CHILEAN JOURNAL of AGRICULTURAL RESEARCH

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RESEARCH ARTICLE

Nutritive value of maize and soybean silages at different ratio in a subtropical climate condition

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Received: 5 March 2024; Accepted: 15 May 2024, doi:10.4067/S0718-58392024000400540

ABSTRACT

Climatic conditions cause variation in the availability and nutritional quality of forages; therefore, the use of corn (*Zea mays* L.) silage has been proposed. However, this crop has a low protein concentration, so the combination with legumes can improve this characteristic. The objective of this study was to evaluate the nutritive value of silage in different proportions of soybean (*Glycine max* (L.) Merr.) and corn forage grown in a subtropical region. In Tamaulipas, Mexico, six treatments were evaluated: Soybean 100% (S100), corn 100% (C100), and soybean-corn proportions (80%-20%: S80C20; 60%-40%: S60C40; 40%-60%: S40C60, and 20%-80%: S20C80). The variables that were evaluated were: Density, pH, crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), lignin, non-fibrous carbohydrates (NFC), starch, crude fat, net energy for lactation (NEL), net energy for weight gain (NEG), and metabolizable energy (ME) and mineral content. Data were analyzed as a completely randomized design with three replicates per treatment. Treatment S100 showed the highest values ($p < 0.05$) in CP, ADF, crude fat, NEL, and NEG. The C100 had the highest values ($p < 0.05$) in starch and NFC, and the lowest pH value ($p < 0.05$). Meanwhile, the S40C60, S60C40, S20C80 combinations showed the highest values ($p < 0.05$) of TDN, ENL, and ENG. In the case of the combinations, the one with the best values was S40C60. In this regard, the mean values were: CP 143 g kg^{-1}; NEL 1.43 Mcal kg^{-1}; and pH 3.9. According to these values, it is classified as a silage of good nutritional quality, and we recommend its use in subtropical climates.

Key words: Forage conservation, *Glycine max*, nutrition ruminants, protein increase.

INTRODUCTION

The United Nations (UN), to make projections of world population, used a Bayesian probabilistic methodology and population data up to the year 2012, and found that it is very unlikely that the world's population will stop growing during this century. Therefore, by the year 2100, it is very likely (80%) that the world's population will increase by 32% to 71%, which would represent between 9.5 and 12.3 billion people. This is partly due to higher fertility rates, as well as a significant decrease in the ratio of older people to people of working-age (Gerland et al., 2014). This population growth puts significant pressure on natural resources and presents major challenges to ensure food security and the availability of animal protein in the coming years (Miassi and Dossa, 2023). Therefore, it is necessary to optimize the areas designated for livestock activities and reduce the expansion of land dedicated to these activities, because this affects biodiversity and causes significant carbon dioxide emissions (Wirsenius et al., 2010; Lal, 2023). The above could be achieved by improving the genetics of the animals and the diet (Rojas-Downing et al., 2017), thereby reducing the number of animals, but the productive parameters per unit of area would increase (Benoit and Mottet, 2023). Diversified crops and combined cropping and livestock systems can also be used, as they are a resource-efficient and profitable option (Weindl et al., 2015), and livestock diets can include forage plants with high nutritional value, but that are also useful for biodiversity, biological control, nectar and pollen production and other ecosystem services (Rauw et al., 2023). Therefore, an association between soybean and corn would not only increase the nutritional value of the silage, but could have biological benefits for both microorganisms in the soil and pollinators in the environment.

It is predicted that by 2050, the world demand for livestock products will double, in particular, due to the improvement in the living conditions of the population (Rojas-Downing et al., 2017). To feed this population, beef production will need to increase from 60 to 130 million tons, with 70% of this production (49 million tons) expected to come from tropical and subtropical regions of the world (Cooke et al., 2020a); where the crossing *Bos indicus* × *B. taurus* represents a proven strategy to improve adaptation to thermal tolerance and parasites (Cooke et al., 2020b). Likewise, warm-season perennial C_4 grasses predominate in these regions, which are the dominant forages, have resilience to adverse conditions, greater forage production and, due to the efficient photosynthetic pathway they present, have the potential to increase mitigation of CO_2; since the greatest proportion of biomass accumulation in this type of grasses occurs underground, which increases the concentration of C in the soil and the possible sequestration of C (Vendramini et al., 2023).

