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Agronomic and Nutritional Evaluation of INIA 910—Kumymarca Ryegrass (*Lolium multiflorum* Lam.): An Alternative for Sustainable Forage Production in Department of Amazonas (NW Peru)

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Abstract: Grassland ecosystems cover about 25% of the Earth's surface, providing essential ecosystem services that benefit nature, people, and food security. This study evaluated agronomic and nutritional parameters of ryegrass (Lolium multiflorum Lam.) based on fertilization levels and cutting frequency in the Amazonas department. The INIA 910—Kumymarca variety was used with nitrogen fertilization rates (0, 60, 120, 180 kg/ha) and cutting intervals of 30 and 45 days for agronomic traits and 30, 45, and 60 days for nutritional traits. A randomized complete block design with eight treatments and three replications was applied. Repeated measures analysis and Tukey's mean comparison tests ($p < 0.005$) were performed, along with Pearson correlation and response surface analysis using the central composite design in R. The results showed that applying 180 kg/ha of nitrogen with a 45-day cutting interval provided the highest dry matter yield (460 kg/m^2) and superior agronomic traits, including plant height (96.73 cm), number of tillers, and stem diameter. Non-fertilized treatments had the highest crude protein content (17.45%) and digestibility, while higher nitrogen doses increased crude fiber and acid detergent fiber, reducing digestibility. Significant correlations were observed between fresh and dry weight with plant height ($p = 0.000$; r = 0.84), fiber contents ($p = 0.000$; r = 1), and ash and protein content ($p = 0.000$; r = 0.85). The optimal management practice was cutting every 45 days with 180 kg/ha of nitrogen (T8), maximizing forage yield and quality. Proper fertilization and cutting management can improve ryegrass production, benefiting livestock feeding and rural economies.

Keywords: forage quality; dry matter; livestock; high Andean pastures; optimal cutting time

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1. Introduction

Grassland ecosystems, covering a significant 25% of the Earth's land surface, are not just vast expanses of greenery. They are the unsung heroes of our planet, providing crucial ecosystem services that are essential for both nature and food security [1]. These services, including carbon storage, net primary productivity, soil recovery, nutrient retention, and habitats for multiple species [2,3], underscore the urgent need for their preservation. Moreover, rangelands are not just open spaces; they are critical for livestock grazing, which is a lifeline for rural development in many regions [4].

Livestock production relies, to a large extent, on grasses and forages whose nutritional quality depends on the time of cutting, which affects nutrient intake, digestibility, and absorption [5]. Despite their importance, native grasslands have been little studied [6], and their degradation has accelerated in different parts of the world by up to 49% [7]. Climate change, land use intensification, and overgrazing have been recognized as the two main drivers of grassland degradation [8,9]. While intensive use promotes forage production, it can also decrease ecosystem services and biodiversity [10].

Forage represents the most economical and accessible source of ruminant feed [11]. Key properties defining the importance of forages include their nutritive value, digestibility, and dry matter yield, which vary among species [12]. In this context, *Lolium multiflorum* Lam., known as ryegrass, stands out for its rapid growth and high nutritive value, being widely used in livestock systems [13]. However, this nutritive value will depend, among other factors, on the optimum cutting time, which, according to Mamani et al. [14], is at the beginning of flowering since this is the phenological stage with the highest forage production and quality, and the frequency between cuts should be no less than 30 days and no more than 50 days.

Recent research conducted in the northern Andes of Peru has underscored the importance of local adaptation. The study evaluated the performance of *Lolium multiflorum* Lam. under acid soil conditions in several locations, comparing local genotypes such as LM-58 and LM-43. The results were clear: LM-58 excels in biomass yield and crude protein production, reaching a forage yield of 4.49 Mg ha^{-1} and a crude protein of 13.48% [15]. These results underline the importance of selecting genotypes adapted to local conditions, a key factor in maximizing forage yield and quality. This stress on local adaptation should make the audience feel the importance of context in their research.

In the Amazon department, approximately 405,000 ha of pastures, cultivated and natural [16], were registered until 2020, distributed mainly in three cattle basins. These pasture areas constitute a key source of forage for livestock and are located between 120 and 4900 masl under different climatic conditions ranging from warm temperate to warm dry, slightly humid, and humid [17]. The sown area of *Lolium multiflorum* Lam. is estimated at 9000 ha in the region [18]. Given this scenario, evaluating the agronomic and productive parameters and the optimal cutting time is essential to ensure quality feeding and efficient grazing management.

Nitrogen fertilization is a common practice to enhance pasture productivity. Therefore, it is crucial to establish fertilization thresholds that maximize production without compromising the environment. In general, the recommended nitrogen application rate for ryegrass is 120 kg/ha. In this context, determining optimal nitrogen fertilization rates that balance productivity and environmental sustainability is essential. It is hypothesized that applying up to 180 kg N ha^{-1}, combined with appropriate cutting times, will significantly improve the yield and nutritional quality of ryegrass in the Amazon department. This study aims to evaluate the agronomic and productive parameters of *Lolium multiflorum* Lam., variety INIA 910—Kumymarca, under different nitrogen fertilization levels and cutting times.

2. Materials and Methods

2.1. Location of the Experimental Area

The experiment was carried out at the Amazonas Agrarian Experiment Station of the National Institute for Agrarian Innovation (INIA), located at Fundo San Juan (Figure 1) between the extremes of coordinates 6°12′2.59″ and 6°12′32.86″ S south and 77°52′9.37″ and 77°51′53.77″ west. The study area is located at an altitude of 2446 masl with an average annual temperature of 14.04 °C, relative humidity of 78.9% and annual precipitation of 876 mm (Chachapoyas Meteorological Station of SENAMHI). Politically, it is located in the district of Huancas, province of Chachapoyas, in the Amazonas department of northern Peru.

