Article

Sustainability Potential of Kikuyu Grass (*Pennisetum clandestinum*) in Livestock Farming of Peru's Highland Regions

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Abstract: Sustainable Kikuyu (*Pennisetum clandestinum*) production in the Peruvian highlands was evaluated through productivity, growth, and chemical composition. This study assessed the effects of nitrogen (N) rate, organic matter application, and cutting frequency on Kikuyu grass's yield, chemical composition, plant height, and growth rate. The experiment followed a randomised block design with split plots. A multivariate analysis of variance (MANOVA) assessed the differences across study factors. Applying 120 kg of N ha^{-1} yr^{-1} raised the protein yield to 3454.53 kg ha^{-1}, with a crude protein (CP) content of 23.54%. Moreover, fencing with cypress (*Cupressus lusitanica*) trees influenced the Kikuyu biomass, producing 19,176.23 kg of dry matter (DM) ha^{-1} yr^{-1} at 8.5–11.5 m from the tree base. Organic matter enhanced the Kikuyu aboveground biomass. While dry matter production showed no significant difference between 30- and 60-day cutting intervals, CP content was higher at 30 days ($p < 0.05$). Peak daily dry matter (DM) production occurred at 45 days, achieving a biomass accumulation of 21,186.9 kg of DM ha^{-1} yr^{-1}. Given its high yield and favourable chemical composition, Kikuyu is a viable option for dairy cattle feed, especially in highland areas. Implementing a plant improvement programme for Kikuyu could further enhance its nutritional value for high-production dairy cows.

Keywords: grassland; nutritive value; cattle feeding; high altitudes; acid soils; silvopastoral system

1. Introduction

The dairy basin of the Cajamarca region, located in the northern highlands of Peru, ranks first in milk production (401,010 tonnes per year), representing 19% of national production [1]. In this region, producers rely on cultivated pastures such as ryegrass 'ecotype Cajamarquino' (*Lolium multiflorum* L.), white clover (*Trifolium repens* L.), and Kikuyu (*Pennisetum clandestinum*), the latter considered by some producers as an alternative pasture and an invasive species in many places at high altitudes [2]. Kikuyu can contribute to the recovery of saline areas, as it is a plant with phytoremediation capacity [3–5]. Kikuyu is highly resilient to adverse environmental conditions, making it a species of interest in the face of new climate variability scenarios, especially in high Andean regions [6]. Kikuyu is widespread in northern Peru, mainly in ryegrass–clover pastures [7]. It makes up between 2.8% and 39.78% of the forage base and is an excellent alternative [8,9]. It is a dietary base for many species of herbivores, being an easily accessible food source due to its nutritional contribution and high digestibility [10,11], in addition to its palatability for livestock [12].

Kikuyu grass produces an average of 15.8% crude protein (CP) in dry matter (DM) and an availability of 3335 kg of DM. ha^{-1} per grazing cycle, with a residue of 2032 kg of DM ha^{-1} [13]. The nitrogen fertilisation required by Kikuyu is between 50 and 70 kg of nitrogen (N) per ha, which has a significant effect on the soil structure and the contents of specific physicochemical properties that facilitate better absorption of the chemical supplement, favouring the quality and production of green fodder [14]. Furthermore, organic (poultry manure) and chemical fertilisation at a rate of 200 kg of N ha^{-1} in Kikuyu has a positive effect ($p < 0.05$) on regeneration at the first cutting frequency, plant height (47.12 cm), biomass (6.22 Mg of DM ha^{-1}), ash (19.34%), and CP (20.04%) [15], and it can reach up to 25% CP [16,17]. Under drought conditions, Kikuyu can reach 10.07% ash, 60.82% carbohydrate, 15.24% CP, and 30.42% crude fibre (CF) [18]. Meanwhile, during the rainy season in the South American highlands, 14.6% CP, 11.1% ash, 48.3% neutral detergent fibre (NDF), and 29.7% acid detergent fibre (ADF) are obtained [19]; in Cajamarca, a contribution of 17.35% CP, 10.94% ash, and 38.02% NDF has been reported [7].

