Review Article: Animal science and dairy.

Applied research on dairy cattle feeding systems in Colombian high tropics

Investigación aplicada en sistemas de alimentación de bovinos de leche en el trópico alto colombiano

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ARTICLE DATA

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ABSTRACT

Sustainable intensification of dairy production is a strategy to consolidate a competitive sector. However, technologies adoption is limited due to the difficulty to accessing to research results. The objective of this document was to review a compilation of research works carried out mainly by the Colombian Agricultural Research Corporation (Agrosavia) in specialized dairy feeding systems of Colombian high tropics. In soils issue, research has been carried out on soil recovery and grassland renewal. Recently, the growth of grasses has been evaluated under different environmental conditions to generate efficient forage management schemes. In 2018 was registered Altoandina oat to forage use, but, in Colombian high tropic, there is a limited offer to forages due to absence of breeding program and evaluation of germplasm. Integrated management of *Collaria scenica* has been developed. Characterization and use of tree and shrub species have been carried out to silvopastoral systems (SSPs). In feeding systems, Agrosavia has been working on determining chemical and nutritional compositional of feed resources and design of supplementation schemes to improve animal response. Methane production increases when mature forage species are used, contrary a balanced diet or grazing in SSPs reduces methane emissions. Finally, research developments must incorporate and recognize the production costs of the system to ensure the adoption of technologies.

Key words: Production costs; dairy cattle; grazing management; forage production; silvopastoral systems.

RESUMEN

La intensificación sostenible de la producción láctea es una estrategia para consolidar un sector competitivo. Sin embargo, la adopción de tecnologías es limitada debido, entre otras cosas, a la dificultad para acceder a los resultados de investigación. El objetivo de este trabajo fue realizar una compilación de trabajos de investigación realizados principalmente por la Corporación Colombiana de Investigación Agropecuaria (Agrosavia) en sistemas de alimentación de lechería especializada del trópico alto colombiano. Se han realizado investigaciones en prácticas de recuperación de suelos y renovación de praderas para mejorar la productividad de la biomasa forrajera. Recientemente, se evaluó el crecimiento de especies forrajeras en diferentes condiciones ambientales, para generar esquemas de manejo eficientes. En 2018 se registró un cultivar de avena forrajera Altoandina, pero, existe una limitada oferta de forrajes, debido a la ausencia de programas de mejoramiento y evaluación de germoplasma. Se ha generado información respecto al manejo integrado de la chinche de los pastos *Collaria scenica*. En sistemas silvopastoriles (SSP) se ha realizado la caracterización y utilización de especies arbóreas y arbustivas. En los sistemas de alimentación se ha realizado el reconocimiento composicional de los recursos alimenticios y el diseño de esquemas de suplementación que mejoren la respuesta animal. Se concluye que la

producción de metano incrementa a medida que las especies forrajeras presentan mayor madurez, además, una dieta balanceada reduce las emisiones de metano, incluyendo los SSPs. Finalmente, los desarrollos de investigación deben incorporar y reconocer los costos de producción del sistema, para asegurar la adopción de las tecnologías desarrolladas.

Palabras clave: costos de producción; ganado de leche; manejo de pastoreo; producción forrajera; sistemas silvopastoriles.

INTRODUCTION

Nowadays, the increase in the demand for animal protein, due to population growth, is a challenge for the sustainability of anthropogenic activities (Gerber *et al.*, 2013). In this sense, to develop sustainable animal production systems that promote intensification, reduce the impact on the environment and maintain the quality of life of the rural population (Makkar, 2016). In Colombia, milk production is a main activity in the agricultural sector because it guarantees food security and food sovereignty. Besides, within products of animal origin, milk generates the lowest greenhouse gas emissions per unit of product, which, gives it importance in the framework of the development of sustainable animal production systems (Gerber *et al.*, 2013).

Production and consumption of milk in the world is led by the United States, but, New Zealand is the country with the highest participation to milk powder exports. Brazil leads the production and consumption of milk in South America; however, Colombia shows growth in milk production in recent decades (2.4% annually), making it necessary to develop sustainable intensification schemes for this activity (Espinal *et al.*, 2005; CNL, 2010). Despite this growth, Colombia has high production costs and low milk productivity (Conpes, 2010), due to a high investment in feeding supplementation and grassland management (AC-Lácteos, 2017).

