AGROECOLOGY AND SUSTAINABLE FOOD SYSTEMS
https://doi.org/10.1080/21683565.2025.2541376

Tree species selection for silvopastoral systems from an ethnoecological approach: I. The new ethnoecological selection index (EESI) and key interactions in the pastoral agroecosystem

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ABSTRACT

We aimed to integrate local and scientific knowledge to select tree species for elaborate silvopastoral systems with the proposition of a multi-criteria decision-making support tool. We conducted a pilot study in the south of Espírito Santo, a tropical Brazilian region. The survey of trees took place on 136.9 ha of pastureland at nine rural properties. We interviewed 42 family farmers that practiced cattle ranching and had trees in their pastures. A multi-attribute utility function was created to select and order ten tree species with cultural and ecological potential for pasture afforestation. We evaluated these species regarding their interactions with soil cover, herbaceous biomass and bovine grazing. The ten selected tree species showed orderly decreased EESI (Ethnoecological Selection Index) values ranging from 0.8327 to 0.5958. All ten species were native, 30% were nitrogen fixers, 70% had Use Value, and none were invasive. Regarding soil cover, herbaceous biomass, and grazing, the under the crown and outside the crown strata showed no statistical differences between them. The crown base height and herbaceous ground cover positively correlated, while the canopy cover and herbaceous ground cover negatively correlated. The EESI creates an interface between the traditional knowledge of family farmers and scientific knowledge.

KEYWORDS

Silvopastoralism; knowledge systems; traditional ecological knowledge; Agroecology; Social-ecological system

SUSTAINABLE DEVELOPMENT GOALS

SDG 11: Sustainable cities and communities; SDG 12: Responsible consumption and production; SDG 13: Climate action; SDG 15: Life on land

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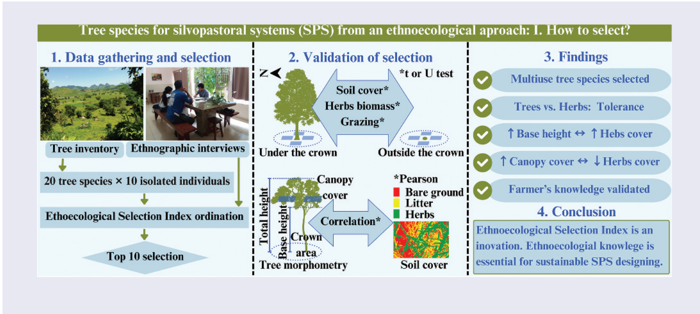
Supplemental data for this article can be accessed online at https://doi.org/10.1080/21683565.2025.2541376



Introduction

Organizing and creating systems are natural tendencies of the human species (Assche et al. 2019). In this context, the classification and ordering of ecological data help humans to understand natural processes, such as ecological interactions in ecosystems (Gotelli and Ellison 2013). Natural ecosystems are changed regarding functioning during the creation of agroecosystems according to human interests and needs, based on perceptions and experiences, and transmitted culturally (Almeida 2013). Ecological knowledge is essential to develop sustainable social-ecological systems because it guides the decision-making process by identifying key ecological properties to be preserved, while increasing the range of management options that stakeholders can explore (Berthet et al. 2019).

Silvopastoral systems (SPS) are complex agroecosystems whose functional dynamics make the construction of silvopastoralism difficult to plan and study (Jose, Walter, and Kumar 2019). According to Jose and Dollinger (2019), designing and maintaining productive silvopastoral systems adapted to each local context can be challenging. Thus, ethnoecological studies have assisted scientists make decisions about selecting potential tree species for the development of silvopastoral systems, taking into account the traditional knowledge of farmers (Fremout et al. 2022), since ethnoecology is the science of how people understand the relationship between humans, animals, plants, and physical elements of a local environment (Davidson-Hunt 2000).

Technological advances have been achieved by combining traditional empirical and systematized scientific knowledge to select multifunctional tree species, composing arrangements for afforestation of pasture with regional key species. Examples include focusing on multiple services or timber production (Andrade, Salman, and Oliveira 2012), ecosystem services for different farm profiles (Barton et al. 2016) and climate change adaptation and mitigation (Balehegn 2017).

We aimed to integrate local and scientific knowledge to select tree species for elaborating silvopastoral systems with the proposition of a multi-criteria decision-making support tool (Mendoza and Martins 2006). The tool can assist scientists and decision-makers to systematically choose key regional species and investigate the main ecological interactions between trees and herbs such as facilitation, tolerance, inhibition, and competition (*sensu* Connell and Slatyer 1977; Mazía et al. 2016) identified in spontaneous silvopastoral agroecosystems (*sensu* Lerner et al. 2015), which are based on scattered trees empirically retained in pastures by farmers (Prevedello et al. 2018). Areas with scattered trees support greater levels of biodiversity than open areas and may enhance the provision of ecosystem services that might benefit owners of rural properties, such as shading for cattle to graze in better microclimatic conditions with intensified feed diversity, regulation of nitrogen dynamics and carbon sequestration and better herbaceous production (Barton et al. 2016; Prevedello et al. 2018; Zanon et al. 2022). By using a Brazilian tropical region for a pilot study focused mainly of family-based rural properties (Brazil 2006) located in the Southern region of Espírito Santo, this study contributes to the creation of an interface between traditional empirical and theoretical ecological knowledge applied by a multi-attribute utility function (Keeney and Raiffa 1993).

Material and methods

Study site

The Southern region of the State of Espírito Santo, Brazil, has 379,514.00 ha of land occupied by pastures (36.7%), of which 48,498 ha are degraded (12.8%) and without vegetative cover. This region has an effective bovine herd, which refers to the total number of cattle in a given region or country in a given period, of 525,077 head (dairy and beef) and an annual production of 183,816,000 L of milk (Instituto Brasileiro de Geografia e Estatística - IBGE 2019). This region is characterized by the predominance of soils with medium to low fertility, with corrugated relief in the interior and flat to corrugated relief near the coast, the climate is predominantly warm with rainy summer and dry winter. It usually rains between October and March, with mean rainfall around 1,200 mm per year (Feitosa et al. 2010).

The municipalities of Alegre, Cachoeiro de Itapemirim, and Jerônimo Monteiro are in Southern Espírito Santo. Forty-one rural properties were used for ethnoecological studies (Figure 1), all located in the phytogeographic domain of the Atlantic Forest (Instituto Brasileiro de Geografia e Estatística - IBGE 2012). The Atlantic Forest is a Brazilian biome considered a global biodiversity hotspot, combining high biological diversity and a high degree of threat from habitat loss and species extinction (Rezende et al. 2018). Among the 41 properties, the individual areas ranged from 4.8 ha (in Cachoeiro de Itapemirim) to 120.0 ha (in Jerônimo Monteiro), the mean area was 27.4 ha, 76.3% occupied with pastures. The area of the P1 to P9 properties, used for

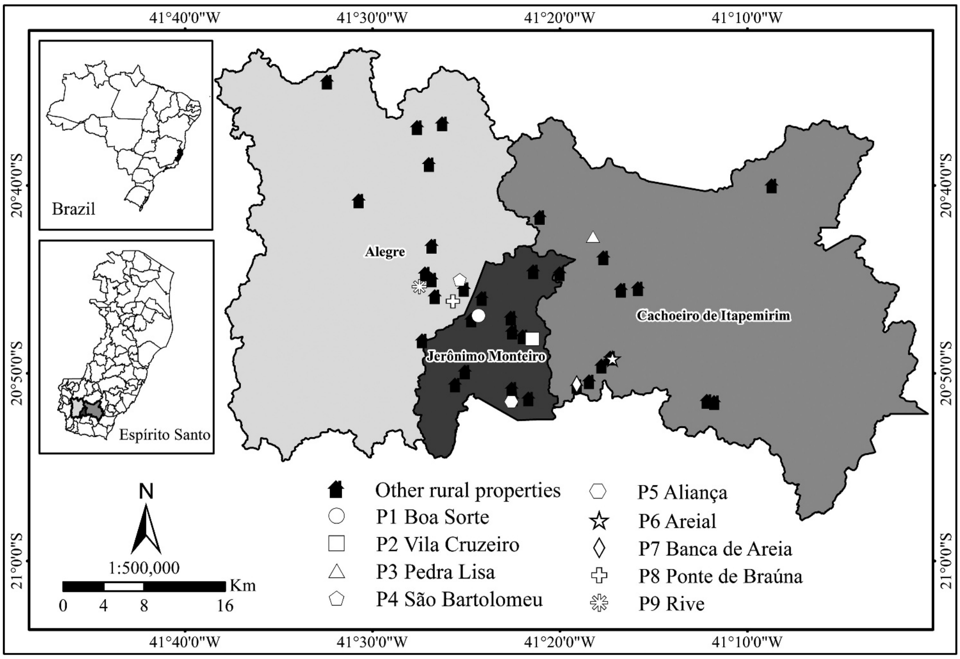


Figure 1. Map of the location of the 41 rural properties used for ethnoecological studies in the municipalities of Alegre, Cachoeiro de Itapemirim and Jerônimo Monteiro, in the southern macro-region of Espírito Santo, Brazil. The nine rural properties (P1 to P9) used for ecological field data sampling are highlighted with different symbols.

ethnoecological studies and ecological field data sampling, varied from 4.8 ha (P7) to 74.6 ha (P1). Regarding wooded pastures, which show scattered trees empirically retained in pastures by farmers, these nine properties represented the three municipalities chosen from the southern region of Espírito Santo.