Among the most representative exotic species of the Peruvian highlands, Kikuyu is a perennial C4 grass that spreads above or below ground by stolons or rhizomes and can reach heights of about 50 to 60 cm. The leaves can be between 4.5 cm and 20 cm long and 6 to 15 mm wide [20]. It is very tolerant of acidic and saline soil conditions [21]. When 150 kg of poultry manure plus 50 kg of N ha^{-1} is used as urea, it improves nutrient uptake and increases pasture persistence, yield, and nutritional quality, directly affecting milk response and reducing costs per kg of milk [22]. In addition, Kikuyu has protein levels ranging from 15.04% to 17.77% in open fields or with *Alnus acuminata* systems at 3 m × 5 m intervals, considering that the association between these species has a positive effect on forage quality, thus contributing to better digestibility [23].

The frequency of defoliation has no effect on the yield components (proportion of leaves, sheaths, stems, and dead material). NDF and ADF values remain consistent regardless of the frequency of defoliation, provided that the ideal consumption is between 4.5 and 6 leaves per animal, with a residue height of 5 cm [24]. The sustainability of Kikuyu was evaluated for use in the northern livestock production zone of Peru under highland conditions, taking into account the specific conditions of the northern zone of Cajamarca. This research focused on the impacts of N fertilisation rates, organic matter (OM) application, cutting frequency, phenological stages, and proximity to living cypress fences on the biomass production, growth rate (measured in kilograms and millimetres), and chemical composition of Kikuyu grass.

2. Materials and Methods

2.1. Study Area Description

This study was developed at the Centro de Investigación y Promoción Pecuaria (CIPP) 'Huayrapongo' of the Facultad de Ingeniería en Ciencias Pecuarias of the Universidad Nacional de Cajamarca, located in Los Baños del Inca District, Cajamarca Province, Peru (latitude 07°09′49″ S, longitude 78°30′00″ W, 2718 masl). The research was carried out between November 2022 and December 2023 over an area of 2 ha of naturalised Kikuyu grazing land. The study site has a dry, temperate, and sunny climate during the day. Nights are cold, with temperatures ranging from 4 °C to 23 °C. Rainfall in the last 20 years has ranged from 493.4 to 908.8 mm, with an annual average of 704 mm per year (source: Senamhi, 2024) [25] (Figure 1).
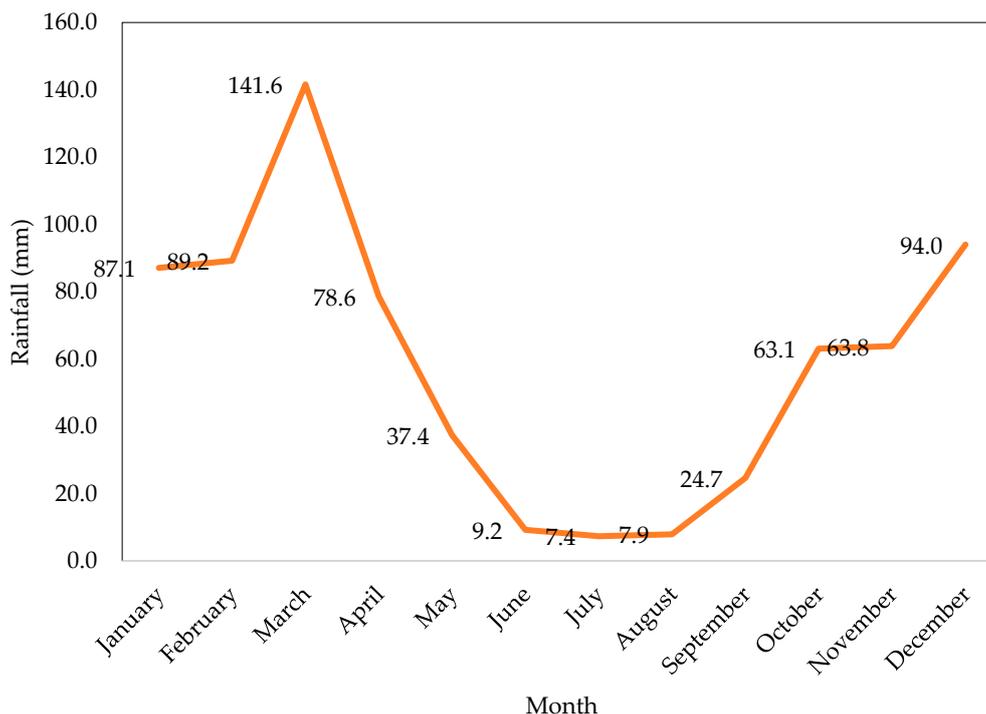
Figure 1. Average annual rainfall at the Centro de Investigación y Promoción Pecuaria (CIPP) 'Huayrapongo', Los Baños del Inca District, Cajamarca Province, Peru.

