Scientific Paper

Variation in the concentration of soluble solids in three forage shrub species of the high tropic of Colombia

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Abstract

Objective: To evaluate the concentration of soluble solids in three forage shrub species with different ages, in Pasto, Nariño, Colombia.

Materials and Methods: Measurements were taken in *Tithonia diversifolia* (Hemsl.) Gray, *Sambucus nigra* L. and *Smallanthus pyramidalis* (Triana) H. Rob., established in a silvopastoral system; a complete randomized block design was used, with 3 x 3 factorial arrangement, product of three species and three cutting ages (45, 60 and 75 days) for the variables nutritional quality (CP, NDF, digestibility, NSC and NLE, soluble solids and biomass production). The concentration of soluble solids was measured at three times (7:30 a.m., 11:30 a.m. and 3:00 p.m.), under a factorial arrangement (3 x 3 x 3). The data were processed through a variance analysis.

Results: The age influenced significantly the concentration of soluble solids of *T. diversifolia* and *S. nigra* (6,8 and 13,7 % respectively). Interaction was observed between the time of day and the cutting age of *S. nigra*, with the highest values of soluble solids (15,6 %) after 45 days at 3:00 p.m. The highest quantity of biomass was found at 45 days in all the species. The cutting age did not affect significantly the nutritional content of the shrubs; at 45 days the species had the highest concentration of soluble solids. At 75 days the three species showed the highest biomass production.

Conclusions: This study showed the nutritional potential of the three forage species, due to their concentration of soluble solids, for which they could be used as part of the diet of ruminants in productive systems of the Colombian high tropic.

Keywords: biomass, quality, silvopastoral systems

Introduction

In the Colombian high tropic, animal husbandry systems are extensively established and specially the monoculture of *Cenchrus clandestinus* (Hochst.) ex Chiov., grass of moderate quality, prevails, which leads to an excessive use of synthesis fertilizers in the grasslands; the utilization of tree or shrub species within such systems is scarce (Cardona-Iglesias *et al*., 2019a). The climate variation directly affects the reduction of the forage offer in grazing systems of the high tropic, leading to nutritional unbalances and low productivity of the animals (Mora-Delgado *et al*., 2014; Castro-Rincón *et al*., 2019).

Subsequently, animal husbandry systems in these zones should be focused on the utilization of adapted species with resilience to the climate change, supporting their productivity from the environmental, social and economic point of view (Gallego-Castro *et al*., 2014). In this context, an animal husbandry reconversion is necessary, which promotes sustainability in agricultural production. Silvopastoral systems (SPS) could be a strategy that offers multiple services regarding the protection of biodiversity, soil and water. Their utilization in the nutritional contribution of plant biomass and energy-protein balance to the livestock diet has also been acknowledged (Cardona-Iglesias *et al*., 2019b).

Woody shrub species such as Mexican sunflower [*Tithonia diversifolia* (Hemsl.) Gray], elderberry (*Sambucus nigra* L.) and colla negra [*Smallanthus pyramidalis* (Triana) H. Rob.], are renowned for their adaptation to the conditions of the Colombian high tropic, their optimum biomass production and high nutritional value where their energy content is emphasized, which could improve the protein-energy balance in the rumen (Cardona-Iglesias *et al*., 2019a). That is why these forage species can constitute an alternative for animal supplementation in the Andean high tropic; however, their efficient utilization depends on the management and knowledge about their phenological status, because their

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nutritional content varies depending on the maturity status of forage (Escobar, 2018; Guatusmal-Gelpud *et al*., 2020). In this aspect, the content of soluble solids (degrees brix) is used as an indicator of the nutritional value of forages, as they are related as an energy source within animal feeding, and varies according to the plant age and time of day; this fluctuation is due to the cessation of photosynthesis with the evening light reduction and in a parallel way, to the subsequent consumption of part of the available carbohydrates to maintain plant activity during the night (Villalobos and Sánchez, 2010).

