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The effect of different levels of tree cover on milk production in dual-purpose livestock systems in the humid tropics of the Colombian Amazon region

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Abstract Caquetá, Colombia, has a bovine population of 1,809,702 head, of which 88% are in dual purpose livestock systems; it ranks fifth in milk production at the national level. The aim of this study was to evaluate the effect of different levels of tree cover on milk production in dual-purpose livestock systems in the humid tropics of Colombia's Amazon region. The work was carried out in the Centro de Investigaciones Amazonicas CIMAZ Macagual. It is within the tropical humid forest life zone. Nine pastures of one hectare each were selected, covered by improved pastures (*Brachiaria decumbes)* and dispersed trees. Treatments were defined by the percentage of tree cover: (1) high (20.43 $\pm$ 0.47), (2) medium (14.83 $\pm$ 0.58) and (3) low (4.20 $\pm$ 0.85). The spatial distribution of the dispersed trees was obtained using the *SexI-FS* simulator. Nine milking cows with similar characteristics were selected and managed following a 3 $\times$ 3 Latin square experimental design (Cross Over), repeated three

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times. The ANOVA using the general linear mixed model revealed that milk production varied with the levels of tree cover ($p < 0.05$), getting the highest milk production with the medium and high level of tree cover, (4.43 ± 0.21 and 4.39 ± 0.21 kg cow^{-1} day^{-1} respectively), followed by the low levels of tree cover (4.13 ± 0.21 kg cow^{-1} day^{-1}).

Keywords Animal thermal comfort · Dispersed trees in pastures · Milk production · Silvopastoral systems

Introduction

The department of Caquetá, Colombia, has 1,809,702 head of cattle, with 88% managed in dual-purpose systems. It represents the highest bovine herd in the Colombian Amazon region. The fifth place in milk production at the national level. Livestock farming is the main source of employment and economic security for Caquetá's rural population, underlining the necessity for study, reactivation and development to consolidate its productivity (Torrijo et al. 2018).

Animal well-being and productivity can be put at risk by adverse environmental factors that influence animal behavior. Each animal has a range of behaviors that serve as tools for adapting to the environment. The animals must perceive the changes in the environment to manifest a response; thus, they consciously monitor their environment in several ways, using vision, hearing, taste, smell, temperature and touch, which are stimulators for specific receptors located in various parts of the body (Curtis 1983). In tropical zones, when climate elements act in a very intense form, isolated or in interaction with others, they generate heat stress, reduce productivity and, in the most serious cases, even lead to the death of animals (Marques 2000).

Generally, dual-purpose livestock with a high proportion of *Bos indicus* breeds begin to undergo heat stress when the air temperature rises above 32 °C, affecting animal production (Cruz and Ibrahim 2013). This results in (1) an increase in respiratory rate greater than 70 breaths per minute and elevated peripheral blood flow and perspiration; (2) an increase in body temperature above 38.3 °C, which reduces food intake due to a decrease in grazing to less than six hours a day; (3) an increase in water consumption up to 65 L day^{-1}; and (4) a decrease in calf growth and milk production (Cruz and Ibrahim 2013; Solorio et al. 2016). Under those conditions, animals seek places with wind and shade (Gaughan et al. 1998; Mitlöhner et al. 2002; West 2003; Gallardo et al. 2005). The presence of woody perennials in livestock systems can contribute directly to the productivity of the system, regulating or counteracting the intensity of the adverse climate factors on the animals and indirectly creating a microclimate that favors the growth and quality of the pastures that the animals consume (Torres 1983) and changes in behavior and productivity of grazing animals (Blackshaw and Blackshaw 1994).

Among those behavioral changes favored by the presence of woody perennials are an increase in grazing and ruminating time, a decrease in water requirements, greater thermoregulation mechanisms, an increase in voluntary intake, a reduction in the mortality of young animals (better body condition and milk production by the mothers and better immune response to diseases), improvement in the herd's reproductive behavior (earlier puberty, greater regularity of estrous cycles, improved libido, higher semen quality, higher conception rate and lower embryonic loss). All those result in improved cattle production, i.e., live weight gain and milk yield (Johnson et al. 1962; Djimde et al. 1989; Bird et al. 1992; Pezo and Ibrahim, 1999; Cruz and Ibrahim 2013). Consequently, silvopastoral systems are considered win-win options because they result in increased livestock productivity improved adaptation to climate change through the microclimatic conditions that trees and shrubs provide to animals and pastures, and enhanced total income and diversification (Albarrán-Portillo et al. 2019; Kallenbach et al. 2006; Pezo et al. 2019).

