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Fertilization and defoliation drive the structure and productivity of Kikuyu grass *Cenchrus clandestinus* (Hochst. ex Chiov.) Morrone

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La fertilización y la defoliación determinan la estructura y la productividad del pasto Kikuyo Cenchrus clandestinus (Hochst. ex Chiov.) Morrone

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ABSTRACT

Keywords:
Nitrogen fertilization
Residual height
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Tiller density

Forage management practices, such as defoliation intensity and fertilization, have the potential to modify forage structure and productivity, thereby enhancing the sustainability of forage-based systems. This study examined how defoliation intensity (residual height, RH) and fertilization affect the growth and structure of Kikuyu grass (*Cenchrus clandestinus)* in the Colombian highlands. The experiment design was a split-plot with three blocks. Residual height (6 or 12 cm) was the main plot, fertilization level (control, medium, and high) was the subplot, and time was a continuous factor (accumulated days of the test). Kikuyu grass plots were defoliated at a five-leaf stage for 14 months. The following variables were measured: interval between defoliation (IBD), leaf length (LL), the number of dead leaves (NDL), undisturbed plant height (UPH), tiller density (TD), quantity (QST) and length (LST) of secondary tillers, daily growth rate (DGR), leaf area index (LAI), and plant composition (leaves, stems, and dead material). Fertilization reduced TD, QST, dead material and leafiness when Kikuyu grass was cut at 6 cm but not 12 cm. Plants required a longer regrowth period (+8 d) to reach five leaves, had fewer NDL (-0.2) and shorter LL (-1.5 cm), but grew faster (+19%) and had more stems and a lower (-46%) leaf-stem ratio when cutting at 6 cm compared to 12 cm. Fertilization reduced defoliation interval (-2.4 days) and increased UPH (+4.7 cm) and DGR (+13 kg DM per day). In conclusion, defoliation of Kikuyu grass at 12 cm, combined with nitrogen applications (274 and 462 kg N ha^{-1} per year), produces leafy plants and reduces defoliation intervals.

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RESUMEN

Palabras clave:
Fertilización nitrogenada
Altura residual
Estolonífero
Densidad de macollos

El manejo de los pastos como son, la intensidad de la defoliación y la fertilización tienen el potencial para modificar la estructura, la productividad y la sostenibilidad de los pastos. Este estudio examinó cómo la intensidad de la defoliación (altura residual, AR) y la fertilización modifican el crecimiento y la estructura del *Cenchrus clandestinus* (pasto Kikuyo) en el trópico alto colombiano. El experimento utilizó un diseño de parcelas divididas con tres bloques. La altura residual de defoliación (6 o 12 cm) fue la parcela principal, el nivel de fertilización (control, medio y alto) fue la subparcela y el tiempo fue un factor continuo (días acumulados del ensayo). Las parcelas de Kikuyo fueron defoliadas en el estado de cinco hojas durante 14 meses. Se midió el intervalo de defoliación (ID), la longitud de las hojas (LH), el número de hojas muertas (NHM), la altura de la planta (AP), la densidad de los macollos (DM), la cantidad y longitud de los macollos secundarios (CMS) (LMS), y la tasa de crecimiento diario (TDC), índice de área foliar (IAF) y la composición vegetal (hojas, tallos y material muerto). La fertilización redujo la DM y la CMS, el material muerto y la frondosidad cuando el Kikuyu se cortó a 6 cm, pero no a 12 cm. Las plantas cortadas a 6 cm tardaron más (+8 días) en alcanzar cinco hojas, tuvieron menos NHM (-0,2) y LH más cortos (-1,5 cm), pero crecieron más rápido (+19%) y tuvieron más tallos y una menor relación hoja-tallo (-46%), con respecto a las cortadas a 12 cm. La fertilización redujo el intervalo de defoliación (-2,4 días), aumentó la AP (+4,7 cm) y mejoró la TDC (+13 kg MS por día). En conclusión, la intensidad de la defoliación y la fertilización a lo largo del tiempo generan cambios en variables estructurales como DM, CMS, acumulación de tallos y proporción de hojas de

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In Colombia, approximately 2,538,290 hectares in the high-altitude Andes (>1,800 meters above sea level (masl)) are suitable for producing Kikuyu grass (*Cenchrus clandestinus* (Hochst. ex Chiov.) Morrone) (Acero-Camelo et al. 2020; UPRA 2019). This stoloniferous and invasive species grows well at high altitudes (1,800 to 2,800 masl) (Arango-Gaviria et al. 2019), and is crucial for dairy production systems (Carulla and Ortega 2016). Kikuyu grass is a low-cost feed source for grazing animals (Vargas et al. 2018). Kikuyu grass pasture is managed empirically (fertilization, rest periods, defoliation) in commercial systems and often uses electric fences in rotational grazing (Carulla and Ortega 2016). Its productivity is highly variable (5 to 25 t DM ha^{-1} per year), mainly influenced by environmental factors such as precipitation, soil characteristics, and altitude (Vargas et al. 2018) as well as management practices (Acero-Camelo et al. 2020).

However, defoliation intensity (i.e., remaining height after grazing or cutting) (Ferri et al. 2015) and nitrogen application modify the productivity and structure of Kikuyu pastures (Acero-Camelo et al. 2020; Martins et al. 2020; Viljoen et al. 2020). Increasing defoliation intensity (i.e., less residual height) reduces plant height (Correa et al. 2018) and leaf size but increases tiller density (Miqueloto et al. 2020), potentially leading to similar dry matter production (Martins et al. 2020). Conversely, other studies report that greater defoliation intensity reduces residual leaf area, leading to increased reliance on carbohydrate reserves for tiller production, thereby delaying both leaf growth (Martins et al. 2020) and dry matter production (Correa et al. 2018; Molina 2018). Apparent differences among studies may be related to the magnitude of defoliation intensity, where defoliation below 5 cm may compromise plant growth. Furthermore, nitrogen fertilizer increases tillers and leaf growth in stoloniferous grasses like Kikuyu (*Cenchrus clandestinus* (Hochst. ex Chiov.) Morrone) and Pangola (*Digitaria decumbens)*, resulting in larger plants (Cruz and Boval 2000), with a greater tissue (live-to-dead ratio) (Acero-Camelo et al. 2020) and enhanced biomass production (Viljoen et al. 2020).

