

Article

Buffel Grass (*Pennisetum ciliare*) Ecotypes Suitable for Subtropical Livestock in the North Central Region of Mexico

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Abstract: The objective was to determine the forage production and nutritional quality of six buffel grass ecotypes in vegetative and physiological maturity stages. The experiment was carried out at the Los Cañones Experimental Station in Zacatecas, Mexico. The ecotypes were as follows: E-42, E-45, E-66, E-72, E-S245, and the Titan variety as a control. The experiment design was a completely randomized block with three replications, and the evaluation years were from 2020 to 2022. The variables measured were as follows: plant height (PH), dry matter yield (DMY), leaf (Lf) and stem-inflorescence (St), crude protein (CP), neutral (NDF), and acid detergent fiber (ADF). Pearson's correlation and a combined analysis of variance were performed for each growth stage. A correlation analysis showed significant relationships ($p < 0.05$) between variables. In the vegetative stage, ecotypes E-42, E-45, and E-S45 showed accumulations of over 12% of CP, which were higher ($p < 0.05$) than the ones for Titan. Low values of E-S245 ($p < 0.05$) for NDF (63.44%) and ADF (44.49%) stood out among all ecotypes. In the maturity stage, Titan was surpassed by E-45 and E-S245 with CP higher than 4%. The neutral and acid fibers in E-42, E-45, and E-S245 were less than in Titan ($p < 0.05$). Ecotypes E-42 and E-S245 are alternatives to improve feed efficiency in the dry subtropical climate of Zacatecas.

Keywords: forage production; nutritional quality; crude protein; buffel grass; vegetative; maturity

1. Introduction

Livestock production in tropical and subtropical regions plays a fundamental role in ensuring food security, as it produces meat, milk, and other animal products. Warm-season perennial grasses (C4) are the primary feed source in these regions, making them indispensable for cattle production [1]. Nevertheless, as grass growth progresses, fiber content increases and forage intake decreases, highlighting the need for strategies to enhance the nutritional quality of these species [2]. Moreover, the degradation of the soil's physical, chemical, and biological qualities, exacerbated by climate variability and intense soil use, threatens nutritional quality beyond the component of grass growth [3]. According to Brychkova et al. [4], forage production in Africa is at risk due to climate change, including variations in temperature and precipitation, which have a negative impact on the supply of

feed for cattle. Additionally, they suggest grass species like buffel grass, which is excellent at adapting to changing climate circumstances while still having high potential as a feed source. Native to Africa, buffel has spread throughout the world due to its natural ability to survive in saline soils with little capacity for retaining moisture. It has even managed to withstand fire and overgrazing [5–7]. Another distinctive characteristic of this grass is its deep root structure, which facilitates the effective use of soil moisture, encouraging rapid regrowth and aiding in soil retention [8,9]. Estrada et al. [10] predict that Mexico will face a 2 °C rise in temperature, a 20% reduction in precipitation, and an increased risk of drought due to climate change. Forage crops will be adversely affected by these conditions. It is highly probable that buffel will find appropriate niches for growth and development in the subtropical regions of Mexico, even after the year 2100, despite climate change [11]. Medina et al. [12] identified 96,624 hectares that present the optimal conditions for the production of buffel in the southern area of Zacatecas State, Mexico. This area is characterized by a tropical dry environment [13], and according to SIAP [14], it offers the potential to feed about 130,000 cattle heads in the region. A recent evaluation of a germplasm collection consisting of 17 materials and 2 varieties (Formidable and T-4464) by INIFAP in Mexico has revealed five outstanding ecotypes for forage and seed production [15]. On the other hand, it has been reported that the Titan variety is a good option for forage production in the arid areas of Mexico [16]. However, no information has been documented on the agronomic and nutritional characteristics of Titan and these materials in the tropical dry climates of Zacatecas. Therefore, the objective of the study was to determine the forage production and nutritional quality of six buffel grass ecotypes in two growth stages under rain-fed conditions in Huanusco, Zacatecas, Mexico. Findings of this research could contribute to enhancing the resilience of cattle feed supply in subtropical regions by identifying ecotypes of buffel grass suitable for growth and development in tropical dry climates.

