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Management of productive systems

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Nutritional and productive profile of shrub species in tropical lowlands of Antioquia (Colombia)

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Abstract

The soils used for livestock in the Bajo Cauca (Antioquia, Colombia) are characterized by having acid pH, low fertility, erosion, compaction, and overgrazing. For this reason, there are deficiencies in nutritional quality and forage production, especially in dry seasons. Therefore, it is necessary to evaluate the use of forage resources adaptable to this area. To compare the nutritional and productive profile of the species *Crescentia cujete, Gliricidia sepium,* and *Tithonia diversifolia*, experimental plots were established in Hacienda La Candelaria, using a completely randomized block design with and factorial arrangement. Plant height, green forage and dry matter yield (DM), dry matter content (DM%), neutral detergent fiber (NDF%), acid detergent fiber (ADF%), and crude protein (CP%) were evaluated. An analysis of variance and Tukey's test were performed with significant differences ($p \leq 0.05$) for dry matter yield, with a projected annual production of 13.75 t/ha for *Crescentia cujete*, 23.2 t/ha for *Gliricidia sepium*, and 18.47 t/ha for *Tithonia diversifolia*. Significant differences were found for NDF ($p = 0.0349$), ADF ($p < 0.0001$) and CP ($p = 0.0037$). *Crescentia cujete* showed the highest NDF (46.5 %) and ADF (25.1 %) contents, whereas *Tithonia diversifolia* recorded the lowest values (32.6 % NDF and 14.4 % ADF). The CP content was 25.2 % for *Tithonia diversifolia*, 24.3 % for *Gliricidia sepium*, and 15.0 % for *Crescentia cujete*. These results suggest that these species have a potential use in livestock systems in poor soil conditions.

Keywords: *Crescentia cujete*, forage yield, *Gliricidia sepium*, sustainable agriculture, *Tithonia diversifolia*

Perfil nutricional y productivo de especies arbustivas en trópico bajo, Antioquia (Colombia)

Resumen

Los suelos destinados a ganadería en la región del Bajo Cauca (Antioquia, Colombia) se caracterizan por presentar pH ácido, baja fertilidad, erosión, compactación y sobrepastoreo. Debido a esto, presentan defic iencias en calidad nutricional y producción de biomasa, especialmente en épocas secas. Por lo anterior, se requiere evaluar el uso de recursos forrajeros adaptables a la zona de interés. Para comparar el perfil nutricional y productivo de las especies *Crescentia cujete, Gliricidia sepium* y *Tithonia diversifolia*, se establecieron en la hacienda La Candelaria parcelas experimentales en un diseño por bloques completamente aleatorizado con un arreglo factorial. Se evaluó altura de las plantas, rendimiento de forraje verde y materia seca (MS), y contenido de materia seca (MS %), fibra detergente neutro (FDN %), fibra detergente ácido (FDA %) y proteína cruda (PC %). Se realizó análisis de varianza y prueba de Tukey y se obtuvieron diferencias significativas ($p \leq 0,05$) para el rendimiento de materia seca, con una producción anual proyectada de 13,87 t/ha para *Crescentia cujete*, 23,2 t/ha para *Gliricidia sepium* y 18,47 t/ha para *Tithonia diversifolia*. Hubo diferencias significativas para FDN ($p = 0,0349$), FDA ($p < 0,0001$) y PC ($p = 0,0037$). *Crescentia cujete* presentó el mayor contenido de FDN (46,5 %) y FDA (25,1 %), mientras *Tithonia diversifolia* registró los valores más bajos (32,6 % en FDN y 14,4 % en FDA). El contenido de

PC fue de 25,2 % en *T. diversifolia*, 24,3 % en *G. sepium* y 15,0 % en *C. cujete*. Los resultados sugieren el potencial de estas especies en sistemas ganaderos con suelos pobres.

Palabras clave: agricultura sostenible, *Crescentia cujete*, *Gliricidia sepium*, rendimiento del forraje, *Tithonia diversifolia*

Introduction

Colombian livestock has been characterized by being mostly extensive, allocating pastures from large areas to meet the nutritional needs of animals at the expense of ecosystems, which deteriorate due to deforestation (Mauricio et al., 2019). Despite the expansion of the agricultural frontier, livestock farms have low production rates due to poor quality and low forage production derived from inadequate grassland management and the demotion of the physical, chemical and biological properties of the soil (Cubillos et al., 2016; Mauricio et al., 2019). To make matters worse, prolonged droughts, frosts, and severe flooding as a result of climate change (Tapasco et al., 2015), socioeconomic difficulties and lack of access to technical assistance and technologies (López-Vigoa et al., 2017; Navas, 2017) have increased the vulnerability of these production systems (Cuartas et al., 2014).

Most of the beef production systems are distributed in lowland tropical regions (0-1,200 m a.s.l.) exhibiting various edaphic characteristics (Carulla & Ortega, 2016). Livestock farms located in soils with low fertility, acid pH, high aluminum saturation, low organic matter, and problems of compaction and erosion are especially vulnerable (Gaviria-Uribe et al., 2015; Sossa & Barahona, 2015), since, in addition to extensive management, pastures usually show a low production and energy-protein ratio (Rincón et al., 2018, 2019).

Therefore, it is necessary to look for measures to improve the productive performance of these systems under the concepts of sustainability and adaptation to climate change. One of the alternatives that have been implemented in recent years is the use of silvopastoral systems (SPS), which consists of combining pastures, shrubs, and trees in different spatial arrangements (multi-layer in high density, forage banks, live fences, windbreak barriers, scattered trees) to optimize the use of areas, increase the food supply and promote the recovery of soils and the sustainable use of natural resources (Mauricio et al., 2019).