2.2. Soil Characteristics and Preparation of the Experiment

This research comprised two experiments, referred to as EXP1 and EXP2. EXP1 was conducted using a split-plot design within a randomised block structure to minimise experimental error and enhance the precision and reliability of the results. This design was chosen for its robustness in accommodating variability and ensuring the accuracy of the findings. Twelve experimental units measuring 3 m × 3 m (9 m^2) were established and distributed across three blocks, resulting in 48 subplots. This layout was designed to ensure the representativeness and comparability of the collected data. This study also evaluated the effect of cultivar spacing from the cypress living fence, incorporating block distribution as a study factor. A comprehensive soil analysis was conducted one month before the homogenisation cut and at the beginning of evaluations in the experimental area. This analysis assessed soil fertility and provided critical insights into the initial soil fertility levels of the study site.

Ten representative soil samples were collected from the experimental area at a depth of 20 cm. Subsequently, the samples were analysed at the Soil, Water, and Foliar Laboratory (LABSAF) of the Baños del Inca Agrarian Experimental Station, part of IN-IA-Cajamarca [26]. The soil analysis revealed the following characteristics: a pH (H$_2$O) of 7.6, OM content of 9.5%, phosphorus concentration of 29.02 ppm, potassium concentration of 360 ppm, and electrical conductivity of 32.1 mS/m.

The biological material employed was the naturalised and established Kikuyu (*Pennisetum clandestinum*). The vegetation was then cut and homogenised, and seven days later, the OM was applied. The OM was commercial chicken manure composed of 3.4% N, 3.05% P$_2$O$_5$, and 2.0% K$_2$O, as recommended by the laboratory. Following soil analysis, urea, triple calcium superphosphate, and potassium chloride were used as chemical fertilisers.

The experimental design involved the application of varying N concentrations. The four treatments comprised 0%, 50%, 100%, and 150% of the recommendation (80 kg N). The treatments above by were evaluated by OM application (2 Mg per hectare of poultry manure) and no application, respectively, with a cutting frequency of 30 and 60 days. The experimental units were defined in terms of distances to the live cypress (*Cupressus lusitanica*) fences, with a distance of three metres between the trees. Block I was situated

between 1. 5 and 4.5 metres perpendicular to the trunks of the trees, Block II between 5.0 and 8.0 metres, and Block III between 8.5 and 11.5 metres. The average distance from the base to the crown of the trees was 8 metres, with a branch radius of 5.5 metres. The trees were pruned to a height of 2.5 metres from the base.

The second experiment (EXP2) was conducted using a randomised complete blocks design and evaluated over six months from March to October 2023. The objective was to determine the dry matter yield, plant length, stolon density per square metre, and growth ratio per day in dry matter production and plant development. The main aim was to establish the relationship between phenology and productivity of the pasture under highland conditions. The fertilisation of EXP2 was conducted according to the recommendations outlined in the soil analysis, with an application rate of 80 kg of N and 2 Mg of poultry manure.

