Scientific Paper

Productive response of *Cenchrus clandestinus* (Hochst. ex Chiov.) Morrone to fertilization, residual height and defoliation timing

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Abstract

Objective: To evaluate the response of *Cenchrus clandestinus* (Hochst. ex Chiov.) Morrone to fertilization by nutrient extraction rate, residual height and defoliation timing in the Colombian high tropics.

Materials and Methods: Two residual heights (6 and 12 cm) and four fertilization doses were evaluated in plots that were cut with four, five or six live leaves. Agronomic response was evaluated during one year and chemical composition during the months of highest and lowest rainfall. The information was analyzed using a spatially and temporally divided-plot design with three replications.

Results: The growth of *C. clandestinus* was superior when harvested with five leaves and 6-cm residual height in the dry season, and six leaves and 6 cm residual height or five leaves and 12 cm residual height in the rainy season. The nutritional quality of *C. clandestinus* was higher when it was harvested with greater residual height or when doses of 648 kg N/ha and 114 kg P/ha were used. In addition, it was higher when the plant showed four live leaves in the dry season, but similar in the rainy season.

Conclusion: The moment to obtain the maximum growth rate of *C. clandestinus* depends on the time and residual height of harvest. In addition, higher efficiency is achieved in this forage when edaphic fertilization is applied during the rainy season.

Keywords: growth, digestibility, milk production

Introduction

The Colombian dairy sector plays a crucial role in the national economy and accounts for 24,1 % of agricultural GDP and 1,76 % of total GDP, in addition to generating more than 736 000 jobs in the value chain (MADR, 2020). Despite the predominance of pastoral systems, due to their low cost of production, dairy cattle farming faces significant challenges, such as dependence on external feeding resources and production unsustainability (González-Cárdenas, 2021).

The forage base in Colombian high tropic animal husbandry systems is mainly centered on *Cenchrus clandestinus* (Hochst. ex Chiov.) Morrone, a grass that, under proper management, offers high nutritional quality and persistence to intensive grazing (Vargas-Martínez *et al*., 2018). However, inadequate management can reduce its productivity and nutritional quality (Mila-Prieto and Corredor-Sanchez, 2004). In Colombia, the phenotypic expression of *C. clandestinus* is influenced by grazing management and environmental conditions (Castillo-Sierra *et al*., 2023).

To achieve sustainable intensification of animal husbandry systems, efficient forage production and management are essential to promote animal productivity and farm profitability while minimizing environmental impact (Rao *et al*., 2015). Optimization of the plant-animal ratio needs to synchronize the daily requirement of animals with the growth rate and nutritional composition of forages, which can be achieved through fertilizer application and programmed grazing management (Escobar-Charry *et al*., 2020; Medeiros-Martins *et al*., 2021).

Proper management of defoliation frequency and grazing intensity is crucial to provide high quality forage in tropical perennial species (Chapman and Lemaire, 1996). Defoliation frequency affects grassland recovery and soluble carbohydrate accumulation; while grazing intensity determines vegetation characteristics and grassland diversity (Zainelabdeen *et al*., 2020; Venter *et al*., 2021; Zanella *et al*., 2021).

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Mineral deficiency in the soil and the use of low doses of fertilizers can deplete reserves, resulting in low pasture productivity (Govindasamy *et al*., 2023). Also, excessive fertilizer use can lead to nutrient loss and high environmental impact (Fonseca-López *et al*., 2020). Despite the fertilization programs developed for *C. clandestinus*, information on fertilizer rates for intensive management is limited, especially under variable environmental conditions (Govindasamy *et al*., 2023).

This study aimed at evaluating the response of *C. clandestinus* to fertilization by nutrient extraction rate, residual height and defoliation timing in the Colombian high tropics.

Materials and Methods

Location and temporality. This study was conducted in a 760-m^2 plot, previously established with *C. clandestinus*, at the Tibaitatá research center, located in the Mosquera municipality, Colombia (latitude 4°35'56''N and longitude 74°04'51''W), from July, 2020, to June, 2021.

Soil characteristics. Prior to the establishment of the experiment, a representative soil sample was taken and sent to Agrosavia's soil laboratory for chemical analysis. In addition, a brush cutter was used to eliminate the formation of mattresses in the *C. clandestinus* meadow. The chemical analysis of the soil showed adequate nutrient contents (organic matter: 8,64 %, P: 73,8 mg/kg, S: 38,3 mg/kg, Ca: 12,8 cmol/kg, Mg: 4,2 cmol/kg and CEC: 20,4 cmol/kg) and mode-rately acid pH (5,60).

