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Original Article

Silvopastoral systems as a tool for recovering degraded pastures and improving animal thermal comfort indexes in Northern Ecuador

Sistemas silvipastoris como ferramenta para recuperação de pastagens degradadas e melhoria dos índices de conforto térmico animal no norte do Equador

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Abstract

Athropogenic changes have caused profound repercussions, which have led to a progressive degradation of natural resources. In the case of the Ecuadorian Amazon, the high rate of deforestation, changes in land use and extensive livestock management have led to low production rates with an eminent threat to the thermal comfort of ruminants. The present study aimed to contrasts how the use of SPs represents a viable option for the reconversion of extensive livestock farming. The current study compared the use of silvopastoral systems (SPs) versus a conventional pastoral system, as an alternative for the recovery of degraded areas. Therefore, under a completely randomized block design, *Brachiaria decumbens* was evaluated with three of treatments, such as Control = conventional pastoral, SPs1 = density 100 trees/ha^{-1} and SPs2 = 150 trees/ha^{-1}. All environmental variables and bioclimatic indicators (temperature and radiant heat load: RHL) were shown to be mitigated under SPs ($P < 0.001$), which translates into better thermal comfort for ruminants (RHL; 638 vs. 1749 ± 40; $P < 0.001$). Although, the treatments affected all the agronomic variables of *Brachiaria decumbens* ($P < 0.001$ to 0.004), the month conditioned most of the chemical determinations ($P < 0.001$). This means that the use of SPs in the medium or long term could contribute to the recovery of pastures in degradation processes. Consequently, SPs as a clean production alternative would help improve aspects such as soil quality, agronomic yields, as well as greater nutritional quality of pastures. In any case, long-term studies should be performed to contrast our responses.

Keywords: *Brachiaria decumbens*, biodiversity, degraded pastures, forage quality, silvopastoral system, thermal comfort.

Resumo

As mudanças antropogênicas têm causado profundas repercussões, que levaram a uma degradação progressiva dos recursos naturais. No caso da Amazônia equatoriana, a alta taxa de desmatamento, as mudanças no uso da terra e o manejo extensivo da pecuária têm levado a baixas taxas de produção, com uma ameaça iminente ao conforto térmico dos ruminantes. O presente estudo teve como objetivo contrastar como o uso de sistemas silvipastoris (SPs) representa uma opção viável para a reconversão da pecuária extensiva. O presente estudo comparou o uso de sistemas silvipastoris *versus* um sistema pastoral convencional, como alternativa para a recuperação de áreas degradadas. Portanto, sob um delineamento em blocos inteiramente casualizados, *Brachiaria decumbens* foi avaliada com três tratamentos: Controle = pastoral convencional, SPs1 = densidade 100 árvores/ha^{-1} e SPs2 = 150 árvores/ha^{-1}. Todas as variáveis ambientais e indicadores bioclimáticos [temperatura e carga de calor radiante (RHL)] mostraram-se mitigados sob SPs ($P < 0{,}001$), o que se traduz em melhor conforto térmico para ruminantes (RHL; 638 vs. 1.749 ± 40; $P < 0{,}001$). Embora os tratamentos tenham afetado todas as variáveis agronômicas de *Brachiaria decumbens* ($P < 0{,}001$ a 0,004), o mês condicionou a maioria das determinações químicas ($P < 0{,}001$). Isso significa que o uso de SPs em médio ou longo prazo pode contribuir para a recuperação de pastagens em processos de degradação. Consequentemente, os SPs como alternativa de produção limpa ajudariam a melhorar

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alguns aspectos, como qualidade do solo e rendimentos agronômicos, bem como maior qualidade nutricional das pastagens. De qualquer forma, estudos de longo prazo devem ser realizados para contrastar nossas respostas.

Palavras-chave: *Brachiaria decumbens*, biodiversidade, pastagens degradadas, qualidade da forragem, sistema silvipastoril, conforto térmico.