On the other hand, the studies in forage shrubs have been focused on determining the biomass content, growth and bromatological composition and the studies about content of soluble solids are still incipient; that is why the objective of this study was to evaluate the concentration of soluble solids in three forage shrub species with different ages, in Pasto, Nariño-Colombia.

Materials and Methods

The study was conducted at the Obonuco Research Center of AGROSAVIA (Colombian Corporation of Agricultural Research) located in the San Juan de Pasto city (Nariño), coordinates 77°18'23''W - 1°11'54''N at 2 710 m.a.s.l. of altitude, 13 ºC of temperature, 84,4 % of relative humidity and 840 mm of rainfall, life zone catalogued as low mountain dry forest (LMdf) according to Holdridge (1996).

The design of the experiment was complete randomized design with 3 x 3 factorial arrangement, product of three species and three cutting ages (45, 60 and 75 days), for the variables nutritional quality, soluble solids and biomass production. The soluble solids were also measured, according to harvest age and time of day, under a 3 x 3 x 3 factorial design, product of three species, three cutting ages (45, 60 and 75 days) and three times (hours) of observation during the day (7:30 a.m., 11:30 a.m. and 3:00 p.m.).

Experimental procedure

The research was conducted in a silvopastoral system of mixed forage bank with three forage shrubs of the Colombian high tropic: *T. diversifolia*, *S. nigra* and *S. pyramidalis*. The SPS was established in 2016 in a total area of 240 m^2. The planting distance was one meter between plants and one meter between rows, with a total of 51 shrubs of each species. The evaluation period comprised the months from January to September, 2019, and corresponded to two well-defined climate seasons: a rainy season between January and May and a dry season from July to September.

At three regrowth ages (45, 60 and 75 days) manual pruning was performed, the shrubs were cut at a height of 70 cm over the soil level for *S. nigra* and *T. diversifolia,* and at 120 cm for *S. pyramidalis*.

Pruning consisted in a chiseled cut of fresh stems and leaves from each shrub; the forage was weighed in a precision scale and the data were tabulated for their later analysis (López and Santamaría, 2003).

From the plant material (leaves and fresh stems) 300 g were randomly harvested simulating grazing by cattle; the forage was chopped (stainless scissors) and macerated in a mortar until obtaining the plant sap (Suárez-Paternina *et al*., 2015). From the result of the maceration a small sample was taken with the aid of a dropper and it was placed on the prism of a digital refractometer and three readings were made, from which an average was obtained.

Determination of the nutritional value. The nutritional value was determined for each species, and in each evaluation cycle. During the shrub pruning 500 g of forage sample (leaves and fresh stems) were collected. Such samples were dried in a forced-air stove at 65 ºC during 72 h. The samples were analyzed at the Laboratory of Animal Nutrition of the Tibaitatá Research Center (Agrosavia) in Mosquera city (Cundinamarca), and crude protein (CP), neutral detergent fiber (NDF), non-structural carbohydrates (NSC), net lactation energy (NLE) and digestibility (DIG), were determined, through the near infrared reflectance spectroscopy (NIRS) technique, according to Ariza-Nieto *et al*. (2018).

Statistical analysis. For the data of soluble solids, biomass production and nutritional quality of the forage species, a variance analysis was carried out through the statistical software R. V.3.5.1., accompanied by a Tukey's mean comparison test ($p < 0,05$) for those variables that showed statistical differences.

Results and Discussion

Regarding the nutritional quality of the forage species, no statistical differences were observed for the evaluated fractions (table 1).

In the three shrubs the protein was reduced as the cutting age increased, which coincides with Naranjo and Cuartas (2011), who found in perennial forage plants that the protein content gradually decreased with their maturity.

Table 1. Nutritional composition of the forage species in different cutting ages.