Of the spatial arrangements that can be implemented, forage banks (planting tree or shrub species in high densities) are an alternative solution to produce high-quality food in a smaller area, useful for supplementation, either fresh or by forage conservation methods such as silage (Calle et al., 2012).

There are several shrub species, such as botón de oro [Spanish] or wild sunflower (*Tithonia diversifolia* Hemsl A. Gray [Asteraceae]) (Gallego-Castro et al., 2017), matarratón [Spanish], gliricidia or forest lilac (*Gliricidia sepium* Jacq. [Fabaceae]) (Silva et al., 2017), and totumo [Spanish], calabash tree or bottle gourd (*Crescentia cujete* L. [Bignoniaceae]) (Gómez et al., 2015), which due to their nutritional characteristics and adaptation to several altitudes (thermal floors) and edaphic conditions, can be used in forage banks.

The species *T. diversifolia* is suggested to have the ability to take advantage of scarce nutrients in low-quality soils and contribute to soil improvement due to the levels of nitrogen, phosphorus, and amino acids in its leaves (Medina et al., 2009; Ojeniyi et al., 2012). *Gliricidia sepium* is also a species recognized for adapting to low fertility soils, but it is also a legume, so it contributes to the nitrogen fixation to the soil (Cubillos-Hinojosa et al., 2012). This is the reason why it has been used in agroforestry systems to improve the productivity of species such as corn (Smethurst et al., 2017) and cacao (Hosseini et al., 2017). On the other hand, *C. cujete* is recognized for its plasticity in adapting to different biogeographic conditions (Arango-Ulloa et al., 2009) and for presenting good nutritional characteristics not only in its leaves (Rodríguez & Roncallo, 2013) but also in its fruits (Flórez, 2012).

Tithonia diversifolia can achieve a green forage production of 24.7 t/ha and dry matter (DM) of 5.6 t/ha in its pre-flowering stage (Ferreira et al., 2016), with crude protein (CP) contents ranging between 13.0 % (Gallego-Castro et al., 2017) and 28.0 % (Verdecia et al., 2011). For its part, without high-density planting management, *G. sepium* can annually produce 17.5 t/ha of green forage (Vennila et al., 2016) and 8.57 t/ha of DM in the dry season (López, 2005), with CP contents between 16.0 % and 25.0 % (Silva et al., 2017). Both the forage and fruits of *C. cujete* can be used with green forage production of 14.0-16.0 t/ha and fruit production of 20.0 t/ha (Gómez et al., 2015). Regarding its DM production, from the leaves and stems of *C. cujete* with 120 days of age, 689.2 kg/ha can be obtained (Rodríguez & Roncallo, 2013), while, from the fruits, 11.0 t/ha have been recorded (Gómez et al., 2015). This species can have CP percentages of 14.0 % in leaves and stems (Gómez et al., 2015) and 8.38 % in fruits (Ejelonu et al., 2011). Accordingly, the aim of this study was to compare the nutritional and productive profile of *T. diversifolia*, *G. sepium*, and *C. cujete* in a tropical lowland in Antioquia (Colombia).

Materials and methods

The study was carried out at Hacienda La Candelaria, located in the municipality of Caucasia (Antioquia) at 08°01'49" N and 75°13'03" W, with an average temperature of 26 °C, an altitude of 50 m a.s.l., annual average rainfall of 2,100 mm, and 75.0 % relative humidity; 15.0 % of the region has a flat topography and 85.0 % shows undulating terrain.

Establishment of experimental plots

The research was carried out for 13 months, starting from the establishment phase (five months) and until the evaluation of the last cut in the rainy season (eight months). The experimental plots were established in soils that are characterized by having a loamy-sandy texture, acidic pH, poor organic matter, high aluminum saturation, compaction and erosion, and a high degree of stoniness (table 1).

Table 1. Soil characteristics of Hacienda La Candelaria, 2017

Characteristic	Value
Texture	Sandy-loam
Aluminum saturation	46.9 %
Cations meq/100 g soil	
Organic matter	1.6
P (mg/kg)	8.33
pH	4.67
Al	2.13
Ca	1.83
Mg	0.60
K	0.09
Na	0.04
Cations (ppm)	
Cu	2.0
Fe	88.67
Mn	37.33
Zn	1.67
B	0.27
S	8.67
Cation exchange capacity	4.70

Source: Elaborated by the authors

An area of 792.0 m^2 was selected and divided into two parts of 18.0 m × 22.0 m (396.0 m^2) each, according to the topography and by distinction as a semi-plane (SMP) and slope (SP). In preparing the land, the area was cleaned with a commercial systemic herbicide according to the product's recommendations to remove the plant material. Subsequently, animal traction plowing (buffalo) was carried out, and eight experimental plots of 8.0 m×7.0 m (56.0 m^2) were established, four in SMP and four in SP, leaving alleys of 2.0 m between these. The four species were then randomly distributed within each topographic condition (SMP and SP). In each plot, planting was performed with a double row model and a distance of 20.0 cm between plants, 75.0 cm between single rows, and 1.0 m between double rows, for a planting density of 6.25 plants/m^2.

Planting the species

Sexual seed of *T. diversifolia, G. sepium,* and *C. cujete* were used for planting in the experimental plots. An amount of 1.0 kg of *T. diversifolia* seed was mixed with 10.0 kg of dry chicken manure and direct sowing was carried out in the field at less than 2.0 cm of depth. The *G. sepium* seed was hydrated for twelve hours (0.5 kg), dried in the sun for six hours and sown in the field at a depth of 2.0 cm. Finally, the *C. cujete* seed was planted at a depth of less than 2.0 cm, without separating the seed from the fruit pulp. Reseeding was performed 15 days later with seedlings previously established in the seedbed.