1. Introduction

Pastures and forage crops comprise 26% of the land and 70% of the global agricultural area (FAOSTAT, 2022) and are the main component of the diet of ruminant livestock (Waghorn and Clark, 2011; Costa et al., 2016; Capstaff and Miller, 2018; Driehuis et al., 2018). Consequently, livestock farming worldwide has great economic relevance, since it contributes 40% to the total agricultural gross domestic product (GDP) (Thornton and Gerber, 2010; Hörtenhuber et al., 2022). In the case of Ecuador, the livestock sector contributes no more than 0.76% of the GDP, which is concentrated in the central highlands region (Cayambe et al., 2021; Torres et al., 2022; Navarrete, 2023). By the year 2050, the great challenge we may face is to produce 60% more than the current supply of food, feed and fiber considering a population growth of 9.3 billion people (FAO, 2021). In fact, current figures indicate that 34% of the arable surface area worldwide is allocated to the production of livestock feed, in response to the growing demand for food (Flores-Coello et al., 2023). These anthropogenic changes according to (IPCC, 2022) have contributed to about 25% of greenhouse gas emissions (10 to 12 Pg CO_2 eq yr^{-1}). These results have led to profound climate variability, with serious repercussions on the population's livelihoods (Toulkeridis et al., 2020; Beauchemin et al., 2022).

On the other hand, the Ecuadorian Amazon is experiencing an alarming expansion of the agricultural frontier, as a result of deforestation and changes in land use (Torres et al., 2021; Echeverría-Puertas et al., 2023; García-Cox et al., 2023). Data indicated by INEC- ESPAC (2022) estimate that in 2022 there were 3.8 million hectares of grasslands, intended for extensive livestock farming, to provide meat and milk (Torres et al., 2021). An interesting study conducted by González-Marcillo et al. (2023) in Orellana Province (NE Ecuador) revealed that pastures managed in monoculture showed low nutritional quality, negatively impacting animal responses. In addition to this, Guamán-Rivera et al. (2023b) yielded different types of livestock farms, highlighting the so-called subsistence group (75% of the total farms), given a clear decrease in the forestry component of their farms in an attempt to compensate for the low agronomic yields of pastures. In this sense, scientific evidence from the last decade has revealed that livestock farming based only on pastures, that is, monoculture, degrades soil and pasture resources (Flores-Coello et al., 2023). Therefore, ruminants kept in these conditions represent an important source for the emission of anthropogenic methane (CH_4) (Poma et al., 2021; Flores-Coello et al., 2023). Along the same lines, tropical areas represent a difficult therm al environment for animals (Kendall et al., 2006; Gomes et al., 2019; 2020). Indeed, many experimental studies have determined that animals subjected to heat stress conditions reduce food intake, with an increase in respiration rate and body temperature (Gomes et al., 2020; Viciedo et al., 2021). Cattle as homeothermic animals, regardless of climatic fluctuations, maintain their internal body temperature relatively constant (Giro et al., 2019). Furthermore, although bovines of *Bos indicus* origin indicate higher tolerance to tropical areas, however, environmental variations could trigger the animal to allocate energy to dissipate heat and maintain its thermal balance, with significant losses in productivity (Wheeler et al., 1994; Baruselli et al., 2003; Sartori and Barros, 2011).