Gathering ethnoecological and phytosociological data

Ethnoecological data

The 42 family farmers (40 male and two females), owners and/or employees, chosen for sampling were non-probabilistic (Vieira 2011). They were chosen because people have practiced cattle ranching for at least ten years (including some in apprenticeships) and live on small rural properties (up to 120 ha) that had trees in pastures. All participants freely consented to participate in the research (Albuquerque et al. 2014) and were aged between 24 and 75 years. The interviews were conducted between January and April 2018.

The sampling method was purposive, in which informants are experts in a particular cultural domain, chosen according to their qualities that are essential for answering specific research questions (Tongco 2007). The "Snowball" intentional sampling technique was used to increase the sample size (Albuquerque et al. 2014). The farmers were directly observed

(Malinowski 2001) in their activities where it was perceived how they worked with the cattle and how they managed the tree species in the properties.

The ethnoecological data were obtained by applying semi-structured questionnaires (Albuquerque et al. 2014). Out of 42 interviews. In one of the properties two people agreed to participate, while the main pattern was one interview per property in the other 40 (Figure 1). The main ethnoecological indicator was the Use Value of species (UVs), calculated according to Phillips and Gentry (1993).

After an initial friendly dialogue about "trees in pastures" to create rapport with each informant (Albuquerque et al. 2014), the following question was asked: Among the species you have mentioned until now, which do you prefer or are the most important for you? The free-listing technique was used to obtain the list (Quinlan, Quinlan, and Nolan 2002), setting 1.5 min. for individual response. After that, for each species mentioned, a form was filled in to discriminate the uses attributed to the species by the participant. In the interviews, 38 out of 42 people reported a total 46 tree species with UVs.

Phytosociological data

The sampling of the nine rural properties (P1 to P9) in which tree inventories were conducted was non-probabilistic (Vieira 2011). Properties of up to 120 ha engaged in cattle farming were sought. Each had scattered trees in their pastures and did not present major difficulties in terms of access for data collection. The inventory took place between July 2017 and April 2018.

From a phytosociological survey, mainly by census of dispersed trees in pastures, with trunk diameter ≥5.0 cm at 1.30 m above the ground and total height ≥3.0 m, 143 tree species were inventoried among 2,253 trees in 136.9 ha of discontinuous pastures spread among the nine small rural properties (P1 to P9, Figure 1). A total of 1,544 trees (68.53%) were grouped with other trees (groups ≥2 individuals), while 709 trees were isolated from the others (31.47%), i.e., those whose crowns were not touched by or overlapped with other trees.

Elaboration of multi-attribute utility function to select tree species

Only isolated tree species represented from a minimum population of ten trees in the field were considered in this analysis, prioritizing those with larger trunks, as they are supposedly the oldest ones. Regarding isolated trees, more caution was used to evaluate the effect and interactions of each tree compared to other biotic and abiotic components of the silvopastoral agroecosystem. Only 20 species had a minimum population of ten individuals isolated in the pastures.

To create an interface between traditional empirical and theoretical applied ecological knowledge, as well as to improve the use of time and resources, this pre-list underwent a series of criteria to select ten species with the greatest ethnoecological potential for afforestation of pasture, proposed for the first time in the scientific literature. The authors of this study, considered to be the decision-makers, took into account seven main criteria for choosing the ten species and subsequently investigated their ecological interactions in the pastoral agroecosystem:

(1) Phytogeographic origin in relation to the Atlantic Forest: It was assumed that native species should be prioritized because they are ecologically adapted to the phytogeographic region where they evolved (Andrade, Salman, and Oliveira 2012);
(2) Use Value of the species indicated in interviews: It was understood that selecting tree species valued for their potential use by farmers could increase the chances of acceptance in future silvopastoral system projects containing such species, as this could increase farmers' sense of ownership (Albuquerque et al. 2017);
(3) Natural regeneration potential observed in pastures: We saw the need to check the natural regeneration potential of species in the field because species with high regeneration potential can become invasive and infest pastures and compete for environmental resources with forage (Archer et al. 2017), so they should be avoided. The analysis of this criterion (Table 1) was based on the vegetative characteristics observed in the species, documented by notes in the worksheets and photographs showing stumps and roots that had intense spontaneous sprouting and/or observation of densely growing seedlings and young individuals (Fig. A.1, Appendix A);
(4) Potentially beneficial and preferably maintained trees indicated in interviews: It was assumed that species considered beneficial and preferably maintained in pastures by farmers could also increase the chances of acceptance (Albuquerque et al. 2017) in future silvopastoral system projects. Thus, decision-makers chose to place greater value on species that received a higher number of positive opinions;
(5) Potentially harmful and preferentially eliminated trees indicated in interviews: It was conjectured that species considered harmful and preferentially eliminated from pastures by farmers could increase the chances of rejection (Albuquerque et al. 2017) in future silvopastoral system projects. In this case, decision-makers chose to place less value on species that received a higher number of negative opinions;
(6) Presence of physical structures in tree species that could potentially cause accidents involving animals: It was observed in the field that some species had physical structures such as strut roots in which cattle could supposedly get their legs stuck, sharp thorns or spines which could pierce the animals' skin and Y-shaped forked branches in which animals

Table 1. Hierarchical decision tree built to formulate a multi-attribute utility function for selecting tree species with higher ethnoecological potential for afforesting pastures in Southern Espírito Santo, Brazil.

	First level attributes				Second level attributes			Third level attributes		
Function	Criterion	Straight Rank	Weight	Rank Sum	Subcriteria 1	Utility degree	Swing Weighting*/ Mean Weight**	Subcriteria 2	Utility degre	Swing Weighting
Maximise	Phytogeographical origin in relation to the Atlantic Forest.	1	7	0.2500	Native	5	1.0000*	none	none	none
					Exotic	0	0.0000*	none	none	none
Maximise	Use Value of the species indicated in interviews (n = 38 informant farmers).	3	5	0.1786	With Use Value.	5	1.0000*	none	none	none
					Without Use Value.	0	0.0000*	none	none	none
Minimise	Potential for natural regeneration observed in pastures (n = 09 rural properties).	2	6	0.2143	Species with no evidence of high potential for regeneration observed in field.	5	1.0000*	none	none	none
					Species with evidence of high potential for regeneration in field (documentation of infestation of seedlings, young plants and regrowth).	0	0.0000*	none	none	none
Maximise	Potentially beneficial and preferably maintained tree indicated in interviews (n = 42 informant farmers).	6	2	0.0714	Potentially beneficial tree indicated in interviews (n = 42 informant farmers). Answers to question 1.	5	0.5000**	≥03 cit.	5	0.4167
								02 cit.	4	0.3333
								01 cit.	3	0.2500
								00 cit.	0	0.0000
					Preferentially maintained tree indicated in interviews (n = 42 informant farmers). Answers to question 2.	5	0.5000**	≥03 cit.	5	0.4167
								02 cit.	4	0.3333
								01 cit.	3	0.2500
								00 cit.	0	0.0000
Minimise	Potentially harmful and preferentially eliminated tree indicated in interviews (n = 42 informant farmers).	7	1	0.0357	Potentially harmful tree indicated in interviews (n = 42 informant farmers). Answers to question 3.	5	0.5000**	00 cit.	5	0.4167
								01 cit.	4	0.3333
								02 cit.	3	0.2500
								≥03 cit.	0	0.0000
					Preferably eliminated tree indicated in interviews (n = 42 informant farmers). Answers to question 4.	5	0.5000**	00 cit.	5	0.4167
								01 cit.	4	0.3333
								02 cit.	3	0.2500
								≥03 cit.	0	0.0000
Minimise	Presence of physical structures in tree species that could potentially cause accidents involving animals.	5	3	0.1071	No evidence of these structures	5	1.0000*	none	none	none
					With evidence of strut roots, thorn or pointed aculeus, Y-shaped forked branches	0	0.0000*	none	none	none

(*Continued*)

Table 1. (Continued).