Experimental design and treatments. The selected area was divided into 72 plots of 0,9 x 1,5 m, with distance of 1 m between them and 3 m towards the edges. The treatments were applied in an experimental design of plots subdivided into three different blocks. Two residual forage heights (6 and 12 cm) were imposed with the use of a mower (Husqvarna 7021P 160 cc) in the main plot. In each plot, four doses of nitrogen and phosphorus fertilization were applied to achieve daily growth rates between 20 and 80 kg/DM/ha/d (table 1), according to the methodology proposed by Cuesta-Muñoz *et al.* (2005). In addition, all plots received doses of 350 kg/ha/yr of magnesium sulfate to improve cation ratios. Plots were cut when more than 90 % of the plants had four, five or six new live leaves. For each experimental combination, three replications (blocks) were used and residual height was considered as the main plot, fertilization dose as a subplot and cutting time as a sub-subplot in time.

Experimental procedure. After defining the experimental plots, the meadow was uniformly cut. For the calculation of the fertilizer dose, the estimated time for the appearance of a new leaf in *C. clandestinus* (preliminary trial), which was 8,3 days, was considered. Thus, the initial number of cutting periods per year was 10,9; 8,7 and 7,3 rotations, for plots with four, five and six live leaves, respectively. As the treatments affected the recovery of the plots, the regrowth time recorded in each measurement was taken into account to adjust the next dose to be applied and the fertilizer and the remaining time of the study were considered.

Evaluated variables and laboratory analyses. The agronomic response of the different treatments was measured during one year, between July, 2020, and June, 2021. The chemical composition was determined in samples obtained during November, 2020, which corresponded to the highest rainfall season (180 mm/month), and during January and February, 2021, which coincided with the lowest rainfall season (40 mm/month). Plant height (cm) was determined in each plot using a plastic ruler.

Forage from each plot was harvested and dried to determine dry forage production (g DM/m^2). Additionally, daily growth rate (DGR, kg DM/ha/day) was determined as the relationship between dry matter accumulation and cutting period. Forage samples were preserved and the concentration of crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), nonstructural carbohydrates (NSC), calcium (Ca) and phosphorus (P) were determined using NIRS methodology in Agrosavia's analytical chemistry laboratory. In addition, net lactation energy (NEL) was estimated with equations used in Agrosavia's AlimenTro platform. *In situ* digestibility of dry matter (ISDMD) (Ørskov and MacDonald,

Table 1. Fertilization plans evaluated in the study.

Expected growth rate (kg DM/ha/days)	N (kg/ha/year)	P_2O_5 (kg/ha/year)
20	0	0
40	274	6,8
60	461	60,3
80	648	113,8

1979) was determined in Agrosavia's animal nutrition laboratory.

Statistical analysis. Agronomic and compositional variables were analyzed using a design of plots subdivided in space and time, with the use of the MIXED procedure of SAS Institute Inc. (2018). The analysis was performed independently, according to the climate season associated with rainfall (rainy or dry season). Adjusted means were compared using Tukey's test, with 5 % significance level. In addition, significances lower than 10 % and higher than 5 % were reported as trends. Fertilizer application was evaluated by orthogonal contrasts to determine the linear, quadratic and cubic effect of this treatment. The experimental errors of the evaluated variables met the assumptions of homogeneity of variances and normality.

Results

Dry season response. C. clandestinus plots, which were cut at 6 cm height, took 7,1 days longer ($p < 0,05$) to reach harvest time and recorded lower ($p < 0,05$) plant height and number of senescent leaves, compared with those harvested at 12 cm (table 2). In addition, the lower cutting height resulted in lower ($p < 0,05$) CP and ISDMD concentration, but showed ($p < 0,01$) higher dry matter (DM) accumulation, which translated into higher growth rate (62,0 % more forage per day).

Fertilization linearly affected ($p < 0,05$) the agronomic response of *C. clandestinus* plots. Fertilizer application to obtain growth rate of 60 or 80 kg DM/ha/day increased biomass accumulation and plant height with regards to the control (table 2). In addition, the DGR was higher ($p < 0,05$) in the treatments with high fertilizer doses compared with those with low doses. Similarly, increasing fertilization promoted a linear increase ($p < 0,05$) in the concentration of CP, P and NEL, but linearly reduced the NSC content (table 2).

Defoliation frequency, as determined by the number of live leaves, had significant effect ($p < 0,05$) on cutting time. The plots with four live leaves required 19,8 days less to cut, compared with plots with 5 leaves, and, in turn, those of 5 live leaves, 16,4 days, compared with the ones with 6 leaves. In addition, plants with fewer leaves showed lower height, fewer senescing leaves, and lower gauging and DGR, compared with the plots harvested with five or six live leaves. A quadratic trend in DGR was found, suggesting that the theoretical maximum would be reached at 5,3 live leaves during the dry season. Defoliated *C. clandestinus*, with four live leaves, showed higher percentage of CP and estimated NEL, as well as lower NDF and P concentration compared with other treatments ($p < 0,05$).

