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Pearl Millet-Cowpea Forage Mixture Planting Arrangement Influences Mixture Yield and Nutritive Value in Semiarid Regions

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Abstract: Pearl millet (*Pennisetum glaucum* (L.) R. Br.) and cowpea (*Vigna unguiculata* L. Walp.) are well-adapted to semiarid regions. A two-year study at New Mexico State University's Rex E. Kirksey Agricultural Science Center at Tucumcari, NM, USA, compared monoculture pearl millet and cowpea with their mixtures in various row arrangements in four randomized complete blocks each year. Treatments included monoculture pearl millet (millet) and cowpea (cowpea), pearl millet and cowpea mixture planted in the same row (millet–cowpea), the species planted in alternate rows (millet–cowpea 1:1), the species planted in two adjacent rows alternating between species (millet–cowpea 2:2), and the species planted in four adjacent rows alternating between species (millet–cowpea 4:4), Mixture neutral detergent fiber (NDF) was reduced i millet–cowpea 1:1 and millet–cowpea 2:2 compared to millet (673, 662, 644, 646, and 666 g NDF kg^{-1} for millet, millet–cowpea, millet–cowpea 1:1, millet–cowpea 2:2, and millet–cowpea 4:4, respectively, LSD = 18, $p \leq 0.05$). Crude protein tended to be increased in millet–cowpea 2:2. Based on these results two rows of cowpea alternated with two rows of pearl millet, all spaced at 15 cm and harvesting for hay at the pearl millet boot stage likely optimizes the compromise of DM yield and the nutritive value of the mixture.

Keywords: pearl millet; cowpea; *Pennisetum glaucum*; *Vigna unguiculata*; forage; nutritive value

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1. Introduction

The demand for forages with high nutritive value to sustain livestock enterprises continues to increase globally in semiarid regions [1–3]. Over the past decade, the area planted with hay other than alfalfa in New Mexico, located in the semiarid Southwestern USA (SWUSA), has increased by over 17% [4]. Simultaneously, alfalfa acreage has decreased by over 37% [4] due to long-term drought [3]. Much of the increase in other hay was likely in the form of warm-season annual grasses (WSAG), such as sorghum–sudangrass (SxS; *Sorghum bicolor* × *S. sudanense* (Piper) Stapf.) [3,5,6] and pearl millet (PG; *Pennisetum glaucum* (L.) R. Br.) [3,6–10]. Both species are well adapted to semiarid regions and require less water than maize (*Zea mays*), which is generally grown for silage [3,7,11]. While SxS has long been used in the semiarid SWUSA, recognition of PG as a potential forage crop is increasing in the region [2,8] and elsewhere [12].

The nutritive value of SxS and PG is generally similar [2,13], although PG can have greater crude protein (CP) [7] and provides greater animal gains than SxS [9]. Nitrogen is required by WSAG to maximize productivity and nutritive value, particularly CP. Increasing the CP content of harvested forage by planting with a legume [5,11,14–18] also generally leads to increased crop productivity [19]. It also leads to reduced applications of nitrogen fertilizer [17,20] as well as a reduced need to supplement livestock rations with protein to meet animals' requirements [16]. Comparing FS and PG, Bhattarai et al. [7] reported that

PG generally yielded less dry matter (DM) than forage sorghum (FS; *Sorghum bicolor*) at 60, 75, and 90 days after planting (DAP). Either crop would be harvested for hay at 60–90 DAP, depending on the stage of maturity [18].

Cowpea (VU; *Vigna unguiculata* L. Walp.) is a well-adapted legume and is productive in semiarid regions, such as the irrigated areas of the semiarid SWUSA and similar environments [10,21], including in mixtures with FS [5,22]. However, its performance in mixtures with PG for forage under irrigation has not been thoroughly evaluated, despite PG-VU being commonly grown together throughout many parts of the world [20,23]. Iqbal et al. [16] reported that VU's more extensive root system made it more competitive with PG and FS in mixtures compared to guar (*Cyamopsis tetragonoloba* (L.) Taub.) and soybean (*Glycine max*). In that same study, they [16] also found that PG was highly competitive with FS and all legumes. Otherwise, Angadi et al. [22], reported that, although the legume proportion of FS-VU mixtures was lower than other legumes they tested, mixture yields were equal to monoculture FS. The total forage CP was increased in that study when the other mixtures either did not increase CP or compromised yield [22].