Tropical forests constitute an ecological biome of global importance for carbon cycles, climate patterns and biodiversity (Neugebauer, 1988; Sheldon et al., 2006). In the province of Orellana, Yasuní is located, which is considered one of the richest biodiversity reserves in the world (Bass et al., 2010; Lozano et al., 2020). However, extensive livestock farming has caused a growing threat due to the indiscriminate felling of forests to plant pastures as a monoculture (Clavo-Peralta et al., 2022). Under a scenario of fight against climate change, in other latitudes, livestock farming has taken on new horizons (Yadav et al., 2019). In this sense, reducing enteric CH_4 emissions from ruminant production is strategic to limit the increase in global temperature to 1.5 °C in 2050 (Beauchemin et al., 2022). Some studies performed with degrading pastures suggest that the introduction of trees not only increases carbon storage in surface pools, but also creates more stable soil carbon pools (Baldassini et al., 2018; Beauchemin et al., 2022). Therefore, the use of silvopastoral systems (SPs) represents one of the most practical ways to adapt to the increase in global temperatures and mitigate the emission of greenhouse gases (Moorby and Fraser, 2021). According to FAO (2022), agroforestry, including silvopastoral systems, is classified as a climate-smart agricultural practice that provides ecological diversity and protection against erosion, in addition to benefits in carbon absorption (Soder and Brito, 2023). Considering the global fight against climatic change and providing greater comfort conditions for ruminants is an objective of the scientific community. Therefore, the present study aimed to contrasts how the use of SPs represents a viable option for the reconversion of extensive livestock farming in the northern Amazon of Ecuador.

2. Materials and Methods

2.1. Experimental site

The present research work was conducted in the La Belleza parish, belonging to the Province of Orellana, Ecuador. The geographical coordinates are south latitude between (0° 42 10.0¨) and west longitude (77° 1 12.0¨). In the study area, according to INAMHI (2021), rainfall ranges from 2800 mm per year, while the annual temperature averages of about 26.19 °C and the relative humidity appears to be higher than 80%. Before starting the experimental period, soil samples were collected at a depth of 0 to 10 cm to perform chemical analyses (Table 1).

2.2. Treatments and experimental design

According to a completely randomized block design, for this study, nine experimental units were established, which in turn each of these was subdivided into three lots whose dimensions were 100 × 33.33 m. After that, the following treatments were randomly assigned:

Control, conventional treeless pastoral system

SPs1, silvopastoral system with a density of (100 trees ha^{-1})

SPs2, silvopastoral system with a density of (150 trees ha^{-1})

The different spatial arrangements of silvopastoral systems evaluated in this experiment were composed of *Brachiaria decumbens*, which had been established more than 10 years ago. In addition, the paddocks considered as SPs had the presence of scattered trees native to the area such as laurel (*Laurus nobilis*), leucaena (*Leucaena leucocephala Lam.*), Cedar (*Cedrela odorata*) and Sangre de gallina (*Dialyanthera* gracilipes). On the other hand, within the fruit trees they included Guaba (*Inga edulis*) and Guava (*Psidium guajava*) mainly. The conventional pastoral system was characterized instead by not having the forestry component. It should be noted that in the northern Amazon of Ecuador, these species are the most representative from the ecological point of view, abundance, frequency and dominance.

Table 1. Soil chemical analysis taken at a depth of (0 to 10 cm) of the study area.

Item	Value
pH	4.39
OM, %	3.92
Macroelements, meq/100 mL	
P	4.43
K	0.19
Ca	2.25
Mg	0.72
S	2.80
Zn	2.16
Microelements, ppm	
Cu	2.02
Fe	295
Mn	19.50
B	0.30
Textural class %	
Sand	35
Silt	30
Clay	35
Cationic Relationships	
Ca Mg	3.16
Mg K	5.30
Ca + Mg K	5.30
Σ Bases, meq/100 mL	3.15

2.3. Environmental variables and bioclimatic indicators

Air temperature and relative humidity (HMP45A temperature and humidity sensor, Vaisala, Helsinki, Finland), wind speed (Hall effect anemometer No. 40, NRG Systems, Hinesburg, VT, USA), precipitation (spoon rain gauge tilting, Pronamic Silkeborg, Denmark), solar radiation (Licor Li200x pyranometer, Campbell Scientific Inc. Logan, UT, USA) and black globe temperature (CSI 107 black globe temperature sensor, Campbell Scientific Inc., BGT) were recorded at 10-min intervals with a data logger (CR10X, Campbell Scientific Inc.) at meteorological stations located both in the conventional pastoral system and within the SPs.

