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Effect of harvest frequency and application of amendments on the productivity of *Cenchrus clandestinus* Hochst. ex Chiov Morrone

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Abstract

Objective: To evaluate the effect of harvest frequency and application of lime and organic matter on the forage production, nutritional value and costs of *Cenchrus clandestinus* Hochst. ex Chiov Morrone.

Materials and Methods: The work was done in three 208-m^2 blocks, divided into four plots, to which four doses of organic matter (0, 2, 4 and 6 t ha^{-1}) were applied. Each plot was divided into three subplots, in which three doses of lime (0, 3 and 6 t ha^{-1}) were used. Afterwards, each subplot was divided into five sub-subplots, in which one of the five harvest frequencies (28, 35, 42, 49, and 56 days) was used. The agronomic response and chemical composition during the rainy and dry seasons were evaluated. In addition, the production cost of the pasture *C. clandestinus* was calculated. The results were analyzed with a split-plot design.

Results: The harvest frequencies of 35 and 49 days showed higher daily growth rate during the rainy and dry seasons, respectively. However, the harvest frequency did not affect the nutritional values. The application of lime and organic matter did not show an evident effect on the forage production or quality. The 35-day harvest frequency showed lower production cost.

Conclusion: The harvest or grazing of the pasture *C. clandestinus* is variable, and should not be static throughout the year.

Keywords: organic matter, biomass production, grazing systems

Introduction

The kikuyu pasture (*Cenchrus clandestinus* Hochst. ex Chiov Morrone) is a C_4 species that tolerates acid soils, and responds efficiently to the application of nitrogen and water. In addition, it is the prevailing grass in the systems with ruminants of the Colombian high tropic (Vargas-Martínez *et al*., 2018). The intensification of grazing cattle productive systems requires improving the biomass production, animal efficiency, farm cost-effectiveness, besides reducing the environmental impact, to promote sustainable systems (Rao *et al*., 2015). The literature refers different strategies to increase the dry matter production and nutritional quality in the pasture *C. clandestinus*. There is also information about the evaluation of supplementation, soil management, nitrogen fertilization, lower age for harvest and association with legumes and trees (Vargas-Martínez *et al*., 2018). However, there are few references about the application of lime and organic matter (OM) and its effect on the production, nutritional quality and production costs of the pasture *C. clandestinus* in the Colombian high tropic (Castillo *et al*., 2019).

Grazing management is a strategy for maximizing the use of forage and promoting its persistence. The grazing intensity, frequency and optimum moment are tools to modulate the productivity, nutritional quality and ecosystemic services in animal husbandry systems (Sollenberger *et al*., 2020a).

In Colombia, studies related to the harvest frequency (number of leaves) suggest adjusting a defoliation frequency in pastoral systems of *C. clandestinus* according to the environmental conditions (Fonseca *et al*., 2016; Molina-Gerena, 2018; Escobar-Charry *et al*., 2020). The plant morphology can also vary, due to the environmental conditions or to grazing management, limiting the relation with forage yield and nutritional quality (Shepard *et al*., 2018; Martins *et al*., 2021). The technical recommendations of grazing frequency are supported by the static rotation of the duration of day; while the morphological characteristics of the pasture *C. clandestinus* are not considered (Escobar-Charry *et al*., 2020). There are no reports either of the effect of grazing or harvest frequency on the yield, nutritional quality and costs in systems with cattle fed pasture *C. clandestinus*.

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In this context, the objective of this study was to evaluate the effect of harvest frequency and application of lime and OM on the forage production, nutritional quality and evaluation of costs of the pasture *C. clandestinus* in the Colombian high tropic.

Materials and Methods

Location, soil and treatments. An area of 625 m^2 was selected in the Tibaitatá research center, belonging to the Colombian Corporation of Agricultural Research (Agrosavia), located in the Mosquera municipality, at an altitude of 2 516 m.a.s.l., 4°35´56´´N latitude and 74°04´51´´W longitude, average temperature of 16 ºC and relative humidity of 75 %. A moderately acid soil was selected to evaluate the harvest frequency and the doses of dolomite lime and OM. Before the experimental period, a soil sample was taken and analyzed in the soil laboratory of Agrosavia. The soil chemical analysis showed adequate concentrations of nutrients. For such reason, the nitrogen fertilization (40 kg ha^{-1}) was applied at the beginning and amid the experimental period (table 1). The OM used for this experiment was cattle dung from the dairy farm of the Tibaitatá R.C. A cut was also made to stadardize the selected area, at a height of 10 cm.

