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AGRONOMIC EVALUATION OF TROPICAL GRASSES ASSOCIATED WITH *Canavalia brasiliensis* IN DRY TROPIC

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ABSTRACT

Livestock production in some tropical regions is characterized by the use of naturalized forages in extensive management with low production rates. The use of improved grass-legume associations represents a sustainable intensification opportunity for this type of agroecosystems. The objective was to evaluate the production in establishment of forage associations for grazing systems in the dry tropics of Colombia. In a randomized complete block design with slope as the block factor and experimental units of 2700 m^2 with four replications, the agronomic and nutritional quality characteristics of six treatments were compared: *Urochloa* hybrid cultivar Mulato II, *U. brizantha* cultivar Toledo and *Megathyrsus maximus* cultivar Mombasa, established alone or associated with *Canavalia brasiliensis*, against the control *Dichantium aristatum*, a naturalized forage of the region. Mulato II, Toledo and Mombasa alone and in association showed greater ($p \leq 0.05$) vigour, height, cover and forage production than the control. Mombasa produced 10.7 Mg ha^{-1} MS (Megagrams of dry matter per hectare), exceeding ($p \leq 0.05$) by 74, 53 and 84 % that were recorded in Mulato II, Toledo and control, respectively. *C. brasilienses* promoted higher productivity in the association with Mulato II and improved nutritional characteristics in the associations with Toledo and Mombasa compared to specific monocultures and the control. The improved grasses alone or associated with *C. brasiliensis* were a better forage option than *Dichantium aristatum*. It was concluded that *M. maximus* and *Urochloa* hybrid associated with *C. brasiliensis* are relevant forage options for agroecologically similar regions to the Colombian dry tropics.

Keywords: forage association, legumes, *Urochloa* hybrid Mulato II, *Urochloa brizantha* Toledo, *Megathyrsus maximus* Mombasa, tropical livestock.

INTRODUCTION

Livestock contributes substantially to improving rural livelihoods and meeting socioeconomic needs for the population of the world, particularly in developing countries (Makkar, 2016). In Colombia, this sector contributes 1.45 % of the national gross domestic product and generates about 6 % of jobs in the country (FEDEGAN, 2017). However, despite its economic importance, it is an activity questioned for productive performance and environmental impact. More than one third of land area in Colombia is covered by pasture for cattle grazing and the carrying capacity is 0.60 livestock units per hectare, which shows the low production of Colombian livestock systems, typical of the tropics (Lerner *et al*., 2017); this makes it necessary to implement sustainable intensification strategies in those systems (Rao *et al.*, 2015; Lerner *et al*., 2017).

In tropical livestock production systems, feeding is essentially based on pasture, which is considered to have low nutritional value and large seasonal variations in forage quantity and quality (Boval *et al.*, 2015). In these systems during the dry season, the availability of dry matter decreases, as well as the levels of crude protein, minerals and some vitamins in forages and as a result productivity is reduced (Murgueitio *et al.*, 2015). Pasture-based systems are likely to be more affected by climate change, due to their dependence on feed quality and availability, where changes in temperature and variations in precipitation are critical factors for production (Rojas-Downing *et al*., 2017). The use of improved species (grasses and legumes) in mixed production grasslands is an important strategy to increase the resilience of agroecosystems to drought and flooding associated with climate change, relative to native or naturalized plants (Rao *et al*., 2015).

Multipurpose forage legumes such as *Canavalia brasiliensis* are promising species evaluated for their potential in the tropics, due to improving soil fertility or increasing animal production (Douxchamps *et al.*, 2014; Garcia *et al.*, 2018). The mixture of legumes and *Urochloa* or *Megathysus* species in pastures is expected to improve production and nutritional quality for tropical livestock systems. These grasses were the first products of the selection and improvement of forage grasses conducted by the International Center for Tropical Agriculture (CIAT) in Colombia and are of importance for regions such as Sub-Saharan Africa, Latin America and the Caribbean (Rao *et al*., 2015; Maass *et al*., 2015).

Studies comparing these forages in association with legumes in large-scale trials are few (Pérez-López and Afanador-Téllez, 2017; Martínez-Mamian *et al*., 2020). Therefore, it is necessary to continue with the evaluation of these associations in a larger area and coverage; also, from their establishment to evaluate the feasibility of implementation in efficient production systems that would offer solutions to producers in critical times as an option to improve and enhance livestock farming.

Under the hypothesis that the association of *Canavalia brasiliensis* with improved grasses can increase the production and nutritional quality of these species and be an alternative for grazing systems compared to naturalized forages; the objective of the research was to evaluate the vigour, production and forage quality in the establishment of forage associations comparing them with naturalized forages, in order to define forage alternatives for grazing systems for regions with agroecological conditions similar to the dry tropics of Colombia.