The presence of dispersed trees in pastures benefit animal productivity by reducing heat stress, thus animals spend less time resting underneath tree shade, increasing the consumption of dry matter (Esquivel et al. 2003; Carnevalli et al. 2019). This is the important role shade provision plays (Abreu 2002), resulting in additional benefits to the animal and the environment (Mahecha and Angulo 2012). The importance of trees with respect to livestock behavior and well-being is widely known; however, studies evaluating the relationship between the presence of trees and milk productivity in dual-purpose livestock systems are lacking in the Amazon region of

Colombia. The objective of this study was to evaluate the effect of three different levels of tree cover on milk production in dual-purpose livestock systems in the humid tropics of Colombia's Amazon region. The knowledge generated by this research is important for the development, management and structuring of silvopastoral models for cattle production for Caquetá Department, to guide appropriate technologies for the development of resilient, sustainable and efficient livestock systems.

Materials and methods

Study area

The work was carried out between the months of September and October in the Centro de Investigaciones Amazonicas CIMAZ Macagual, located 22 km from the Municipality of Florencia, in the southern part of the Department of Caquetá, Colombia, which has about 380 ha dedicated to livestock farming and different agroforestry arrangements. The research center is located in the Amazon region of Colombian at 1°37′ N and 75°36′ W, and 300 m a.s.l. According to Climate Classification, the area represents the Afm class (warm tropical rainforest climate) (Köppen, 1936), and according to Life Zones Classification, the area corresponds to the tropical humid forest (THF) life zone (Holdridge 1987). The average annual rainfall is 3793 mm, sunshine measures 1707 h year^{-1}, the average temperature is 25.5 °C and the relative humidity is 84.25% (Rodríguez et al. 2018).

The experiment was run between September and November 2017, and the prevalent climatological conditions are shown un Table 1. Nine paddocks of one hectare each, covered by *Brachiaria decumbes* and dispersed trees were selected. A census of trees in each of the selected pastures was done, taking dasometric measurements of each one, such as diameter at breast height (DBH), commercial height, total height, and the diameter of the tree crowns. Using those dasometric measurements as a base, each tree in the census was modeled in *SexI-FS* to find its distribution in the pasture area (Harja and Vicent, 2005) and the percentage of tree cover (percentage of the area of the fields covered by the crowns of trees dispersed in them) was estimated using the following formulas:.

$$Dc = \sum_{i=4}^{n} D_{ci} \Big/ n \tag{1}$$

$$Ac = {}^{\pi}/_{4} \times Dc^2 \tag{2}$$

$$\%C = \sum_{i=n}^{n} Ac \Big/ \mathrm{A} \times 100 \tag{3}$$

where$\boldsymbol{Dc}$ = Diameter of average crown (m). $\boldsymbol{D_{ci}}$ = Diameter of medium crown (m).$\boldsymbol{Ac}$ = Area of crown (m^2).$\boldsymbol{A}$ = Land area.$\boldsymbol{\%C}$ = Percentage of tree cover.

Using these data, three treatments based on the level of canopy cover were defined: (i) high (20.43 ± 0.47%), (ii) medium (14.83 ± 0.58%) and (iii) low (4.20 ± 0.85%). Milk production per cow per day was the response variable measured using nine cows with one milking a day. As cows were managed under a dual-purpose cattle system, milking started after cows were stimulated by a brief contact with their suckling calves, then milking machines were attached; afterwards, the milk produced was weighed and the cows left the milking area to graze with the calves for two hours. After this period, calves were separated from the dams until the next milking. At the time cows entered the experiment, their average age was 65.07 ± 2.86 months, days in lactation was 90.56 ± 14.25 and the number of births was 2.00 ± 0.17. Seven out of the nine cows were crossbreeds—50% Holstein and 50% Brahman; one

Table 1 Weather conditions during the months of the experiment

Months	Climate variables				
	Precipitation (mm)	Temperature (°C)			Relative humidity (%)
		Max.	Min.	Mean	
September	411.9	32.1	22.0	27.0	81.3
October	392.3	31.2	22.2	26.7	83.6
November	334.5	32.3	22.5	27.4	80.7

was 62% Holstein, 12% Brahman and 26% Gyr; and one was 50% Gyr, 25% Holstein and 25% Brahman.

The predominant color of the cows' fur was black—five cows; two were grayish brown and one was cream-colored (Table 2). They received a supplement of 1 kg of commercial concentrate (18% CP and 2630 kcal kg^{-1} ME) at the time of milking and the variable registered was the daily production of milk.

Experimental design

Nine paddocks of one hectare each were selected: three with high tree cover, three with medium cover and three with low cover (Fig. 1). All paddocks had similar forage availability and it was enough for *ad libitum* intake of the three cows assigned. Each paddock was grazed by three cows at the same time during a 15-day period. In the first 15-day grazing period, cows identified with the numbers 1, 5 and 7 entered a low-cover pasture, cows 2, 4 and 8 entered a high-cover pasture and cows 3, 6 and 9 entered a medium-cover pasture. Then the cows that were in a pasture corresponding to one treatment were placed in a pasture with another treatment, until the experiment was completed; thus each cow was evaluated in the three levels of tree cover and evaluated in the three periods of grazing (G_1, G_2 and G_3) (Fig. 2). In each grazing period, 5 days were for the cows' adaptation to the levels of tree cover and 10 for measuring milk yield. So, each cow was under the tree cover treatments for a total of 45 days.