Species	Cutting age, days	CP, %	NDF, %	DIG, %	NLE, Mcal kg DM^{-1}	NSC, %
	45	28,1	31,3	77,5	1,6	23,5
	60	27,2	33,1	76,5	1,6	23,1
T. diversifolia	75	23,4	37,1	72,5	1,5	23,4
	SE ±	3,0	1,6	2,7	0,06	2,23
	P-Value	0,546	0,075	0,448	0,453	0,991
	45	28,9	26,8	78,8	1,7	30,5
	60	25,7	30,4	77,0	1,6	37,9
S. nigra	75	25,2	27,3	76,4	1,6	33,5
	SE ±	2,4	1,1	2,07	0,05	2,24
	P-Value	0,572	1,140	0,703	0,722	0,405
	45	28,0	30,6	77,7	1,6	27,5
	60	24,3	32,0	74,9	1,6	29,2
S. pyramidalis	75	22,9	32,6	74,0	1,5	33,8
	SE ±	1,9	1,5	1,4	0,03	2,39
	P-Value	0,233	0684	0,242	0,222	0,738

CP: crude protein, NDF: neutral detergent fiber, DIG: digestibility, NLE: net lactation energy, NSC: non-structural carbohydrates.
Means with different letters in the columns differ among them according to Tukey's test ($p < 0,05$).

The CP values in *T. diversifolia* at 60 days (27,3 %) coincide with the report by Lezcano *et al.* (2012), who found values of 28,6 %. On the other hand, Cardona-Iglesias *et al.* (2019a) informed protein contents of 18,3 % for *T. diversifolia* at 75 days, lower than the one found in this study (23,3 %).

In *S. nigra* the highest CP value was observed at 45 days, followed by 25,7 % at 60 days; this last value coincides with the report for the Andean high tropic by Guatusmal-Gelpud *et al.* (2019) in plants harvested at 60 days.

For the case of *S. pyramidalis* the highest CP value was found at 45 days (27,98 %); in this regard, Cortés-Jojoa and Ramos-Obando (2018) found values of 22,7 % CP and catalogued this species as a forage resource with a protein of good nutritional value for livestock species.

Regarding NDF no significant differences were shown for the three species; however, it was found to increase proportionally with regards to the cutting age. For *T. diversifolia*, the NDF varied between 31,3 and 37,1 %, which coincides with the report by Ápraez *et al.* (2014), about the characterization of *T. diversifolia* at 75 days (pre-flowering), where 39 and 41 % of NDF were reported. Cardona-Iglesias *et al.* (2017) found for *T. diversifolia* 39 % of NDF at 70 days of harvest, and a higher value of fiber at that age, with regards to lower harvest ages.

The highest percentages of NDF for *S. nigra* and *S. pyramidalis*, respectively, was obtained, at 60 and 75 days after cutting. These values were within the recommended fiber range in dairy cows, which stimulates rumination, without decreasing the passage rate at rumen level (Medina *et al.*, 2009).

The DM digestibility indicated a homogeneous performance for the three forage shrubs (table 1); there was an inversely proportional relation between digestibility and cutting age (at higher age, lower digestibility), performance that coincides with the description made by Espinoza-Canales *et al.* (2017), who state that, at higher plant age, the lignin fraction in the cell wall becomes higher, which reduces digestibility in pastures and forages. According to the report by Van Soest (1994), the obtained digestibility values for the forage species are considered optimum, because it could be expected that large quantity of nutrient fractions are utilized by the animal.

The estimation of the content of net lactation energy (NLE) and of non-structural carbohydrates can provide an idea of the energy content of the forage and of its effect on milk production (Téllez-Sanabria and Mendoza-Brand, 2014). The shrubs did not show significant differences regarding NLE. The values were higher than 1,15 Mcal kg

DM-1 of NLE, recorded as average by the basis grass *C. clandestinus* of the dairy systems of the Colombian high tropic (Marais, 2001). NSCs are considered as a source of fast available energy for microorganisms at rumen level; their content is related to the utilization of other nutrients such as protein, and with a higher milk synthesis (Correa *et al.,* 2019).

The content of soluble carbohydrates of forages is determined by different factors related to photosynthesis, respiration, and nutrient distribution and can be modified in correspondence with the physiological status of the forage, as long as the climate conditions are not a limitation (Montoya *et al*., 2004).

