Comparison between TaurusWebs and a laboratory

for the bromatological analysis of Rodas grass (Pennisetum sp.): A case study in Santa Ana

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Abstract

The purpose of this study is to compare the results of the Rodas grass (Pennisetum sp.) trial, utilizing TaurusWebs software, with those obtained using traditional laboratory methods, emphasizing on the variables protein, dry matter, net lactation energy, neutral detergent fiber, acid detergent fiber, and minerals. The research was conducted in two defined grassland areas in the Santa Ana canton, Manabí province, where an experimental design based on three samplings during periods of 15, 30, and 45 days was applied. The study considered various light conditions and three capture altitudes (20, 50, and 100 m a.s.l.) to evaluate the accuracy of the response to environmental variability.

According to statistical runs, it is concluded that image analysis software is a viable and efficient tool for estimating protein, dry matter, and minerals in Rodas grass. However, limitations were identified in the prediction of energy and fiber fractions. These discrepancies do not invalidate the tool but rather stem from intrinsic differences between spectroscopy and laboratory chemical methods. On the other hand, its use should be seen as a support to the traditional method, especially when measuring fiber, because the values can vary greatly due to the way the processing algorithms work. These findings underscore the importance of promoting the use of digital technologies in local livestock management, optimizing nutritional decision-making in an agile and economical manner.

Keywords:
comparative analysis, near-infrared spectroscopy, detergent fiber, forages, crude protein, nutritional value.

Introduction

In Ecuador, the province of Manabí ranks first in terms of cattle population, with approximately 711,011 live animals. However, according to data from the Continuous Agricultural Area and Production Survey (ESPAC), productivity in relation to land area is 1.00 head/ha, a figure that is lower than those reported for Guayas, Los Ríos, El Oro, and Esmeraldas. This places the province seventeenth nationwide, highlighting the need to improve the efficient management of forage resources in the livestock sector, which remains the main challenge for the economic sustainability of cattle production (National Institute of Statistics and Census - INEC, 2024).

Fierro Cordero (2018) states:

> In Ecuador, one of the main problems in pasture management is the lack of knowledge regarding the species being used, which leads to inappropriate pasture utilization and prevents the achievement of optimal production results. This is compounded by deficiencies in soil nutrients, the lack of irrigation systems, and the use of species that are not adapted to local agroecological conditions, all of which contribute to the shortage of forage dry matter during certain times of the year (p. 10).

In the Santa Ana canton, livestock production depends directly on the nutritional quality of pastures; however, there is a marked deficiency in the technical monitoring of these resources. As a result, Rodas grass (Pennisetum sp.) is utilized without accurate bromatological support, leading to inadequate supplementation and unnecessary increases in production costs per unit of output.

The motivation for this research arises from the need to validate technological alternatives that facilitate decision-making in the field. Traditionally, forage characterization has relied on laboratory analysis, which, although considered the reference method for accuracy, requires financial and time investments that many local producers cannot afford on a regular basis. In this context, the implementation of Livestock 4.0 tools, specifically the TaurusWebs software, represents an innovative solution. The central objective of this study is to determine whether digital nutrient estimation can provide results comparable to those obtained through conventional laboratory methods under the specific conditions of Santa Ana.

To address this issue, the general objective of this study is to conduct a comparative bromatological evaluation of Rodas grass (Pennisetum sp.) by comparing data generated by the TaurusWebs software with laboratory results. To achieve this objective, specific goals were established to complement the quantification of key variables, including crude protein, dry matter, energy, neutral detergent fiber, acid detergent fiber, and minerals, with the aim of determining the reliability of this technological tool under local conditions.

The quantification of the forage nutritional components required the application of specific analytical protocols for each variable evaluated. Crude protein content was determined using the Kjeldahl method, based on the distillation of total nitrogen in the sample. Gravimetric techniques were used to determine crude fat, moisture content, and ash percentage by measuring weight differences after subjecting the samples to controlled thermal treatments. Carbohydrates were also determined in the laboratory through indirect calculation, and this value was subsequently used to estimate the forage's energy contribution.

To strengthen the comparison with the TaurusWebs software, additional analyses of neutral detergent fiber (NDF) and acid detergent fiber (ADF) were incorporated. These parameters, which are essential for estimating the digestibility of Rodas grass (Pennisetum sp.), were processed according to gravimetric principles (Van Soest method), thereby maintaining methodological consistency and the rigor required to validate the accuracy of digital systems against conventional laboratory standards. For minerals present in the grass, including sodium, potassium, calcium, iron, magnesium, copper, zinc, and manganese, the flame atomic absorption (AA) spectroscopy technique, also used for heavy metal determination, was applied.

The TaurusWebs platform integrates analytical capabilities based on the principles of near-infrared spectroscopy (NIRS) for the estimation of bromatological components. This process is based on data acquisition through airborne sensors mounted on the drone, which captures spectral information using RGB algorithms. This technology decomposes the light reflected by the Rodas grass canopy into its three primary color bands—Red, Green, and Blue—allowing the system to interpret wavelengths associated with photosynthetic activity and vegetative vigor in order to estimate the nutritional value of the forage. The NIRS method is capable of providing reliable estimates of nutritional composition, including neutral detergent fiber, acid detergent fiber, protein, dry matter, and other components (Ariza Nieto, 2018).

This research is based on the hypothesis that there are no statistically significant differences between the values reported by the two evaluation methods. If this assumption is confirmed, a rapid and low-cost diagnostic methodology is proposed for the livestock sector in Santa Ana, enabling the optimization of animal diets and improving the competitiveness of local farms.

Methods

The study was conducted in the Santa Ana canton, located in the central-western area of the province of Manabí, Republic of Ecuador. The area selected for the analysis of Rodas grass is geographically located at 1°12′ South latitude and 80°22′ West longitude, at an approximate elevation of 50 m above sea level. This environment presents the typical agroecological conditions of the region, characterized by a climate that directly influences the bromatological composition of the forages evaluated in this study.

The area has distinct dry and rainy seasons. It has a humid tropical climate with a mean annual temperature of 26°C. Annual precipitation ranges from 500 mm to 1,000 mm. The study site covers an area of 6 hectares and 56 square meters.

Sampling design

To ensure data quality, the drone camera's white balance was calibrated by setting the value to 5,200 K. This adjustment is essential for standardizing image acquisition and must be adapted to the technical specifications of the aircraft used, as recommended by the software (TaurusWebs, 2025), thereby avoiding chromatic interference during image acquisition.

Data collection was carried out in two plots within the same field by capturing images at three altitude levels: 20, 50, and 100 meters. These flights were conducted under clear-sky conditions and stable solar illumination in order to prevent the formation of cast shadows that could introduce irregularities or bias into the bromatological image processing.

To determine the most appropriate time window for multispectral data acquisition, three sampling times were established: 10:00, 14:00, and 17:00 hours, specifically on days 30 and 45 of the crop cycle. The evaluation at day 15 was omitted for this schedule, and only one image was captured at each altitude after determining that vegetation cover density was insufficient for a representative analysis.

Because the software generated a greater volume of data than the frequency of the chemical analyses, daily averages were calculated for each evaluated variable. This normalization procedure aligned the granularity of the digital information with the laboratory reports, which provided a single value for each sampling day. This adjustment was essential to strengthen the statistical analysis framework and ensure consistency in the comparison between the two methodologies.

Image analysis was performed individually to determine protein content, dry matter, net energy for lactation (MJ/kg), neutral detergent fiber (NDF), and acid detergent fiber (ADF). In addition, microminerals (Cu, Fe, Zn, Mn, B) and macrominerals (K, P, Ca, S, Mg) present in the dry matter of the grasses were quantified. This procedure was carried out using mathematical algorithms incorporated into the software, which are decoded through the RGB bands provided by the images captured by the drone.

This approach enables the interpretation of the reflectance of wavelengths associated with photosynthetic activity in chloroplasts, facilitating the indirect estimation of nutrient and mineral concentrations in plant tissue. Pesantez (2024) indicates that spectral images captured by conventional RGB cameras have enabled the monitoring of vegetation status, land cover analysis, and the identification of different types of stress, including both water and nutritional stress (p. 17).

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Laboratory sample collection

For laboratory sampling, GPS coordinates were established within the two Rodas grass plots, which were georeferenced using a drone. This procedure was carried out to ensure a precise and reliable comparison between the results obtained from both analytical methodologies.

Before collecting the grass samples, the image captured at an altitude of 100 meters was initially processed using the corresponding software. This processing made it possible to identify the area of the crop with the best conditions. Within the software, the image is displayed using color bands, where areas with greater vegetative vigor are represented by an intense green color; however, these areas were verified to ensure that they actually corresponded to the crop under study.

Once the most representative area of the pasture had been selected, sample collection was carried out. A total of six samples were collected and then thoroughly mixed to form a composite sample. This composite sample was subsequently stored in a hermetically sealed polystyrene bag for shipment and laboratory analysis.

Each sample was properly labeled with the exact coordinates of the collection point and received the appropriate treatment in accordance with the laboratory's requirements. The amount of material collected depended on the specifications established by the CESECCA laboratory, which required a total of 200 grams of sample per plot.

This procedure was carried out during the three sampling events corresponding to the two scheduled days. On these occasions, the preliminary software analysis was omitted for sampling events 2 and 3 in order to maintain a continuous record and minimize potential errors during sample collection. In addition, a single fixed sector was defined for sample collection.

For the mineral, ADF, and NDF analyses, one kilogram of biomass was collected per plot, complying with the sample submission requirements of the Agrocalidad laboratories in Tumbaco. The samples were hermetically sealed and transported under refrigerated conditions. This procedure was performed only during the final phase of the study to complement the comparison of data with the advanced functions of the software, since these specific analyses were not available at the CESECCA laboratory.

To obtain the results, several analytical methods were used. The percentage of crude protein was determined using the Kjeldahl method, a chemical analytical procedure that quantifies the total nitrogen content of the sample. As explained by the University of Zaragoza (2024), this technique involves "digesting the proteins and other organic components of food in a mixture with sulfuric acid in the presence of catalysts" (p. 2). In this way, the nitrogen content of the grass allows the calculation of its crude protein content.

The quantitative determination of the ether extract fraction (crude fat) and the moisture content of the forage was based on gravimetric analysis. Specifically, the volatilization method was applied, which consists of accurately measuring the variation in sample mass after the removal of volatile components through controlled thermal treatments in a muffle furnace and drying oven. This procedure made it possible to isolate and quantify each residue with the rigor required for subsequent statistical comparison with the digital estimates. Montero (2021) states that "the strategy is modified if the analyte is volatilized and its accumulation after volatilization is measured; subsequently, the weight loss is related to the analyte that has been volatilized" (p. 20).

Dry matter was determined using the classical gravimetric method, an analytical chemistry procedure standardized by the AOAC (Association of Official Analytical Chemists). The calculation was performed by subtracting the moisture percentage from the total sample (100%), representing the sum of the solid components of the grass: carbohydrates, dry matter, ash, and crude protein, following the protocols established by the CESECCA laboratory.

To estimate the energy content of the forage, the laboratory used the formula developed by Wilbur Olin Atwater, a pioneer in nutrition in the United States who focused on livestock and agricultural research (Farías Reyes, 2025, p. 2). This mathematical model is based on the principle of energy conservation and uses the percentages of protein, fat, and carbohydrates as the main variables. The equation used was: Energy = 4(%P) + 9(%G) + 4(%C). For the determination of ADF and NDF, the Van Soest detergent method was used. This fractionation process employs specific detergent solutions to quantify the structural components of the cell wall (Sniffen, 1992, as cited in Lery, 2016, p. 3).

According to Lery (2016), sample processing began with registration, drying, and grinding, after which the samples were transferred to vegetable filter paper bags. For the determination of NDF, a neutral detergent solution (NDS), composed of distilled water, lauryl sulfate, sodium sulfate, disodium phosphate, and 2-ethoxyethanol, was added. The mixture was boiled for one hour on a heating plate while maintaining a constant volume by adding distilled water. Subsequently, the samples were dried in an oven to quantify the final residues. An analogous method was used to determine ADF, replacing the reagent with an acid detergent solution (ADS), which contains 1N sulfuric acid and cetyltrimethylammonium bromide (Lery, 2016).