Data analysis

An analysis of variance was performed using a general linear mixed model for a 3 × 3 Latin square type design, repeated three times, with the cover factor fixed and the period and cow factors as random crosses (Di Rienzo et al. 2012). Fisher's least significant difference (LSD) test ($p < 0.05$) was used to determine differences among treatments. To identify the most prevalent trees by level, frequency tables were constructed for each level of tree cover and each pasture. The analysis was carried out using the InfoStat program (Di Rienzo et al. 2018).

Results

The average number of trees per hectare found for the high, medium and low tree cover levels were 38.33 ± 1.45, 48.33 ± 0.88 and 26.67 ± 5.49 trees, respectively, and the most frequent tree species for the paddocks with high cover were *Pictocoma discolor* (59.76%), *Bellucia pentamera* (10.98%) and *Vitex orinocensis* (8.54%); for the medium cover, *Pictocoma discolor* (45.16%), *Psidium guajava* (9.68%) and *Bellucia pentamera* (8.60%); and for low cover, *Pictocoma discolor* (28.89%), *Bellucia pentamera* (22.22%) and *Psidium guajava* (6.67%) (Table 3). All trees showed a homogenous canopy. The average tree height was 7.98 ± 0.50, 6.86 ± 0.27 and 7.30 ± 0.64 m for the high, medium and low tree cover, respectively; and the mean basal area were 0.03 ± 0.01, 0.02 ± 0.01, and 0.05 ± 0.02 m for the high, medium and low tree cover, respectively.

After running the *SExI-FS* simulator, the spatial distribution and cover area of the trees in paddocks 4, 6

Table 2 Characteristics of selected cows

Cow	Age (months)	% Breed	Parturition	Color	Lactation days
1	64.8	50% Hol–50% Bra	2	Grayish brown	79
2	66.0	50%Hol–50%Bra	2	Cream	84
3	86.4	50%G–25%Hol–25%Bra	3	Cream	79
4	60.0	50%Hol–50%Bra	2	Black	73
5	57.6	62%Hol–12%Bra–26%G	1	Black	56
6	58.8	50%Hol–50%Bra	2	Black	65
7	63.6	50%Hol–50%Bra	2	Grayish brown	52
8	62.4	50%Hol–50%Bra	2	Black	167
9	66.0	50%Hol–50%Bra	2	Black	160