These regions are characterized by having three well-defined seasons: Rainy season, when precipitation and temperature are higher and favor active growth of forage; winter season, which has high cloudiness and a drop in temperature, causing slow growth in plants; and dry season, in which forage growth is low or null (Muñoz-González et al., 2016; Robles-Vega et al., 2020). In this sense, the annual forage production is distributed in 70%, 16% and 14%, during the rainy, dry and winter seasons, respectively (Robles-Vega et al., 2020). This variation in weather conditions generates seasonality in forage production and variation in its nutritional value (Muñoz-González et al., 2016; Lee, 2018), a condition that directly affects the productive parameters of beef cattle, since the offspring of crosses of *B. taurus* × *B. indicus* born during the rainy season tend to be 4% heavier than those born in the winter or dry season (35.5 *vs.* 34.1 kg; García-Esquivel et al., 2023). One way to counteract these effects has been the implementation of the association of grasses and legumes, with which the crude protein content has increased 120 *vs.* 10.9 g kg^{-1} DM and the daily weight gains in cattle in beef cattle (0.436 *vs.* 0.350 kg $animal^{-1}$ d^{-1}; Braga et al., 2020). Likewise, it has been mentioned that the partial replacement of corn with tropical legumes increases the crude protein content of silages (80 *vs.* 110 g kg^{-1} DM), constituting an alternative for feeding ruminants mainly during the dry season, where the main nutrient deficient in forages is protein (Da Silva et al., 2023).

To minimize the effects of this weather variation and the consequent lack of feed during the dry season, an alternative that has been used is the use of silage, in particular, from corn (*Zea mays* L.) (Daniel et al., 2019). This crop is the third most important in the world, after rice and wheat; it is grown for human and animal consumption. As a feed source for ruminants, corn silage has the ability to provide forage high in energy, starch, soluble carbohydrates, and fiber (Parra et al., 2019; Rosa et al., 2020; Zhao et al., 2021), and its use is safe in animal feed at any stage of growth. Although corn silage is an excellent source of energy (Erdal et al., 2016), it has a low protein content (Wassie et al., 2019). For this reason, additional supplements to balance ruminant diets, as protein is an essential nutrient for the development and reproduction of animals. Due to the above, the use of legumes has been proposed as an option to increase protein content in animal diets. This is particularly important for livestock production in tropical and subtropical climates when forages are low in protein (Wassie et al., 2019). In addition, the cost of carrying out protein supplementation represents a high cost (Bautista-Martínez et al., 2020).

In this sense, it has been documented that the associated crops of corn and soybeans have greater efficiency and productivity in the use of resources, a decrease in erosion and an increase in soil fertility and control of pests, diseases and weeds. However, it must be taken into account that, in this type of topological arrangement, soybeans could present a lower capture of solar radiation and affect its production, therefore more research is required to find the optimal planting density to improve the efficiency of the crops (Blessing et al., 2022). The soybean (*Glycine max* (L.) Merr.) is a legume with a high protein concentration, which is why it can contribute to improving the nutritional quality of corn silage (Zhao et al., 2021). The positive effects of combining corn and soybean silage on silage quality have already been documented (Erdal et al., 2016; Parra et al., 2019; Rosa et al., 2020; Zhao et al., 2021). In Mediterranean climate conditions (Ds), it has been reported that the silage of the soybean plant with the corn plant improved the nutritional value of the silage, however, by adding more than 40% of soybean forage, there is a decrease in lactic acid values and an increase in silage pH and acetic propionic and butyric acid values, which could affect feed quality and animal acceptance (Kizilsimsek et al., 2017). However, the available information on the nutritional quality of these combinations in tropical and subtropical climates is limited. Therefore, the objective of this study was to evaluate the nutritional value of silage in different proportions of soybean and corn forage grown in a subtropical region.

MATERIALS AND METHODS

Experimental site and treatments

The research was carried out from September to December 2019, at the Zootechnical Post of the School of Engineering and Sciences of the Autonomous University of Tamaulipas, located in the municipality of Güémez (23°56'26.5" N, 99°05'59.9" W; 193 m a.s.l.), Tamaulipas, Mexico. The climate of the place is of the BS1(h') hw type (Vargas et al., 2007). The soil has clay texture, with a pH of 8.3, without salinity problems (SAR = 0.19), 4.2% organic matter, and 0.25% N.

