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Forage and Silage Quality Performance of Maize and Sorghum Intercropped with Soybean, Cowpea and Guar in Northwest Türkiye

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Intercropping provides benefits over monocultures, such as improved soil fertility, higher yield potential, and better forage quality across different conditions. This study evaluated the forage and silage yield and quality of maize- and sorghum-based intercropping with soybean, cowpea and guar in northwest Türkiye. Field experiments were conducted over two seasons (2016 – 2017) using a randomized complete block design with three replications. The measured parameters included green weight (GW), dry weight (DW), and various quality indicators: dry matter (DM), digestible DM (DMD), crude protein, ash, neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin (ADL), gross energy (GE), and digestible energy (DE). Overall, intercropping systems produced slightly less total forage than monocultures, as shown by land equivalent ratios below one. However, intercropping significantly improved the forage and silage quality of cereals: Sorghum NDF decreased from 62.9% (monoculture) to 49.6% (with soybean) and 58.3% (with cowpea). Maize crude protein increased from 8.06% alone to 11.21% (with soybean) and 11.38% (with cowpea). Although sole-crop maize produced the highest silage yield, intercropping with soybean or cowpea significantly enhanced silage nutritive value without greatly reducing yield. Guar, a new legume in this region, performed poorly both alone and in mixtures, showing low GW and DW. We recommend maize–soybean and maize–cowpea intercropping for farmers aiming for better silage quality with minimal loss in yield. Future research should focus on identifying guar varieties better suited to northwest Türkiye and improving cereal–legume intercropping practices for local conditions.

Keywords: intercropping, maize, sorghum, soybean, cowpea, guar, silage

Cereals are the primary source of animal feed worldwide, with maize being one of the most important forage crops (Klopfenstein *et al.* 2013; Wrigley 2017). Maize is utilised not only for human and animal consumption, but also in various industries, including bioethanol production (Klopfenstein *et al.* 2013). Sorghum, while primarily consumed by humans in Africa, is also widely used as livestock feed (Nasidi *et al.* 2019). Both crops are commonly ensiled, and properly prepared silage extends shelf life and poses no health risks for animal consumption (Weinberg *et al.* 2003; Driehuis *et al.* 2018). According to FAO (2022), global maize production in 2022 covered 203,470,007 ha and yielded 1,163,497,300 t, while sorghum was cultivated on 40,762,472 ha and produced 57,581,944 t. In Türkiye, based on data from the Turkish Statistical Institution (TÜİK 2024), maize was cultivated on 528,612 ha, yielding 28,653,531 t of silage. In contrast, sorghum was grown on 3,765 ha with a silage production of 159,850 t.

Forage quality is one of the most prominent

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factors influencing nutritional value and overall quality of animal-derived products (Moore 1980). The production of high-quality, protein-rich and easily digestible animal products depends largely on the availability of nutrient-dense forage resources (Makkar *et al.* 2014; Nouman *et al.* 2014; Bengtsson *et al.* 2019). In contrast, the consumption of low-digestible forage has been linked to increased physiological stress in animals, which may lead to reduced product quality (Cavallini *et al.* 2022; Gouvêa *et al.* 2022). While cereals serve as valuable forage sources, their inherent limitations include relatively low protein content and digestibility (Humer & Zebeli 2017). Ensiling cereals is an effective strategy to improve their digestibility and prolong shelf time (Muck *et al.* 2018). Furthermore, intercropping cereals with legumes can enhance the protein content and nutritional value of both forage and silage.

Cowpea (*Vigna unguiculata*), also known as black-eyed pea, is a versatile leguminous plant native to West Africa and widely cultivated across tropical and subtropical regions (Abebe & Alemayehu 2022). While cowpea holds significant importance in African countries such as Nigeria, Niger and Burkina Faso (FAO 2022), its cultivation area in Türkiye has drastically decreased from 22.094 ha in 2012 to just 1.129 ha in 2024 (TUİK 2024). Cowpea is considered an orphaned crop, and is often intercropped with maize in Africa, a practice that has been shown to improve silage quality in the region (Timko *et al.* 2007). Another notable legume, soybean (*Glycine max*), is native to East Asia and has emerged as a globally important crop due to its protein-rich seeds and oil content. It is extensively cultivated for both human consumption and animal feed (Colletti *et al.* 2020). Globally, soybeans covered 133’791’633 ha and yielded 348’856’427 t in 2022 (FAO 2022); in Türkiye, 32,684 ha were cultivated in 2023, and this figure, along with the corresponding yield, has shown little change over the past two decades (TUİK 2024). Despite its global significance, the potential of soybeans as a forage crop remains largely underutilized in Türkiye.

Guar (*Cyamopsis tetragonoloba*), of which approximately 70% of global production occurs in India, is a versatile, late-maturing, warm-season annual crop known for its drought tolerance. It is cultivated across North and South America, Africa, Australia, and the Indian subcontinent (Chudzikowski 1971; Vishnyakova *et al.* 2023). Guar is widely utilized in the food, cosmetic, and petroleum industries (Mudgil *et al.* 2014), and is also used as animal fodder (Thomas *et al.* 1980; Rao & Northup 2013) and silage (Olfaz *et al.* 2019). However, studies have shown that excessive consumption of guar gum by animals may lead to adverse health effects, such as reduced food intake (Mudgil *et al.* 2014). In Türkiye, researchers from Çanakkale Onsekiz Mart University introduced guar for the first time and tested its adaptability to local agroclimatic conditions (Akçura *et al.* 2020). Additional research from the same institution explored the effects of row spacing on hay yield and its components (Cebeci *et al.* 2016). Despite these efforts, only a limited number of studies have been conducted to evaluate guar in the region. Therefore, further research is needed to comprehensively assess its potential as a forage crop in Türkiye.