With the increase in leaf number, harvest time increased. However, this response can be associated with residual height. Thus, harvest time was shorter ($p < 0,05$) for plants with five or six live leaves, when cut at 12 cm with regards to 6 cm. Meanwhile, it was similar for harvesting with four leaves (figure 1A). DGR in plots cut at residual height of 6 cm was higher ($p < 0,05$) when they showed five leaves, compared with four or six leaves. However, the response was similar for five or six leaves and higher ($p < 0,05$), compared with four leaves, when cut at 12 cm (figure 1B). This indicates that the optimum time to obtain the highest DGR is when the plants have between five and six live leaves.

NDF concentration increased ($p < 0,05$) with time to harvest when the meadow was cut at 6 cm, but not when cut at 12 cm (figure 2A). Moreover, this cell wall fraction was lower in plants with six leaves, which were cut at a height of 12 cm, compared with that at 6 cm. On the other hand, NSC concentration was reduced when the plots were cut at 6 cm, but not when cut at 12 cm, being lower for plants with six leaves with regards to those with four (figure 2B).

Rainy season response. During the rainy season, harvesting *C. clandestinus* grass at a height of 6 cm delayed ($p < 0,05$) the time of cutting by 7,9 days, increased ($p < 0,05$) by 0,7 the number of senescent leaves and made ISDMD 5,7 % lower ($p < 0,05$) with regards to defoliation at 12 cm height (table 3).

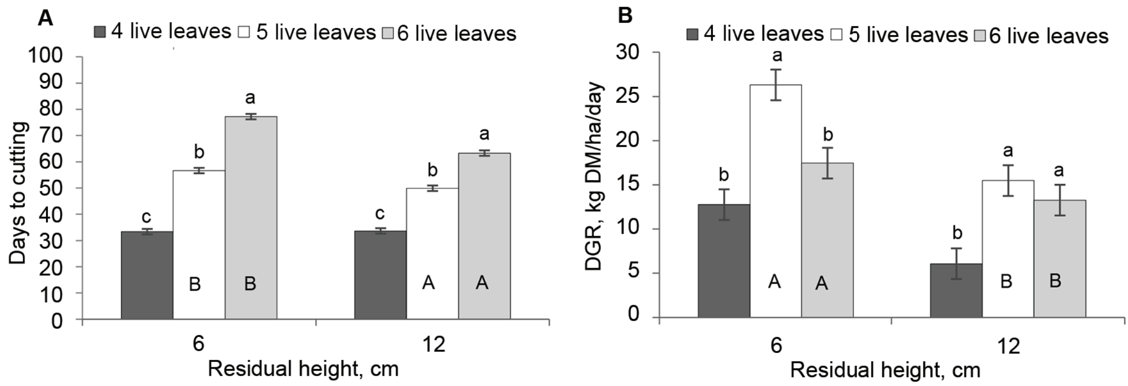
The increasing dose of edaphic fertilizers linearly affected ($p < 0,05$) the harvest time and agronomic response of *C. clandestinus* during the rainy season (table 3). Thus, increased fertilization increased ($p < 0,05$) gauging and growth rate. The ratio between the observed and expected DGR was 1,37; 0,89; 0,84 and 0,78, for 20, 40, 60 and 80 kg/ha/day, which responds to a decreasing increase curve. The highest efficiency was achieved with the application of low doses of fertilization. The increase in fertilization promoted a linear increase ($p < 0,05$) in the concentration of CP, P and NEL (table 3), so that the content of these nutrients and the estimated net energy were higher ($p < 0,05$) in the treatment with the highest dose of fertilization, compared with the treatments DGR20 and DGR40 (CP and P) or only DGR20 (NEL).

Defoliation frequency affected ($p < 0,05$) regrowth time, plant height, number of senescent leaves and forage production. Plant height and num-

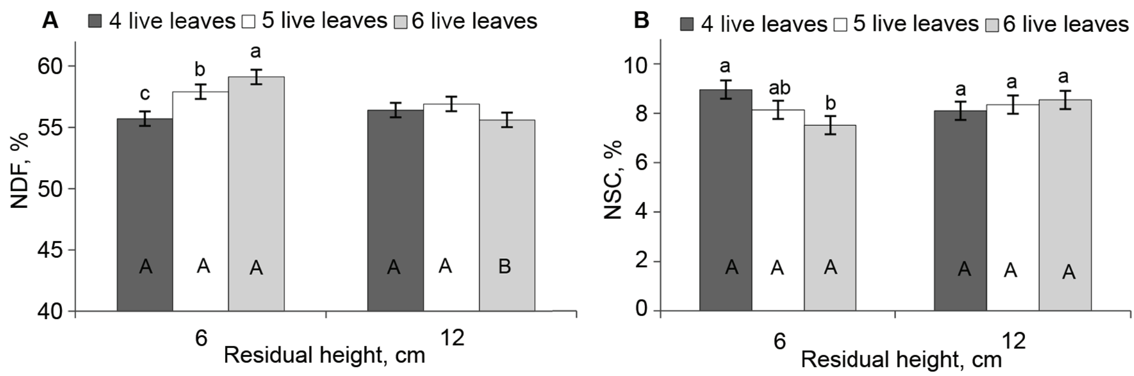
Table 2. Effect of residual height, fertilization and harvest timing on agronomic and compositional response of *C. clandestinus* in the dry season[1].