2.3. Experimental Design

Each treatment was randomly assigned after separating the plots and subplots (Figure 2). The irrigation system was initiated in May 2023 for EXP1 and EXP2 due to the lack of precipitation, as illustrated in Figure 1. Irrigation was conducted at a frequency of 20 days, with a variation of five days. Per the recommendations, each subplot was fertilised with organic matter at the experiment's outset, in addition to triple superphosphate and potassium chloride. Urea was dosed to be applied in each cut.
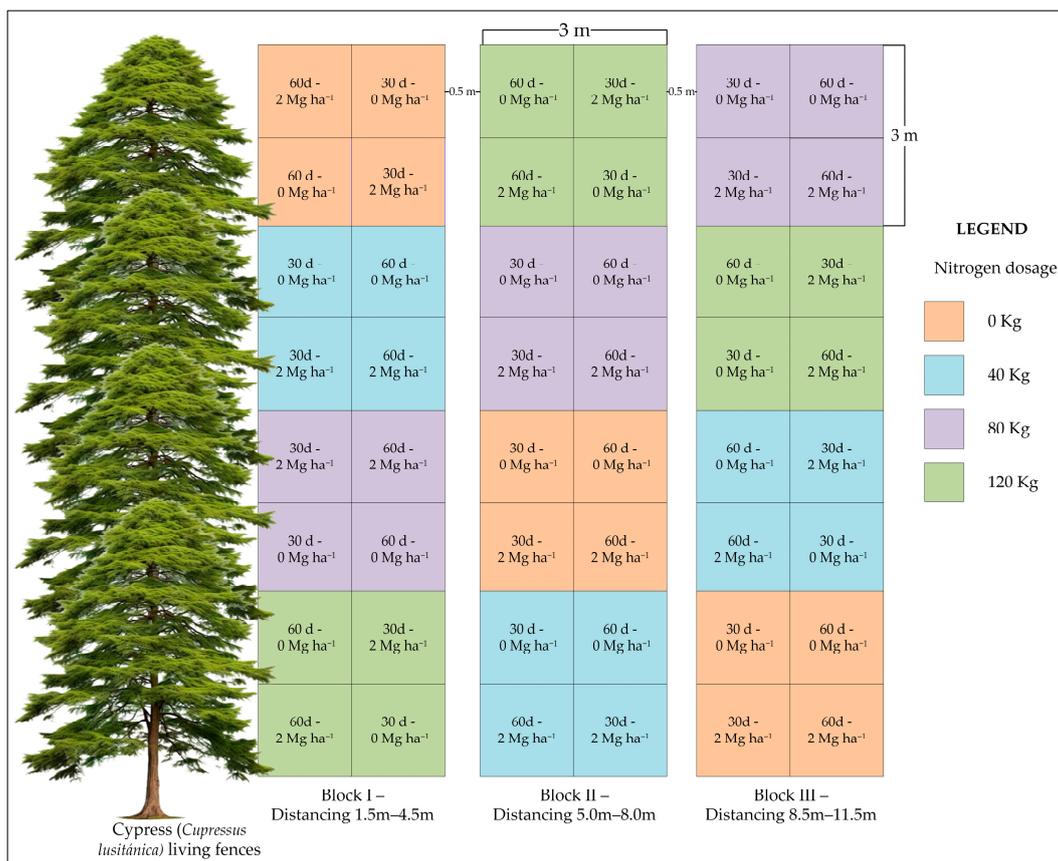
Figure 2. Experimental design (EXP1) using split plots as the main factor for the nitrogen and subplots for cutting frequency and organic matter application.

Following the establishment of EXP1, the crop was subjected weeding to remove weeds, particularly cow's tongue (*Rumex crispus*). The same procedure was carried out in EXP2 before the initial evaluation.

2.4. Collection of Grass Samples and Evaluation of Parameters

The green forage yield was determined using a square metre quadrant methodology to assess yield. The entire forage within each subplot was cut (Figure 3) and weighed using a digital scale. Two samples were collected. The first sample was taken to the Laboratory of Pastures and Forages of the Faculty of Engineering in Livestock Sciences of the National University of Cajamarca for the determination of dry matter. The second sample was taken to the LABSAF for the determination of proximal analysis using 200 g. The cut was carried out, leaving a 5 cm high remnant from the base of the soil. The evaluation was conducted during six successive cuts to minimise experimental error and achieve a one-year evaluation.

Figure 3. Photographs of the evaluation of the experiment: (**A**) Homogenisation and signposting of the experiment. (**B**) Cleaning of alleys and establishment of the experiment. (**C**) Cutting of subplots after 30 days. (**D**) Cutting of subplots after 60 days.

In EXP2, samples were taken at 15, 30, 45, 60, 75, and 90 days. Where plant height was measured, a one-metre square was utilised to quantify plant density and height in centimetres. Subsequent replications were conducted at least twice for 75 and 90 days to enhance the reliability of the results. After evaluating green forage and dry matter production in each subplot, estimates were made for the yield per hectare. Additionally, the annual yield was estimated by employing the dry matter and protein percentage values.