	First level attributes				Second level attributes			Third level attributes		
Function	Criterion	Straight Rank	Weight	Rank Sum	Subcriteria 1	Utility degree	Swing Weighting*/ Mean Weight**	Subcriteria 2	Utility degre	Swing Weighting
Maximise	Conservation priority of species in relation to the IUCN extinction threat category.	4	4	0.1429	Critically Endangered (CR)	5	0.3333*	none	none	none
					Endangered (EN)	4	0.2667*	none	none	none
					Vulnerable (VU)	3	0.2000*	none	none	none
					Near Threatened (NT)	2	0.1333*	none	none	none
					Least Concern (LC), Data Deficient (DD) or Not Evaluated (NE)	1	0.0667*	none	none	none
					Non conservation	0	0.0000*	none	none	none

Notes:
Question 1) Which tree species do you think benefit the pasture? Why?
Question 2) Which spontaneously occurring trees (native or not) do you keep in your pasture?;
Question 3) Which tree species do you think harm the pasture (productivity/grass/cattle)? Why?;
Question 4) Which spontaneously occurring trees (native or not) would you eliminate, or would you like to eliminate from your pasture? What are the main reasons?
Abbreviations: cit. = Number of citations; IUCN = The International Union for Conservation of Nature.

could get their heads stuck (Andrade, Salman, and Oliveira 2012; Fremout et al., 2021). Some farmers showed aversion to species with such structures, so we preferred to avoid them;

(7) Conservation Priority of species in relation to the IUCN (The International Union for Conservation of Nature) extinction threat category: We looked at the possibility of conservation through sustainable use of species, thinking about future cultivation in silvopastoral systems (Rolim et al., 2019; Carriazo, Labarta, and Escobedo 2020). We decided to prioritize the most threatened species, while making sure to follow the legal guidelines for managing them without putting them at risk.

To formulate a multi-attribute utility function (Keeney and Raiffa 1993) in order to obtain maximum benefits and minimum losses in the overall additive function for species selection, the main criteria were first considered, followed by the sub-criteria for maximizing or minimizing each individual utility function. For this purpose, a hierarchical tree of attributes was constructed, subdivided into three levels (Table 1). At the first level, the criteria were ranked according to priority, where 1 is the most important criterion and 7 is the least important out of the seven criteria using the Straight Rank technique. They were subsequently converted from an ordinal to a cardinal scale, varying the weights of the scores from 1 (lowest weight) to 7 (highest weight). At the second and third levels, each sub-criterion was ranked according to the utility degree assigned by the decision-makers, with scores ranging from 0 (worst choice – to be avoided) to 5 (best choice). To calibrate first-level weights, the Rank Sum technique was used; for second-level weights, the Swing Weighting or Mean Weight techniques were used; and for third-level weights, the Swing Weighting technique was used (Odu 2019). The worst theoretical decision (benchmark) for the overall function was considered as being non-afforesting pastures.

Thus, using MS Office Excel to perform the calculations, based on the information contained in Table 1 a multi-attribute utility function was proposed for obtaining the Ethnoecological Selection Index (EESI) from Equations 1, 2 and 3:

Equation 1: $EESI = (0.2500 \times O) + (0.1786 \times UVs) + (0.2143 \times NR) + (0.0714 \times BMT) + (0.0357 \times HET) + (0.1071 \times AA) + (0.1429 \times CP)$

Considering:
EESI = Ethnoecological Selection Index
O = Origin of the taxon
UVs = Presence or absence of Use Value of the species
NR = Presence or absence of intense natural regeneration in the field
BMT = Potentially beneficial and preferably maintained tree (Eq. 2)

HET = Potentially harmful and preferentially eliminated tree (Eq. 3)
AA = Structures that could potentially cause accidents involving animals
CP = Conservation priority
Equation 2: $BMT = 0.5 \times (Beneficial\ potential + Maintenance\ preference)$
Equation 3: $HET = 0.5 \times (Harmful\ potential + Preference\ for\ elimination)$

Field procedures, data collection, and mathematical formulae

The ten tree species evaluated with the highest EESI values were studied regarding possible interactions with soil cover, herbaceous biomass production, and grass consumption by the cattle to validate the proposed method. The crown projection of each tree was considered a sampling unit. Each of the ten species was represented by ten trees, totaling 100 trees evaluated. The evaluations performed under the crown (UC) were repeated in control points outside the crown projection (OC). The control was performed in a similar area for each tree, adjacent to each unit, at least 10.00 m in line from the edge of the crown projection (Figure 2).

The projection of the individual crown area (CA) was gauged with a tape measure and then calculated using the following ellipse formula: $CA = a \times b \times \pi/4$ (Equation 4), in which: $a = length\ of\ projection$, $b = width\ of\ projection$ and $\pi = 3.1416$. Total height (TH) was defined as the vertical distance from the base of the tree (rooting) to the top (foliage of the highest branch) and the crown base height (BH) was defined as the shortest vertical distance between the ground and the foliage of the most basal branch of the tree (Figure 3).

The canopy cover (CC) density of the ten tree species was characterized using a digital camera and a Fisheye lens mounted on a tripod 1.05 m above the ground, positioned at half the radius (r/2), under the crown projection (UC), to the North and South (two subplots), to collect hemispherical photographs (Figure 3). Daytime photographs were taken, avoiding the hours between 10:00 and 16:00 h, when direct solar radiation penetrated the canopy. Twenty photographs per species were collected.

To assess ground cover UC and OC of the ten tree species, flat photographs were taken at 1.05 m above the ground, with the camera attached to a tripod located at half the radius (r/2) of each sample unit (Figure 2), totaling 20 per species (10 × UC + 10 × OC). An objective lens with aperture set at 35.00 mm, facing the ground, was used to photograph four rectangular subplots of ground cover (North, South, East, and West), each with $0.24\ m^2$ (0.40 × 0.60 m), totaling $0.96\ m^2.plot^{-1}$. A total of 80 photographs (subplots) per species (40 × UC + 40 × OC) were taken.

To evaluate the biomass production of tropical grasses (Poaceae, of the C4 group), of the forbs group (mainly non-monocots, of the C3 group, without species separation) and of the total (grasses + forbs), four sample subplots were

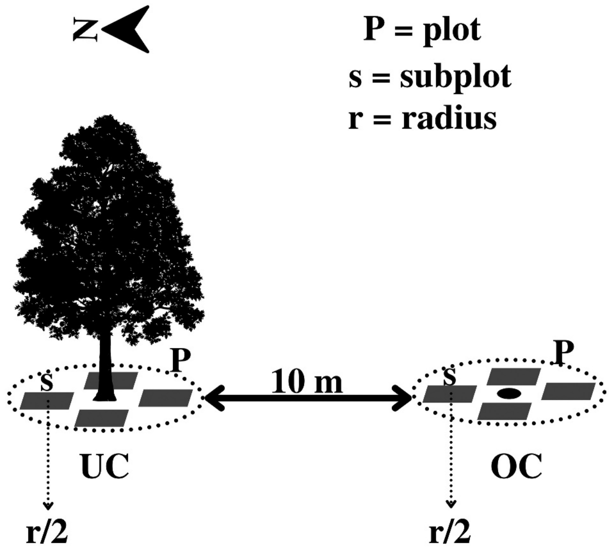


Figure 2. Spatial distribution scheme of sample plots under the crown (UC) and outside the crown (OC) of the trees, in pastures, in the south of Espírito Santo, Brazil. The subplots were used to evaluate herbaceous biomass production, relative soil cover and bovine grazing. Only the subplots were always allocated following the same cardinal point orientation.