Cutting and maintenance cycle of the species

All three species, *T. diversifolia, G. sepium,* and *C. cujete,* were established successfully. Before the leveling cut and during the evaluation period of the plots, manual and chemical weed control was performed monthly. The leveling cut was carried out five months after establishment, using a bevel angle to cut at 0.70 m from the ground for all species. Subsequently, four samplings were carried out, one in December (beginning of the dry season), one in February (dry season), one in April (moderate rains), and the last in May (heavy rains). The samplings during the low precipitation period were carried out every 60 days, while in the high precipitation period, these were made every 45 days. For the evaluated species, the same uniformity cut procedure was followed, considering the topographic difference of the area (SMP and SP).

Climate behavior

During the agronomic and nutritional composition evaluations of the analyzed species, the behavior of the climatic variables (temperature, precipitation, solar radiation, and relative humidity) was monitored through the weather station of the farm (RainWise®).

Variables evaluated

Height

In each plot, 50 plants were randomly selected, and a graduated ruler was used to measure their height from the ground to the terminal bud of the main stem in the first and last sampling. The objective was to observe the behavior immediately after the levelling cut –considering that it was a newly established forage bank (5 months)– and after intermediate cuts (13 months post-establishment).

Nutritional composition

The contents of dry matter (DM), crude protein (CP), neutral detergent fiber (NDF), and acid detergent fiber (ADF) were evaluated. Two samples of leaves and young stems (0.2 kg each) were taken from each plot (in each block); one sampling was carried out in February (dry season) and the other in April (moderate rains). The nutritional composition was examined with near-infrared spectroscopy (NIRS) in the Animal Nutrition Laboratory of the Faculty of Agricultural Sciences of Universidad de Antioquia and Corporación Colombiana de Investigación Agropecuaria - AGROSAVIA.

Usable green forage and dry matter yield per plant

From each plot, 50 plants were randomly selected to be cut and weighed. Sampling was carried out at the beginning of the dry season (December), in the moderate rainy season (April), and during the heavy rain season (May). The dry season (February) was not evaluated because the plants were in critical condition due to the severe drought. The green material obtained was weighed with a digital scale, separating leaves and tender stems from thick stems and senescent material, to differentiate between usable and unusable material. From 50 plants, the production per plant in each plot was estimated. A sample of 0.2 kg was taken in each plot and transported to the Animal Nutrition Laboratory to be dried in a forced ventilation oven for 16 hours at 70 °C, and DM yield was measured. The percentage of DM obtained by NIRS was set as a reference to estimate the DM yield per plant from the green forage yield per plant. The performance variables of green forage and DM were expressed in kg/plant.

For the projection of the green forage yield per hectare, the planting density applied in the plots (6.25 plants/m^2) was considered, and for the annual projection of the DM yield per hectare, the planting density of 6.25 plants/m^2 and six yearly cuts were taken into account.

Experimental design

The data were analyzed using a completely randomized block (CRB) design with a 3 × 2 factorial arrangement, where the block was the topography of the terrain (SMP and SP), and the factors were the species and the sampling. The information of the study variables was analyzed with the *nlme* package for mixed linear models in the R Project software, version 3.6.0. An analysis of variance of each of the variables and Tukey's test ($p \leq 0.5$) were performed to compare means.

Results and discussion

Climatic behavior

The sampling carried out in December (beginning of the dry season) was made during the first week, when the plots had been without rain for seven days. However, after this first sampling, the drought lasted throughout the month, so a precipitation value of 0.0 mm, an average temperature of 27.2 °C, relative humidity of 81.9 %, and solar radiation of 274.75 W/m^2 were obtained. As the survival of the plants was compromised, light irrigation was applied uniformly on all the plots. This was done three times a week, from mid-December to early March, at a rate of 360.0 l of water/plot in each irrigation. Irrigation lasted until March due to the climatic conditions of January and February, and registered precipitations of 3.5 mm and 24.1 mm, an average temperatures of 27.8 °C and 28.6 °C, relative humidity of 75.2 % and 71.4 %, and solar radiation of 286.7 W/m^2 and 298.2 W/m^2, respectively. This irrigation only served as an aid to the survival of the plants but was not sufficient for their proper recovery. For this reason, when the evaluation of February (dry season) arrived, there was just enough forage to take and perform the bromatological analysis, but not to make an evaluation of the forage yield. Therefore, the plants were not cut. The third sampling was carried out in early April (moderate rains). In addition to irrigation, the plants had received rains in March (approximately 97.0 mm) and the first ones in April (62.2 mm). Finally, the sampling carried out at the end of May corresponded to a period of heavy rains (approximately 550.0 mm) (figure 1 and figure 2).