Hol Holstein, *Bra* Brahman, *G* Gyr

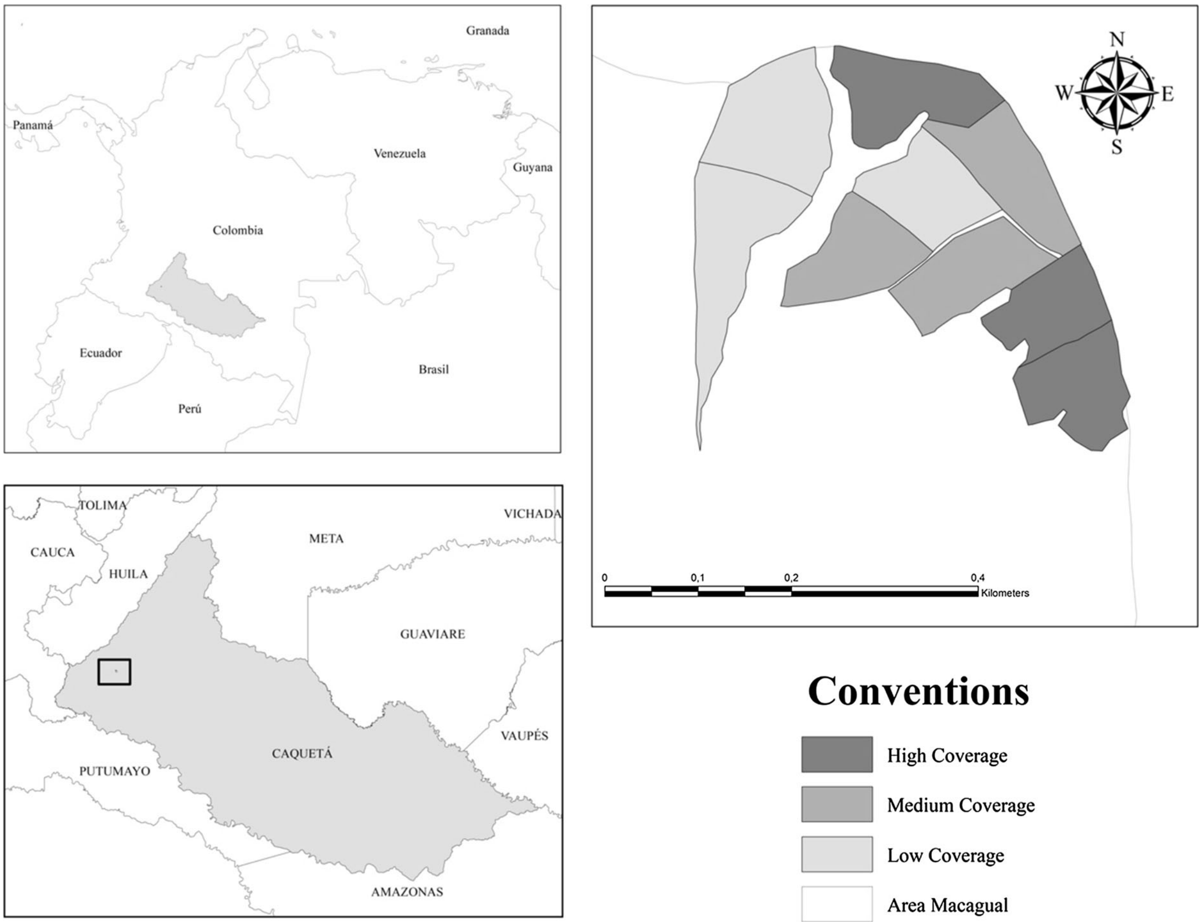

Fig. 1 Design of the nine pastures with different levels of cover in dual-purpose livestock systems in the humid tropics of the Colombian Amazon region

	Cow_1	Cow_2	Cow_3	Cow_4	Cow_5	Cow_6	Cow_7	Cow_8	Cow_9
G_1	C_L	C_H	C_M	C_H	C_L	C_M	C_L	C_H	C_M
G_2	C_H	C_M	C_L	C_L	C_M	C_H	C_H	C_M	C_L
G_3	C_M	C_L	C_H	C_M	C_H	C_L	C_M	C_L	C_H

Fig. 2 Diagram of the 3 × 3 Latin square experimental design (Cross Over) with three repetitions to evaluate the effect of the levels of shade from the dispersed trees in dual-purpose livestock systems in the Colombian humid tropics. C_H = High coverage, C_M = Medium coverage and C_L = Low coverage are the levels of shade; G_1 = Grazing one, G_2 = Grazing two and G_3 = Grazing three are the three evaluation periods

and 5 (representative of the high, medium and low cover, respectively) were as shown in Fig. 3. The analysis of variance showed that milk production was affected ($p = 0.0076$) by tree cover in pastures, with the highest level of saleable milk obtained from paddocks with medium and high tree cover (4.43 ± 0.21 and 4.39 ± 0.21 kg cow^{-1} day^{-1} respectively), followed by those with low tree cover

Table 3 Frequency of tree species in paddocks with different levels of tree cover in a dual-purpose livestock farm in the Colombian Amazon humid tropics

Species	Level of coverage					
	High		Medium		Low	
	AF	RF%	AF	RF%	AF	RF%
Andira inermis (W. Wright) DC.	1	1.22	3	3.23	3	6.67
Annona sp.	1	1.22	0	0.00	1	2.22
Astrocaryum chambira Burret	1	1.22	0	0.00	0	0.00
Astrocaryum murumuru Mart.	0	0.00	0	0.00	2	4.44
Bellucia pentamera Naudin	9	10.98	8	8.60	10	22.22
Cecropia distachya Huber	2	2.44	1	1.08	0	0.00
Cedrela odorata L.	0	0.00	1	1.08	0	0.00
Citrus limon (L.) Osbeck	1	1.22	0	0.00	1	2.22
Cupania latifolia Kunth	0	0.00	0	0.00	1	2.22
Ficus trigona L.f.	0	0.00	1	1.08	0	0.00
Ficus yoponensis Desv.	1	1.22	1	1.08	0	0.00
Gmelina arbórea Sm.	1	1.22	1	1.08	1	2.22
Inga edulis Mart.	0	0.00	6	6.45	3	6.67
Jacaranda copaia (Aubl.) D. Don.	1	1.22	1	1.08	0	0.00
Miconia elata (Sw.) DC.	1	1.22	3	3.23	1	2.22
Ocotea longifolia Kunth	3	3.66	6	6.45	3	6.67
Ormosia paraensis Ducke	2	2.44	0	0.00	0	0.00
Pictocoma discolor (Kunth) Pruski	49	59.76	42	45.16	13	28.89
Psidium guajava L.	0	0.00	9	9.68	3	6.67
Tabebuia rosea (Bertol) A.DC.	1	1.22	1	1.08	1	2.22
Terminalia catappa L.	0	0.00	1	1.08	0	0.00
Vismia baccifera (L.) Triana	1	1.22	2	2.15	0	0.00
Vitex orinocensis Kunth	7	8.54	6	6.45	2	4.44

(4.13 ± 0.21 kg cow^{-1} day^{-1}) (Fig. 4). Live weight gain of calves was not measured, because they only functioned as stimulators of oxytocin release to promote milk ejection (Tancin et al. 2001).