The experimental area was divided into three blocks of 208 m^2 each. The blocks were separated by a 2-m alley. Each block was divided into four plots for the random application of OM (0, 2, 4, and 6 t ha^{-1}). Each plot was separated by a 2-m alley from the other and was divided into three subplots. Each one was assigned from one to three doses of dolomite lime (0, 3, and 6 t ha^{-1}). Each subplot was separated by a 1-m alley from the others and was divided into five sub-subplots, and each one was assigned one of the five harvest frequencies (28, 35, 42, 49 and 56 days). The area of each evaluation subplot was 1,6 m^2. The sub-subplots were harvested at a height of 10 cm and it was continuously done, since the standardization cut (December, 2018) until the end of the experiment (August, 2019) according to the harvest frequency. The forage production and nutritional value were evaluated during the rainy season (April to May, 2019) and the dry season (July to August, 2019). Figure 1 shows the performance of rainfall during the evaluation stages.

Evaluated variables and laboratory analyses. During the evaluation periods the average pasture height (PH) was determined in each sub-subplot. An area of 0,08 m^2 from each subplot, characterized by its height, was selected, without disturbing the number of leaves and other morphometric variables The number of green leaves (NGL), concentration of chlorophyll (CC) (Minolta SPAD 502 Plus), leaf length (LL) and width (LW) were

Table 1. Chemical characteristics of the soil where the experiment was conducted.

pH	OM	P	S	Fe	Mn	Zn	Cu	B	Ca	Mg	K	Na	CEC
	%	mg kg^{-1}							Cmol kg^{-1}				
5,9	8,3	62,0	40,4	1082,0	6,6	36,4	2,8	0,4	15,0	4,4	1,6	1,4	22,7
Moderately acid	Moderate	High	High	High	Moderate	High	Moderate	High	High	High	High	Non-saline	High

OM organic matter, CEC cation exchange capacity

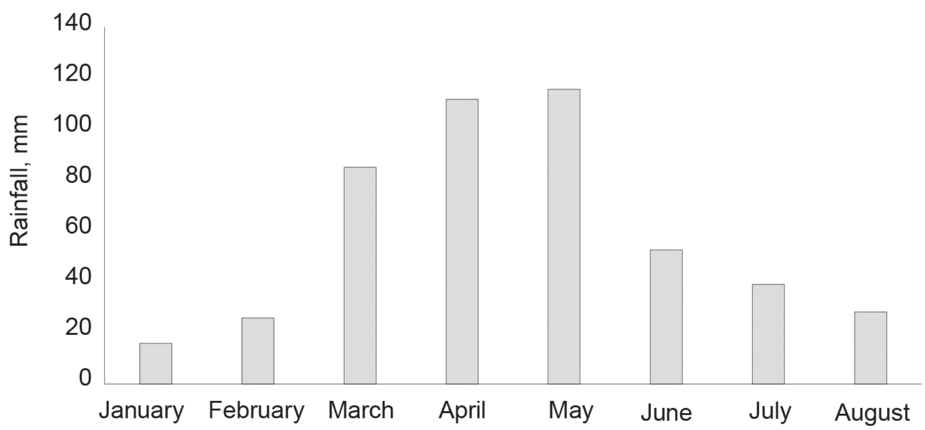

Figure 1. Rainfall during the experimental period, mm per month.

evaluated in each stem. Also, in each sub-subplot the forage was harvested and the forage yield was measured. A subsample from each sub-subplot was dried and preserved for its later analysis. The dry matter production (DMP) was calculated as the product between forage yield and DM concentration. The daily growth rate (DGR) was calculated as the ratio between DMP and the growth period. Finally, the crude protein (CP), soluble crude protein (SCP), neutral detergent fiber (NDF, acid detergent fiber (ADF), non-structural carbohydrates (NSC), calcium (Ca), phosphorus (P), dry matter digestibility (DMD) and net lactation energy ($N_L E$) were determined with the NIRS (Near-infrared spectroscopy) methodology, proposed by Ariza-Nieto *et al.* (2017).

In order to calculate the cost of DM, N, and energy production, a dry season of 200 days and a rainy period of 165 were considered. In addition, the total biomass production was calculated with the DGR in each period. The basis establishment cost per hectare was 365,000 $ Colombian pesos (COP). The cost of dolomite lime and OM was 200,000 and 360,000 $COP per ton, respectively.