In 2016, the bovine inventory in Colombia was 27.2 million animals, distributed in 623,794 farms (DANE, 2016). Milk production in Colombia in 2018 was 7,257 million liters (Fedegan, 2019), of which,

between 45 and 52% comes from specialized dairy systems (Corpoica, 2005; Cardozo, 2008). The fate of dairy production is 41.3% for industry, 35% for intermediaries and 20% for self-consumption. This activity represents 24.3% of livestock GDP and generates 633,647 direct jobs. Finally, the national per-capita milk consumption was 143 liters during 2019 (Fedegan, 2019).

Most milk production systems belongs to smallholders. In this sense, 66% of the productive units have less than eight cows. Besides, low animal productivity (4.8 liters per animal day, average) is evident compared to other countries in the region. Cundinamarca participates with 20% of the national dairy production, followed by Antioquía and Boyacá with 12 and 10%, respectively (CNL, 2010).

Feeding systems of dairy cows are mainly supported on pastures and strongly influenced by environmental conditions. Animal productivity increases in periods of high precipitation, associated with higher production of dry matter (DM), and animal productivity decreases with drought (Corpoica, 2005; Gachetá *et al.*, 2016). The pastures, in high tropic, are located on 6 million hectares in the departments of Cundinamarca, Boyacá, Antioquia and Nariño. This area concentrates 87% of the country's specialized dairy farms (Cardozo, 2008; Santana *et al.*, 2013).

Milk production systems in Colombia have a variety of cost structures, however, for specialized milk production systems, items associated with labour (26.9%), feeding (37.0%) and forage management (7.4%) have great impact in cost structure (Espinal *et al.*, 2005; Cardozo, 2008; FEDEGAN

et al., 2013). In Colombia, production costs are higher than countries with high efficiency (CLA, 2001). For example, Corpoica (2005) reported that production costs were US$ 0.16 per liter, presenting a higher value (US$ 0.21) in specialized dairy farms, during 1998. Besides, the price of milk is associated with the climate, showing higher prices in dry seasons and lower in rainy seasons (Espinal *et al.*, 2005). Besides, production and marketing of milk are very fluctuating because milk is a perishable product and marketing channels are limited (CLA, 2001).

Soil recovery and chemical fertilization. Studies of soils in specialized dairy production systems have not presented enough historical interest when considering a static component or with an unknown relationship for milk production. However, soil degradation processes result in a decrease in dry matter (DM) production and milk production, generating the need to identify the current state of the soils and carry out interventions physical, chemical and biological. To carry out these interventions, Gachetá *et al.* (2016) developed a guide that describes how to take and send soil samples to certified laboratories. Also, the literature describes the methodology for interpreting the soil analysis and generating the recommendations that allow replacing nutrient deficiencies (Corpoica, 2011a; Gachetá *et al.*, 2016).

Corpoica (now Agrosavia) has made researches on pastures in Colombian high tropic seeking for alternatives that reduce soil degradation processes, the seasonality of production and the low offer of forages (Corpoica, 2011a). In this sense, studies have been focused on recovering and renewing of grasslands and evaluation, establishment and management of grazing forages and the production of forage crops for ruminant feed systems.

Regarding the renovation of pastures, Mila and Corredor (2004) evaluated the botanical composition of *Kikuyu grassland* after making different mechanization process like i) brushcutter, ii) Vertical tillage (renovator), iii) harrow, iv) brushcutter + renovator and v) brushcutter + renovator + harrow. This experiment evaluated three levels of composting application (0, 300 and 600kg/ha). The renovation increased kikuyu's coverage by 20% and reduced the coverage of other grasses (10%), legumes (2%) and weeds (10%). Arrieta (2004) observed that renewal of pastures reduces up to 23% the weed population, considering this practice like a strategy to reduce the proportion of weeds. However, the effect of this practice on desirable species such as legumes and herbaceous is evaluated.