2. Materials and Methods

2.1. Site Descriptions

The experiment was carried out at the “Los Cañones” Experimental Station of the National Institute of Forestry, Agricultural, and Livestock Research (INIFAP), located at the geographical coordinates 21°44′43″ North Latitude and 102°58′02″ West Longitude in Huanusco, Zacatecas, Mexico. The altitude is 1508 m above sea level, and it experiences a dry tropic climate with an average precipitation of 525 mm during the crop cycle [17] (Figure 1). The soil at the experimental site has a sandy loam texture and is moderately alkaline (pH 7.9), with a depth greater than 1.5 m and a bulk density of 1.62 g/cm³. The soil contains 2.1% organic matter, with an inorganic nitrogen content of 14 mg/kg and Olsen phosphorus of 2 mg/kg.

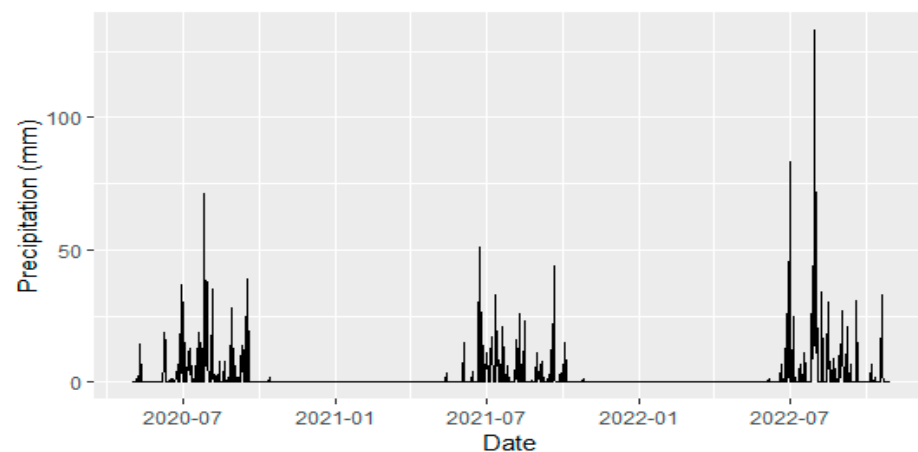


Figure 1. Daily rainfall (mm) at the Los Cañones Experimental Station from May to November from 2020 to 2022.

2.2. Experimental Design and Field Management

Six different buffel grass ecotypes were evaluated in the experiment: E-42, E-45, E-66, E-72, E-S245, and the Titan variety as a control. For the establishment, five caryopses were sown for each ecotype in seedling trays with substrate in April 2019. A total of 15 days after emergence, thinning was carried out, leaving two plants per cavity. Subsequently, the seedlings were transplanted to the field in August 2019 under a completely randomized block design with three replications. Fifteen days after transplanting, a 12 mm irrigation was applied to ensure plant survival. Once completed, the irrigation system was removed to carry out the experiment under rain-fed conditions. The experimental plot was five rows of 0.76 m wide and 10 m long, and a useful plot for each vegetative stage consisted of three central rows of 3 m long; the total area was 6.84 m². A standardization cut was performed at a height of 5 cm above the soil level on May 12, 11, and 31, 2020, 2021, and 2022, respectively. Plant sampling was performed in two growth stages: vegetative, between 57 and 62 days, and physiological maturity, between 118 and 126 days (DAC). The days were counted when the first rainfall was greater than 10 mm after standardization cutting.

2.3. Measurements

The variables measured for each growth stage were as follows: plant height (PH), dry matter yield (DMY), leaf (Lf) and stem-inflorescence production (St), crude protein (CP), neutral detergent fiber (NDF), and acid detergent fiber (ADF). Three randomly chosen plants were measured for height using a measuring tape, which was extended from the ground to the highest point on the forage or the tip of the inflorescence. For DMY, fresh forage was first cut and weighed with a clock scale, and then a random sample of 0.5 kg was taken for drying. For this, the samples were subjected to a forced air oven at a temperature of 55 °C for 72 h. Once dried, the samples were weighed to determine the dry matter content, which was calculated by dividing the dry weight by the green weight. Finally, DMY per hectare was estimated by multiplying the dry matter content by the fresh weight of the plot and extrapolating to weight per hectare. For leaf and stem-inflorescence production, another 0.5 kg sample was selected, and the vegetative parts were manually separated. Then, they were subjected to the drying process and weighed to determine the percentage of dry matter in each one. To estimate the kilograms per component, the percentage of dry matter was multiplied by the production. The whole plant samples were ground in a Willy mill with a sieve at a size of 1 mm. To calculate the percentage of CP, the nitrogen concentration was determined utilizing the DUMAS method using LECO® (Leco FP-428, Leco Corporation, St. Joseph, MI, USA) and multiplied by 6.25. For the NDF and ADF content, 0.5 g of the sample was weighed and placed in F-57 bags, then placed in the ANKOM fiber analyzer, and FDN was first determined with a neutral detergent solution, alpha-amylase, and sodium sulfite. Finally, the samples were again subjected to the analyzer, and ADF was determined with H₂SO₄ and CTAB (A200, Ankom Technology, Macedon, NY, USA).