A main goal of mixing grasses and legumes for forage is to improve the nutritive value of the harvested product [24]. However, planting mixed species has also been evaluated, and was found to mitigate the influence of water scarcity and drought on crop production [24]. Yield is an important component, however, and land equivalency ratio (LER) is used as a measure of the efficacy of mixing species vs. growing them separately [1,16,20,25,26]. The LER of monocultures is 1.00; it should be $\geq$1.00 for the mixture to be feasible. Unpublished data under rainfed conditions from the location of the study to bedescribed indicated that planting PG and VU planted in the same row decreased DM yield compared to monoculture PG (Darapuneni & Lauriault, unpublished data). This is likely due to competition for soil resources [16].

Alternate rows are the predominant mixed cropping arrangement for grain and fodder production systems [24]. Previous research [20] found that VU responded to planting arrangement (0.76 m row spacing for monoculture, wide (alternating 6-row) or narrow (alternating 2-row) strip cropping, or 0.38 m alternate rows). In that study [20], there was a significant grain yield reduction in one of four site years and similar trends for numeric reductions in the other three site years, while PG grain yields were uninfluenced by planting arrangement. Islam et al. [17] reported a single year of data comparing alternating single rows of PG and VU with alternating two rows of one species with 1 row of the other, with the monocultures, all with 30 cm spacing. All mixtures had reduced DM yields of both species compared to their monocultures, as well as total forage yield; however, CP was increased by mixtures, even compared to monoculture VU. Other research has reported PG-VU mixture compatibility based on hill plantings, mostly for grain that are common elsewhere in the world [10,15,23,25–28]. Consequently, research evaluating the value of PG as forage on a global basis is encouraged [2,11,12,16], especially in mixtures used to improve forage yield and nutritive value [16]. The objectives of the present study were to evaluate various planting arrangements of PG and VU for forage DM yield and nutritive value.

2. Materials and Methods

2.1. Site Description, Climate, and Weather

Two identical studies were conducted over two years (2019, 2022) at the New Mexico State University Rex E. Kirksey Agricultural Science Center at Tucumcari, NM USA (35°12′0.5″ N, 103°41′12.0″ W; elev. 1247 masl). Research was interrupted due to COVID-19 restrictions in 2020 and the unavailability of irrigation water in 2021. The soils were Canez (fine-loamy, mixed, thermic Ustollic Haplargid) fine sandy loam in 2019 and Redona (fine-loamy, mixed, superactive, thermic Ustic Calciargids) fine sandy loam in 2022.

The climate in the region is Köppen–Geiger cold semiarid (BSk; http://www.cec.org/north-americanenvironmental-atlas/climate-zones-of-north-america/, accessed on 22 May 2023), which is characterized by cool, dry winters and warm, moist summers. Approximately 83% of the precipitation occurs as intermittent, relatively intense rainfall events from April through October [29]. Weather data were collected from a National Weather Service cooperative station located within 1 km of the study area (Table 1).

Table 1. Monthly and annual mean air temperatures, total precipitation and total irrigation at Tucumcari, NM USA, during 2019 and 2022 and the long-term (1905–2022) means.

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
						Temperature, °C							
2019	3.4	2.7	9.1	15.7	21.4	26.0	29.0	25.9	23.9	15.4	7.6	4.7	15.4
2022	3.8	5.7	8.6	14.3	17.4	23.9	27.8	27.6	25.0	12.3	3.2	5.7	14.6
Long-term	3.5	5.6	9.5	14.2	19.1	24.3	26.2	25.2	21.6	15.2	8.6	4.0	14.7
						Precipitation/irrigation, mm							
2019	4	5	19	0	3	54/140	48/165	86/57	1	50	7	0	278/362
2022	4	1	6	24	47	31/133	51/184	34/159	43	35	25	15	316/476
Long-term	10	12	19	28	47	47/---	67/---	68/---	39	34	17	16	398/---