Cereal legume intercropping is widely recognized for its ability to enhance forage protein content (Bacchi *et al.* 2021). In addition to improving forage quality, intercropping has been associated with increased yield, enhanced soil fertility (Li *et al.* 2021), and greater yield stability (Raseduzzaman & Jensen 2017). These benefits are particularly relevant for Türkiye, where the average organic matter content in agricultural soils has declined significantly from the 1970s to the 2000s (Celik, 2005). Intercropping systems have been studied extensively worldwide, including in the Mediterranean region. Examples include barley intercropped with Hungarian vetch (*Vicia pannonica* L.) (Yılmaz *et al.* 2015), pea (*Pisum sativum* L.) with ryegrass (*Lolium multiflorum* Lam. var. Westerwoldicum) (Di Miceli *et al.* 2023), maize with cowpea (Salama *et al.* 2022), maize with soybean (Du *et al.* 2018), sorghum with cowpea (Oseni 2010), and sorghum with soybean (Lesoing & Francis 1999). Guar has also been studied in intercropping systems with various crops (Clark & Myers 1994; Ahmadabad *et al.* 2022); however, its intercropping performance with cereals remains unexplored, mainly in the region.

In Türkiye, limited research has been conducted on maize-soybean intercropping, and no studies have evaluated the performance of maize and sorghum intercropped with cowpea and guar. Therefore, the objective of this study was to assess the intercropping performance of selected cereals and legumes in terms of forage yield, forage and silage quality, and land-use efficiency. The land-equivalent ratio (LER) was used to compare the intercropping systems with monoculture cropping. Furthermore, the study hypothesizes that guar may hold potential as a forage, whether grown alone or in combination with cereals, under the conditions of Northwest Türkiye.

MATERIAL AND METHODS

Study Area

This study was conducted at Çanakkale Onsekiz Mart University, located in Northwest Türkiye (40°1 ′N 26°4 ′E, 2 meters above ground), which experiences Mediterranean climatic conditions with the growing seasons of 2016 and 2017, from May to August. The region receives an average annual precipitation of 615 mm and has a mean annual temperature of 15°C. Summers are typically hot and dry, occurring from June to September. In 2016, the temperatures were above average, and precipitation levels were lower than the long-term mean (533.3 mm), whereas in 2017, both temperature and rainfall (714.6 mm) were closer to historical averages (Figure 1). According to the soil taxonomic classification of FAO/UNESCO, the soil type in the experimental field is classified as Eutric Vertisol (IUSS 2015). The soil composition is 33.60% clay, 36% silt, and 30.4% sand, corresponding to a clay loam texture. The pH value of the soil is 7.02, the electrical conductivity is 0.39 (dS/m), the $CaCO_3$ content is 11.86%, and the organic matter content is 2.08% (Özaslan Parlak *et al.* 2011).

Experimental Design and Field Management

In this experiment, we assessed the intercropping performance of cereals and legumes and the sole cropping of each treatment by row-intercropping (Vandermeer 1992; Mousavi & Eskandari 2011). The cereals crops used were maize (*Zea mays* L.) and sorghum (*Sorghum bicolor* (L.) Moench × *Sorghum sudanense* (Piper) Stapf), intercropped with legumes including soybean (*Glycine max*), cowpea (*Vigna unguiculata*) and guar (*Cyamopsis tetragonoloba*).

Maize was sown with a row spacing of 70 cm and a within-row spacing of 15 cm. Sole legume was planted with a row spacing of 35 cm and a within-row spacing of 10 cm. Sorghum was sown simi-

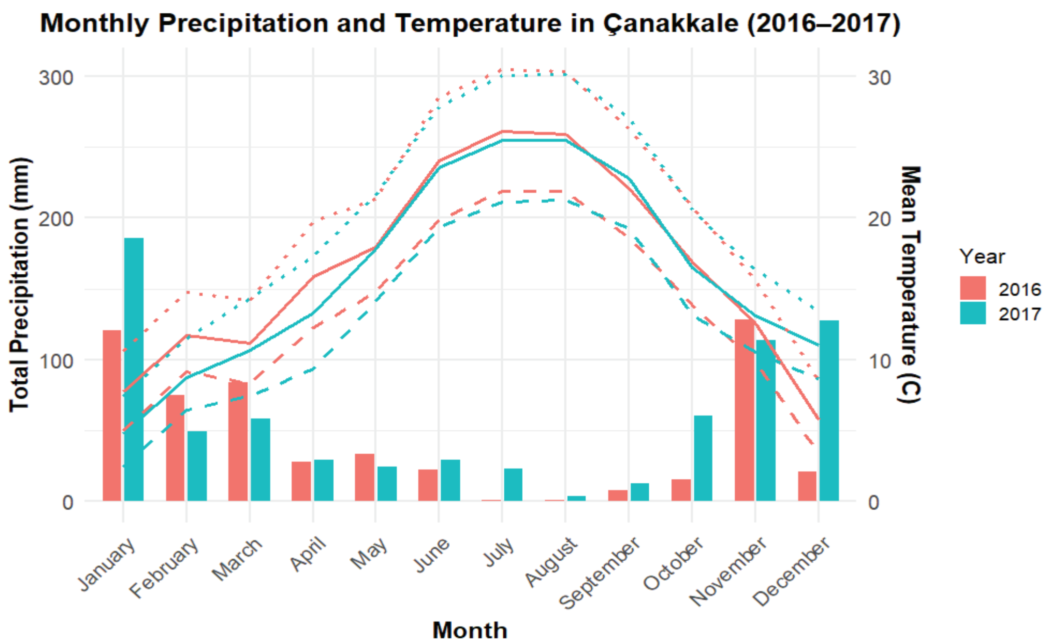

Figure 1. Shows the minimum (long dashed lines), maximum (short dashed lines), and mean temperature (solid lines) for 2016 (red) and 2017 (cyan) at the experimental location. The cyan and red bars indicate the precipitation for each month of the respective years.

larly to the sole legume cropping but with a seeding rate of 0.4 kg/ha and a row spacing of 35 cm. The intercropping of maize and legumes had row spacings of 35 cm between rows, 15 cm within rows for maize, and 10 cm for legumes. Intercropping between sorghum and legume row spacings was 15 cm and 10 cm within legume rows, with a seeding rate of 570 g per row for sorghum (Figure 2).

The field trial was conducted as a randomised complete block design with three replications. A compound fertiliser (15:15:15) was applied at a rate of 0.1 kg/ha (N, P_2O_5, and K_2O) before sowing. Field preparation included plowing in autumn and disc harrowing in the spring. Trials were sown on October 13 – 14 in both 2016 and 2017. Drip irrigation was applied every five days. Weed control was performed manually. Due to heavy grass infestation, hand weeding continued until plants had 3 – 5 leaves, after which mechanical hoeing was used. Plants were harvested by hand when cereals reached the dough stage. The sorghum-sudangrass hybrid matured earlier than maize and was harvested separately: August 11, 2016, and August 03, 2017. Maize was harvested on August 18, 2016 and August 15, 2017. In order to account for border effects, the initial and final rows, as well as the initial and final 50 cm of each plot, were excluded. The remaining area was then designated as the harvest area.