The evaluated treatments were combinations of soybean (*Glycine max* (L.) Merr.) and corn (*Zea mays* L.; hybrid P4039) silage (Table 1). The soybean forage used was the commercial 'Huasteca 200', which was harvested at the reproductive stage R 6.0 (Fehr et al., 1971). The corn was harvested at a milky-doughy stage. Both forages were harvested 90 d after sowing (DAS).

Table 1. Description of treatments and proportions of soybean 'Huasteca 200' and corn hybrid P4039 forage.

Treatments	Description
S100	100% Soybean forage
S80C20	80% Soybean forage + 20% corn forage
S60C40	60% Soybean forage + 40% corn forage
S40C60	40% Soybean forage + 60% corn forage
S20C80	20% Soybean forage + 80% corn forage
C100	100% Corn forage

Crop sowing and management

The soil was prepared with fallow and crossed tilling, to later make the furrows at a distance of 0.8 m. Soybeans and corn were planted in separate plots. In soybean crop there were 20 ± 2 plants m^{-1} (≈ 250 000 plants ha^{-1}), while in corn there were 5 plants m^{-1} (≈ 62 500 plants ha^{-1}). Eight days before sowing, a 25 cm depth of water was applied. Subsequently, two relief irrigations were applied, one in the vegetative stage and the other during grain filling, both with 30 cm applied water. Weed control was carried out by hand. There were no pests in the soybean crop while in the corn crop a spinetoram (5.87%) application was carried out at a dose of 100 mL ha^{-1} to control the fall armyworm (*Spodoptera frugiperda*).

Elaboration of the silage

One day before making the silage, three samples were taken from each forage; they were separated into morphological components: Leaf, stem, pod (valve + seed), senescent material (> 60% chlorotic tissue), ear, bract, and panicle. Subsequently, the methodology described by Garay-Martínez et al. (2018) was used to determine the forage yield and DM content (Table 2).

A double row forage harvester was used to cut both corn and soybean forages. The cut was made 20 cm above the ground with a particle size of 3.0 ± 1.0 cm. Then they were weighed and mixed until all the proportions to be evaluated were obtained (Table 1). The mixtures were deposited in PVC micro-silos (15.24 cm × 40 cm, with a fixed lid at one end), compacted, sealed, and stored for 90 d; they were opened and samples were obtained for analysis.

Table 2. Forage yield, morphological composition of soybean 'Huasteca 200' and corn hybrid P4039 forages at the time of preparing the silage. [1]Valves + seeds; TGM: total green matter; TDM: total DM.

Forage	TGM	TDM	Leaf	Stem	Pod[1]	Senescent material	Ear	Bract	Panicle
	t ha^{-1}		%						
Soybean	14.17	4.25	44	21	25	10	-	-	-
Corn	39.46	11.05	29	12	-	-	46	12	1

Evaluated variables

The contents (g kg^{-1}) of crude protein, non-fibrous carbohydrates, starch, and crude fat were determined (AOAC, 2019), as well as neutral detergent fiber, acid detergent fiber, and lignin (van Soest et al., 1991). Net energy values (Mcal kg^{-1}) for lactation, weight gain, and metabolizable were estimated using Agricultural and Food Research Council model (AFRC, 1993). The total of digestible nutrients was estimated from the equation: TDN (%) = (digestible crude protein + digestible non-structural carbohydrates + fiber in digestible neutral detergent corrected for protein + 2.25 × digestible ethereal extract)/100 (Pond et al., 2004). The mineral content (g kg^{-1}) was estimated using the methodology described by the AOAC (2019).

Statistical analysis

Data were analyzed with the GLM procedure of SAS (SAS Institute, Cary, North Carolina, USA) based on a completely randomized design with three replicates per treatment. The comparison of means was carried out using the Tukey test ($\alpha = 0.05$).

RESULTS

The silage that contained only soybean forage presented the highest density ($p < 0.001$; Table 3), which decreased as soybean inclusion decreased in the silage. In the case of pH, silages that contained a higher corn ratio had lower pH values. Crude protein was highest in the S100 silage and lowest in C100 ($p < 0.001$; Table 3). The neutral detergent fiber was lowest in S100 and, as expected, the acid detergent fiber was highest in this same treatment ($p < 0.001$; Table 3); in addition, this treatment had the highest values of lignin and crude fat ($p < 0.001$). In the case of non-fibrous carbohydrates and starch content, the highest values were found in C100 ($p < 0.001$).