2.2. Study Layout, Experimental Design, and Management

Pearl millet cv "Wonderleaf" and cowpea cv. "Iron and Clay" were used in this study. Clark and Myers [20] reported that seeding rates for legumes in mixtures should be greater than the grass component because the grass is generally more competitive for resources than the legume. Consequently, monoculture PG was sown at 28 kg ha^{-1} and monoculture VU was sown at 56 kg ha^{-1} and mixtures were planted to achieve half the seeding rate of each monoculture over the entire plot. Treatments (TRT) were monoculture PG (millet) and monoculture VU (cowpea) or mixtures planted in the same row (millet–cowpea), in alternate single rows (millet–cowpea 1:1), twin rows alternating (millet–cowpea 2:2), or four rows alternating (millet–cowpea 4:4)., with four randomized complete blocks. Plots (1.5 × 6.1 m) were planted on 11 June 2019 and 9 June 2022 into a previously prepared conventionally tilled flat seedbed. Each plot had eight 15 cm rows when fully planted by making two passes in opposite directions with a disk drill fitted with a single cone arranged to plant four rows at a time. For both monocultures, cowpea–millet, and millet–cowpea 4:4, four adjacent 15 cm rows on half the toolbar were planted on each pass. Species seed for millet–cowpea were combined in the same packet. For millet–cowpea 1:1, four 30 cm rows were distributed across the toolbar but offset by 7.5 cm. For millet–cowpea 2:2 two sets of two 15 cm rows were separated by a 45 cm gap, also offset by 7.5 cm. For millet–cowpea 1:1, millet–cowpea 2:2, and cowpea–millet 4:4, each species was planted on a separate pass. A 1.5% solution of Glyphosate [isopropylamine salt of N-(phosphonomethyl)glycine] was applied on 12 June 2019 and 11 June 2022 to control weeds that had emerged since the land preparation. On 21 July 2022, 2.34 L ha^{-1} sodium salt of bentazon [*(3-{1-melhylethyl)-1H-2,1,3-benzothiadiazin-4. (3H)-one 2.2*-dioxide)] was applied. On 30 June 2022, 31 kg N ha^{-1} was applied to the entire test area. No other pesticides or fertilizers were applied. Monthly irrigation amounts from June through August are reported in Table 1.

2.3. Measurements

On 29 August 2019 (81 DAP), and 24 August 2022 (76 DAP), a 0.37 m^2 area within each plot including all 8 planted rows was hand-clipped to near ground level to estimate forage yield. Species in mixtures were bagged separately. The harvested biomass was weighed, dried for 48 hr at 65 °C, and reweighed to determine the dry matter (DM) yield of each species and legume DM proportion. Land equivalency ratios were also calculated for every plot, where LER of mixtures = (mixture millet yield/monoculture millet yield in the replicate) + (mixture cowpea yield/monoculture cowpea yield in the replicate), and LER of monocultures = 1. Dried samples were ground to pass a 1 mm screen and delivered to Ward Laboratory (Kearney, NE USA) for CP, neutral detergent fiber (NDF), and 48-h NDF digestibility (NDFD) analysis via near infrared spectroscopy. The nutritive value of the mixture was calculated as the weighted mean of the component species.

2.4. Statistical Description

Data were combined across years and the DM yield and nutritive value of each species, as well as the total forage DM yield, legume proportion, LER, and nutritive value of the total forage harvested, were analyzed using the Mixed procedure of SAS [30]. Terms in the statistical model included the year and TRTs, as well as the year × TRT interaction, with replicates identified as unique within each year and considered random. When differences among TRTs or interactions were significant ($p \leq 0.10$), lsmeans were separated at $p \leq 0.10$ by the least significant difference using the PDMIX800 macro [31]. All unprotected pairwise comparisons ($p \leq 0.10$) generated via the mixed procedure [30] are also recognized when considered biologically important when the overall analysis returned results of $p \leq 0.20$. When the millet TRT is discussed relative to the other TRTs as a group, the group of mixed TRTs is called "mixtures."

3. Results and Discussion

3.1. Cowpea DM Yield and Nutritive Value

The results of the statistical analysis and year and TRT means for VU DM yield and nutritive value are presented in Table 2. The year effect was significant for all cowpea variables, likely due to climatic differences (Table 1). This is counterintuitive, however, because more water for growth (June through August) was available in 2022 than in 2019. Perhaps temperature changes over the three-month period influenced VU growth because, although July 2019 was warmer, reduced temperatures in August may have allowed for recovery while sustained temperatures in 2022 may have prevented recovery (Table 1).

Table 2. Dry matter (DM) yield and nutritive value of monoculture cowpea and cowpea in pearl millet–cowpea mixtures when irrigated with treated municipal wastewater at Tucumcari, NM USA in 2019 and 2022. Values are the lsmeans of four replicates within each year.