Data Collection of the Treatments' Yield and Nutrient Composition

Above-ground biomass was first measured as green weight (GW). Then, 500 g samples were collected and dried at 60°C for 48 hours to calculate dry matter (DM) and hay yield, expressed in decare units.

Following both harvests, the plant branches were processed through a shredder, resulting in small pieces measuring 0.6 – 2.5 cm for silage production. Shredded plant samples were silaged into plastic bags using a vacuum packaging machine. The silages were stored in a dark environment at room temperature until November 14 of each year. Silage DM was determined by drying at 60°C for 48 hours. Dried samples were ground using a 0.5 mm sieve for chemical analyses. The nitrogen (N) content of silage and forage samples was determined using the Kjeldahl method (Lynch & Barbano 1999), and the

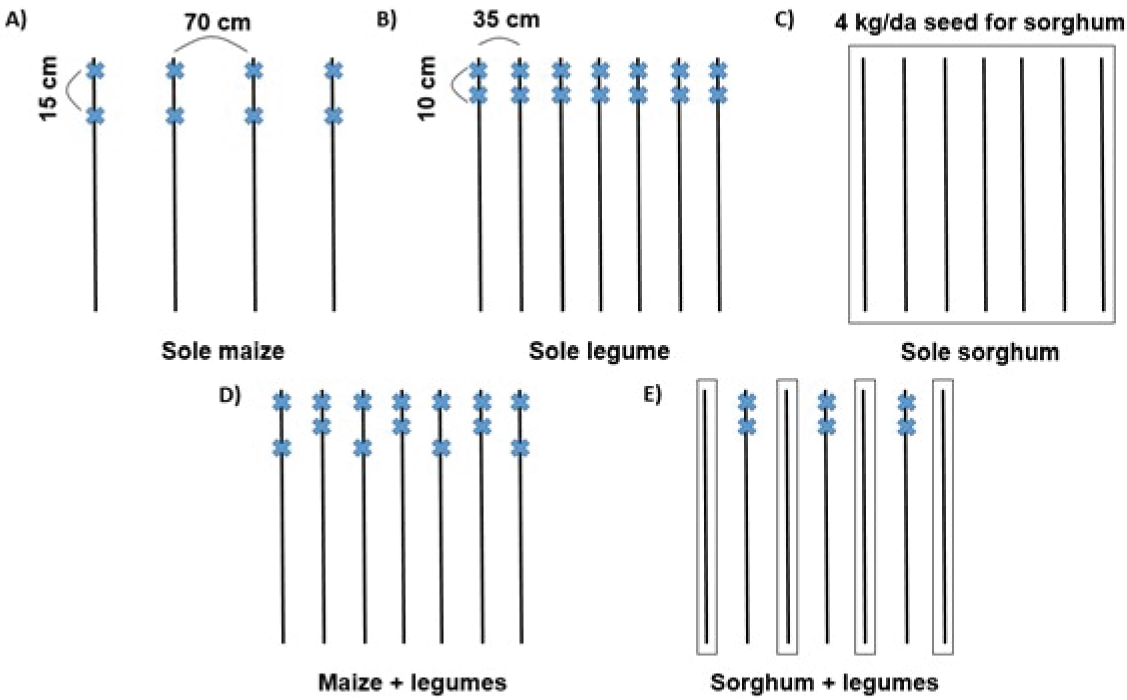

Figure 2. Schematic description of sole and intercropping planting configurations. The sole sowing of maize row space was 15 cm, and between rows was 70 cm (A). The sole sowing of legume row space and between row space were 10 and 35 cm, respectively (B). Sole sorghum sowing was 0.4 kg/ha (C). Intercropping of legumes with maize. Row spacing for maize was 15 cm and 10 cm for legumes, but between the row spacing was 35 cm (D). Sorghum + legume intercropping. 570 g per row per decare for sorghum, and the distance between rows was 35 cm (E).

crude protein content was calculated by multiplying the nitrogen content by 6.25. NDF (neutral detergent fiber), ADF (acid detergent fiber), and ADL (acid detergent lignin) were analysed following Van Soest *et al.* (1991). The ash content was determined using the method described by Thiex *et al.* (2012). Silage pH was measured with a pH meter. Digestible dry matter (DMD) was calculated using the following formula: DMD% = 83.58 – 0.824 × ADF (%) + 2.626 × N [%] (Oddy *et al.* 1983; Özaslan Parlak *et al.* 2011).

The land equivalent ratio (LER) was calculated according to Mead and Willey (1980), representing the relative land area required under monoculture to match the yield of an intercropping system. It is calculated using Formula 1:

$$\mathrm{LER} = \sum_{i-1}^{m} \frac{\mathrm{IY_i}}{\mathrm{SY_i}}$$

Formula 1: Land equivalent ratio (LER), IY is the intercropped yield of the ith crop, and SY is the sole yield.

Digestible energy (DE) and gross energy (GE) are calculated according to the formulas described by MAFF (Ministry of Agriculture, Fisheries and Food) 1975 and AAFCO (Association of American Feed Control Officials) 1997, respectively (Gaafar *et al.* 2024).

$$\mathrm{GE(Mcal/kg\ DM)} = \frac{(0.226 \times \mathrm{CP} + 0.177 \times \mathrm{CF} + 0.407 \times \mathrm{EE} + 0.192 \times \mathrm{NFE})}{4.184}$$

Formula 2: Gross energy (Mcal/kg DM) (GE), DM is the dry matter, CP is the crude protein, EE is the ether extract, and NFE is the nitrogen-free energy.

$$\mathrm{DE(Mcal/kg\ DM)} = \frac{(\mathrm{DE} \times (87.9 - (0.88 \times \mathrm{CF})))}{100}$$

Formula 3: Digestible energy (Mcal/kg DM) (DE), DM is the dry matter, and CF is the crude fiber.