To broaden the comparison between the variables analyzed by the software and the empirical data, complementary mineral analyses were performed at the Agrocalidad laboratory using samples collected on day 45. Allende Céspedes (2024) indicates that the DUMAS method, based on the complete combustion of the sample, was used to determine nitrogen. This process was carried out in a furnace at 950 °C for 2.8 minutes, followed by transfer to a sealed purge chamber. Combustion generates a gaseous mixture that is homogenized in a ballast chamber, from which a representative portion is extracted for final detection by the analyzer.

For phosphorus quantification, the colorimetric method was used (Páez Ordóñez & Ortiz Burbano, 2015) that states:

> According to the literature, the standard method for phosphate determination is based on the reaction of phosphorus with molybdenum and antimony ions to form a complex, which can be reduced using stannous chloride or ascorbic acid, producing a characteristic blue color that can be detected by colorimetry (p. 41)

The remaining elements (K, Ca, Mg, Fe, Mn, Cu, and Zn) were determined by atomic absorption spectroscopy. According to Peñaloza (2023), this procedure consists of introducing the liquid sample into the instrument's nebulizer, where it is carried to the flame and transformed into free atoms. The air-acetylene flame reaches approximately 2,300 °C, a temperature sufficient for the atomization of various elements. However, to achieve higher thermal energy, a nitrous oxide-acetylene mixture may be used, capable of producing temperatures close to 2,900 °C. Once the free atoms are in the gaseous state, they are exposed to the thermal radiation emitted by the hollow cathode lamp (constructed from a glass tube containing an inert gas such as neon or argon).

The fraction of radiation that is not absorbed continues its path to the detector. During this process, electrons absorb energy and temporarily move to a higher energy level. By measuring the difference between the emitted and detected energy at a specific wavelength, the absorbed radiation is quantified using the Lambert–Beer law, thereby establishing a direct relationship between the measured signal and the concentration of the analyzed element (Peñaloza, 2023).

Experimental design

The present study was based on the comparison of two analytical systems applied to the same experimental units, with the aim of evaluating the agreement or differences between the methods. This technical design enabled a direct comparison between the digital estimates generated by TaurusWebs and the laboratory chemical reports, with the objective of determining the efficiency of each tool and its actual impact on optimizing the economic resources of livestock producers in the Santa Ana canton.

For data processing, the comparison between both methods was performed using Student's t-test for paired samples. This statistical tool made it possible to determine the presence or absence of significant differences between the results obtained by the two methods, thereby providing a precise bromatological assessment of the forage by identifying possible discrepancies between the measurements.

The variables included in the study were as follows:

- Dependent variable: bromatological analysis results of Rodas grass (Pennisetum sp.), expressed as percentages of crude protein, dry matter, and net energy for lactation.
- Independent variable: bromatological analysis performed by laboratory methods and by the TaurusWebs software.

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Results

Table 1
Comparison of average bromatological parameters in Plot 1

Day	Method	Protein (%)	NDF (%)	ADF (%)	Dry matter (%)	Energy (NEL) MJ/kg
15	TaurusWebs	7,25	64,96	35,20	18	3,95
30	TaurusWebs	10,74	61,42	33,59	18	4,39
45	TaurusWebs	19,11	51,59	22,65	18	5,42
15	Laboratory	2,56			12,12	0,18
30	Laboratory	2,20			10,91	0,15
45	Laboratory	2,51	91,31	56,07	19,96	0,29

The comparative bromatological results presented in Table 1 reveal substantial discrepancies between the estimates generated by the TaurusWebs software and the analytical laboratory determinations. Regarding the protein fraction, the software projected an atypical increase, reaching 19.11% on day 45, whereas the chemical analysis reported significantly lower and more stable values (mean 2.42%), indicating a theoretical overestimation by the digital model.

This trend becomes even more pronounced in the structural components of the cell wall. On day 45, the gravimetric laboratory method recorded critical values of 91.31% for NDF and 56.07% for ADF, in contrast to the lower fiber contents predicted by the software (51.59% and 22.65%, respectively). This divergence is explained by methodological differences: TaurusWebs operates using predictive mathematical models that, in this study, demonstrated limitations in extrapolating the actual lignification kinetics under field conditions. In contrast, the laboratory method (Van Soest) is gravimetric in nature, enabling the physical quantification of the structural components of the cell wall.

A critical point of variation was observed in dry matter, where the software maintained a constant parametric value of 18%. This homogeneity reflects the use of preconfigured or default values based on averages from standard nutritional tables. However, the chemical analysis identified moisture fluctuations, with dry matter values of

12.12% on day 15 and 19.96% on day 45. These analytical differences directly affected the calculation of net energy for lactation (NEL); whereas the software projected a progressive increase from 3.95 MJ/kg to 5.42 MJ/kg based on its estimate of lower fiber content, the laboratory determined an increase from 0.18 MJ/kg to 0.29 MJ/kg, because ADF (lignin) mathematically penalizes digestibility and energy availability.

Table 2
Student's t-test for protein determined by both methodologies, Plot 1

Day	Software analysis (A)	Laboratory analysis (B)	A-B	$(A-B)^2$
15	7,25	2,56	4,69	22
30	10,74	2,20	8,54	72,93
45	19,11	2,51	16,60	275,56
Σ	32,1	7,27	29,83	370,49
$\bar{x}$	12,37	2,42	9,94	123,50
S^2	$\sqrt{S^2}$	DF	Tukey values	t
12,31	3,51	2	0,05 = 4,303 0,01 = 9,925	2,83

To determine the reliability of Livestock 4.0 tools compared with conventional methods, a Student's t-test for paired samples was applied. The protein content obtained using the software (A) was compared with that obtained by laboratory analysis (B). For this analysis, the values recorded by the software on days 15, 30, and 45 were averaged to obtain a representative value for each stage, allowing direct comparison with the laboratory results.

The statistical results showed a calculated t value (2.83) lower than the critical values established for the 5% (4.303) and 1% (9.925) significance levels. Consequently, the hypothesis of similarity between the software estimates and the laboratory analyses was accepted for the evaluated parameter.

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Table 3
Student's t-test for dry matter determined by both methodologies, Plot 1

Day	Software analysis (A)	Laboratory analysis (B)	A-B	(A-B)²
15	18	12,12	5,88	34,57
30	18	10,91	7,09	50,27
45	18	19,96	-1,96	3,84
Σ	54	42,99	11,01	88,68
$\bar{x}$	18	14,33	3,67	29,56
S²	√S²	DF	Tukey values	t
8,04	2,84	2	0,05 = 4,303 0,01 = 9,925	1,29

The software analysis (A) showed complete stability, maintaining a constant value of 18 throughout the three sampling days, whereas the laboratory analysis (B) exhibited substantial variation, with a mean value of 14.33. Although an arithmetic difference was observed, the data indicate that there is no statistical evidence to conclude that one method is superior to the other or that they systematically produce different results.

Table 4
Student's t-test for energy (MJ/kg) determined by both methodologies, Plot 1

Day	Software analysis (A)	Laboratory analysis (B)	A-B	$(A-B)^2$
15	3,9	0,18	3,72	13,84
30	4,4	0,15	4,25	18,06
45	5,40	0,29	5,11	26,11
Σ	13,7	0,62	13,08	58,01
$\bar{x}$	4,57	0,21	4,36	19,34
S^2	$\sqrt{S^2}$	GL	Tukey values	t
0,16	0,41	2	0,05 = 4,303 0,01 = 9,925	10,77

When comparing energy yield using the two proposed methodologies, it was determined that the software and laboratory did not produce equivalent results. The calculated t value (10.77) exceeded the critical reference values for the 5% and 1% Tukey confidence levels. Consequently, the hypothesis of equality was rejected, and it was concluded that there is a statistically significant difference between the two analytical methods during the 15-, 30-, and 45-day evaluation periods.

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Table 5

Comparison of ADF and NDF results on day 45, Plot 1

Day	Method	NDF	ADF
45	TaurusWebs	51,60	22,70
45	Laboratory	91,31	56,07

Additionally, neutral detergent fiber (NDF) and acid detergent fiber (ADF) were determined during the final sampling stage (day 45). When both methodologies were compared in Table 5, a substantial discrepancy was identified in the absolute values obtained.

Table 6

Comparison of average mineral parameters in Plot 1 on day 45

Day	Method	Ca (%)	P (%)	Mg (%)	K (%)	Cu (%)	Fe (mg/kg)	Zn (mg/kg)	Mn (mg/kg)	N (%)
45	TaurusWebs	0,32	0,40	0,16	4,28	6,35	164	29,11	50,56	3,06
45	Laboratory	0,22	0,17	0,15	2,62	9	170	28	51,50	2,13

The mineral analysis conducted on the farm in Santa Ana made it possible to identify the elemental composition of Rodas grass, a key factor in the metabolic balance of livestock. Relative stability was observed among the macronutrients, with average levels of calcium (0.32%), phosphorus (0.40%), magnesium (0.16%), potassium (4.28%), and nitrogen (3.06%). Likewise, the software identified the presence of micronutrients such as iron (164 mg/kg), zinc (29.11 mg/kg), and manganese (50.56 mg/kg). Compared with the laboratory results, it was found that the estimated values were not substantially different from the measured values. The laboratory reported calcium (0.22%), phosphorus (0.17%), magnesium (0.15%), potassium (2.62%), and nitrogen (2.13%), while the micronutrient analysis identified iron (170 mg/kg), zinc (28 mg/kg), and manganese (51.50 mg/kg).

Plot 2

In Plot 2, the evaluation of Rodas grass using the TaurusWebs software showed an increasing trend in nutrient concentration as the phenological cycle progressed. On day 15, an initial average crude protein content of 4.20% was recorded, which increased significantly to 16.61% by the end of the 45-day period.

As in Plot 1, a marked discrepancy was observed when these data were compared with the laboratory analyses, particularly during the final stages of crop development. While the software estimated protein levels above 16%, the chemical method reported a concentration of 2.85% on day 45. A similar discrepancy was observed for net energy for lactation (NEL), where the digital system projected 5.11 MJ/kg compared with the 0.33 MJ/kg validated by laboratory analysis.

Table 7
Comparison of average bromatological parameters in Plot 2

Day	Method	Protein (%)	NDF (%)	ADF (%)	Dry matter	Energy (NEL) MJ/kg
15	TaurusWebs	4,20	68,41	35,14	18	3,57
30	TaurusWebs	10,89	60,86	33,54	18	4,40
45	TaurusWebs	16,61	54,41	26,98	18	5,11
15	Laboratory	2,91			9,66	0,14
30	Laboratory	2,03			16,57	0,24
45	Laboratory	2,85	92,61	56,57	22,37	0,33

With respect to the fiber fraction, the laboratory determined values of 92.61% for NDF and 56.57% for ADF. These values greatly exceeded the software estimates, reinforcing the hypothesis regarding the spectral interpretation performed by the RGB algorithm.

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Table 8
Student's t-test for protein determined by both methodologies, Plot 2

Day	Software analysis (A)	Laboratory analysis (B)	A-B	$(A-B)^2$
15	4,20	2,91	1,29	1,66
30	10,89	2,03	8,86	78,50
45	16,61	2,85	13,76	189,34
Σ	31,7	7,79	23,76	269,50
$\bar{x}$	10,57	2,60	7,97	89,83
S^2	$\sqrt{S^2}$	DF	Tukey values	T
13,15	3,63	2	0,05 = 4,303 0,01 = 9,925	2,20

The evaluation of protein content in Plot 2 did not show a critical discrepancy between the digital method and the laboratory analysis. After performing the statistical comparison, a test statistic of 2.20 was obtained. Since this value was below the significance thresholds, it was concluded that the differences between the two methods were not statistically significant, indicating agreement between the reported results.

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Table 9
Student's t-test for dry matter using both methodologies, plot 2

Day	Software analysis (A)	Laboratory analysis (B)	A-B	$(A-B)^2$
15	18	9,66	8,34	69,56
30	18	16,57	1,43	2,04
45	18	22,37	-4,37	19,10
Σ	54	48,6	5,40	90,70
$\bar{x}$	18	16,20	1,80	30,23
S^2	$\sqrt{S^2}$	DF	Tukey values	t
13,49	3,67	2	0,05 = 4,303 0,01 = 9,925	0,49

Using the same method, the dry matter content obtained by both diagnostic techniques was evaluated. The calculated t value (0.49) was substantially lower than the minimum critical value (4.303); therefore, the analysis falls entirely within the acceptance region of the null hypothesis.