On the other hand, the total digestible nutrients were higher in the corn and soybean combinations ($p = 0.0014$). In the case of net energy for milk production and weight gain, the S40C60, S60C40, and S20C80 combinations showed higher values ($p = 0.0052$); however, S80C20 showed the contrary. Metabolizable energy was highest in the silage with only corn ($p < 0.001$) (Table 4).

The P concentration was highest in S40C60 ($p = 0.0171$). Calcium was higher in treatments S100 and S80C20 ($p < 0.001$; Table 5). The K concentration decreased as corn inclusion in silage increased ($p < 0.001$; Table 5). On the other hand, the Cl concentration was higher in C100 ($p < 0.0285$; Table 5). In contrast, S concentration was higher in S100 and S80C20 and S60C40 combinations ($p < 0.001$; Table 5).

Table 3. Physico-chemical characteristics of the silage of corn and soy forages and their different proportions, in a subtropical climate. S100: Soybean 100%; S80C20: soybean 80% + corn 20%; S60C40: soybean 60% + corn 40%; S40C60: soybean 40% + corn 60%; S20C80: soybean 20% + corn 80%; C100: corn 100%; GM: green matter. Different letters between columns, indicate a significant difference (Tukey; α = 0.05).

Variable	Treatments						p-value
	S100	S80C20	S60C40	S40C60	S20C80	C100	
Density, GM; kg m^{-3}	805.0^{a}	757.0^{ab}	727.0^{bc}	703.0^{bc}	649.0^{d}	689.0^{dc}	< 0.001
pH	4.7^{a}	4.3^{b}	4.1^{c}	3.9^{d}	$3.8.0^{e}$	3.7^{f}	< 0.001
Crude protein, g kg^{-1}	193.0^{a}	173.0^{b}	154.0^{c}	143.0^{c}	113.0^{d}	91.0^{e}	< 0.001
Neutral detergent fiber, g kg^{-1}	394.0^{b}	402.0^{ab}	420.0^{ab}	421.0^{ab}	431.0^{ab}	440.0^{a}	0.0191
Acid detergent fiber, g kg^{-1}	369.0^{a}	346.0^{b}	326.0^{c}	323.0^{c}	330.0^{bc}	293.0^{d}	< 0.0001
Lignin, g kg^{-1}	67.0^{a}	55.0^{bc}	48.0^{b}	57.0^{cd}	47.0^{d}	41.0^{d}	< 0.0001
Non-fibrous carbohydrates, g kg^{-1}	260.0^{d}	313.0^{c}	327.0^{c}	344.0^{bc}	381.0^{ab}	406.0^{a}	< 0.0001
Starch, g kg^{-1}	38.0^{c}	55.0^{c}	73.0^{bc}	83.0^{bc}	156.0^{ab}	204.0^{a}	0.0012
Crude fat, g kg^{-1}	51.0^{a}	37.0^{b}	35.0^{b}	34.0^{b}	29.0^{c}	25.0^{c}	< 0.0001

Table 4. Average values of total digestible nutrients (TDN), net energy for lactation (NEL) and weight gain (NEG) and metabolizable energy (ME) in silage of corn and soybean forages and their different proportions, in a subtropical climate. S100: Soybean 100%; S80C20: soybean 80% + corn 20%; S60C40: soybean 60% + corn 40%; S40C60: soybean 40% + corn 60%; S20C80: soybean 20% + corn 80%; C100: corn 100%. Different letters between columns indicate significant difference (Tukey; α = 0.05).