Other studies observed that renewal of pastures increased biomass production in 92%, besides milk production per hectare increased and farm's animal carrying capacity doubled, due to the presence of ryegrass and clovers in the pasture. Also, increased crude protein percentage of the forage (10%) and decreased rotation days (50%) (Sánchez and Villaneda, 2007). Báez *et al.* (2003) emphasized the need to frequently monitor the physical, chemical and biological characteristics of the soil to establish a scheme for fertilization, grassland renewal and pest and diseases control, which promotes productivity of milk farms.

To improve the quality and production in pastures, since 2003, Corpoica carried out research aimed at recovering degraded soils according to physical parameters such as: density, porosity, retention of humidity, structural stability, infiltration and resistance to penetration. Generating appropriate recommendations for soil mechanization processes (Báez *et al.*, 2003).

Studies carried out by Cuesta (2005) and Sánchez (2007), report degraded soils in the dairy systems of the high tropics. The penetration resistance presented values higher than 1 Megapascal (Mpa) and high micropore levels (>35%). Soil degradation

affected radical development, the activity of flora and fauna of soils, anchorage of vegetal species and structural stability with particles smaller than 1mm. Besides the area to capture nutrients and water decreased. The pasture productivity decrease affects the profitability of production systems. In this sense, Sánchez *et al.* (2013) mention that vertical mechanization practices improve the physical conditions of the soil and increase productivity between 17.3 and 48%.

Programs for evaluating the productive response of forages to different fertilization protocols were developed until the 1970s, resulting in recommendations for Colombian high tropic grasses. That protocols recommend between 400-600 kg N.ha^{-1}, 150-300 kg. P$_2$O$_5$.ha^{-1} and 200-400kgK$_2$O.ha^{-1} (ICA, 1992). However, no fertilization schemes are reported for new varieties with higher biomass productions in varying environmental conditions (Vargas *et al.*, 2018).

Improving soil quality increases the profitability of the system, but, is necessary to do several chemical, physical and biological studies, especially in the application effect of amendments, organic and chemical schemes of fertilization and soil structure. In the Cundiboyacense region the use of nitrogen fertilizers, together with irrigation, increase productivity of dairy farms, but increases production costs, that's why it is necessary to determine the economic response of N application (Holmann *et al.*, 2003). Also, macronutrient and micronutrient requirements of forages used in Colombian high tropics in contrasting environmental conditions should be evaluated. Finally, it is necessary to update management recommendations for species that have the high grow potential and intensive grassland management schemes.

Forage resources and grazing management. Few studies have evaluated forages in Colombian high tropics, recently. Agrosavia obtained the registration of Alto Andina oat cultivar as a supplementation strategy for dairy production systems in the Andean region, Cundiboyacense highlands and Nariño plateau. Corpoica (2011a) measured the response, among others, of ryegrass, Kikuyu, clover, lotus, wheat and barley in different locations of the Colombian high tropics, recognizing differences between the materials evaluated. On the other hand, Vargas *et al.* (2018) found no differences during establishment and production phase of diploid and tetraploid ryegrasses in two regions of Colombian high tropics. In this same work, these authors mention that white clover, unlike the red clover, disappeared in the locality that presented less precipitation. Besides, Posada *et al.* (2013) evaluated diploid and tetraploid intercropping ryegrasses in a Kikuyu pasture, finding a better response for diploid ryegrass, possibly due to a lower nutrient requirement. These studies suggest that agro-ecological conditions modulate the productive response of forages, suggesting that it is necessary to evaluate these especies in specific microregions under different environments (Corpoica, 2011b; Corpoica, 2012; Vargas *et al.*, 2018).

Regarding pests, Corpoica (2016c) generated a recommendation for integrated management of the pasture bedbug (*Collaria scenica* (Hemiptera: Miridae)), in which emphasizes in the proper pasture and pesticides management . On the other hand, Posada-Florez *et al.* (2014) reported that there may be moderate damage (31.3%) in Kikuyu grass by the aphid (*Sipha flava*), observing yellowing in the basal part of the plant; however, these researchers do not mention how this insect affects the quality of Kikuyu grass.