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Table 10
Student's t-test for energy (MJ/kg) determined by both methodologies, Plot 2

Day	Software analysis (A)	Laboratory analysis (B)	A-B	$(A-B)^2$
15	3,57	0,14	3,43	11,76
30	4.4	0,24	4,16	17,31
45	5,11	0,33	4,78	22,85
Σ	13,08	0,71	12,37	51,92
$\bar{x}$	4,36	0,24	4,12	17,31
S^2	$\sqrt{S^2}$	DF	Tukey values	T
0,15	0,39	2	0,05 = 4,303 0,01 = 9,925	10,57

The results for energy density (MJ/kg) show a critical divergence between the two methods. The calculated test statistic (10.57) is well above the Tukey critical values, requiring rejection of the null hypothesis of equality.

Table 11
Comparison of ADF and NDF results on day 45, Plot 2

Day	Method	NDF	ADF
45	TaurusWebs	54,41	26,98
45	Laboratory	92,61	56,57

Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were evaluated during the final stage of the sampling process. The comparison revealed a substantial bias between the values obtained, indicating poor agreement between the laboratory determinations and the software estimates.

Table 12
Comparison of average mineral parameters in Plot 2 on day 45

Day	Method	Ca (%)	P (%)	Mg (%)	K (%)	Cu (%)	Fe (mg/kg)	Zn (mg/kg)	Mn (mg/kg)	N (%)
45	TaurusWebs	0,33	0,36	0,19	3,46	5,66	138	28,44	55,89	2,66
45	Laboratory	0,19	0,18	0,14	2,38	8,5	127	36,49	12,15	1,87

The analysis of inorganic components in Plot 2 established a profile of essential nutrients for cattle. Average concentrations of calcium (0.33%), phosphorus (0.36%), magnesium (0.19%), potassium (3.46%), and nitrogen (2.66%) were determined. The software also identified the presence of micronutrients such as iron (138 mg/kg), zinc (28.44 mg/kg), and manganese (55.89 mg/kg). Compared with the laboratory results, the estimated values were found to be reasonably close to the measured values. The laboratory reported calcium (0.19%), phosphorus (0.18%), magnesium (0.14%), potassium (2.38%), and nitrogen (1.87%), while the micronutrient analysis identified iron (127 mg/kg), zinc (36.49 mg/kg), and manganese (12.15 mg/kg).

These indicators are essential for livestock producers in Santa Ana, as they make it possible to correlate soil quality with the nutritional value of Rodas grass, facilitating the design of site-specific fertilization or mineral supplementation plans.

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Figures

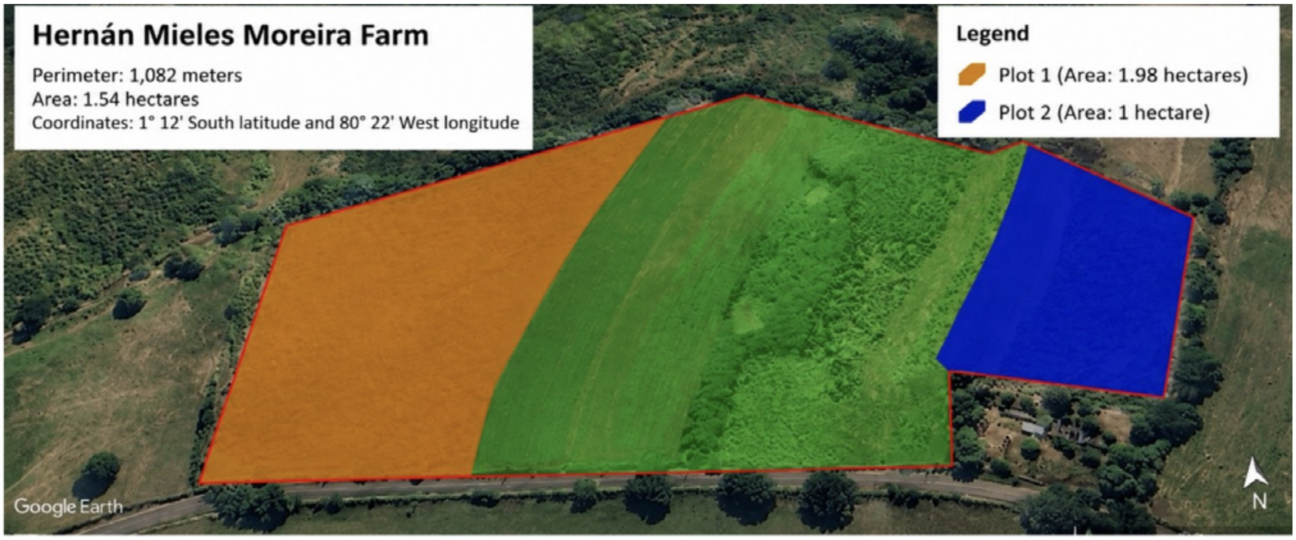

Figure 1

Farm polygon of Hernán Mieles Moreira.

Note. To perform the bromatological analysis of Rodas grass, sampling units were selected within the total area of the farm (Figure 1). Biomass collection was specifically conducted in Plot 1, covering 1.98 hectares, and Plot 2, covering 1.00 hectare. This subdivision of the farm, located in Santa Ana canton, made it possible to capture forage variability under real field conditions, facilitating the correlation between the farm's spatial management and the nutritional indicators obtained from laboratory analyses and the software.

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Plot 1

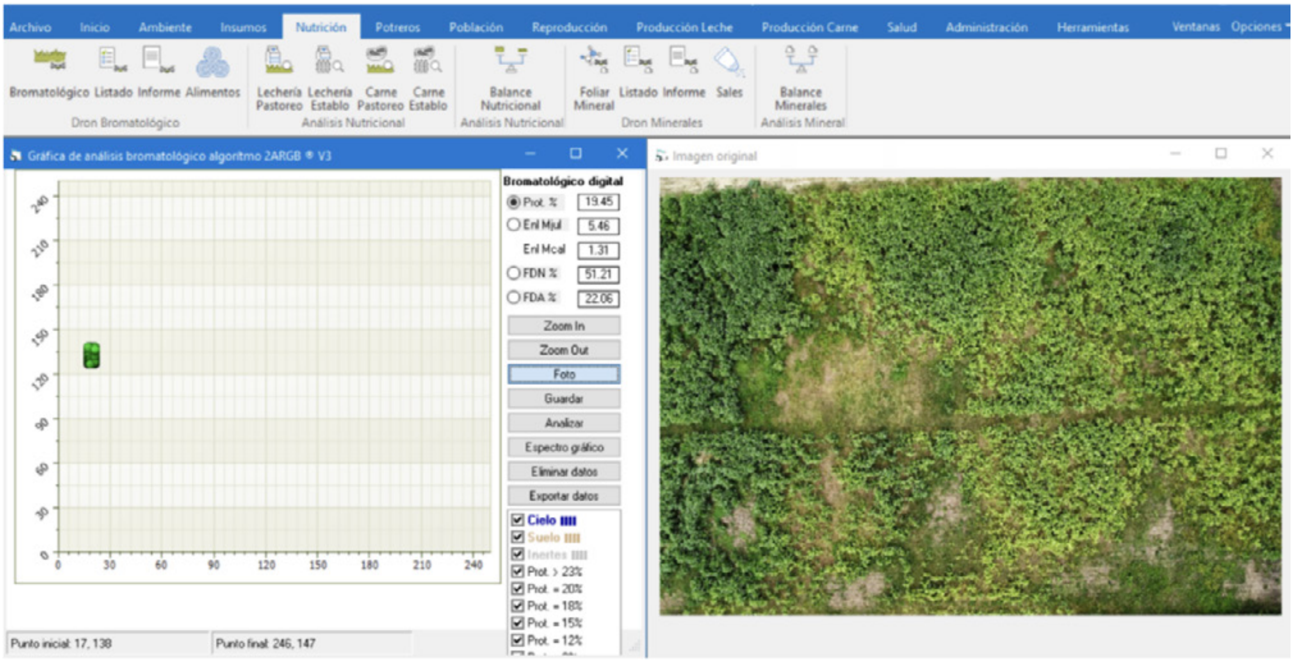

Figure 2

Bromatological analysis at 100 m altitude

Note. The sequence comprising Figures 2 to 9 illustrates the remote sensing and digital processing workflow applied in the study. These figures show the terrain morphology and foliage density through aerial images captured at altitudes of 100 m, 50 m, and 20 m. The graphical sequence demonstrates the integration of these images into the TaurusWebs software, where data interpretation was performed to estimate the bromatological and mineral parameters of Rodas grass in Santa Ana canton.

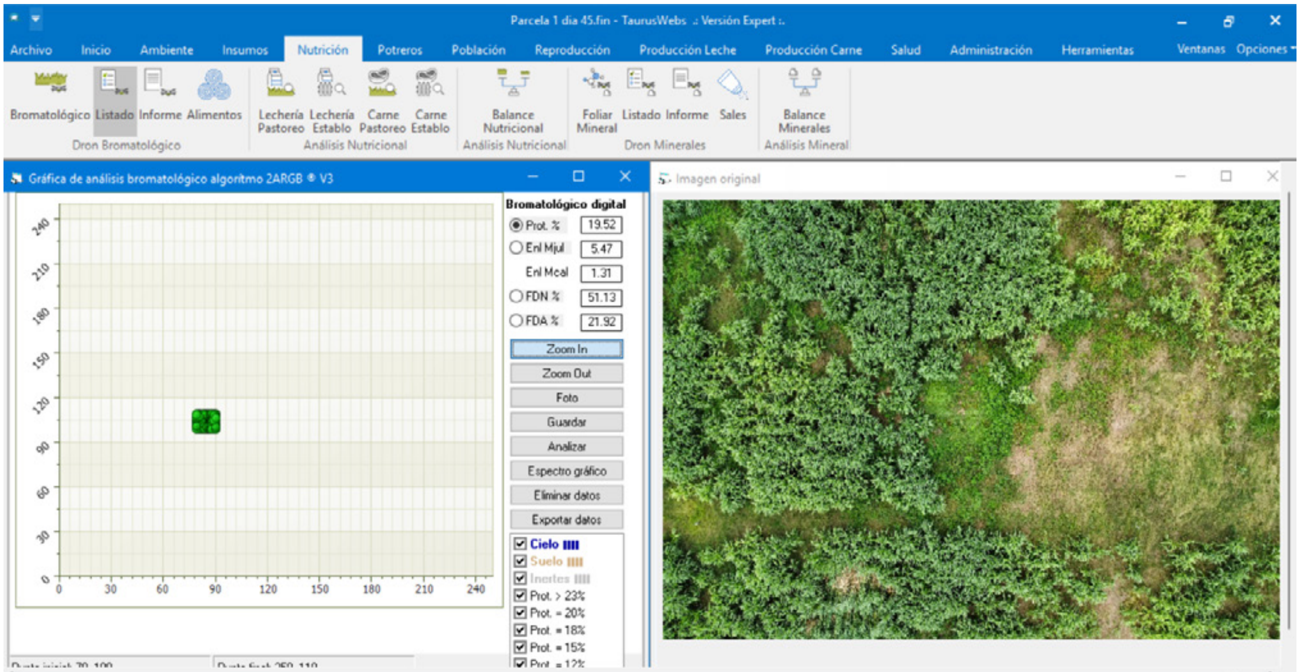

Figure 3

Bromatological analysis at 50 m altitude

Note. Image captured at an intermediate altitude to evaluate biomass resolution and its impact on the accuracy of digital estimates. Processing was performed using the TaurusWebs platform, following the methodological procedures described above.