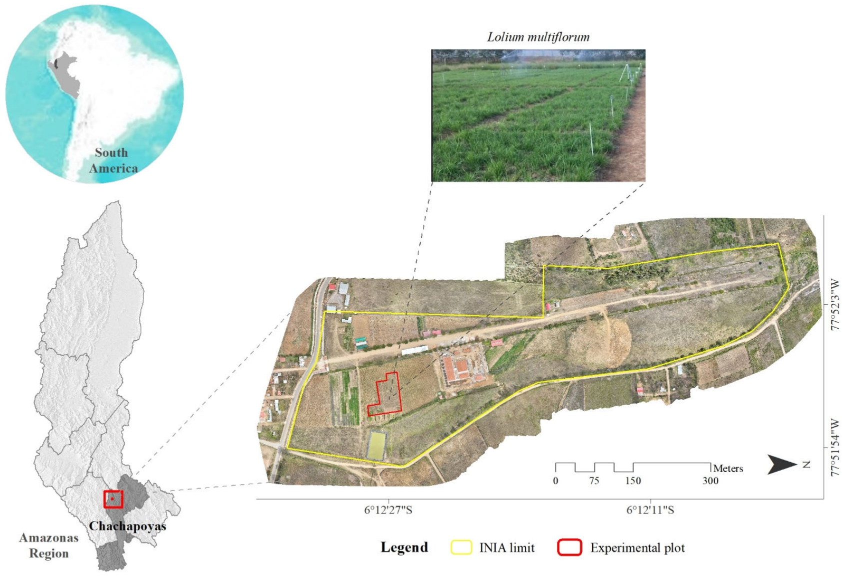

Figure 1. Location of the experimental area at the Amazonas Agrarian Experimental Station of the National Institute for Agrarian Innovation (INIA).

Figure 2 shows the evaluation process of the agronomic, productive and nutritional parameters of ryegrass (*Lolium multiflorum* Lam.) and the determination of the optimal cutting time of INIA 910—Kumymarca with different fertilization levels (0, 60, 120, 180 kg/ha of Nitrogen) and cutting times (30 and 45 days).

2.2. Biological Material

The *Lolium multiflorum* Lam. variety, also known as INIA 910—Kumymarca (https://www.gob.pe/institucion/inia/normas-legales/1366723-0138-2020-inia, accessed on 23 November 2024), has the advantage of being grazed or harvested between 30 and 45 days after the homogenization cut, depending on factors such as altitude or time of year. It can even be used for seed production, achieving approximately 270 kg/ha. Other interesting qualities are its adaptation to climate change and its benefits as a semi-evergreen plant, which can remain perennial with proper management. Its recommended planting density is 30 kg/ha [19].

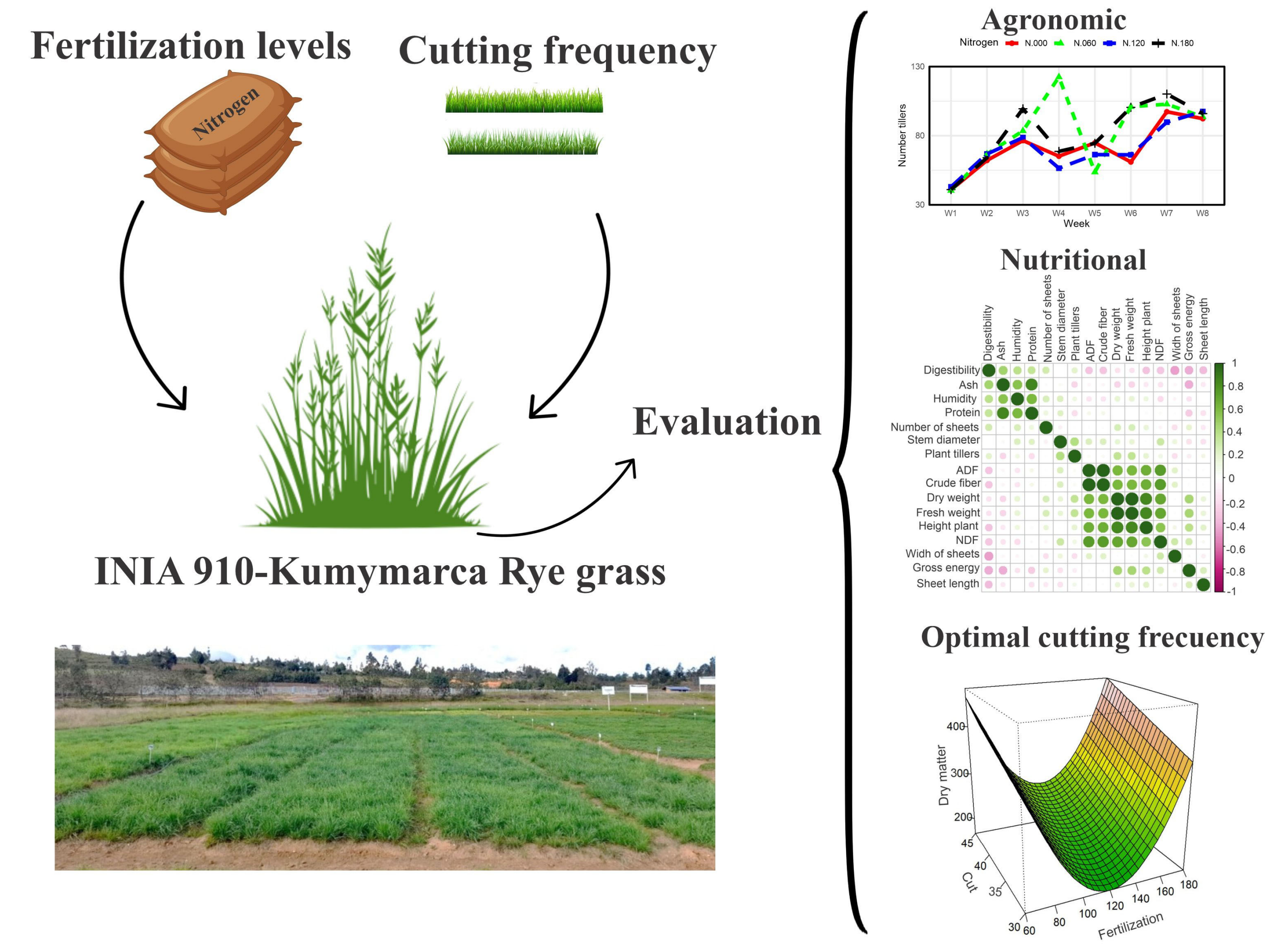

Figure 2. Process of evaluating the agronomic, productive and nutritional parameters of ryegrass (*Lolium multiflorum* Lam.) and determining the cutting frequency.

2.3. Management and Experimental Design

The experimental area consisted of 32 plots, each measuring 2 m in width by 3 m in length, with a 0.3 m distance between plots and 1 m access paths surrounding the perimeter of the experimental area. Land preparation began with the removal of surface vegetation, ensuring an area free of residues that could interfere with crop growth. Mechanical tillage was then performed, primarily to loosen and aerate the soil, creating a structure suitable for planting and crop rooting.