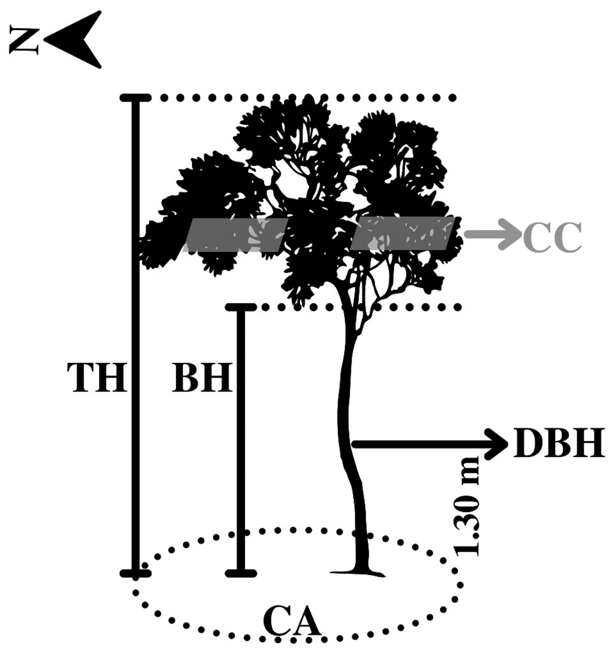


Figure 3. Individual tree dendrometric sampling scheme, in grasslands, in the south of Espírito Santo, Brazil. CA = crown projection area (m^2); TH = total height (m); BH = crown base height (m); CC = canopy cover (%); DBH = diameter at breast height (cm).

allocated, with individual area of 0.25 m^2, at half of the radius (r/2) of each sample unit (4 × UC + 4 × OC) to the East, West, North and South, totaling 1.00 m^2.plot^{-1} (Figure 2). A total of 20 plots were delimited for each of the ten tree species (10 × UC and 10 × OC). In the plots, herbaceous samples were harvested at 0.05 m above the ground and packed in paper bags. In the laboratory, the samples were dried in a forced circulation oven at 65°C for 72 h and then weighed on precision weighing scales. The physiological classification of the groups (C3 and C4) followed Gibson (2009).

To estimate the grass grazing intensity by the cattle, five scores were proposed based on the bite marks on the plants left by the cattle, regardless of the species evaluated (Fig. B.1, Appendix B): 0.0 (No grazing: intact plant); 1.0 (Apex and leaves: apical portion partially or totally grazed); 2.0 (Except for stolon and rhizome: partial grazing of the culm and its morphological variations erect and decumbent); 3.0 (Prostrate culms rooted on the soil: erect and decumbent culms fully grazed and consequent exposure of the stolon and/or crown) and 4.0 (No visible aerial parts: absence of stolon and other living aerial parts, underground parts such as rhizome and roots may be hidden in the soil). The morphological classifications of grasses were based on Gibson (2009).

Grazing scores attributed to the presence of each grass species or the absence of evidence of grasses were noted in a field spreadsheet to calculate using MS Office Excel. The mean grazing score of the plot was obtained from the sum of partial scores of each subplot divided by four, assigning the result to each sample stratum (10 × UC and 10 × OC) per tree species (Figure 2). Equations 5 and 6 were proposed to calculate the grazing intensity from the scores in the subplot (GIS) and in the plot (GIP):Equation 5:

$$GIS = \frac{Gi + \ldots + Gn}{N}$$

In which:

GIS = Grazing index in the subplot

Gi = Grazing score (G) assigned to the i-th occurrence of grass species in the subplot Gn = Grazing score (G) assigned to the n-th occurrence of grass species in the subplot

N = Total number of grass(es) species in the subplot

We agreed to use *N = 1* in the case of absence of visible aerial parts of living grasses in the subplot (*P0 = 4.0*).Equation 6:

$$GIP = \frac{GINS + GISS + GIES + GIWS}{4}$$

In which:

GIP = Grazing index in the plot

GINS = Grazing index in the North subplot
GISS = Grazing index in the South subplot
GIES = Grazing index in the East subplot
GIWS = Grazing index in the West subplot

All collections of hemispherical canopy photographs, flat photographs of ground cover, herbaceous biomass collections and grazing intensity assessment were conducted between December 2018 and February 2019, since the summer is the season of higher production of tropical grasses (Gibson 2009).

The botanical identification of the trees and grasses, according to their respective families, followed the classification system proposed by Angiosperm Phylogeny Group et al. (2016). The collection of the Capixaba herbarium (CAP) of the Universidade Federal do Espírito Santo (UFES) was consulted for species identification. The consultations were based on specialized bibliographies to collect the virtual herbarium REFLORA by the site <http://reflora.jbrj.gov.br/reflora/herbarioVirtual/> and the site "Flora e Funga do Brasil" <http://floradobrasil.jbrj.gov.br/>. In the latter, we checked the spelling, authorship, and origin of the taxa.

Data analysis

The discourse analysis method was used to assist in the interpretation of the answers to the questions 1, 2, 3, and 4 to record and interpret the imagination of the subject interviewed (Orlandi 2009) about environmental perception and management preferences of trees in pastures.

The hemispherical images were analyzed using GLA 2.0 - Gap Light Analyzer software (Frazer, Canham, and Lertzman 1999) to obtain the canopy cover index in percentage.

The flat photographs were analyzed according to the percentages of herbaceous cover, litter cover and bare soil with the aid of the SisCob software (Jorge and Silva 2009). The images were interpreted by a semi-supervised classification, adding representative samples of patterns of each cover class to the program memory. Ten neural networks were then created and trained (one for each tree species) to evaluate the images based on the inserted cover patterns and classified into ten separate blocks for each set of 80 images, relative to each of the ten species.

For each treatment (UC and OC), the ground cover of the plot was considered from the means of the relative covers of each class. The unpaired Student's t-test at 5% probability (Zar 1984) was used to individually compare each class of ground cover variable (herbaceous, litter, and bare soil) between UC and OC, for each tree species, separately and entirely.

To investigate the existence of interactions between the morphometry of the sampled trees and ground cover (Figures 2 and 3), the following aspects were correlated: (1) the total height (TH) of each tree; (2) the vertical crown projection area (CA) on the ground; (3) the crown base height (BH); (4) the canopy cover percentage (CC) as an indirect measure of the luminosity penetrating the canopy and reaching the ground, and (5) the relative ground cover under the crown projection (bare soil (BS), herbaceous (HC) and litter (LC)). Pearson's correlation matrices were constructed between all these variables. Correlations were performed in a general way between the means of each set of variables of the ten species together. The decision level $\alpha = 5\%$ was adopted. Only the significant correlations were shown in the results.

The dry matter sample means of herbaceous plants, under the crown and outside the crown, for each tree species and the total, were subjected to the unpaired Student's t-test or Mann-Whitney U-test (in case of non-normality) to compare independent samples, with a decision level of $\alpha = 5\%$ (Zar 1984). The dry matter masses of the grass group, the forbs group and the total group (grass + forbs) were compared separately. The unpaired Student's t-test was used to compare, with decision level of $\alpha = 5\%$, the grass grazing intensity in UC and OC positions, for each tree species and the total.

The interpretation of the statistical significance of correlations (Pearson) and the mean tests (t and U), according to the p-value, followed Sokal and Rohlf (1981). Thus, correlations and means with probability > 5% ($p > 0.05$) were considered non-significant (ns), significant (*) when $p \leq 0.05$, very significant (**) when $p < 0.01$ and highly significant (***) when $p < 0.001$.

Before proceeding with the statistical tests, the normality of the data was tested using the Shapiro-Wilk test. When the data did not show normality, they were transformed to meet the assumptions by the Box-Cox procedure. Non-parametric analyses were performed when, even after transformation, the data did not show normality. The normality tests (Shapiro-Wilk), data transformation (Box-Cox), comparison of means (t and U tests) and the correlation analyses (Pearson and Spearman) were performed with the Bioestat 5.0 software (Ayres et al. 2007).

The structure and associations between trees and herbaceous species composition (UC and OC) were evidenced by the construction of clustering dendrograms. The dissimilarity of herbaceous species composition (presence/absence) was estimated by the Bray-Curtis (Sorensen) index (Brower and Zar 1984). The calculations and the dendrogram by the unweighted pair-group method with arithmetic (UPGMA) means were obtained using the FITOPAC 2.1 software (Shepherd 2010).