Discussion

The positive effect of the presence of dispersed trees in pastures on milk production and body condition has been demonstrated by different authors (Abreu et al. 1999; Betancourt et al. 2003; Paciullo et al. 2014; Mancera et al. 2018) however, an excess of shade could affect negatively pasture growth and availability (Sotelo et al. 2017, Pezo et al. 2019; Álvarez et al. 2020). Hence, to get the beneficial effects of trees in silvopastoral systems, shade should not exceed a threshold level (Maurucio and Sousa 2010; Paciullo et al. 2011).

Mauricio (2012) has proposed that the tree shade threshold level for milk production could be ≥ 29%. Along this line, Yamamoto et al. (2007), working in the central region of Nicaragua, found that a tree cover of approximately 20% had positive effects on milk yield working with dual-purpose cattle. In this study, carried out under the conditions of the Amazon Piedmont, with dual-purpose cows milked after brief stimulus by their calves presence, and grazing in pastures dominated by *B. decumbes*, milk production was higher in the medium and high tree cover in pastures, as compared to low tree cover (14.83% with 48.43 trees ha^{-1} and 20.43% with 38.33 trees ha^{-1}, respectively); however, the slight decline with the highest level of tree cover may suggest that under the conditions of this study, the threshold for tree cover might be between 14.8% and 20.4%.

On Embrapa Beef Cattle in Campo Grande in the state of Mato Grosso do Sul, Brazil, Karvatte et al.

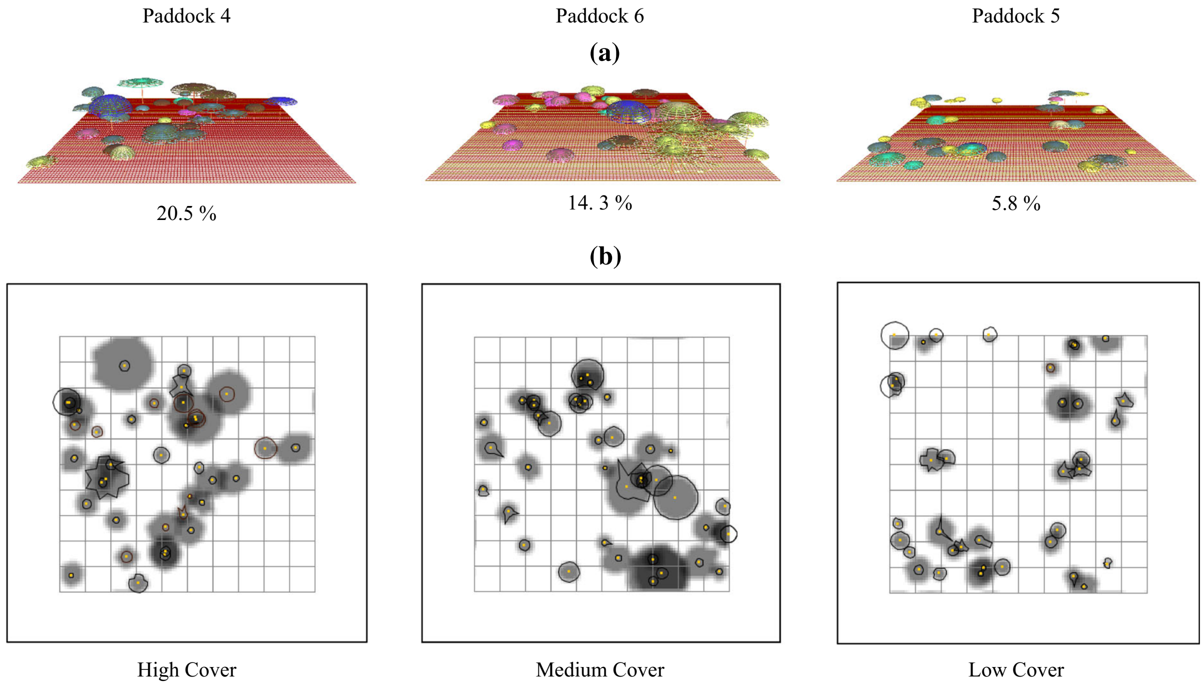

Fig. 3 SExI-FS simulator images for paddocks 4, 6 and 5, representative of high, medium and low tree cover. **a** Spatial 3D distribution of dispersed trees in the paddocks; **b** Crown area of trees in pastures represented in gray color