2.5. Kikuyu Chemical Composition

The following parameters were analysed simultaneously to determine the dry matter percentage: each 200 g sample was dehydrated at 65 °C for 24 h and subsequently sent to the LABSAF. The methods used were AOAC 984.13 for protein analysis [27], AOAC 920.39 for ethereal extract [28], AOAC 962.09 for crude fibre, and AOAC 942.05 for ash [29].

2.6. Statistical Analysis

The data obtained from the field sheets were digitised and stored in an organised manner in the field book before being transferred to an Excel workbook (Microsoft Office 365, personal licence). Tests for normality and homogeneity of variances were then performed for each response variable using Levene's test ($p < 0.05$) and the Shapiro–Wilk test ($p < 0.05$), respectively. Simple (ANOVA) and multiple (MANOVA) analyses of variance were used to compare the differences in the levels of nitrogen doses, cutting frequency, organic matter application, and distance to the living fence for the productive yield, nutritional value, and growth rate variables. The statistical analyses were performed with Infostat Version 2020e software [30], and Duncan's test ($p < 0.05$) was used to compare the means of the different factors.

3. Results

3.1. Kikuyu Yield and Phenological Development

Table 1 presents the parameters of green forage yield per cut per year, as well as dry matter yield per cut per year. Furthermore, the estimated annual protein production was subjected to a multiple variance analysis, with the objective of evaluating the clustering in each factor. Significant differences were observed between the groups ($p = 0.0004$) in terms of the level of nitrogen used in fertilisation and its impact on annual protein yield.

Table 1. Productive yield in green forage and dry matter of Kikuyu (*Pennisetum clandestinum*) for nitrogen dose, distance to live fences, organic matter use, and mowing frequency.

Factors	Green Forage (Kg ha^{-1})		Dry Matter (Kg ha^{-1})		Protein (Kg ha^{-1} yr^{-1})	MANOVA
	Cut	Year	Cut	Year		Group
Nitrogen (kg ha^{-1})						
120	14,097.76	111,466.94	1810.09	14,730.39	3454.53 a	a
80	13,059.64	106,633.66	1727.07	14,502.46	2900.20 ab	b
40	11,870.20	95,091.97	1579.18	13,100.81	2408.63 bc	bc
0	12,044.05	93,886.10	1657.10	13,463.57	2133.74 c	c
p	0.5046	0.2000	0.6793	0.4949	0.0004	<0.0001
Distancing—Block						
8.5–11.5	17,948.80 a	143,361.94 a	2321.85 a	19,176.23 a	3779.90 a	a
5.0–8.0	13,850.00 b	109,191.98 b	1878.31 b	15,247.38 b	2943.89 b	b
1.5–4.5	6504.94 c	52,755.08 c	879.92 c	7424.31 c	1449.03 c	c
p	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Organic Matter						
NO	13,847.63	109,409.25 a	1801.84	14,679.40	2639.71	a
SI	11,688.20	94,130.08 b	1584.88	13,219.22	2808.84	b
p	0.0691	0.0301	0.1245	0.1036	0.4278	0.0002
Cutting Frequency (days)						
30	7922.75 b	96,393.30	1199.33 b	14,591.95	3046.05 a	a
60	17,613.08 a	107,146.03	2187.39 a	13,306.66	2402.50 b	b
p	<0.0001	0.1215	<0.0001	0.1505	0.0041	<0.0001

For each response variable, comparisons were made by ANOVA, and the levels of each factor were compared using Duncan's test ($p < 0.05$). For the group, MANOVA was used through Wilk's parametric test ($p < 0.05$). a, b and c represent differences and clustering on each factor.

Table 2 illustrates the phenological growth of *Pennisetum clandestinum* in relation to the frequency of cutting. It was observed that its dry matter yield per year in EXP2 at 30 days was 16,236 kg of DM ha^{-1} yr^{-1}, which is comparable to the yield observed in EXP1 (14,591.95 kg of DM ha^{-1} yr^{-1}). A comparison of the data for the same farm reveals that the yields are very similar. The Kikuyu plant exhibited continuous growth, reaching a length of 89.5 cm after 90 days. The frequencies were found to be statistically different ($p < 0.0001$).