Variable	Treatments						p-value
	S100	S80C20	S60C40	S40C60	S20C80	C100	
TDN, g kg^{-1}	590.00^{b}	615.00^{ab}	635.00^{a}	635.00^{a}	645.00^{a}	580.00^{b}	0.0014
NEL, Mcal kg^{-1}	1.36^{ab}	1.41^{a}	1.43^{a}	1.43^{a}	1.43^{a}	1.30^{b}	0.0052
NEG, Mcal kg^{-1}	0.70^{ab}	0.76^{a}	0.81^{a}	0.80^{a}	0.81^{a}	0.63^{b}	0.0013
ME, Mcal kg^{-1}	2.30^{c}	2.39^{b}	2.44^{ab}	2.42^{b}	2.42^{b}	2.49^{a}	< 0.0001

Table 5. Average values for mineral content in corn and soybean forage silage and their different proportions, in a subtropical climate. S100: Soybean 100%; S80C20: soybean 80% + corn 20%; S60C40: soybean 60% + corn 40%; S40C60: soybean 40% + corn 60%; S20C80: soybean 20% + corn 80%; C100: corn 100%. Different letters between columns indicate significant difference (Tukey; α = 0.05).

Variable	Treatments						p-value
	S100	S80C20	S60C40	S40C60	S20C80	C100	
P, g kg^{-1}	2.4^{b}	2.4^{b}	2.7^{ab}	3.0^{a}	2.7^{ab}	2.3^{b}	0.0171
C, g kg^{-1}	14.6^{a}	13.4^{a}	9.5^{b}	9.5^{b}	5.6^{c}	2.9^{d}	< 0.0001
Mg, g kg^{-1}	3.2^{ab}	3.5^{a}	3.2^{ab}	2.7^{abc}	1.8^{c}	2.1^{bc}	0.0019
K, g kg^{-1}	27.6^{a}	20.9^{b}	19.7^{bc}	15.5^{cd}	11.9^{de}	9.8^{e}	< 0.0001
Cl, g kg^{-1}	2.1^{b}	2.1^{b}	2.1^{b}	2.1^{b}	2.0^{b}	2.7^{a}	0.0285
S, g kg^{-1}	2.5^{a}	2.3^{a}	2.1^{a}	1.6^{b}	1.3^{b}	1.4^{b}	< 0.0001

DISCUSSION

The faster and steeper drop in pH in corn silage and in mixtures with higher corn content is due to the higher concentration of soluble carbohydrates in said forage compared to soybean forage (Zhao et al., 2021). This can be corroborated with our results, since there was a higher concentration of non-fibrous carbohydrates observed in the C100 treatment as well as in the combinations that contained a higher percentage of corn compared to S100. A similar behavior was observed in the starch concentration (Table 3).

In this regard, pH values in the corn silage process, generally between 3.7 and 4.2, result in high quality silage (Erdal et al., 2016). In our study, pH values in C100 silage or in the combinations with a high proportion of corn are within this range. In the case of soybean silage, the greater buffering capacity (having a higher concentration of proteins and minerals) with respect to corn, could have caused a prolonged fermentation, which in turn caused a lower drop in pH in S100 and the combinations with higher proportion of soybean (Parra et al., 2019). In this sense, a delay in pH drop at the beginning of fermentation can favor the development of proteolytic and heterofermentative microorganisms (Yücel et al., 2017), which causes a decrease in the aerobic stability of the ensiled forage and, consequently, a less desirable fermentation pattern (Bolson et al., 2020).

On the other hand, the difference in the chemical composition of the silages was mainly due to the proportions of the forages. In this sense, the CP concentration in the silage increased with the inclusion of soybean forage, which coincides with previous reports (Parra et al., 2019; Rosa et al., 2020; Bolson et al., 2020). However, other indicators that determine the nutritional quality of forages are the concentrations of neutral detergent fiber (NDF) and acid detergent fiber (ADF) (van Soest et al., 1991). In this sense, the concentration of ADF and forage digestibility are negatively correlated; that is, the lower the ADF value, the higher the digestibility of the feed (van Soest et al., 1991). In our study, the ADF concentration increased with soybean treatment; this causes a lower digestibility in silage with soybean forage (Zhao et al., 2021). This negative impact of soybean on fiber digestibility is evidence that cellular content (NDF) has a higher digestibility in soybean than in corn; at the same time, it shows the lower quality of the cell wall of soybean forage. Despite the aforementioned, the ADF and NDF values are within the optimal ranges for corn silage (Erdal et al., 2016).

The value of crude fat increased in the treatments that contained more soybean, which is similar to the results reported by Erdal et al. (2016). This explains the higher net energy value for lactation and weight gain in S100 silages or their combinations compared to corn silage (Table 4). On the other hand, metabolizable energy represents the energy in the cell content, which is highly digestible, as it contains a high concentration of sugars and starches (Lasek et al., 2020). It is because of this that S100 was the treatment that showed the highest ME value.