2.4. Statistical Analysis

Prior to the statistical analysis, it was tested whether the data complied with normality and homogeneity of variance. Then, different analyses were performed using the SAS statistical package. The first analysis was a Pearson correlation analysis to observe the relationship between variables. Afterwards, a combined analysis of variance was performed to compare the factors year, ecotypes, and the interaction year*ecotype. PROC GLM of the SAS package was used for each growth period, and the means were compared with Lsmeans. The comparisons were declared significant when they presented $p < 0.05$ [18].

3. Results

3.1. Correlation Analysis between All Characteristics

A correlation analysis showed significant relationships ($p < 0.05$) between all agronomic and nutritional variables studied. ADF and stem-inflorescence had the lowest

correlation coefficient ($r_{xy} = 0.661$), while PC and DAC had the greatest ($r_{xy} = -0.966$; Figure 2). Furthermore, Figure 2 illustrates that DMY accumulation increased from 671 to 11,743 kg/ha between 60 days after regrowth and maturity. Crude protein decreased from 14.93 to 2.8%, NDF increased from 61.2 to 80.8%, and ADF increased from 37.2 to 66.1%.

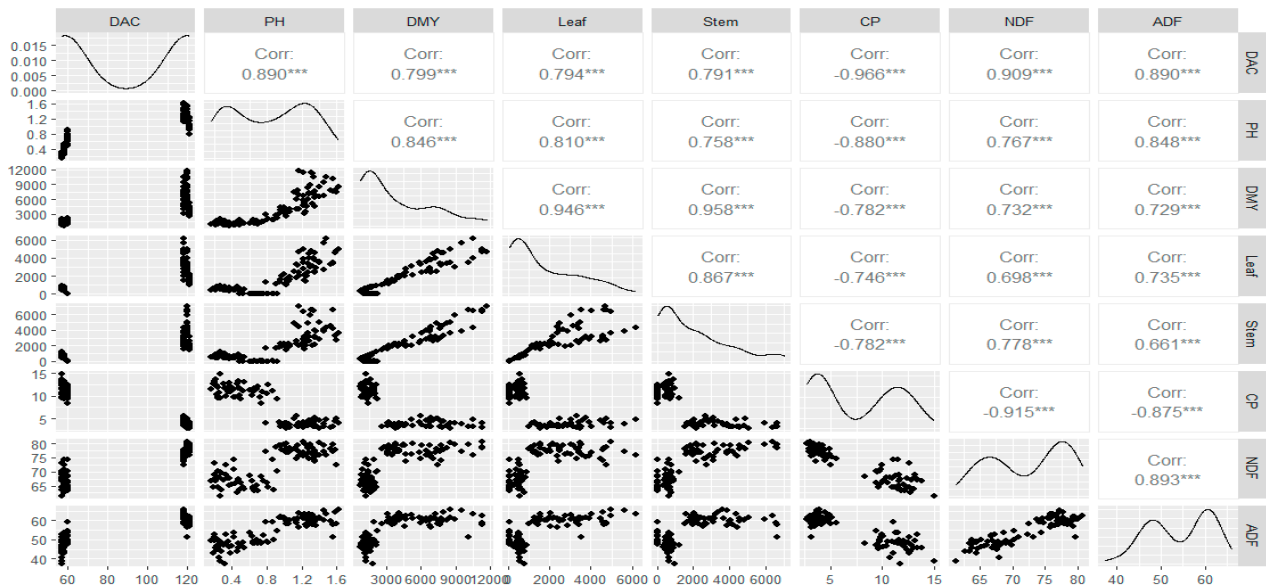


Figure 2. Correlation coefficient among agronomic and nutritional characteristics of buffel ecotypes in the Los Cañones Experimental Station. *** p -value < 0.001.