MATERIALS AND METHODS

Study area

The research was conducted in the municipality of Patía (Cauca, Colombia) located at 02° 28′ 01.8′′ N and 076° 33′ 01′′ E at 550 m average altitude. The area has a bimodal rainfall distribution (Figure 1). During the study in the second rainfall period (October to January) the accumulated precipitation was 829 mm, and the average temperature was 27 °C (IDEAM, 2017). Prior to forage establishment, soil samples were taken at 20 cm depth and their composition was determined: pH= 6.58; Ca and Mg= 18.19 and 9.43 cmol kg^{-1} and P-rayII (mg kg^{-1}) = 4.97

Experimental material

The forage material was *Urochloa brizantha* cultivar (cv) Toledo CIAT 26110, *Urochloa* hybrid cv Mulato II- CIAT 36087, *Megathyrsus maximus* cv Mombasa CIAT 6962 and *Canavalia brasiliensis*- CIAT 17009. These species were selected for their promising results as forage alternatives for the tropical forage program under the International Center for Tropical Agriculture (CIAT) and Nutrifaca research group of the Universidad del Cauca. Those same institutions supplied the seeds.

Treatments

The treatments evaluated were six forage arrangements and a naturalized forage from the region considered as a control: *Urochloa* hybrid cv. Mulato II; *U. brizantha* cv. Toledo; *Megathyrsus maximus* cv. Mombasa, alone and in association with *Canavalia brasiliensis* and *Dichantium aristatum* cv. Angleton alone (control), in an area of 8.6 ha.

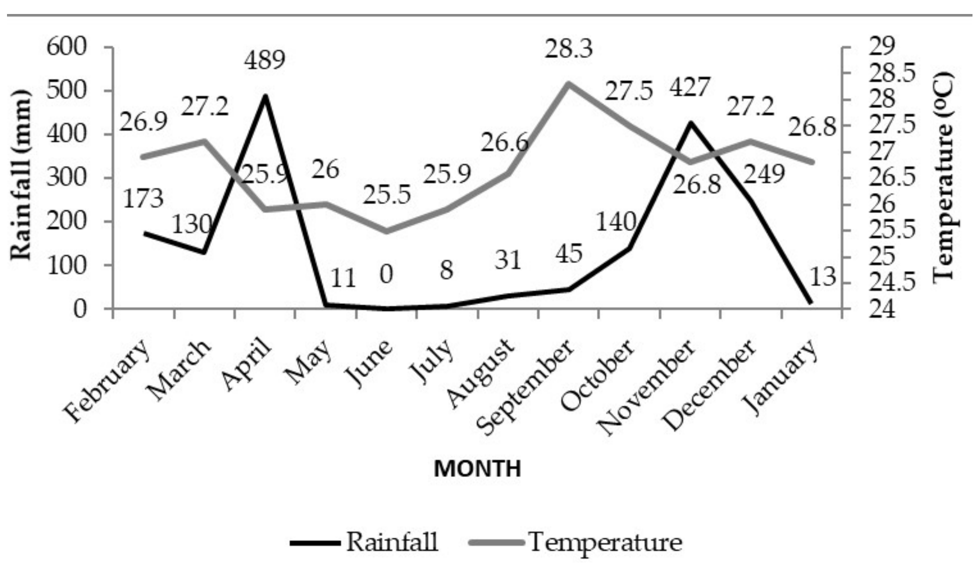

Figure 1. Climatic conditions in 2016-2017 (weather station of Patía (Cauca), Colombia).

Sowing and management of the establishment

Soil preparation was carried out with conventional tillage and an amendment (Calfos, 20 % P_2O_5 and 28 % CaO) was incorporated at a dose of 500 kg ha^{-1}, with the objective of increasing the available phosphorus in the soil and improving the Ca:Mg ratio to a value of 2:1. The grasses were manually sown, using 8 kg of seed ha^{-1} for Toledo and Mulato II and 6 kg for Mombasa, quantities determined by the cultural value and amount of pure viable seed of each species (Peters *et al*., 2011). For the control, *Dichanthium aristatum* (Angleton), no seed was used and only sprouting was expected after soil preparation, a common practice in the region of the study.

Canavalia brasiliensis was sown at 8.5 kg of seed ha^{-1}, for a sowing density of 10 000 plants per ha. For the control of broadleaf weeds and cyperaceae (*Cyperus rotundus*), in those treatments that did not incorporate legumes, chemical control was applied with Tordon XT® (Picloram + 2, 4-D) at a dose of 3 L ha^{-1}.

Variables evaluated

For the evaluation of the different agronomic variables, the methodology for type B regional trials of the International Network for the Evaluation of Tropical Pastures (RIEPT; Toledo, 1982) was adapted. At week 12 of the establishment stage; time when forages are fully established and under specific conditions of animal load and occupancy time are subjected to a first grazing (Gutierrez *et al*., 2018), the variables vigour, coverage, height, presence of pests and forage production were measured as follows:

Vigour

Vigour was evaluated on the basis of plant growth, health and development, stem thickness, quantity and colour of leaves produced. Characterized on a scale of 1 to 5; 1 the worst and 5, excellent.