The temperature-humidity index (THI) was calculated using the Equation 1, described by Tucker et al. (2008). Where T is the air temperature (°C), RH is the relative humidity (%)

$$\boldsymbol{THI} = (1.8 \times T + 32) - \begin{pmatrix} (0.55 - 0.0055 \times RH) \times \\ (1.8 \times T - 26) \end{pmatrix} \quad (1)$$

In addition, the radiant heat load (RHL) was calculated as a way to express the total radiation received either directly or indirectly by the animal (Maloney, 2008; Giro et al., 2019), according to the following Formula 2.

$$\boldsymbol{RHL} = \sigma \times \left(Tm^{2} \right) \quad (2)$$

Where, σ is the Stefan–Boltzmann constant, 5.67 9 10-8 kg s-3 K-4 (W m^{-2}) and *Tm* is the mean radiant temperature (W m^{-2}) (Oliveira et al., 2018; Santos Neto et al., 2022)

2.4. Pasture measurements

For the present study, a grazing frequency of every 35 days was used for *Brachiaria decumbens*, as determined by Figueroa-Saavedra and Guamán-Rivera (2023) and González-Marcillo et al. (2023). Before each cut, the plant height was recorded. Hereby, we used a quadrant of one square meter, while plants were randomly selected and with the help of a flexometer (Guamán-Rivera et al., 2023a) it was taken from the basal surface of the plant, to the terminal half of the leaf, in order to determine an average height. Likewise, following the methodology of Onyeonagu and Asiegbu (2013), and validated by Figueroa-Saavedra and Guamán-Rivera (2023) and González-Marcillo et al. (2023) the base coverage was estimated with the double sampling method through direct observation where (1), < 20% = very low, (2), 20 to 39% = low, (3), 40 to 59% average, (4), 60 to 79% high and (5), 80 to 100% very high. To determine the stem-leaf ratio, in each sampling, 1 kg of green forage from each treatment was collected, which was used to manually separate leaves from the stems and then obtain their proportion by difference. Herbage mass (HM, kg ha^{-1}) was obtained using the double sampling technique described by NRC (1962). Therefore, as a direct measure, a 0.25 m^2 square was used to collect random samples in each treatment. In addition, with the measurements of HM and plant height, the bulk density of the forage (kg DM ha^{-1} cm^{-1}) was calculated as described (Nascimento et al., 2021). Meanwhile, the grass ration was calculated based on the usable herbage (kg DM/ha^{-1}) and the live weight of the cattle (Costa et al., 2016; Berça et al., 2021). In our study, a weight of 274 kg was taken as a reference, which corresponds to that of an adult animal of *Bos indicus* (Brahman) origin for the study area as determined by Guamán-Rivera et al. (2023b; 2024).

2.5. Chemical composition and forage quality

Grass samples (0.5 kg) were collected from each treatment to perform chemical determinations in duplicate according to the AOAC (2000) procedures. Dry matter (DM) was obtained by subjecting 100 grams of HM for 48 hours in a forced ventilation oven at 106°C. Similarly, the ash content in an oven for 5 hours at 550°C (AOAC, 2000). With this ash value, the organic matter (OM) was obtained as 100 - % ash. For crude protein (CP) values, the Kjeldahl method was used (Kjeltec Auto 1030 Analyzer, Tecator, Höganäs, Sweden) and using $CuSO_4$/Se as a catalyst instead of $CuSO_4$/TiO_2). While in parallel, the content of structural carbohydrates (NDF, ADF and lignin), according to Van Soest et al. (1991) and Guamán-Rivera et al. (2023c) after adding sodium sulfite and α-amylase in a semi-automatic equipment (F800 Fiber Analyzer, Hanon Advanced Technology Group, China). Regarding to values of forage quality (RFV, RFQ, GE and TDN) these were calculated as described (Guamán-Rivera et al., 2023c).