Factor	Regrowth age, days	Plant height, cm	Senescent leaves No.	Dry forage production, g DM/m^2	DGR, kg DM/ha/day	CP	NDF	ADF	NSC	Ca	P	ISDMD	NE_Lm Mcal/kg
						%							
Residual height (RH, cm)													
6	55,7	11,6	1,3	105,5	19,3	15,6	57,6	33,4	8,2	0,34	0,32	69,7	1,26
12	48,6	14,5	1,8	58,8	12,3	17,4	56,3	31,8	8,3	0,35	0,32	74,5	1,29
SEM[2]	1,57	0,49	0,10	12,5	1,35	0,23	0,43	0,32	0,25	0,013	0,009	0,85	0,005
Fertilization (F)													
DGR 20	53,1	12,1^{b}	1,3	60,2^{b}	11,4^{b}	15,4^{b}	56,5	32,0	9,5^{a}	0,36	0,30^{b}	70,9	1,26^{b}
DGR 40	53,5	12,5^{ab}	1,8	72,5^{ab}	13,1^{b}	16,4^{ab}	56,5	32,7	9,6^{a}	0,36	0,30^{b}	71,6	1,27^{ab}
DGR 60	52,3	13,8^{a}	1,8	97,1^{a}	19,4^{a}	16,6^{ab}	57,3	32,0	7,2^{b}	0,34	0,34^{a}	72,5	1,28^{ab}
DGR 80	49,8	13,8^{a}	1,4	98,8^{a}	19,5^{a}	17,7^{a}	57,3	32,9	6,8^{b}	0,34	0,33^{a}	73,3	1,29^{a}
SEM	2,1	0,53	0,16	11,1	1,56	0,29	0,58	0,48	0,36	0,016	0,011	1,21	0,006
Cut (C, No. live leaves)													
4	33,5^{a}	11,8^{b}	0,8^{a}	34,6^{b}	9,4^{b}	17,3^{a}	56,0^{a}	32,1^{a}	8,5	0,36	0,31^{b}	73,2	1,30^{a}
5	53,3^{b}	13,0^{ab}	1,7^{b}	99,3^{a}	20,9^{a}	16,6^{ab}	57,4^{b}	31,7^{a}	8,2	0,34	0,34^{a}	70,5	1,28^{b}
6	69,7^{c}	14,4^{a}	2,2^{c}	112,6^{a}	17,1^{a}	15,7^{b}	57,4^{b}	33,4^{b}	8,0	0,35	0,32^{ab}	72,5	1,26^{c}
SEM	1,78	0,48	0,10	10,4	1,36	0,24	0,42	0,35	0,26	0,014	0,008	1,05	0,005
Effects[3]													
RH	*	*	*	+	*	*	ns	+	ns	ns	ns	*	+
F	ns	*	ns	*	**	*	ns	ns	**	ns	*	ns	*
C	***	***	***	***	***	***	**	***	ns	ns	*	ns	**
RH*F	ns	ns	ns	ns	ns	+	ns	ns	ns	+	ns	ns	+
RH*C	*	ns	ns	+	ns	ns	*	*	*	ns	ns	ns	+
F*C	**	ns	ns	+	ns	ns	ns	ns	ns	+	ns	ns	ns
RH*F*C	ns	+	ns	ns	ns	+	ns	ns	ns	ns	ns	ns	ns
Effect F[4]	ns	L*	Q*	L**	L**	L**	ns	ns	L**	ns	L*	ns	L**

[1]DGR = Daily growth rate; CP = Crude protein; NDF = Neutral detergent fiber; ADF = Acid detergent fiber NSC= Non-structural carbohydrates; Ca = Calcium; P = Phosphorus; ISDMD = *In situ* dry matter digestibility; NE_L= Net lactation energy; [2]SEM= Standard error of the mean, [3]+: $p < 0,1$; *: $p < 0,05$; **: $p < 0,01$; ***: $p < 0,001$; [4]Effect of edaphic fertilization, L: linear effect, Q: quadratic effect. a, b and c Different letters in the same column indicate significant differences



a,b and c Different lowercase letters between defoliation times for each residual height differ for p < 0,05.
A, B Different capital letters for the same defoliation timing between residual heights differ for p < 0,05.
Figure 1. Effect of residual height and defoliation timing on days to harvest (A) and daily growth rate (B) in *C. clandestinus*.