Coverage

At five random points in each treatment, a 0.25 m^2 (0.50 x 0.50 m) frame was dropped and the apparent proportion in which species covered this area was observed. Values were recorded within the range of 0 to 100 % per m^2.

Plant height

Five plants were randomly selected in each treatment and their height (cm) was recorded from the ground to the highest point of the plant, without stretching and without counting inflorescences. The average per treatment was used for the analysis.

Presence of pests (foliage stalks) and diseases

The material was evaluated and classified according to damage on a scale of 1 to 4; where: 1, presence; 2, slight damage; 3, moderate damage; and 4, severe damage.

Forage production

A 0.25 m^2 (0.5 x 0.5 m) frame was randomly thrown 5 times in each treatment and the forage within it was cut at a height of 20 cm. Subsequently, a precision balance was used (vibra® AJ-12KE) to weigh the total green forage per treatment and a subsample of 200 g was taken to determine the dry matter (MS) content by oven-drying (RIOSSA® HCF-82 D) with controlled ventilation at 72 °C average temperature. In the treatments with *C. brasiliensis*, the grass:legume ratio observed in regard to the total biomass produced was 80:20, 70:30 and 65:35, in Mulato II, Toledo and Mombasa, respectively, ratios that were preserved at the time of sampling for dry matter and subsequent chemical analysis.

Forage quality analysis

At CIAT's forage laboratory, organic matter (MO) was determined according to AOAC (1990), crude protein (PC) by the Kjeldahl method (AOAC, 1990), neutral detergent fibre (FDN), acid detergent fibre (FDA) and *in vitro* dry matter digestibility (DIVMS) with Ankom Technology (2005).

Experimental design and statistical analysis

The six treatments and a control were evaluated in a randomized complete block design, with four replicates. Each experimental unit had an area of 2700 m^2 for a total of 8.6 ha, with slope as the block factor.

IBM SPSS v. 23.0 was used for the analysis of variance, with the following model:

$$y_{ij} = \mu + \tau_i + \beta_j + \varrho_{ij}$$

where: y_{ij}, response variable; μ, overall mean; τ_i, effect of treatments; β_j, effect due to block; and ϱ_{ij}, residual variation. Afterwards at significance, the Tukey's multiple comparisons test was performed with $p \leq 0.05$.

RESULTS AND DISCUSSION

Vigour, height, coverage and presence of pests

The improved forages showed higher vigour ($p \leq 0.05$) compared to the control (*Dichantium aristatum*) (Table 1). An average height of 84.7 cm was found and the treatments with Mombasa had higher heights ($p \leq 0.05$) than Mulato II and the control, treatments with an average height 44.8 cm lower than the mean for this variable. Toledo alone and in association and Mulato II in association presented intermediate heights ($p > 0.05$) with values close to this mean.

The results for vigour and height indicate that the improved forages adapted to the agroecological conditions of the study area (pH, 6.5; average height 550 m and 829 mm of precipitation during the evaluation period). According to Gutiérrez *et al.* (2018) species evaluated here are adapted to soils with medium fertility, pH (4.5 to 8), altitudes between 0 and 1800 m and rainfall of 1000-3500 mm per year.

Table 1. Mean values for the agronomic variables vigour, height, cover and presence of pests.

Treatment	Vigour (1 to 5)	Height (cm)	Coverage (%)	Pests (1 to 5)
Mulato II	3.83a	56.6b	41.3cd	1.3ab
Toledo	4.08a	81.2ab	73.5ab	1.3ab
Mombasa	4.73a	134.7a	85.9a	1.1b
Mulato II + *C. brasiliensis*	4.00a	69.8ab	54.2bc	1.6a
Toledo + *C. brasiliensis*	4.25a	84.8ab	76.3ab	1.7a
Mombasa + *C.brasiliensis*	4.67a	132.8a	88.8a	1.5a
Control†	1.25a	33.0b	24.2d	0.3c
EEM¶	0.558	29.509	10.547	0.201

a,b,c,d: means in the same column with different letters are statistically different ($p \leq 0.05$). †Control: *Dichantium aristatum*; ¶EEM: standard error of the mean.

Differences in height between cultivars are attributed to the growth type of each species. The performance of Mombasa, which alone and in association showed an average height 49 cm greater than the general average, is noteworthy. This cultivar is characterized by erect growth, reaching heights between 1.5 to 3 m, while Toledo and Mulato II, show semi-erect to erect and semi-erect to decumbent growth and a height potential of 1.6 and 1 m respectively (Peters *et al*., 2011).