Results

Ethnoecologically selected tree species

The ten tree species selected with the greatest ethnoecological potential for elaborating silvopastoral systems showed orderly decreased EESI values ranging from 0.8327 for *Handroanthus arianeae* (A.H.Gentry) S.Grose to 0.5958 *Cybistax antisyphilitica* (Mart.) Mart. (Table 2). The next 10 species are also included.

Abbreviations: O = Phytogeographical origin regarding the Atlantic Forest; UVs = Use Value of the species for the interviewed farmers ($n = 38$ informants); NR = Potential for natural regeneration of the species in the evaluated pastures ($n = 09$ rural properties); BMT = Potentially beneficial and preferably maintained tree in the pasture by interviewed farmers ($n = 42$ informants); HET = Potentially harmful and preferably eliminated tree by interviewed farmers ($n = 42$ informants); AA = Presence of physical structures in tree species that could potentially cause accidents to animals; CP = Conservation

Table 2. Decreasing order of 20 tree species occurring in pastures in Southern Espírito Santo, Brazil, according to the EESI, calculated from scores (ranging from 0 to 1) of seven utility functions merged into an additive multi-attribute utility function.

Order	Species	O	UVs	NR	BMT	HET	AA	CP	EESI
1st	*Handroanthus arianeae* (A.H. Gentry) S.Grose	0.2500	0.1786	0.2143	0.0298	0.0149	0.1071	0.0381	0.8327
2nd	*Ramisia brasiliensis* Oliv.	0.2500	0.1786	0.2143	0.0268	0.0134	0.1071	0.0190	0.8092
3rd	*Gallesia integrifolia* (Spreng.) Harms	0.2500	0.1786	0.2143	0.0298	0.0104	0.1071	0.0095	0.7997
4th	*Dalbergia nigra* (Vell.) Allemão ex Benth.	0.2500	0.1786	0.2143	0.0149	0.0060	0.1071	0.0286	0.7994
5th	*Balfourodendron riedelianum* (Engl.) Engl.	0.2500	0.1786	0.2143	0.0238	0.0134	0.1071	0.0095	0.7967
6th	*Anadenanthera colubrina* (Vell.) Brenan	0.2500	0.1786	0.2143	0.0268	0.0060	0.1071	0.0095	0.7923
7th	*Cupania oblongifolia* Mart.	0.2500	0.1786	0.2143	0.0089	0.0149	0.1071	0.0095	0.7833
8th	*Zeyheria tuberculosa* (Vell.) Bureau ex Verl.	0.2500	0.0000	0.2143	0.0000	0.0149	0.1071	0.0190	0.6054
9th	*Albizia polycephala* (Benth.) Killip ex Record	0.2500	0.0000	0.2143	0.0089	0.0149	0.1071	0.0095	0.6048
10th	*Cybistax antisyphilitica* (Mart.) Mart.	0.2500	0.0000	0.2143	0.0000	0.0149	0.1071	0.0095	0.5958
11th	*Peltophorum dubium* (Spreng.) Taub.	0.2500	0.1786	0.0000	0.0208	0.0000	0.1071	0.0095	0.5661
12th	*Handroanthus ochraceus* (Cham.) Mattos	0.2500	0.1786	0.0000	0.0000	0.0060	0.1071	0.0095	0.5512
13th	*Eucalyptus* cf. *grandis* W.Hill × *E. urophylla* S.T.Blake	0.0000	0.1786	0.2143	0.0238	0.0149	0.1071	0.0095	0.5482
14th	*Psidium guajava* L.	0.0000	0.1786	0.2143	0.0119	0.0134	0.1071	0.0095	0.5348
15th	*Cecropia glaziovii* Snethl.	0.2500	0.0000	0.2143	0.0000	0.0149	0.0000	0.0095	0.4887
16th	*Machaerium hirtum* (Vell.) Stellfeld	0.2500	0.1786	0.0000	0.0119	0.0060	0.0000	0.0095	0.4560
17th	*Phyllostylon brasiliense* Capan. Ex Benth. & Hook.f.	0.2500	0.0000	0.0000	0.0000	0.0134	0.1071	0.0095	0.3801
18th	*Syzygium cumini* (L.) Skeels	0.0000	0.1786	0.0000	0.0298	0.0089	0.1071	0.0095	0.3339
19th	*Corymbia citriodora* (Hook.) K.D.Hill & L.A.S.Johnson	0.0000	0.1786	0.0000	0.0000	0.0119	0.1071	0.0095	0.3071
20th	*Tabernaemontana laeta* Mart.	0.2500	0.0000	0.0000	0.0000	0.0000	0.0000	0.0095	0.2595

priority for the species in relation to its IUCN (The International Union for Conservation of Nature) extinction threat rating; EESI = Ethnoecological selection index.

Interactions with ground cover

Only the species *A. colubrina* and *H. arianeae* showed statistically significant differences by the Student's t-test, for at least one of the three different types of ground cover between the strata under the crown (UC) and outside the crown (OC) (Table 3). For *A. colubrina*, ground cover by herbaceous plants was significantly higher in the UC stratum compared to OC. For *H. arianeae*, the UC stratum had significantly less ground cover by litter compared to the OC.

Table 4 shows the amplitude of the mean values for the dendrometric and ground cover parameters under the crowns of the tree species assessed. Table C.1 shows the detailed information (Appendix C).

For the set of tree species, Pearson's correlations between total height and crown area, the crown base height and herbaceous ground cover and between crown area and canopy cover were significant and directly proportional. The correlations between crown base height and canopy cover, canopy cover and herbaceous cover and between herbaceous cover and litter cover were significant and inversely proportional (Table 5).

Abbreviations: TH = Total height of the tree; BH = Crown base height of the tree; CA = Crown projection area of the tree; CC = Canopy cover of the tree (or canopy cover index); HC = Herbaceous cover; LC = Litter cover.

Interactions with herbaceous species' richness and composition

The total richness of herbaceous species (Tab. D.1, Appendix D) in the 200 sample plots (100 × UC + 100 × OC), regardless of the related tree species and the strata sampled, consisted of 15 grass species (Poaceae) plus the forbs group (non-grasses). Considering only the UC stratum, the richness was also 15 grass species plus the forbs group regardless of the tree species, while for the OC stratum, regardless of the related tree species, the richness decreased to 12 grass species plus the forbs group (Tab. D.1, Appendix D).

The richness of herbaceous species (including forbs group) varied from five in both UC and OC strata of *Z. tuberculosa* to 12 in the UC stratum of *A. colubrina* and *B. riedelianum* species. Regarding the composition of herbaceous plants, the group of forbs plants and the grass species *U. brizantha* were present in all sets (20) of situations evaluated. The two grasses with most occurrences were *P. maritimum* (19) and *U. humidicola* (15). Table D.2 shows more details (Appendix D).

Regarding the Bray-Curtis (Sorensen) dissimilarity of the occurrence of herbaceous species (Figure 4), the minimum distance was 0.11 and the

Table 3. Mean percentage (n = 10) of ground cover by herbaceous, litter and bare soil under the crown (UC) and outside the crown (OC) of ten tree species in pasture areas in the south of Espírito Santo, Brazil. Decision level: α = 5%.

