et al.* (2016) reported that in a SPSi with leucaena the kilograms of CO_2-eq emitted in the production of one kilogram of fat and protein corrected milk (FPCM) decreased in 12 %; with regards to an intensive system based on star grass, with irrigation, concentrate feed offer and fertilization, under tropical conditions (2,05 *vs*. 2,34 kg of CO_2-eq, respectively). In turn, in the system with leucaena the GHG emissions associated with the production of one kilogram of fat and protein decreased in 19 and 23 % (42,3 *vs*. 54,9 CO_2-eq kg^{-1} and 47,3 vs 58,3 CO_2-eq kg^{-1}, respectively).

Rivera *et al*. (2016) reported that in systems based on *L. leucocephala* the intensity of the emis-

Table 6. *In vivo* emissions of enteric methane in heifers fed with diets based on grasses (*C. plectostachyus* and *M. maximus*) and SPSi with *L. leucocephala*

	Monocrop	SPSi	P value
Molina *et al*. (2015)			
CH_4 (L day^{-1})	243,1	228	0,6
CH_4 (g kg^{-1} of CDM)	26,9	20,6	0,05
CH_4 (g kg^{-1} of DDM)	55,7	37,6	0,01
Ym (%)	9,09	6,74	0,04
Molina *et al*. (2016)			
CH_4 (L day^{-1})	202,2	208,6	0,78
CH_4 (g kg^{-1} of CDM)	30,8	26,6	0,23
CH_4 (g kg^{-1} of DDM)	57,7	39,5	0,04
Ym (%)	9,42	7,96	0,32

Monocrop: system based on *C. plectostachyus,* SPSi: intensive silvopastoral system with leucaena densities higher than 10 000 shrubs ha^{-1} and *C. plectostachyus,* CDM: consumed dry matter, DDM: degraded dry matter; Ym: consumed crude energy, lost as CH_4.

sions is reduced due to their high productivity, diet quality, low dependence on external inputs (such as fertilizers and concentrate feeds) and high stocking rate. Likewise, Naranjo *et al*. (2012) estimated that, under conditions of high shrub density and presence of trees in the grazing zones, the balance between emissions and removals can be negative, because in SPSi between 17 and 32 t CO_2 ha^{-1} $year^{-1}$ can be captured and close to 12 t CO_2 ha^{-1} $year^{-1}$ can be emitted.

Regarding the emissions in pasturelands with the presence of leucaena, Harrison *et al*. (2015) reported that these gas flows can be lower than those of conventional systems with similar N offer in the diet. Under tropical dry forest conditions, Rivera *et al*. (2015) found fewer losses of N deposited in feces and urine by cattle as N_2O in an intensive silvopastoral system, with regards to a traditional system (p = 0,002). Thus, in the SPSi only 1,37 % of the excreted N was emitted via feces, compared with 1,77 emitted in the traditional system; while for urine the emissions were 3,47 *vs*. 0,3 % for the traditional system and the SPSi, respectively. When observing the flows of the pasturelands, these authors found that the emissions of a system with leucaena were similar to those of a forest (p > 0,05) and much lower than those of a monocrop grass system with irrigation and fertilization (p = 0,001). In the results, the high fertilization intensity in the conventional system (420 kg of N ha^{-1} $year^{-1}$) and irrigation, undoubtedly, favored the conditions to increase denitrification processes and, thus, the net emissions of N_2O to the atmosphere.

Mechanisms that explain the productive responses and CH_4 emissions with the presence of *L. leucocephala*

From the nutritional point of view, an aspect to be considered in this type of species is its degradability, indicator that describes the quantity of truly available nutrients for the animals. Makkar (2003) and Mota *et al*. (2005) stated that, although leucaena is not highly digestible due to the presence of secondary metabolites, such as condensed tannins, its combination with grasses increases the degradability of the forage mixture if it is compared with the individual values of each species, which increases the availability of nutrients to be used at rumen level and by the animal. Likewise, Barahona-Rosales *et al*. (2000), Molina *et al*. (2013) and Gaviria *et al*. (2015a) found degradability values over 60 %, which shows possible environmental effects that affect the nutritional characteristics of *L. leucocephala*. It is common to observe 10 % increases in the digestibility when *L. leucocephala* is included along with grasses like *M. maximus* or *C. plectostachyus*.