Likewise, Arango *et al.* (2017) carried out a morphological study of Kikuyu grass in seven municipalities of the department of Antioquia at different altitudes, reporting that Kikuyu

pasture has high morphological variation, due his plasticity, and no pattern of similarity or dissimilarity was found in his morphology per the municipality,. Moreover, altitude has effects in some morphological traits. Agrosavia (2019) evaluated the morphology of Kikuyu grass in six municipalities on the Andean region. In this study, it was found high morphological variation in this pasture, this result promoted a genetic diversity study in six departments of Colombia.

Management of grasslands allows optimizing the use of forage and animal production. In this context, Cuesta (2005) reported that defoliation understood as the removal of aerial part of plants, is the main effect caused by the animal on the grassland and defines its productivity, according to accumulated reserve nutrients in a period. Further, Arreaza *et al.* (2005a) mention that proper management of the grassland requires the incorporation of some concepts such as rest and occupation periods, grazing pressure and carrying capacity, which allows maximizing the production of good quality biomass throughout the year.

In Colombian high tropic biomass production is not constant and depends on management practices and environmental conditions in each production system. In this sense, Corpoica (2016a) and Vargas *et al.* (2018) reported differences in the production of biomass of Kikuyu and ryegrass in different dairy regions of the Colombian high tropics (Table 1). Fonseca *et al.* (2016) mentioned growth rates of Kikuyu grass that ranged between 75.4 and 95.3kg DM ha^{-1}d^{-1}. Besides, recent research conducted by Corpoica (2017) reported in Altiplano Cundiboyacense show lowest growth rates of Kikuyu grass in Cucunubá (5kg DM.ha^{-1}.d^{-1}) and the highest growth rate was reported in Mosquera (150kg DM.ha^{-1}.d^{-1}). These results imply differential grassland management schemes between seasons and regions.

Arreaza *et al.* (2005a) and Arreaza *et al.* (2005b) generated an expert prairie management software or Manejo Experto de Praderas, MEP-2®, which estimates dry matter intake (DM) from biomass digestibility, crude protein concentration, soluble carbohydrates and fractions of fibre. In this sense, carrying capacity for animals depends on occupation and rest periods and availability of forage. This software was validated, and it was determined that there is a low correlation between predicted dry matter intake and the composition of the forage. Besides, a better adjustment was presented during the rainy period concerning drought period. Developments like this should continue to generate tools that allow the producer to make right decisions.

Table 1. Maximum growth rates (kg DM/ha/d) of forage in rainy season (R) and drought (D) present in specialized dairy production systems in high Colombian tropics.

Species	Ubaté-Chiquinquirá		Alto Chicamocha		Sabana de Bogotá		Altiplano Nariñense		Source
	R[1]	D[2]	R	D	R	D	R	D	
Kikuyu	144,2	57,9	144,2	31,2	79,2	28,7	47,7	25,5	Corpoica, 2016a
Ryegrass			70,1	38,8	54,3	41,9	90,2	65,3	Corpoica, 2016a
Ryegrass			77,8		20,6				Vargas *et al.*, 2018
Clover			44,1		43				Vargas *et al.*, 2018

R[1]: Rainy season; D[2]: Drought season.

In Colombia, there is not a vegetal germplasm selection and evaluation programs for ruminant feeding systems for high tropic. One strategy is to generate alliances with research centres, academy and commercial distributors. To increase milk production and impact on higher economic income in farmers. Also, knowledge of native and naturalized species that are more resilient to environmental offerings in the Colombian upper tropics should be promoted. Finally, the generation of information systems should be encouraged to explain and predict the productive response and allow better management of the grasslands.