3.2. Vegetative Growing Stage Evaluation

The agronomic characteristics of vegetative growth showed differences ($p < 0.05$) throughout the three evaluation years. The highest mean values were observed in 2021, with 71 cm of plant height, 1629 kg/ha of DMY, 756 kg/ha of leaf, and 872 kg/ha of stem-inflorescence. In terms of forage nutritional characteristics, differences ($p < 0.05$) were only found in ADF, with the highest accumulation in 2021 at 50.2%. Crude protein ranged from 10.8 to 11.7%, and NDF ranged from 66.5 to 67.28%. No statistical differences were found in the year*ecotype interaction ($p > 0.05$) for any of the variables determined. Plant height differences ($p < 0.05$) were observed among ecotypes. However, none of them exceeded the 48 cm of the Titan control. Similar values were found for DMY, leaf, and stem-inflorescence production among ecotypes; the mean values ranged from 1217 to 1527 kg/ha, 550 to 713 kg/ha, and 638 to 814 kg/ha, respectively. Ecotypes E-42, E-45, and E-S45 ($p < 0.05$) showed accumulations of more than 12% of crude protein, which were higher than the 10% reported for Titan. The low values of E-S245 ($p < 0.05$) for NDF (63.44%) and ADF (44.49%) stood out among all ecotypes (Table 1).

Table 1. Forage characteristics of six ecotypes of buffel grass (*Pennisetum ciliare*) in the vegetative growing stage under rain-fed conditions from 2020 to 2022 at the Los Cañones Experimental Station.

Year	PH (cm)	DMY (kg/ha)	Leaf (kg/ha)	St (kg/ha)	CP (%)	NDF (%)	ADF (%)
2020	23.33 c	1310 b	603 b	707 b	11.7	67.28	46.2 b
2021	71.16 a	1629 a	756 a	872 a	10.85	66.5	50.2 a
2022	40.27 b	1134 b	524 b	609 b	11.4	67.1	47.7 b
Ecotypes							
E-42	40.1 b	1336	697	638	12.02 a	66.17 b	47.9 b
E-45	39.6 b	1217	550	666	12.21 a	66.45 b	48.23 b
E-66	48.6 a	1302	572	729	9.68 c	66.86 b	47.44 b

Table 1. Cont.

Year	PH (cm)	DMY (kg/ha)	Leaf (kg/ha)	St (kg/ha)	CP (%)	NDF (%)	ADF (%)
E-72	44.2 ab	1372	621	750	11.29 ab	66.87 b	47.61 b
E-S245	48.4 a	1527	713	814	12.4 a	63.44 c	44.49 c
Titan	48.4 a	1393	613	779	10.5 bc	72.12 a	52.67 a
Year*ecotype	0.465	0.399	0.365	0.491	0.923	0.246	0.314
R ²	0.914	0.673	0.612	0.56	0.66	0.8	0.75
CV	17.62	22.4	22.5	23.61	4.5	2.62	2.59

PH = plant height; DMY = dry matter yield; St = stem-inflorescence; CP = crude protein; NDF = neutral detergent fiber; ADF = acid detergent fiber; R² = determination coefficient; CV = coefficient of variation. Mean values with different lowercase letters are statistically different $p < 0.05$.

3.3. Maturity Growing Stage Evaluation

During the three-year evaluation period, differences ($p < 0.05$) were identified in all variables at the maturity stage. Mean values decreased significantly in the last year of the study, with 103 cm being the lowest plant height, the minimum DMY being 3698 kg/ha, and the least leaf and stem-inflorescence production being 2121 and 1618 kg/ha, respectively. The nutritional quality of the forage in 2021 had the lowest ($p < 0.05$) levels of NDF (75.7%) and the highest crude protein (4.4%). However, the ADF values for that year were greater ($p < 0.05$), with an accumulation of 62.1%. The year*ecotype interaction was also not significant for the variables evaluated. Similar agronomic characteristics were found ($p > 0.05$), and Titan was not surpassed by the ecotypes. DMY ranged from 6000 to 7045 kg/ha, the plant height ranged from 114 to 129 cm, and the leaf and stem-inflorescence production ranged from 2767 to 3255 kg/ha, respectively. On the other hand, differences were observed ($p < 0.05$) in nutritional traits. Titan was surpassed by ecotypes E-45 and E-S245 with crude protein percentages higher than 4%. The NDF and ADF accumulation in ecotypes E-42, E-45, and E-S245 were less than those of Titan ($p < 0.05$), with values not exceeding 78% for NDF and 60% for ADF (Table 2).