Table 2. Kikuyu dry matter yield, plant length, and stolon density according to phenological age or cutting frequency.

Cut-Off Age (Days)	Dry Matter (kg ha^{-1})		Plant Length (cm)	Density—Stolons (Number m^{-2})
	Cut	Year		
15	474.27 c	11,539.9 d	16.8 e	28.0 e
30	1334.47 b	16,236.0 bc	26.9 d	57.0 de
45	2612.07 a	21,186.9 a	28.9 d	73.3 cd
60	3118.53 a	18,971.0 ab	39.5 c	100.0 c
75	3004.47 a	14,621.7 cd	77.0 b	154.3 b
90	2892.37 a	11,730.2 d	89.5 a	238.7 a
SE	198.05	1157.69	2.74	12.45
p	<0.0001	0.0003	<0.0001	<0.0001

Different letters in each column represent significant differences (Duncan's test, $p < 0.05$).

Yield per cut was similar for cut-off ages of 45, 60, 75, and 90 days, indicating that crop development reaches a point of stability at 45 days. This is evidenced by the daily dry matter accumulation per hectare, which reached 58.05 kg ha^{-1} day^{-1} (Figure 4).
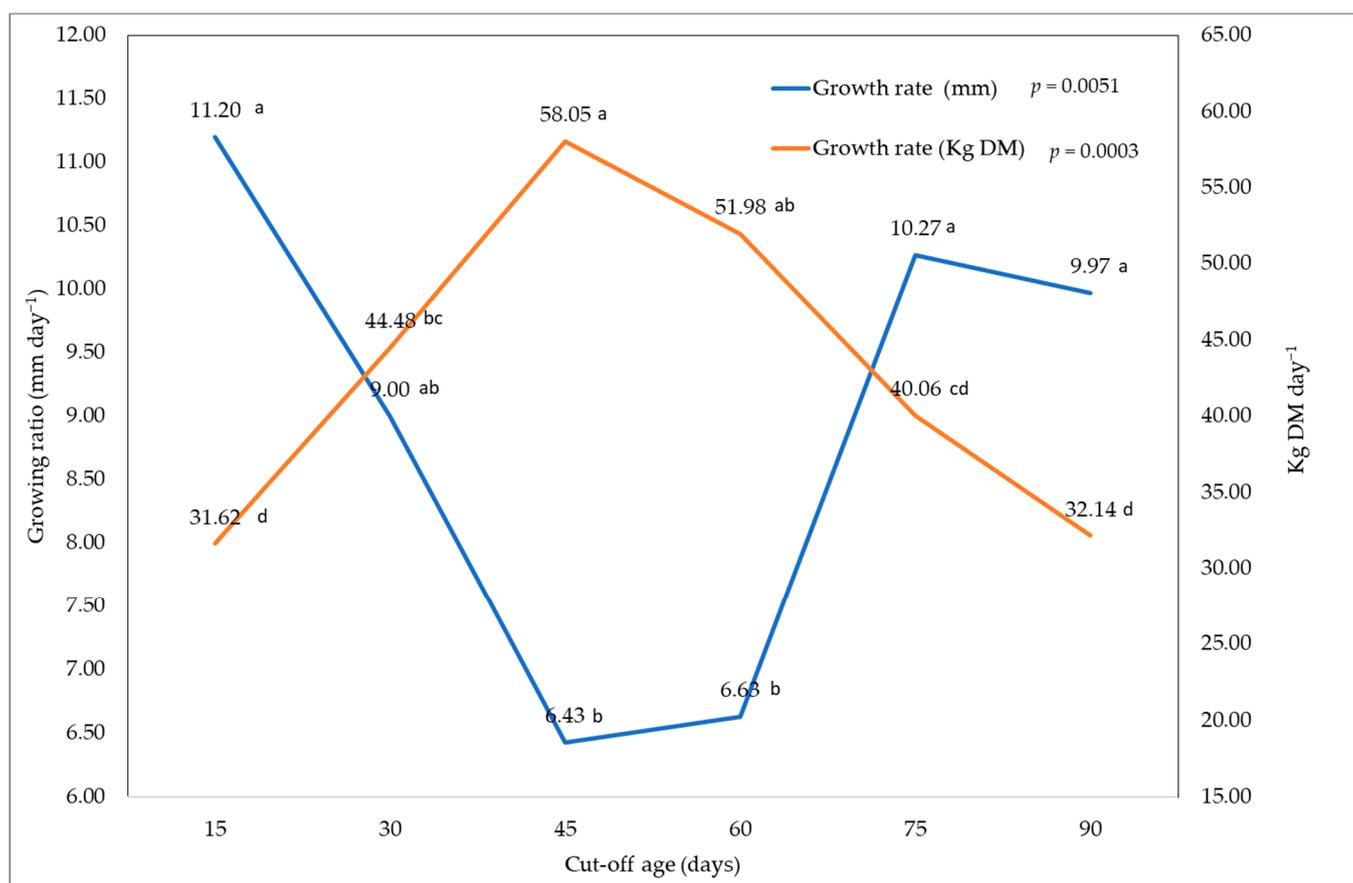
Figure 4. The growth rate in millimetres and dry matter accumulation per day at different cutting frequencies or phenological ages. Different letters in each column represent significant differences (Duncan's test, $p < 0.05$).