A sprinkler irrigation system was installed with a flow rate of 30 L/s, programmed to operate three times per week. This system was implemented to optimize water supply to the crop, ensuring uniform and efficient distribution across the entire surface of the field. The irrigation design and frequency were determined based on the crop's water requirements and the growing season, considering factors such as soil type, evapotranspiration, and local climatic conditions. Sowing was carried out using the broadcasting method with botanical seed (25 kg/ha) at the start of the rainy season. The experiment was designed with two factors: Factor A corresponded to fertilization levels (0, 60, 120, and 180 kg of Nitrogen/ha), and Factor B represented the two cutting intervals (30 and 45 days) following the uniformity cut (100 days). These factors had four replicates, making up 32 experimental units.

Weeding was performed after each cut and during each fertilization stage to ensure proper experiment management, avoiding nutrient competition and measurement biases. This activity was carried out manually by trained technical staff familiar with the identification of this species. The soil in the experimental area was clayey, with a pH of 7.8 and an organic matter content of 1.90%. To improve soil conditions and ensure proper pasture rooting, poultry manure was applied as organic fertilizer at a rate of 40 kg/ha immediately after the uniformity cut, conducted 90 days after sowing. Chemical fertilization, based on nitrogen, was applied at four levels (0, 60, 120, and 180 kg of Nitrogen/ha), beginning after the scheduled cuts at 30 and 45 days. The cutting times were established considering that pastures are harvested definitively at 60 days. As part of the research treatment, the evaluation began 30 days after the homogenization cut, with subsequent cuts every 15 days, completing a total of 45 days for agronomic parameters. However, to improve accuracy and allow for a comparison of nutritional data across different cutting times, three evaluation points were included: 30, 45, and 60 days. Cutting was performed manually using a sickle. The ryegrass variety INIA 910—Kumymarca was evaluated under eight experimental treatments (T1 to T8), as detailed in Table 1.

Table 1. Chemical fertilization levels and mowing frequency according to treatment.

Rye Grass	Nitrogen (as Urea) kg/ha	Mowing Frequency (Days)
T1	0	30
T2	0	45
T3	60	30
T4	60	45
T5	120	30
T6	120	45
T7	180	30
T8	180	45

2.4. Agronomic Parameters

The evaluated parameters were measured according to each variable. Plant height was assessed randomly over eight weeks (60 days), corresponding to the establishment phase of the pastures.

2.4.1. Plant Height

The evaluation was conducted by randomly selecting five plants within each plot. Data collection involved measuring from the base of the stem (ground level) to the tip of the highest leaf (secondary leaf) using a graduated ruler, as described by Gutiérrez et al. [20].

2.4.2. Stem Diameter

The diameter of the plant was measured at half its total height using a vernier to obtain a better characterization of the structure, as described by Gutiérrez et al. [20] and Caballero and López et al. [21]. The measurement was recorded as the diameter of the plant, which was multiplied by the value of π to obtain its stem circumference.

2.4.3. Number of Leaves

For each selected plant, we counted the total number of green and functional leaves, excluding dry or senescent leaves, as described by Gutiérrez et al. [20].

2.4.4. Leaf Length

As reported by Fernandez et al. [22], the length of each selected leaf was measured from the ligule to the apex of the leaf lamina using a ruler. For each selected plant, a given number of fully expanded and functional leaves were chosen, generally the three youngest leaves.

2.4.5. Leaf Width

The width of each selected leaf was measured using a vernier in the middle part of the leaf lamina [22].

2.4.6. Number of Tillers

The number of tillers was recorded individually for each sampled plant by manually counting the total number of tillers, considering both main and secondary tillers [20].

2.4.7. Fresh and Dry Matter

The fresh matter yield per unit area (kg/m^2) was calculated using the fresh weight and the sampling area. A 1 m^2 quadrat was placed in the sampling area, and plants within this quadrat were cut using a sickle, ensuring a residue was left to promote regrowth [20]. The freshly cut biomass was immediately weighed in the field using a gram-scale balance [22].

To determine the dry matter yield, a representative subsample of the fresh biomass was taken and placed in paper bags. The samples were then oven-dried at 65 °C until reaching a constant weight. The dry matter content was calculated by relating the dry weight to the fresh weight, and the dry matter yield per unit area (kg/m^2) was subsequently estimated [22]. This process enabled an accurate assessment of the biomass produced, evaluated independently and cumulatively.

2.4.8. Nutritional Parameters

Samples collected from ryegrass INIA 910—Kumymarca were collected in 1 m^2 for each treatment; the samples were transported and then dried at 60 °C for 48 h until a constant weight was obtained [21,22]. Then, they were ground, packed, and sealed in plastic Roll Bag homogenizing bags.

The nutritional evaluation of ryegrass samples included the determination of crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF), and in vitro digestibility (IVD). Crude protein was measured using AOAC method No. 928.08 (2005), involving sample digestion with sulfuric acid and conversion of nitrogen to ammonia, which was quantified by titration with hydrochloric acid.

The ANKOM A200 procedure (https://www.ankom.com/, accessed on 14 November 2024) was applied for ADF and NDF determinations. ADF was measured using an acid detergent solution, followed by filtering and oven-drying processes, while NDF was assessed using a neutral detergent solution, alpha-amylase, and sodium sulfite, with subsequent acetone rinsing and oven drying.

In vitro digestibility was evaluated using the ANKOM Daisy system, where samples were incubated with a prepared inoculum and buffer solution at 39 °C, and digestibility was calculated based on post-incubation weight according to AOAC (https://www.researchgate.net/publication/292783651_AOAC_2005, accessed on 14 November 2024). Additionally, moisture content was determined using AOAC method 930.15 (2005), and gross energy was assessed through calorimetry, following the manufacturer's recommended protocol for the Daisy II incubator system used in in vitro digestibility determination.

2.5. Data Analysis

To perform the statistical analysis of the physical and chemical biometric data and their growth, R software [23] and RStudio were used (R version 4.3.2) [24]. For descriptive statistical analysis, libraries such as "GGally" [25], "corrplot", "ggplot2" were used. Univariate analysis was performed, as well as ANOVA and comparison of means SNK.test (Alpha = 0.05) for a factorial statistical design in dbca 4 × 2; in this analysis, the library "agricolae" [26], "inti" [27] was used. To summarize the database by experimental unit, we used the "doBy" library [28], and for the imputation of missing data or units, we used "randomForest" [29]. A Pearson correlation test was performed to determine the existing correlations between the evaluated variables. In addition, the analysis of response surfaces for two factors was carried out using the central composite design to determine the optimal cutting time and fertilization application based on dry matter yield and protein content, for which 38 days and 120 kg of fertilization were considered central points. The data obtained were adjusted to a second-order polynomial model.