Although the degradability of the shrub may seem low, its presence contributes to a higher quantity of N in the rumen as well as in the duodenum, because it makes a considerable contribution of total as well as bypass protein. This leads to a balance of N for the synthesis of microbial protein and to satisfy the needs of the animal (Mota *et al*., 2005). The *in vitro* degradability of the leucaena protein varies between 47,8 (García *et al*., 2009) and 66,9 % (Gaviria *et al*., 2015b).

Finally, with regards to the fermentation dynamics at rumen level of leucaena, different authors report properties that contribute to the better animal performance and utilization of forage resources. Sommart *et al*. (2000) suggested that the gas volume is a good parameter to predict degradability and synthesis of microbial protein in the rumen. In addition, it has been proven that the DM and organic matter (OM) digestibility has high correlation with the produced gas volume. Molina *et al*. (2013) and Rivera *et al*. (2015) reported that when *L. leucocephala* or other shrubs are mixed with grasses there is higher gas production in early hours, which favors a higher quantity of substrates of fast utilization by microorganisms present in the rumen and, thus, higher efficiency.

It has been suggested that what exerts higher influence on the methane emission in the gastrointestinal tract is the diet composition, particularly the protein and lipid value and the type of carbohydrates (Ulyatt and Lassey, 2001); followed by elements such as the forage species, maturity status, conservation methods, chemical or physical treatments (Tan *et al*., 2011) and the presence of secondary metabolites (Archimède *et al*., 2011), which participate directly or indirectly in the digestibility, passage rate, intake level and live weight of the animal (Singh *et al*., 2014). As discussed above, in most of these factors the inclusion of *L. leucocephala* generates benefits, which in turn explains why with this legume less methane is emitted during the enteric fermentation.

One of the mechanisms through which the inclusion of *L. leucocephala* can inhibit the methane production is its content of condensed tannins (CT), which are polyphenols with the capacity of binding and precipitating proteins, carbohydrates and other molecules (Haslam, 1986). Considered antiherbivory plant components, most of the studies in animal nutrition with CT were initially conducted to characterize their impact on the protein and energy availability in animals that consumed tanniferous legumes (Barahona-Rosales *et al*., 2000).

As advances were made in the research, tannins with beneficial (vgr *Lotus corniculatus* L.) or deleterious (vgr *Lotus uliginosus* Schkuhr) nutritional effects could be identified, which were later associated to differences in the molecular weight of tannins in both species (Foo *et al*., 1997). In a comparison of seven tropical legumes, Barahona-Rosales *et al*. (2006) proved that the tannins of different legumes varied in their inhibitory effects on the activity of cellulolytic and hemicellulolytic enzymes, in response to changes in their content of anthocyanidins and their molecular weight.

One of the most significant advances in recent years is that the presence of condensed tannins in legumes can contribute to a reduction in the CH_4 emissions between 13 and 16 % (Patra and Saxena, 2010). Nevertheless, in most cases, such decreases have been accompanied with reductions of the fiber digestibility, which counteracts the benefit of the reduction in emissions, by negatively affecting productivity in response to the limited energy availability from the forage fiber. In the studies conducted by Barahona-Rosales *et al*. (2000) and Barahona-Rosales *et al*. (2006), it was proven that the CTs of L. *leucocephala* are beneficial, unlike most tannins from other tropical legumes, which act rather as antinutritional agents (table 7).