2.6. Statistical analysis

The data were analyzed using the PROC MIXED procedure of SAS version 9.4 (SAS Institute Inc., Cary, NC, USA). Prior to analysis, all variables were checked for normality using the PROC UNIVARIATE procedure. Likewise, the homogeneity of the variances was checked with the Kolmogorov-Smirnov test. Different structures of the variance-covariance matrix were tested, and the composite symmetry structure was chosen based on the smallest Bayesian information criterion (BIC). For our study, the statistical model considered the treatments (Control, SPs1 and SPs2), the month, as well as their interaction as fixed effects. While the block and the residual error were considered as random effects. The means were obtained as least squares with the PDIFF option of SAS and compared with a Tukey test. Significant differences were declared at $P < 0.05$ and trends at $P < 0.10$.

3. Results

3.1. Environmental variables and bioclimatic indicators

Table 2 lists the averages obtained with respect to the environmental variables recorded during the study period. Marked differences were observed in the environmental variables (P < 0.001), when we compared a conventional pastoral system versus a silvopastoral system. Under grazing conditions, an average temperature of 31.5 °C is observed in a conventional system compared to 28.9 °C for an SPs. Therefore, in relative humidity we have observed a difference of 4.5% when there is the presence of the forest component (P < 0.001). Furthermore, as expected, solar radiation yielded a difference of 83 W/m^2 when animals are kept in pastures without the presence of trees (85 vs. 235 ± 83 W/m^2; P < 0.001; Table 2). Consequently, an enormous value of radiant heat load was observed in a conventional pastoral system compared to a SPs (1749 vs. 638 ± 40 W/m^2; P < 0.001; Table 2).

3.2. Pasture measurements

The yields of *Brachiaria decumbens* under different spatial arrangements of silvopastoral systems are listed in Table 3. With the exception of the stem/leaf ratio, which did not vary between treatments (45 ± 5; *P* > 0.19). Highly significant differences were observed for the rest of the variables evaluated (*P* < 0.001 to 0.004). In general, *Brachiaria decumbens* demonstrated higher values under a conventional grazing system compared to those obtained in pastures with low tree densities (i.e. 100 to 150 tree/ha^{-1}). While comparing the observed values of *Brachiaria decumbens* in two densities of trees/ha^{-1} (Table 3), no significant differences were observed (*P* = 0.32 to 0.88). Regarding the measurements of *Brachiaria decumbens* grass according to the month of evaluation, no significant differences were observed (*P* = 0.11 to 0.78; Table 3). In addition to that, no interaction was detected between Treat × Month for any of the determined variables (Table 3).

Table 2. Agroclimatic data registered during the experimental period.

Items	Livestock systems			SEM	*P* < value
	Silvopastoral	Conventional	Differences		Treatment
Temperature, (°C)	28.90^b	31.35^a	2.4	1.62	0.001
Relative Humidity (%)	73.22^a	68.66^b	4.5	0.1	0.001
Solar radiation, W/m^2	85^b	235^a	82.6	60	0.001
THI[1]	80^b	83^a	3.0	1.5	0.001
RHL[2]	638^b	1749^a	1111	40	0.001

[1]Temperature–humidity index.[2]Radiant heat load; SEM, standard error of the mean. $^{a-b}$Means with different letter in the same row, differ at *P* < 0.05.

Table 3. Agronomic measurements of *Brachiaria decumbens* under conventional pasture and silvopastoral systems.

Item	Treatments			SEM	*P = value*		
	Control	SPs1	SPs2		Treatment	Month	T × M
Plant heigh, cm	64[a]	43[b]	38[b]	3	0.001	0.78	0.86
Plant cover, % m^2	73[a]	38[b]	34[b]	6	0.001	0.63	0.99
Stem leaf ratio	45	44	42	5	0.19	0.78	0.95
Herbage mass, kg ha^{-1}	12354[a]	4869[b]	4742[b]	2473	0.001	0.14	0.48
DM, kg ha^{-1}	3706[a]	1460[b]	1422[b]	742	0.001	0.12	0.53
Herbage bulk density, kg cm-1 ha^{-1}	191[a]	110[b]	122[b]	15	0.004	0.11	0.10
Total usable herbage, kg DM ha^{-1}	2594[a]	1023[b]	996[b]	519	0.001	0.15	0.48
Herbage allowance, kg DM/100 kg BW^2	10[a]	4[b]	4[b]	2	0.001	0.12	0.48