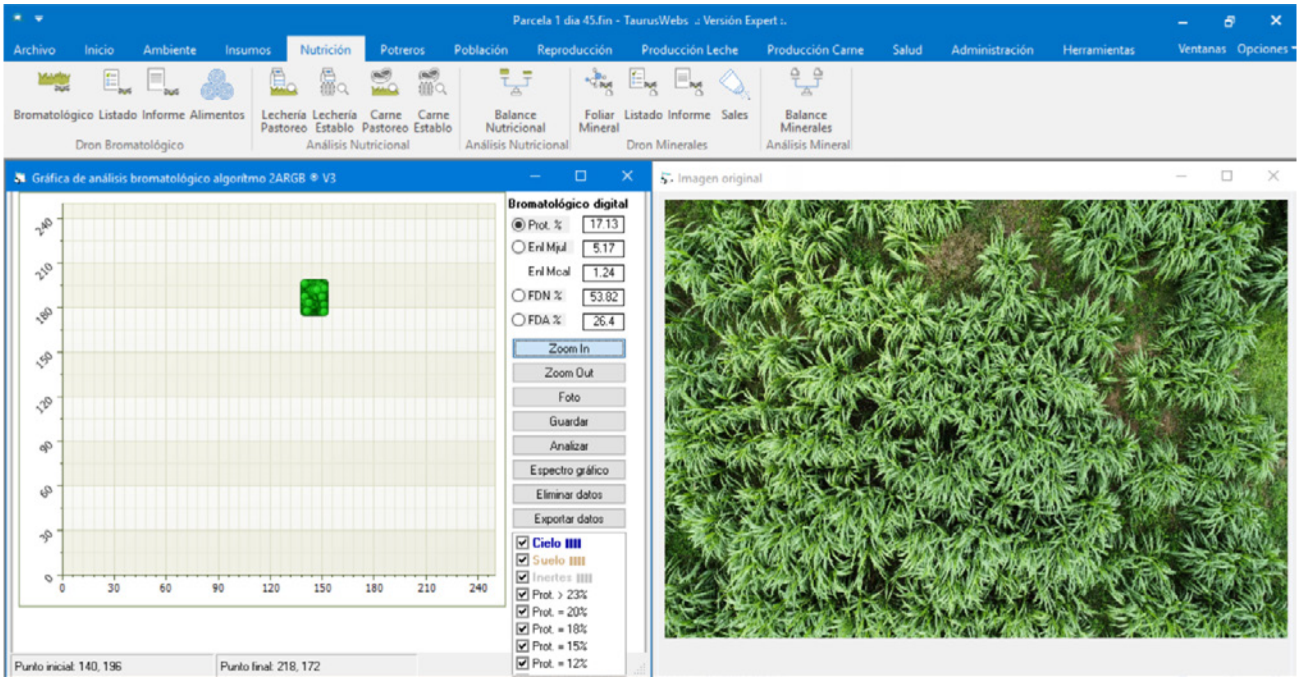

Figure 4

Bromatological analysis at 20 m altitude

Note. High-resolution image allowing a detailed assessment of forage density and quality in the study plots.

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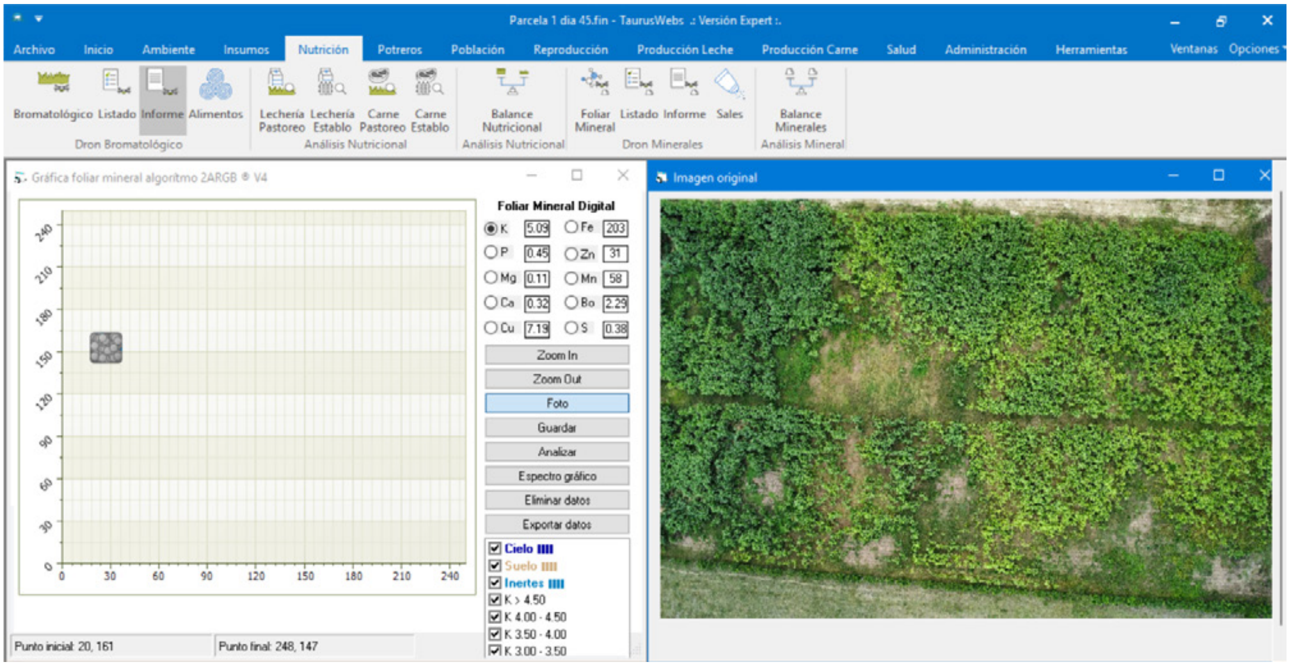

Figure 5

Mineral analisys

Note. Processed image used to identify specific mineral concentrations.

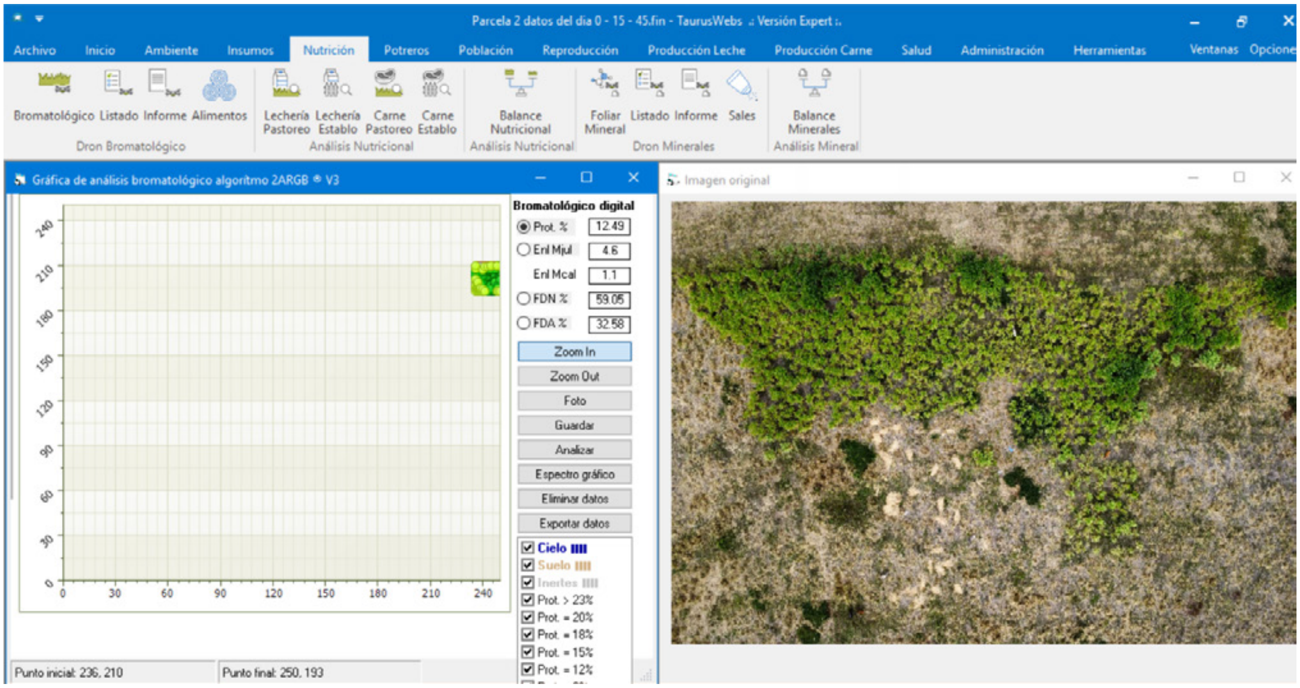

Figure 6

Bromatological analysis at 100 m altitude in Plot 2

Note. Aerial image of the selected area used to validate the bromatological profile in the TaurusWebs software.

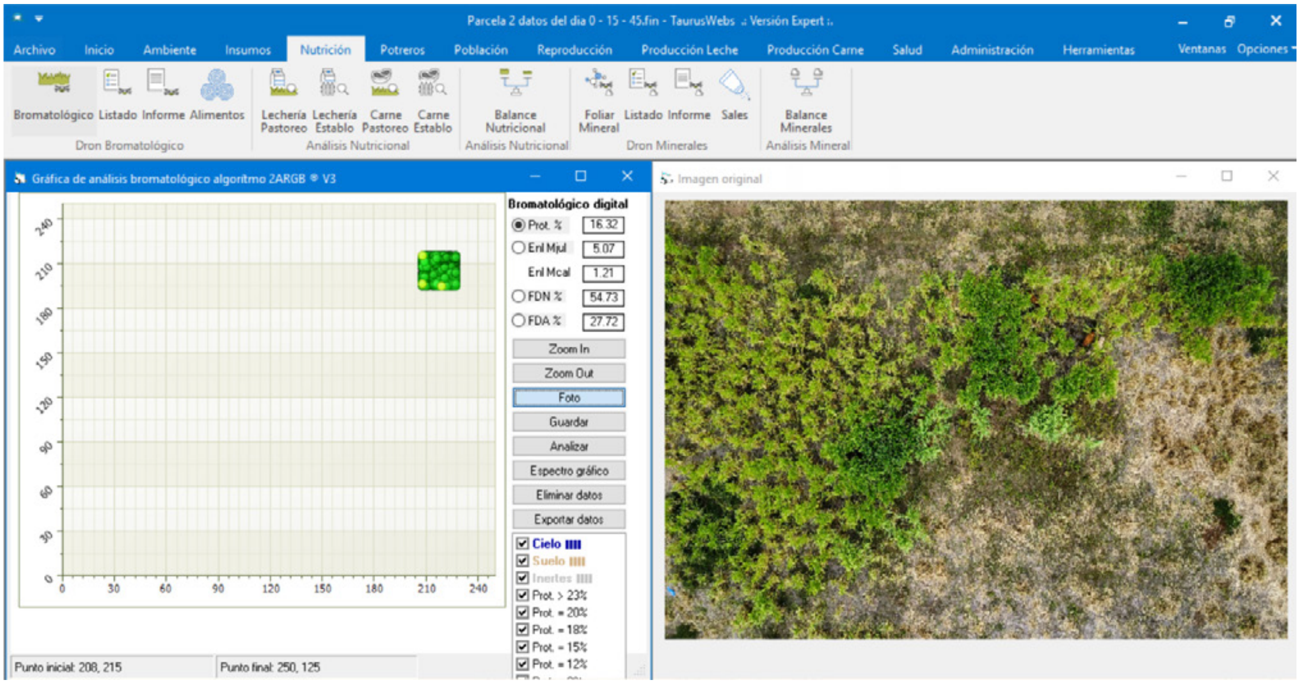

Figure 7

Bromatological analysis at 50 m altitude.

Note. Multispectral image used to compare the nutritional levels of Rodas grass.