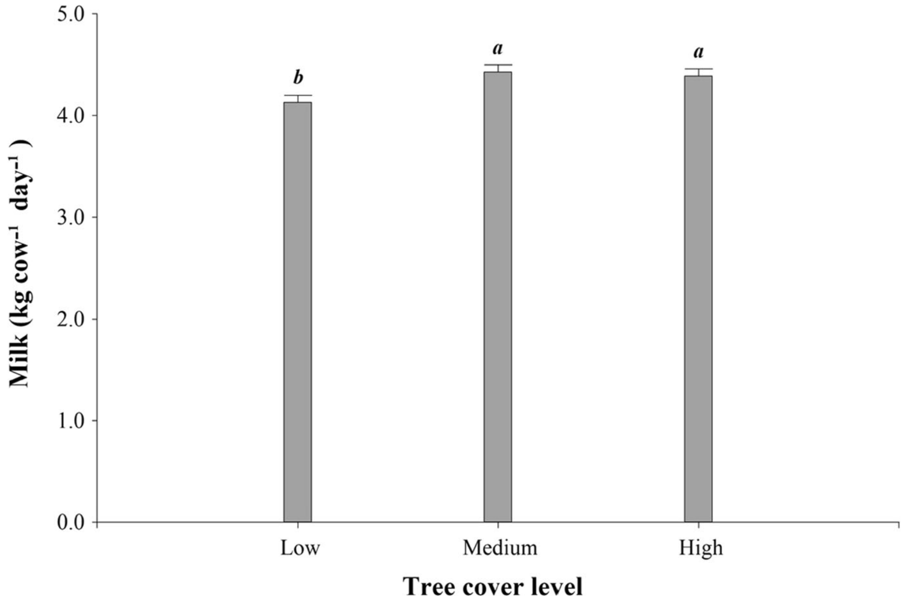

Fig. 4 Average milk yield obtained for the three levels of tree cover (means with different letters are differents, $p < 0.05$)

(2016) did an evaluation of microclimate and determined the thermal comfort indices of livestock under sun and shade and under different arrangements of eucalyptus and native trees. They observed that with the presence of trees in pastures, a temperature index reduction of up to 3.7% was achieved and 10.2% in the index of humidity, concluding that the presence of trees and their arrangement in the systems provided better microclimatic conditions and animal thermal comfort in grazing areas. These results support the importance of maintaining some level of tree cover in grazing areas as means to regulate the zone of thermoneutrality conditions of grazing animals to favor better animal welfare conditions and higher animal performance.

The thermal condition, determined not only by ambient temperature but in conjunction with relative humidity and wind velocity, is the most important ecological factor influencing growth, development and productivity of domestic animals (Collier and Gebremedhin 2015). Nakamura and Morrison (2008) proposed that thermoregulation is a neural process that connects information from the external environment to a response, i.e. blood vessels constriction, hair erection and panting, which helps animals to maintain a stable internal environment in relation to a variable external environment. However, the increase in productivity of domestic animals through breeding and selection has resulted in reduced plasticity in heat-regulating responses; this thermal plasticity and the degree of acclimatization are critical factors determining livestock capacity to respond to environmental changes; hence some farmers need greater investment in systems that help reduce the variability of the thermal environment (Collier and Gebremedhin 2015). However, for grazing systems, the presence of trees in pastures is a natural intervention for reducing heat stress, with positive effects on food consumption, milk production and growth rate (Abreu 2002).

Additional benefits of the introduction of woody perennials into pastures and their eventual use as sources of supplemental feed, particularly in dry periods (Zamora et al. 2001; Pezo et al. 2019) are (1) maintenance of body condition, (2) fewer production losses, if any, (3) increased frequency of estrus and reduction in calving interval, (4) reduced disease incidence and mortality, and (5) less need for moving animals to other areas (transhumance) in search of forage. As an example, Restrepo-Sáenz et al. (2004) working in the sub-humid tropics of Costa Rica, reported that Brahman heifers managed in pastures with scattered trees showed higher live weight gains than in pastures with no trees (13% and 14% more for pastures above those in pastures with medium and low tree cover, respectively). However, the benefits achieved by using silvopastoral options is a function of the equilibrium among pastures, trees and animals; if it fails, the sustainability of the system becomes non-viable (Maurucio and Sousa 2010; Paciullo et al. 2011).

Conclusions

Based on the results obtained in this study, the presence of scattered trees in pastures, in the Amazon Piedmont region helps increase milk production in dual purpose cattle systems; however, such effect increases when tree cover goes up to 14.8 and 20.4%. Additional studies are needed to assess how such tree cover levels affect the botanical composition, nutritive value and availability of pastures managed under grazing. These results are even more important considering the post-conflict dynamics in the territory, because those silvopastoral options could be an opportunity for the conservation of woody perennials in livestock farms of the Colombian Amazon.