Statistical Analysis

Linear mixed models (LMMs) were developed for each observation using the lme4 package in R (Bates *et al.* 2015). Significant treatment effects were assessed using Tukey's honestly significant difference (HSD) test (Tukey, 1949). In the LMM structure, treatment (cropping system) was treated as a fixed effect, while blocks nested within years were considered random effects.

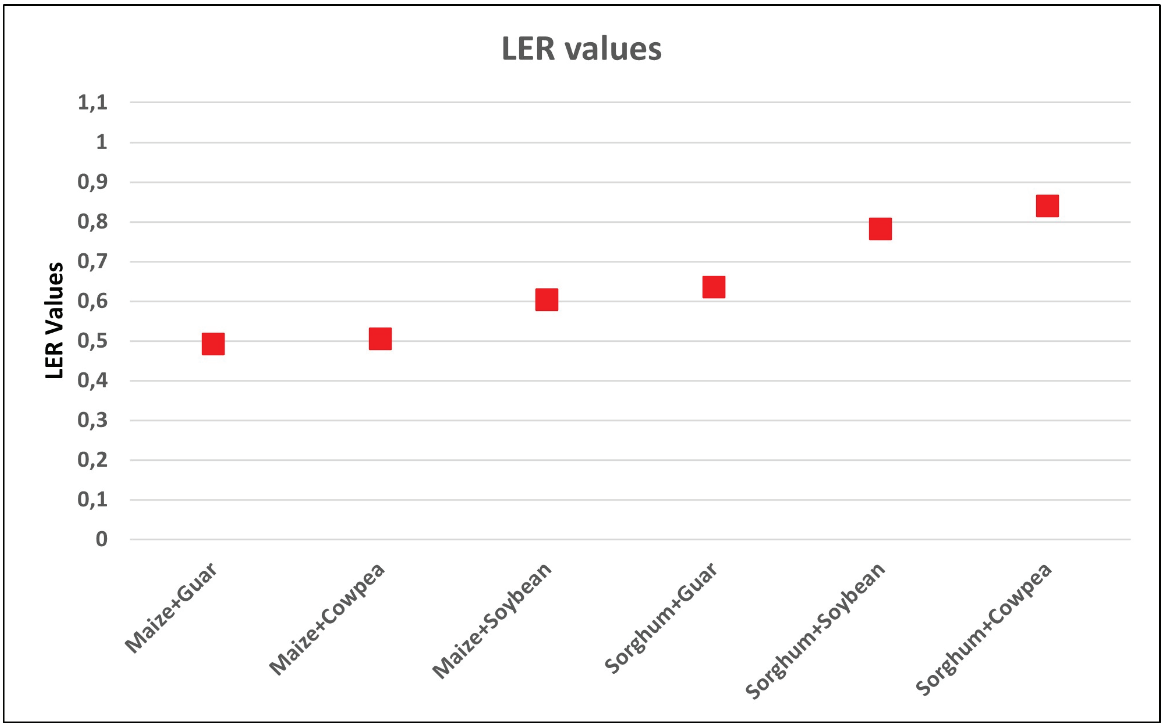

Figure 3. The intercropping treatments' land equivalent ratio (LER) values.

RESULTS

Yield and LER Parameters

The highest green weight (GW) and dry matter yields (DW) were obtained from the sole cereal crops (Table 1, Figure 4 (E)). Maize monoculture produced the highest yields, with 930.2 kg/ha GW and 336.4 kg/ha DW, followed by sorghum monoculture, which yielded 485.5 kg/ha GW and 192.5 kg/ha DW. In contrast, legume monocultures yielded significantly lower, with guar showing the lowest DW at just 17.6 kg/ha. Among the intercropping combinations, maize-soybean (154.2 kg/ha DW) and maize-cowpea (137.5 kg/ha DW) performed moderately well. However, the maize-guar intercrop exhibited poor performance, yielding only 72.8 kg/ha DW. Sorghum-cowpea intercropping produced comparatively higher yields among the sorghum-legume mixtures with 383.5 kg/ha GW and 157.7 kg/ha DW.

Land equivalent ratio (LER) values for intercropping systems were consistently below 1.0, indicating no yield advantage compared to sole cropping. The sorghum-cowpea intercrop had