3.2. Chemical Composition

Table 3 details the values of crude protein (CP), ash, ether extract, crude fibre (CF), and nitrogen-free extract (NIFEX) for the factors of nitrogen dose, cutting frequency, and organic matter application.

Table 3. Chemical composition of Kikuyu (*Pennisetum clandestinum*) for nitrogen dose, mowing frequency, and organic matter application.

Factors	CP(%)	Ash%	Ether%	CF%	NIFEX%
Nitrogen (kg ha^{-1})					
120	23.54 a	12.15 a	3.46 a	24.56	36.29 c
80	20.11 b	11.23 b	2.85 b	25.11	40.70 b
40	18.42 c	11.58 b	2.95 b	25.53	41.53 b
0	15.55 d	10.32 c	3.29 a	23.57	47.27 a
p	<0.0001	<0.0001	0.0020	0.2775	<0.0001
Cutting Frequency (days)					
30	20.68 a	11.41	3.79 a	20.40 b	43.73 a
60	18.14 b	11.23	2.49 b	28.99 a	39.17 b
p	<0.0001	0.1975	<0.0001	<0.0001	0.0001
Organic Matter					
NO	17.53 b	10.96 b	3.00 b	24.27	44.25 a
SI	21.28 a	11.68 a	3.28 a	25.12	38.65 b
p	<0.0001	<0.0001	0.0226	0.2531	<0.0001

Different letters for each factor's column represent significant differences (Duncan's test, *p* < 0.05).

4. Discussion

In the high Andean region of Cajamarca, Peru, Kikuyu (*Pennisetum clandestinum*) constitutes 24.2% of the forage floor [31]. Considering these statistics, it is imperative to conduct a comprehensive assessment of the sustainability of livestock farming in the northern highland macro-region, with Kikuyu grass serving as the primary focus of the studies. Nitrogen fertilisation at 150% of the recommended laboratory dose (120 kg of N ha^{-1}) significantly influences annual protein content, yielding 3454.53 kg of CP ha^{-1} yr^{-1}, statistically similar to the application of 80 kg of N ha^{-1}. This N level has a significant influence on soil nitrogen levels, thereby improving the cultivar's response in terms of protein quality [14]. The incorporation of protein, an essential nutrient for livestock, has been demonstrated to increase productivity and enhance feed response [32]. The nitrogen fertiliser dose influences the chemical composition [15].

Applying OM did not significantly affect the yield parameters; however, an association was observed with the annual production of green forage (Table 1). MANOVA analysis identified two distinct groups, suggesting that the application of OM consistently has a positive impact on Kikuyu grass cultivation, particularly in enhancing the availability of green fodder [15] On the other hand, the evaluation of cutting frequency revealed significant differences between 30 and 60 days. Additionally, the timing of Kikuyu cutting or grazing influenced the grass quality, as recognised in the local context [7]. However, farmers only sometimes consider the protein content when determining the optimal timing for pasture use. Our results indicate that, while there are no significant differences in annual biomass yield, the use timing affects the quality of the forage or pasture available to the cattle [23]. Kikuyu grass, whether grown as a monoculture or integrated into silvopastoral systems, demonstrates greater resilience to the environmental conditions of the northern highlands. This enhanced resistance can be attributed to its stoloniferous morphology, which influences its growth rate and adaptability to the region's climate [12].