a, b and c Different lowercase letters between defoliation times for each residual height differ for p < 0,05.
A, B Different capital letters for same defoliation timing between residual heights differ for p < 0,05.
Figure 2. Effect of residual height and defoliation timing on NDF content (A) and nonstructural carbohydrates (B) in *C. clandestinus* grass.

ber of senescent leaves were similar (p > 0,1) for biomass harvested with five or six live leaves, but higher (p < 0,05) compared with forage harvested with four live leaves. The emergence of the fifth and sixth live leaves required 7,8 and 10,1 days, respectively. Likewise, biomass harvest with five live leaves represented 65,8 g DM/m^2 more (p < 0,05) compared with four live leaves; while harvest with six live leaves accumulated 36,9 g DM/m^2 more (p < 0,05) with regards to five live leaves. Regarding forage chemical composition, CP concentration was affected (p < 0,05) by harvest time, being higher (p < 0,05) in plants with four live leaves with respect to those with six live leaves.

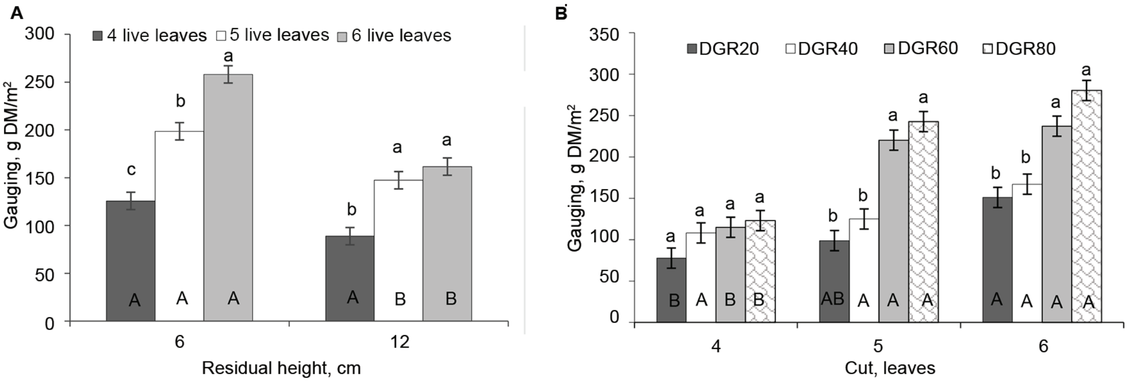
Forage production per area unit in meadows cut at a height of 6 cm increased (p < 0,05) when plant material was harvested with six live leaves compared with two other defoliation moments (figure 3A). Meanwhile the highest gauging was recorded in plots harvested with five or six live leaves, compared with four live leaves, in meadows cut at 12 cm. In addition, forage production harvested with four live leaves was similar (p > 0,1) when harvested at 6 or 12 cm; while in the other two cutting times, the gauging was higher when cut at 6 cm height (figure 3A). When *C. clandestinus* was harvested with four live leaves, there were no differences in forage accumulation associated with fertilizer application; whereas, when harvested with five or six leaves, forage accumulation was higher in those plots that received the highest doses of fertilizer (figure 3B).

When *C. clandestinus* was harvested at a residual height of 6 cm, there was higher (p < 0,05)

Table 3. Effect of residual height, fertilization and harvest timing on agronomic and compositional response of *C. clandestinus*.