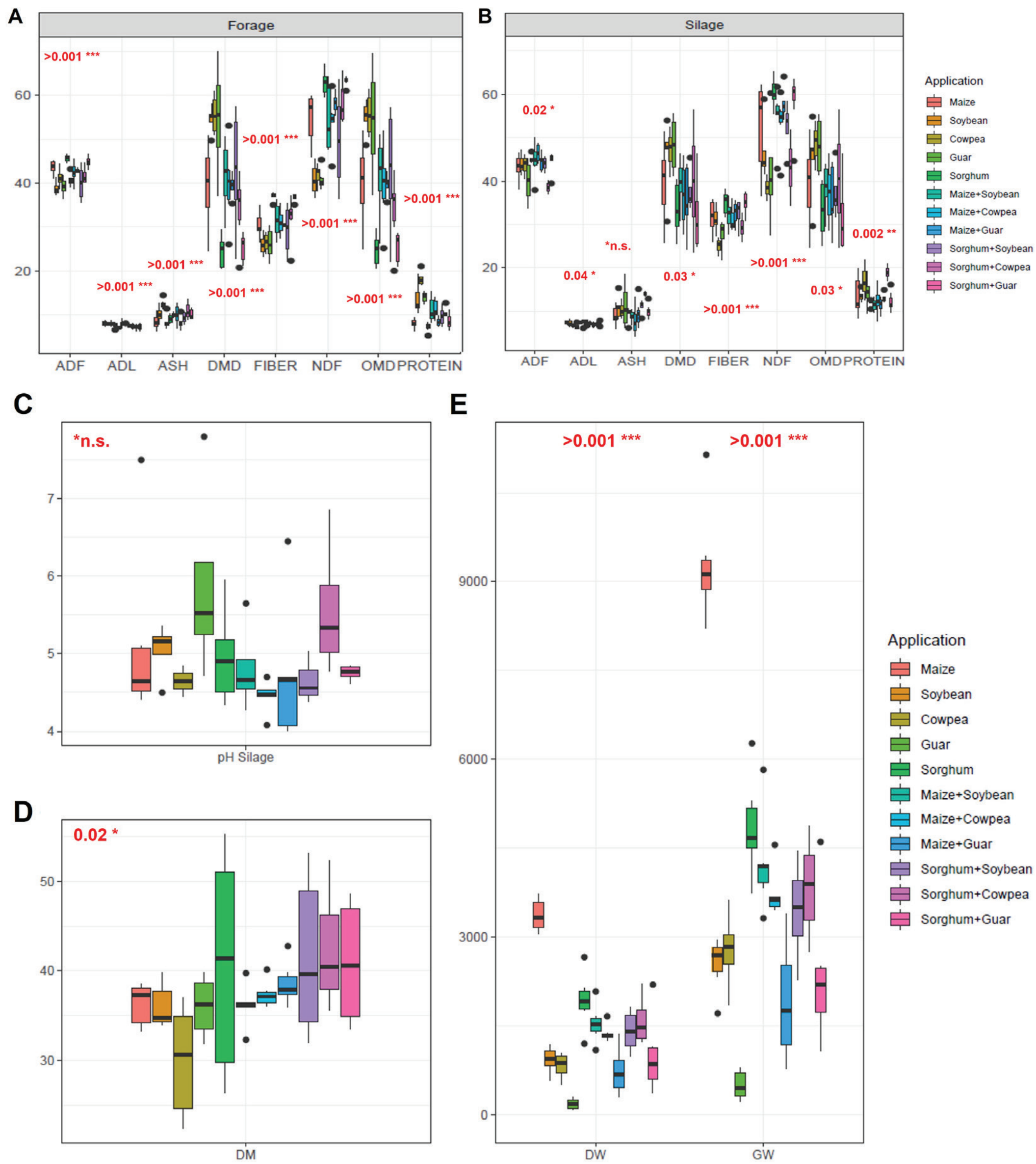

Figure 4. Statistical significance values of observations for each treatment. Each color in the box plots represents different treatments for quality parameters: Acid detergent fiber (ADF), acid detergent lignin (ADL), Ash, digestible dry matter (DMD), fiber, neutral detergent fiber (NDF), organic matter digestibility (OMD), and Protein for forage (A) and silage (B); pH values for silage (C); DM values (D); and DW and GW values (E), which are shared in the figure.

T a b l e 1

Green weight (GW), dry weight (DW), dry matter (DM), acid detergent fiber (ADF) of dry matter (ADF_D), ADF of silage (ADF_S), acid detergent lignin (ADL) of silage (ADL_S), dry and silage ash (ASH_D, ASH_S), dry matter digestibility (DMD_D, DMD_S), dry and silage fiber (FIBER_D, FIBER_S), dry and silage, neutral detergent fiber (NDF) (NDF_D, NDF_S), the protein content of dry and silage (PROTEIN_D, PROTEIN_S), organic matter digestibility of dry and silage (OMD_D. OMD_S), and pH values of silage (pH_S) of maize, soybean, cowpea, guar, maize + soybean, maize + cowpea, maize + guar, sorghum + soybean, sorghum + cowpea, sorghum + guar treatments in 2016 and 2017 harvest seasons

Treatment	GW		DW		DM		ADF_D		ADL_D		ASH_D		DMD_D		FIBER_D		NDF_D		OMD_D		PROTEIN_D	
Maize	9302	A	3364	A	36.3	AB	43.6	ABC	8.1	A	8.5	BC	39.4	BCD	30.45	AB	54.7	AB	40	ABC	8.1	F
Soybean	4855	EF	920	DE	36.0	AB	38.7	D	8.1	A	10.2	ABC	54.1	AB	26	B	40.8	C	54.4	A	13.7	BC
Cowpea	2779	DEF	826	E	29.9	B	41.3	ABCD	8.1	A	12.6	A	54.9	AB	26.51	B	41.9	C	54.8	A	18.2	A
Guar	490	G	176	F	36.1	AB	39.2	CD	7.6	AB	8.5	C	54.7	A	26.16	B	40.8	C	54.3	A	14.1	B
Sorghum	4855	B	1925	B	40.8	A	45.6	A	7.1	B	9.1	BC	24.2	D	36.86	A	62.9	A	24.4	D	7.3	F
Maize+Soybean	4262	BC	1542	BC	36.1	AB	40.8	BCD	8.0	A	10.1	BC	41.7	ABC	31.58	AB	54.6	AB	41.7	AB	11.2	CD
Maize+Cowpea	3734	CD	1375	CD	37.4	AB	42.4	ABCD	7.9	AB	10.1	BC	39.9	ABCD	31.12	AB	54.2	AB	39.6	ABCD	11.4	CD
Maize+Guar	1906	F	728	E	38.6	A	42.8	ABCD	7.7	AB	8.3	C	38.7	CD	30.46	AB	58.2	AB	38.3	BCD	8.5	EF
Sorghum+Soybean	3447	CDE	1406	CD	41.5	A	40.0	CD	7.4	AB	9.4	BC	43.4	ABC	29.33	B	49.6	BC	43.2	AB	9.8	DEF
Sorghum+Cowpea	3835	BCD	1577	BC	42.4	A	41.6	ABCD	7.3	AB	11.0	AB	34.2	CD	31.95	AB	58.3	AB	33.9	BCD	10.6	DE
Sorgum+Guar	2369	EF	999	DE	40.9	A	44.8	AB	7.3	AB	10.1	ABC	25.1	D	36.62	A	63.1	A	25.3	CD	8.6	EF
Mean	3592		1349		37.8		41.9		7.7		9.8		40.8		30.7		52.7		40.9		10.1	
CV [%]	19.94		25.06		8.3		4.65		4.9		13.82		17.31		10.3		9.26		17.49		12.29	
P-Value treatment ($p > 0.05$)	<.0001 $^{+++}$		<.0001 $^{+++}$		<.0001^{+++}		<.0001^{+++}		<.0001 $^{+++}$		<.0001 $^{+++}$		<.0001 $^{+++}$		<.0001^{+++}		<.0001^{+++}		<.0001 $^{+++}$		<.0001 $^{+++}$	
P-Value year ($p > 0.05$)	n.s.		0.0230 $^{+}$		<.0001^{+++}		n.s.		0.01318 $^{+}$		0.03592 $^{+}$		n.s.		n.s.		n.s.		n.s.		0.008793 $^{++}$	
P-Value TXY ($p > 0.05$)	0.02839 $^{+}$		0.022048 $^{+}$		<.0001^{+++}		n.s.		0.03483 $^{+}$		n.s.		0.03706 $^{+}$		n.s.		n.s.		0.02792 $^{+}$		0.004200 $^{++}$	