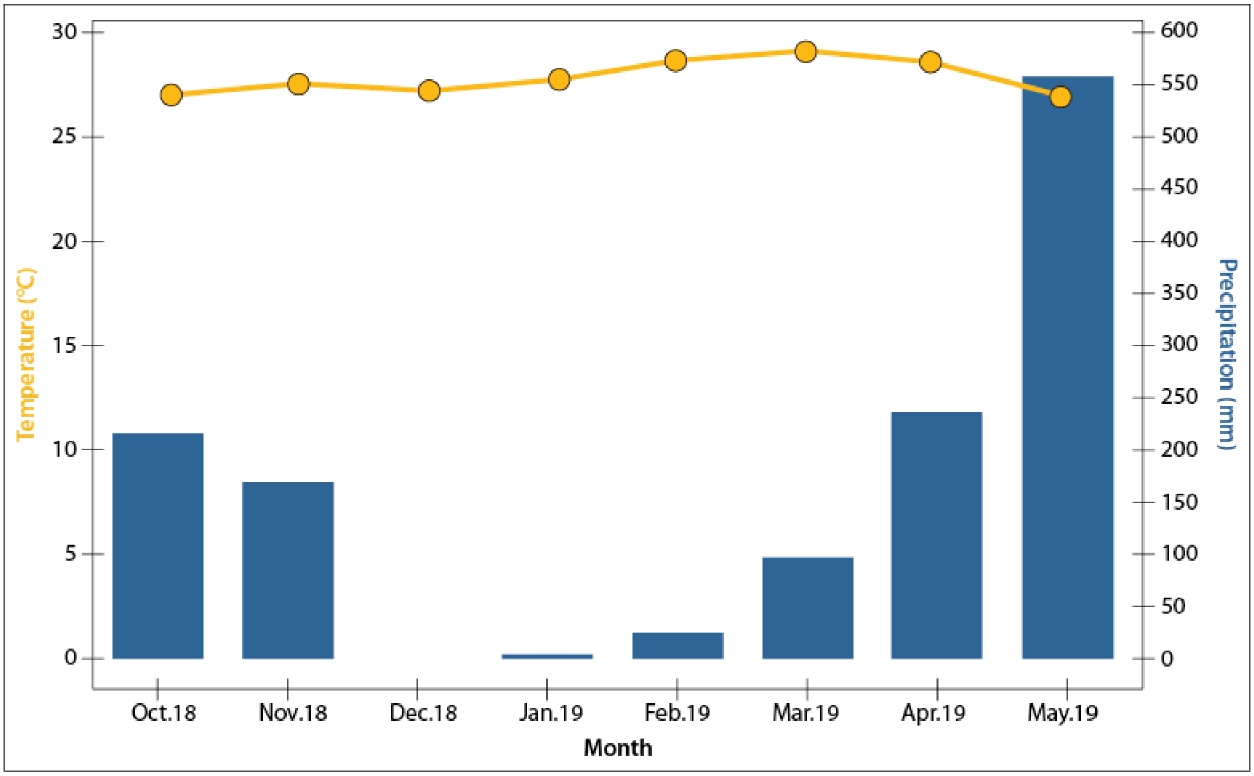

Figure 1. Temperature and precipitation behavior during the experimental period.
Source: Elaborated by the authors

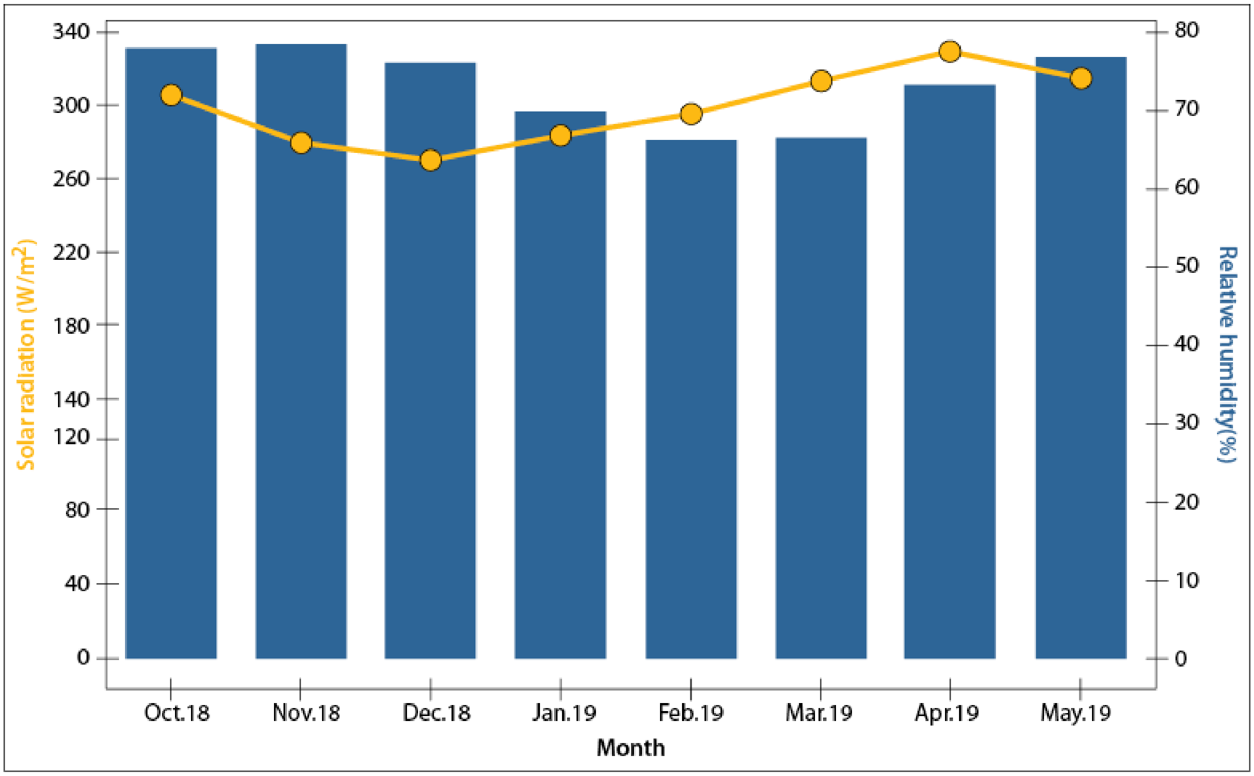

Figure 2. Solar radiation and relative humidity behavior during the experimental period.
Source: Elaborated by the authors