Despite the existing knowledge, the combined effects of defoliation intensity and fertilization on the structure and growth of Kikuyu grass in the Colombian highlands have not been thoroughly studied, even though they are highly relevant to current Kikuyu pasture-based systems. It was hypothesized that fertilizing Kikuyu grass allows harvest at a lower residual height (6 cm) without reducing dry matter production, which would result in taller plants with more leaves and less dead material than when harvested at greater residual height (12 cm). This study aimed to evaluate the effect of two defoliation intensities and three fertilization levels on Kikuyu grass growth and structure in the highlands of the Colombian Andes.

MATERIALS AND METHODS

Location and experimental conditions

The experiment was conducted at the Tibaitatá Research Center (Agrosavia) in Mosquera (Cundinamarca) at 2,550 masl. (4°35'56''N latitude and 74°04'51''W longitude). An area of 0.1 ha of Kikuyu grass meadow established 30 years ago was selected. A representative soil sample was taken for chemical analysis at the Agrosavia Soil Laboratory. The soil contained adequate levels of most nutrients (except K and S, which were high) but was moderately acidic (Table 1).

Table 1. Chemical characterization of the soil in the experimental area, in a 0-20 cm layer.

pH	OM	Nt	P	S	Fe	Mn	Zn	Cu	B	Ca	Mg	K	Na	CEC
	%		mg kg^{-1}							cmol kg^{-1}				
5.60	8.64	0.4	73.8	38.3	609	20.0	4.1	3.1	0.60	12.8	4.2	2.1	1.3	20.4

OM: Organic matter, P: phosphorus, S: sulfur, Fe: iron, Mn: manganese, Zn: zinc, Cu: copper, B: boron, Ca: calcium. Mg: magnesium, K: potassium, Na: sodium, CEC: Cation exchange capacity.

The experiment was conducted over a 14-month period, from November 2020 to December 2021. During this time, the average monthly precipitation was 107 mm, solar radiation was 122 h of light, and the mean temperature was 13.5 °C (Table 2).

Table 2. Distribution of monthly average precipitation, brightness, and temperature during the experimental period in Tibaitatá, Cundinamarca-Mosquera (November 2020 to December 2021).

Year	Month	Temperature (°C)	Precipitation (mm per month)	Brightness (h per light per month)
2020	November	13.7	180	93.6
	December	13.4	58	164.2
2021	January	13.0	17	183.1
	February	13.8	64	122.3
	March	13.2	174	60.5
	April	14.0	134	115.9
	May	13.9	180	98.4
	June	13.3	138	108.6
	July	13.4	61	122.0
	August	13.3	103	111.6
	September	13.1	59	127.1
	October	13.4	179	118.7
	November	13.5	130	141.5
	December	13.8	42	162.2

°C: degrees centigrade, h: hour, mm: millimeters.

Experimental treatments

A 60 m^2 area was enclosed by a fence and subdivided into 18 plots of 0.9x1.5 m each (six treatments by three replicates). The distance between plots was 1 m, and the plots were located 3 m from the fence edges. The treatments were defined as the combination of two residual heights (6 and 12 cm), obtained by adjusting the cutting height using an adjustable base frame, and three levels of chemical fertilization (control, medium, and high (Table 3)) defined according to soil analysis and crop extraction levels, to achieve three growth rates of Kikuyu grass based on the historical performance in the research station and following the methodology of Pezo and García (2018). Fertilization of P and N was applied using diammonium phosphate and urea. Additionally, magnesium sulfate (350 kg ha^{-1} per year) was applied to balance cationic relationships. Initially, annual fertilization was split into applications based on a 40-day regrowth period. Forty days was the estimated period for Kikuyu grass tillers to reach five leaves under the environmental conditions of the experiment (preliminary study). However, because the treatments affected the days of regrowth, the fertilizer dose was adjusted after each defoliation to ensure that the annual fertilization level initially proposed (kg ha^{-1} per year) was achieved.

Table 3. Evaluated fertilization levels by year.

Fertilization	Projected growth rate (kg DM ha^{-1} per day)	N (kg ha^{-1} per year)	P_2O_5 (kg ha^{-1} per year)
Control	20	0	0
Medium	40	274	6.8
High	60	461	60.3

N: nitrogen; P_2O_5: phosphorus pentoxide. DM: dry matter.

Experimental management

Sixty days before the experiment began, the experimental area was mowed to a height of 6 cm to homogenize height and regrowth age. Following a 40-day regrowth period, plots were mowed according to defoliation treatment and fertilized on the same day. Subsequently, treatment plots were mowed and re-fertilized once 80% of the tillers reached the target number of five leaves. The percentage of tillers reaching the target leaf stage was estimated by counting leaves on 15 tillers per plot every three days, starting from week two of the regrowth period.

Additionally, after the first defoliation (Experimental Day 0), five tillers per plot were identified and marked using clip hooks and black wire (8 caliber) for monitoring the structural variables individually. When a selected tiller died, it was replaced by another with similar characteristics.

Variables measured

Proportion of leaf, stem, dead material and forage mass

These variables were determined in two steps: a) At each defoliation event and within each plot, an area of 0.25 m^2 was randomly selected and harvested at the defined height (i.e., 6 or 12 cm). This sample was weighed using a portable scale (Ohaus, V11C6) and separated into three fractions: leaves, stems, and dead material. Each fraction was dried for 48 h at 65 °C in a forced-air oven (Grieve-Hendry Co., INC.) to determine its dry matter percentage (DM), calculated as the ratio of dry forage weight to fresh weight. b) The remaining forage from each plot was then harvested to a residual height of 6 or 12 cm using scissors and a 1.1 m^2 adjustable base frame, and weighed using a portable scale (Ohaus, V11C6). The two harvested masses (from the 0.25 and 1.1 m^2 frames) were added to estimate the total forage mass per plot, incorporating each fraction's dry matter percentage and fresh weight.