Table 2. Forage characteristics of six ecotypes of buffel grass (*Pennisetum ciliare*) in the maturity growing stage under rain-fed conditions from 2020 to 2022 at the Los Cañones Experimental Station.

Year	PH (cm)	DMY (kg/ha)	Leaf (kg/ha)	St (kg/ha)	CP (%)	NDF (%)	ADF (%)
2020	132 a	8631 a	5203 a	3428 a	3.44 b	78.63 a	59.45 b
2021	135 a	6641 b	2801 b	3840 a	4.35 a	75.74 b	62.14 a
2022	103 b	3698 c	2121 c	1618 b	3.58 b	78.36 a	60.25 b
Ecotypes							
E-42	125	6005	3167	2837	3.72 bc	76.29 d	59.38 b
E-45	124	6017	3183	2833	4.03 ab	76.54 cd	59.61 b
E-66	127	7045	3789	3255	3.41 c	78.47 a	60.64 ab
E-72	121	6317	3390	3009	3.89 abc	78.13 ab	62.22 a
E-S245	114	6155	3387	2767	4.2 a	77.39 bc	59.89 b
Titan	129	6403	3333	3069	3.52 c	78.66 a	61.94 a
Year*ecotype	0.261	0.878	0.693	0.97	0.677	0.98	0.558
R ²	0.73	0.79	0.862	0.72	0.699	0.739	0.65
C.V.	10.12	23.17	21.55	26.21	6.04	1.37	1.56

PH = plant height; DMY = dry matter yield; St = stem-inflorescence; CP = crude protein; NDF = neutral detergent fiber; ADF = acid detergent fiber; R² = determination coefficient; CV = coefficient of variation. Mean values with different lowercase letters are statistically different $p < 0.05$.

4. Discussion

4.1. Weather Conditions during Evaluation

Buffel is recognized as a species highly tolerant to drought. According to reports, it can survive in areas with less than 250 mm of rainfall [19]. Rainfall at the experimental

site during the evaluation years of the current study was ideal for buffel growth. In 2020 (587 mm) and 2021 (539 mm), the study site received slightly higher rainfall than the historical average (525 mm), which kept them in the usual range. However, because of the delayed rainy season and a 43% increase over the historical average, 2022 (755 mm) is considered an abnormal year. Due to non-significant year*ecotypes interactions ($p > 0.05$), buffel is a species that adapts to different environmental conditions in the tropical dry climates of Zacatecas.

4.2. Correlation Analysis between All Variables at Two Growth Stages

The significant correlation between the variables and values presented in Figure 2 is consistent and similar to those findings from research on buffel grass [20,21]. Similar to other C4 grasses, in buffel, it has been found that biomass accumulation rises with plant growth time, but over time, the quality of nutrients declines. As reported by Kisambo et al. [22], the primary cause of this is an increase in fiber content and a drop in crude protein concentration. Livestock farmers may find this information helpful in determining the best time to harvest in order to satisfy dry matter (maturity) or nutrient (vegetative) requirements.

4.3. Dry Matter Yield for Both Growing Stages

The amount of forage available in grazing areas is a determining factor in the profitability of livestock farming, as it defines the number of animals that can be fed in a specific area [23]. In 2021, DMY was approximately 34% higher in the vegetative stage compared to the other years. This discrepancy may have resulted from a longer wet season, as seen in Figure 1. However, at the maturity stage, the amount of DMY decreased from the first year (8631 kg/ha) to the third (3698 kg/ha). Determining the ideal annual fertilization rate to sustain forage production throughout the productive life is required because the absence of fertilization may be the root of the problem. Although there were no significant differences ($p > 0.05$) in DMY and its constituent parts (leaf and stem-inflorescence) between the ecotypes, this finding may be a reflection of the previous selection work performed by Terrazas and Chavez [15]. Therefore, at every growth stage, the animal-carrying capacity of every ecotype is the same. During the vegetative stage, the plant height range was from 23.3 to 71.6 cm; this variation suggests that the plants are grazing-suitable. The plant reached heights of more than one meter at maturity, making this stage the best option for preserving the forage for later use if it is not grazed directly. Finally, conducting a thorough investigation into grazing frequency and intensity is crucial for maximizing grazing efficacy [24].