Ortega-Aguirre *et al*. (2015) in the dry tropics of Mexico, at 90 days of agronomic evaluation of the same entries evaluated here, recorded heights of 60.2, 80.3 and 69.6 cm for Mulato, Toledo and Mombasa, respectively. Similar values for Mulato II and Toledo in monoculture, but lower than the 133.8 cm on average presented for Mombasa, thus indicating a better adaptation of this cultivar to the conditions of the Colombian dry tropics. In the same area of this study, Carvajal-Tapia *et al.* (2021) reported an average height of 130 cm for a collection of 130 accessions of *Megatyrsus maximus.* Those authors mentioned the good agronomic development of this species under the conditions of the region.

The association of *C. brasiliensis* with improved grasses showed no significant evidence of an effect of legume incorporation on the growth of these species when compared to their monocultures. This corroborates what was reported by Pérez- López and Afanador-Téllez (2017) in the Eastern plains of Colombia, who at evaluating forage mixtures with *Pueraria phaseoloides* (Kudzu) found no increase in the height of different cultivars of the genus *Brachiaria* (*Urochloa*) in association with the legume in regard to grass monocultures.

Mombasa and Toledo alone and in association with *C. brasiliensis,* presented higher cover ($p \leq 0.05$) than that found for Mulato II alone and the control, treatments with a soil cover lower than 50 %. Inferior cover ($p \leq 0.05$) of Mulato II with *C. brasiliensis* was found compared to the cultivar Mombasa alone or in association.

The low coverage of the treatments incorporating Mulato II may have occurred because the experiment was established at the beginning of the rainy season (October) after a dry period of 5 months (Figure 1), then the soil did not have enough moisture for the emergence of seeds. Mulato II seeds, unlike Toledo and Mombasa seeds, require more moisture. Argel *et al.* (2007) indicated that the commercial seed of Mulato II is coated or pelletized and the substances used in this process are hygroscopic in nature and if seeds do not obtain adequate moisture, they present problems of emergence, something that occurred in this research and caused a delay in their establishment, allowing the increase of weeds, thus affecting the coverage of the species of interest.

Pérez-López and Afanador-Téllez (2017) reported coverages of 56.8 % for Mulato II and on average 89.97 % for *Brachiaria* (*Urochloa*). The results recorded here are below those reported by those authors, which is attributed to the fact that in this research recently established pastures were evaluated and due to the growth in clumps of these species, there was not a total soil covering at that stage. However, this situation tends to improve due to the rooting capacity of the stems once they are subjected to trampling by grazing animals (Peters *et al*., 2011).

The association of *Canavalia brasiliensis* with Mulato II favoured an increase of 12.9 % in coverage compared to the monoculture of this grass and an increase of 2.8 % when associating this legume with Toledo in regard to the pasture with only Toledo. The flighty, creeping growth habit of *C. brasiliensis* allowed it to cover a larger area, characteristic of a multipurpose forage used also as a coverage crop (Douxchamps *et al*., 2014). These results corroborate what was found by Pérez-López and Afanador-Téllez (2017), who reported higher coverages in the association of *Brachiaria* with Kudzu in regard to *Brachiaria* monocultures.

A lower presence of pests was found in the control ($p \leq 0.05$) but those treatments that incorporated the legume were affected to a greater extent by pests. This is due to the susceptibility of *C. brasilienses* to attack by leaf cutters (Peters *et al*., 2011). However, this did not impact the forage production of the treatments.

The performance of the *Dichantium aristatum* control in all variables except pest damage was below that of the improved forages. The establishment tasks, such as weed control and soil preparation, caused slow regrowth and thus a delay in development compared to the other forages evaluated.

Forage production

Mombasa alone or in association with *C. brasiliensis*, presented a similar production ($p > 0.05$) to Mulato II in association, but higher ($p \leq 0.05$) in regard to the other treatments (Table 2). Mulato II and Toledo alone and in association showed no difference ($p > 0.05$) in forage production. The control recorded the lowest ($p \leq 0.05$) yield.

It is possible that the moisture limitations that affected the initial cover of Mulato II had an impact on production by generating a lower amount of biomass per unit area. García *et al.* (2018) in the dry corridor of Central America, also reported low yields for this cultivar compared to Toledo and Mombasa, explained by lower adaptation to the dry conditions of the tropical ecosystem.

Table 2. Agronomic variables (forage production).

Treatment	MS† (Mg ha^{-1})
Mulato II	2.74bc
Toledo	4.98b
Mombasa	10.95a
Mulato II + *C. brasiliensis*	7.21ab
Toledo + *C. brasiliensis*	5.60b
Mombasa + *C.brasiliensis*	10.52a
Control¶	1.72c
EEM §	1.53

a,b,c: Means with different letters are statistically different. ($p \leq 0.05$). † MS: dry matter production; ¶Control: *Dichantium aristatum*; §EEM: standard error of the mean.