Plant structure

Before harvest, the following variables were determined for five marked tillers in each plot: a) the undisturbed height of each tiller, b) size (length) and the number of secondary tillers (aerial branches of the main tiller), c) the number of alive and dead leaves, and d) length of the leaf blade. A ruler was used to measure the undisturbed height and length of secondary tillers and leaf blades. Undisturbed height was measured from the ground to the top of the canopy. The length of secondary tillers was measured from their origin (i.e., main tiller) to the endpoint in the canopy. The length of leaves was measured from the base of the blade (Ligule) to the apex of the blade. The number of alive and dead leaves per tiller was counted from the bottom of the tiller to its top. A leaf was considered dead if more than 50% of its blade was yellow or brown. Leaves at the tiller base with ruptured or damaged blades were excluded from this count, as they were assumed to be remnants of the previous harvest.

Subsequently, the leaf area index (LAI) and tiller density were also measured in each plot. The LAI was measured on the leaf fraction harvested from the 0.25 m^2 sampling area using a portable laser meter (CID Bio Science model CI-202). The leaf area index was calculated using Equation 1 (Molina 2018).

$$LAI = (\text{Leaf area}/\text{soil area}) \qquad (1)$$

Tiller density was measured at three random points within each plot. For this, tillers located in a 10x10 cm (0.01 m^2) frame were harvested and counted. The leaf appearance rate (LAR) was calculated using the number of alive leaves and the regrowth age in each plot at the time of harvest.

Statistical analysis

The morphometric and productive variables were analyzed using a split-plot design with repeated measures over time employing the MIXED procedure of SAS® (2017). The main plot was the residual height, and the sub-plot was the fertilizer levels, randomized in three blocks (replications). Because the treatments modified the time required to reach five leaves per tiller, sampling the different plots was not carried out on the same date. Therefore, sampling was not considered a discrete factor. However, to estimate the cumulative effect of the treatments over time, the accumulated days at the time of each harvest (sampling) were included in the model as a continuous variable. In addition, the average of the recorded environmental variables (precipitation, brightness, and temperature) was included as a covariate during each plot's growth period. The interactions between the factors (treatments) and time were tested (e.g., accumulated days x residual height; accumulated days x fertilization; accumulated days x residual height x fertilization). When these interactions were not significant (*P*>0.05), they were excluded from the final model. Finally, the main factors and their interaction were evaluated using the PDIFF option for least-squares means (LSMEANS) with a significance level of 5%. The linear model is described in Equation 2:

$$Y_{ijks} = \mu + \beta_1(X_{ij} - \overline{X}..) + \rho_i + \tau_j + \eta_{ij/s} + \alpha_k + (\tau\alpha)_{jk} + (\alpha\eta)_{ijk/s} + \varepsilon_{ijk} \quad (2)$$

Where, i =1,2,3; j=1,2; k=1,2,3, s is the continuous time interval, Y_{ijk} are the response variables, μ is the overall mean; ρ_i is the effect of the i -th block; τ_j is the effect of the j -th residual height, $\eta_{ij/s}$ is the random error of the main plot (block x height residual) with the effect of with the effect of time s on the main plot, α_k is the effect of k -th fertilizer level, $(\tau\alpha)_{jk}$ is the interaction between residual heights and fertilization levels, β_1 is the linear regression coefficient corresponding to the covariates precipitation, brightness and temperature; being X_{ij} the value of the covariate in the i -th block, j -th plot (residual height), and $\overline{X}..$ is the general average of the covariate, $(\alpha\eta)_{ijk/s}$ is the interaction of the s time interval with the entire plot and ε_{ijk} is the experimental error of the subplot (fertilizer).

Different covariance structures were evaluated for the mixed model. The final model was selected based on the criterion of Schwarz Bayesian Information Criterion (BIC), with the structure exhibiting the lowest BIC value deemed most appropriate for the dataset. Interactions between experimental factors and time were evaluated using a test of the homogeneity of slopes.

RESULTS AND DISCUSSION

This research evaluated whether the morphological and productive responses of Kikuyu pastures to defoliation intensity were consistent under different nutrient inputs (fertilization). Defoliation frequency was maintained at a fixed physiological stage (five leaves per tiller), a stage previously identified in studies (Acero-Camelo et al. 2020) as optimizing digestible nutrient yield. The response of Kikuyu grass to fertilization and defoliation intensity (i.e., residual pasture height) was independent for most variables measured (11/16). Only for a few variables (5/16) did the plant's response to defoliation vary with nutrient input (Tables 4 and 5).

Table 4. Structural response and tiller number of Kikuyu grass *(Cenchrus clandestinus)* to management under two residual heights (RH) and three fertilization levels (2020-2021).

Variable[1]	Defoliation interval (d)	LAR ($l\ d^{-1}$)	LAI ($m^2\ m^{-1}$)	Tillers (No. m^{2-1})	Plant height (cm)	Dead leaves (No. $Plant^{-1}$)	Secondary tillers, (No. $Plant^{-1}$)	Blade length (cm)	Secondary tillers length (No. $Plant^{-1}$)
					Interaction[2]				
					RH (6 cm)				
Control	47.4 *(0.82)*	0.106 *(0.002)*	3.7 *(0.38)*	16189^{aA} *(331)*	13.6 *(0.49)*	1.5 *(0.13)*	1.5^{a} *(0.14)*	5.2 *(0.33)*	9.5 *(0.61)*
Medium	44.9 *(0.83)*	0.113 *(0.002)*	4.5 *(0.38)*	13759^{bA} *(333)*	15.7 *(0.50)*	1.5 *(0.13)*	1.7^{a} *(0.15)*	6.4 *(0.96)*	8.9 *(0.64)*
High	44.3 *(0.84)*	0.114 *(0.002)*	6.5 *(0.39)*	12012^{cA} *(339)*	17.4 *(0.50)*	1.1 *(0.13)*	0.7^{b} *(0.15)*	7.5 *(0.34)*	10.8 *(0.68)*
					RH (12 cm)				
Control	39.0 *(0.79)*	0.129 *(0.002)*	3.0 *(0.36)*	13179^{aB} *(316)*	17.2 *(0.48)*	1.7 *(0.12)*	1.6^{a} *(0.14)*	6.7 *(0.32)*	9.7 *(0.58)*
Medium	37.9 *(0.75)*	0.133 *(0.002)*	4.5 *(0.34)*	11482^{bB} *(301)*	19.5 *(0.46)*	1.5 *(0.11)*	1.3^{a} *(0.13)*	8.1 *(0.30)*	11.0 *(0.55)*
High	36.2 *(0.75)*	0.140 *(0.002)*	5.5 *(0.34)*	10882^{bB} *(302)*	22.8 *(0.46)*	1.6 *(0.12)*	0.9^{b} *(0.13)*	9.0 *(0.30)*	10.9 *(0.62)*