Factor	Regrowth age, days	Plant height, cm	Senescent leaves	Gauging, g DM/m^2	DGR, kg DM/ha/day	CP	NDF	ADF	NSC	Ca	P	ISDMD	NE_L, Mcal/kg
			Number			%							
Residual height (RH, cm)													
6	41,0^b	18,4	1,5^a	191,6	47,1	16,5	54,8	33,1	7,4	0,34	0,29	70,8^b	1,27
12	33,1^a	19,6	2,2^b	132,5	40,8	18,0	50,7	30,4	9,3	0,36	0,27	76,5^a	1,32
SEM[2]	0,97	0,95	0,14	4,97	1,91	0,22	0,41	0,49	0,18	0,011	0,004	0,22	0,005
Fertilization (F)													
DGR 20	39,4	15,8^b	1,9	108,9^c	27,3^c	16,1^c	54,1	32,9	8,2	0,35	0,27^b	72,3	1,27^b
DGR 40	36,8	17,3^{ab}	2,0	133,4^c	35,6^c	16,8^{bc}	52,6	31,9	8,0	0,35	0,27^b	73,4	1,29^{ab}
DGR 60	36,3	22,1^a	1,8	190,7^b	50,4^b	17,9^{ab}	51,6	31,0	8,5	0,36	0,29^{ab}	75,4	1,31^a
DGR 80	33,9	20,8^a	1,7	215,3^a	62,4^a	18,5^a	52,7	31,0	8,6	0,34	0,30^a	73,4	1,32^a
SEM	1,24	1,09	0,17	7,03	2,44	0,32	0,62	0,56	0,26	0,015	0,005	1,12	0,007
Cut (C, No. live leaves)													
4	28,5^a	17,3^b	1,2^a	105,9^c	37,3^b	17,8^a	53,3	32,3	8,3	0,34	0,29	73,1	1,30
5	36,3^b	20,1^a	2,1^b	171,7^b	49,0^a	17,3^{ab}	52,4	31,5	8,5	0,35	0,28	74,6	1,30
6	46,4^c	19,5^a	2,2^b	208,6^a	45,5^a	16,8^b	55,6	31,4	8,3	0,37	0,28	73,2	1,27
SEM	1,02	1,00	0,16	6,09	2,18	0,23	0,49	0,52	0,23	0,011	0,005	1,46	0,005
Effects[3]													
RH	*	ns	*	+	+	ns	+	+	+	ns	ns	*	+
F	ns	*	ns	**	*	*	ns	+	ns	ns	*	ns	*
C	***	**	***	***	**	**	ns	ns	ns	ns	ns	ns	ns
RH*F	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
RH*C	+	+	ns	***	*	ns	ns	+	ns	ns	ns	ns	ns
F*C	ns	ns	ns	**	**	ns	ns	ns	ns	ns	ns	ns	ns
RH*F*C	ns	ns	ns	+	ns	ns	ns	ns	ns	ns	ns	ns	ns
Effect F[4]	L*	L**	ns	L**	L**	L*	ns	L*	ns	ns	L*	ns	L**

DGR = daily growth rate; CP = crude protein; NDF = neutral detergent fiber; ADF = acid detergent fiber; NSC = nonstructural carbohydrates; Ca = calcium; P = phosphorus; ISDMD = *in situ* digestibility of dry matter; NEL = net lactation energy; [2]SEM = standard error of the mean; [3] +: p < 0,1; *: p < 0,05; **: p < 0,01; ***: p < 0,001. [4]Effect of edaphic fertilization: L linear effect.



a,b and c Different lowercase letters between defoliation times for each residual height (A) or between fertilization levels for defoliation time (B) indicate significant differences (p < 0,05).
A, B Different capital letters for the same defoliation time between residual heights (A) or for the same fertilization level between defoliation times (B) indicate significant differences (p < 0,05).
[1]DGR= Daily growth rate.

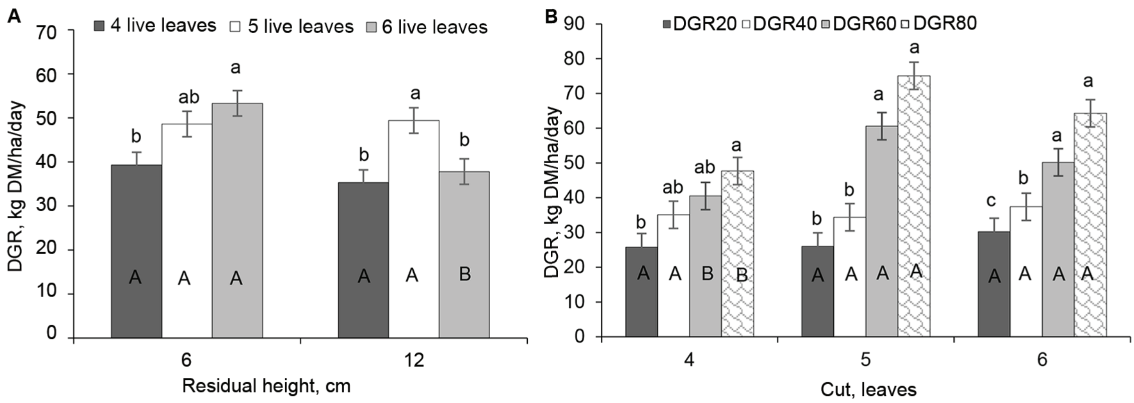
Figure 3. Effect of residual height, defoliation timing (A) and fertilization (B) on biomass production of *C. clandestinus*.

DGR in plots that had six live leaves compared with those with four live leaves (figure 4A); while when cut at 12 cm from the ground the highest DGR was recorded in plots harvested with five live leaves relative to the other two harvest times (figure 4A). In addition, with the change in harvest height, between 6 and 12 cm, the biomass accumulation rate of plots having six live leaves was affected (p < 0,05). The increase in fertilizer dose promoted linear increase in all plots, independent of the number of leaves. However, the response was greater (p < 0,05) at the higher doses, when harvested with five or six live leaves (p < 0,05), when compared with the other two fertilizer schemes (figure 4B).

The response surface analysis for nitrogen application (figure 5) in the rainy season indicated that the highest predicted growth rate of *C. clandestinus* was obtained when the fertilizer dose was low, in plants with five leaves; while with increasing fertilizer dose the highest response was obtained when plants had six live leaves.