In Colombia, under a silvopasture system, where the incorporation of trees favours the regulation of the microclimate for the pasture; Martínez-Mamian *et al.* (2020) reported a production of 3.5 Mg ha^{-1} MS for the Cayman cultivar (also a hybrid of *Urochloa*), which evidences the potential of these hybrids for forage production in this type of conditions. In turn, in regions with higher rainfall such as the humid tropics of Ecuador, Garay *et al.* (2017) reported higher yields for Mulato II (6.57 Mg ha^{-1} MS). Generally, this grass presents better development under similar agroecological conditions (Argel *et al.*, 2007).

The production of cv. Toledo in monoculture was lower than that reported in the literature for the region, but similar when compared to production under association. Ortega-Aguirre *et al*. (2015) in the dry tropics of Mexico report a production of 5.6 Mg ha^{-1} MS and Garay *et al*. (2017) in the humid tropics of Ecuador report 6.27 Mg ha^{-1} MS for this cultivar. These differences can be explained by the conditions of each experiment and location, in the case of Mexico this production corresponds to a time of 120 d and in Ecuador there was a higher rainfall, which may have favoured the higher production of this location.

The productive performance of Mombasa alone and in association was outstanding, with an average dry matter production of 10.7 Mg ha^{-1}, which was 74, 53 and 84 % higher than those found for Mulato II, Toledo and the control, respectively. In the study area, Mombasa has an excellent development and higher forage yields compared to other forage materials of the *Urochloa* genus such as Toledo and Cayman (Martínez-Mamian *et al*., 2020). A performance favoured by its adaptability to a wide range of conditions, tall growth habit and greater quantity of leaves (Peters *et al*., 2011), which explains these differences.

The increase in production with the incorporation of improved forages in regard to naturalized forages has been observed in another research (Garcia *et al*., 2018). The slow establishment of *D. aristatum* had an impact on its low yield and, in turn, this species has low-biomass production potential due to its morphological structure, Peters *et al*. (2011) described the species with smaller size than 5 to 60 cm; unlike Mulato II, Toledo and Mombasa, which are cultivars with greater height. This variable is linearly related to forage production, the greater the height, the greater the biomass of leaves and stems due to their elongation (Ruggieri *et al*., 2020). This corroborates that the higher yield recorded for cv. Mombasa is related to size.

The association with *C. brasiliensis* was positive for Mulato II with an increase of 64 % in production in this association in regard to the monoculture of this grass, and the same effect, although not significant, was observed with Toledo, with an increase of 13 % in the production of the association compared to the monoculture.

Valles-de la Mora *et al.* (2017) identified a 69 % higher production in the Toledo-*Cratylia argentea* association in regard to Toledo alone and Villegas *et al.* (2020) determined that the integration of legumes in tropical pastures can increase biomass production of *Urochloa* grasses by approximately 74 %; a value similar to that found in this research with Mulato II in association. There are several mechanisms by which this increase can be generated, among which stand out the contribution of nitrogen to the system as a result of the fixation of atmospheric N_2 by the legume, the capacity of legumes to increase the availability of this nutrient for themselves and for nearby plants, and the dry matter contribution of legume biomass (Lüscher *et al.*, 2014).

Perhaps this last factor was the determining factor for the increase observed in the association with Mulato II, where growth in the form of clumps and lower height possibly limited the competition with the legume. This would allow the legume to develop better and contribute more biomass to the system, in addition to directly favoured nitrogen fixation, since dry matter production also depends on nitrogen (Lüscher *et al.*, 2014). This behaviour is reported for forages from temperate zones, where *Tripholium spp*, influences on biomass production (green and dry) of forage grasses (Fonseca- López *et al*., 2020).

The above would explain why the same effect was not observed in the Mombasa+ *C. brasiliensis* association as with Mulato II. The Mombasa cultivar is characterized by earliness and erect growth (Peters *et al.*, 2011), which may have interfered with the light interception of the legume, which during the first days of establishment did not develop climbing habit (Peters *et al*., 2011) thus affecting the biomass production of the legume, also reducing nitrogen fixation gain.

Forage quality

Crude protein (PC) content increased between 10 and 24 % with the incorporation of *C. brasiliensis* compared to grass monocultures (Table 3). These increases can occur by different mechanisms, one of them is the atmospheric nitrogen fixed by the legume and absorbed by the grass, resulting in a contribution to the nutritive value of the pasture and the other is the PC content of the legume biomass contributed to the association (Lüscher *et al*., 2014). Since the PC contents were the product of the mixture of legume

Table 3. Mean forage quality values (g kg^{-1} MS).