When evaluating the CTs of *L. leucocephala* hybrid-Rendang, Tan *et al*. (2011) found that the in vitro methane production of *M. maximus* was linearly reduced between 1 and 3 %, in the presence of increasing CT levels. On the other hand, Sallam *et al*. (2010), when evaluating the CTs of several legumes including leucaena, identified that tannins could reduce in up to 88 % the *in vitro* methane production. The effect of CTs is ascribed to the indirect action on methanogenesis, because of the reduction of the H_2 production resulting from the OM degradation and the direct action on methanogenic bacteria. Likewise, Tavendale *et al*. (2005) reported that CTs can reduce up to 12 % of the populations of methanogenic bacteria and Puchala *et al*. (2012) could identify reductions in the protozoan populations;

Table 7. Comparison of nutritional and fermentative characteristics of *L. leucocephala* with those of other tropical legumes

Ítem	*L. leucocephala*	Other legumes
Tannin content (% of dry matter)♦		
Soluble	2,42	2,52
Bound	7,76	7,24
Total	10,18	9,76
Characteristics of fermentation*		
Acetic acid (mmol)	28,29	20,93
Propionic acid (mmol)	9,28	7,36
Butyric acid (mmol)	2,25	1,64
Total volatile fatty acids (mmol)	41,92	31,00
In vitro disappearance of dry matter (%)	61,96	39,36
Characteristics of purified tannins		
Molecular weight (Dalton)♦♦	2370	4010
Inhibition of glucose degradation (%)♦♦♦	19,50	30,56
Inhibition of cell wall degradation (%)♦♦♦	6,63	21,71
Inhibition of the carboxymethyl cellulase (%)♦♦♦	57,25	75,56
Inhibition of the xylanase activity (%)♦♦♦	86,77	91,77
Inhibition of the ferulic acid esterase activity (%)♦♦♦	38,85	81,43

♦Barahona-Rosales *et al*. (2000), ♦♦Barahona-Rosales (1999), ♦♦♦Barahona-Rosales *et al*. (2006). Other legumes: *Calliandra calothyrsus, Clitoria fairchildiana* R.A. Howard, *Desmodium ovalifolium* (Sw.) DC., *Flemingia macrophylla, Leucaena macrophylla* and *Leucaena pallida*.

although Angarita *et al.* (2015) did not find effect of the presence of leucaena tannins on the population of methanogenic bacteria.

As can be observed in table 7, in spite of containing almost the same quantity of bound, soluble and total tannins in its forage as the average of other legumes, the *L. leucocephala* forage was 1,57 times more degradable and had higher accumulation of volatile fatty acids ($p < 0,05$) when it was fermented in gas production trials (Barahona-Rosales *et al.*, 2000). When evaluating the capacity of purified tannins from the same legumes, in order to inhibit the *in vitro* degradability of several substrates or the activity of some hydrolytic enzymes produced by the anaerobic fungus *Neocallimastix hurleyensis* Vavra & Joyon ex I.B.Heath, on most occasions the lowest reductions in these parameters were observed in the presence of *L. leucocephala* tannins (Barahona-Rosales *et al.*, 2006).

It is important to emphasize that precisely the *L. leucocephala* tannins were the ones that showed the lowest molecular weight in the experiment conducted by Barahona-Rosales *et al.* (2006) (table 7). The molecular weight of *L. leucocephala* suggests a molecule which, in average, has eight anthocyanidins (i.e pelargonidin, delphinidin, fisetinidin, among others). Due to their lower molecular weight, the *L. leucocephala* tannins are not as efficient when they bind and precipitate protein and other nutrients, because they are not available anymore for the microorganisms in cattle rumen (Barahona-Rosales *et al.*, 2006). Hence, among the evaluated legumes, *L. leucocephala* was the one with the highest degradability and the highest production of volatile fatty acids. This suggests that if the *L. leucocephala* tannins participate in the reduction of enteric methane emission, they probably do it due to mechanisms of toxicity against microorganisms of the *Archaea* domain.

Final considerations

The SPSis which use leucaena constitute and advantageous alternative to increase meat and milk production between two and five times more per area unit, because they provide a higher amount of DM, CP, energy and some minerals, as well as a lower content of NDF and ADF, and higher efficiency in rumen fermentation.