In our study, all silages had mineral concentrations below the required values for dairy cows and goats (NRC, 2007; NASEM, 2021). However, these values cannot be neglected when calculating the diet of the animals. For example, a milk-producing cow with a consumption of 26 kg DM, if in said consumption, 10.5 kg are corn silage, the contribution of Ca, K, Mg, P, and S would be 9%, 34%, 23%, 12%, and 15% of its daily requirements, respectively (Rosa et al., 2020). It is important to consider the mineral contribution of forages to avoid mineral imbalance, since this cause increases in production costs and environmental pollution (Weiss, 2017).

CONCLUSIONS

Based on the results obtained and the experimental conditions of the study, it is concluded that as more soybean was incorporated into the corn silage, the nutritional value increased, but the values of non-fibrous carbohydrates and starch decreased, so the treatment that had the best nutritional quality, without seriously compromising the silage process, it was the combination of 60% corn and 40% soybeans.

Author contribution

Conceptualization: J.R.G.M., L.D.G.R. Methodology: J.E.G.R., F.L.R., S.J.C. Investigation: J.R.G.M., L.D.G.R., J.A.M.J. Writing-original draft preparation: J.R.G.M., L.D.G.R., Y.B.M. Writing-review and editing: J.A.M.J., Y.B.M. Visualization: J.E.G.R., F.L.R. Supervision: J.R.G.M., L.D.G.R., S.J.C. All co-authors reviewed the final version and approved the manuscript before submission.

Acknowledgements
We thank the Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias for the financing with the project 14505534871: Potencial forrajero de líneas experimentales de soya (*Glycine max* L. (Merr.)) para el Centro y Sur de Tamaulipas (ETAPA 1 de 2).

References

AFRC. 1993. Energy and protein requirements for ruminants. Agricultural and Food Research Council (AFRC), CAB International, Wallingford, UK.

AOAC. 2019. Official methods of analysis of AOAC International. Association of Official Analytical Chemists (AOAC), Rockville, Maryland, USA.

Bautista-Martínez, Y., Granados-Zurita, L., Joaquín-Cancino, S., Ruiz-Albarrán, M., Garay-Martínez, J.R., Infante-Rodríguez, F., et al. 2020. Factores que determinan la producción de becerros en el sistema vaca-cría del Estado de Tabasco, México. Nova Scientia 12(25):1-21. doi:10.21640/ns.v12i25.2117.

Benoit, M., Mottet, A. 2023. Energy scarcity and rising cost: Towards a paradigm shift for livestock. Agricultural Systems 205:103585. doi:10.1016/j.agsy.2022.103585.

Blessing, D.J., Gu, Y., Cao, M., Cui, Y., Wang, X., Asante-Badu, B. 2022. Overview of the advantages and limitations of maize-soybean intercropping in sustainable agriculture and future prospects: A review. Chilean Journal of Agricultural Research 82:177-188. doi:10.4067/S0718-58392022000100177

Bolson, D.C., Pereira, D.H., dos Santos Pina, D., Xavier, I.M., Barbosa, P.L., Pedreira, et al. 2020. Corn silage rehydrated with crude glycerin in lambs' diets. Tropical Animal Health and Production 52:3307-3314. doi:10.1007/s11250-020-02362-y.

Braga, G.J., Ramos, A.K.B., Carvalho, M.A., Fonseca, C.E.L., Fernandes, F.D., Fernandes, C.D. 2020. Liveweight gain of beef cattle in *Brachiaria brizantha* pastures and mixtures with *Stylosanthes guianensis* in the Brazilian savannah. Grass and Forage Science 75(2):206-215. doi:10.1111/gfs.12473.

Cooke, R.F., Cardoso, R.C., Cerri, R.L.A., Lamb, G.C., Pohler, K.G., Riley, D.G., et al. 2020b. Cattle adapted to tropical and subtropical environments: genetic and reproductive considerations. Journal Anila Science 98(2):skaa015. doi:10.1093/jas/skaa015.