3. Results

3.1. Agronomic Parameters of Ryegrass INIA 910—Kumymarca

The agronomic parameters of the INIA 910—Kumymarca ryegrass are shown in Figure 3. These figures show the effect of nitrogen levels (N.000, N.060, N.120, N.180) and cutting frequencies (C.30 and C.45) on four plant growth variables over eight weeks: plant height, number of tillers, number of leaves, and leaf length. The interpretation for each figure is detailed below:

Figure 3a shows that higher nitrogen doses (N.120 and N.180) result in greater plant heights, reaching 96.73 $\pm$ 4.62 cm in week 8, while lower doses (N.060) and no nitrogen (N.000) exhibit slower growth. Figure 3b indicates that less frequent cuts (C.45) allow for greater heights, reaching nearly 90 cm, whereas frequent cuts (C.30) limit growth to around 60 cm.

In Figure 3c, plants treated with N.060 show a temporary increase in the number of tillers around week 4, but this effect does not persist. Higher nitrogen levels (N.120 and N.180) lead to more tillers by week 8. Figure 3d shows that less frequent cuts (C.45) favor a higher number of tillers, especially after week 4, while frequent cuts (C.30) limit this variable.

According to Figure 3e, the number of leaves tends to stabilize or decrease after week 4 across all nitrogen treatments, although intermediate levels (N.060) exhibit a slight initial increase. In Figure 3f, it is observed that less frequent cuts (C.45) promote a greater number of leaves during the early weeks, but these differences diminish by the end of the period.

For leaf length, Figure 3g shows that the N.060 treatment produces longer leaves in the early weeks, while higher doses (N.120 and N.180) outperform the other treatments by the end of the period, reaching lengths close to 25 cm. In Figure 3h, it is evident that less frequent cuts (C.45) result in longer leaves (close to 29 cm), while frequent cuts (C.30) limit leaf length.

In Figure 4i, for the leaf width variable, variations over time in response to nitrogen levels are shown. The N.060 treatment induces an early increase in leaf width, especially around week 3, but this effect diminishes in subsequent weeks. Higher levels (N.120 and N.180) show more stable widths, although slightly smaller than N.060 at the beginning. In Figure 4j, less frequent cuts (C.45) result in greater leaf width compared to cuts at 30 days (C.30), particularly in weeks 5 and 7, highlighting the importance of a longer interval to enable better leaf development. Stem diameter shows similar patterns in the nitrogen treatments, with an increase in the early weeks followed by stabilization. The N.060 level produces a more noticeable increase by week 3, while N.120 and N.180 reach larger diameters by the end of the period (Figure 4k). Less frequent cuts (C.45) favor a greater stem diameter compared to cuts at 30 days (C.30), with differences particularly evident in weeks 5 and 7 (Figure 4l).

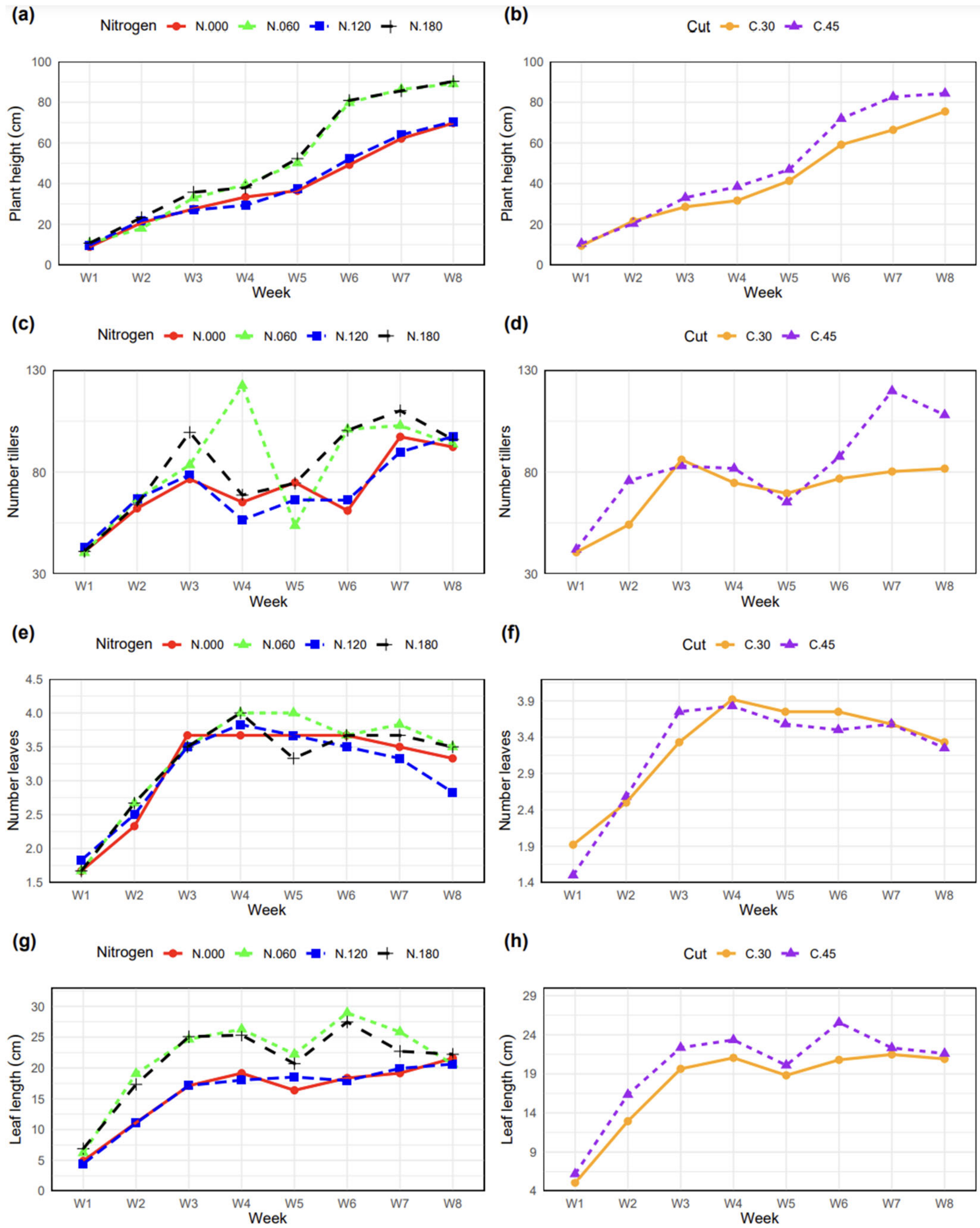

Figure 3. Line graph representing the agronomic parameters of ryegrass INIA 910—Kumymarca, evaluated over eight weeks according to fertilization and cutting times, where (**a**) plant height per fertilization, (**b**) plant height per cutting frequency, (**c**) number of tillers per fertilization, (**d**) number of tillers per cutting frequency, (**e**) number of leaves per fertilization, (**f**) number of leaves per cutting frequencies, (**g**) leaf length per fertilization, and (**h**) leaf length per cutting frequency.