The concentration of soluble solids for *T. diversifolia*, *S. pyramidalis* and *S. nigra*, at different cutting ages is shown in figures 1a, 1b and 1c; in the three species the highest numerical value of soluble solids was recorded at 45 days. Nevertheless, it did not differ from the one obtained at 75 days; no difference was found either between the values at 75 and 60 days.

The lowest numerical value of soluble solids for the three forage plants occurred at the age of 60 days (*T. diversifolia*-7,7; *S. pyramidalis*-5,6 and in *S. nigra*-12,1 %). In general, the species showed a potential in concentration of soluble solids over the grasses traditionally used to feed cattle in the Colombian high tropic, such as kikuyu (*C. clandestinus*) for which average values of 2,1 % are reported (Rojo *et al*., 2011).

The species *S. nigra*, which showed good potential regarding its content of soluble solids at the three ages, should be highlighted; besides, this species also had a high content of NLE (higher than or equal to 1,6 Mcal kg DM-1 and NSCs higher than 30 % at all ages (table 1). Regarding the optimum energy content of *S. nigra*, Carvajal-Salcedo and Cuesta-Peralta (2016) sustain that its forage could constitute an important energy source of energy at rumen level, which would improve the degradation of structural carbohydrates.

In the animal husbandry of the high and low tropic of Colombia, farmers use different grass species to feed cattle and look for synchrony between

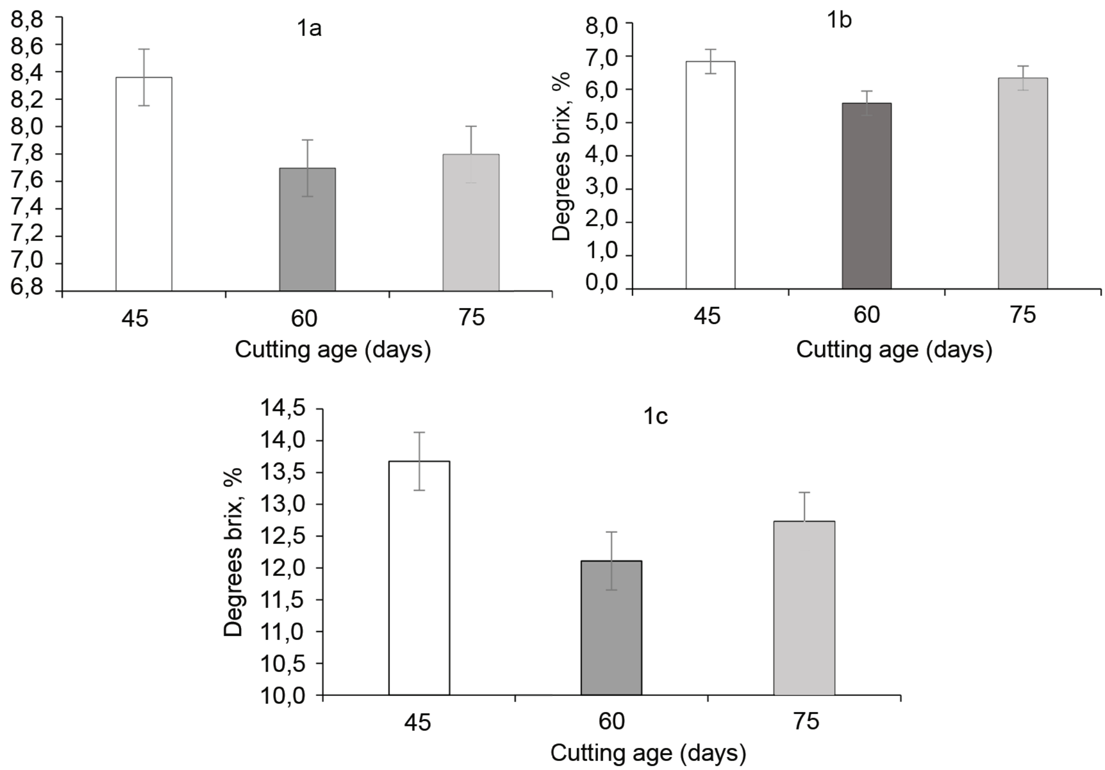

Figure 1. a. Soluble solids of *T. diversifolia*, b. Soluble solids of *S. pyramidalis*, and c. Soluble solids of *S. nigra* evaluated at three cutting ages.