Cover class	UC (%)	OC (%)	t-Test	p (bilateral)
		Albizia polycephala		
Herbaceous	51.33	38.08	1.7474	0.0975^{ns}
Litter	26.08	26.87	−0.2181	0.8298^{ns}
Bare soil	22.49	35.05	−1.6693	0.1123^{ns}
		Anadenanthera colubrina		
Herbaceous	49.02	41.51	131.4117	<0.0001***
Litter	30.29	35.34	−0.8661	0.3978^{ns}
Bare soil	20.69	23.15	−0.4723	0.6424^{ns}
		Balfourodendron riedelianum		
Herbaceous	45.42	46.88	−0.1832	0.8567^{ns}
Litter	45.95	44.82	0.1779	0.8608^{ns}
Bare soil	8.62	8.30	0.1271	0.9003^{ns}
		Cupania oblongifolia		
Herbaceous	51.90	51.35	0.0854	0.9329^{ns}
Litter	29.39	31.49	−0.5719	0.5745^{ns}
Bare soil	18.72	20.51	−0.1813	0.8582^{ns}
		Cybistax antisyphilitica		
Herbaceous	54.62	45.84	1.1644	0.2594^{ns}
Litter	21.29	26.14	−1.2337	0.2331^{ns}
Bare soil	24.09	28.02	−0.6269	0.5386^{ns}
		Dalbergia nigra		
Herbaceous	61.50	57.64	0.3866	0.7036^{ns}
Litter	16.31	17.29	−0.2144	0.8327^{ns}
Bare soil	22.19	25.07	−0.5029	0.6211^{ns}
		Gallesia integrifolia		
Herbaceous	48.38	43.93	0.5248	0.6061^{ns}
Litter	27.55	27.68	−0.0240	0.9811^{ns}
Bare soil	24.07	28.40	−0.9616	0.3489^{ns}
		Handroanthus arianeae		
Herbaceous	48.71	40.58	1.5018	0.1504^{ns}
Litter	21.11	24.83	−2.1595	0.0445*
Bare soil	30.18	34.60	−0.8462	0.4085^{ns}
		Ramisia brasiliensis		
Herbaceous	29.72	42.09	−1.7698	0.0936^{ns}
Litter	38.72	28.69	1.8601	0.0792^{ns}
Bare soil	31.56	29.23	0.4899	0.6301^{ns}
		Zeyheria tuberculosa		
Herbaceous	39.99	29.10	1.5915	0.1288^{ns}
Litter	33.17	30.93	0.4035	0.6913^{ns}
Bare soil	26.85	39.98	−1.2532	0.2261^{ns}
		Average of all ten tree species.		
Herbaceous	48.06	43.70	1.1995	0.2458^{ns}
Litter	28.99	29.41	−0.1174	0.9078^{ns}
Bare soil	22.95	27.23	−1.2357	0.2324^{ns}

*= significant ($p \leq 0.05$).
***= highly significant ($p < 0.001$).
^{ns}= not significant ($p > 0.05$).

maximum was 0.85. Three main groups were formed, Group 1 separated at a distance of 0.85 from the other two and these at a distance of 0.52. The maximum distances were ≤ 0.44 within the three main groups. Within Group 1, two out of eight sample conditions (treatments and controls)

Table 4. Amplitude of the mean values (n = 10) for the dendrometric and ground cover parameters under the crowns of the tree species, in pastures in the south of Espírito Santo, Brazil.

Parameter	Minimum observed (*species*)[1]	Maximum observed (*species*)[2]
Total height of the tree (m)	6.23 (*Cybistax antisyphilitica*)	13.72 (*Gallesia integrifolia*)
Crown base hight of the tree (m)	0.85 (*Ramisia brasiliensis*)	3.83 (*Albizia polycephala*)
Tree crown projection area (m^2)	14.54 (*Cybistax antisyphilitica*)	152.70 (*Gallesia integrifolia*)
Tree canopy cover (%)	36.17 (*Cybistax antisyphilitica*)	86.09 (*Ramisia brasiliensis*)
Herbaceous cover (%)	29.72 (*Ramisia brasiliensis*)	61.50 (*Dalbergia nigra*)
Litter cover (%)	16.3 (*Dalbergia nigra*)	45.96 (*Balfourodendron riedelianum*)
Bare soil (%)	8.62 (*Balfourodendron riedelianum*)	31.56 (*Ramisia brasiliensis*)

[1, 2]= Species for which the minimum and maximum values were observed.

Table 5. Overall correlation matrix between means of dendrometric and ground cover data under the crowns of ten tree species analyzed together (n = 100), in pastures in the south of Espírito Santo, Brazil. Decision level: α = 5%.

Species	Statistics	TH × CA	BH × CC	BH × HC	CA × CC	CC × HC	HC × LC
All	r (Pearson) =	0.8967	−0.7404	0.7707	0.6343	−0.6752	−0.7246
	p =	0.0004***	0.0143*	0.009**	0.0488*	0.0321*	0.0177*

*significant ($p \leq 0.05$).
**very significant ($p < 0.01$).
***highly significant ($p < 0.001$).

represented the OC stratum. Within Group 2, two out of ten sampling conditions represented the UC stratum. Group 3 had two treatments in the UC stratum.

Interactions with herbaceous biomass production

Regarding the mean dry matter production (biomass) of herbaceous plants (Table 6), there were statistically significant differences between UC and OC strata, by Student's t-test or Mann-Whitney U test, for *B. riedelianum*, *H. arianeae*, and *R. brasiliensis*. *B. riedelianum* showed significantly higher mean production of forbs in the UC stratum compared to the OC by the U-test. *H. arianeae* and *R. brasiliensis* showed a significantly lower mean total dry matter production of herbaceous plants (grasses + forbs) in the UC stratum compared to the OC, respectively, by the t and U tests.

Interactions with bovine grazing

Regarding the mean grass grazing intensity by the cattle compared to the UC and OC strata (Table 7), a statistically significant difference was observed by Student's t-test for the tree species *R. brasiliensis*, which showed greater grazing intensity under the crown.

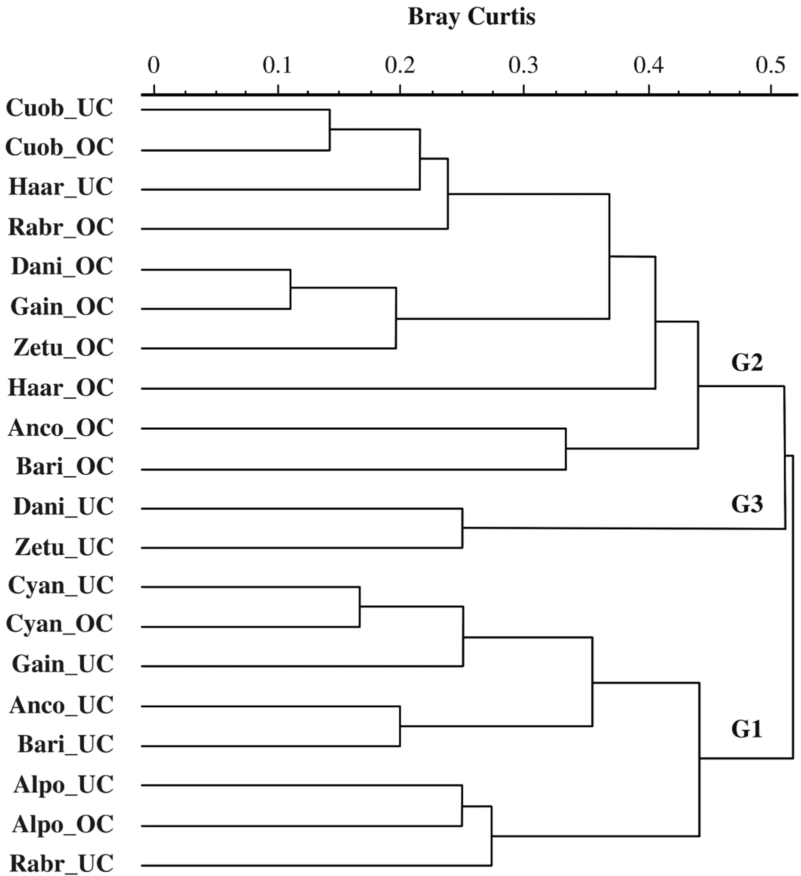


Figure 4. Bray-Curtis (Sorensen) dissimilarity dendrogram constructed by unweighted pair-group method with arithmetic (UPGMA) means for the presence of herbaceous species (grasses plus forbs group) under the crowns and outside the crowns of ten tree species in pastures in the south of Espírito Santo, Brazil. G1 = group 1; G2 = group 2; G3 = group 3; UC = under the crown; OC = outside the crown; alpo = *Albizia polycephala*; Anco = *Anadenanthera colubrina*; Bari = *Balfourodendron riedelianum*; cuob = *Cupania oblongifolia*; cyan = *Cybistax antisyphilitica*; Dani = *Dalbergia nigra*; gain = *Gallesia integrifolia*; Haar = *Handroanthus arianeae*; rabr = *Ramisia brasiliensis*; zetu = *Zeyheria tuberculosa*. Cophenetic correlation: 0.6073.

Discussion

Ethnoecological selection of tree species

Contextualizing the ten selected species with the highest EESI (Tables 1, 2 and E.1, Appendix E), we observed that the method was effective in selecting native species (Criterion 1), however *A. polycephala*, *Z. tuberculosa* and *C. antisyphilitica* were not cited by farmers with Use Value (UVs). All seven selected species that showed UVs (Criterion 2) showed multiple timber and non-timber uses, according to the family farmers consulted. Multiple-use species are essential for sustainability of silvopastoral systems, since

Table 6. Mean dry matter production (n = 10) of herbaceous under the crown (UC) and outside the crown (OC) of ten tree species in pasture areas in the south of Espírito Santo, Brazil.