Effect	Yield		CP	NDF	NDFD
Year	Mg DM ha^{-1}		g kg^{-1}	g kg^{-1}	g kg^{-1}
2019	1.26		162	337	503
2022	0.54		187	428	576
Treatment (TRT)					
Cowpea	2.07	A	175	360	532
Millet–cowpea	0.51	B	179	393	552
Millet–cowpea 1:1	0.67	B	175	382	532
Millet–cowpea 2:2	0.51	B	168	386	547
Millet–cowpea 4:4	0.76	B	177	392	535
LSD, 0.10	0.31		21	37	49
			p-values		
Year	0.0009		0.0142	0.0026	0.0033
TRT	<0.0001		0.9187	0.4980	0.8860
Year × TRT	0.0821		0.4685	0.7110	0.7016

Cowpea, millet–cowpea, millet–cowpea 1:1, millet–cowpea 2:2, millet–cowpea 4:4, CP, NDF, NDFD, and LSD, 0.10 signify monoculture cowpea, the species mixture planted in the same row, the species planted in alternate rows, the species planted in two adjacent rows alternating between species, the species planted in four adjacent rows alternating between species, crude protein, neutral detergent fiber, NDF digestibility, in vitro true dry matter digestibility, and the least significant difference between means at $p \leq 0.10$, respectively. Treatment means within a column that have the same letter are not significantly different at the 10% alpha level.

In general, the VU DM yields in this study (Table 2) were considerably greater than those reported by [22] for VU (0.13 Mg DM ha^{-1}) grown with FS from a study conducted 80 km to the southeast of the present study location. Maman et al. [23] also reported rainfed VU post-grain harvest fodder yields averaging 0.48 Mg ha^{-1} when intercropped with PG with no difference among fertilizer N or P treatments. No other legume in the study by [22] attained > 0.32 Mg DM ha^{-1} when mixed with FS. Contreras et al. [5], however, reported VU DM yields of 4.5 Mg ha^{-1} when sown in close rows (20 cm) with FS or SxS. Ibrahim et al. [1] also reported VU DM yields of 1.95 Mg ha^{-1} when planted in close rows (30 cm) with maize. Comparable to the present study, Contreras et al. [14] reported 2.26 Mg ha^{-1} monoculture VU DM yields of approximately 77 DAP, which is similar to the harvest timing of the present study being 81 and 76 DAP for 2019 and 2022, respectively. But this is considerably less than that reported by [16] (7.26 Mg ha^{-1}) during Pakistan's rainy season.

The Year × TRT interaction was significant for VU DM yield because all TRT had reduced yield in 2022, except millet–cowpea, which did not change across years in VU yield. Millet–cowpea also had a lesser yield in 2019 than the other mixtures but was no different from them in 2022. For the main effect of TRT, VU yields were reduced when grown with PG in any planting arrangement (Table 2). In a study in the high-precipitation northeastern region of the USA [19], cowpea yields were suppressed by the grass component in multispecies mixtures including either or both of PG and SxS and sunn hemp (*Crotalaria juncea*), all of which grow tall. Nelson et al. [24] reported that VU growth can be sensitive to management and environmental influences, which could include competition between mixture components.

Greater VU CP in 2022 may be due to the N application made about 3 weeks after planting. Greater NDF in 2022 may be indicative of a temperature influence (Table 2). Soil type, which contributed to the difference between years, also influences VU nutritive value due to micronutrient status, as previously reported by [21]. In that study [21], VU grown in Redona soil had greater NDFD than VU grown in Canez soil, but the CP and NDF were the same. Individual plant weight and population also were no different (Lauriault unpublished data). Contreras et al. [14] reported that micronutrient deficiency symptoms in cowpea disappeared by 30 DAP. Nutritive value of VU was not influenced by TRT in the present study (Table 2). Additionally, no unprotected pairwise comparisons were significant at $p \leq 0.10$ for any VU variable. Ding et al. [10] found no difference in the CP content of VU grown in metal-contaminated and uncontaminated soils. Their [10] results (mean 90 g CP kg^{-1}) were considerably less than those measured for Cowpea in the present study (Table 2). Interestingly, though not significant, there is a noticeable difference between the VU CP of millet–cowpea 2:2 and all other TRT.