On the other hand, because of the considerable biomass offer, in the SPSis with leucaena a higher stocking rate can be used (up to four times more than in a degraded conventional system and up to two times more than in a system with improved pastures), and better-quality products are obtained. In addition, as consequence of the remarkable efficiency in rumen fermentation and the lower dependence on external inputs, such as fertilizers and commercial concentrate feeds, 15 % less GHG emissions per unit of product and around 20 % less per kilogram of consumed and degraded DM are generated. Such characteristics could favor these systems to enter markets that demand low carbon animal husbandry products which contribute to improve human health.

Regarding research perspectives, it is recommended to expand knowledge on such topics as bioactive quality of animal products to profile them as nutraceutical products, determine the impact of these systems on GHG emissions from the soil and animal excretions, and conduct detailed economic evaluations under different production conditions. In addition, it is recommended to evaluate carbon capture and the beneficial effects on the health of the soil and the associated fauna.

Bibliographic References

Angarita, Erika; Molina, Isabel; Villegas, G.; Mayorga, Olga; Chará, J. & Barahona, R. Quantitative analysis of rumen microbial populations by qPCR in heifers fed on *Leucaena leucocephala* in the Colombian Tropical Dry Fores. *Acta Sci., Anim. Sci.* 37 (2):135-142. http://www.scielo.br/pdf/asas/v37n2/1807-8672-asas-37-02-00135.pdf, 2015.

AOAC. *Animal feed. Determination of ash content by ashing. 942.05.* 18 ed. Gaithersburg, USA: AOAC International, 2005.

Archimède, H.; Eugène, M.; Magdeleine, Marie; Boval, M.; Martin, C.; Morgavi, D. P. *et al.* Comparison of methane production between C_3 and C_4 grasses and legumes. *Anim. Feed Sci. Technol.* 59-64:166-167, 2011.

Barahona-Rosales, R. *Condensed tannins in tropical forage legumes: their characterisation and study of their nutritional impact from the standpoint of structure-activity relationships.* PhD Thesis. United Kingdom, University of Reading, 1999.

Barahona-Rosales, R.; Lascano, C. E.; Narvaez, N.; Owen, E.; Morris, P. & Theodorou, M. K. *In vitro* degradability of mature and immature leaves of tropical forage legumes differing in condensed tannin and non-starch polysaccharide content and composition. *J. Sci. Food Agric.* 83 (12):1256-1266, 2000.

Barahona-Rosales, R. & Sánchez, S. Limitaciones físicas y químicas de la digestibilidad de pastos tropicales y estrategias para aumentarla. *Revista*

CORPOICA. 6 (1):69-82. http://www.redalyc.org/pdf/4499/ 449945018010.pdf, 2005.

Barahona-Rosales, R.; Sánchez, Solange; Lascano, C. E.; Owen, E.; Morris, P. & Theodorou, M. K. Effect of condensed tannins from tropical legumes on the activity of fibrolytic enzymes from the rumen fungus *Neocallimastyx hurleyensis*. *Enzyme Microb. Tech*. 39 (2):281-288, 2006.

Boval, M. & Dixon, R. M. The importance of grasslands for animal production and other functions: a review on management and methodological progress in the tropics. *Animal*. 6 (5):748-762, 2012.

Broom, D. M.; Galindo, F. A. & Murgueitio, E. Sustainable, efficient livestock production with high biodiversity and good welfare for animals. *P. Roy. Soc. Lond. B Bio.* 2025:1471-2954. http://rspb.royalsocietypublishing. org/content/royprsb/280/1771/20132025.full.pdf, 2013.

Cajas-Girón, Yazmín S.; Cuesta, P. A.; Arreaza-Tavera, L. C. & Barahona-Rosales, R. Implementación de estrategias tecnológicas para mejorar la productividad y sostenibilidad de sistemas de doble propósito en las sabanas de la región Caribe colombiana. *Rev. Colomb. Cienc. Pecu*. 24 (3):495, 2011.