In Figure 4m, dry weight increases significantly with higher nitrogen levels (N.120 and N.180), with a steady accumulation starting from week 3. N.060 shows a notable initial increase but is surpassed by the higher levels in subsequent weeks. N.000 results in the lowest dry weight throughout the period. Less frequent cuts (C.45) allow for greater dry weight accumulation, reaching significantly higher values than the cuts at 30 days (C.30) by the end of the period (Figure 4n). For fresh weight (Figure 4o), the higher nitrogen levels (N.120 and N.180) produce a sustained accumulation of fresh weight, reaching values greater than 1500 g by the end of the period. N.060 shows a notable initial increase but is surpassed by the higher levels in the last weeks. N.000 maintains the lowest fresh weight over time. Less frequent cuts (C.45) favor a greater accumulation of fresh weight, with marked differences compared to cuts at 30 days (C.30), particularly in the later weeks (Figure 4p).

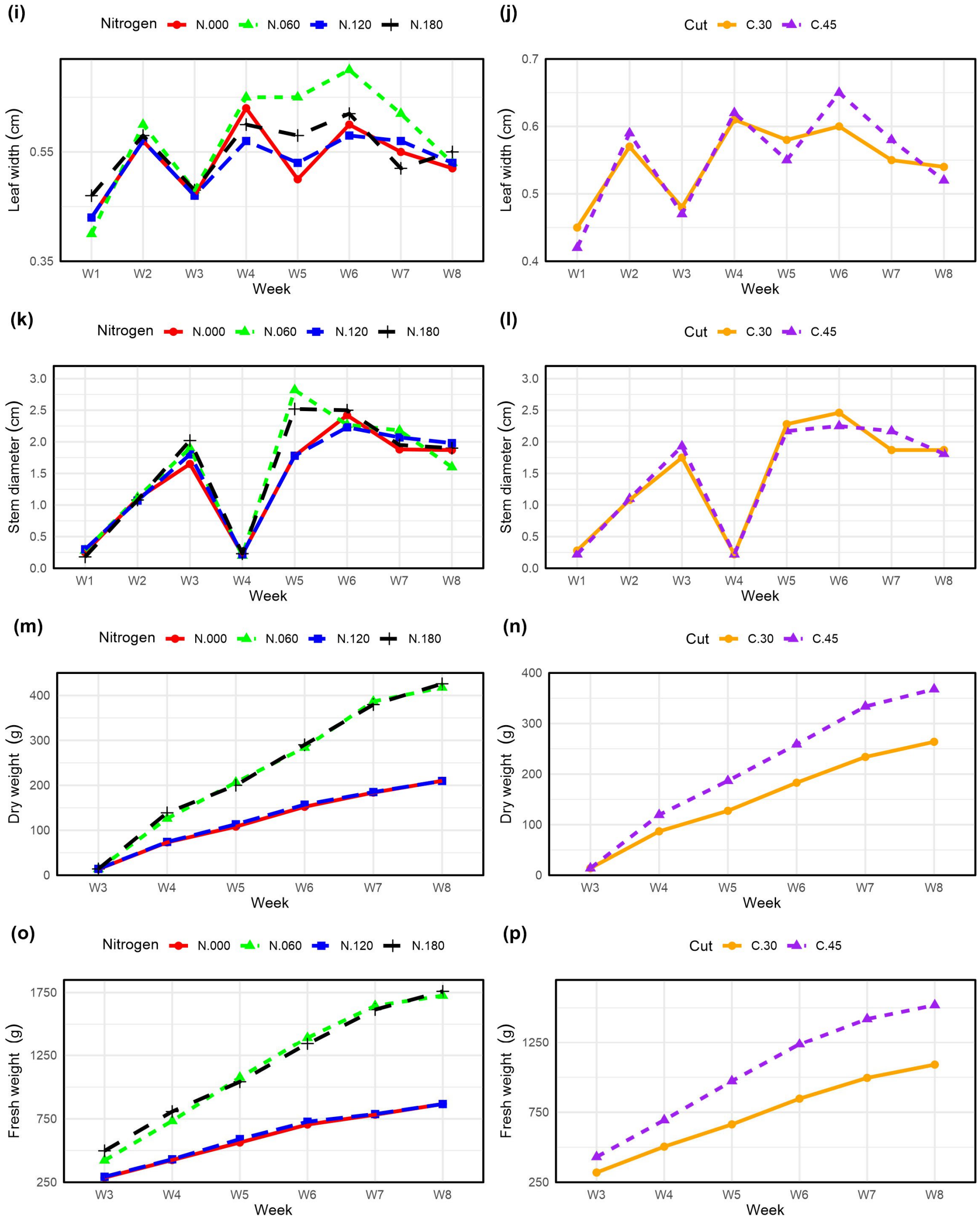

Figure 4. Agronomic parameters of INIA 910—Kumymarca ryegrass, evaluated during eight weeks of 8 treatments, where (**i**) leaf width per fertilization, (**j**) leaf width per cutting frequency, (**k**) stem diameter per fertilization, (**l**) stem diameter per cutting frequency, (**m**) green matter per fertilization, (**n**) green matter per cutting frequency, (**o**) dry matter per fertilization, and (**p**) dry matter per cutting frequency.

3.2. Nutritional Parameters of Ryegrass INIA 910—Kumymarca

The humidity in treatment 6 consistently reported the lowest values (4.59 ± 0.06%), while treatment 2 showed the highest humidity content at the third cutting with 7.52 ± 0.59% (Figure 5a). The significant statistical differences observed in the three cuts for the treatments evaluated indicate that humidity content in ryegrass INIA 910—Kumymarca varies considerably according to the treatment applied. The highest protein averages in the first and third cuts were obtained by treatment 1 with 17.45 ± 3.23% and 15.34 ± 0.49%, respectively, and in the second cut by treatment 2 with 16.75 ± 0.29%, in which nitrogen fertilization was not applied for either treatment (Figure 5b). The percentage of crude fiber in the first and second cuts reached the highest values with treatment 4, registering 22.59 ± 1.87% and 21.40 ± 1.21%, respectively (Figure 5c).