3.2. Pearl Millet DM Yield and Nutritive Value

The results of the statistical analysis and year and TRT means for PG DM yield and nutritive value are presented in Table 3. Unlike VU, the DM yield of PG was uninfluenced by the year. Machicek et al. [2] reported that warm June and July temperatures and cool August–September temperatures likely reduced PG yield in one of two years. That said, the temperatures during 2019 of the present study were warmer in June and July and sustained in August, compared to a slightly cooler June with warmer temperatures in July and August (Table 1). Similar to VU DM yield, the PG DM yields measured in this study as monoculture and in mixtures (Table 3) also were considerably greater than those reported by [22] for monoculture FS and FS mixed with legumes (7.38 Mg DM ha^{-1}). They were also greater than those measured by Machicek et al. [2] for PG harvested 90 DAP and by Oskey et al. [18] for a first harvest monoculture PG at early heading. The PG DM yields measured in this study as monoculture and in mixtures (Table 3) were slightly greater than those for monoculture PG reported by others [9,16]. Yields reported by [9] for PG were planted later than the present study and harvested at the season's end about 4 months after planting.

Compared to literature [2,7], the CP of PG in the present study was similar or greater and the NDF was greater (Table 3). The year effect was significant for CP and NDF, again, likely due to climatic differences (Table 1). That CP was greater in 2022 was again likely due to the N application that year. Ding et al. [10] found no difference in the CP content of PG grown in metal-contaminated and uncontaminated soils. Their [10] results (mean 110 g CP kg^{-1}) were similar to those measured for the millet TRT in the present study (Table 3). The lack of a year effect on PG NDFD is not well understood, but it may also have been a factor of increased soil N availability [32]. While micronutrient deficiencies have been observed for VU, FS, and SxS at the study location, no such symptoms were evident in the PG [6].

Table 3. Dry matter (DM) yield and nutritive value of monoculture pearl millet and pearl millet in millet–cowpea mixtures when irrigated with treated municipal wastewater at Tucumcari, NM USA in 2019 and 2022. Values are the lsmeans of four replicates within each year.

Effect	Yield	CP	NDF		NDFD	
Year	Mg DM ha^{-1}	g kg^{-1}	g kg^{-1}		g kg^{-1}	
2019	9.24	85	693		568	
2022	8.92	136	664		564	
Treatment (TRT)						
Millet	12.09	107	676	AB	577	A
Millet–cowpea	8.57	111	683	A	574	A
Millet–cowpea 1:1	6.99	110	678	AB	560	AB
Millet–cowpea 2:2	9.20	121	664	B	574	A
Millet–cowpea 4:4	8.55	105	693	A	546	B
LSD, 0.10	3.30	11	16		20	
		p-values				
Year	0.8006	<0.0001	0.0146		0.7592	
TRT	0.1508	0.1834	0.0611		0.0770	
Year × TRT	0.4292	0.4087	0.5312		0.2144	

Millet, millet–cowpea, millet–cowpea 1:1, millet–cowpea 2:2, millet–cowpea 4:4, CP, NDF, NDFD, and LSD, 0.10 signify monoculture pearl millet, the species mixture planted in the same row, the species planted in alternate rows, the species planted in two adjacent rows alternating between species, the species planted in four adjacent rows alternating between species, crude protein, neutral detergent fiber, NDF digestibility, in vitro true dry matter digestibility, and the least significant difference between means at $p \leq 0.10$, respectively. Treatment means within a column that have the same letter are not significantly different at the 10% alpha level.

Based on the overall analysis, the DM yield of PG was not influenced by growing with cowpea in any planting arrangement (Table 3). Unprotected ($p \leq 0.10$) pairwise comparisons, however, indicated that the PG DM yield of millet was greater than all mixtures, except millet–cowpea 2:2. Crookston et al. [8] reported that the PG DM yield was not influenced by row spacings of 0.76 or 0.19 cm. As also reported by [19], the PG yield in all mixtures, except millet–cowpea 2:2, was reduced in the present study (Table 3). Oskey et al. [18] attributed reduced PG DM yield in mixtures to reduced plant populations due to the seeding rate compared to the monoculture. In the present study, within-row seeding rates were equivalent across all treatments for both PG and VU, based on their respective monoculture seeding rates, except for millet–cowpea in which the seeding rates were 50% of the monoculture. However, that does not account for millet–cowpea 1:1 and millet–cowpea 4:4 having lesser PG DM yields than millet or millet–cowpea 2:2.