Discussion

In this experiment, pasture management with a residual height of 6 cm increased the growth



a,b and c Different lowercase letters between defoliation times for each residual height indicate significant differences (p < 0,05).
A, B Different capital letters for the same defoliation time between residual heights (A) or for the same fertilization level between defoliation times (B) indicate significant differences (p < 0,05).
DGR: Growth rate

Figure 4. Effect of residual height and defoliation timing (A) and defoliation timing and fertilization (B) on daily growth rate of *C. clandestinus* in the rainy season.

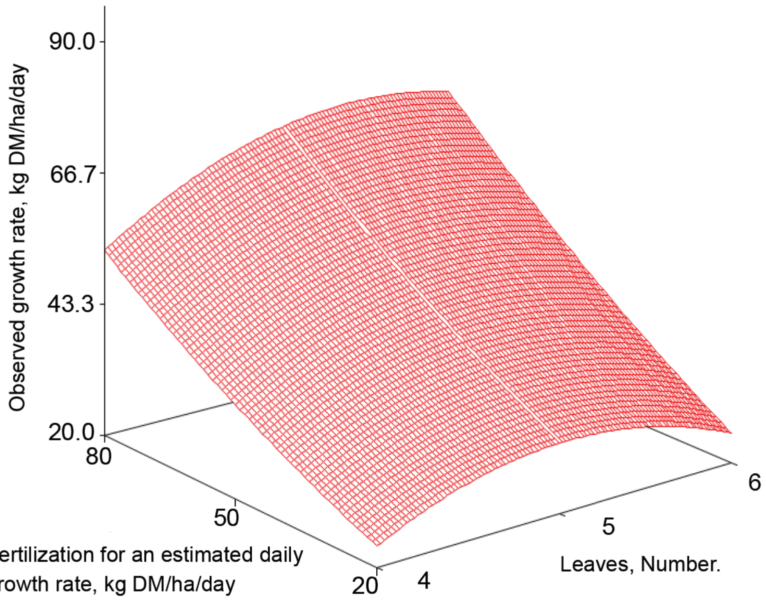


Figure 5. Growth rate response surface of *C. clandestinus* associated with number of leaves and fertilizer dose for an expected growth rate.

response of *C. clandestinus*, but delayed cutting time and reduced forage quality. In this regard, intensification in defoliation increases the period of time required to replenish the carbon balance of the plant (Mayel *et al*., 2021), which delays the emergence of new leaves.

Fulkerson *et al*. (1999) observed that the annual biomass yield of *C. clandestinus* is highest when harvested at a height of 3 cm. However, later studies such as those conducted by Molina-Gerena (2018) and Martins *et al*. (2021) indicate a decrease in DM production of *C. clandestinus* with lower defoliation heights. This finding is corroborated by the study of Medeiros-Neto *et al*. (2020), which indicates that defoliations higher than 50 % can negatively affect forage accumulation of this grass.

In general, heavy defoliation reduces the residual leaf area, making the plant dependent on non-structural carbohydrate reserves to produce new tissues (Fulkerson *et al*., 1999). However, the growing points present in stoloniferous grasses, such as *C. clandestinus*, are located at ground level, above the modified stem called stolon, which makes them less susceptible to intense defoliation (Vallentine, 2000). Higher defoliation intensity stimulates the generation of new shoots by higher light penetration through a less leafy canopy (Martins *et al*., 2021), which can lead to greater efficiency in solar energy capture and, in turn, greater growth, as was recorded in this study. In addition to the morphological characteristics of the plants, the contradictory results can be explained by differences in climate conditions during the experiment. For example, in the rainy season, the production of *C. clandestinus* increased (table 3). Avellaneda-Avellaneda *et al*. (2020) report that biomass production of *C. clandestinus* is strongly influenced by rainfall in pastoral systems.

As previously mentioned, forage harvested with lower residual height registered lower nutritional quality, with an average reduction of 5,3 % in ISDMD in the two evaluated seasons and lower CP content in drought (-1,8 %). In other works, it has been recorded that lower residual forage height increases the cell wall biomass of *C. clandestinus,* especially the ADF concentration (Fulkerson *et al*., 1999), which has been related to higher amount of dead material (Molina-Gerena, 2018). In addition, with low defoliation heights, greater presence of stems has also been reported (Molina-Gerena, 2018), which confers them lower nutritional quality, as reported by Mganga *et al.* (2021) in tropical forages from Africa. However, other authors (Fonseca *et al*., 2016; Mocelin *et al*., 2022) report that no differences in chemical and nutritional composition were evidenced among different residual heights, which could be related to the adaptation and plasticity of *C. clandestinus* (Castillo-Sierra *et al*., 2023).