Silvopastoral Systems. Silvopastoral Systems (SSPs) are an alternative for the milk production system in the high tropic. SSPs offers quantity and quality of forage, animal welfare, improves the quality of soils, provides solutions to environmental problems and contributes to the application of agro-ecological principles. Agrosavia, CIPAV and some universities have started research to offer feeding alternatives to milk farmers in Colombian high tropics. The main species research ananalyzed SSPs are bushes i) *Sambucus peruviana* (Corpoica, 2015) ii) *Sambucus nigra* L. (Carvajal *et al.*, 2012) iii) *Tithonia diversifolia* (Hemsl.) Gray iv) *Morus alba* L. and v) *Trichanthera gigantea* (Humboldt & Bonpland) Nees, and some arboreal trees i) *Montanoa quadrangularis Sch.Bip.* ii) *Alnus acuminata Kunth* (Naranjo and Cuartas, 2011) iii) *Acacia decurrens Willd*. (Quiceno and Medina, 2006). Besides, Sánchez *et al.* (2009) observed that incorporated, in the diet, *Alnus acuminata Kunth* increased forage production (53%), live material (23%), the life/dead forage ratio (85%), carrying capacity (100%), crude protein (23%) and reduces the content of the lowest-available protein fraction (30 - 50%). These results are associated with higher production per unit area and higher system profitability. However, these authors mention the need to assess a greater variety of shrub and tree to reduce establishment periods, production costs, increase carbon capture and resilience of pastoral systems. The research has been focused on the use and characterization of these species, but there is still research on issues such as economic evaluation, environmental impact, establishment, fertilization, pests and animal diseases and welfare, among others.

In silvopastoral systems, Corpoica (2015) presented the chemical composition of *Sambucus peruviana* to Cundiboyacense region, Carvajal *et al.* (2012) *Sambucus nigra* L and *Acacia melanoxylon* to Bogotá savannah, finally Naranjo and Cuartas (2011) in Antioquia, presented the chemical composition of some shrub and arboreal species that can be used in the Colombian high tropics (Table 2).

Table 2. Chemical composition (% DM) of resources of tree and shrub species with potential for food in dairy farming systems in the high Colombian tropics.

Resource	CP	NDF	ADF
Sambucus peruviana	24.10	29.4	9.91
Acacia decurrens Willd	14.1	55.1	26.5
Sambucus nigra L.	19.4	37.4	15.7
Alnus acuminata Kunth	16.9	35.8	31.1
Tithonia diversifolia (Hemsl.) Gray	24.1	38.6	33.7
Morus alba L	24.8	33.6	32.7
Trichanthera gigantea gigantea (Humboldt & Bonpland) Nees,	21.2	43.7	41.7
Montanoa quadrangularis Sch.Bip	26.3	43.9	33.7

CP: Crude protein, NDF: Neutral Detergent Fibre, ADF: Acid Detergent Fibre.

Nutrition and feed. Description of the chemical composition of feed sources available in high tropic to generate feeding systems that meet the nutritional requirements of the animals of different age groups is required. Corpoica (2013) presented the chemical composition of food resources most used in specialized dairy farms in the Colombian high tropics (Table 3).

Table 3. Chemical composition (% DM) of feed resources used in dairy farming systems in the high Colombian tropics.

Feedstuff	CP	NDF	ADF	EE	NSC	Ca	P
Grazing forages							
Kikuyu	17.3	63.1	28.7	2.7	3.6	0.42	0.49
Kikuyu + ryegrass	19.5	59.2	27.1	3.4	5.3	0.58	0.45
Ryegrass	22.2	50.1	24.2	4.2	6.8	0.73	0.46
Forage cutting and carry							
Lucerne	25.1	46.9	31.2	2.9	8.4	1.5	0.5
Brazilian grass	22.8	59.0	27.8	2.3	4.5	0.5	0.5
Forage beet	16.1	38.7	9.9	1.2	9.6	1.5	0.1
Preserved forages							
Oat silage	12.1	66.5	37.8	2.1	12.3	0.48	0.34
Corn silage	9.1	60.1	34.0	2.9	15.3	0.69	0.34
Angleton hay	3.6	79.9	48.0	1.7	2.1	0.09	0.22
Kikuyu haylage	15.4	68.5	31.0	2.9	2.9	0.61	0.51
Raw feed stuffs							
Brewers grains	28.5	38.6	20.2	10.4	30.1	0.26	0.56
Distiller's Grains with S	31.1	43.2	3.8	4.6	11.3	0.32	1.4
Malt germ	24.2	42.0	19.1	0.6	1.1	0.26	0.52
Barley grain	12.7	30.1	9.0	2.9	53.2	0.07	0.39
Wheat grain	13.7	27.5	10.2	3.1	35.7	0.06	0.39
Corn grain	8.4	9.3	2.8	3.0	70.2	0.03	0.27
Palm kernel	14.2	81.7	26.2	3.4	24.8	0.25	0.59
Cotton seed	19.3	46.9	27.0	17.2	9.1	0.16	0.62
Soybean extruded	40.0	12.0	7.1	8.6	10.2	0.35	0.62
Cotton cake	35.3	45.1	28.0	0.6	14.8	0.23	1.4
Soybean meal	55.5	13.4	3.2	13.3	19.8	0.40	0.72