Similarly to DM yield, also based on the unprotected ($p \leq 0.10$) all pairwise comparisons, the CP content of the millet TRT was not different from any mixture, except millet–cowpea 2:2 (Table 3). This coincides with the numeric difference in VU CP show in Table 2 with millet–cowpea 2:2 having lesser CP. Perhaps at this planting arrangement, the N fixed by the VU is more accessible to the PG in the adjacent row due to less competition by PG compared to millet–cowpea and millet–cowpea 1:1 because each VU row is adjacent to only one PG row leading to greater CP (Table 3). Otherwise, the distance to VU by the two center PG rows of millet–cowpea 4:4 are too distant from the nearest VU rows to compete for fixed N.

The NDF of PG was equal, but numerically greater in all mixtures compared to millet, except for millet–cowpea 2:2, which had lesser NDF than millet, although non-significantly, based on the overall analysis (Table 3). Fiber components, such as NDF, are negatively correlated with digestibility [33,34]. Lauriault et al. [32] attributed greater digestibility of maize to increased N [34,35] and P [36] availability. While VU nodulation for N-fixation was not evaluated in the present study, previous research at this location indicates that the appropriate bacteria are ubiquitous, leading to natural nodulation. Kouyaté et al. [15] reported that well-nodulated VU could fix significant amounts of N depending on management rather than precipitation or irrigation [28]. They [15] also found that both PG and

VU promoted mycorrhizal activity, which Miller [36] reported would increase P availability. The increase in VU nodule numbers reported by Kouyaté et al. [15] was greatest for alternate row planting, compared to a denser hill planting arrangement, and the nodule efficiency was greatest for monoculture VU and the alternate row planting. They [15] did not evaluate a 2:2 row arrangement such as the one implemented in this study. Islam et al. [17] reported greater CP content in mixed PG-VU forage planted in alternating two rows of one species with 1 row of the other compared to alternating single rows of PG and VU and denser stands. In the present study, the even wider spacing of millet–cowpea 2:2 had greater PG CP than all other mixtures regardless of the proximity of the species (Table 3), based on the unprotected ($p \leq 0.10$) pairwise comparisons.

3.3. Total Forage DM Yield and Nutritive Value

The results of the statistical analysis and year and TRT means for Total DM yield and nutritive value are presented in Table 4. Because PG constituted the major component of the mixture, the results for total forage followed those for PG (Table 3). Only CP was influenced by the effect of year, which has been explained in relation to the TRT components. Planting arrangement TRT had no influence on DM yield, legume proportion, or LER (Table 4). Because of greater PG DM yields (Table 3), total DM yields in this study (Table 4) were considerably greater than those reported by [22] (7.55 Mg DM ha^{-1}) for monoculture FS and FS-legume mixtures. The values estimated for total forage CP in the present study (Table 4) were similar in 2022 to those reported for FS-VU by [5], but less in 2019. This was likely due to the application of N by [5] at the same location as the present study and in 2022, but not in 2019, during the present study. Contreras et al. [5] reported similar CP for a study 80 km to the south as 2019 of the present study when little to no N was applied in either study.

Table 4. Dry matter (DM) yield, legume proportion, land equivalency ratios, and nutritive value of the total yield of monoculture pearl millet and millet–cowpea mixtures when irrigated with treated municipal wastewater at Tucumcari, NM USA in 2019 and 2022. Values are the lsmeans of four replicates within each year.

	Yield	Legume	LER	CP	NDF		NDFD	
Year	Mg DM ha^{-1}	%	-----	g kg^{-1}	g kg^{-1}		g kg^{-1}	
2019	9.96	11.89	1.08	92	659		563	
2022	9.17	4.12	0.91	138	657		564	
Treatment (TRT)								
Millet	12.09	-----	1.00	107	673	A	577	A
Millet–cowpea	9.08	7.02	0.93	115	662	ABC	571	A
Millet–cowpea 1:1	7.66	10.52	0.90	118	644	C	554	AB
Millet–cowpea 2:2	9.71	6.58	1.01	123	646	BC	571	A
Millet–cowpea 4:4	9.31	7.91	1.14	112	666	AB	544	B
LSD, 0.10	3.33	3.89	0.29	11	18		19	
			p-values					
Year	0.5345	0.0434	0.1598	<0.0001	0.8774		0.9088	
TRT	0.2725	0.3415	0.6281	0.1468	0.0475		0.0513	
Year × TRT	0.4162	0.1991	0.4097	0.2930	0.6853		0.2383	