Treatment	MO†	FDN¶	FDA§	PCþ	DIVMS¤
Mulato II	878.40	567.30	251.20	153.30	757.40
Toledo	922.48	689.22	384.76	104.28	614.00
Mombasa	918.03	716.40	426.20	90.50	608.57
Mulato II + *C. brasiliensis*	888.72	576.33	307.18	172.02	722.36
Toledo + *C. brasiliensis*	920.26	652.39	391.92	138.58	619.90
Mombasa + *C.brasiliensis*	918.97	668.54	403.06	115.40	614.65
Control††	925.40	702.20	390.30	122.80	640.90
EEM¶¶	7.06	22.474	23.525	10.738	22.840

†MO: organic matter; ¶FDN: neutral detergent fibre; §FDA: acid detergent fibre; þPC: crude protein; ¤DIVMS: *in vitro* dry matter digestibility; ††Control: *Dichantium aristatum*; ¶¶EEM: standard error of the mean.

and grass biomass, and 28 % of the total PC content corresponded to *C. brasiliensis,* a species characterized by a high PC content (19-25 %, Gutiérrez *et al.* 2018), these results are mainly attributed to the latter mechanism.

Similar to what was presented with PC, the association of the legume with lower quality forages such as Toledo and Mombasa, favoured a decrease in the fibre content and in turn an increase in the *in vitro* dry matter digestibility (DIVMS) in regard to the monoculture of these species, due to the effect of the biomass contributed by the legume. Pérez-López and Afanador-Téllez (2017) reported similar effect on digestibility in the association of grasses of the genus *Brachiaria* with Kudzu, regarding the pasture fertilized without incorporation of the legume. In turn, Valles-de la Mora *et al.* (2017) reported lower fibre contents in the association Toledo with *C. argentea* compared to Toledo alone. The same effect has been found in temperate zones, where *Tripholium spp* has positively influenced the nutritional quality of forage grasses (Fonseca-López *et al*., 2020). In the case of the association of Mulato II with *C. brasiliensis*, it only showed an effect on PC content.

Given the association of *C. brasiliensis* with Mombasa and Toledo, it was possible to obtain better quality in terms of PC and DIVMS in regard to the control, which was noticeable for PC and DIVMS values exceeding the cultivars monocultures. However, due to lower MS ha^{-1} production, the total amount of PC (g kg^{-1}) and digestible MS (g kg^{-1}) produced per hectare was lower than in the improved forages.

According to the NRC (2000), the PC requirements necessary for a growing animal when fed *ad libitum* are close to 13.5 %. Due to the association of *C. brasiliensis* with Toledo and Mombasa, a better supply of PC was allowed to meet these needs, which did not occur with the monoculture of these grasses. Mulato II was the only entry that, without the need for association, presented sufficient PC content to meet these requirements.

The quality of a forage depends on a set of factors such as species, plant part, time of year, climatic and soil conditions in each location. In this study, Mulato II stood out for its high nutritional value, in terms of high DIVMS and PC content.

Mulato II is a tetraploid hybrid with a high forage quality compared to other tropical grasses, due to its PC content between 8 and 16 % (Argel *et al*., 2007), digestibility that can be close to 70 % and FDN content of up to 64 % (Ortega-Aguirre *et al*., 2015). When comparing Mulato II with genotypes of *Urochloa brizantha*, Pérez- López and Afanador-Téllez (2017) reported a 5.6 % higher PC content and an 8.1 % higher digestibility in Mulatto II, with a fibre content 8.3 % less in this cultivar. Likewise, Ortega-Aguirre *et al.* (2015) report higher DIVMS and lower fibre contents in Mulato compared to Mombasa and Toledo.

The content of PC, fibre and DIVMS found for the Toledo and Mombasa monoculture are also in agreement with the literature. Ortega-Aguirre *et al.* (2015) reported PC and FDN contents of 9.55 and 70.79 % for Toledo and PC of 9.33 % and FDN of 67.4 % for Mombasa. Peters *et al.* (2011) found *in-vitro* digestibility between 55 and 70 % for Toledo and between 60 and 65 % for Mombasa, with crude protein contents of 7 to 14 % 10 to 14 % respectively. Likewise, Carvajal *et al*. (2021) in a collection of 130 accessions of *M. maximus* evaluated in the same region of this study, recorded a mean PC content of 10.7 % (8.48 to 11.3 %) and DIVMS of 58.65 % (55.29 - 61 %) similar to those presented by this species in this research.

CONCLUSIONS

The incorporation of *Canavalia brasiliensis* showed greater benefits in the association with *Urochloa* hybrid, a species that, due to its growth type and lower height, allowed a better development of the legume and thus a greater contribution of quality biomass to the association.

The plots with improved forage species in monoculture and associated species showed better overall agronomic performance than *Dichantium aristatum*, a traditional forage species naturalized in the area.

Megathyrsus maximus cv Mombasa and *Urochloa* hybrid associated with *Canavalia brasiliensis*, are a productive alternative for regions with agroecological conditions similar to the Colombian dry tropics; *M. maximus* for height, coverage and production and *U. hybrid* for forage production and quality.