In this research, fertilization generated linear reduction in days to harvest during the rainy season (table 3), which is related to the positive effect that nitrogen has on the accumulation of NSC reserves at the base of plants (León *et al*., 2018; Molina-Gerena, 2018). The latter results in faster recovery after grazing. In addition, edaphic fertilization generated a linear response in forage production in the two evaluated seasons (tables 2 and 3).

The improvement in DM production has been previously recorded (Herrero *et al*., 2000; Acero-Camelo *et al*., 2020) and is complemented by the improvement in the live forage: dead forage ratio and plant height, due to higher leaf elongation (Acero-Camelo *et al*., 2020). Viljoen *et al*. (2020) point out that pasture production was not modified by applying low doses of nitrogen (< 40 kg N/ha).

In this experiment, the growth response was similar between DGR20 and DGR40 (numerical difference of 2,183 kg DM/ha/year) despite the application of more than 200 kg N/ha/year, which indicates the association of forage growth with soil conditions or environmental supply. Nitrogen fertilization increases plant leaf area (Zanine *et al*., 2020), because it promotes the acceleration of leaf growth and development processes by activating buds and enhancing space occupancy (Matthew *et al*., 2000).

As edaphic fertilization increased, CP and NEL content increased in *C. clandestinus*, which coincides with reports from several authors, who point out that the application of fertilization increases the crude protein content of forage (Viljoen *et al*., 2020; Ortiz *et al*., 2021). Acero-Camelo *et al*. (2020) state that nitrogen fertilization in general terms improves pasture quality, since it decreases the concentration of lignin in leaves and reduces the NDF and ADF content in leaves and stems. In addition, there was a reduction in NSC concentration with increasing fertilization, a response also reported by Soto *et al*. (2005) in *C. clandestinus*. This is associated with increased energy and carbon skeleton consumption for N assimilation and plant growth (Invers *et al*., 2004).

In this experiment, the time of appearance of each leaf for four, five and six live leaves was 8,4; 10,7 and 11,6 days in the dry season and 7,1; 7,3 and 7,7 days in the rainy season (tables 2 and 3), which indicates that the water stress of the dry season had a negative effect on plant development. In the dry season, higher productivity was achieved when plants were harvested with 5 and 5,5 live leaves, for residual heights of 6 and 12 cm, respectively. Meanwhile, the highest productivity was found when plants had six and five live leaves, for 6 or 12 cm residual forage height, in the rainy season. This may indicate that the time and type of management affect the optimum harvest time, if only the growth rate is considered.

Among the work conducted on *C. clandestinus*, Escobar-Charry *et al*. (2020) reported that biomass accumulation was higher as the number of leaves increased (from four to seven) and the leaf emergence rate was eight days on average. Fonseca *et al*. (2016) found that when the pasture showed six leaves, the highest biomass production was obtained. Other authors state that the harvest time where the highest yield in nutrient accumulation is obtained corresponds to five live leaves, similar to that found in this study (Acero-Camelo *et al*., 2020; Escobar-Charry *et al*., 2020).

With the increase in the number of live leaves, there was a decrease in the quality of *C. clandestinus* pasture, especially in the dry season (tables 2 and 3). These results are similar to those reported by Escobar-Charry *et al*. (2020) in the Ubaté province (Cundinamarca-Colombia), who found that as the number of leaves increased, CP and DM digestibility decreased in a range of four to seven leaves. Similarly, the response in compositional quality of *C. clandestinus* in the rainy season was similar to that referred by Fonseca *et al*. (2016) in the Alto Chicamocha province (Boyacá-Colombia), who found that the NDF and ADF concentration was not different between defoliation frequencies of three to six leaves.

Conclusions

The moment of defoliation that allows obtaining the maximum growth rate of *C. clandestinus* depends on the season and residual height. Thus, to obtain a higher growth rate of *C. clandestinus* in the dry season, a defoliation height of 6 cm is recommended and harvesting when there are five live leaves; while, in the rainy season, it can be with a residual height of 6 cm and six live leaves or a residual height of 12 cm, but with five live leaves.

The response to fertilization by nutrient extraction rate is better when the soil has good moisture conditions. In addition, to find favorable response to nitrogen and phosphorus fertilization, in terms of capacity, it is recommended to harvest *C. clandestinus* when it shows five or six live leaves.

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Conflict of interests

The authors declare that there is no conflict of interests among them.

Authors' contribution

- Yesid Avellaneda-Avellaneda. Conceptualization, experimental design, data compilation, data analysis, writing and revision.
- Edgar Augusto Mancipe-Muñoz. Experimental control, data compilation, writing and revision.
- Javier Castillo-Sierra. Conceptualization, data compilation, writing and revision.
- Franklin G. Mayorga Cubillos. Experimental control, data compilation, writing and revision.
- Juan de Jesús Vargas-Martínez. Conceptualization, experimental design, writing and revision.

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