Table 1 - continued

Treatment	ADF_S		ADL_S		ASH_S		DMD_S		FIBER_S		NDF_S		OMD_S		PROTEIN_S		pH_S
Maize	43.4	ABC	7.4	A	9.6	BC	36.5	AB	32.9	A	60.9	A	34.2	AB	9,6	B	4.57
Soybean	45.2	AB	7.4	A	11.1	B	36.5	AB	29.3	AB	43.1	BC	49.0	A	13.0	B	5.23
Cowpea	41.8	BC	7.1	AB	9.4	BC	51.1	A	24.8	B	39.9	C	45.9	AB	14.5	AB	4.55
Guar	40.3	C	6.3	B	13.4	A	49.5	AB	29.3	AB	50.4	B	42.0	AB	11.9	B	6.61
Sorghum	44.3	ABC	7.1	AB	8.8	BC	38.0	AB	35.6	A	61.3	A	32.6	AB	11.7	B	4.01
Maize+Soybean	44.0	ABC	7.4	A	8.9	BC	37.5	AB	30.0	AB	54.1	B	41.7	AB	10.8	B	4.85
Maize+Cowpea	46.2	A	7.5	A	9.6	BC	35.6	AB	31.6	AB	56.6	AB	35.2	AB	10.7	B	4.27
Maize+Guar	45.6	AB	7.5	A	8.0	C	36.5	AB	32.4	A	56.7	AB	34.5	AB	11.9	B	4.84
Sorghum+Soybean	43.6	ABC	6.8	AB	10.1	B	39.4	AB	31.2	AB	49.3	B	39.2	AB	13.9	AB	3.71
Sorghum+Cowpea	41.6	BC	7.3	A	12.0	AB	35.2	AB	29.6	AB	49.1	B	30.7	B	19.0	A	4.62
Sorgum+Guar	42.3	ABC	7.3	A	11.6	AB	31.7	B	34.4	A	56.5	AB	35.3	AB	13.4	B	3.81
Mean	43.5		7.2		10.2		37.9		31.4		51.9		38.3		13.5		4.97
CV [%]	5.44		5.73		21.85		20.44		9.51		12.72		20.47		17.11		15.24
P-Value treatment (p>0.05)	0.004858 $^{++}$		n.s.		0.048850^{+}		n.s.		0.0047^{++}		0.0002^{+++}		0.04474^{+}		0.0006^{+++}		n.s.
P-Value year ($p>0.05$)	n.s.		n.s.		n.s.		n.s.		n.s.		n.s.		n.s.		0.0002 $^{+++}$		n.s.
P-Value T×Y ($p>0.05$)	0.012172^{+}		n.s.		0.0014^{+}		n.s.		n.s.		n.s.		n.s.		n.s.		n.s.

Means followed by the same lowercase letter within rows and the same uppercase letter within columns, for the same variable, do not differ by the Tukey test at 5% probability of error ($P<0,05$). T – treatment effect; Y – year effect; T × Y – treatment-year; *CV* – coefficient of variation.; n.s. – non-significant. Asterisks indicate significance levels ($^{+++}$ $p<0.001$, $^{++}$ $p<0.01$, $^{+}$ $p<0.05$).

the highest LER (0.84), whereas the maize-guar combination showed the lowest performance with an LER of 0.49 (Figure 3, Supplementary Figure 1).

Forage Quality Parameters

Forage quality was assessed through digestibility indicators. The key parameters included neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL). High NDF values indicate increased levels of cellulose, hemicellulose, and lignin, which are undesirable due to their low digestibility (Jung 1997). As shown in Table 1, Figure 4 (A), both dry matter digestibility (DMD) and organic matter digestibility (OMD) were inversely related to NDF, as digestibility decreased with increased cell wall components. Fiber content, a major determinant of forage quality, was positively correlated with NDF (Supplementary Figure 2).

High NDF values were recorded in the study in sole crops: with 54.7% for maize and 62.9% for sorghum. In contrast, legumes showed lower NDF values: 40.8% for soybean, 41.9% for cowpea, and 40.8% for guar. Sorghum intercropped with legumes showed reduced NDF values compared to sole sorghum cropping, except for the sorghum + guar combination. NDF values for the sorghum-based intercropping systems were 49.6%, 58.3% and 63.1% for sorghum + soybean, sorghum + cowpea, and sorghum + guar treatments, respectively. For maize-legume intercropping combinations, NDF values were similar to those of the sole maize, and differences were statistically insignificant (Figure 4 (A)).

Sole cereal plots had the highest ADF values: 43.6% for maize and 45.6% for sorghum. Legume monocultures exhibited significantly lower ADF values: 38.7% for soybean, 41.3% for cowpea and 39.2% for guar. Intercropping of maize with legumes resulted in slightly reduced ADF levels compared to sole maize: 40.8%, 42.4% and 42.8% for maize + soybean, maize + cowpea, and maize + guar, respectively. Similar reductions were observed in sorghum-legume combinations: 40.0%, 41.6% and 44.8% for sorghum + soybean, sorghum + cowpea, and sorghum + guar (Figure 4 (A)).

Only slight differences were found in ADL values across treatments, ranging from 7.1% and 8.1%. The lowest ADL was recorded in sole sorghum, while the highest values were observed in sole maize, soybean, and cowpea treatments (Figure 4 (A)).

Ash content ranged from 8.3% to 12.6%. The lowest ash level was observed in the maize + guar intercrop (8.3%), while soybean and cowpea combinations had higher ash content (10.2% and 12.6%, respectively). Sole maize and sorghum had ash values of 8.8% and 9.1%, respectively. Overall, ash content in intercropping systems ranged between 8.3% and 11% (Figure 4 (A)).

Protein content varied widely. Among sole-crops, it ranged from 7.3% in sorghum to 18.2% in cowpea. Intercropping generally enhanced protein values except in combinations with guar. Protein levels were 8.5% for maize + guar and peaked at 11.4% for maize + cowpea (Figure 4 (A)).