Cuartas, C. A.; Naranjo, J. F.; Tarazona, A.; Correa, G. & Barahona-Rosales, R. Dry matter and nutrient intake and diet composition in *Leucaena leucocephala* - based intensive silvopastoral systems. *Trop. Subtrop Agroecosyst*. 18:303-311. http://www.revista.ccba.uady.mx/ojs/index.php/TSA/article/view/2125/991, 2015b.

Cuartas, C. A.; Naranjo, J. F.; Tarazona, A. M.; Barahona-Rosales, R.; Rivera, J. E.; Arenas, F. *et al.* Valor nutritivo y cinética de fermentación *in vitro* de mezclas forrajeras utilizadas en sistemas silvopastoriles intensivos. *Zootecnia Trop*. 33 (4):295-306, 2015a.

Cuartas, C. A.; Naranjo, J. F.; Tarazona, A. M. & Barahona, R. Uso de la energía en bovinos pastoreando sistemas silvopastoriles intensivos con Leucaena leucocephala y su relación con el desempeño animal. *CES Medicina Veterinaria y Zootecnia*. 8 (1):70-81. http://revistas.ces.edu.co/index.php/mvz/article/view/2858/ 2065, 2013.

Cuartas, C. A.; Naranjo, J. F.; Tarazona, A. M.; Murgueitio, E.; Chará, J. D.; Ku Vera, J. *et al.* Contribution of intensive silvopastoral systems to the adaptation and mitigation of climate change. *Rev. Cienc. Pecu*. 27:76-94. http://rccp.udea.edu.co/index.php/ojs/article/viewFile/920/1048, 2014.

Foo, L. Y.; Lu, Y.; McNabb, W. C.; Waghorn, G. & Ulyatt, M. J. Proanthocyanidins from *Lotus pedunculatus*. *Phytochemistry*. 45:1689-1696, 1997.

García, D. E.; Wencomo, Hilda B.; Medina, María G.; Moratinos, P. & Cova, L. J. Caracterización de la calidad nutritiva de 53 accesiones del género *Leucaena* en condiciones tropicales. *Pastos y Forrajes*. 32 (1):65-80. http://scielo.sld.cu/pdf/pyf/v32n1/pyf06109.pdf, 2009.

Gaviria-Uribe, Xiomara; Naranjo-Ramírez, J. F.; Bolívar-Vargas, D. & Barahona-Rosales, R. Consumo y digestibilidad en novillos cebuínos en un sistema silvopastoril intensivo. *Arch. Zootec*. 64 (245):21-27. http://www.uco.es/organiza/servicios/publica/az/php/img/web/17_09_57_03_12_3311_4.pdf, 2015c.

Gaviria, Xiomara; Naranjo, J. F. & Barahona-Rosales, R. Cinética de fermentación *in vitro* de *Leucaena leucocephala* y *Megathyrsus maximus* y sus mezclas, con o sin suplementación energética. *Pastos y Forrajes*. 38 (1):55-63. http://scielo.sld.cu/scielo.php?script=sci_arttext&pid=S0864-03942015000100006, 2015a.

Gaviria, Xiomara; Naranjo, J. F. & Barahona-Rosales, R. Nutritional quality and fractionation of carbohydrates and protein in the forage components of an intensive silvopastoral system. *Pastos y Forrajes*. 38 (2):194-201. http://scielo.sld.cu/scielo.php?script=sci_arttext&pid=S0864-03942015000200007, 2015b.

Gaviria, Xiomara; Sossa, C. P.; Chará, J.; Barahona-Rosales, R.; Lopera, J. J. & Córdoba, C. P. Producción de carne bovina en sistemas silvopastoriles intensivos en el trópico bajo colombiano. *Memorias VII Congreso Latinoamericano de sistemas agroforestales para la producción animal sostenible*. Belém do Pará, Brasil. p. 661-665, 2012. https://www.researchgate.net/publication/262936613_Produccion_de_Carne_Bovina_en_ Sistemas_Silvopastoriles_Intensivos_en_el_Tropico_Bajo_Colombiano. 2012.