Table 4

Variable[1]	Defoliation interval (d)	LAR (l d^{-1})	LAI (m^2 m^{-1})	Tillers (No. m$^{2-1}$)	Plant height (cm)	Dead leaves (No. Plant^{-1})	Secondary tillers, (No. Plant^{-1})	Blade length (cm)	Secondary tillers length (No. Plant^{-1})
					Main Factors[2]				
					RH (cm)				
6	45.5^a *(0.49)*	0.111^b *(0.001)*	4.9 *(0.22)*	13987 *(196)*	15.6 *(0.35)*	1.4^b *(0.08)*	1.3 *(0.09)*	6.4^b *(0.36)*	9.7 *(0.37)*
12	37.7^b *(0.45)*	0.134^a *(0.001)*	4.3 *(0.21)*	11848 *(180)*	19.9 *(0.33)*	1.6^a *(0.07)*	1.2 *(0.08)*	7.9^a *(0.18)*	10.5 *(0.34)*
					Fertilization				
Control	43.2^a *(0.57)*	0.118^b *(0.002)*	3.3 *(0.26)*	14684 *(228)*	15.4^c *(0.34)*	1.6 *(0.09)*	1.5 *(0.10)*	5.9 *(0.23)*	9.6 *(0.42)*
Medium	41.4^b *(0.55)*	0.123^a *(0.001)*	4.5 *(0.25)*	12620 *(222)*	17.6^b *(0.33)*	1.5 *(0.08)*	1.5 *(0.09)*	7.3 *(0.50)*	10.0 *(0.42)*
High	40.2^b *(0.56)*	0,127^a *(0.002)*	6.0 *(0.26)*	11447 *(224)*	20.1^a *(0.34)*	1.3 *(0.09)*	0.8 *(0.10)*	8.2 *(0.22)*	10.9 *(0.46)*
					Effects[3]				
RH	***	***	+	ns	+	*	*	**	+
F	**	**	ns	***	***	+	+	ns	ns
RH*F	ns	ns	ns	*	ns	ns	***	ns	ns
AD	ns	ns	***	+	***	***	**	ns	***
ADI	ns	ns	F (***)	AR (**)	AR (*)	ns	AR (*) AR*F(**)	F (*)	AR (**)
					Covariates[4]				
P	***	***	*	ns	ns	*	ns	ns	ns
B	ns	ns	ns	ns	***	**	*	+	*
T	ns	ns	ns	ns	ns	ns	*	ns	ns

[a, b, c] Different letters (lowercase) for the "Interaction" effect represent significant differences between fertilization levels at each residual height, and the "Main factors" effect represents significant differences between levels of each factor. [A, B, C] Different letters (uppercase) for the "Interaction" effect represent significant differences between residual heights within each fertilization level. [1]LAR: leaf appearance rate; LAI: leaf area index; cm: centimeter; d: days; l: leaves; m: meter; No: number. [2] Values in parentheses: standard error of the mean. [3] AD: is the effect of time as a continuous factor (accumulated days). ADI: is the effect of the interaction between accumulated days and the factors (only those significant in the model are included); RH: is the interaction effect between AD and residual height. F: is the effect of the interaction between AD and fertilization. RH*F is the effect of the interaction between AD and residual height and fertilization; +: P<0.1; *: P<0.05; **: P<0.01; ***: P<0.001; ns: insignificant. [4] Effect of covariates, P: average precipitation. B: average brightness. T: average ambient temperature.

Morphometric response and number of tillers

Increased defoliation intensity (lower residual height) in Kikuyu plots led to an increased defoliation interval and reduced leaf appearance rate (LAR), dead leaves per tiller, and leaf blade length. These effects were independent of fertilization level. Specifically, tillers in more intensely defoliated plots required, on average, an additional eight days to reach five leaves, exhibited 0.2 fewer dead leaves, and developed leaves 1.5 cm shorter (Table 4).

Mayel et al. (2021) suggest that post-grazing residual height impacts the time a plant needs to replenish its carbon balance, with more severe defoliation implying longer periods to reach a new equilibrium. Furthermore, severe pasture defoliation reduces residual leaf area index (LAI), thereby increasing the time needed to achieve the maximum forage accumulation rate (Martins et al. 2020). Consequently, the pasture relies more heavily on stored carbohydrates for the emergence of new leaves. The observed morphological response of

Kikuyu pastures to defoliation intensity (residual height) aligns with reports on other species. Higher defoliation intensities resulted in a reduced leaf elongation rate, a longer harvest period, changes in sheath tube length, and a marked decrease in leaf length (Gastal and Lemaire 2015).