Silage Quality Parameters

In this study, we evaluated both forage and silage quality across cropping systems. The NDF values of the silage were similar to those of the corresponding forage, with cereal silage showing a slight reduction in NDF compared to forage. DMD and OMD values remained generally consistent between forage and silage, except for sorghum. Notably, the sorghum + cowpea intercrop exhibited a significant improvement in quality parameters after ensiling (Table 1, Figure 4 (A, B)). Similar effects of fermentation on digestibility enhancement have been reported in previous studies (Contreras-Govea *et al.* 2013).

Silage NDF values in silage ranged from 39.9% to 61.3%, with the lowest found in sole cowpea and the highest in sorghum. Legume monocultures showed NDF values of 39.9% (cowpea), 43.1% (soybean) and 50.4% (guar). For cereals, maize and sorghum silages had NDF values of 60.9% and 61.3%, respectively. Intercropping generally reduced NDF values, although combinations with guar did not differ significantly from their respective sole cereal counterparts (Table 1, Figure 4 (B)).

ADF values in silage ranged from 40.3% to 46.2%. Only two treatments- guar sole and sorghum + cowpea differed significantly from the rest. As for ADL, the lowest content was observed in the guar monoculture (6.3%). Sorghum, cowpea, and sorghum + guar (7.1%, 7.1% and 6.8%, respectively) formed a statistically similar group with lower ADL than other treatments (Table 1, Figure 4 (B)).

Ash content varied significantly. The highest ash content was found in the guar (13.4%), while the lowest was observed in maize + guar (8.0%). Sorghum-based mixtures with cowpea and guar followed (12.0% and 11.6%, respectively). Soybean and sorghum + soybean had intermediate values (11.1% and 10.1%). Most remaining treatments formed a statistically similar group, with values higher than the lowest but lower than the guar monoculture (Table 1, Figure 4 (B)).

Although pH values varied slightly across treatments, no statistically significant differences were found (Figure 4 (C)).

Protein content in silage was generally higher in legumes than in cereals. The highest protein value was observed in the sorghum + cowpea treatments (19.0%), followed by cowpea (14.5%) and sorghum soybean (13.9%). The remaining treatments had statistically similar, lower protein contents. The lowest was observed in the maize (9.6%). Among intercrops, only sorghum + cowpea and sorghum + soybean improved protein levels compared to sole cereals (Table 1, Figure 4 (B)).

Gross and Digestible Energy

GE and DE values were compared across forage and silage. For the forage, there were statistically significant differences in GE among the treatments. The highest GE was recorded in the guar treatment (4.26 Mcal/kg), whereas the lowest was in the sorghum + cowpea intercrop (4.10 Mcal/kg). Other treatments did not differ statistically in GE values (Table 2).

DE values for forage also showed significant

T a b l e 2

Gross energy for dry matter (GE_D) and silage (GE_S), digestible energy of dry matter (DE_D) and silage (DE_S) of maize, soybean, cowpea, guar, maize + soybean, maize + cowpea, maize + guar, sorghum + soybean, sorghum + cowpea, sorghum + guar treatments in 2016 and 2017 harvest seasons

Treatment	GE_D		GE_S	DE_D		DE_S	
Maize	4.20	AB	4.16	2.57	AB	2.45	AB
Soybean	4.18	AB	4.13	2.72	AB	2.56	AB
Cowpea	4.10	AB	4.22	2.65	ABC	2.79	A
Guar	4.26	A	4.01	2.76	A	2.49	AB
Sorghum	4.16	AB	4.21	2.30	D	2.38	B
Maize + Soybean	4.15	AB	4.21	2.50	BCD	2,59	AB
Maize + Cowpea	4.15	AB	4.17	2.51	ABCD	2.51	AB
Maize + Guar	4.21	AB	4.25	2.58	ABCD	2.53	AB
Sorghum + Soybean	4.18	AB	4.17	2.59	AB	2.52	AB
Sorghum + Cowpea	4.10	B	4.13	2.45	BCD	2.56	AB
Sorgum + Guar	4.12	AB	4.10	2.29	CD	2.36	B
Mean	4.17		4.16	2.54		2.52	
CV [%]	1.63		2.47	4.84		6.17	
P-Value treatment ($p > 0.05$)	0.012387 $^{+}$		n.s.	<.0001^{+++}		0.01536 $^{+}$	
P-Value year ($p > 0.05$)	0.008819 $^{++}$		n.s.	n.s.		n.s.	
P-Value TXY ($p > 0.05$)	n.s.		0.004438 $^{++}$	n.s.		n.s.	

Note: Means followed by the same lowercase letter within rows and the same uppercase letter within columns, for the same variable, do not differ by the Tukey test at 5% probability of error ($p < 0.05$). T – treatment effect; Y – year effect; T × Y – treatment-year; *CV* – coefficient of variation; n.s. – see Table 1. Asterisks indicate significance levels ($^{+++}p < 0.001$, $^{++}p < 0.01$, $^{+}p < 0.05$).

variation among treatments. The highest DE values were found in soybean and guar (2.72 and 2.76 Mcal/kg, respectively), while the lowest values were recorded in the sorghum and sorghum + guar intercropping. Cowpea (2.65 Mcal/kg) and maize (2.57 Mcal/kg) had the highest energy density (Table 2).

No statistical differences were observed in GE values among the treatments for the silage. However, a significant interaction was found between treatment and year (Table 2). In contrast, DE values for silage differed significantly among treatments. The highest DE was recorded in the cowpea silage (2.79 Mcal/kg), while the lowest values were observed in sorghum (2.38 Mcal/kg) and sorghum + guar (2.36 Mcal/kg). The remaining treatments formed an intermediate group with no significant differences among them (Table 2).