González, J. M. Costos y beneficios de un sistema silvopastoril intensivo (SSPi), con base en *Leucaena leucocephala* (Estudio de caso en el municipio de Tepalcatepec, Michoacán, México). *RIA*. 17 (3):35-50. http://www.redalyc.org/articulo.oa?id=83728497004, 2013.

Harrison, M. T.; McSweeney, C.; Tomkins, N. W. & Eckard, R. J. Improving greenhouse gas emissions intensities of subtropical and tropical beef farming systems using *Leucaena leucocephala*. *Agr. Syst.* 136:138-146, 2015.

Haslam, E. Hydroxybenzoic acid and the enigma of gallic acid. In: E. E. Conn, ed. *The Shikimic acid Pathway, recent advances in Phytochemistry.* New York: Plenum Press. vol. 20. p. 163-200, 1986.

Havlík, P.; Valin, H.; Mosnier, A.; Obersteiner, M.; Baker, J. S.; Herrero, M. *et al.* Crop productivity and the global livestock sector: Implications for land use change and greenhouse gas emissions. *Am. J. Agric. Econ*. 95 (2):442-448, 2013.

Haydock, K. P. & Shaw, N. H. The comparative yiel method for estimating dry metter yield of pasture. *Aust. J. Exp. Agric. Anim. Husb.* 15 (76):663-670, 1975.

Huang, X. D.; Liang, J. B.; Tan, H. Y.; Yahya, R. & Ho, Y. W. Effects of Leucaena condensed tannins of differing molecular weights on *in vitro* CH_4 production. *Anim. Feed Sci. Technol.* 166-167:373-376, 2011.

ICONTEC. *Alimentos y materias primas. Determinación de los contenidos de grasa y fibra cruda*. NTC 668. Bogotá: Instituto Colombiano de Normas Técnicas y Certificación, 1973.

ICONTEC. *Alimento para animales. Determinación del contenido de nitrógeno y cálculo del contenido de proteína cruda. Método Kjeldahl*. NTC 4657. Bogotá: Instituto Colombiano de Normas Técnicas y Certificación, 1999.

ICONTEC. *Alimento para animales. Determinación de los contenidos de calcio, cobre, hierro, magnesio, manganeso, potasio, sodio y zinc. Método usando espectrometría de absorción atómica*. NTC 5151. Bogotá: Instituto Colombiano de Normas Técnicas y Certificación, 2013.

ISO. *Animal feeding stuffs, animal products, and faeces or urine-Determination of gross calorific value-Bomb calorimeter method.* ISO 9831. Geneva, Switzerland: International Organization for Standardization, 1998.

Mahecha, Liliana; Corral, Gabriela; Murgueitio, María M.; Sánchez, C.; Ángulo, J.; Olivera, Martha *et al.* Calidad de carne SSPi en Colombia y México. *Carta Fedegan*. 129:60-65. http://es.slideshare.net/Fedegan/carta-fedegan-129, 2012.

Makkar, H. P. *Quantification of tannins in tree and shrub foliage. A laboratory manual.* Netherlands: Kluwer Academic Publishers, 2003.

Mauricio, R. M.; Mould, F. L.; Dhanoa, M. S.; Owen, E.; Channa, K. S. & K., Theodorou. M. A semi-automated *in vitro* gas production technique for ruminant feeds tuff evaluation. *Anim. Feed Sci. Technol*. 79 (4):321-330, 1999.

Mayes, R. W.; Lamb, C. S. & Colgrove, Patricia M. The use of dosed and herbage n-alkanes as markers for the determination of herbage intake. *J. Agric. Sci*. 107 (1):161-170, 1986.