Statistical analysis. The agronomic and compositional information was analyzed through a split-plot design, according to the GLM procedure of SAS. The dry and rainy seasons were independently evaluated. The means were compared through Tukey's test and the significant differences were considered with an alpha level lower than 5 %. The homogeneity and normality assumption was fulfilled. The linear and quadratic effects were also evaluated for the applications of OM and dolomite lime.

Results

Agronomic and compositional response of the pasture C. clandestinus during the rainy period. The application of OM showed a quadratic effect on the variables PH, CC, LL and LW and linear on NGL. However, it did not affect (p > 0,05) DMP or DGR. The application of dolomite lime did not modify (p > 0,05) NGL, PH, LL, LW, and showed quadratic effect on the CC, DMP, and DGR. The harvest frequency did not modify (p > 0,05) CC and NGL. However, it reduced (p < 0,05) to 0,49; 0,28 and 0,003 cm days $^{-1}$ the PH, LL and LW, respectively. In addition, when harvesting at 28 days, there was 53,4 % less (p < 0,05) DMP with regards to other frequencies. Besides, when the pasture *C. clandestinus* was 35 days old it showed the highest DGR (62 %) compared with other harvest frequencies (table 2).

The application of dolomite lime showed linear effect on the CP and increased (p < 0,05) by 8,3 % the Ca concentration. Likewise, the dolomite lime showed quadratic effect on the NDF, but it did not reveal significant differences (p > 0,05) in the SCP, ADF, P, DMD and $N_L E$. The application of OM did not show effects on the SCP, NSC and P. However, it showed linear effect on the ADF, and quadratic effect on the CP, NDF, Ca, DMD, and $N_L E$. The frequency of 28 days showed 6,6 % more (p < 0,05) CP concentration compared with 56 days. The 35-day harvest period had 13,4 % more (p < 0,05) NSC than other frequencies. In other chemical analyses it could be seen that the harvest treatment was not affected (p > 0,05) (table 3).

Agronomic and compositional response of the pasture C. clandestinus during the dry season. The application of dolomite lime showed quadratic effect on the PH, DMP, and DGR, but it did not influence the characteristics of the leaves. The application of OM only affected quadratically the NGL. The harvest frequency did not have influence on the LW and CC. Yet, the PH, LL and DGR were higher in the 49-day harvest frequency. The frequencies of 49 and 56 days also increased (p < 0,05) the DMP (table 4).

The application of OM showed quadratic effect on the CP, NDF, Ca, P, DMD, and $N_L E$, but did not affect (p > 0,05) SCP, ADF and NSC. The application of dolomite lime had lineal effect on CP, ADF, Ca, DMD and $N_L E$, but did not modify (p > 0,05) SCP, NSC and P. Likewise, for each ton of applied lime the NDF was reduced by 0,25 % (p < 0,05). The 28-day frequency increased the NSC, but reduced the concentration of Ca (p < 0,05). The 49-day frequency had higher NDF and ADF (p < 0,05). Finally, the harvest frequency did not modify the CP, NSC, P, DMD and $N_L E$ (table 5).

Production costs of the pasture C. clandestinus with different harvest frequencies and application of dolomite lime and OM. As there was no interaction among the experimental factors, the calculations are present for the average of each level, according to the different evaluated factors. The 28-day frequency showed the highest cost of DMP, N and $N_L E$; while the 35-day one had the lowest. In addition, the frequency of 42 or 49 days had equal costs in the DMP. The application of dolomite lime and OM increased the production cost of *C. clandestinus*. One ton of dolomite lime increased 11,9

Table 2. Agronomic response of the pasture *C. clandestinus* with different harvest frequencies, doses of dolomite lime and organic matter during the rainy period.