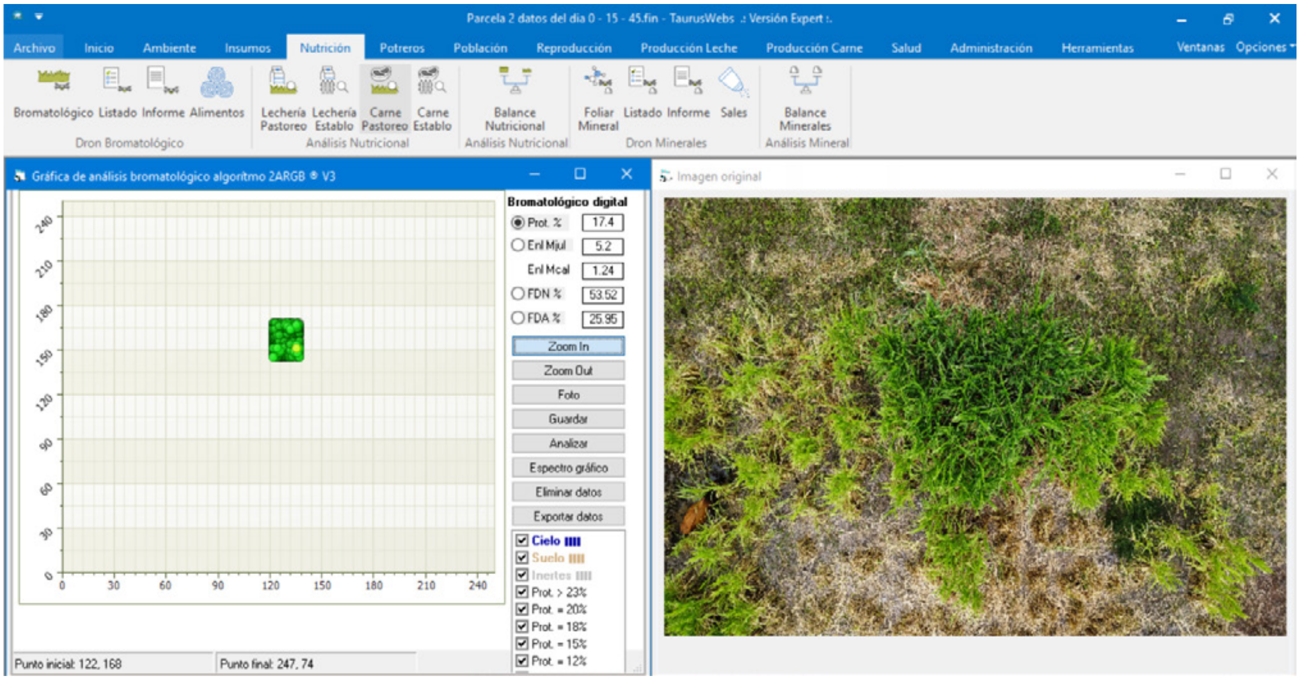

Figure 8

Bromatological analysis at 20 m altitude.

Note. Image used to validate the nutritional parameters of Rodas grass in TaurusWebs.

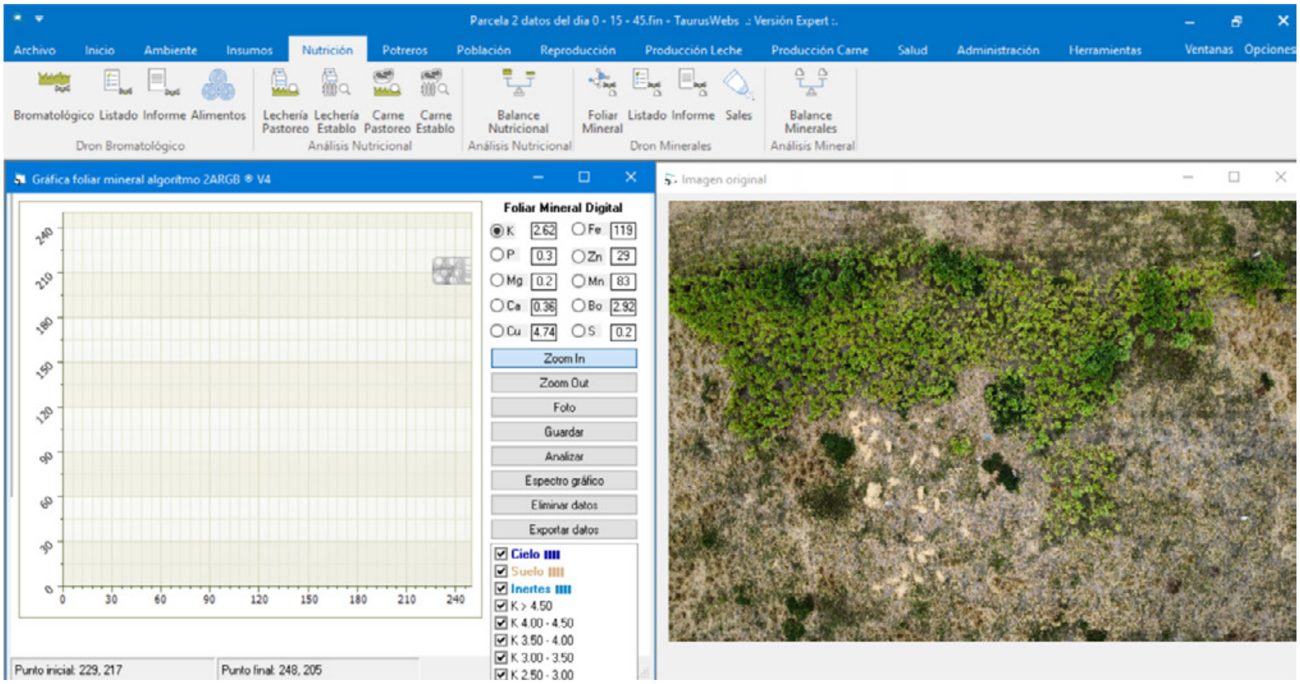

Figure 9

Mineral analysis.

Note. Image used to complement the study of the mineral parameter of Rodas grass.

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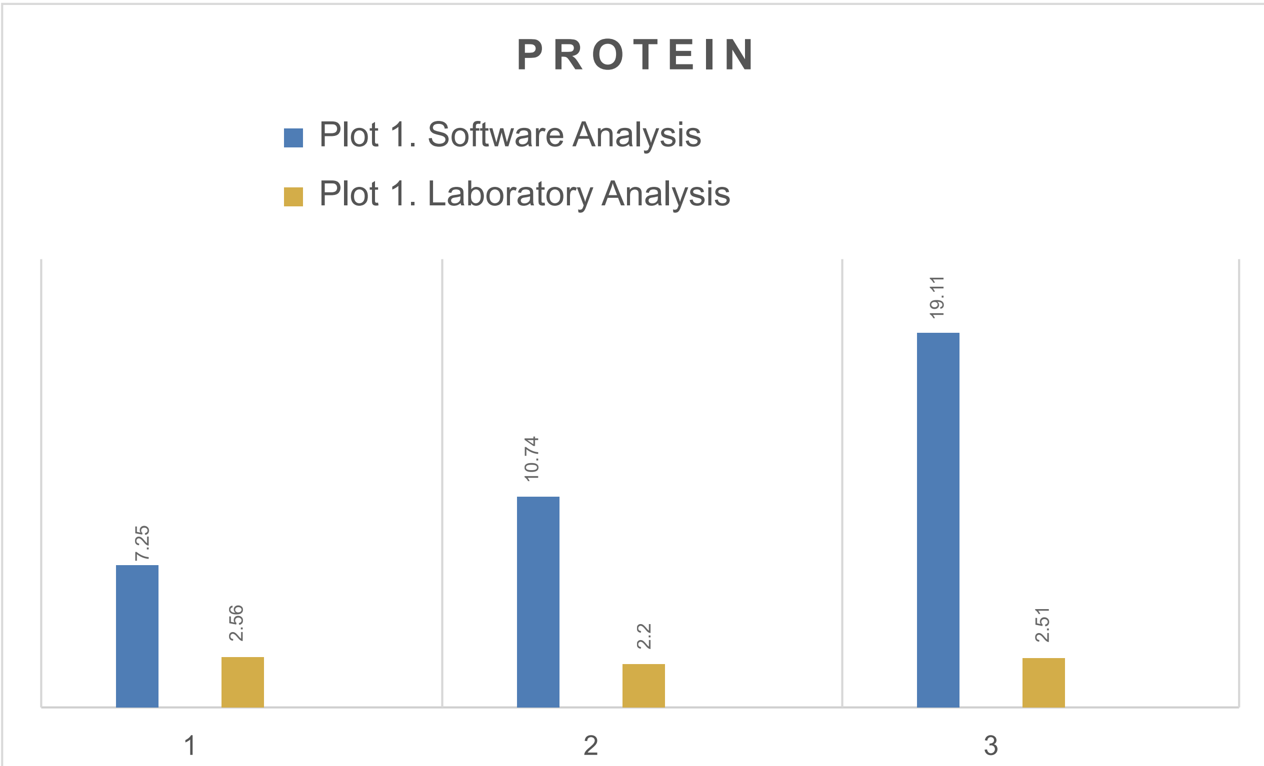

Figure 10

Comparison of protein levels in Plot 1: digital estimates from TaurusWebs software vs. instrumental laboratory analysis.

Note. The values shown in the bars correspond to the results obtained from the sampling conducted within the same management unit in Santa Ana. The visual difference between the software and the laboratory makes it possible to evaluate the research hypothesis regarding the accuracy of digital tools for the analysis of Rodas grass.

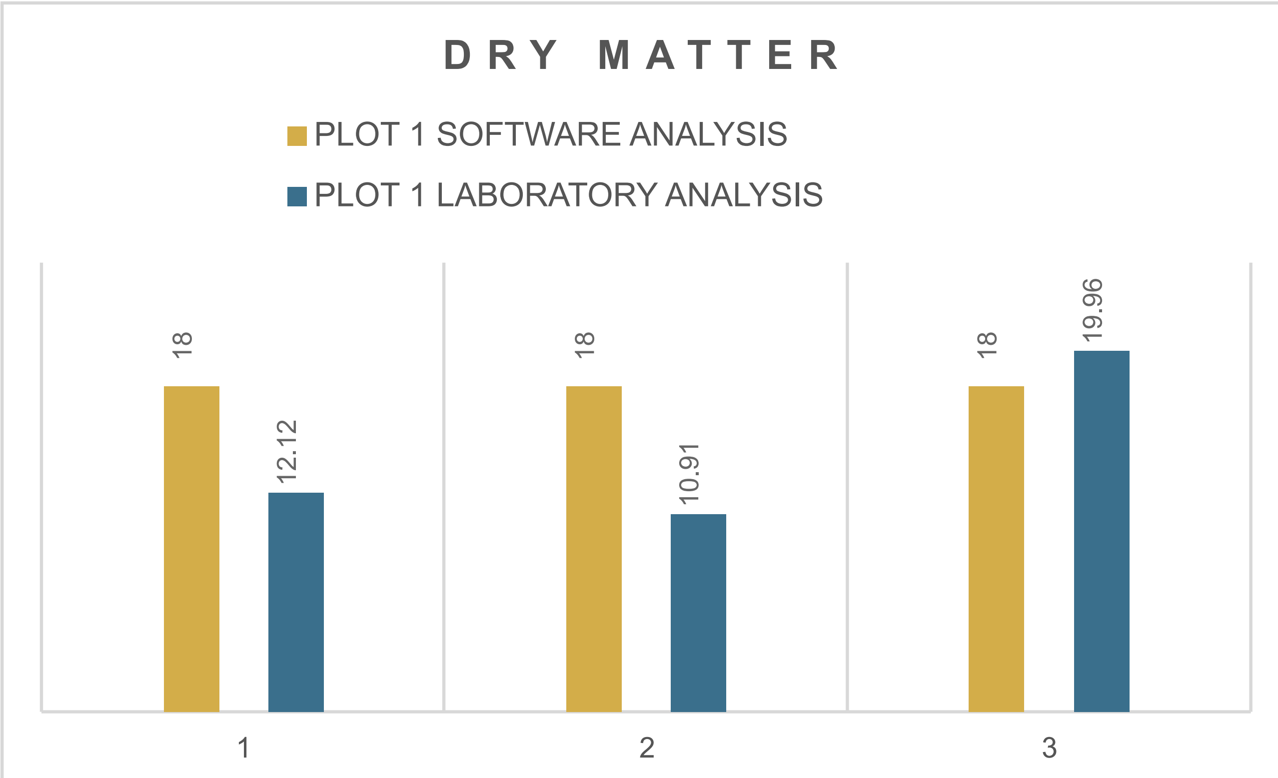

Figure 11

Comparison of dry matter levels in Plot 1: digital estimates from TaurusWebs software vs. instrumental laboratory analysis.

Note. The values shown in the bars correspond to the results obtained from the sampling conducted within the same management unit in Santa Ana. The visual difference between the software and the laboratory makes it possible to evaluate the research hypothesis regarding the accuracy of digital tools for the analysis of Rodas grass.