Mohammed, A. H. M.; Aguilar-Pérez, C. F.; Ayala-Burgos, J.; Bottini-Luzardo, María B.; Solorio-Sánchez, F. J. & Ku-Vera, J. C. Evaluation of milk composition and fresh soft cheese from an intensive silvopastoral system in the tropics. *Dairy Sci. Technol*. 96 (2):159-172, 2015.

Molina, I. C.; Angarita, E. A.; Mayorga, O. L.; Chará, J. & Barahona-Rosales, R. Effect of *Leucaena leucocephala* on methane production of Lucerna heifers fed a diet based on *Cynodon plectostachyus*. *Livest. Sci*. 185:24-29, 2016.

Molina, I. C.; Cantet, J. M.; Montoya, S.; Correa, G. & Barahona-Rosales, R. *In vitro* methane production from two tropical grasses alone or in combination with *Leucaena leucocephala* or *Gliricidia sepium*. *CES Medicina Veterinaria y Zootecnia*. 8 (2):15-31. http://www.scielo.org.co/pdf/cmvz/v8n2/v8n2a02.pdf, 2013.

Molina, I. C.; Donney`s, G.; Montoya, S.; Rivera, J. E.; Villegas, G.; Chará, J. *et al.* La inclusión de *Leucaena leucocephala* reduce la producción de metano de terneras Lucerna alimentadas con *Cynodon plectostachyus* y *Megathyrsus maximus*. *LRRD*. 27 (5). http://www.lrrd.org/lrrd27/5/moli27096.html, 2015.

Montoya, C.; García, J. F. & Barahona-Rosales, R. Contenido de ácidos grasos en carnes de bovinos cebados en diferentes sistemas de producción en el trópico colombiano. *Revista de la Facultad de Ciencias Farmacéuticas y Alimentarias*. 22 (3):205-214, 2015.

Mota, M.; Rodríguez, R.; Solanas, E. & Fondevila, M. Evaluation of four tropical browselegumes as nitrogen sources: comparison of *in vitro* gas production with oher methods to determine N degradability. *Anim. Feed Sci. Technol*. 123-124 (1):341-350, 2005.

Murgueitio, E.; Calle, Zoraida; Uribe, F.; Calle, Alicia & Solorio, B. Native trees and shrubs for the productive rehabilitation of tropical cattle ranching lands. *Forest Ecol. Manag.* 261 (10):1654-1663, 2011.

Murgueitio, E.; Xóchitl, M.; Calle, Zoraida; Chará, J.; Barahona-Rosales, R.; Molina, C. H. *et al.* Productividad en sistemas silvopastoriles intensivos en América Latina. En: Florencia Montagnini, E. Somarriba, E. Murgueitio, H. Fassola y B. Eibl, eds. *Sistemas agroforestales. Funciones productivas, socioeconómicas y ambientales*. Turrialba, Costa Rica, Cali, Colombia: CATIE, CIPAV. p. 59-101, 2015.

Naranjo, J. F.; Cuartas, C. A.; Murgueitio, E.; Chará, J. & Barahona-Rosales, R. Balance de gases de efecto invernadero en sistemas silvopastoriles intensivos con *Leucaena leucocephala* en Colombia. *LRRD*. 24 (8). http://www.lrrd.org/lrrd24/8/nara24150.htm, 2012.

Paciullo, D. S.; Pires, M. F.; Aroeira, L. J.; Morenz, M. J.; Maurício, R. M.; Gomide, C. A. *et al.* Sward characteristics and performance of dairy cows in organic grass-legume pastures shaded by tropical trees. *Animal*. 8 (8):1264-1271, 2014.

Patra, A. K. & Saxena, J. A new perspective on the use of plant secondary metabolites to inhibit methanogenesis in the rumen. *Phytochemistry*. 71:1198-1222, 2010.

Puchala, R.; Animut, G.; Patra, A. K.; Detweiler, G. D.; Wells, J. E.; Varel, V. H. *et al.* Methane emissions by goats consuming *Sericea lespedeza* at different feeding frequencies. *Animal*. 175 (1-2):76-84, 2012.