Factor	PH	LL	LW	CC	NGL	DMP	DGR
		cm		SPAD		g m^2	kg DM ha^{-1} d^{-1}
Harvest frequency, days							
28	14,1[b]	12,7[b]	0,43[b]	32,7	5,6	154[b]	55,0[b]
35	21,8[ab]	12,5[b]	0,42[b]	33,6	6,6	363[a]	103,9[a]
42	23,9[a]	16,8[a]	0,49[a]	33,9	6,3	307[a]	73,2[b]
49	26,0[a]	18,0[a]	0,49[a]	32,9	6,3	326[a]	66,5[b]
56	29,0[a]	19,7[a]	0,50[a]	31,5	6,1	340[a]	60,7[b]
SEM	1,50	0,61	0,01	0,99	0,27	18,0	4,5
Dolomite lime, t ha^{-1}							
0	23,0	16,3	0,47	33,1	6,2	294	71,3
3	23,6	16,4	0,47	34,1	6,3	311	74,5
6	22,3	15,1	0,46	31,6	6,1	289	69,9
SEM	0,67	0,77	0,01	0,67	0,17	14,4	3,5
OM, t ha^{-1}							
0	21,1	15,2	0,43	30,5	5,8	306	73,2
2	24,9	16,6	0,51	32,9	6,2	303	73,5
4	24,0	17,3	0,49	35,1	6,2	291	70,2
6	22,0	14,7	0,43	33,0	6,4	292	70,6
SEM	1,48	1,33	0,03	0,57	0,25	23,1	6,1
Effects							
Harvest frequency	*	*	*	NS	NS	**	**
Dolomite lime	NS	NS	NS	+	NS	NS	NS
OM	NS	NS	NS	NS	NS	NS	NS
Dolomite lime effect	NS	NS	NS	Q	NS	Q	Q
OM effect[1]	Q	Q	Q	Q	L	NS	NS

PH: pasture height, LL: leaf length, LW: leaf width, CC: concentration of chlorophyll, NGL: number of green leaves, DMP: dry matter production, DGR: daily growth rate, SEM: standard error of the mean
[1]L linear effect, Q quadratic effect
[a,b] Different letters within the same treatment show significant differences
NS: not significant
*p < 0,05 ** p < 0,01

and 422 $COP per kilogram of DM and N, respectively, and 9,2 $ COP per Mcal of N_LE. Meanwhile, the application of 1 t of OM increased 21,3 and 748 $ COP per kg of DM and N, respectively, and 16,6 $COP per Mcal of N_LE (table 6).

Discussion

Agronomic and compositional response of the pasture C. clandestinus. Phenotypical variation was shown in northern Antioquia, affected by geography, altitude and management (Arango-Gaviria *et al*., 2017). There was also relation among the days of regrowth, PH and DMP (Fonseca *et al*., 2016; Benvenutti *et al*., 2020; Avellaneda-Avellaneda *et al*., 2020). In this experiment, a short regrowth period or higher harvest frequency decreased PH, LL and DMP, in the dry and rainy periods (tables 2 and 4). In the rainy season the DMP also increased with regards to the dry season. This result contrasts with studies conducted in Costa Rica, which report higher DMP in dry seasons (Nuñez-Arroyo *et al*., 2022). This difference could have been given by the environmental conditions, such as solar radiation. However, it is necessary to corroborate this hypothesis. Likewise, rainfall is a factor for the DGR to vary in time, as is shown in this experiment, and in the report by Correa *et al.* (2018). This study proved that

Table 3. Chemical composition of the pasture *C. clandestinus* with different harvest frequencies, doses of dolomite lime and organic matter during the rainy period.

Factor	CP	SCP	NDF	ADF	NSC	Ca	P	DMD	N_LE
	%								Mcal kg^{-1}
Harvest frequency, days									
28	16,7[a]	38,9	58,1	34,9	6,5[b]	0,25	0,30	61,8	1,27
35	16,3[ab]	39,7	58,4	35,3	7,6[a]	0,23	0,31	61,3	1,26
42	16,1[ab]	39,6	58,4	34,9	6,6[b]	0,26	0,31	61,4	1,26
49	15,9[ab]	38,9	59,5	35,8	6,7[b]	0,27	0,29	61,7	1,25
56	15,6[b]	38,9	58,3	35,7	7,0[b]	0,27	0,28	60,9	1,24
SEM	0,15	0,48	0,61	0,41	0,08	0,02	0,01	0,79	0,01
Dolomite lime, t ha^{-1}									
0	16,3	39,2	58,9	35,7	6,8	0,24[b]	0,30	61,7	1,26
3	16,3	39,2	57,6	35,0	6,9	0,26[a]	0,29	61,4	1,26
6	15,7	39,2	59,1	35,2	6,9	0,26[a]	0,30	61,1	1,24
SEM	0,29	0,58	0,65	0,33	0,10	0,01	0,01	0,34	0,01
OM, t ha^{-1}									
0	15,7	34,8	59,0	35,0	7,0	0,27	0,30	61,4	1,26
2	16,3	43,4	58,3	35,2	6,5	0,24	0,28	61,8	1,27
4	17,0	38,3	57,4	35,1	7,5	0,26	0,30	62,0	1,27
6	15,4	40,2	59,5	35,9	6,6	0,26	0,30	60,5	1,22
SEM	0,53	3,14	0,89	0,53	0,48	0,03	0,01	0,28	0,01
Effects									
Harvest frequency	*	NS	NS	NS	**	NS	+	NS	NS
Dolomite lime	NS	NS	NS	NS	NS	*	NS	NS	NS
OM	NS	NS	NS	NS	NS	NS	NS	NS	NS
Effect of dolomite lime	L	NS	Q	NS	NS	L	NS	NS	NS
Effect of OM	Q	NS	Q	L	NS	Q	NS	Q	Q