Traditionally, compositional analyses of the feedstuff's resources destined to the feeding of ruminants have been developed through destructive methods (Van Soest, 1991; AOAC, 2005). However, Vásquez *et al.* (2004) mentioned how the near-infrared methodology allows describing the chemical composition of Guinea grass and corn. This methodology predicted with precision DM, ether extract, ashes, crude protein, neutral detergent fibre, neutral detergent acid and in vitro digestibility of DM, but not for the non-structural carbohydrates and non-protein nitrogen. Recently, Ariza *et al.* (2017) adjusted the equations to predict the composition of 13 nutrients, product of the analysis of 4737 grass, 677 legumes and 419 trees.

One of the main problems to specialized dairy farms in high tropics is a low level of DM of forages available in the grassland, due to the characteristics of the forages, high levels of fertilization and environmental conditions. Water concentration in forages has an inverse relationship concerning voluntary consumption, which, is restricted due to the volume of material. In this sense, Sánchez (2007) found that DM content of available forage in grassland varied between 12.6 and 25.4% as rest period increased from 42 to 73 days, respectively. In this sense, the availability of DM presented values that ranged between 13.1 to 25.5kg DM/

cow/day, relatively low when compared with those suggested by the literature (25 to 40kg DM/cow/day, Bargo *et al.*, 2003). Therefore, implement strategies to optimize the management of grasslands are necessary to guarantee adequate DM intake and nutrients, according to the state of lactation and the productive level of the cows.

In Colombian high tropics, the nitrogen levels in grasslands are higher, due to the high application doses, and short regrowth days. Also, low levels of non-structural carbohydrates and inadequate levels of energy supplementation increase ammoniacal nitrogen levels in rumen and energy requirements of the animal, due to urea synthesis processes, which increases nitrogen excretion in milk and urine, and contaminates in soils and waters. Sánchez (2007) found that levels of milk urea nitrogen (MUN) on different farms, were higher than $18mg.dl^{-1}$, indicating excess of soluble nitrogen and/or fermentable energy deficiency in the diet. Therefore, it is necessary to evaluate different supplements and levels of inclusion that allow the proper use of nutrients, optimizing the production and quality of the final product. Sánchez (2007) reported the concentration of crude protein, soluble protein and cell wall of forages from different dairy regions in the high Colombian tropics (Table 4).

Table 4. Nutritional quality of grasslands of specialized dairy farms in high tropics (Sánchez, 2007).

Regions	Nutritional Quality Indicators		
	Crude Protein (% DM)	Soluble Protein (% CP)	Cell Wall (% DM)
Antioquia	14.3 - 22.4	35.5 - 43.5	51.4 - 58.9
Ubaté-Chiquinquirá	15.2 - 23.3	38.7 - 44.1	53.7 - 59.7
Sabana de Bogotá	13.6 - 21.4	32.8 - 42.0	53.5 - 67.8
Alto Chicamocha	15.2 - 19.6	31.4 - 43.4	55.9 - 60.1
Nariño	12.1 - 16.5	35.6 - 37.8	43.7 - 49.8

The study carried out on ruminant feeding systems has focused on the evaluation of supplementation strategies to increase nutritional efficiency. In this sense, Corpoica (2016b) evaluated in four farms the supplementation with diets formulated at minimum cost and with low protein content, according to the nutritional requirements of the animals. Results showed that supplementation reduced MUN concentrations and supplementation costs and did not change production and dairy compositional quality.