Rivera, J. *Análisis del ciclo de vida (ACV) en un sistema silvopastoril intensivo (SSPi) y un sistema intensivo convencional orientados a la producción de leche bajo condiciones de bs - T.* Tesis de Maestría: Facultad de Ciencias Agrarias, Universidad Nacional de Colombia, Sede Medellín, 2015.

Rivera, J.; Cuartas, C. A.; Naranjo, J. F. & Barahona-Rosales, R. Comparación del comportamiento productivo y calidad de la leche en vacas bajo un sistema silvopastoril intensivo y un sistema de producción convencional en el valle del Río Cesar. *Rev. colomb. Cienc. Pecu*. 22 (3):514, 2009.

Rivera, J.; Chará, J. & Barahona-Rosales, R. Análisis del ciclo de vida para la producción de leche bovina en un sistema silvopastoril intensivo y un sistema intensivo convencional bajo condiciones de bosque seco tropical. *Trop. Subtrop. Agroecosyst*. 19 (3):237-251, 2016.

Rivera, J.; Molina, I. C.; Donney`s, G.; Villegas, G.; Chará, J. & Barahona-Rosales, R. Dinámica de fermentación y producción de metano en dietas de sistemas silvopastoriles intensivos con *Leucaena leucocephala* y sistemas convencionales orientados a la producción de leche. *LRRD*. 27 (4). http://www.lrrd.org/lrrd27/4/rive27076.html, 2015.

Rivera, J.; Naranjo, J. F.; Cuartas, C. A. & Arenas, F. A. Fermentación *in vitro* y composición química de algunos forrajes y dietas ofrecidas bajo un sistema silvopastoril en el trópico de altura. *LRRD*. 25 (10). http://www.lrrd.org/lrrd25/10/rive25174.htm, 2013.

Sallam, S. M.; Bueno, I. C.; Godoy, P. B.; Nozella, E. F.; Vitti, D. M. & Abdalla, A. L. Ruminal fermentation and tannins bioactivity of some browses using a semi-automated gas production technique. *Trop. Subtrop. Agroecosyst*. 12 (1):1-10. http://www.redalyc.org/pdf/939/93913074001.pdf, 2010.

Singh, S.; Anele, U. Y.; Edmunds, B. & Südekum, K. H. *In vitro* ruminal dry matter degradability, microbial efficiency, short chain fatty acids, carbohydrate and protein fractionation of tropical grass-multipurpose tree species diets. *Livest. Sci*. 160:45-51, 2014.

Sommart, K.; Parker, D. S.; Rowlinson, P. & Wanapat, M. Fermentation characteristics and microbial protein synthesis in an *in vitro* system using cassava, rice straw and dried ruzi grass as substrate. *Asian-Australas. J. Anim. Sci*. 13 (8):1084-1093, 2000.

Sossa, Claudia P.; Correa, G. A. & Barahona-Rosales, R. Consumo y excreción de nutrientes en novillos de carne pastoreando en trópico de altura con y sin suplementación energética. *Zootecnia Trop*. 33 (2):117-128, 2015.

Tan, H. Y.; Sieo, C. C.; Abdullah, N.; Liang, J. B.; Huang, X. D. & Ho, Y. W. Effects of condensed tannins from *Leucaena* on methane production, rumen fermentation and populations of methanogens and protozoa *in vitro*. *Anim. Feed Sci. Technol*. 169 (3-4):185-193, 2011.

Tavendale, M. H.; Lane, G. A.; Schreurs, Nicola M.; Fraser, K. & Meagher, Lucy P. The effects of condensed tannins from *Dorycnium rectum* on skatole and indole ruminal biogenesis for grazing sheep. *Aust. J. Agric. Res*. 56 (12):1331-1337, 2005.

Ulyatt, M. J. & Lassey, K. R. Methane emissions from pastorla systems: the situation in New Zealand. *Arch. Latinoam. Prod. Anim*. 9 (1):118-126, 2001.

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