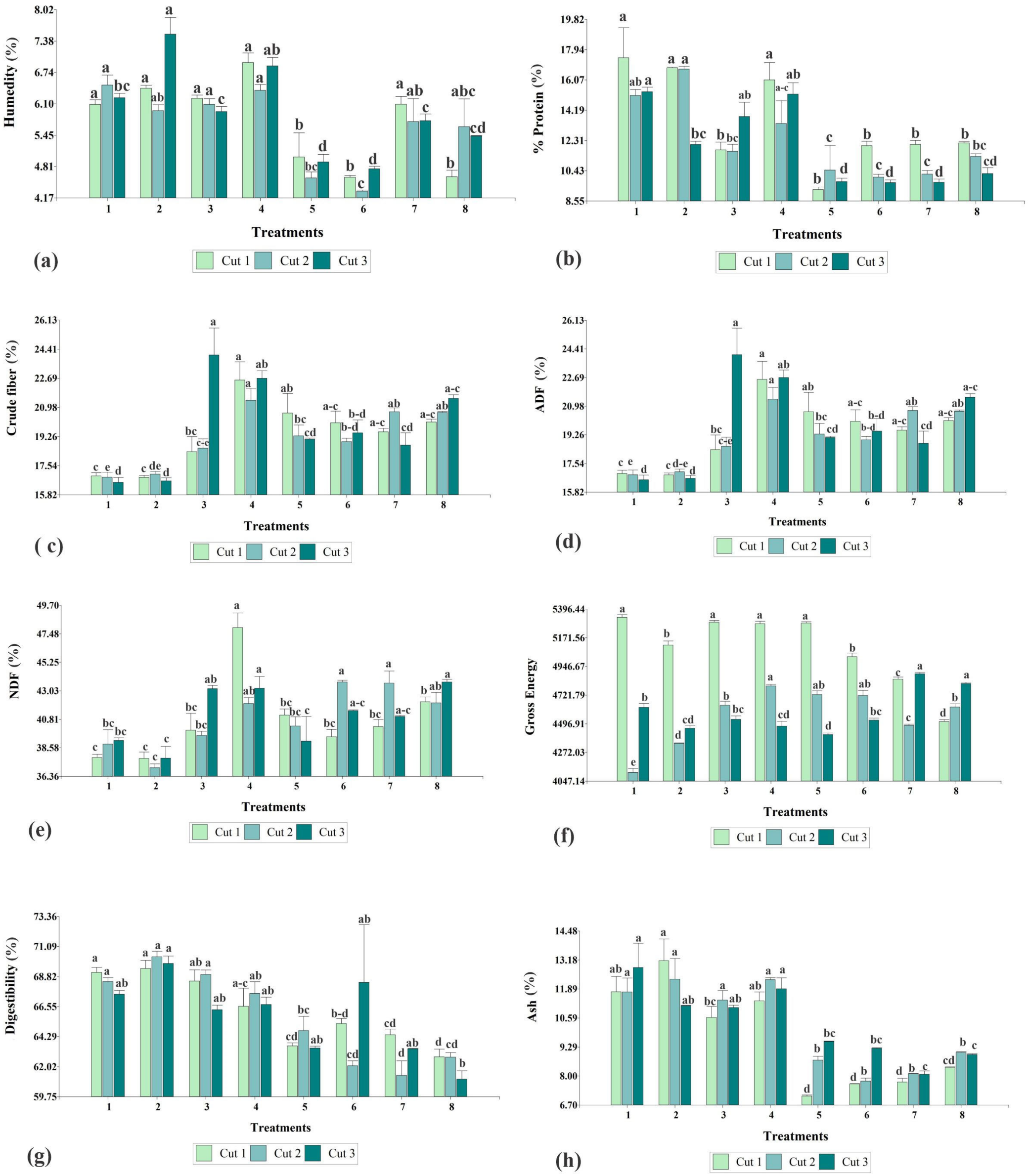

Figure 5. Nutritional parameters of ryegrass INIA 910—*Kumymarca* evaluated during eight weeks of 8 treatments, where (**a**) humidity (%), (**b**) protein (%), (**c**) crude fiber (%), (**d**) Acid Detergent Fiber (%), (**e**) Neutral Detergent Fiber (%), (**f**) Gross Energy, (**g**) Digestibility (%), and (**h**) Ash (%). Different letters above the bars indicate significant differences (SNK.test, alpha = 0.05).

Regarding Acid Detergent Fiber (ADF), statistically significant differences were observed across the three cuts. Treatments 1 and 2 showed the lowest ADF percentages in all cuts. In the first cut, they recorded values of 16.94% and 16.86%, respectively; in the second cut, 16.87% and 17.04%; and in the third cut, 16.57% and 16.65% (Figure 5d). This indicates a lower concentration of less digestible components, which is favorable from a nutritional perspective.

Neutral Detergent Fiber (NDF) levels also varied among treatments. Treatment 2 (without nitrogen fertilization) consistently showed the lowest NDF values in all cuts (cut 1: 37.76%, cut 2: 37.04%, and cut 3: 37.79%) (Figure 5e). A lower NDF content indicates greater availability of digestible material for ruminants.

Gross energy content showed highly significant statistical differences among the eight treatments across the three cuts. The highest average gross energy values were achieved with treatments 1 (5.33 ± 0.04 MCal/kg), 4 (4.79 ± 0.03 MCal/kg), and 7 (4.89 ± 0.02 MCal/kg) in cuts 1, 2, and 3, respectively (Figure 5f).

Digestibility percentages were highest in treatment 2, with records of 69.44 ± 1.07%, 70.32 ± 0.72%, and 69.81 ± 0.96% for cuts 1, 2, and 3, respectively. In contrast, treatment 8 (180 kg/ha of N) showed lower digestibility values in cuts 1 and 3, registering 62.77 ± 1.01% and 61.08 ± 1.08% (Figure 5g).

Finally, ash content was maximized in treatment 2 during cuts 1 and 2, with values of 13.15 ± 1.69% and 12.33 ± 1.59%. Treatment 1 showed the highest ash content in the third cut, with 12.85 ± 1.87% (Figure 5h). In all cuts, treatments without nitrogen fertilization consistently produced the highest ash percentages, which may be related to a higher proportion of essential minerals.