Cooke, R.F., Daigle, C.L., Moriel, P., Smith, S.B., Tedeschi, L.O., Vendramini, J.M.B. 2020a. Cattle adapted to tropical and subtropical environments: Social, nutritional, and carcass quality considerations. Journal of Animal Science 98(2):1-20. doi:10.1093/jas/skaa014.

Da Silva, L.M., Costa, K.A.P., Silva, J.A.G., Costa, J.V.C.P., Costa, A.C., Severiano, E.C., et al. 2023. Fermentative profile and nutritive value of maize, legume and mixed silage. Semina: Ciências Agrárias 44(5):1909-1926. doi:10.5433/1679-0359.2023v44n5p1909.

Daniel, J.L.P., Bernardes, T.F., Jobim, C.C., Schmidt, P., Nussio, L.G. 2019. Production and utilization of silages in tropical areas with focus on Brazil. Grass and Forage Science 74(2):188-200. doi:10.1111/gfs.12417.

Erdal, S., Pamukcu, M., Curek, M., Kocaturk, M., Dogu, O.Y. 2016. Silage yield and quality of row intercropped maize and soybean in a crop rotation following winter wheat. Archives of Agronomy and Soil Science 62:1487-1495. doi:10.1080/03650340.2016.1153801.

Fehr, W.R., Caviness, C.E., Burmood, D.T., Pennington, J.S. 1971. Stage of development descriptions for soybeans, *Glycine max* (L.) Merrill. Crop Science 11(6):929-931. doi:10.2135/cropsci1971.0011183X001100060051x.

Garay-Martínez, J.R., Joaquín-Cancino, S., Estrada-Drouaillet, B., Martínez-González, J.C., Joaquín-Torres, B.M., Limas-Martínez, et al. 2018. Acumulación de forraje de pasto buffel e híbridos de *Urochloa* a diferente edad de rebrote. Ecosistemas y Recursos Agropecuarios 5(15):573-581. doi:10.19136/era.a5n15.1634.

García-Esquivel, F.J., Martínez-González, J.C., Castillo-Rodríguez, S.P., Hernández-Meléndez, J., Parra-Bracamonte, G.M. 2023. Producción de carne en el trópico seco de Tamaulipas, México: cruzamiento de *Bos taurus* y *Bos indicus*. Archivos Latinoamericanos de Producción Animal 31(Suplemento):87-92. doi:10.53588/alpa.310516.

Gerland, P., Raftery A.E., Ševčíková, H., Li, N., Gu, D., Spoorenberg, T., et al. 2014. World population stabilization unlikely this century. Science 346(6206):234-237. doi:10.1126/science.1257469.

Kizilsimsek, M., Ozturk, C., Yanar, K., Ertekin, I., Ozkan, C.O., Kamalak, A. 2017. Associative effects of ensiling soybean and corn plant as mixtures on the nutritive value, fermentation and methane emission. Fresenius Environmental Bulletin 26(10):5754-5760.

Lal, R. 2023. Farming systems to return land for nature: It's all about soil health and re-carbonization of the terrestrial biosphere. Farming System 1(1):100002. doi:10.1016/j.farsys.2023.100002.

Lasek, O., Barteczko, J., Barć, J., Micek, P. 2020. Nutrient content of different wheat and maize varieties and their impact on metabolizable energy content and nitrogen utilization by broilers. Animals 10(5):907. doi:10.3390/ani10050907.

Lee, M.A. 2018. A global comparison of the nutritive values of forage plants grown in contrasting environments. Journal of Plant Research 131:641-654. doi:10.1007/s10265-018-1024-y.

Miassi, Y.E., Dossa, K.F. 2023. Forecasting animal protein supply in Asia and Europe in light of climate change, population growth and land pressure. Tropical Plants 2:22. doi:10.48130/TP-2023-0022.

Muñoz-González, J.C., Huerta-Bravo, M., Lara, A., Rangel, R., de la Rosa, J.L. 2016. Producción y calidad nutrimental de forrajes en condiciones del Trópico Húmedo de México. Revista Mexicana de Ciencias Agrícolas 16:3315-3327. doi:10.29312/remexca.v0i16.399.

NASEM. 2021. Nutrient requirements of dairy cattle. 8th ed. National Academies of Sciences, Engineering, and Medicine (NASEM), The National Academies Press, Washington, DC, USA. doi:10.17226/25806.