CP: crude protein, SCP: proteína bruta soluble, NDF: neutral detergent fiber, ADF: acid detergent fiber, NSC: non-structural carbohydrates, Ca: calcium, P: phosphorus, DMD: dry matter digestibility, N_LE: net lactation energy
SEM: standard error of the mean
L: linear effect, Q: quadratic effect
[a,b] Different letters within the same treatment show significant differences.
NS: not significant
*p < 0,05 **p < 0,01

the harvest frequency of 35 and 39 days showed the highest DGR for the two periods, ad that the rainy period stood out. The literature refers that the DGR of the pasture *C. clandestinus* is between 23 and 144 kg DM ha^{-1} d^{-1} in the Colombian high tropic, but is affected by the environmental conditions and pasture management (Fonseca *et al*., 2016: Correa *et al*., 2018; Vargas-Martínez *et al*., 2018; Escobar-Charry *et al*., 2020).

Plasticity allows plants to modify the morphological characteristics in the face of the external stress that disturbs their density or the orientation of leaves and stems (Sollenberger *et al*., 2020b). Altitude has effect on the morphology of *C. clandestinus* (Arango-Gaviria *et al*., 2017; Escobar-Charry *et al*., 2020). In addition, the pasture can modify some characteristics when defoliation increases, maintaining the same number of GL. Yet, it is necessary to prove this hypothesis in future experiments.

The effect of NL and non-static frequency have been evaluated in other experiments (Fulkerson *et al*., 1999). Thus, a large number of leaves per stem or regrowth period was related to higher biomass production and plant height (Fonseca *et al*., 2016).

Table 4. Agronomic response of the pasture *C. clandestinus* with different harvest frequencies, doses of dolomite lime and OM during the dry period.

Factor	PH	LL	LW	CC	NGL	DMP	DGR
		cm		SPAD		g m^2	kg DM ha^{-1}d^{-1}
Harvest frequency, days							
28	10,0^b	7,3^b	0,42	30,8	4,7	38,1^d	13,6^c
35	12,1^b	7,5^b	0,52	32,6	4,8	81,2^c	23,2^b
42	16,7^{ab}	9,3^{ab}	0,45	34,5	5,6	99,2^b	23,6^b
49	18,7^a	11,3^a	0,45	33,8	5,7	148,9^a	30,4^a
56	13,0^{ab}	9,4^{ab}	0,41	33,6	5,8	148,7^a	26,5^{ab}
SEM	0,99	0,46	0,07	1,20	0,25	3,4	0,90
Dolomite lime, t ha^{-1}							
0	14,3	8,4	0,50	33,2	5,4	104,1	23,8
3	14,5	9,2	0,43	33,6	5,4	98,5	22,3
6	13,6	8,7	0,43	32,5	5,2	107,1	24,2
SEM	0,28	0,41	0,05	0,51	0,13	7,0	1,70
OM, t ha^{-1}							
0	14,6	8,8	0,49	32,1	5,5	110,7	25,5
2	12,4	8,2	0,44	33,0	5,2	84,1	19,1
4	15,8	8,9	0,43	33,2	5,1	115,9	26,2
6	13,6	9,1	0,45	33,9	5,4	102,2	23,1
SEM	1,67	0,66	0,06	0,96	0,07	14,5	3,20
Effects							
Harvest frequency	*	*	NS	NS	+	***	**
Dolomite lime	NS	NS	NS	NS	NS	NS	NS
OM	NS	NS	NS	NS	+	NS	NS
Dolomite lime effect	Q	NS	NS	NS	NS	Q	Q
OM effect[3]	NS	NS	NS	NS	Q	NS	NS