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References

Abreu MHS, de (2002) Contribution of trees to the control of heat stress in dairy cows and the financial viability of livestock farms in humid tropics

Abreu MHS, de., Ibrahim M, Sales Silva J (1999) Arboles en pastizales y su influencia en la producción de pasto y leche. In Memorias Primer Congreso Latinoamericano de agroforestería para la producción animal., Cali-Colombia, pp 25–29

Albarrán-Portillo B, García-Martínez A, Ortiz-Rodea A, Rojo-Rubio R, Vázquez-Armijo JF, Arriaga-Jordán CM (2019) Socioeconomic and productive characteristics of dual purpose farms based on agrosilvopastoral systems in subtropical highlands of central Mexico. Agrofor Syst 93:1939–1947. https://doi.org/10.1007/s10457-018-0299-2

Álvarez C, Casanoves F, Suarez S, Sterling A (2020) Influence of the shade of trees dispersed in pastures on the net primary aerial productivity of grasses in the Colombian Amazon foothills. Florencia - Caquetá

Betancourt K, Ibrahim M, Harvey C (2003) Efecto de la cobertura arbórea sobre el comportamiento animal en fincas ganaderas de doble propósito en Matiguás, Matagalpa, Nicaragua. Agroforesteria en las Am 10:47–51

Bird PR, Bicknell D, Bulman PA, Burke SJA, Leys JF, Parker JN, van der Sommen FJ, Voller P (1992) The role of shelter in Australia for protecting soils, plants and livestock. Springer, Dordrecht, pp 59–86. https://doi.org/10.1007/978-94-011-1832-3_3

Blackshaw JK, Blackshaw AW (1994) Heat stress in cattle and the effect of shade on production and behaviour: A review. Aust J Exp Agric 34:285–295. https://doi.org/10.1071/EA9940285

Carnevalli RA, de Mello ACT, Coletti AJ, Garcia LF, Xavier DB (2019) Shade controls the ruminating and idleness times of dairy heifers in tropical integrated systems. Agrofor Syst. https://doi.org/10.1007/s10457-019-00448-7

Collier RJ, Gebremedhin KG (2015) Thermal biology of domestic animals. Annu Rev Anim Biosci 3:513–532. https://doi.org/10.1146/annurev-animal-022114-110659

Cruz F, Ibrahim M (2013) Los árboles en los potreros para la reducción del estrés calórico del ganado en los trópicos. sidalc.net 36

Curtis SE (1983) Environmental management in animal agriculture. Environ. Manag. Anim. Agric

Di Rienzo RJA, Casanoves F, Balzarini MG, González L, Tablada M, Robledo, C.W., 2018. InfoStat

Di Rienzo RJA, Macchiavelli E, Casanoves F (2012) Modelos lineales mixtos: aplicaciones en InfoStat

Djimde M, Torres F (International C. for R. in A.N. (Kenya)), Migongo-Bake, W., 1989. Climate, animal and agroforestry

Esquivel H, Harvey CA, Villanueva C (2003) Árboles dispersos en potreros de fincas ganaderas en un ecosistema seco de Costa Rica

Gallardo MR, Valtorta SE, Leva PE, Gaggiotti MC, Conti GA, Gregoret RF (2005) Diet and cooling interactions on physiological responses of grazing dairy cows, milk production and composition. Int J Biometeorol 50:90–95. https://doi.org/10.1007/s00484-005-0276-0

Gaughan JB, Goodwin PJ, Schoorl TA, Young BA, Imbeah M, Mader TL, Hall A (1998) Shade preferences of lactating Holstein-Friesian cows. Aust J Exp Agric 38:17–21. https://doi.org/10.1071/EA97039

Harja D, Vicent G (2005) SExI-FS: Spatially Explicit Individual-based forest simulator|world agroforestry|transforming lives and landscapes with trees

Holdridge LR, (Leslie R (1987) Ecología basada en zonas de vida, Libros y Materiales Educativos (IICA). Instituto Interamericano de Cooperación para la Agricultura

Johnson H, Ragsdale A, Berry I, Bulletin MS-SR, U (1962) Effect of various temperature-humidity combinations on milk production of Holstein cattle. MO. Agric. exp

Kallenbach RL, Kerley MS, Bishop-Hurley GJ (2006) Cumulative forage production, forage quality and livestock performance from an annual ryegrass and cereal rye mixture in a Pine Walnut Silvopasture. Agrofor Syst 66:43–53. https://doi.org/10.1007/s10457-005-6640-6

Karvatte N, Klosowski ES, de Almeida RG, Mesquita EE, de Oliveira CC, Alves FV (2016) Shading effect on microclimate and thermal comfort indexes in integrated crop-livestock-forest systems in the Brazilian Midwest. Int J Biometeorol 60:1933–1941. https://doi.org/10.1007/s00484-016-1180-5

Köppen vonW (1936) Das geographische system der Klimate Handbuch der Klimatologie in fünf Bänden

Mahecha L, Angulo J (2012) Nutrient management in silvopastoral systems for economically and environmentally sustainable cattle production: a case study from Colombia. In: Soil fertility improvement and integrated nutrient management: a global perspective, pp 201–216