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REFERENCES

ANKOM. 2005. Procedures (for NDF, ADF and *In vitro* true digestibility). Ankom Technology Method. http://www.ankom.com (Retrieved: April 2018).

AOAC (Association of Official Analytical Chemists). 1990. Official methods of analysis. (15th Edition) Helrick K (ed.); Association of Official Analytical Chemist, Washington DC. 771 p.

Argel PJ, Miles JW, Guiot JD, Cuadrado H, Lascano CE. 2007. Cultivar Mulato II (*Brachiaria* hybrid CIAT 36087): Gramínea de alta calidad y producción forrajera, resistente a salivazo y adaptada a suelos tropicales ácidos bien drenados. Centro Internacional de Agricultura Tropical (CIAT). Cali, Colombia. 11 p. https://repository.agrosavia.co/bitstream/handle/20.500.12324/19000/Ver_Documento_56236.pdf?sequence=3&isAllowed=y (Retrieved: April 2018).

Boval M, Edouard N, Sauvant D. 2015. A meta-analysis of nutrient intake, feed efficiency and performance in cattle grazing on tropical grasslands. Animal 9 (6): 973–982. https://doi.org/10.1017/S1751731114003279

Carvajal-Tapia JI, Morales-Velasco S, Villegas DM, Arango J, Vivas-Quila NJ. 2021. Biological nitrification inhibition and forage productivity of *Megathyrsus maximus* in Colombian dry tropics. Plant, Soil and Environment 67: 270–277. https://doi.org/10.17221/445/2020-PSE

Douxchamps S, Rao IM, Peters M, Van der Hoek R, Schmidt A, Martens S, Polania J, Mena M, Binder C, Scholl R. 2014. Farm-scale tradeoffs between legume use as forage versus green manure: The case of *Canavalia brasiliensis*. Agroecology and Sustainable Food Systems 38: 25–45. https://doi.org/10.1080/21683565.2013.828667

FEDEGAN (Federación Colombiana de Ganaderos). 2017. Cifras de referencia del sector ganadero colombiano. Federación Colombiana de Ganaderos. Bogotá, Colombia. https://estadisticas.fedegan.org.co (Retrieved: March 2021).

Fonseca-López D, Bohórquez-Masmela IA, Rodríguez-Molano CE, Vivas-Quila NJ. 2020. Efecto del periodo de recuperación en la producción y calidad nutricional de algunas especies forrajeras. Rev. Biotecnología en el sector Agropecuario y Agroindustrial 18: 135–144. https://doi.org/10.18684/BSAA(18)135-144

Garay JR, Joaquín S, Zarate P, Ibarra MA, Martínez JC, Gonzáles RP, Cienfuegos EG. 2017. Dry matter accumulation and crude protein concentration in *Brachiaria* spp. cultivars in the humid tropics of Ecuador. Tropical Grasslands-Forrajes Tropicales 5: 66–76. https://doi.org/10.17138/tgft(5)66-76

Garcia E, Siles P, Eash L, Van Der Hoek R, Kearney SP, Smukler SM, Fonte SJ. 2018. Participatory evaluation of improved grasses and forage legumes for smallholder livestock production in Central America. Experimental Agriculture 55(5): 776–792. https://doi.org/10.1017/S0014479718000364

Gutiérrez JF, Hering J, Muñoz JJ, Enciso K, Bravo AM, Hincapié B, Sotelo M, Urrea JL, Burkart S. 2018. Establecimiento y manejo de pasturas mejoradas–Algunos aspectos clave a considerar. Publicación CIAT No. 471. Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia. 20 p. http://hdl.handle.net/10568/96261 (Retrieved: March 2022).

IBM Corp. 2015. IBM SPSS Statistics for Windows, Version 23.0. Armonk, NY. 122 p.

IDEAM (Instituto de Hidrología, Meteorología y Estudios Ambientales). 2017.Consulta y descarga de datos hidrometeorológicos. Bogotá, Colombia. http://dhime.ideam.gov.co/atencionciudadano/. (Retrieved: June 2019).

Lerner AM, Zuluaga AF, Chará J, Etter A, Searchinger T. 2017. Sustainable cattle ranching in practice: moving from theory to planning in Colombia's livestock sector. Environmental Management 60 (2): 176–184. https://doi.org/10.1007/s00267-017-0902-8

Lüscher A, Mueller-Harvey I, Soussana JF, Rees RM, Peyraud JD. 2014. Potential of legume-based grassland-livestock systems in Europe: A review. Grass and Forage Science 69: 206–228. https://doi.org/10.1111/gfs.12124