Cowpea, millet–cowpea, millet–cowpea 1:1, millet–cowpea 2:2, millet–cowpea 4:4, CP, NDF, NDFD, and LSD, 0.10 signify monoculture cowpea, the species mixture planted in the same row, the species planted in alternate rows, the species planted in two adjacent rows alternating between species, the species planted in four adjacent rows alternating between species, crude protein, neutral detergent fiber, NDF digestibility, in vitro true dry matter digestibility, and the least significant difference between means at $p \leq 0.10$, respectively. Treatment means within a column that have the same letter are not significantly different at the 10% alpha level.

No difference existed among TRT for total DM yield or LER (Table 4). Bybee-Finley et al. [19] also reported that mixture yields were generally similar to monoculture grass yields due to a reduction in grass yield coupled with yield contributions by other components of the mixture. Nelson et al. [24] reported that total crop grain yields of PG-UV were driven by PG yields and increased with water supply and that PG had to dominate the mixture to maximize productivity. Clark and Myers [20] found that the LER of alternate (0.38 cm) rows of PG and VU was no different from that of the monocultures, which was 1.00. Low legume DM yield (Table 2) and proportion (Table 4) likely influenced the results for LER by moderating the unprotected ($p \leq 0.10$) pairwise differences described for PG yield (Table 3). The legume proportion in the present study (Table 4) was considerably greater than the 0.3% reported for VU mixed with FS and SxS under semiarid rainfed conditions previously at the location of the present study and at the irrigated study 80 km to the south. But it was much less than the 60% with irrigation reported by [5] at the present study location or the 24% VU planted with maize under irrigation by [1]. In their review of sorghums and pennisetums, Hanna and Torres-Cardona [11] reported that FS, SxS, and PG yields are considerably reduced in rainfed semiarid regions unless irrigated. The productivity of annual legumes such as VU is also influenced by the amount of moisture available for growth [14]. Closer planting in the present study (15 cm) and the competitive nature of PG [19] may have been a factor in the DM contribution by UV (Table 2), as indicated by the legume proportion (Table 4).

While the overall analysis for CP indicated no difference among TRTs, the unprotected ($p \leq 0.10$) pairwise comparisons showed that millet–cowpea 1:1 and millet–cowpea 2:2 had greater CP than the millet TRT. Millet–cowpea 1:1 and millet–cowpea 2:2 were also the only mixtures that significantly reduced NDF compared to millet (Table 4). It is interesting that across variables for total forage, millet–cowpea 4:4 had the least positive influence on the nutritive value of the total forage. The CP and NDF measured in this study for PG and mixtures were greater than those reported by [22] for FS and FS-legume mixtures, but NDFD was similar. This is reflective of the typically greater nutritive value of PG compared to sorghum forages (FS and SxS) [9]. That said, Fontaneli et al. [13] reported no difference in CP among SxS and PG cultivars, measuring somewhat greater CP for both forages compared to the PG in the present study (Table 3). Oskey et al. [18] reported a negligible influence of PG-VU mixtures on total forage nutritive value other than CP, which generally led to a 10 g kg^{-1} increase over monoculture PG. They [18] stated that the 10 g kg^{-1} increase was unlikely to significantly influence animal response. The difference indicated between millet and millet–cowpea 2:2 by the unprotected ($p \leq 0.10$) pairwise comparisons in the present study was 16 g kg^{-1} (Table 4).

4. Conclusions

Based on the results of the present study and a review of the literature, two rows of VU alternated with two rows of PG, all spaced at 15 cm and harvesting for hay at the PG boot stage likely optimizes the compromise of DM yield and the nutritive value of the mixture. To accomplish this planting arrangement in a single pass, producers could use a grain drill equipped with a small-seeded legume box to plant the PG and plant the VU through the grain box with each box set for the species' appropriate seeding rate. Planter seedcups could be blocked off in each box with tape as needed to accomplish the desired alternating two-row seed distribution. Additional research could elucidate the mechanisms, such as the possibility that increased microbial activity by mycorrhizae and a less competitive 2:2 row arrangement could be more optimal for N uptake by grasses via rhizobial fixation.

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