NRC. 2007. Nutrient requirements of small ruminants: Sheep, goats, cervids and new camelids. National Research Council (NRC), The National Academy of Sciences, Washington D.C., USA.

Parra, C.S., Bolson, D.C., Jacovaci, F.A., Nussio, L.G., Jobim, C.C., Daniel, J.L.P. 2019. Influence of soybean-crop proportion on the conservation of maize-soybean bi-crop silage. Animal Feed Science and Technology 257:114295. doi:10.1016/j.anifeedsci.2019.114295.

Pond, W.G., Church, D.C., Pond, K.R., Schoknecht, P.A. 2004. Basic animal nutrition and feeding. John Wiley & Sons, Hoboken, New Jersey, USA.

Rauw, W.M., Izquierdo, E., Torres, O., García, M., Beascoechea, E.M., Benayas J.M., et al. 2023. Future farming: protein production for livestock feed in the EU. Sustainable Earth Reviews 6:3. doi:10.1186/s42055-023-00052-9.

Robles-Vega, F.J., Granados-Rivera, L.D., Joaquín-Cancino, S., Aguado-Lara, G., Rivas-Jacobo, M.A., Garay-Martínez, J.R. 2020. Forage yield of *Urochloa* cultivars in a warm sub-humid environment. Agroproductividad 13(12):75-81. doi:10.32854/agrop.v13i12.1902.

Rojas-Downing, M.M., Nejadhashemi, A.P., Harrigan, T., Woznicki, S.A. 2017. Climate change and livestock: Impacts, adaptation, and mitigation. Climate Risk Management 16:145-163. doi:10.1016/j.crm.2017.02.001.

Rosa, L.O., Pereira, O.G., Ribeiro, K.G., Filho, S.C.V., Cecon, P.R. 2020. Chemical composition in soybean silages with inoculant and molasses. Ciência Animal Brasileira 21:e-58211. doi:10.1590/1809-6891v21e-58211.

van Soest, P.J., Robertson, J.B., Lewis, B.A. 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. Journal of Dairy Science 74(10):3583-3597. doi:10.3168/jds.S0022-0302(91)78551-2.

Vargas, T.V., Hernández, R.M.E., Gutiérrez, L.J., Plácido, D.C.J., Jiménez, C.A. 2007. Clasificación climática del estado de Tamaulipas, México. CienciaUAT 2(2):15-19.

Vendramini, J.M.B., Silveira, M.L., Moriel, P. 2023. Resilience of warm-season (C_4) perennial grasses under challenging environmental and management conditions. Animal Frontiers 13(5):16-22. doi:10.1093/af/vfad038.

Wassie, S.H., Ali, A.I.M., Korir, D., Butterbach-Bahl, K., Goopy, J., Merbold, L., et al. 2019. Effects of feed intake level on efficiency of microbial protein synthesis and nitrogen balance in Boran steers consuming tropical poor-quality forage. Archives of Animal Nutrition 73:140-157. doi:10.1080/1745039x.2019.1572343.

Weindl, I., Lotze-Campen, H., Popp, A., Müller, C., Havlík, P., Herrero, M., et al. 2015. Livestock in a changing climate: Production system transitions as an adaptation strategy for agriculture. Environmental Research Letters 10:094021. doi:10.1088/1748-9326/10/9/094021.

Weiss, K. 2017. Volatile organic compounds in silages-effects of management factors on their formation: a review. Slovak Journal of Animal Science 50(1):55-67.

Wirsenius, S., Azar, C., Berndes, G. 2010. How much land is needed for global food production under scenarios of dietary changes and livestock productivity increases in 2030? Agricultural Systems 103(9):621-638. doi:10.1016/j.agsy.2010.07.005.

Yücel, C., Avcı, M., Inal, İ., Yücel, D. 2017. Yield and silage quality of soybean-maize intercrop under different mixing ratios and harvest stages. International Journal of Agronomy and Agricultural Research 10:95-105.

Zhao, C., Wang, L., Ma, G., Jiang, X., Yang, J., Lv, J., et al. 2021. Cellulase interacts with lactic acid bacteria to affect fermentation quality, microbial community, and ruminal degradability in mixed silage of soybean residue and corn stover. Animals 11(2):1-15. doi:10.3390/ani11020334.