Maass BL, Midega CAO, Mutimura M, Rahetlah VB, Salgado P, Kabirizi JM, Khan ZR, Ghimire SR, Rao IM. 2015. Homecoming of *Brachiaria*: Improved Hybrids Prove Useful for African Animal Agriculture. East African Agricultural and Forestry Journal 81 (1): 71-78. https://doi.org/10.1080/00128325.2015.1041263

Makkar HPS. 2016. Smart livestock feeding strategies for harvesting triple gain the desired outcomes in planet, people and profit dimensions: a developing country perspective. Animal Production Science 56 (3): 519–534. https://doi.org/10.1071/AN15557

Martínez-Mamian CA, Vivas-Quila NJ, Morales-Velasco S. 2020. Agronomic response of forage mixtures in a silvopastoral system in the Colombian dry tropics. DYNA 87: 80–84. https://doi.org/10.15446/dyna.v87n213.79900

Murgueitio E, Barahona R, Chará JD, Flores MX, Mauricio RM, Molina JJ. 2015. The intensive silvopastoral systems in Latin America sustainable alternative to face climatic change in animal husbandry. Revista Cubana de Ciencia Agrícola 49 (4): 541-554. http://www.redalyc.org/articulo.oa?id=193045908017 (Retrieved: March 2022)

NRC (National Research Council). 2000. Nutrient requirements of beef cattle. 7th ed. National Academy Press, Washington, DC. 469 p.

Ortega-Aguirre CA, Lemus-Flores C, Bugarín-Prado JO, Alejo-Santiago G, Ramos-Quirarte A, Grageola-Núñez O, Bonilla-Cárdena JA. 2015. Agronomic characteristics, bromatological composition, digestibility and consumption animal in four species of grasses of the genera *Brachiaria* and *Panicum*. Tropical and Subtropical Agroecosystems 18 (3): 291–301. http://www.revista.ccba.uady.mx/urn:ISSN:1870-0462-tsaes.v18i3.1935 (Retrieved: March 2021)

Peters M, L.H. Franco., A. Schmidt, y B. Hincapié. 2011. Especies forrajeras multipropósito: Opciones para productores del trópico americano. Cali, Colombia. http://ciatlibrary.ciat.cgiar.org/forrajes_tropicales/pdf/Books/Especies%20Forrajeras%20MultipropositoTropico%20Americano.pdf (Retrieved: April 2020).

Pérez-López O, Afanador-Téllez G. 2017. Comportamiento agronómico y nutricional de genotipos de *Brachiaria spp*. manejados con fertilización nitrogenada, solos y asociados con *Pueraria Phaseoloides*, en condiciones de la altillanura colombiana. Revista de la facultad de medicina Veterinaria y de Zootecnia 64 (3): 52–77. https://doi.org/10.15446/rfmvz.v64n3.68694

Rao I, Peters M, Castro A, Schultze-Kraft R, White D, Fisher MJ, Miles J, Lascano C, Blümmel M, Bungenstab D, Tapasco J. 2015. LivestockPlus–The sustainable intensification of forage-based agricultural systems to improve livelihoods and ecosystem services in the tropics. Tropical Grasslands-Forrajes Tropicales 3: 59–82. https://doi.org/10.17138/tgft(3)59-82

Rojas-Downing MM, Nejadhashemi AP, Abouali M, Daneshvar F, Al Masraf SAD, Herman MR, Zhang Z. 2017. Pasture diversification to combat climate change impacts on grazing dairy production. Mitigation and Adaptation Strategies for Global Change 23 (3): 405–431. https://doi.org/10.1007/s11027-017-9740-5

Ruggieri AC, Cardoso AdS, Ongaratto F, Casagrande DR, Barbero RP, Brito LdF, Azenha MV, Oliveira AA, Koscheck JFW, Reis RA. 2020. Grazing Intensity Impacts on Herbage Mass, Sward Structure, Greenhouse Gas Emissions, and Animal Performance: Analysis of *Brachiaria* Pastureland. Agronomy 10: 1750. https://doi.org/10.3390/agronomy10111750

Toledo JM. 1982. Manual para la evaluación Agronómica: Red Internacional de Pastos Tropicales (RIEPT). Centro Internacional de Agricultura Tropical (CIAT). Cali, Colombia, pp: 97-110.

Valles-de la Mora B, Castillo-Gallego E, Alonso-Díaz MÁ, Ocaña-Zavaleta E, Jarillo-Rodríguez J. 2017. Live-weight gains of Holstein x Zebu heifers grazing a *Cratylia argentea*/Toledo-grass (*Brachiaria brizantha*) association in the Mexican humid tropics. Agroforestry Systems 91: 1057–1068. https://doi.org/10.1007/s10457-016-9980-5

Villegas DM, Velasquez J, Arango J, Obregon K, Rao IM, Rosas G, Oberson A. 2020. *Urochloa* grasses swap nitrogen source when grown in association with legumes in tropical pastures**.** Diversity 12 (11): 419. https://doi.org/10.3390/d12110419,