Height

There was no effect of the factors studied or their interactions on the height variable (p > 0.05). The observed means by species were 1.32 m, 1.24 m, and 1.11 m for *G. sepium, T. diversifolia,* and *C. cujete*, respectively. According to the observed behavior, the non-significant differences for the species × sampling interaction could be because the December sampling (beginning of the dry season) was preceded by the rains of October and November (figure 1). This could have favored the growth of the plants in a similar way to the May sampling, carried out in times of heavy rain. Likewise, the plant´s height, found for the December and May sampling, suggests that the age of the crop did not affect the development of the plants negatively, despite having passed 13 months since their establishment.

Variations in plant growth (height and diameter, among others) can be attributed not only to genetic factors, but also to the interaction with the environment, where climatic factors (temperature, precipitation, wind, and radiation, among others), as well as edaphic (physical, chemical, and biological properties) and phytosanitary factors, as well as the competition between individuals, converge (Imaña & Encinas, 2008; Mora, 2018). Although no significant differences in height were observed between December and May samplings, it should be noted that the three species presented considerable heights concerning other studies. Regarding *G. sepium*, Gómez et al. (2008) reported a height of 2.76 m at 12 months of its establishment at a planting distance of 0.60 m, while, in the current study, the species reached an average of 1.32 m in high density and with frequent pruning. Some species of the Fabaceae family have shown high values in the root/stem ratio, allowing them to maximize their contact surface with the soil to obtain nutrients and water. In other words, they possess higher competitive ability even under poor edaphic conditions, which could explain the development observed for *G. sepium* in this study (Mayo-Mendoza et al., 2018).

The height found for *T. diversifolia* was higher compared to that reported by Gallego (2016) at 56 days of age (0.69 m) in the tropical highland (≥ 2,000 m a.s.l.); meanwhile, *C. cujete* had a higher height with respect to the one recorded by Rodríguez and Roncallo (2013), which was 0.96 m at nine months of age in the tropical lowland (≤ 1,000 m a.s.l.). These data indicate that despite the poor soil conditions in which the study was carried out, the plants had an adequate recovery in terms of growth and reached average cutting heights above 1.0 m.

Nutritional composition

Dry material

The DM content showed effects for the interaction between the species × sampling factors ($p \leq 0.05$) and for the species and sampling factors. *C. cujete* was the species with the highest DM content, both in the February sampling, which coincided with the dry season and in the April sampling, corresponding to the moderate rainy season. For its part, the DM content of *T. diversifolia* showed the lowest values in relation to *C. cujete* and *G. sepium*, both in the April and February samples. In the February sampling (dry season), *G. sepium* did not show significant differences with *T. diversifolia*, although it obtained statistical differences in the April sampling (moderate rains) with a higher DM content compared to *T. diversifolia* (table 2).

Table 2. Nutritional composition of the evaluated species

Variable	Species			Sampling						p		
				February			April					
	BO	M	T	BO	M	T	BO	M	T	Sp.	Sa.	Sp. × Sa.
DM (%)	19.0^{c}± 5.28	22.0^{b}± 2.86	33.4^{a}± 4.90	23.7^{cd}± 2.10	24.1^{cd}± 2.31	37.8^{a}± 2.29	14.3^{f}± 1.20	19.9^{e}± 1.46	29.1^{b}± 0.79	<0.0001	<0.0001	0.0194
NDF (%)	33.7^{c}± 2.09	38.5^{b}± 0.65	45.7^{a}± 1.33	34.8^{ef}± 1.42	38.4^{cd}± 0.43	44.9^{ab}± 1.47	32.6^{ef}± 2.26	38.7^{cd}± 0.86	46.5^{ab}± 0.57	<0.0001	0.1124	0.0349
ADF (%)	14.5^{c}± 3.41	20.3^{b}± 1.61	25.1^{a}± 1.06	14.4^{a}± 4.87	19.2^{a}± 1.65	25.1^{a}± 0.28	14.5^{a}± 1.87	21.4± 0.23	25.1^{a}± 1.59	<0.0001	0.9671	0.1571
CP (%)	25.2^{ab} ±4.78	24.3^{ab}± 1.26	15.0^{c}± 1.92	26^{a}± 5.89	24.1^{a}± 2.31	13.6^{a}± 1.42	24.4^{a}± 4.10	23.5^{a}± 0.78	16.5^{a}± 1.05	0.0037	0.2072	0.2825

BO: *T. diversifolia*, M: *G. sepium*, T: *C. cujete*, Sp.: species, Sa.: sampling. Different letters indicate significant differences ($p \leq 0.05$, a > b) according to Tukey's mean comparison test.

Source: Elaborated by the authors

The DM percentage of *C. cujete* was much higher than that recorded by Rodríguez and Roncallo (2013), which were 15.8 % and 14.9 % at 56 days and 84 days of regrowth in the rainy season. Regarding *T. diversifolia*, Naranjo and Cuartas (2011) and Gallego-Castro et al. (2017) found in the tropical highland 19.1 % and 12.5-12.7 % of DM, respectively.

These values were lower compared to those found in the current study for the February sampling (dry season), although similar to the April sampling (moderate rainfall). Regarding *G. sepium*, Oliveira et al. (2018) reported 21.6 % of DM, while Anis et al. (2016) found from 18.4 % to 24.7 %, which increased with the cutting age. The value found in the February sampling (dry season) was higher than the one described by Oliveira et al. (2018) and also showed a behavior similar to the one identified by Anis et al. (2016).