Vertical bars represent confidence intervals at 95 % and different letters show significant differences according to Tukey ($p < 0,05$).

the energy and protein of the diet, which maximizes animal productivity. Suárez-Paternina *et al*. (2015), in grasses of the Colombian low tropic report for such species as *Brachiaria. híbrido* cv. Mulato II, star grass (*Cynodon nlemfuensis* Vanderyst) and Guinea grass [*Megathyrsus maximus* (Jacq.) cv. Mombasa] concentrations of soluble solids of 9,0, 8,2 and 7,1 %, respectively, similar values to the one found in this work for *T. diversifolia* (fig. 1a), which is a forage plant that adapts very well in the low as well as the high tropic (Londoño *et al.,* 2019).

Figures 2a, 2b and 2c show the percentage of soluble solids of *T. diversifolia*, *S. pyramidalis* and *S. nigra,* respectively, at three cutting ages and at different hours of day. For *T. diversifolia* there was no difference in the sampling hours, for the ages of 45 and 60 days and at 75 days at 3:00 p.m. the highest value of soluble solids was recorded (p < 0,05).

For *S. pyramidalis* there was no effect of the sampling time for any harvest age, and in *S. nigra* there were no differences at 45 days; nevertheless, at 60 days the highest (p < 0,05) concentration of soluble solids was recorded at 3:00 p.m., and at the age of 75 days there was no difference between the results of 7:30 a.m. and 11:30 a.m.; while the soluble solids of 3:00 p.m. differed from the ones found at 7:30 a.m.

Velásquez *et al.* (2003) did not find difference when evaluating during several times of day (6, 9, 12, 15 and 18 h) the concentration of soluble solids in tropical forage grasses such as *Brachiaria decumbens* Stapf., *Hyparrhenia rufa* (Nees) Stapf., *M. maximus* Jacq. and *Paspalum notatum* Flugge. Meanwhile Suárez-Paternina *et al.* (2015) found in the pasture *C. nlemfuensis*, higher quantity of soluble solids in the sampling hours of the noon and afternoon, compared with the morning times.

In this regard, Arriaga *et al*. (2014) sustain that the variation of photosynthates along the day depends on the photosynthetic rate of the plant; in the days when solar radiation is constant (cloudy days) little variation in the soluble solids would be expected, with regards to the days with marked solar radiation towards the noon and afternoon.

According to Rojo and Montoya (2011) generally the highest photosynthetic rate in the forages appears in the afternoon hours, for which grazing systems should be designed for the animals to consume the highest quantity of forage in those hours, and to utilize a higher energy content of the plants.

Gaviria *et al.* (2015) stated that perennial forage plants and grasses show a higher content of non-structural carbohydrates (NSC) compared with grasses; the nutritional value of this type of