Conversely, increased fertilization rate decreased the defoliation interval (five leaves per tiller), while increasing LAR and plant height (Table 4). This led to faster leaf emergence rates (+6%), resulting in shorter days to harvest (-2.4 days) and taller plants (+31%) compared to unfertilized plots. Nitrogen fertilization is known to influence both structural characteristics (e.g., increased leaf size and tiller number) and morphogenetic characteristics (e.g., higher leaf appearance and senescence rates) (Paiva et al. 2023). Furthermore, literature indicates that nitrogen enhances Non-Structural Carbohydrate (NSC) reserves at the base of plants (Molina 2018), which may promote faster recovery after defoliation. The use of different fertilizer levels also promotes overall plant growth, manifested as increased height (Sbrissia et al. 2018; Miqueloto et al. 2020) and leaf elongation, particularly with nitrogen doses of 100 - 150 kg N ha^{-1} per year (Acero-Camelo et al. 2020). While faster tiller development due to higher fertilization might suggest quicker senescence, as some studies propose (Delevatti et al. 2019). Plants with increased fertilization showed a decrease in the number of dead leaves.

Kikuyu plants were much more sensitive to defoliation intensity than to fertilization for some variables. The impact of defoliation on LAR was greater than that of increased fertilization and was independent of it, resulting in additive effects of defoliation and fertilization on the days to reach harvest time (five leaves per tiller). Thus, plots with high fertilization and greater residual height underwent 10 defoliations in 1 year, whereas those harvested at a lower residual height and low fertilization experienced only 7.7 defoliations. However, the response of tiller density and the number of secondary tillers was modulated by the intensity of defoliation (6 and 12 cm) and by the fertilization levels (interaction) (Table 4).

Contrary to most reports, the number of tillers per unit of area was reduced with fertilization, but the magnitude of this effect was modulated by pasture height (Table 4). Tiller density increased with reduced residual height and decreased with increased fertilization. However, the magnitude of the reduction in the number of tillers due to fertilization was greater for the lowest residual height (26%) than for the highest (18%). The response of secondary (aerial) tillers to the treatments was less clear: the highest fertilization level significantly reduced secondary tillers (-44% at 6 cm residual height and -63% at 12 cm), but the number of secondary tillers per plant remained similar for both the control and medium fertilization levels across the two residual heights (Table 4). While research on the combined effects of defoliation and fertilization on Kikuyu pasture structure is limited, some reports on stoloniferous grasses indicate an increase in tiller growth associated with fertilization and intense defoliation (Cardoso Sanchês et al. 2020).

In the present study, the number of tillers increased at lower residual heights, suggesting that more severe defoliation stimulates the appearance of new tillers, a finding consistent with Miqueloto et al. (2020) for this species. A greater number of tillers in pastures defoliated more severely is often attributed to the increased light penetration through the pasture canopy (Gastal and Lemaire 2015). It has been reported that greater defoliation intensity can stimulate LAI and tiller growth due to improved light penetration (Martins et al. 2020). However, pastures defoliated more severely are characterized by a greater population of small tillers, whereas those subjected to light defoliation intensity tend to have a lower population of larger tillers (Miqueloto et al. 2020). For Kikuyu grass, Martins et al. (2020) reported that not only did tiller density increase at lower residual heights (7.5 vs 12 cm), but also that at lower grazing intensities (higher residual heights), the tiller death rate increased, contributing to a lower plant density. Similarly, Sbrissia et al. (2018) found a negative linear effect of residual defoliation height (5, 7.5, 10, and 12.5 cm) on the tiller population. Cruz and Boval (2000) have suggested that the number of tillers in a pasture is directly related to LAR. In this study, LAR and LAI showed an inverse relationship with the number of tillers; defoliating to 12 cm resulted in plants with longer leaves, more dead leaves, and greater height compared to those defoliated to 6 cm. Taller plants and longer leaves may prevent light from reaching the base of the plants, thereby limiting the appearance of new tillers, a phenomenon observed by others (Martins et al. 2020). Additionally, a higher LAR can lead to faster senescence and death of lower leaves due to more rapid canopy closure.

Finally, the response of some morphometric variables of Kikuyu plants to management (defoliation, fertilization) became more pronounced over time (accumulated days) (Data not shown). For example, tiller density increased over time in those plots defoliated at a lower residual height and decreased in those defoliated with a higher residual height. Therefore, the difference between the treatments became more evident by the end of the experimental period. Furthermore, LAI increased with increasing days for the high fertilization level treatment, but decreased for the lowest fertilization level treatment, thus magnifying the difference between the treatments over the course of the experiment.

Growth and distribution of Kikuyu parts

Defoliation intensity affected the daily growth rate (DGR), stem proportion, and leaf-to-stem ratio of the Kikuyu pasture. More intensely defoliated plots (6 cm) had a DGR 19% higher than those defoliated at 12 cm and exhibited a greater proportion (+12.5%) of stems. Differences in DGR were primarily associated with a higher accumulation of stems in the more intensely defoliated plots, while the less intense defoliation promoted a greater accumulation of leaves. Therefore, increasing the residual height of the pasture from 6 to 12 cm improved the leaf-to-stem ratio 2.5 times, resulting in a more leafy pasture (Table 5).

Table 5. Productive response and component proportions of Kikuyu grass (*Cenchrus clandestinus*) under two residual heights and three fertilization levels (2020–2021).