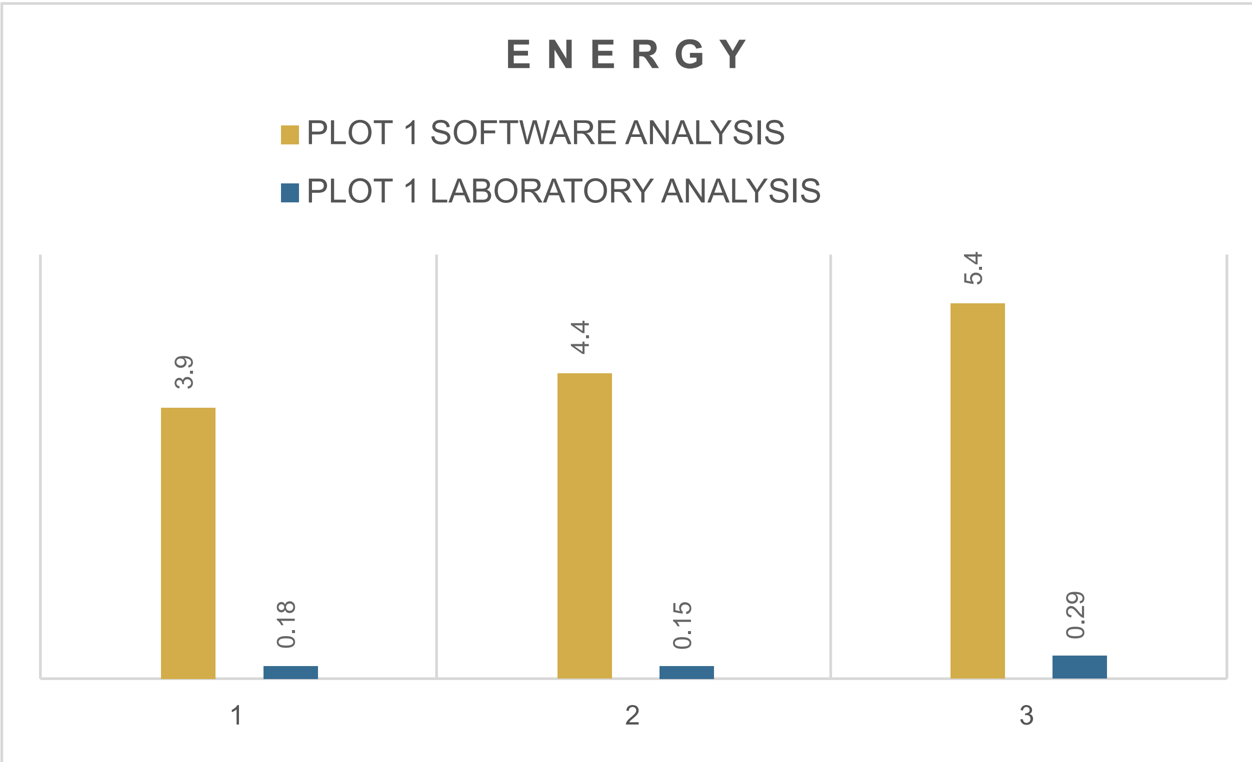

Figure 12

Comparison of energy levels in Plot 1: digital estimates from TaurusWebs software vs. instrumental laboratory analysis.

Note. The values shown in the bars correspond to the results obtained from the sampling conducted within the same management unit in Santa Ana. The visual difference between the software and the laboratory makes it possible to evaluate the research hypothesis regarding the accuracy of digital tools for the analysis of Rodas grass.

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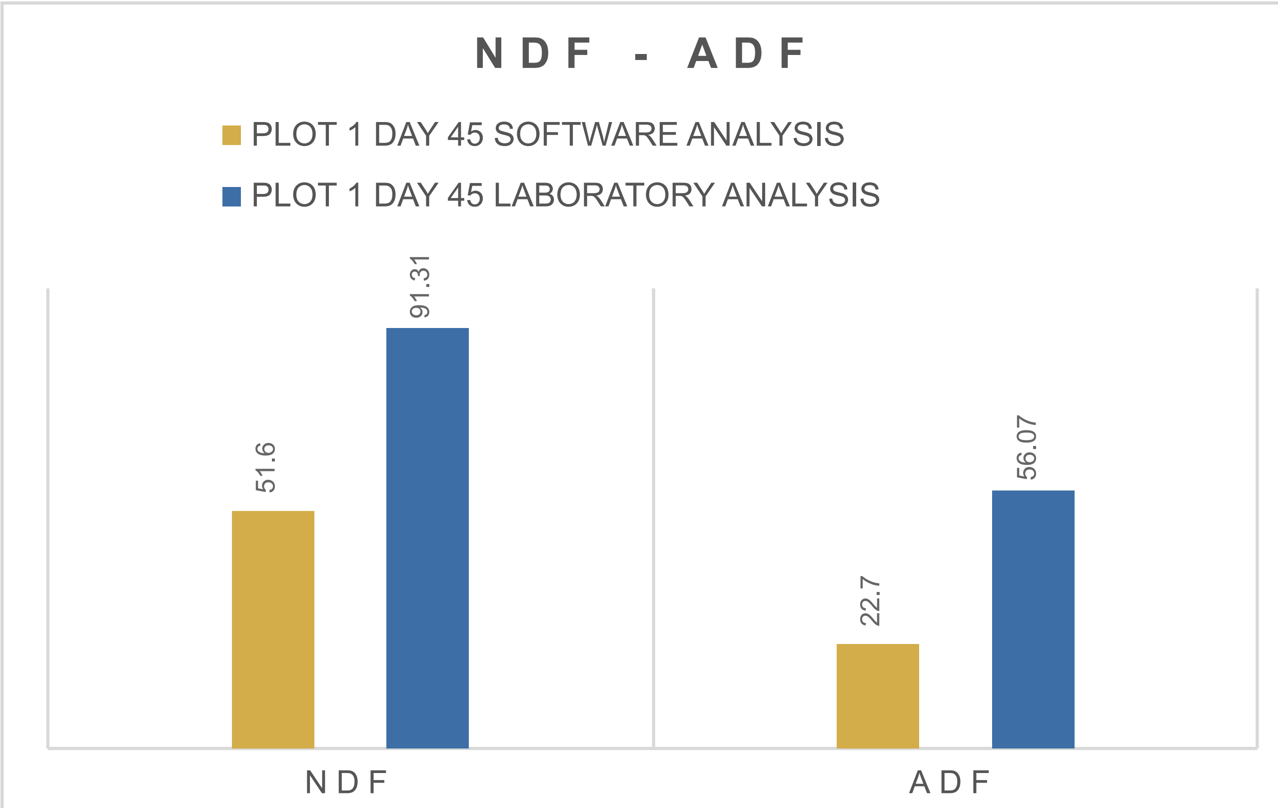

Figure 13

Comparison of NDF and ADF levels in Plot 1: digital estimates from TaurusWebs software vs. instrumental laboratory analysis.

Note. The values shown in the bars correspond to the results obtained from the sampling conducted within the same management unit in Santa Ana. The visual difference between the software and the laboratory makes it possible to evaluate the research hypothesis regarding the accuracy of digital tools for the analysis of Rodas grass.

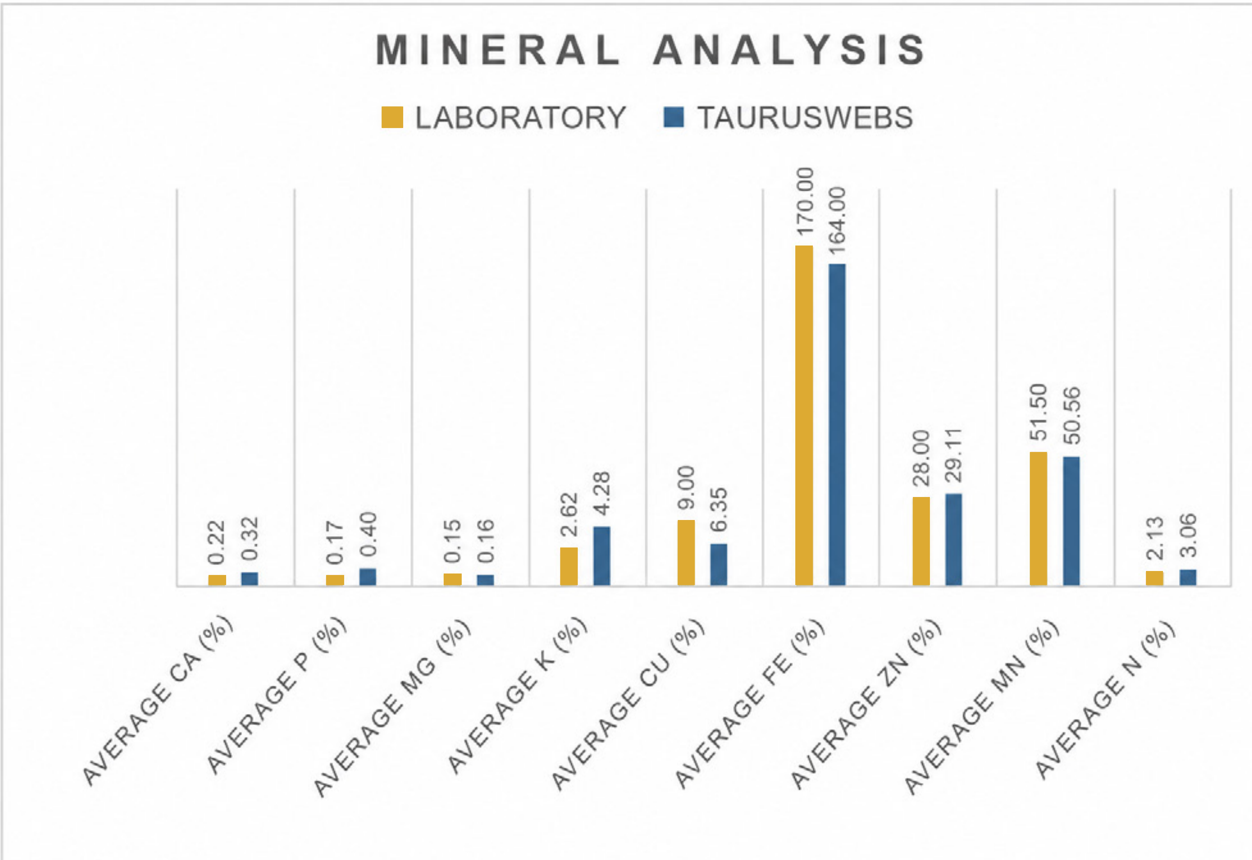

Figure 14

Comparison of mineral levels in Plot 1: digital estimates from TaurusWebs software vs. instrumental laboratory analysis.

Note. The values shown in the bars correspond to the results obtained from the sampling conducted within the same management unit in Santa Ana. The visual difference between the software and the laboratory makes it possible to evaluate the research hypothesis regarding the accuracy of digital tools for the analysis of Rodas grass.