Treatments, Control = pastoral conventional; SPs1, density of 100 tree/ha^{-1}; SPs2, density of 150 tree/ha^{-1}; SEM, standard error of the mean; T × M, treatment × month interaction. [a-b]Means with different letter in the same row, differ at $P < 0.05$.

Table 4. Chemical composition and forage quality of *Brachiaria decumbens* under conventional pasture and silvopastoral systems.

Item	Treatments			Month		SEM	*P = value*		
	Control	SPs1	SPs2	January	Jun		Treat	Month	T × M
Composition, %									
DM at 103°C	94.92	94.01	94.74	95.39[a]	94.0[b]	0.3	0.14	0.001	0.95
Ash	7.9	11.8	9.2	10.3	9.0	2.1	0.22	0.49	0.76
OM	92.1	88.2	90.8	89.7	91.0	2.1	0.21	0.49	0.75
Ether extract	3.2	3.8	3.2	4.1[a]	3.0[b]	0.4	0.30	0.001	0.14
CP	4.1	4.0	4.0	3.9	4.1	0.1	0.79	0.23	0.99
CF	23.3	24.5	22.2	26.3[a]	20.4[b]	0,8	0.23	0.001	0.20
Nitrogen-free extractives	65	60	65	59.5[b]	67.0[a]	2.0	0.05	0.001	0.52
NDF	51.6	52.6	50.5	54.2[a]	49.0[b]	1.3	0.24	0.001	0.20
ADF	27.2	27.8	26.0	29.4[a]	24.5[b]	1.2	0.26	0.001	0.26
Forage quality									
RFV	122	120	128	113[b]	133[a]	3.5	0.18	0.001	0.15
RFQ	117	115	122	109[b]	129[a]	3.4	0.18	0.001	0.15
GE, Mcal kg/DM	3.5	3.4	3.4	3.4	3.4	6.1	0.41	0.89	0.64
TDN	62	61	63	60[b]	63[a]	1.0	0.26	0.001	0.26

Treatments, Control = pastoral conventional; SPs1, density of 100 tree/ha^{-1}; SPs2, density of 150 tree/ha^{-1}; SEM, standard error of the mean; Nitrogen-free extractives, (OM-CP+CF); T × M, treatment × month interaction.[a-b]Means with different letter in the same row, differ at $P < 0.05$.

3.3. Chemical composition and forage quality

The chemical composition data of the *Brachiaria decumbens* grass evaluated under conventional pasture and SPs are listed in Table 4. None of the chemical determinations of the grass varied between treatments ($P = 0.05$ to 0.79). The averages of the main values were OM (90.4 ± 2.1% DM^{-1}), CP (4 ± 0.1% DM^{-1}), NDF (52 ± 1.3% DM^{-1}) and ADF (27 ± 1.2% DM^{-1}). Furthermore, as expected, as no differences were found between treatments for any of the chemical determinations (Table 4), forage quality lacked to vary between treatments in terms of RFV (123 ± 3.5, on average), RFQ (118 ± 3.4, on average), GE (3.4 ± 6.1 Mcal kg/DM, on average) and TDN (62 ± 1.0, on average).