PH: plant height, LL: leaf length, LW: leaf width, CC: Concentration of chlorophyll, NGL: green leaves, DMP: dry matter production, DGR: daily growth rate, SEM: standard error of the mean, L: linear effect, Q: quadratic effect.
[a,b,c] Different letters within the same treatment show significant differences
NS: not significant; +; P<0,1*p < 0,05 **p < 0,01; **p < 0,01; ***p < 0,001

However, the leaf emergence rate is associated with the altitude or ambient temperature (Escobar-Charry *et al*., 2020). In this experiment, there was no relation between frequency and number of GL during the rainy or dry season (tables 2 and 4), which suggests that the pasture *C. clandestinus* can maintain a constant number of available leaves for photosynthesis.

There is little information about the effect of the application of dolomite lime and OM on the agronomic response of *C. clandestinus*. The incorporation of dolomite lime is a common recommendation in the Colombian high tropic, due to the low pH levels and high aluminum levels in the soil, which causes low productivity of crops and pastures, especially of legumes (Osorno-Henao, 2012). The pasture *C. clandestinus* showed reduction in the yield and nutritional value, when the soil pH was below 4,5 (Awad *et al*., 1976). In contrast, the application of OM improved the biomass production and the soil physical properties and humidity (Apráez and Moncayo, 2003; Ruiz, 2007).

The application of dolomite lime increased the DMP in the pasture *C. clandestinus* in Antioquia (David-Giraldo *et al*., 2020). A similar result was obtained in this experiment, where the application of 3 t ha^{-1} of dolomite lime showed a quadratic response, increasing the biomass production and

Table 5. Chemical composition of the pasture *C. clandestinus* with different harvest frequencies, doses of organic matter and dolomite lime during the dry season.

Factor	CP	SCP	NDF	ADF	NSC	Ca	P	DMD	N_LE
	%								Mcal kg^{-1}
Harvest frequency, days									
28	19,2	51,2[a]	50,4[ab]	31,7[ab]	4,8	0,41[b]	0,26	64,8	1,33
35	20,0	48,3[ab]	46,7[b]	30,9[b]	4,9	0,49[ab]	0,24	65,7	1,35
42	19,0	51,0[ab]	50,0[ab]	31,1[ab]	4,3	0,41[b]	0,26	64,8	1,33
49	18,2	48,9[ab]	52,0[a]	33,2[a]	4,5	0,48[ab]	0,25	63,6	1,31
56	19,1	46,9[b]	48,0[ab]	31,0[ab]	4,5	0,55[a]	0,25	65,0	1,34
SEM	0,43	0,53	0,61	0,40	0,16	0,02	0,01	0,42	0,01
Dolomite lime, t ha^{-1}									
0	18,8	48,9	50,3[b]	32,2	5,2	0,42	0,25	64,4	1,32
3	19,1	49,3	49,2[ab]	31,4	5,3	0,46	0,25	64,9	1,34
6	19,3	49,6	48,8[a]	31,2	5,2	0,47	0,25	65,1	1,34
SEM	0,28	0,26	0,38	0,34	0,16	0,01	0,01	0,33	0,01
OM, t ha^{-1}									
0	20,2	51,5	48,1	30,1	5,2	0,48	0,26	66,1	1,36
2	17,4	47,6	52,3	33,9	4,8	0,38	0,24	62,7	1,28
4	19,4	49,8	48,2	30,9	5,6	0,46	0,25	65,2	1,34
6	19,4	48,1	49,1	31,5	5,3	0,47	0,25	65,1	1,34
SEM	1,06	2,20	1,80	1,70	0,20	0,03	0,01	1,4	0,03
Effects									
Harvest frequency	NS	*	*	*	+	*	NS	NS	NS
Dolomite lime	NS	NS	*	NS	NS	NS	NS	NS	NS
OM	NS	NS	NS	NS	NS	NS	NS	NS	NS
Effect of dolomite lime[3]	L	NS	L	L	NS	L	NS	L	L
Effect of OM	Q	NS	Q	NS	NS	Q	Q	Q	Q

CP crude protein, SCP soluble crude protein, NDF neutral detergent fiber, ADF acid detergent fiber, NSC non-structural carbohydrates, Ca calcium, P phosphorus; DMD dry matter digestibility; N_LE: net lactation energy.
SEM standard error of the mean, L linear effect, Q quadratic effect
[a,b]. Different letters within the same treatment show significant differences
NS: not significant; +; P<0,1;p<0,1 * p<0,05 ** p<0,01

DGR during the rainy period, but not in the dry one. The application of OM had a quadratic response: 2 and 4 t ha^{-1} increased PH, LL, LW and CC during the rainy season, but not in the dry one. It is evident that the soil moisture increases the effectiveness of OM and dolomite lime. This can be due to better mineralization and absorption of minerals during the rainy season.