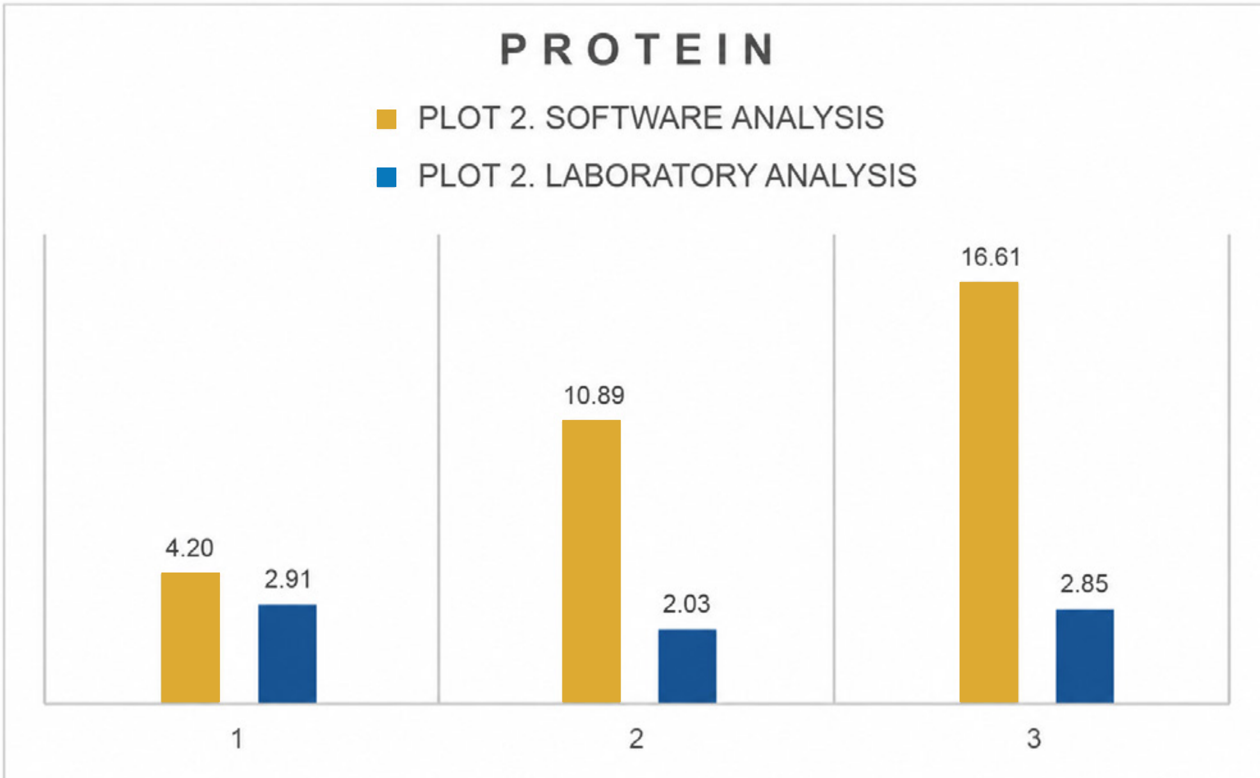

Figure 15

Comparison of protein levels in Plot 2: digital estimates from TaurusWebs software vs. instrumental laboratory analysis.

Note. The values shown in the bars correspond to the results obtained from the sampling conducted within the same management unit in Santa Ana. The visual difference between the software and the laboratory makes it possible to evaluate the research hypothesis regarding the accuracy of digital tools for the analysis of Rodas grass.

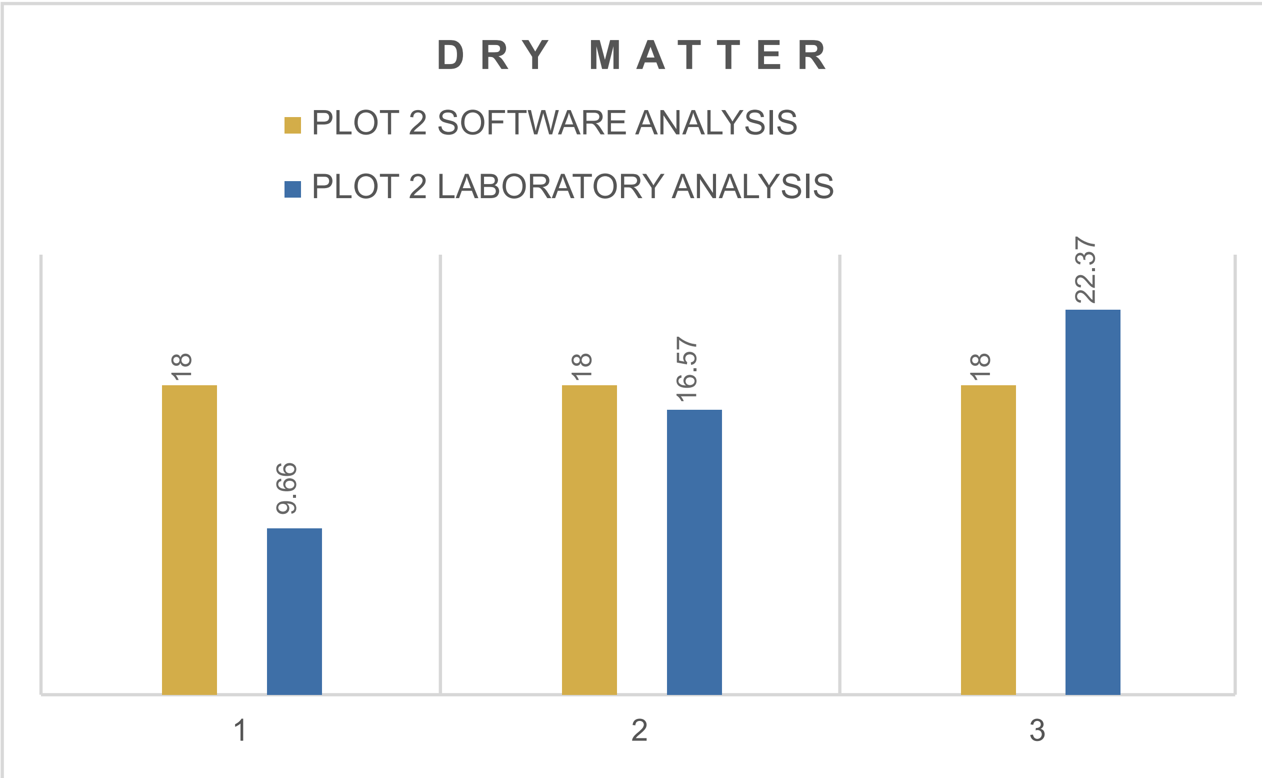

Figure 16

Comparison of dry matter levels in Plot 2: digital estimates from TaurusWebs software vs. instrumental laboratory analysis

Note. The values shown in the bars correspond to the results obtained from the sampling conducted within the same management unit in Santa Ana. The visual difference between the software and the laboratory makes it possible to evaluate the research hypothesis regarding the accuracy of digital tools for the analysis of Rodas grass.

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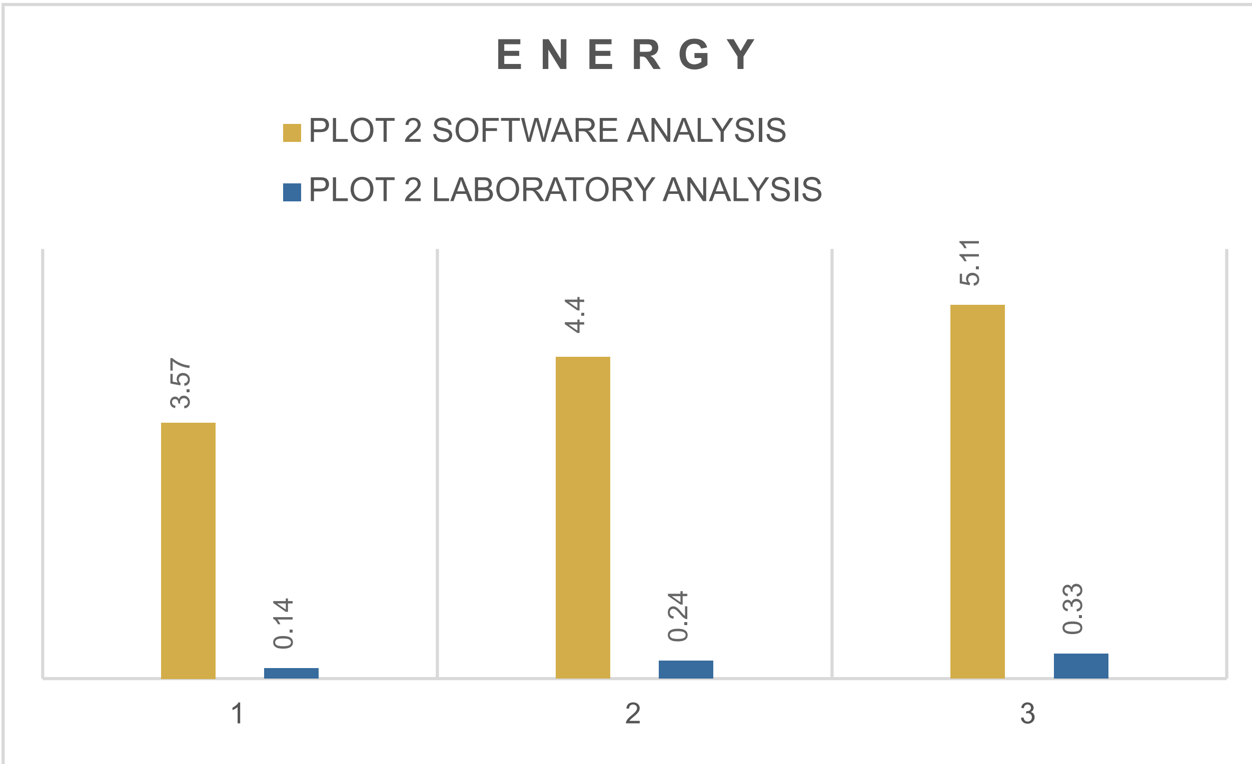

Figure 17

Comparison of energy levels in Plot 2: digital estimates from TaurusWebs software vs. instrumental laboratory analysis.

Note. The values shown in the bars correspond to the results obtained from the sampling conducted within the same management unit in Santa Ana. The visual difference between the software and the laboratory makes it possible to evaluate the research hypothesis regarding the accuracy of digital tools for the analysis of Rodas Grass.

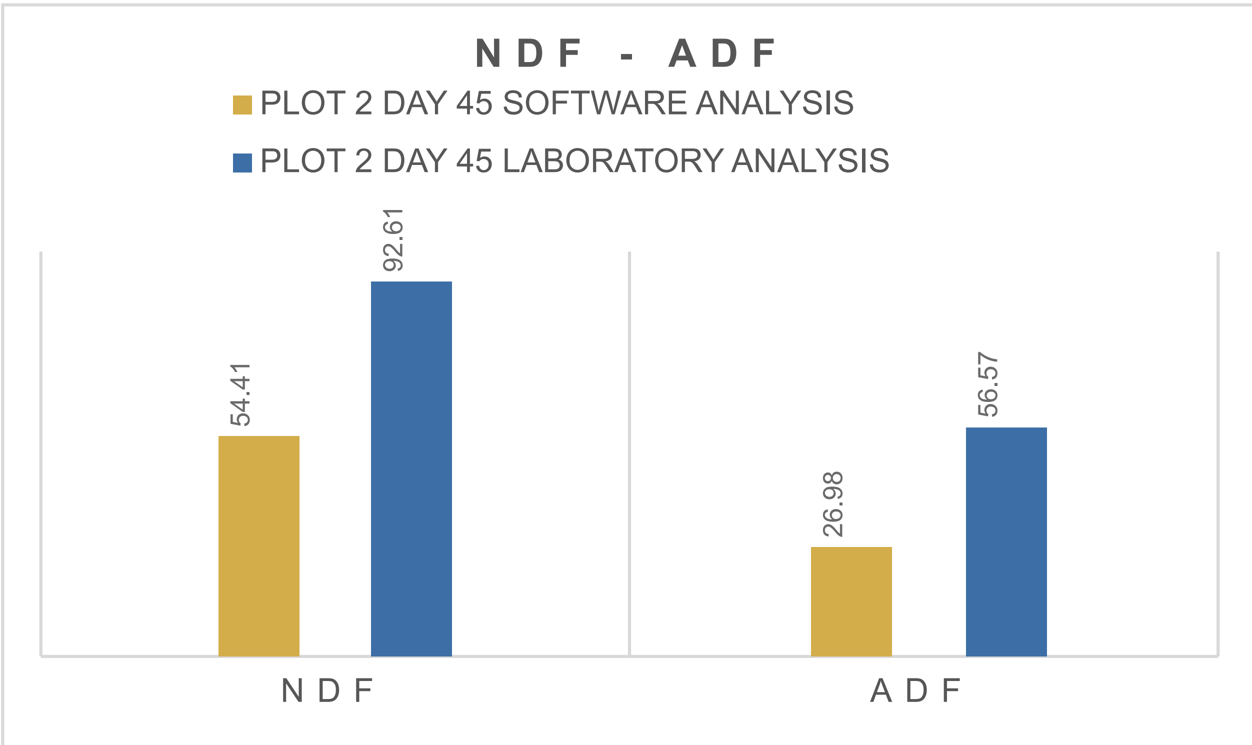

Figure 18

Comparison of NDF and ADF levels in Plot 2: digital estimates from TaurusWebs software vs. instrumental laboratory analysis.