DISCUSSION

It is well established that cereals produce higher dry weight (DW) and green weight (GW) than legumes. Also, intercropping treatments are expected to yield less than the sole cereals. A study by Chimonyo *et al.* (2023) on intercropping cereals with legumes found that intercropping resulted in lower yields than monoculture cereals (Chimonyo *et al.* 2023). Our analysis yielded similar results, with sole maize showing the highest DW (336.4 kg/ha) and GW (930.2 kg/ha) performance among sole cropping and all intercropping methods. However, some studies have reported that sorghum GW yield is higher than that of maize. One reason might be that sorghum is more versatile than maize under stress conditions and performs better than maize. A study was conducted using maize and sorghum under well-watered (WW) and water-deficient (WS) conditions to investigate green weight. They found that under WW, maize yields better than sorghum, but sorghum yields better than maize under average or severe water stress conditions (Farré & Faci 2006). In contrast, a similar study in Greece, but with nitrogen-deficient conditions, found that sorghum yields better than maize under both conditions (WW, WS) than maize (Danalatos *et al.* 2009). As shown, maize thrives under optimal conditions and outperforms sorghum. However, sorghum performs better than maize when conditions are less than ideal.

The guar fodder DW and GW performed lower than those reported for subtropical and tropical regions (Rao & Northup 2013). This suggests that the currently available guar varieties for the region are not suitable for fodder production and should be enhanced through additional breeding efforts. Conversely, a different study using normal rats tested diets containing 0%, 10% and 20% guar (w/w). The results showed significantly lower blood serum cholesterol and triacylglycerols, decreased food intake, and less weight gain; however, there was no evidence indicating protein absorption issues (Dario Frias & Sgarbieri 1998). These findings suggest that while high concentrations of guar gum may be harmful, lower concentrations might benefit animal welfare. Therefore, it must be used with caution in mixtures due to possible adverse effects.

Although none of the treatments surpassed the LER > 1 threshold, other studies have shown that intercropping can achieve better outcomes through alternative methods such as mixed or strip intercropping (Mousavi & Eskandari 2011; Bacchi *et al.* 2021; Weih *et al.* 2021). We observed increased LER values with the row-intercropping method with sorghum + soybean (0.78) and sorghum + cowpea (0.84) intercropping. However, the LER values for sorghum + guar (0.64) and maize + guar (0.49) intercropping were lower than those for the other treatments. One possible explanation for this result could be the light competition (Fujita & Budu 1994). Since maize and sorghum are taller than legumes, the tested guar variety might not have effectively tolerated light competition. Additionally, guar may be unsuitable as fodder for this region, as indicated in previous studies, which could also apply to our research. From the LER values, we observe that none of the intercropping methods outperformed sole cropping. Furthermore, the success of intercropping is influenced by factors such as the chosen intercropping techniques, the competitiveness of non-legume plants, and soil nutrient availability (Hossain 2020). Andersen *et al.* (2004) conducted a study on intercropping pea (*Pisum sativum* L.) with barley (*Hordeum vulgare* L.) and oilseed rape (*Brassica napus* L.), as well as triple intercropping with pea, barley, and oilseed rape, at two different N levels (0.5 and 4 g N/m^2). They found that intercropping with oilrape and pea increased LER and N fixation values, whereas intercropping with barley and pea decreased LER and harvested N fixation values. This suggests that the competitiveness of non-legume plants affects N fixation. They also studied the effect of available sulfur (S) on the intercropping of pea with barley and found that S treatment increased the LER values (Andersen *et al.* 2004; Andersen *et al.* 2007).

While our study was limited to row intercropping due to time and funding constraints, future research should explore alternative intercropping strategies and species combinations to enhance productivity.

Legumes are often noted to contain higher levels of minerals such as calcium and phosphorus compared to cereals (Winter & Gupta 1987). A separate study comparing sorghum, millet, maize, and rice found that brown cowpea had a higher ash content (Kalu *et al.* 2022). The ash content of cereals was generally lower than that of legumes (8.48% maize, 9.11% sorghum), except for guar (8.45%). As expected, intercropping generally increased ash content compared to cereal monocultures, except for the maize + guar intercrop.

In our study, the NDF content was similar for maize sole cropping compared to maize intercropped with legumes. Still, the mixed plots with sorghum had lower NDF values than the sole sorghum plots. The only exception was sorghum and guar intercropping, in which guar intercropping had the lowest yield with maize and sorghum mixtures. This suggests that intercropping legumes with sorghum could improve forage digestibility more than the intercropping of maize and other legumes. Previous studies have shown cereals have a high cellular wall content, resulting in low digestibility, whereas legumes have a lower cellular wall and higher digestibility (López *et al.* 2005; Javanmard *et al.* 2009).

We also observed an increase in protein content in silage compared to corresponding forages in sole cereal treatment. This may be due to sampling bias, where silage samples were unintentionally taken from kernel-rich areas. Nevertheless, as expected, silage from legumes exhibited higher protein content than that from cereal monocultures or intercrops, corroborating earlier studies (Geren *et al.* 2008; Zeng *et al.* 2022).

Silage pH values can vary depending on factors such as silage content, fermentation time, and bacterial activity, which indicates the success or failure of the silage (Muck 1988). The pH values decrease with the increasing lactic acid bacteria, which is important for the silage process. With little or no activity, pH values stay close to the neutral side, and alkaline silage indicates aerobic bacterial activity, which shows spoiled ensilement of fodder (Muck 1988). A study has reported little differences in pH levels between maize and soybean intercropping in comparison to sole treatments (Htet *et al.* 2017); however, we did not find any statistical differences between the pH values of the treatments, but we observed that guar had the highest pH levels, indicating lower lactic acid bacterial activity. Although we did not observe any pathogenic activity that would decrease the quality of silages, non-acidic ensilement could potentially lead to the spoiling of maize silages due to aerobic pathogenic bacterial activity (Rossi & Dellaglio 2007; Santos *et al.* 2013).

CONCLUSIONS

The study evaluated the effects of dry weight, land equivalency rate, and forage quality in cereal and legume cropping systems, focusing on guar as a forage crop in northwest Türkiye. Results showed that maize and sorghum monocultures had the highest DW yields, whereas guar performed poorly, indicating its limited suitability as a forage species under local conditions. All intercropping combinations produced LER values below 1.0, suggesting no yield advantage over sole cropping systems. Neutral detergent fiber content was higher in cereals than in legumes, but intercropping generally enhanced forage digestibility and protein content – except in mixtures involving guar. Silage quality metrics were broadly consistent with forage values, with legumes and certain intercropping systems (e.g., maize + cowpea, sorghum + cowpea) showing improved protein content compared to cereal monocultures. Guar's high gum content, poor adaptation, and low yield emphasize the need for breeding improvements before it can be recommended for practical use as silage or fodder in the region.

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