Chemical composition and nutritional value of the pasture C. clandestinus with different harvest frequencies and application of dolomite lime and OM. Defoliation events modify the plant metabolism and require the reassignment of organic compounds to replace the lost tissue or maintain the energy reserves (Iqbal *et al.*, 2012). However, the harvest by grazing or defoliation of the pasture *C. clandestinus* showed contradictory results. At higher defoliation frequency, in some cases CP, DMD, NDF, N_LE and total digestible nutrients increase (Escobar-Charry *et al.*, 2020), which did not occur in other studies (Fonseca *et al.*, 2016). This can be explained by the differences in the climate conditions, soil characteristics, pasture management, fertilization schemes, evaluation of the plant strata and regrowth periods (Mila-Prieto and Corredor, 2004; Avellaneda-Avellaneda *et al.*, 2020; Benvenutti *et al.*, 2020). En este experimento, la frecuencia de cosecha afectó de forma directa la composición de *C.*

Table 6. Costs of the pasture *C. clandestinus* with different harvest frequencies and doses of dolomite lime and organic matter

Factors	Level	Daily growth rate	Forage production	Production costs	Costs of DM	Cost of N	N_LE cost
		kg DM ha^{-1} d^{-1}	kg DM ha^{-1} year^{-1}	$ COP ha^{-1}	$ COP kg^{-1}		
Harvest frequency, days	28	39,2	14 308	2 045 000	143	4 944	110
	35	58,8	21 444	2 045 000	95	3 252	73
	42	48,4	17 666	2 045 000	116	4 090	89
	49	48,5	17 703	2 045 000	116	4 207	90
	56	43,6	15 914	2 045 000	129	4 585	99
Dolomite lime, t ha^{-1}	0	47,9	17 484	1 445 000	83	2 923	64
	3	48,2	17 593	2 045 000	116	4 074	89
	6	47,0	17 155	2 645 000	154	5 453	119
OM, t ha^{-1}	0	48,5	17 703	965 000	55	1 875	41
	2	47,4	17 301	1 685 000	97	3 601	76
	4	48,2	17 575	2 405 000	137	4 670	105
	6	46,8	17 064	3 125 000	183	6 506	142

DM: dry matter, N: nitrogen, N_LE: net lactation energy, COP: cost of production

clandestinus in both periods. The higher frequency decreased the concentration of CP and NSC during the rainy period and increased the concentration of NDF, ADF and Ca in the dry period (tables 3 and 5). Those differences can be associated with the forage metabolism with regards to the climate conditions.

During the rainy period, the highest biomass production (table 2) required the utilization of CP and NSC, which reduced those compounds (table 3). A higher frequency also shows higher proportion of leaves and green material, which contains higher concentration of P and NSC than stems and dead material (Fulkerson *et al*., 1999; Benvenutti *et al*., 2020). Nevertheless, during the dry season, the low metabolism of the plants showed a high concentration of nutrients, associated with the structure of the cell wall and a slow DGR (tables 4 and 5).

In contrast, the agroecological conditions, grazing intensity, plant stratum and fertilization, modify the forage composition. In this regard, Avellaneda-Avellaneda *et al.* (2020) suggest that the chemical composition of the pasture *C. clandestinus* shows high variation, associated with the ecological conditions, pasture maturity and rainfall. Fulkerson *et al*. (1999) assert that higher residual biomass increases the concentration of soluble carbohydrates in *C. clandestinus*, due to the higher capacity to store energy reserves and lower proportion of stems in the pasture. In addition, according to Benvenutti *et al.* (2020), the pasture *C. clandestinus* showed that the highest strata of plants (leaves) had higher nutritional value than the lower ones (stems).

Gacheta-Sánchez (2019) states that the chemical fertilization in *C. clandestinus* increases CP, and reduces NDF and ADF. Evidently, C_4 pastures require improving the nutritional value to increase animal efficiency (Fulkerson *et al*., 1999). However, *C. clandestinus* showed variation, due to external factors, such as environment and management. This hinders defining a general recommendation. For such reason, it is necessary to recognize the local conditions and management practices to maximize the nutritional value of *C. clandestinus*.