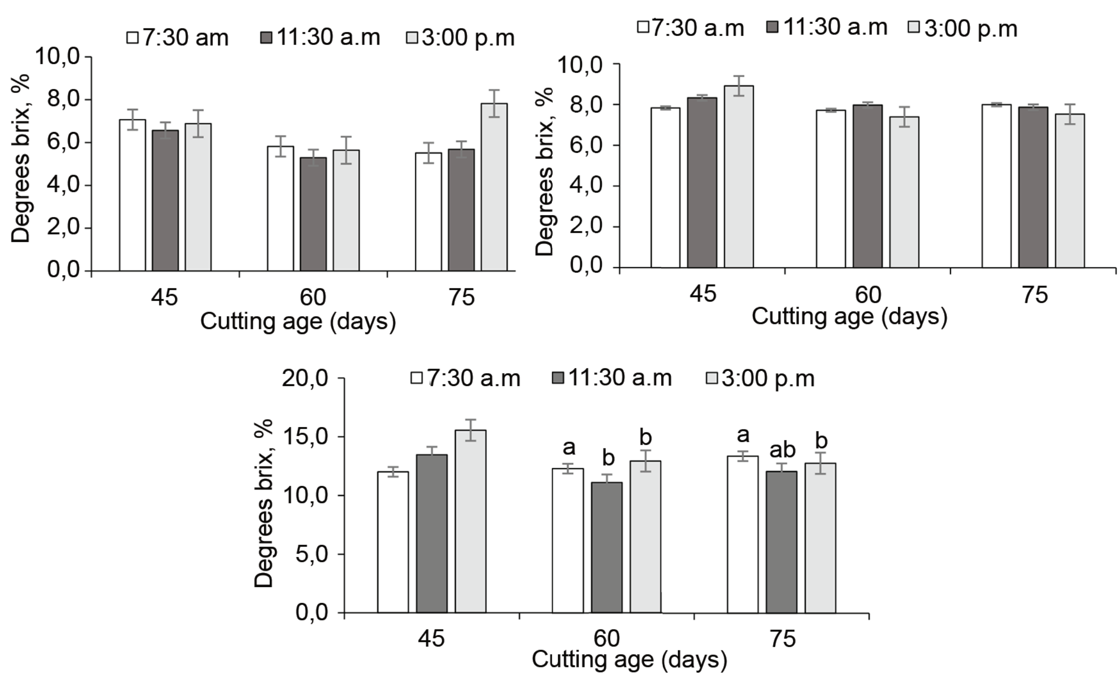

Figure 2. a. Soluble solids in *T. diversifolia*, b. *S. pyramidalis* and c. *S. nigra*.

Vertical bars represent confidence intervals at 95 % and different letters indicate significant differences according to Tukey (p < 0,05).

carbohydrates is due to the fact that they are a fast-available nutritional source for the growth of rumen microorganisms (Castillo-Lopeza and Domínguez-Ordóñez, 2019). Non-structural carbohydrates are related to the concentration of soluble solids in the plant (Rojo and Montoya, 2011); in this study the content of NSCs (table 1) is considered high (>20 %) for all the forage species and is higher than that of the pastures traditionally used to feed cattle, such as kikuyu (*C. clandestinus*), which shows average NSCs of 10,5 % in the Colombian high tropic (Vargas-Martínez *et al.,* 2018), or such as perennial ryegrasses (*Lolium perenne* L.) with NSCs of 17 % in the Nariño department, Colombia (Castro-Rincón *et al.,* 2019).

Taking into consideration that one of the main limitations in cattle husbandry systems of the Colombian high tropic, is the low content of NSCs in the grasses, woody forage species could be a strategy to improve the energy content of the diets, promote a better use of nutrients such as protein in the animal, with which productivity is maximized and the emission of nitrogen compounds to the environment decreases (Londoño *et al.,* 2019, Cardona-Iglesias *et al.,* 2019b).

For the variable biomass content [(kg of green forage (shrub)] significant differences ($p < 0,05$) were observed in the cutting ages and an increase of biomass was noticed at higher harvest age in the three shrubs. At 75 days *S. pyramidalis* showed the highest values of fresh forage, with an average of 8,8 kg of GF shrub^{-1} followed by *T. diversifolia* and *S. nigra* with mean values of 5,8 and 2,6 kg of GF shrub^{-1}, respectively (fig. 3).

In a study conducted by Guatusmal-Gelpud *et al.* (2020), productions of 5,29 kg at 8 months and at 15 months, 17,68 kg of GF plant^{-1}, were found in *S. pyramidalis*; while in this study, with cuttings at lower age a higher yield was obtained for the grren biomass (4,1; 6,7 and 8,8 kg of GF shrub^{-1} at ages of 45, 60 and 75 days of cutting respectively) and compared with the other species it was the one that showed a higher yield.