On the contrary, a strong influence of the month was observed for most of the chemical components of the *Brachiaria decumbes* grass ($P < 0.001$; Table 4). We highlight a slight numerical difference in the CP contents (3.9 vs. 4.1 ± 0.1% DM^{-1}), which were more evident on the NDF (54.2 vs. 49.0 ± 1.3% DM^{-1}; $P < 0.001$) and ADF (29.4 vs. 24.5 ± 1.2%; $P < 0.001$). Therefore, the *Brachiaria decumbens* grass demonstrated a substantial increase in terms of forage quality for RFV (113 vs. 133 ± 3.5; $P < 0.001$), RFQ (109 vs. 129 ± 3.4; $P < 0.00$) and TDN (60 vs. 63 ± 1; $P < 0.00$). In the present study, no Treatment × Month interactions were detected on any of the chemical determinations of the *Brachiaria d*ecumbens grass (Table 4).

4. Discussion

Animals subjected to thermal stress conditions reduce their expression in productive terms, which causes low economic income for families (Pezzopane et al., 2019; Giro et al., 2019). According to statistics from 2014, in the Ecuadorian Amazon, close to 1.2 million hectares of pastures were registered for livestock farming (Ecuador, 2022), 90% of which is managed under extensive pastoral systems (Torres et al., 2018). Consequently, despite the high biological biodiversity of the area (Bass et al., 2010; BÓ et al., 2013; Lessmann et al., 2016; Caballero-Serrano et al., 2017), the livestock practices used are outside the ecological reality of this region. This leads to a constant threat to the conservation and rational use of the biotic resources of the Amazon region. In fact, at the level of the Amazon region of Ecuador, few studies have focused on trying to establish objective strategies that allow for the reconversion of pastures in the process of degradation, as well as quantifying environmental variables that could be determinants for animal responses. Therefore, it is fundamental to highlight the synergies and interactions that occur when livestock farming is developed with the use of silvopastoral systems. In the current study, the temperatures recorded were outside the range considered by de Oliveira et al. (2018) as the best climatic conditions for cattle (10 to 27 °C), although within the relative humidity ranges (60 and 70%). A number of microclimatic indicators have been used to describe the effect of trees compared to conventional pastoral systems. According to Santos et al. (2022) indices such as temperature-humidity, THI, effective temperature, ET, black globe humidity, BGHI, equivalent temperature, ETI and thermal load index, RHL have been widely used to predict the environmental thermal comfort threshold of the cattle (Berman et al. 2016; Behura et al. 2016; Oliveira et al., 2018). This pioneer study conducted in Ecuador has quantified the THI and RHL indices, although we are aware of the importance of air temperature and humidity in heat exchange processes between animals and the environment. However, in the case of animals raised in the tropics, thermal radiation takes on enormous relevance.

A higher relative humidity of the air was observed in the SPs than in the conventional pastoral, which indicates the importance of the forest component to contribute to an environment of better thermal comfort, especially at times of greatest radiation load, as reported (Santos Neto et al., 2022). In any case, according to our data, the THI of both the conventional pastoral system and the SPs yielded values of 80 and 83%, which, being greater than 74, demonstrates that the animals would potentially be subjected to thermal stress (Giro et al., 2019). In this sense, greater THI and RHL, decreased milk production and milk composition due to lower dry matter intake and growth rate. In the same way, studies have shown altered estrus cycles, reducing conception rates and therefore increasing pregnancy loss. This could in part be explained given the low density of trees/ha^{-1} used in this study. Hypothesis that is reinforced by Gomes da Silva and Campos Maia (2013) who have reported that changes in the microclimate under trees are associated with morphological characteristics and plantation density. Indeed, de Oliveira et al. (2018) recorded that a density of 357 trees/ha^{-1} decreased wind speed, promoting changes in the microclimate. Despite all this evidence, it must be considered that the genotype of the animal is an item to consider since this can be decisive due to its susceptibility or tolerance to thermal load (Lees et al., 2019). In our case, bovines of *Bos indicus* origin are widely raised in pastoral conditions (González-Marcillo et al., 2023) which, based on scientific evidence, have a higher tolerance to heat compared to *Bos Taurus* breeds (Gomes da Silva and Campos Maia, 2013). It is also fundamental to highlight that a reduction of −64% in the RHL has been obtained with SPs systems, which would be explained due to the barrier exerted by the tree canopy. Supporting our findings, (Pezzopane et al., 2019; Giro et al., 2019) observed that the presence of the forest component in the pastures led to greater thermal comfort in cattle, which was evidenced by a lower RHL. Reference data from grazing Holstein cows have recorded an estimated 640 W m^{-264}. In its simplest form, Lees et al. (2019) states that shade can reduce an animal's radiant heat load by 30%, basically blocking the sun's rays.