3.3. Optimal Cutting Time

The response surface analysis showed us the combination of grass-cutting time and fertilizer application factors to optimize dry matter yield and protein percentage. The value found for the lack of fit is greater than 5% of significance, which means that the analysis fits a second-order model, being significant ($p < 0.05$), indicating that cutting and fertilization and their interaction have an important effect on the dry matter variables. Figure 6 shows the colored contour plot generated as the dry matter with different fertilization levels and cutting times. The more orange-colored areas represent the high dry matter. This helped us to identify the optimum combination of factors, where the maximum dry matter yield is obtained at 45 days with 180 kg of nitrogen (urea). These results coincide with those reported by Cassol et al. [30], who indicated that this crop had lower nitrogen adduction 45 days after grass establishment.

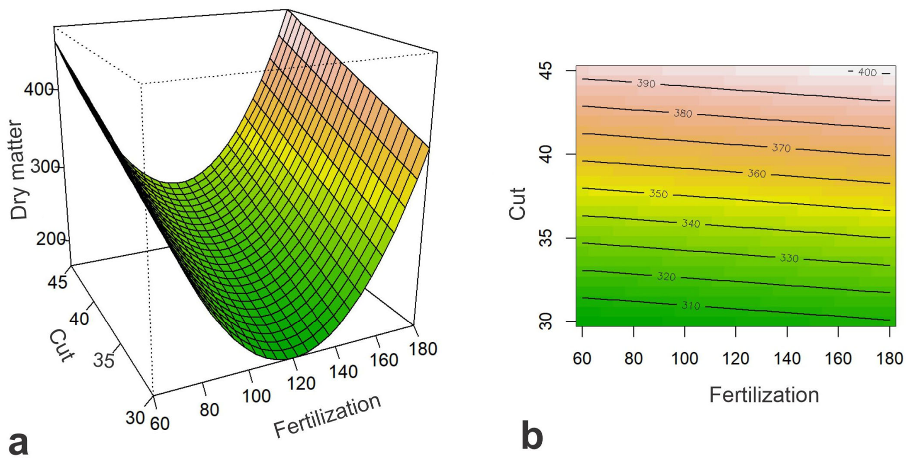

Figure 6. Response area analysis of (**a**): optimum cutting time (green colors indicate lower values, while yellow and reddish colors indicate higher dry matter values) and (**b**): fertilization for dry matter (contour lines and colors indicate specific dry matter levels, where green represents lower values and orange represents higher values).

The correlational analysis of the agronomic and nutritional parameters of ryegrass INIA 910—Kumymarca is presented in Figure 7, highlighting a very strong positive correlation between plant height and both fresh and dry weight (p = 0.000; r = 0.84). A perfect correlation was identified between ADF and CF (p = 0.000; r = 1). Additionally, a strong correlation was observed between Neutral Detergent Fiber (NDF) and Crude Fiber (p = 0.000; r = 0.75). Moreover, a strong positive correlation was found between ash content and protein percentage (p = 0.000; r = 0.85).

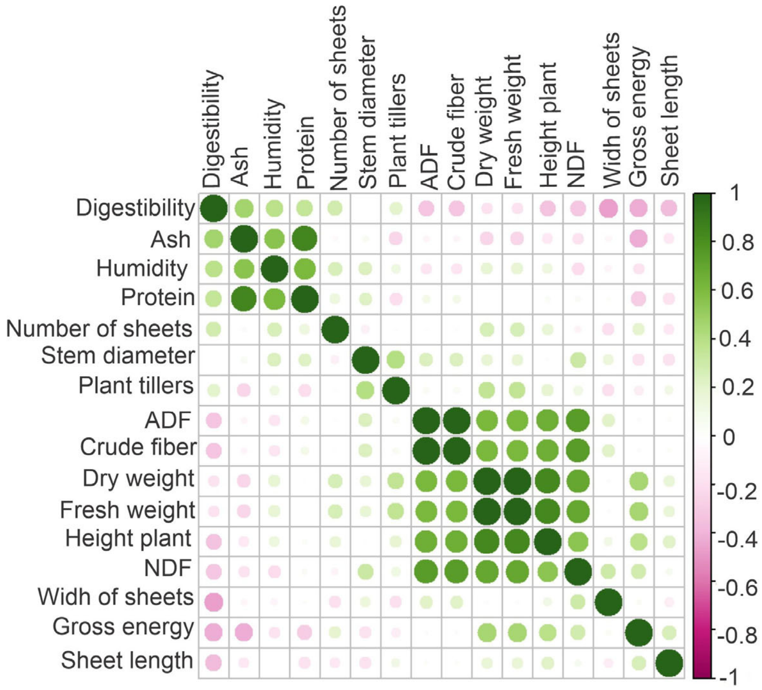

Figure 7. Pearson correlation between evaluated variables, both agronomic and forage quality.

4. Discussion

The evaluation of agronomic parameters such as plant height, number of leaves per plant, leaf width and length, number of tillers per plant and stem diameter in ryegrass INIA 910—Kumymarca for eight weeks and with eight treatments provides a detailed understanding of the growth and development of this key forage species. These data are essential to optimize agronomic management practices that promote optimal yields in terms of biomass and nutritional quality, thus contributing to the sustainability and efficiency of livestock production systems.

In the evaluation period, plant height showed significant differences in all treatments; this could be related to the different levels of fertilization applied in the experimental plots. However, this result coincides with the findings of Jungers et al. [31], who reported that specific fertilization conditions can significantly influence the height growth of forage grasses. In fact, this also influences the number of leaves of grasses, suggesting that certain treatments may have a positive effect on leaf production in the early stages of development, which is consistent with the studies by Peters et al. [32], who reported that nitrogen applications can increase the number of leaves in Lolium plants. Additionally, beyond fertilization, edaphoclimatic and meteorological factors play a crucial role in crop development. Soil characteristics such as texture, organic matter content, and water retention capacity can alter nutrient availability for plants, directly influencing parameters such as height and overall growth [33].

Similarly, meteorological conditions, including temperature, radiation, and solar radiation, significantly affect the response of grasses to fertilization treatments [34,35]. For example, adequate water availability during key growth periods can enhance the effect of applied nitrogen, while water deficits may limit nutrient uptake, as noted by Villalobos-González et al. [36].

Additionally, Glass [37] highlights that lower temperatures can reduce nitrogen absorption efficiency, which could explain certain variations in height response depending on the climatic conditions of the Amazonas department, where an annual average temperature of 11 °C was reported (Chachapoyas Meteorological Station of SENAMHI).