Note. The values shown in the bars correspond to the results obtained from the sampling conducted within the same management unit in Santa Ana. The visual difference between the software and the laboratory makes it possible to evaluate the research hypothesis regarding the accuracy of digital tools for the analysis of Rodas grass.

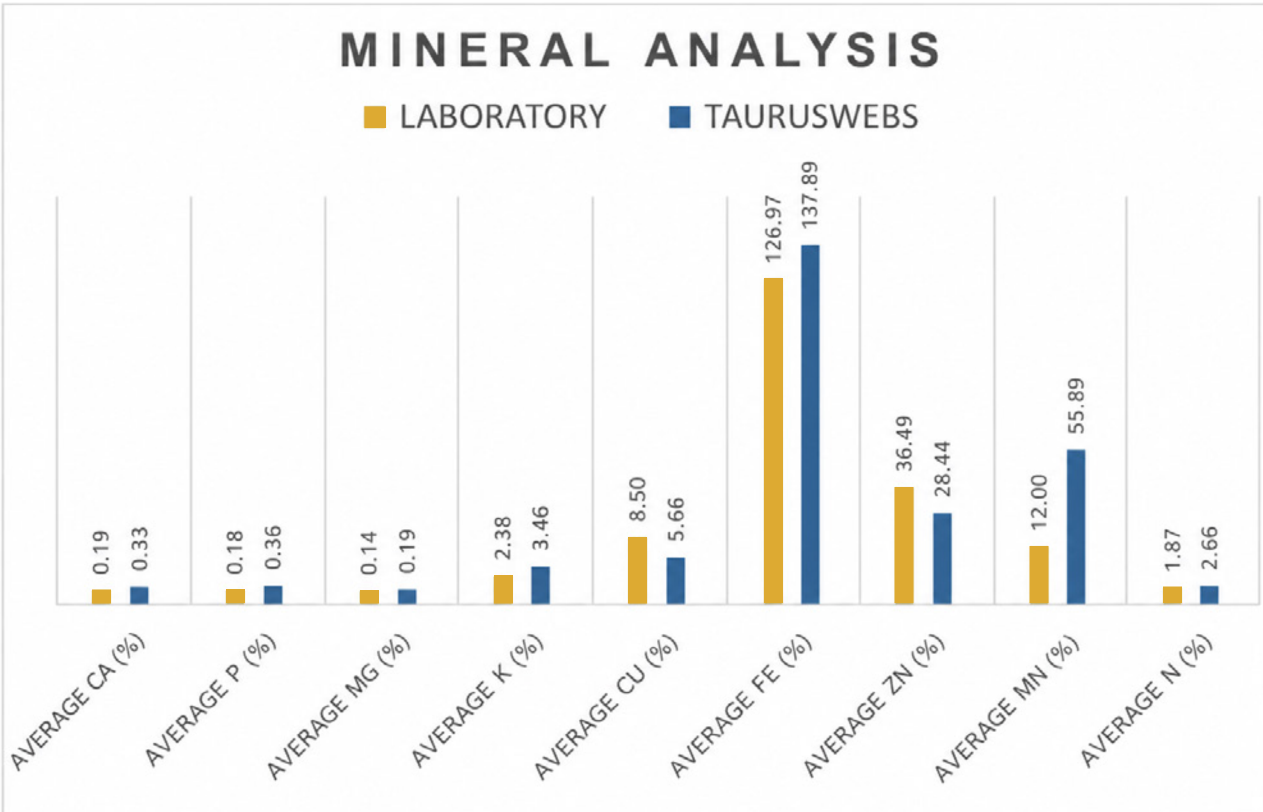

Figure 19
Comparison of mineral levels in Plot 2: digital estimates from TaurusWebs software vs. instrumental laboratory analysis.

Note. The values shown in the bars correspond to the results obtained from the sampling conducted within the same management unit in Santa Ana. The visual difference between the software and the laboratory makes it possible to evaluate the research hypothesis regarding the accuracy of digital tools for the analysis of Rodas grass.

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Equations

$$Null\ Hypothesis$$

$$H_o = V_A = V_B$$

$$Alternative\ Hypothesis$$

$$H_a = V_A \neq V_B$$

$$Variance$$

$$S^2 = \frac{\Sigma D^2 - \frac{(\Sigma D)^2}{n}}{n(n-1)}$$

$$Standard\ Deviation$$

$$\sqrt{S^2}$$

$$Degrees\ of\ Freedom$$

$$df = n_r - 1$$

$$Student's\ t\text{-}Test$$

$$t = \frac{\bar{X}\ D}{S}$$

Discussion

The comparative study of the application of crude protein (CP), dry matter (DM), and net energy for lactation determination techniques demonstrated that there are differences between the values obtained from the analyses performed using both methodologies, columns A and B, as shown in Tables 2, 3, and 4 for Plot 1 and Tables 8, 9, and 10 for Plot 2. This is due to the inherent nature of the conventional analytical procedures performed in the laboratory, namely the Kjeldahl method and gravimetry, whereas the TaurusWebs software relies on RGB image processing algorithms.

Despite the differences in the analytical procedures, the application of Student's t-test made it possible to determine, through the rigorous Tukey comparison (0.05 and 0.01), that there were no significant differences between the results obtained on the three sampling days for the protein and dry matter variables. This indicates that, despite the differences in physicochemical and algorithmic principles, there is agreement between the estimates in the case of Rodas grass (Pennisetum sp.).

These results are consistent with those reported by Ospina (2020), who evaluated the correlation between remote sensing techniques and laboratory (NIRS) analysis. In that study, using non-parametric tests such as Kendall's correlation, Spearman's correlation, and the Kruskal-Wallis test (0.05), a high correlation and the absence of significant differences were demonstrated in the determination of protein parameters. This validates that indirect methods based on optical sensors or image-processing algorithms have comparative strengths relative to reference chemical methods (p. 4).

With respect to the determination of dry matter, the results exhibited variability between the methodologies employed. However, the statistical analysis showed the absence of significant differences, as detailed in Tables 3 and 9. It is worth noting that the values generated by the software remained remarkably constant throughout the three sampling phases; this is because the tool does not quantify moisture dynamically but instead operates using a preset parameter.

Since moisture is a determining factor for the calculation of dry matter by the gravimetric method, this characteristic of the algorithm could suggest a theoretical limitation. Nevertheless, the statistical evidence confirms that image processing using the software provides precision comparable to conventional methods under controlled conditions. These findings are consistent with those reported by de Oliveira et al. (2021), who indicate that high-resolution RGB images represent highly promising techniques for estimating dry matter yield in pastures.

The contrast coefficients detailed in the energy tables (4 and 10) are above the critical values established by Tukey. This discrepancy is based on the fact that the software identifies the actual amount of energy that the animal utilizes for milk production and maintenance (net energy for lactation), whereas the laboratory analysis provides the total (or gross) energy contained in the feed (grass).

In this regard, Ospina Rivera (2021) reported the existence of a correlation between laboratory results and those obtained through the TaurusWebs algorithm; this relationship was validated using Student's t-test, in which no significant differences were observed in net energy for lactation (NEL). These previous findings confirm that both study methodologies are complementary and support the efficiency of the software in estimating the nutritional parameters of grass.

Although complete laboratory data were not available for neutral detergent fiber (NDF), acid detergent fiber (ADF), and the mineral composition of Rodas grass (Pennisetum sp.), these parameters were included in the final evaluation, allowing a basic comparison between both methodologies, as shown in Tables 5, 6, 11, and 12. In the case of NDF and ADF, differences between the values can be observed; however, Ospina (2021) indicated that "there is a high correlation between neutral detergent fiber (NDF) results calculated by near-infrared spectroscopy (NIRS) and RGB image analysis" (p. 5). These conclusions derive from studies aimed at evaluating the similarity between software-generated values and laboratory results calibrated using NIRS, supporting the findings obtained in this research.

Regarding acid detergent fiber (ADF), Ospina (2020), based on a comparative study between software and laboratory methodologies using NIRS as the analytical reference, states that "there is a strong correlation between ADF results calculated by NIRS and those obtained from RGB image analysis" (p. 7), reinforcing the reliability of estimates obtained through image-based tools.

The mineral profile of Rodas grass evaluated in the Santa Ana area shows a close correlation between the software estimates and laboratory determinations, particularly for minerals such as magnesium and zinc. This level of precision suggests that Livestock 4.0 databases are reliable tools for diagnosing these parameters in the region.

However, the variations observed in potassium and nitrogen levels between the two methods highlight the direct influence of local soil characteristics and fertilization management within the plot. The identification of these indicators is essential for the local livestock sector, as it enables a transition from generic to site-specific mineral supplementation. For example, the calcium and phosphorus levels detected provide a basis for designing mineral supplements that optimize the electrolyte balance of cattle in Santa Ana, minimizing economic losses and improving herd metabolic efficiency.

The stability observed in mineral levels between both methods can be attributed to the fact that the Agrocalidad laboratory employed techniques such as colorimetry and atomic absorption spectroscopy, which, like the software, are based on the interaction of light, either through chemical and energy composition or through image analysis.

The 2ARGB® algorithm and plasma induction spectroscopy (PIS) produce statistically equivalent results in the estimation of macrominerals (K, P, Ca, Mg, and S) in the dry matter of grasses. This finding, demonstrated by Ospina Rivera and Baracaldo Martínez (2024), validates digital image analysis as a precise, non-destructive alternative and supports the implementation of image analysis technologies alongside traditional laboratory methodologies. Consequently, these results reinforce the usefulness of the software for accelerating nutritional diagnosis and designing mineral supplementation or fertilization plans, provided that the data are calibrated according to the type of aircraft used and the lighting conditions of the study area.

Conclusions

The present study demonstrates that Livestock 4.0 tools, specifically those based on image processing algorithms such as TaurusWebs, constitute a viable alternative for nutritional monitoring. Following statistical analysis using Student's t-test, the following conclusions were reached:

- High-agreement parameters (protein and minerals): The absence of statistically significant differences between the digital model and the analytical chemical determination of crude protein and the mineral profile was confirmed. The stability observed in these indicators reinforces the reliability of the software for rapid field diagnosis, enabling informed decision-making regarding the nutritional status of Rodas grass (Pennisetum sp).
- Dry matter and biological variability: Although the software operated using constant parametric values (18%), the statistical analysis confirmed its similarity to the laboratory averages. Nevertheless, the gravimetric method was found to be superior in capturing fluctuations caused by environmental factors and the phenological stage, particularly by day 45 of sampling.
- Discrepancies in energy and fiber fractions (NDF/ADF): Statistically significant differences exceeding the critical reference values were identified for energy (NEL) and fiber parameters. These statistical discrepancies do not result from methodological inconsistency but rather from the intrinsic nature of the parameter evaluated in each case.
- Strengths of the optical model: The stability observed in mineral determination reinforces the theory that light interaction-based methods possess high comparative strength, positioning them as a valuable complement for monitoring in modern livestock production.

For future research, it is recommended that bromatological analyses be conducted in specialized centers that ensure rigorous instrument calibration, prioritizing the use of near-infrared spectroscopy (NIRS). This technology enables a smooth transition between chemical analyses and digital models because, by using wavelengths to identify specific chemical bonds, it reduces methodological discrepancies between laboratory analyses and software algorithms such as TaurusWebs.

Likewise, it is essential to standardize environmental conditions during data collection to minimize experimental error and optimize the performance of optical sensors. Measurements should be carried out on clear days between 09:00 and 16:00 hours, when solar stability and the zenith angle promote uniform canopy reflectance. This lighting precision is crucial for the software to process the information without interference caused by cloud cover or diffuse light, allowing the resulting nutritional quality indicators to achieve a high degree of reliability and thereby support informed decision-making.

Conflict of Interest Statement

The authors declare that they have no conflicts of interest.

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Author Contributions (CRediT)

Victoria Anais Delgado Tejena: Conceptualization; methodology; software; validation; formal analysis; investigation; resources; data curation; writing – original draft; writing – review & editing; visualization; supervision; project administration.

Denzel Andrés Chevez Paredes: Conceptualization; methodology; software; validation; formal analysis; investigation; resources; data curation; writing – original draft; writing – review & editing; visualization; supervision; project administration.

Diego Javier Nevárez Pérez: Conceptualization; methodology; software; validation; formal analysis; investigation; resources; data curation; writing – original draft; writing – review & editing; visualization; supervision; project administration.

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