The content of DM can vary due to factors such as age and cutting frequency, time of year, agronomic management, and association with other species (Gallego-Castro et al., 2017). The high DM content in the February sampling (dry season) could be related to an increase in light intensity (figure 2) that can generate changes in the cellular structure of the forages, in particular, thicker cell walls in comparison with plants that grow in conditions of low light intensity (De Castro et al., 2018). Likewise, exposure to a higher light intensity generates higher transpiration rates and, hence, a lower concentration of water in the tissues contributes to raising the DM content (Soares et al., 2009).

The behavior of precipitation, temperature, relative humidity, and solar radiation during the evaluation period (figure 1 and figure 2) suggests that the DM percentages observed in the species could be related to the climatic conditions of the two samplings, the dry season and the moderate rainy season. *C. cujete*, which presented the highest DM contents in both samples, is a species recognized for its adaptation to semi-arid environments and tolerance to water stress (Arango-Ulloa et al., 2009). Furthermore, it has a good capacity for the absorption of water and nutrients and supports high photosynthetic and transpiration rates, such as those observed in this study (Piña & Arboleda, 2010).

Neutral detergent fiber and acid detergent fiber

The interaction between the species × sampling factors was significant ($p = 0.0349$) for the NDF content. In the April sample (moderate rainfall), *C. cujete* had a higher NDF compared to the other species in both samples. On the other hand, *T. diversifolia* showed the lowest NDF value in both samples and concerning *C. cujete* and *G. sepium*. The latter presented values lower than *C. cujete*, but higher than *T. diversifolia* in the two samples evaluated (table 2).

In this investigation, the NDF values of *T. diversifolia* were lower than those found by Verdecia et al. (2011) that were 40.4 % in the period of minimum precipitation and 43.6 % in the rainy season 60 days after regrowth. In contrast, Cardona-Iglesias et al. (2017) found 39.0 % of NDF in the tropical highland. In the case of *G. sepium*, in a study carried out in the dry season, León et al. (2012) reported a value of 55.9 % of NDF in plants with more than 90 days of regrowth, while Edwards et al. (2012) observed NDF values of 58.2 % in plants of 42 days; both studies were conducted under tropical lowland conditions. When contrasting these values with those of the current study (38.4 % to 38.7 %), the mentioned reports show much higher values and could be associated with the features of each crop, such as cutting age, soil characteristics, and biogeographic conditions in which the studies were carried out (León et al., 2012).

Regarding *C. cujete*, the values found (44.9 % to 46.5 %) are in a similar range to those related by Rodríguez and Roncallo (2013), who found 48.8 % at three months of age, and 52.8 % at four months. It should be noted that in this research, no significant differences were observed in the NDF fraction between the sampling of February (dry season) and that of April (moderate rains), while these authors found an increase in this value as the cutting age increased.

The NDF is considered the fraction that determines forage intake in ruminants, so that, at higher values, lower feed intake occurs, given the slow degradation in the rumen and the filling effect it generates (Apraéz et al., 2012; Naranjo & Cuartas, 2011). Therefore, low NDF values could be related to better intake by animals. In tropical conditions, forages tend to have high NDF values, which increase with age and time of the year (zero or low precipitation). The maximum NDF content should be between 54.0 % and 60.0 % to achieve forage intakes higher than 2.0 % of body weight. However, the NDF values of the tropical grasses, which are the main food source of cattle, exceed these values (Cruz & Sánchez, 2000). This high content of NDF in grasses tends to limit the intake and degradability of DM, which may be 13.0 % lower in relation to pastures from other latitudes (Barahona & Sánchez, 2005).

Regarding the ADF content, no significant effect was observed in the sampling factor or in the interaction of the species × sampling factors. Significant differences were only found for the species factor ($p < 0.0001$), and *C. cujete* was the species with the highest ADF value (25.1 %) compared to *G. sepium* (20.3 %) and *T. diversifolia* (14.5 %).

When evaluating a silvopastoral system in the Caribbean region, Barragán (2013) reported ADF values for *C. cujete* under grazing between 48.36 % and 52.5 %, much higher than those found of the current study. This difference could be related to the management of the plants in the evaluated system, since in forage banks, frequent pruning is carried out to control the cutting height and the harvest of the material, while under grazing, the harvest of the material and its cutting height are not controlled, favoring the development of more woody stems.

Regarding *G. sepium*, Edwards et al. (2012) recorded an increase in the ADF fraction of 40.5 % and 43.8 % at 42 and 84 days of age, respectively. In the current study, the value was much lower, and the same was observed in *T. diversifolia* in comparison with the results of Cardona-Iglesias et al. (2017) and Verdecia et al. (2011), who reported ADF percentages of 27.2 % and 24.1-27.6 %, respectively. The ADF fraction groups cellulose and lignin, two cell wall components that increase with the age of the plant or with a high stem-leaf ratio (Apraéz et al., 2012). The lowest values in this study could be related to the age of the plants when cut; frequent pruning could have favored the presence of lower ADF content.

Higher NDF and ADF generate low energy availability, less digestibility, and less food intake (Naranjo & Cuartas, 2011). It should be noted that the NDF and ADF contents of the bushes evaluated were lower compared to grasses used in acid and low fertility soils such as *Urochloa humidicola* (NDF 80.8 %, ADF 42.4 %), *Urochloa decumbens* (NDF 69.5 %, ADF 43.46 %), and *Urochloa brizantha* (NDF 7.3 %, ADF 43.03 %) (Mahecha-Ledesma et al., 2017; Rivera et al., 2015). Given that the tropical grasses have high contents of NDF and ADF, and acid soils –due to their low fertility and high aluminum saturation– are an additional limitation for the establishment of grasses with better nutritional profiles, the results obtained in the current study show that the use of species such as *T. diversifolia*, *G. sepium* and *C. cujete* is an alternative to diversify the forage supply and improve its quality.