Under the given conditions, the poor availability of high-productivity adapted forage materials, together with inadequate pasture management, has caused a rapid decline in productivity and low income for livestock farmers. The present study demonstrated that *Brachiaria decumbens* was relatively sensitive to the shade effect despite the low tree densities used (100 to 150 trees/ha^{-1}), contrary to what was observed by Baruch and Guenni (2007) who reported that this species was the most suitable for use in SPs with moderate densities. Another theory that we have considered is that we could be dealing about genetic degeneration of *Brachiaria decumbens* since they are pastures that have been established for more than ten years and have received no type of intervention. It is expected, as has been observed in other studies, that the adoption of SPs would increase, in the medium to long term, the biomass on the soil surface, the level of OM in the surface horizon, with it, the availability and recycling of nutrients improving the structural index of the soil (Huera-Lucero et al., 2020). Baldassini et al. (2018) for their part stated that the presence of trees could reduce the performance of pastures through competition for light. Although the conventional pastoral system demonstrated higher agronomic yields compared to SPs (Table 2), these are lower than other reference studies Baruch and Guenni (2007), therefore, they do not necessarily reflect higher nutritional values Figueroa-Saavedra and Guamán-Rivera (2023). In ruminant nutrition, CP values $< 7\%$ on a dry matter basis are not recommended (Givens et al., 2000). However, this study indicated that *Brachiaria decumbens* would not meet the ammonia needs for microbial protein synthesis in the rumen (Russell et al., 1992). Furthermore, under these conditions, grasses of low nutritional quality would contribute to the emission of more greenhouse gases (GHG) of enteric origin by ruminants (CH_4) (Beauchemin & Yang, 2005). The above described could be supported according to Améndola et al. (2019) who demonstrated that forages with low CP content limit the ingestion of DM, in correspondence with high content of structural carbohydrates, as observed in our study. Therefore, increasing fiber in forages reduces the action of microorganisms in fiber digestion. Consequently, establishing sustainable livestock practices could be a viable alternative to mitigate GHG, considering that 30% of the world's land is used for grazing (Souza Filho et al., 2019). Flachowsky et al. (2013), Congio et al. (2018) and Machado et al. (2022) state that the use of silvopastoral systems could contribute to GHG mitigation by removing carbon from the atmosphere and accumulating it as biomass or fixing it to the soil (Giro et al., 2019). Likewise, Baldassini et al. (2018) reported that the interception of radiation by woody plants can decrease forage yield, but, simultaneously, can increase its quality. In addition to this, we highlight that disseminating the use of native forest plants revalue the genetic resources of the Amazon, with incalculable environmental benefits. Consequently, in the long term, the use of SPs directly reduces light intensity and air temperature, which improves soil moisture and organic matter mineralization processes, contributing to improving nutrient absorption and, therefore, the quality of the forage (Gómez et al., 2013; Améndola et al. 2019). Nonetheless, it is fundamental to highlight that under a scenario fighting climate change, it should be combined with recently released grass varieties that have demonstrated more tolerance to this variability in environmental conditions.

5. Conclusion

Based on our results, the use of SPs mitigates the effects of environmental variables that could condition the thermal comfort of the animals. Greater agronomic responses were observed in *Brachiaria decumbens* when it was cultivated under silvopastoral systems, this pasture also had lower contents of structural carbohydrates when compared to conventional pastoral systems, although not statistically significant. Consequently, this first pilot study should be performed in the long term to have more evidence that SPs represent an alternative for the recovery of pastures in the process of degradation.

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