Supplementation studies developed by the Colombian Agricultural Research Corporation (Agrosavia), has used glycerine as a strategic feedstuff for bovine feeding systems, given the high energy value (1.9-2.2Mcal NE_L/kg DM, depending on the concentration of glycerol) and the low cost, compared to maize (about 80%). In a trial, with cows, it was observed that supplementation during early lactation showed a tendency to increase accumulative milk production when 300 or 500g of glycerine/cow/day were applied (Corpoica, 2009). Other supplementation exercises, glycerine has been included up to 30%, favouring homogenization and palatability, besides, the presence of microparticles decreased and the low cost of the supplement has been achieved, the above by the replacement of other sources of carbohydrates, such as corn, sorgo or barley of higher price and difficulty to buy (Corpoica, 2016b).

On the other hand, López and Saavedra (2010) evaluated the supplementation with oat silage and oat silage + supplement (energy: protein) compared to a conventional diet. These authors found no differences between treatments in terms of individual milk production, however, supplementation increasing carrying capacity and production per hectare. On the other hand, Corpoica (2011c) observed that replacing pastures with oat silage increased the net profit per litre of milk between 0.6 and 85%.

Through simulation exercises and using the Cornell Net Carbohydrate and Protein System requirements estimation model (Fox *et al.*, 2004), concluded that specialized dairy systems require higher content of energy ingredients or good quality silages (Cardozo, 2008). In this sense, Blanco *et al.* (2005) mention that silo enriched with molasses improved the in vitro digestibility of DM and is the one that presented the best simulated productive response regarding formic acid use.

The nutrition ruminant's evaluations are focusing on a cases study approach. In this sense, it is necessary to develop programs that recognize the individual characteristics, how the determination of requirements, the definition of DM consumption, differentiation between physiological states, hierarchical behaviours, that are associated with the animal response. Also, it is necessary to know the own food resources and sub products of the region with potential for use in ruminant feed systems. Is important to emphasize the need to determine the costs of interventions to develop technology profitable for the farmer. Finally, the instrumentalization and the acquisition of equipment that allow better the feeding systems and related them with the profitability of the production system should strengthen.

Emission of greenhouse gases. Milk production systems, based on the consumption of Kikuyu grass, have a higher efficiency of energy use, as demonstrated by Noguera and Posada (2017), since the value of Ym, that represented loss of GE as methane was 4.9%, compared to a 6.5% standard.

Applied research that seeks to reduce methane emissions in ruminants for the high tropics of Colombian are few. In general, studies show that the greater the maturity of the forage species, the production of CH_4 increases and, on the other hand, the association of grasses with legumes presents less methane gas production. In a research carried out in

Antioquia, Marín (2013), concluded that methane emissions, product of in vitro ruminal fermentation, are directly related to the nutritional quality of Kikuyu grass and the proportion of supplement in the diet. Also, mixing Kikuyu with ryegrass improved tends to increase the degradation of Kikuyu grass (Restrepo, 2016). However, the degradation leads to increased production of methane gas. Also, grasses with less content of structural carbohydrates, such as ryegrass amson, generate less methane emission (Apráez-Guerrero *et al.*, 2016), indicating that proper management of grasslands can reduce methane emission (Apráez *et al.*, 2014).

Some studies have evaluated the effect of additive consumption to reduce methane emissions. In that sense, Angarita (2007) reports a reduction in methane in rations included containing coconut oil, which shows that there are several strategies to mitigate the effect of methane on dairy systems.

Research to determine methane emissions in milk production systems of the high tropics indicates that the improvement in the forage offer with renewal grassland or silvopastoral systems makes a reduction in the emissions of this greenhouse gas (Silva *et al.*, 2013). However, Donney´s (2015), evaluating the consumption of gold button, found that the silvopastoral system promotes the consumption of dry matter, but does not help to reduce methane emissions.