The yield of *T. diversifolia* in this study for the age of 45 days was 133 t of green forage per year, lower than the one reported by Nieves *et al.* (2011), who obtained 250 t; the highest value of biomass in another was 2,58 kg (85 days); 1,73 kg (60 days) and 0,82 kg of GF shrub^{-1} at 30 days (Lugo-Soto *et al.*, 2012). Compared with the above-mentioned study, in this work higher values of green forage production were found: 1,9; 4,0 and 5,8 kg of GF shrub^{-1}, at 45, 60 and 75 days after cutting, respectively, and both coincided in that as the cutting age increased, there was an increase in green forage production.

In this sense, Ruíz *et al.* (2014) stated that *T. diversifolia* at ages between 70 and 90 days shows a high biomass percentage and also allows higher utilization of the nutrients.

S. nigra had a yield of 8 626, 12 260 and 26 077 kg of GF ha^{-1} per cut at 45, 60 and 75 days, respectively; in a study three harvest ages were evaluated in *S. nigra* (90, 120 and 150 days) and a yield of 18 960, 43 640 and 48 600 kg GF ha^{-1}, respectively, was found; which indicates that 150 days is the best cutting age for the high biomass production (FABEGAN, 2015). Nevertheless, Chamorro and Barreto (2005) stated that the propitious cutting age for *S. nigra* is at 60 days

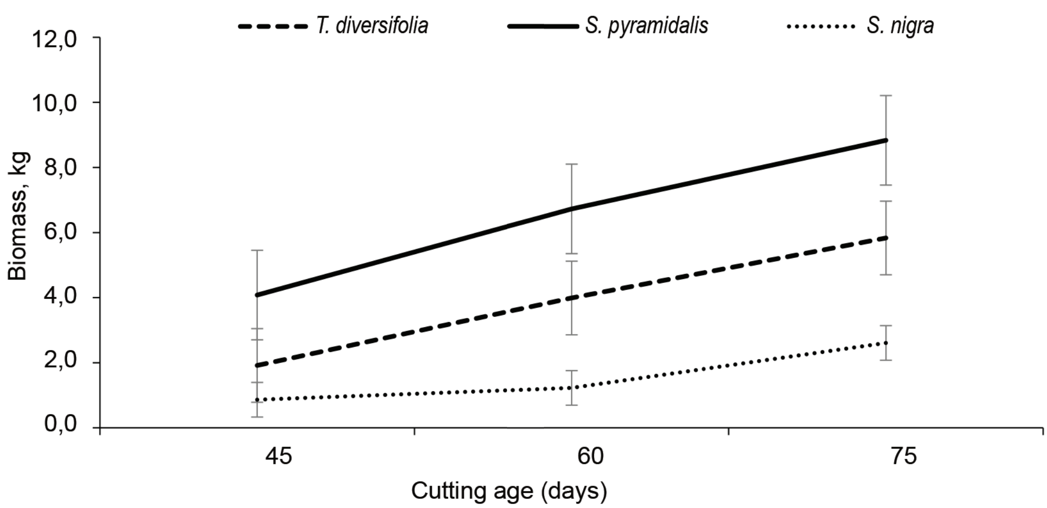

Figure 3. Biomass production of three forage shrubs at three cutting ages.

taking into consideration that the biomass production is 9,8 t DM ha^{-1} $year^{1}$ at a distance of 1 m x 1 m.

Conclusions

This study proved the nutritional potential shown by the forage species *S. nigra*, *T. diversifolia* and *S. pyramidalis*, due to their concentration of soluble solids, for which they could be used as part of the diet of ruminants in productive systems of the Colombian high tropic. In addition, a decrease was observed in the concentration of soluble solids as harvest aged in the three species increased.

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Authors' contribution

- María Fernanda Urbano-Estrada: Substantial contributions to the conception of the work; data acquisition, analysis or interpretation for the work.
- Juan Leonardo Cardona-Iglesias: Conception of the work; data acquisition, information analysis and manuscript writing.
- Edwin Castro-Rincón: Paper writing, critical revision, information analysis.Conflict of interests

The authors declare that there are no conflicts of interests among them.

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