There are still doubts about the effect of the application of dolomite lime and OM on the chemical composition of the pasture *C. clandestinus*. However, it is known that when pig purines are applied the concentrations of N, Ca and P increase (Orozco, 1988), and that chicken dung increases the CP concentrations (Arcos-Alvarez *et al*., 2021). Also, Apráez and Moncayo (2003) and Ruiz (2007) did not find effect of different sources and doses of OM on the chemical composition of *C. clandestinus*. That is why it is important to mention that integral fertilization (microbiological, chemical and organic) has potential to improve efficiency in fertilization plans (Paungfoo-Lonhienne *et al*., 2019). In this experiment, the application of OM increased the CP, $N_L E$ and DMD, and the NDF concentrations decreased during the rainy period. In contrast, 2 t ha^{-1} reduced the concentrations of CP, Ca, P, $N_L E$, and DMD and increased NDF during the dry season (table 3 and 5). On the other hand, the application of dolomite lime increased the CP and fiber concentrations in different forages (Bobadilla-Rivera *et al.*, 2018). The application of dolomite lime showed linear effect with increase of Ca and reduction of the CP concentration during the rainy period, but in dry seasons the CP and Ca concentrations, DMD and $N_L E$ increased. Finally, like the agronomic response, soil humidity can define the different responses of nutrient concentrations of the pasture *C. clandestinus* during the rainy and dry seasons.

Effect of the harvest frequency and application of dolomite lime and OM on the costs of the pasture C. clandestinus. The costs of forage are related to soil type, presence of plants, management practices, type and application rate of the products, presence of diseases and pests, climate conditions, and other factors that vary with regards to the production system. There is little information about the production costs of the pasture *C. clandestinus*. Gómez-Vega *et al.* (2019) reported that the costs of 1 kg DM of the pasture *C. clandestinus* is 109,9 \$COP kg^{-1} under traditional management in the Bogotá Savanna. However, they do not mention management practices or grazing frequencies. In this experiment, the harvest frequency of 35 days showed that the lowest cost of the kg DM (95\$COP, table 6) was due to higher (103,9 kg \$DM d^{-1}) and moderate DGR (23,2 kg DM d^{-1}) during the rainy and dry seasons, respectively (table 2 and 4). Meanwhile the harvest frequency of 28 days had the highest cost (123\$COP) (table 6), because of the low DGR during the evaluation period (average of 34,4 kg DM d^{-1}, table 2 and 4). In this sense, the optimum harvest frequency should vary in the course of the year to maximize the use of biomass and reduce forage costs.

Ruiz (2007) referred that the application of pig, hen, cow or Guinea pig purines increased the cost of *C. clandestinus* by 94, 36, 82, and 89 \$COP kg^{-1} DM compared with no application of OM. Alayón-García (2014) mentioned that biofertilizers reduced the cost-effectiveness of the farm and are not recommended as long-term strategy. In this experiment, one ton of OM or dolomite lime increased 11,9 and 422 \$COP the cost of each kg of DM, respectively. Due to the above-explained facts, the evaluation of an optimum level of dolomite lime and OM should be determined with regards to the response of forage and the production cost in each production system. However, it is necessary to evaluate the long-term effect of the application of dolomite lime and OM on forage production and nutritional value to generate practical recommendations for farmers.

It is concluded that to maximize forage production of the pasture *C. clandestinus*, the harvest frequency should be different during the rainy and dry seasons. Maintaining a constant harvest or grazing frequency throughout the year is not a good practice. In addition, the application of dolomite lime and OM did not increase the DMP or the nutritional value of *C. clandestinus* during the evaluated period. The soil and environment characteristics can define the efficacy of the application of dolomite lime and OM. Long-term experiments should be conducted under other climate and soil conditions to evaluate the effect of dolomite lime and OM. Finally, it is important to consider for future works the microorganisms, macrofauna and physical composition of the soil in order to have better results.

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Conflict of interests

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

Authors' contribution

- Edgar Augusto Mancipe-Muñoz. Conceptualization and experimental design, data compilation and analysis, writing and revision.
- Javier Castillo-Sierra. Data compilation and analysis, writing and revision.
- Yesid Avellaneda-Avellaneda. Conceptualization and experimental design, data compilation and analysis, writing and revision.
- Juan de Jesús Vargas-Martínez. Conceptualization and experimental design, data compilation and analysis, writing and revision.

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