Regarding leaf length and width, significant differences were observed depending on the treatment and the evaluation week. Akdeniz et al. [38] reported similar measurements for Lolium eterna with the application of 70 kg/ha of nitrogen. Concerning stem diameter, the values found in this research are similar to those reported by Türk et al. [39] for ryegrass INIA 910—Kumymarca (3.1 mm) with a nitrogen dose of 30 kg/ha. This highlights the importance of fertilizing frequently and at appropriate doses to ensure forage establishment, development, and environmental protection by applying only what the plant needs, thus avoiding fertilizer loss and associated economic losses.

The evaluation of nutritional parameters such as moisture percentage, protein, crude fiber, acid detergent fiber, neutral detergent fiber, gross energy, digestibility, and ash provides essential information on the chemical composition and nutritional value of this forage. This enables one to plan more sustainable feeding strategies, promoting conversion efficiency and performance in livestock production.

The results of the study reported that forage moisture varies according to the treatment and level of fertilization. These low moisture percentages are useful if the goal is to preserve the forage in pre-wilted form, which are forms in which this forage can be stored for longer periods [40]. On the other hand, at the level of protein percentages, it was found that it is not related to the nitrogen dose. These results contradict what was reported by Benalcazar-Carranza et al. [41], who found that the higher the nitrogen dose, the higher the protein content in *L. multiflorum*. These differences could be attributed to the intrinsic characteristics of the soils and the climate of each altitudinal level where it was sown [42].

Crude fiber presented high values in treatment 4, which coincides with that reported by Chuquicahua [43], who obtained similar values for INIA 910—Kumymarca ryegrass with a nitrogen fertilization level of 50 kg/ha, reaching an average of 22.75% crude fiber for the second cut. The similarities between both investigations could be associated with the fact that they were developed at similar altitudes (2000–2300 masl), and as is known, climatic factors play a fundamental role in the nutritional quality of pastures [44]. In both investigations, the percentage of crude fiber increased with treatments based on nitrogen fertilization; this is in line with the results obtained by Dindová et al. [45]. For its part, the percentage of acid detergent fiber showed differences in each of the treatments, which is similar to that reported by Sierra-Alarcón et al. [46], who obtained values similar to those of this investigation but found no significant differences between treatments with nitrogen fertilization and without fertilization. On the other hand, the percentage of gross energy was high compared to that reported by Castro-Rincón et al. [47], who obtained lower gross energy values for three Lolium eterna cultivars, with values between 4.1 and 4.3 MCal/kg; the differences found could be associated with the fertilization doses used in each experiment.

Vallejos-Fernández et al. [42] presented slightly higher values than treatment 2 for the ryegrass INIA 910—Kumymarca genotype Kodiak (71.04%) with respect to the digestibility percentage, which was sown with a dose of NPK fertilization according to the soil requirements in Cajamarca conditions at an altitudinal level similar to that of this research (2300–2800 masl). These differences could be due to the initial soil conditions of the research since, despite not applying fertilization, higher values were obtained than the treatments with fertilization. The ash percentages were low, which contradicts what was reported by

Sierra-Alarcón et al. [46], who obtained the highest ash percentages for Lolium eternal with treatments based on nitrogen fertilization at doses of 50 and 100 kg/ha.

The correlational analysis of the agronomic and nutritional parameters of ryegrass INIA 910—Kumymarca, shown in Figure 6, shows a very strong positive correlation between plant height and fresh and dry weight (p = 0.000; r = 0.84). This finding is consistent with previous studies indicating that plant height is a good predictor of fresh biomass yield [48]. Plant height is directly related to the amount of photosynthetically active tissue, affecting the accumulation of fresh biomass and, thus, dry biomass [49]. Dry matter is a key indicator of grass's storage capacity and nutritional quality [50].

A perfect correlation was found between ADF and CF (p = 0.000; r = 1). This result agrees with the literature suggesting that both parameters are highly related since CDF is a fraction of CF that includes lignin and cellulose, structural components that affect forage digestibility [51]. Furthermore, the strong correlation between NDF and crude fiber (p = 0.000; r = 0.75) reinforces this relationship since NDF includes hemicellulose in addition to lignin and cellulose, all components of crude fiber [52].

The strong positive correlation between ash content and protein percentage (p = 0.000; r = 0.85) is interesting, as it suggests that higher mineral content in grass is associated with higher protein content [53]. This could be related to soil nutrition and the availability of essential nutrients for plant protein synthesis [54,55]. Ash represents the total mineral content of the forage, which includes elements such as nitrogen, phosphorus, and potassium, which are essential for protein formation [56].

The current study provides valuable insights into the growth, development, and nutritional profile of ryegrass INIA 910—Kumymarca under different fertilization treatments. However, there is still a need for further research to address gaps in knowledge, such as the long-term effects of varying fertilization rates and environmental conditions on the agronomic and nutritional parameters of ryegrass across different seasons and altitudinal gradients. Future studies should also investigate how the interaction between soil properties, climate variability, and fertilization strategies impacts the forage's nutritional quality and overall yield. Moreover, exploring the relationship between the ryegrass's nutrient composition and animal productivity in different livestock production systems would provide a more comprehensive understanding of its role in sustainable livestock feeding practices. These aspects could enhance our ability to develop more efficient agronomic and feeding strategies, ensuring the optimization of forage production and quality in diverse agroecological settings.

5. Conclusions

The study highlighted that effective nitrogen fertilization and cutting frequency are crucial for optimizing the agronomic performance, nutritional value, and sustainability of INIA 910—Kumymarca ryegrass in the Amazonas region, Peru. Applying 180 kg/ha of nitrogen with a 45-day cutting interval yielded the highest dry matter and a balanced nutritional profile.

Agronomic traits such as plant height, tiller number, and leaf dimensions improved with higher nitrogen levels and less frequent cuts. The best treatment achieved a maximum plant height of 96.73 cm and a dry matter yield of 460 kg/m^2, indicating robust growth and high photosynthetic efficiency. Nutritional analysis revealed that treatments without nitrogen showed the highest crude protein content (17.45%), possibly due to specific soil conditions. Higher nitrogen levels increased crude fiber (22.59%) and acid detergent fiber (24.07%), affecting forage digestibility. A positive correlation between ash and protein suggested enhanced mineral content in certain treatments.

Overall, the study demonstrated that integrating proper agronomic and nutritional management practices can significantly improve forage yield, quality, and sustainability, supporting livestock systems in high-Andean regions.

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