Crude protein

No significant differences were found in the CP content for the sampling factor or for the species × sampling interaction. However, significant differences were observed for the species factor (p = 0.0037) (table 2). Tukey's mean comparison test showed differences between the species *T. diversifolia* (25.2 %) and *C. cujete* (15.0 %), and between this latter and *G. sepium* (24.3 %), while between *T. diversifolia* and *G. sepium* there were no differences in the CP content.

Regarding *T. diversifolia*, Gallego-Castro et al. (2017) reported values between 12.7 % and 14.1 % and Naranjo and Cuartas (2011), a value of 24.13 %. In this investigation, the percentage of CP of *T. diversifolia* was high with respect to these studies, considering, besides, the edaphic characteristics of the area in which the establishment of the experimental plots was carried out. Regarding *G. sepium*, Edwards et al. (2012) found values between 25.7 % and 28.4 % with a decrease as age increased; there was no effect of the samplings on the percentage of CP. In the case of *C. cujete*, the CP content was similar to the 14.0 % reported by Rodríguez and Roncallo (2013).

The CP content found for the three species is relevant for the diet of animals in productive conditions of poor soils where pastures with a low percentage of CP such as *U. humidicola* (6.13 %), *U. brizantha* (6.44 %), *U. decumbens* (8.64 %), and *B. hybrid* cv. *Mulato* II (9.88 %) predominate (López-Vigoa et al., 2017; Mahecha-Ledesma et al., 2017; Rivera et al., 2015). Finding species with the ability to take advantage of the scarce nutrients in the soil and express adequate nutritional characteristics would be an alternative for supplementation of tropical lowland livestock systems, considering the poor nutritional quality of grasses and their scarcity during the dry season (Cordoví et al., 2013).

The CP content found in the studied species could be attributed to their ability to adapt and take advantage of soil nutrients and to their agronomic management (Botero et al., 2019; Edwards et al., 2012; Gómez et al., 2015). It is worth mentioning that in this study, all the species were established by sexual seed, allowing a better development of the root system (pivoting root) and, consequently, a higher capacity for nutrient absorption compared to when plants are established through cuttings (Saavedra, 2016). Similarly, height and cutting frequency may have had an effect on CP content, since, at a younger age and cutting height, higher CP content is found (Botero et al., 2019; Edwards et al., 2012; Rodríguez & Roncallo, 2013). On the other hand, as the plant ages, the cell wall increases, and the cell content decreases (Apraéz et al., 2012). In this particular case, despite the poor quality of the soils in the area, the CP percentages observed in the three species are high compared to the studies mentioned above, corresponding to areas with better soil conditions; this suggests that *T. diversifolia*, *G. sepium*, and *C. cujete* possess a good nutrient use adaptation capacity.

The inclusion of sources that provide protein to diets with low-quality tropical forages contributes to improving DM intake and utilization efficiency at the ruminal level (Sampaio et al., 2010). In this way, the bushes evaluated could be a forage source that contributes to improving the intake of livestock diets due to their considerable protein value, their low content of NDF and ADF concerning grasses, and their adaptability and performance in soils with poor soil conditions.

Usable green forage and dry matter yield

The results showed significant differences in the production of usable green forage (GF) for the species × sampling interaction and for the species and sampling factors ($p \leq 0.05$). Tukey's mean comparison test indicated that the differences for the species factor were found between *T. diversifolia* (0.277 kg/plant) and *C. cujete* (0.114 kg/plant), and between the latter and *G. sepium* (0.276 kg/plant). In contrast, between *T. diversifolia* and *G. sepium* there were no differences in the production of usable green forage (table 3). Likewise, the species × sampling interaction reveals that the differences in the production of GF were shown in relation to *C. cujete*, which was the species with the lowest yield. On the other hand, in the interactions between the three evaluation samples, *T. diversifolia* and *G. sepium* presented a similar performance (table 3).

Regarding DM production, significant differences were found by species ($p = 0.00301$), and no difference for the species × sampling interaction ($p > 0.05$) and the statistical trend for the sampling factor ($p = 0.0550$). Tukey's mean comparison test showed that the differences were between *C. cujete* (0.037 kg/plant) and *G. sepium* (0.059 kg/plant) and between the latter and *T. diversifolia* (0.047 kg/plant) (table 3). On the other hand, although the yield in GF was higher for *T. diversifolia* compared to *C. cujete*, when evaluating the yield in DM, no significant differences were found. This could be related to the low DM content of *T. diversifolia* compared to *C. cujete* (table 2), so that, although *C. cujete* had lower production of GF given its higher DM content, it could express DM yield similar to that of *T. diversifolia*.