Variable[1]	DGR (kg MS ha^{-1} per day)	Accumulation of green leaves (kg DM ha^{-1} per day)	Stem accumulation (kg DM ha^{-1} per day)	Leaves (% dry)	Stem (% dry)	Dead material (% dry)	Leaf: stem
			Interaction[2]				
			RH (6 cm)				
Control	20.9 (2.32)	12.6 (1.47)	6.4^{bA} (0.91)	63.0^{bB} (1.77)	29.5 (1.53)	7.5^{aA} (0.59)	3.1 (1.45)
Medium	36.2 (2.33)	22.9 (1.47)	10.6^{aA} (0.91)	66.0^{abB} (1.78)	27.3 (1.54)	6.7^{aA} (0.59)	3.5 (1.46)
High	37.0 (2.37)	24,4 (1.50)	11.0^{aA} (0.93)	70.8^{aB} (1.82)	24.7 (1.57)	4.5^{bA} (0.60)	4.9 (1.49)
			RH (12 cm)				
Control	18.8 (2.21)	14.1 (1.40)	3.8^{B} (0.87)	80.7^{A} (1.69)	15.6 (1.46)	3.5^{B} (0.76)	9.6 (1.39)
Medium	27.0 (2.10)	22.0 (1.33)	3.9^{B} (0.82)	82.2^{A} (1.61)	13.6 (1.39)	4.2^{B} (0.53)	11.2 (1.32)
High	33.2 (2.11)	26.4 (1.34)	5.3^{B} (0.83)	80 .6^{A} (1.62)	15.1 (1.39)	4.2^{A} (0.53)	8.1 (1.32)
			Main Factors[2]				
			RH (cm)				
6	31.4^{a} (1.37)	20.0 (0.87)	9.4 (0.54)	66.5 (1.05)	27.2^{a} (0.90)	6.2^{a} (0.35)	3.9^{b} (0.86)
12	26.3^{b} (1.26)	20.9 (0.79)	4.3 (0.49)	81.2 (0.96)	14.7^{b} (0.83)	4.0^{b} (0.36)	9.6^{a} (0.79)
			Fertilization				
Control	19.9^{b} (1.59)	13.4^{c} (1.01)	5.1 (0.62)	71.9 (1.22)	22.5 (1.05)	5.5 (0.48)	6.3 (1.00)
Medium	31.6^{a} (1.55)	22.5^{b} (0.99)	7.3 (0.61)	74.1 (1.19)	20.5 (1.03)	5.4 (0.39)	7.3 (0.97)
High	35.1^{a} (1.56)	25.4^{a} (0.99)	8.2 (0.61)	75.7 (1.20)	19.9 (1.03)	4.4 (0.40)	6.5 (0.98)

Table 5

Variable[1]	DGR (kg MS ha^{-1} per day)	Accumulation of green leaves (kg DM ha^{-1} per day)	Stem accumulation (kg DM ha^{-1} per day)	Leaves (% dry)	Stem (% dry)	Dead material (% dry)	Leaf: stem
			Effects[3]				
RH	**	ns	***	***	***	***	***
F	***	***	**	+	ns	ns	ns
RH*F	ns	ns	*	*	ns	*	ns
AD	***	***	**	***	***	ns	***
ADI	ns	ns	ns	ns	ns	ns	AR (***)
			Covariates[4]				
P	*	*	*	*	***	***	***
B	**	**	+	ns	ns	**	**
T	ns	ns	ns	ns	ns	ns	ns

[a, b, c] Different letters (lowercase) for the "interaction" effect represent significant differences between fertilization levels at each residual height, and the "Main factors" effect represents significant differences between levels of each factor. [A, B, C] Different letters (uppercase) for the "Interaction" effect represent significant differences between residual heights within each fertilization level. [1]DGR: daily growth rate; d: day; DM: dry matter; ha: hectare; % dry: dry percentage of harvested material. [2] Values in parentheses: standard error of the mean. [3] AD: is the effect of time as a continuous factor (accumulated days). ADI: is the effect of the interaction between accumulated days and the factors (only those significant in the model are included). RH: is the interaction effect between AD and residual height. F: effect of the interaction between AD and fertilization. RH*F: is the effect of the interaction between AD and residual height and fertilization; +: $P<0.1$; *: $P<0.05$; **: $P<0.01$; ***: $P<0.001$; ns: insignificant. [4] Effect of covariates, P: average precipitation. B: average brightness. T: average ambient temperature.

Higher growth rates in more intensely defoliated stoloniferous pastures have been reported by other authors (Pereira et al. 2018). However, others have found an increase in the DGR of Kikuyu grass at lighter defoliation intensities (15 vs 5cm) (Martins et al. 2020; Molina 2018). Furthermore, Martins et al. (2020) reported DGR for defoliation heights of 7.5 and 12.5 cm as 97 and 147 kg ha^{-1} per day, respectively. These values are higher than, and contrary to, those found in the present study (i.e., lower intensity resulted in greater production).

The differences among trials in the response of Kikuyu pastures to defoliation intensity are unclear. Methodological aspects, such as experimental methods, may explain these discrepancies and require special attention. For example, in the experiment reported by Molina (2018), biomass was measured at ground level, which included the residual forage (stolon, stems, and dead material) below the residual height. In contrast, the present study measured dry matter (DM) only above residual height, a method also used by Benvenutti et al. (2019). While the exact impact of such methodological differences on DGR estimations is difficult to assess, harvesting to ground level can overestimate DGR by including DM for previous growth.

The leaf-to-stem ratio is particularly relevant due to its impact on forage intake, and leafier pasture is a highly desirable characteristic (Marín Gómez et al. 2022). Lighter defoliation in this study resulted in a higher proportion of leaves (Table 5), a finding consistent with other reports. For instance, Sbrissia et al. (2013) found that harvesting pastures at a residual height greater than 10 cm resulted in lower stolon accumulation, which improved the leaf-to-stem ratio compared to harvesting at 5 cm. Similarly, Schmitt et al. (2019) observed that Kikuyu pastures with higher residual heights (15 vs 9.4 cm) had a lower proportion of stems and dead material (10.3 vs 36%). In this study, the significant change in leaf-to-stem ratio (2.5 times) strongly suggests that defoliation intensity has a major effect.

Increased fertilization modified DGR response and leaf accumulation in Kikuyu pastures, and this response was independent of residual height. The daily growth of Kikuyu grass increased by 13.5 kg DM ha^{-1} for both medium and high fertilization levels, compared to the control. Furthermore, with the high level of fertilization, the plants accumulated 47.2% more leaves than when no fertilizer was applied (Table 5).

According to the literature, fertilization is known to increase grass growth and forage production (Sousa et al. 2021) by promoting cell proliferation and increasing plant metabolism (Fathi 2022). Consistent with previous findings, fertilization enhanced plant growth by increasing leaf size and, possibly, leaf width. Balocchi et al. (2021) also suggested that nitrogen fertilization leads to leafier pastures.