Herbaceous	UC ($g.m^{-2}$)	OC ($g.m^{-2}$)	t-Test	U-Test	p (bilateral)
		Albizia polycephala			
Grasses	203.95	170.82	0.7424	–	0.4674^{ns}
Forbs	16.11	14.87	–	43.0000	0.5967^{ns}
Total	220.06	185.69	0.8064	–	0.4305^{ns}
		Anadenanthera colubrina			
Grasses	230.00	241.49	–	46.0000	0.7624^{ns}
Forbs	29.07	13.37	1.0040	–	0.3303^{ns}
Total	259.08	254.86	–	45.0000	0.7055^{ns}
		Balfourodendron riedelianum			
Grasses	216.68	245.30	−0.7477	–	0.4643^{ns}
Forbs	8.01	1.30	–	18.0000	0.0156*
Total	224.69	246.60	−0.5747	–	0.5726^{ns}
		Cupania oblongifolia			
Grasses	183.16	191.14	−0.1451	–	0.8862^{ns}
Forbs	21.20	14.99	0.0916	–	0.9280^{ns}
Total	204.36	206.14	−0.0346	–	0.9728^{ns}
		Cybistax antisyphilitica			
Grasses	265.87	253.24	0.1489	–	0.8833^{ns}
Forbs	3.47	9.87	–	41.5000	0.5205^{ns}
Total	269.34	263.11	0.0306	–	0.9759^{ns}
		Dalbergia nigra			
Grasses	220.66	254.47	−0.5793	–	0.5695^{ns}
Forbs	23.48	19.70	–	40.5000	0.4727^{ns}
Total	244.14	274.17	−0.5734	–	0.5735^{ns}
		Gallesia integrifolia			
Grasses	180.89	163.35	0.4095	–	0.6870^{ns}
Forbs	20.91	19.92	–	43.5000	0.6232^{ns}
Total	201.80	183.26	0.4997	–	0.6233^{ns}
		Handroanthus arianeae			
Grasses	138.37	211.54	−1.9345	–	0.0688^{ns}
Forbs	26.08	29.59	−0.2887	–	0.7761^{ns}
Total	164.45	241.13	−2.2185	–	0.0395*
		Ramisia brasiliensis			
Grasses	63.88	132.95	−2.0048	–	0.0602^{ns}
Forbs	24.61	35.82	−0.8827	–	0.3890^{ns}
Total	88.49	168.76	–	24.0000	0.0494*
		Zeyheria tuberculosa			
Grasses	135.99	159.23	−0.3707	–	0.7152^{ns}
Forbs	11.63	11.80	–	50.0000	1.000^{ns}
Total	147.62	171.02	−0.3136	–	0.7575^{ns}
		Average of all ten tree species			
Grasses	183.95	202.35	−0.7927	–	0.4383^{ns}
Forbs	18.18	16.27	0.4289	–	0.6731^{ns}
Total	202.40	219.47	−0.7849	–	0.4427^{ns}

*= significant ($p \leq 0.05$).
^{ns}= not significant ($p > 0.05$).

multifunctional tree portfolios can satisfy a profile of desired ecosystem services and products prioritized by farmers (Barton et al. 2016).

However, decision-makers should cautiously verify the conservation status of species regarding extinction risk when selecting tree species by the EESI, especially those with timber potential. Out of ten species selected in this study, *Balfourodendron ridedelianum* fits as “Near threatened – NT,” *Dalbergia nigra* and *Zeyheria tuberculosa* as “Vulnerable – VU” and *Handroanthus arianeae*,

Table 7. Mean intensity indices (n = 10) of grass grazing by the cattle under the crown (UC) and outside the crown (OC) of ten tree species in pasture areas in the south of Espírito Santo, Brazil.

Species	UC	OC	t-Test	U-Test	p (bilateral)
Albizia polycephala	1.08	1.20	–	45.5000	0.7337^{ns}
Anadenanthera colubrina	1.56	1.35	0.6495	–	0.5242^{ns}
Balfourodendron riedelianum	1.61	1.63	−0.3341	–	0.7422^{ns}
Cupania oblongifolia	0.68	0.76	−0.3283	–	0.7465^{ns}
Cybistax antisyphilitica	1.46	1.30	0.4960	–	0.6259^{ns}
Dalbergia nigra	1.35	0.83	1.0393	–	0.3124^{ns}
Gallesia integrifolia	1.33	1.03	1.0410	–	0.3116^{ns}
Handroanthus arianeae	1.73	1.82	−0.2813	–	0.7833^{ns}
Ramisia brasiliensis	2.19	1.12	2.8791	–	0.0099 **
Zeyheria tuberculosa	1.74	1.99	−0.6404	–	0.5300^{ns}
Average of all ten tree species	1.47	1.30	0.9270	–	0.3662^{ns}

**= very significant ($p < 0.01$).
^{ns}= not significant ($p > 0.05$).

"Endangered – EN" (Martinelli and Moraes 2013). We do not recommend cutting threatened species without prior assessment by the competent inspection body or in disagreement with the local current legislation (Criterion 7). We suggest intensifying investments in technical assistance to stakeholders, public policies and scientific research for the conservation and sustainable timber forestry of such species before beginning to harvest the trees (Carriazo, Labarta, and Escobedo 2020; Rolim et al. 2019).

None of these ten species (Tables 1, 2) showed high potential for natural regeneration in pastures (Criterion 3). Although the proposed method based on notes and photographic documentation is subjective (Albuquerque et al. 2014), it avoided uncertainty (Polasky et al. 2011) for decision-making, and was efficient in selecting species aiming at a silvopastoral potential for a region, since the literature does not show that the list of species pre-selected by the EESI has high potential for natural regeneration in grasslands (Carvalho 2003, 2006; Coutinho et al. 2019; Evaristo, Braga, and Nascimento 2011; Lopes, Rosa-Osman, and Piedade 2012; Lorenzi 2002a, 2002b; Lorenzi 2009; Medeiros et al. 2016). The control of tree species with encroaching characteristics is essential to prevent the decrease of grass productivity and livestock in wooded pastures due to competition for environmental resources (Archer et al. 2017), since the invasion by woody species in pastures has been globally facilitated in the face of extreme climate changes caused by events of intense precipitation (Kulmatiski and Beard 2013).

Regarding the benefits of keeping the species selected by the EESI in the pasture (Tables 1 and 2, Criterion 4), the farmers' reports were essential to confirm the results. According to interviewee E15 "*Ipê-amarelo, where it is, the grass is always green*," for E24 "*Ipê-amarelo and araçá, they bring shade and the leaves fertilize the soil*," in the case of *H. arianeae*. Regarding *G. integrifolia* (pau-d'alho) and *R. brasiliensis* (siriba), for E12 "*Pau-d'alho leaves organic matter, the soil becomes more beautiful*," E20 justified "*Siriba and pau-d'alho because it gives a lot of shade*," E26 reported, "*Pau-d'alho and siriba help the soil, but all* (the trees) *are important*," according to E35, "*The smell of it* (pau-d'alho) *repels flies that could parasitize the animal*," and E27 added, "*Siriba, it gives more grass* (grows more forage) *around it*." In the case of *B. riedelianum* (gumarim), E3 noted, "*Gumarim doesn't get in the way, it has good wood, high canopy, good shade*," and E31 confirmed, "*Gumarim does not harm at all, it has high and rotating shade* (according to the perceived movement of circadian sunlight)." Regarding *C. oblongifolia* (camboatá), its benefit according to E19 is that "*They don't give much shade at the base of the tree, higher canopy*." For the species *A. colubrina* (angico-vermelho), E34 justified, "*Angico-vermelho and ipês, because it grows the pasture underneath and at the same time has shade for the cattle*." For *A. polycephala* (angico-branco), E17 reported that "*All the branches that break and fall help the grass to grow well under it*." The other three species had no justifications regarding the benefit of keeping them in the pasture.