4.4. Crude Protein for Both Growing Stages

Given that forages supply nutrients like protein and energy, which are critical for livestock growth and health, they are an essential source of food for animal production [3,25]. The current study has identified ecotypes with great potential to surpass the animal production of Titan. In the vegetative stage, ecotypes E-42, E-45, and E-S245 showed a crude protein content above 12%. This value meets the protein requirements for 635 kg cows in their first third of gestation, with milk productions of 13.6 kg [26]. However, the variety Titan showed 10.5% crude protein, which does not meet the protein requirements for these cows. At the maturity stage, the ecotypes did not reach the minimum crude protein requirement (>6%) necessary for the ruminal flora to degrade fiber and improve its physiological functions [27,28]. This decrease in crude protein during growth is a normal process in tropical forages. In fact, these forages are recognized as inferior to those of temperate climates [29]. Ecotypes E-45 and E-S245 stood out for presenting significantly higher crude protein values (4%) than the Titan control. Crude protein is indispensable for meeting the nutritional requirements of beef cattle. As ruminants, cattle possess a unique digestive system capable of breaking down fibrous plant material through microbial fermentation in the rumen. However, this process requires adequate nitrogen, primarily

obtained from dietary protein sources. Crude protein serves as a primary nitrogen source, supplying amino acids necessary for muscle development, immune function, and overall physiological processes in cattle. Insufficient protein intake can lead to reduced growth rates, compromised immune function, and reproductive disorders, ultimately impacting the efficiency and profitability of beef production operations. Therefore, ecotypes E-42, E-45, and E-S245 can be used as an alternative to reduce supplementation costs for feed cattle since they showed more crude protein content but similar dry matter yield than the variety Titan.

4.5. Quality Fibers in Both Growing Stages

Characterizing the fiber in forages has been a relevant variable in determining their quality, since components such as hemicellulose, cellulose, and lignin have an impact on the energy supply for the animal and on the digestive physiology of the rumen. They are considered indicators linked to forage intake (NDF) and digestibility (ADF) [30,31]. Thus, producers can improve rumen function, enhance nutrient utilization, and promote efficient growth in grazing cattle by selecting grass varieties with favorable NDF and ADF profiles. In our evaluation, ecotype E-S245 in the vegetative state stood out for presenting the most favorable values in NDF content with 63.4% and ADF with 44.49%, while the rest of the ecotypes exceeded 66% and 47%, respectively. In our evaluation, ecotype E-S245 in the vegetative state stood out for presenting the most favorable values in NDF content with 63.4% and ADF with 44.49%, while the rest of the ecotypes exceeded 66% and 47%, respectively. All ecotypes showed relatively high fiber values at the maturity stage, with accumulations greater than 76%. Benaouda et al. [32] indicate that diets with NDF above 70% are classified as low quality; even Piñeiro et al. [33] report low energy efficiency when NDF content is greater than 67%. Therefore, ecotypes E-42 and E-45, with NDF accumulations around 76.5%, represent an alternative to reduce supplementation costs that will allow better forage degradation. On the other hand, it is convenient to carry out research work related to improving quality. One alternative is the implementation of the silage conservation method, since Singh et al. [34] analyzed 14 ecotypes to evaluate the response to the fermentation process and found 4 with a better response in terms of pH and lactic acid.

5. Conclusions

None of the ecotypes outperformed the control variety (Titan) in dry matter yield across both growth stages. However, certain ecotypes displayed enhanced nutritional profiles relative to Titan. At the vegetative stage, ecotypes E-42, E-45, and E-S245 stood out for their crude protein content, with values higher than 2%. Regarding fiber content, ecotype S-245 presented the lowest accumulations, overtaking the control. At the maturity stage, E-45 and E-S245 again surpassed Titan in crude protein content, with values above 4%. Ecotype E-42 showed the lowest fiber accumulation at this stage. These findings suggest that ecotypes E-42 and E-S245 are a viable alternative to improve feed efficiency in livestock systems within the dry subtropical climate of Zacatecas.

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