However, these results were not entirely consistent with this. Fertilization did increase leafiness (proportion of leaves) in more severely defoliated pastures but not in the lighter ones, and the leaf-to-steam ratio remained unchanged. Changes in the proportion of leaves were primarily explained by differences in dead material rather than a change in the leaf-to-stem ratio itself (Table 5). As reported by others, fertilization increased LAR, which enhanced the daily growth rate of the leaves (Cardoso Sanchês et al. 2020). Therefore, the increased LAI may have enhanced shading at the base of the pasture, stimulating stem elongation (Pereira et al. 2014) and keeping the leaf-to-stem ratio constant due to fertilization. This aligns with the suggestions by Cruz and Boval (2000) that in stoloniferous C_4 grasses, nitrogen stimulates both leaf and internode stem elongation, and that leaf elongation may be limited by stem elongation, keeping leaf-to-stem ratio relatively constant in response to N fertilization.

One of the aims of this research was to determine whether defoliation intensity modified the fertilization response in Kikuyu plots. Significant interactions between these two factors were detected for stem accumulation, leaf proportion, and dead material (Table 5).

Daily stem growth (accumulation rate) was lower for plots defoliated at a higher residual height (12 cm), which resulted in a higher proportion of leaves and a lower total dry matter accumulation in this treatment (Table 5). Furthermore, when plots were defoliated at 6 cm, increased fertilization led to a 40% greater stem growth. However, this response to fertilization on stem growth did not occur with a lighter defoliation (12 cm).

Interestingly, increasing fertilization rates also increased the proportion of leaves and reduced the proportion of dead material in pastures that were more severely defoliated (6 cm), but not in those defoliated at 12 cm (Table 5). Despite this, the proportion of leaves was still greater in pastures defoliated at 12 cm, regardless of the fertilization level. The plots defoliated less intensely (12 cm) also had a lower proportion of dead material, a level comparable only to plots with both higher fertilization and severe defoliation (Table 5).

Research has shown that nitrogen fertilization accelerates development and enhances space occupation (Paiva et al. 2023), increasing the speed at which pastures mature and senesce. Similarly, more intense defoliation has been found to promote the appearance of tillers (Martins et al. 2020). Consistent with these findings, this study found that fertilization decreased the proportion of dead material in the pastures harvested at 6 cm, and this intense defoliation also increased tiller density. In summary, pastures with a greater residual height produced a similar number of leaves but were less productive due to a lower stem growth rate, making them leafier.

CONCLUSION

Pasture management tools, such as defoliation intensity, significantly impacted pasture structure, while fertilization primarily influenced pasture growth. Severely defoliated pastures exhibited higher tiller density and faster growth. They also accumulated more stems and dead material, though their leaf appearance rate was slower. Conversely, less severely defoliated pastures had lower tiller density and less dead material, but a better leaf-to-stem ratio and faster leaf appearance.

Fertilization, particularly with nitrogen, positively influenced production and stimulated the accumulation of green leaves in the Kikuyu grass pastures. It improved the leaf appearance rate but reduced the appearance of new tillers, regardless of defoliation intensity. Stem growth, however, was stimulated by fertilization only in more severely defoliated pastures, where fertilization also reduced dead material. These findings suggest that more severely defoliated pastures are more productive but may have lower quality (i.e., a poorer leaf-to-stem ratio). This quality could be improved by fertilization, leading to greater accumulation and proportion of green leaves.

Effective management of Kikuyu grass, incorporating defoliation at 12 cm and annual applications of 274 or 462 kg of nitrogen per hectare, significantly enhances productivity. This approach results in plants with a higher leaf-to-stem ratio and allows for more frequent defoliation, thereby increasing the pasture's overall production capacity compared to traditional methods lacking fertilization or controlled defoliation.

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CONFLICT OF INTERESTS

The authors declare no conflicts of interest.

REFERENCES

Acero-Camelo A, Pabón ML, Fischer G and Carulla JE (2020) Optimum harvest time for Kikuyu Grass *(Cenchrus clandestinus)* according to the number of leaves per tiller and nitrogen fertilization. Revista Facultad Nacional de Agronomía Medellín 73(3):9243-9253. https://doi.org/10.15446/rfnam.v73n3.82257

Arango-Gaviria J, Echeverry-Zuluaga J and López-Herrera A (2019) Diversity Kikuyu grass *(Cenchrus clandestinus)*: A review. Respuestas 24(2):81-88. https://doi.org/10.22463/0122820X.1834

Balocchi O, Niklitschek M and Loaiza P (2021) Dinámica de crecimiento y calidad nutritiva de una pradera de *Lolium perenne L*. sometida a dos frecuencias de defoliación y dosis crecientes de nitrógeno. Agro Sur 49(2):7-20. https://doi.org/10.4206/agrosur.2021.v49n2-02

Benvenutti MA, Barber DG, Mayer DG et al (2019) Comparison between a laser sensor and mechanical tools to estimate pasture mass in strata of Kikuyu *(Pennisetum clandestinum)* pastures. Animal Feed Science and Technology 249: 31-36. https://doi.org/10.1016/j.anifeedsci.2019.01.013

Cardoso Sanchês SS, Rodrigues RC, Alves de Araújo R et al (2020) Morphogenetic and structural characteristics of gamba grass subjected to nitrogen fertilization and different defoliation intensities. Bioscience Journal 36(5):1676-1686. https://doi.org/10.14393/BJ-v36n5a2020-47944

Carulla E and Ortega E (2016) Sistemas de producción lechera en Colombia: retos y oportunidades. Archivos Latinoamericanos de Producción Animal 24(2):83-87.

Correa HJ, Escalante LF and Jaimes LJ (2018) Efecto de la época del año y la altura remanente posterior al pastoreo sobre el crecimiento y calidad nutricional del pasto Kikuyo *(Cenchrus clandestinus)* en el norte de Antioquia. Livestock Research for Rural Development 30(6). http://www.lrrd.org/lrrd30/6/hjcor30097.html

Cruz P and Boval M (2000) Effect of nitrogen on some morphogenetic traits of temperate and tropical perennial forage grasses. pp. 151-168. In: Lemaire G, Hodgson J, Mraes A, Nabinger C and Carvalho PCF. (eds.). Grassland ecophysiology and grazing ecology. Cabi Wallingford, London, UK. 436 p.