Mancera KF, Zarza H, de Buen LL, García AAC, Palacios FM, Galindo F (2018) Integrating links between tree coverage and cattle welfare in silvopastoral systems evaluation. Agron Sustain Dev 38:1–9. https://doi.org/10.1007/s13593-018-0497-3

Marques S (2000) O Stress ea Nutrição de Bovinos. universitária - Maringá: Imprensa

Mauricio R, Sousa L (2010) Silvopastoral system, cerrado and tropical forest biome in Brazil: Case studies. In Successes and failures with animal nutrition practices and technologies in developing countries: A synthesis of an FAO e-conference

Mauricio RM (2012) Comment to “Pasture shade and farm management effects on cow productivity in the tropics” by Justin AW, Ainsworth SR, Moe C Skarpe [Agric. Ecosyst. Environ. 155 (2012) 105–110]. Agric Ecosyst Environ https://doi.org/10.1016/j.agee.2012.07.012

Mitlöhner FM, Galyean ML, McGlone JJ (2002) Shade effects on performance, carcass traits, physiology, and behavior of heat-stressed feedlot heifers. J Anim Sci 80:2043–2050. https://doi.org/10.1093/ansci/80.8.2043

Nakamura K, Morrison SF (2008) A thermosensory pathway that controls body temperature. Nat Neurosci 11:62–71. https://doi.org/10.1038/nn2027

Paciullo DSC, de Castro CRT, Gomide CA, de M, Maurício, Pires RM, M de F, Müller, Xavier MD, D.F (2011) Performance of dairy heifers in a silvopastoral system. Livest Sci 141:166–172. https://doi.org/10.1016/j.livsci.2011.05.012

Paciullo DSC, Pires MFA, Aroeira LJM, Morenz MJF, Maurício RM, Gomide CAM, Silveira SR (2014) Sward characteristics and performance of dairy cows in organic grass-legume pastures shaded by tropical trees. Animal 8:1264–1271. https://doi.org/10.1017/S1751731114000767

Pezo D, Ibrahim M (1999) Sistemas silvopastoriles. CATIE

Pezo D, Ríos NP, Muhammad I, Gómez M (2019) Silvopastoral systems for intensifying cattle production and enhancing forest cover: the case of Costa Rica

Restrepo-Sáenz C, Ibrahim,; Muhammad, Harvey C, Jean, ;, Harmand M, Morales J (2004) Relaciones entre la cobertura arbórea en potreros y la producción bovina en fincas ganaderas en el trópico seco en Cañas, Costa Rica. Avances de Investigación 29. Agroforestería en las Américas 41, 29–35

Rodríguez SL, Paladines JY, E AS, Lopez CC, Durán BE, Suárez-Salazar JC (2018) Soil macrofauna under different land uses in the Colombian Amazon. Pesqui Agropecu Bras 53:1383–1391. https://doi.org/10.1590/S0100-204X2018001200011

Solorio FJ, Basu SK, Sarabia L, Ayala A, Ramírez L, Aguilar C, Erales JA, Ku JC, Wright J (2016) The Potential of Silvopastoral Systems for Milk and Meat Organic Production in the Tropics. Springer, Cham, pp 169–183. https://doi.org/10.1007/978-3-319-26803-3_8

Sotelo M, Suárez J, Álvarez F, Castro A, Calderon V, Arango J (2017) Sistemas sostenibles de producción ganadera en el contexto amazónico Sistemas silvopastoriles: ¿una opción viable?

Tancin V, Kraetzl WD, Schams D, Bruckmaier RM (2001) The effects of conditioning to suckling, milking and of calf presence on the release of oxytocin in dairy cows. Appl Anim Behav Sci 72:235–246. https://doi.org/10.1016/S0168-1591(01)00113-7

Torres F (1983) Role of woody perennials in animal agroforestry. Agrofor Syst 1:131–163. https://doi.org/10.1007/BF00596354

Torrijo R, Beltran Y, Eslava F (2018) Contexto ganadero regional 2017 - Buscar con Google. Florencia - Caquetá

West JW (2003) Effects of heat-stress on production in dairy cattle. J Dairy Sci 86:2131–2144. https://doi.org/10.3168/jds.S0022-0302(03)73803-X

Yamamoto W, Dewi IA, Ibrahim M (2007) Effects of silvopastoral areas on milk production at dual-purpose cattle farms at the semi-humid old agricultural frontier in central Nicaragua. Agric Syst 94:368–375. https://doi.org/10.1016/j.agsy.2006.10.011

Zamora S, García J, Bonilla G, Aguilar H, Harvey CA, Ibrahim M (2001) Uso de frutos y follaje arbóreo en la alimentación de vacunos en la época seca en Boaco, Nicaragua. Avances de Investigación 31. Agroforesteria en las Am 8:31–38

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