The application of 150% N increased the CP concentrations, which reached 23.54% and 20.11%, with ash content ranging from 10.32% to 12.15%. The OM influences CP, ash, FC, ether, and NIFEX levels or percentages. The values found in the experiment for CP when there was no N or 50% (40 kg ha^{-1}) of the recommendation were similar to the 17.25% obtained at 30 days reported by Vallejos-Cacho et al. (2024) [7]. The cutting frequency affects the chemical composition of Kikuyu; this can affect digestibility [33]. Annual CP production was higher at a 30-day cutting interval, yielding 2808.84 kg of CP ha^{-1} yr^{-1}. The highest daily dry matter production was observed at a 45-day cutting interval, with a biomass accumulation of 21,186.9 kg of DM ha^{-1} yr^{-1}, and a 58.05 kg of DM ha^{-1} day^{-1}

growth rate. Organic matter application enhanced the biomass yield in Kikuyu grass; however, no statistically significant differences were observed in dry matter production between cutting intervals of 30 and 60 days (p = 0.1036).

The distance from the forage to the live cypress fences also affected biomass production. At 8.5 to 11.5 m from the tree base, 19,176.23 kg of DM ha^{-1} yr^{-1} was achieved. Due to the shading effect, a lower biomass yield of 7424.31 kg of DM ha^{-1} yr^{-1} was observed at 1.5 to 4.5 m. A significant effect (p < 0.0001) was observed for annual green and dry biomass and protein yield in relation to the spacing of Kikuyu between the base of cypress (*Cupressus lusitanica*) trees and live fences. This significance may be attributed to the influence of shade levels on productivity in Block I [34], as a consequence of the three-metre live fence density.

Livestock farming is a critical economic activity in the Peruvian highlands. According to the 2012 Censo Nacional Agropecuario (CENAGRO) report [35], the country has 2.3 million agricultural units, with 68% located in the highlands and 19% in the jungle [36]. The current national situation indicates the need for a comprehensive reform of production systems, primarily due to the unsustainable nature of intensive farming practices. Also, in this macro-region, dairy cattle feeding is based on grazing [37]. Therefore, optimising pasture production per hectare is crucial to meet the national demand for meat and milk while enhancing global competitiveness [38]. This is based on the understanding that the species is able to adapt to a range of environmental conditions, including drought, frost, and soil conditions [39]. In highland livestock farming, particularly in the hillside and rural areas, the forage base is often integrated into silvopastoral systems, which incorporate various species and arrangements [2,34]. Additionally, using organic fertilisation in pastures offers a sustainable solution from biological, economic, and environmental perspectives. Given its biological benefits, the widespread application of poultry manure should be encouraged to enhance pasture health and productivity [40–42]. This aligns with ongoing evaluations of poultry manure application in Kikuyu pastures grazed by cattle [22].

Kikuyu grass's resistance to salinity and its adaptability to acidic soils position Kikuyu as a promising candidate for soil utilisation and reclamation. Its ability to germinate and thrive in diverse environments further enhances its potential [21]. The next phase of this research involves selecting accessions for a detailed morphological and productive characterisation across different zones of the northern macro-region of Peru. Additionally, the research will assess animal consumption levels and milk productivity, as there is a lack of local studies on these aspects and the morphological, phylogenetic, and genetic differentiation of Kikuyu grass [43,44] in conditions of the agro-productive zone and livestock interest, as exposed in the present study.

5. Conclusions

Kikuyu grass is considered to be a viable forage for dairy cattle. This grass offers potential for a plant breeding programme to improve the nutritional composition of high-yield cows. Its high yield and favourable chemical composition under highland conditions support its viability as a sustainable forage option. The observed results show that Kikuyu grass has considerable potential to improve livestock productivity due to its good biomass yield, high protein and mineral contents, and good association with cypress fences. Kikuyu responds favourably to nitrogen fertilisation and organic matter; the best time to use it is after 45 days of grazing. Therefore, this study represents an essential step towards improving the agronomic management of Kikuyu under similar agro-climatic conditions.

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