Delevatti LM, Cardoso AS, Barbero RP et al (2019) Effect of nitrogen Application rate on yield, forage quality, and animal performance in a tropical pasture. Scientific Reports 9(1): 7596. https://doi.org/10.1038/s41598-019-44138-x

Fathi A (2022) Role of nitrogen (N) in plant growth, photosynthesis pigments, and N use efficiency: A review. Agrisost 28:1-8. https://doi.org/10.5281/zenodo.7143588

Ferri CM, Sáenz AM and Jouve VV (2015) Términos de uso frecuente en producción y utilización de pasturas. Semiárida Revista Facultad Agronomía UNLPam 25(1): 41-61. https://www.produccion-animal.com.ar/glosarios/02-pasturas.pdf

Gastal F and Lemaire G (2015) Defoliation, shoot plasticity, sward structure and herbage utilisation in pasture: Review of the underlying ecophysiological processes. Agriculture 5(4):1146-1171. https://doi.org/10.3390/agriculture5041146

Marín Gómez A, Laca EA, Baldissera TC et al (2022) Determining the pre-grazing sward height of Kikuyu Grass (*Cenchrus clandestinus* - Hochst. Ex Chiov.) for optimizing nutrient intake rate of dairy heifers. PLoS ONE 17(7):e0269716. https://doi.org/10.1371/journal.pone.0269716

Martins CDM, Schmitt D, Duchini PG, Miqueloto T and Sbrissia AF (2020) Defoliation intensity and leaf area index recovery in defoliated swards: implications for forage accumulation. Scientia Agricola 78(2). http://doi.org/10.1590/1678-992X-2019-0095

Mayel S, Jarrah M and Kuka K (2021) How does grassland management affect physical and biochemical properties of temperate grassland soils? A review study. Grass and Forage Science 76(2):215-244. https://doi.org/10.1111/gfs.12512

Miqueloto T, Bernardon A, Winter FL and Fischer Sbrissia A (2020) Population Dynamics in mixed canopies composed of Kikuyu-grass and Tall Fescue. Agronomy 10(5): 684. https://doi.org/10.3390/agronomy10050684

Molina MRE (2018) Altura de defoliación y recuperación de la pastura de kikuyo *(Cenchrus clandestinus)* en la provincia de Ubaté (Tesis de Maestría). Universidad Nacional de Colombia Sede Bogotá, Colombia. 72 p.

Paiva HS, Sousa SVD, Conceição ECDAD et al (2023) Recommended fertilization and timing of nitrogen fertilization influences the morphogenesis, structural characteristics, and production efficiency on Mombaça grass. Acta Scientiarum. Animal Sciences 45:e60704. https://doi.org/10.4025/actascianimsci.v45i1.60704

Pereira LET, Paiva AJ, Geremia EV and Silva SC (2014) Components of herbage accumulation in elephant grass cvar Napier subjected to strategies of intermittent stocking management. Journal of Agricultural Science 152(6):954-966. https://doi.org/10.1017/

S0021859613000695

Pereira LET, Herling VR, Avanzi JC and Silva SC (2018) Morphogenetic and structural characteristics of signal grass in response to liming and defoliation severity. Pesquisa Agropecuária Tropical 48(1):1-11. https://doi.org/10.1590/1983-40632018v4849212

Pezo D and García FJ (2018) Uso Eficiente de Fertilizantes en Pasturas. Boletín técnico No. 98. 1ª ed. CATIE, Turrialba Costa Rica. 56 p.

SAS (2017) Institute Inc. Online Doc 9.4. SAS Institute Inc., NC, USA.

Sbrissia AF, Euclides V, Barbosa RA et al (2013) Grazing management flexibility in pastures subjected to rotational stocking management: herbage production and chemical composition of Kikuyu grass swards. In: Proceedings of the 22nd International Grassland Congress. The Ecology of Grassland and Forage Ecosystems 22(1):1038-1040. https://uknowledge.uky.edu/igc/22/2-1/2

Sbrissia AF, Duchini PG, Zanini GD, Santos GT, Padilha DA and Schmitt D (2018) Defoliation strategies in pastures submitted to intermittent stocking method: Underlying mechanisms buffering Forage accumulation over a range of grazing heights. Crop Science 58:945-954. https://doi.org/10.2135/cropsci2017.07.0447

Schmitt D, Padilha DA, Medeiros-Neto C et al (2019) Herbage intake by catlte in kikuyugrass pastures under intermittent stocking method. Revista Ciência Agronômica 50(3):493-501. https://doi.org/10.5935/1806-6690.20190058

Sousa CCC, Montagner DB, de Araújo AR et al (2021) La interfaz suelo-planta en *Megathyrsus maximus* cv. Mombasa sometida a diferentes dosis de nitrógeno en pastoreo rotacional. Revista Mexicana de Ciencias Pecuarias 12(4):1098-1116. https://doi.org/10.22319/rmcp.v12i4.5904

UPRA - Unidad de Planificación Rural Agropecuaria (2019) Noticias: Por primera vez en Colombia se identifican las áreas aptas para el cultivo de pastos. Zona UPRA, No. 8. https://www.agronet.gov.co/Noticias/Paginas/Por-primera-vez-en-Colombia-se-identifican-las-%C3%A1reas-aptas-para-el-cultivo-de-pastos.aspx

Vargas J, Sierra A, Mancipe E and Avellaneda Y (2018) El Kikuyo, una gramínea presente en los sistemas de rumiantes en trópico alto colombiano. Revista CES Medicina Veterinaria y Zootecnia 13(2):137-156. https://doi.org/10.21615/cesmvz.13.2.4

Viljoen C, van der Colf J and Swanepoel PA (2020) Benefits are limited with high Nitrogen fertiliser rates in Kikuyu-Ryegrass Pasture Systems. Land 9(6):173-. https://doi.org/10.3390/land9060173