Table 3. Usable green forage and dry matter yield per plant for the species × sampling interaction and for the species factor

Variable	Sampling									p	
	December			April			May				
	BO	M	T	BO	M	T	BO	M	T	Sa.	Sp. × Sa.
GF yield (kg/plant)	$0.230^{abcdefg}$ ±0.05	0.297^{abcdef} ±0.05	0.128^{eghi} ±0.02	0.249^{abcdef} ±0.02	$0.207^{abcdefhi}$ ±0.07	0.104^{fghi} ±0.001	0.351^{acdef} ±0.04	0.325^{bcef} ±0.002	0.110^{fghi} ±0.02	0.0258	0.0447
DM yield (kg/plant)	0.055^{b}± 0.02	0.070^{b}± 0.003	0.048^{b}± 0.009	0.035^{b}± 0.0007	0.039^{b}± 0.008	0.030^{b}± 0.001	0.049^{b}± 0.0008	0.067^{b}± 0.002	0.032^{b}± 0.005	0.0550	0.2239

Variable	Species			p
	BO	M	T	
GF yield (kg/plant)	0.277^{ab} ± 0.06	0.276^{ab} ± 0.06	0.114^{c} ± 0.01	0.0017
DM yield (kg/plant)	0.047^{bc} ± 0.01	0.059^{a} ± 0.01	0.037^{bc} ± 0.01	0.0301

BO: *T. diversifolia*, M: *G. sepium*, T: *C. cujete*, Sp.: species, Sa.: sampling. Different letters indicate significant differences ($p \leq 0.05$, a > b), according to Tukey's mean comparison test.

Source: Elaborated by the authors

Regarding the production of green forage of *T. diversifolia* in conditions of the tropical highland, Gallego (2016) reported 21.81 t/ha per cut in a forage bank established with sexual seed and with cuttings every

56 days at 0.50 m. For their part, Ferreira et al. (2016) recorded 24.7 t/ha per cut in the pre-flowering stage with cuttings at 0.80 m in low tropical conditions, although the cutting age was not reported. When projecting the results obtained in the current study, the production of *T. diversifolia* would be 18.14 t/ha per cut, a lower value compared to the mentioned studies. In the case of *G. sepium*, a projected production per cut of 18.07 t/ha was estimated, which is equally favorable, although lower than that reported by López (2005), which was 25.1 t/ha per cut in the dry season and 60.1 t/ha in the rainy season in Nicaragua. Likewise, Rodríguez and Roncallo (2013) found a cut production of 14.0-16.0 t/ha of green forage of *C. cujete* in the Colombian Caribbean, which in the current study was lower (7.5 t/ha per cut).

When estimating the annual DM production, it is observed that *G. sepium* would have a higher production with 23.18 t/ha, while that of *T. diversifolia* would be 18.47 t/ha and that of *C. cujete*, 13.87 t/ha. When comparing these estimates with other studies, the DM yield is similar for *T. diversifolia* with respect to what was described by Gallego (2016) in the Colombian tropical highland, who reported values between 14.8-19.5 t/ha/year. In contrast, Van Sao et al. (2010) estimated 25 t/ha/year in Vietnam. Regarding *G. sepium*, Beedy et al. (2010) reported values between 2.5-5.7 t/h/year of DM in Malawi, Togo, and Nigeria, lower figures in relation to those of the current study. For their part, Edwards et al. (2012) estimated an increase in DM production at a longer interval between cuts, with values of 8.6 t/ha, 12.7 t/ha, and 15.0 t/ha at 42, 56 and 84 days, respectively, in medium climate in Trinidad and Tobago. Meanwhile, in a multi-layer silvopastoral system, Rodríguez and Roncallo (2013) estimated for *C. cujete* a production of 986.7 kg/DM/ha in the period of minimum precipitation and 2.4 t/DM/ha in the period of maximum rainfall.

It is necessary to clarify that the density of *C. cujete* in the system was low compared to the management given in this research, where high-density sowing was carried out under a plot scheme.

The results on the GF and DM yields are favorable for the three species, considering the quality of the soils in which they were established and the climatic conditions. The yields obtained could be related to the adaptability of the species to take advantage of nutrients, the cutting frequency and the high planting density, which could favor –due to the effect of competition between plants– higher growth (Cordoví et al., 2013; Mora, 2018; Mayo-Mendoza et al., 2018; Noda-Leyva & Martín-Martín, 2017). Competition between plants for space, light, and nutrients can increase their density and growth, depending on how competitive a species is. The less competitive species would be affected by their growth, while a shorter planting distance could favor growth in highly competitive species. The GF and DM yields observed in the evaluated samplings could be explained by the effect of competition between plants suggesting that *G. sepium*, *T. diversifolia*, and *C. cujete* are highly competitive species (Mayo-Mendoza et al., 2018).

Similarly, climatic conditions have also been associated with forage yield, so that the cuts preceded by rains can show a higher production of GF and DM (Navas, 2019). In this study, differences were found between the periods of April (moderate rains) and May (heavy rains), with a higher yield in the latter possibly because in April, the plants were still recovering from the dry season (December-February). The water stress of this season generated a considerable loss of leaves in *T. diversifolia* during the period of less precipitation (figure 1) compared to *C. cujete* and *G. sepium*. The lower loss of leaves in *C. cujete* and *G. sepium* could be because tree species show higher tolerance to the dry season since they develop roots that allow them to take water from deeper profiles (Cordoví et al., 2013; Navas, 2019). This behavior in GF and DM yield between the samplings of April and May would indicate a positive effect of precipitation on the recovery capacity of the studied species and, in turn, an adverse effect of low or no precipitation (December- February) on its development.

Conclusions

The green forage and dry matter yields of the evaluated species are related to the climatic conditions in which they are established; considerable forage productions are recorded in cuttings after moderate to high rainfall seasons. On the other hand, the analysis of the nutritional and productive profile of *T. diversifolia, G. sepium,* and *C. cujete* indicates that these species can adapt to poor soils given their good nutritional and productive characteristics, making them an alternative for strategic supplementation in tropical lowland herds.

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Disclaimers

All authors made significant contributions to the document agreeing with its publication and declare that there are no conflicts of interest in this study.

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