Some farmers considered that some of these ten species could be harmful under certain conditions and would prefer to eliminate them (Tables 1 and 2, Criterion 5), expressing contrary opinions. Regarding *A. colubrina*, interviewee E15 stressed, "*The angico-vermelho, when very old, falls and breaks many branches, and can fall on animals and the fence, causing damage*," and E31 said, "*It does not grow grass around it, it seems that the root pulls the humidity in place*." For *G. integrifolia*, E25 said, "*Pau-d'alho, it doesn't let the grass grow, too many leaves fall and rot the grass. It is not good for the grass*." About *R. brasiliensis*, interviewee E10 expressed a disadvantage and an advantage: "*It has a very closed canopy, and no grass grows underneath, the animal stays there for a long time. However, it helps the animal with the shade*." Regarding the management of the species *D. nigra* (cabiúna), interviewee E33 determined that it could be harmful "*Cabiúna, because it gives seed, it grows and destroys the pasture*"; however, the same person concluded that "*Cabiúnas, even giving problems, would not eliminate but control the management*."

From the discourse of the interviewees, some of the characteristics related to the species was a benefit for some and a disadvantage for others, such as the shade provided by the species *G. integrifolia* and *R. brasiliensis*. Some farmers perceived problems and solutions for the same species, such as *R. brasiliensis* and *D. nigra*. The fact is that there is no ideal species in all situations for all types of farmers, since some species have advantages that outweigh their disadvantages under certain environmental and management conditions (Andrade, Salman, and Oliveira 2012; Barton et al. 2016; Mazía et al. 2016). No species presented structures that could potentially cause accidents involving livestock, which is in line with farmers' wishes (Criteion 6).

Ecological interactions and management

Regarding the ecological interactions of trees toward ground cover, one of the explanations for the statistically significant greater ground cover by herbaceous plants in the stratum under the crown of the *A. colubrina* may be related to this species' potentially nodulating and being a nitrogen-fixing legume, which can form symbiosis with *Rhizobium* bacteria (Sprent, Ardley, and James 2017). This species may have facilitated soil colonization by herbaceous plants, mostly composed of C4 grasses (Mazía et al. 2016).

Although *D. nigra* and *A. polycephala* are also potentially nodulating and nitrogen-fixing legumes (Sprent, Ardley, and James 2017), we did not observe the same patterns of higher herbaceous cover in the stratum under the crown of these species. According to Carlos et al. (2018), the effects of inoculating or not of *D. nigra* with *Rhizobium* depend on the origin of the plant and the nitrogen concentration in the soil. For example, for *D. nigra*, the inoculation or not of *A. polycephala* with *Rhizobium* may depend on the origin and the nitrogen content in the soil, despite the lack of conclusive study on this species.

Regarding the species *H. arianeae*, the significantly lower ground cover by litter in the stratum under the crown may have resulted from the greater protection the canopy offers to forage plants against the effects of the dry spell that occurred in January and February 2019 (summer) in the region, with temperatures above the historical mean (2–3°C above), high accumulated potential evapotranspiration rate (180–200 mm in January), water deficit (20–−40 mm in January), and impaired soil water storage (21–41 mm in January) (Medeiros et al. 2019). According to Mazía et al. (2016), non-leguminous and deciduous tree species (such as *H. arianeae*) can amend stressful conditions in tropical pastures (e.g., thermal and water restriction), rich in C4 grasses and without excessive shading (light restriction).

Since most species and the total set did not show significant differences by the t-test between the UC and OC strata for the three types of ground cover analyzed, the interaction of tolerance between trees and herbaceous plants predominated among the species compared to herbaceous ground cover at the time assessed (Connell and Slatyer 1977), rather than the expected facilitation (Mazía et al. 2016). There was a possible influence by the climatic extremes during the summer in the region (Medeiros et al. 2019).

According to Andrade, Salman, and Oliveira (2012), the characteristics related to the architecture of the tree crowns are determinants of the interference of the tree on the availability of light for the pasture growing under the crown projection area on the ground. According to these authors, taller species are preferred for afforestation of pasture, with a tendency to show lower canopy densities and with greater crown base height, because this would enable greater light availability for the forage plants and less competition from the tree regarding light restriction for the forage plants covering the ground. Overall, the correlation analyses corroborated the information published by these authors. Crown base height and herbaceous ground cover positively correlated, while crown density and herbaceous ground cover negatively correlated.

Although all other morphometric correlations of the trees are essential in our study, the characteristics of canopy cover density and crown base height were considered the main ones when the objective is to facilitate soil coverage by forage and maintain a sustainable production of forage biomass in a silvopastoral system, because they are both easier to manage, and pruning can be applied to thin the crowns and to raise the crown base height by pruning the most basal branches, aiming to increase the entry of sunlight into the silvopastoral system (Andrade, Salman, and Oliveira 2012; Bungenstab et al. 2019).

Despite the negative correlation between the ground coverage by litter and the coverage by herbaceous plants (mainly grasses), the litter is essential for the silvopastoral agroecosystem because it contributes to preventing soil erosion, to the conservation of soil moisture, to the input and cycling of nutrients in the system, to the maintenance of soil life and to carbon sequestration via decomposition of organic matter and decrease of the C/N ratio, especially in the case of nitrogen-fixing legumes (Bungenstab et al. 2019; Mazía et al. 2016).

Regarding richness and composition of herbaceous species, we noticed the highest amount of species under the crowns of the tree species evaluated compared to the sampling strata outside the crowns, as well as the tendency of separation into different groups, based on the occurrence of herbaceous species, as a function of the sampling strata UC and OC. These results differ from Prevedello et al. (2018), but agree with other studies that found increased herbaceous biodiversity associated with isolated trees in grasslands in other regions worldwide (Dorrough et al. 2006; Kiebacher, Scheidegger, and Bergamini 2017).

The forage *Urochloa brizantha* was present in 100% of the treatments/controls. *U. brizantha* is one of the most grown forage grasses in Brazil, which is adaptable to conventional pastures in full sun and in intercropping systems with trees, and can adapt to moderate shading (Bungenstab et al. 2019).

Despite the differentiation of floristic composition groups, considering biomass production in general and each tree species, the strata of UC treatments showed no statistical difference of grass production compared to OC controls. Similar to the study by Bernardi, Jonge, and Holmgren (2016), but in a subtropical environment, which shows that the presence of isolated trees in pastures would not cause losses to farmers regarding food supply to the cattle, at least in the summer evaluated. Such characteristics corroborate the data found on herbaceous cover (mostly grasses) and the theory that tolerance interactions (Connell and Slatyer 1977) predominate between trees and grasses under the conditions evaluated in this study. Even in the case of the species *B. riedelianum*, which showed significantly higher production of spontaneous plants under the canopy, but showed no differences in the grasses. *H. arianeae* and *R. brasiliensis* only showed greater evidence of competition when considering the total production of grasses and spontaneous plants together, which was significantly lower under the crown.

Regarding grass grazing intensities by the cattle evaluated in this study, there was no statistical differentiation between UC and OC strata for most (nine) tree species evaluated alone or the ten together. Despite significantly higher mean grazing intensity by the t-test, under the crown of *R. brasiliensis*, in the same sampling condition, we did not observe a significantly lower production of grasses for the species.

We conducted the field evaluations during the summer, a season in which the production of tropical forages tends to be enhanced (Gibson 2009). We do not know if the results would be similar during the winter or without the interference of climatic extremes of water and thermal stress of this atypical period. The list of the ten selected tree species shows the tree characteristics recommended by Mazía et al. (2016) to facilitate the production of C4 grasses in tropical agroecosystems with nitrogen-fixing legumes and non-legumes potentially deciduous in winter, except under intense climatic aridity.

Conclusions

The selection of tree species using our multi-criteria decision-making support tool by applying the Ethnoecological Selection Index (EESI) creates an interface between the traditional empirical knowledge of family farmers in the southern macro-region of Espírito Santo and scientific knowledge based on the application of ecological theories. The replication or adaptation of the method (e.g., with other software, equipment) may help scientists and decision-makers to choose key species for the afforestation of pastures in other regions worldwide.

The study of the interactions of the tree species with the soil cover (by herbaceous, litter and bare soil), with the grasses and spontaneous plants (richness, composition and biomass production) and with cattle (grazing) contributes to expanding the knowledge on spontaneous silvopastoral agroecosystems in the tropics.

The prior application of the EESI is a pre-selection filter for subsequent evaluation of tree species toward their silvopastoral potential. Therefore, the ethnoecological knowledge of family farmers must be considered when formulating sustainable silvopastoral systems adapted to the target regions.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was supported by the Fundação de Amparo à Pesquisa e Inovação do Espírito Santo [process 76463095]; Secretaria de Estado da Agricultura, Abastecimento, Aquicultura e Pesca – Seag [process 76463095].

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