Recently, Avellaneda *et al.* (2018), evaluated the measurement of enteric methane through the SF6 methodology, comparing a commercial supplementation and supplementation designed for the production system and methane production. They show not differences between treatments, but, the supplement commercial presented a higher production of methane , respect to supplementation designed for the system.

Production costs. The research carried out in specialized dairy production systems has mainly been developed around the technical components, however, the socioeconomic component is a fundamental axis, to processes effective of technology adoption (Corpoica, 2005). In this sense, the production costs are related according to expectations of each family or companies, markets demand and access to means of production. That is why recognizing the costs of production and distribution of the items within the different activities is a strategy that would increase the competitiveness and profitability of dairy systems specialized in Colombian high tropics (CLA, 2001).

The dairy chain of Antioquía (CLA, 2001) evaluated production costs in specialized dairy systems in Antioquía. 73,4% of farmers had less than 34ha, which, 53% produced between 11 and 15thousand L/ha/y, suggesting cost-effective system, while 45% produced less than 10mil L/ha/y, possibly generating losses. Besides, higher productivity in dairy systems was associated with a greater proportion of costs focusing on feeding and forage management. Another hand, Santana *et al.* (2013) selected modal farms in the four dairy basins of Colombia and reported that food (37%) and labour (25%) were the items with the highest participation in the cost structure. The highest costs per litre of milk were determined in Antioquia, followed by Cundiboyacense highlands and the lowest in Nariño. Largest milk production was presented in the Cundiboyacense highlands, followed by Antioquia and Nariño. Finally, these authors mentioned a productivity of 7.04, 5.31 and 3.37L/ha/y for large, medium and small producers, respectively, suggesting a technological gap between producers.

Other authors have evaluated production costs by comparing systems with high and low technological development. In this regards, Gómez-Jurado and Castillo (1997) determined that 28.53 and 43.45% of the costs were represented in capital investments for systems with low and high technological development, respectively. The animal component

constituted 42.3 and 60.7%, for low and high technological development, respectively, with labour and food being the most important items. Finally, in systems with lowtechnological development, the gross margin per litre was 6% higher, although, the productive parameters and the cost-benefit ratio was 0.3% lower, respect to systems with better technological development.

Cardozo (2008) carried out the analysis of the costs of production systems to which pasture renewal processes were carried out, with an horizon of 20 years and assuming that the renewal of pasture increased 10% of dairy production. These authors reported that traditional systems located in Alto Chicamocha have higher profitability compared with Ubaté, Antioquia and Nariño. In Nariño dairy systems were not profitable, when implementing pasture renewal processes Land items (13-22%), infrastructure (11-23%), labour (6-14%), supplements (11 to 24%) and pastures (6 to 26%) presented a higher proportion in the cost structure of the systems evaluated.

Cardozo (2008) suggested that the low profitability of specialized dairy systems is due to improper feeding and feed management practices. Added to this, Santana *et al.* (2013) mention that the absence of the management of the dynamics of the animal population, the limited schooling and the low business vision of the producers have limited the development of the dairy production system. The CLA (2001) mentioned that the small scale of production, the limited access to technology, the high cost of land and the low control of milk prices, are limiting the profitability of production systems.

CONCLUSIONS

Generally, research to feeding systems for the Colombian highlands tend to a systematic approach, however, it is necessary to expand making these studies to identify and characterize with greater

detail the variation in the productive expression of native forage, shrub and tree species; and generate a breeding plants species program in Colombian high tropic. On the other hand, it is convenient to research fertilization plans that include minerals, application times and economically viable in different ecoregions to improve the management of forage resources and the economic efficiency of productive systems. Finally, to mitigate the effect of greenhouse gases is necessary promote programs for the association of legume and SSP, to improve the competitiveness and sustainability of dairy systems in Colombian high tropics.

Research in bovine feeding systems for the high tropics must be immersed in an efficient dairy production model. farmers, academy and commercial allies must actively participate in research needs to develop efficient and sustainable production strategies, to generate recommendations for technological options that strengthen the dairy sector, not only in the high tropics but also throughout the country.

Conflict of interests. The authors declare that there is no conflict of interest.

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