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Sorghum [*Sorghum bicolor* (L.) Moench] and cowpea [*Vigna unguiculata* (L.) Walpers] intercropping improves grain yield, fodder biomass, and nutritive value

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Burkina Faso livestock feeding is characterized by a hot dry season fodder deficit, which affects animal performance and causes economic losses. To overcome this challenge, improving quality fodder production through the use of dual-purpose crops is a potential alternative. Hence, this study aimed at testing dual-purpose cultivars of sorghum and cowpea under monoculture and intercropping in the North Sudan zone in Burkina Faso. To do this, a "Mother and Baby trials" approach was adopted. The mother trial was designed as a randomized complete block with eight treatments (combinations of monoculture and intercropping systems for two cowpeas and two sorghum cultivars) and four replications during two cropping seasons (2019 and 2020) at the INERA research station in Saria. The on-farm "baby" trials involved 30 farmers during two cropping seasons (2019 and 2020) in four communes: *Koudougou*, *Poa*, *Nandiala*, and *Kokologo*. Data were collected on weed biomass and density, fodder biomass and grain yield, intercropping efficiency, and fodder nutritive value. The results of the mother trial showed that intercropping significantly ($p \leq 0.05$) reduced weed density and weed biomass. Sorghum cultivar *Ponta Negra* had the highest fodder biomass yield (10.05 kg DM/ha) while sorghum *Sariaso16* had the highest grain yield (4.42 kg/ha). Cowpea cultivar *KVx745-11P* had greater fodder biomass (4.72 kg DM/ha) than *Tiligré* (3.28 kg DM/ha) with similar grain yield (2.17 and 2.17 kg/ha). Intercropping was the most efficient land-use cropping system for fodder biomass and grain yield improvement both in mother and baby trials. For fodder nutritive value, cultivars *Sariaso16* and *Ponta Negra* had similar crude protein concentrations (ranging from 4.1 to 5.4%), and cowpea cultivar *KVx745-11P* haulms had greater crude protein (ranging from 16.9 to 20.3%). The use of *Ponta Negra* and *KVx745-11P* and *Sariaso16* and *KVx745-11P* under intercropping is likely to optimize grain and quality fodder production for crop-livestock farmers in the North Sudan zone.

KEYWORDS

crop-livestock system, cowpea, burkina faso, food-feed crops, sorghum

1 Introduction

Three main livestock systems used in Burkina Faso for ruminant production include extensive, semi-intensive, and intensive systems (Kristjanson et al., 2012). Local breeds of cattle (*Bos taurus*), sheep (*Ovis aries*), and goats (*Capra hircus*) are the dominant species. The semi-intensive system involves crop-livestock integration, which includes agro-pastoralists, sedentary crop-livestock farmers, and some peri-urban dairy farmers, and it is the most dominant system (MRA, 2015). In this system, livestock do not move too far from the production site because of the use of manure for soil fertility management and crop residues as livestock feed. Animals are grazed on natural pastures with a little feed complementation during the hot dry season using stored fodder such as legume haulms and cereal straws (Kiéma et al., 2019). The crop-livestock system enhances farmers' resilience to environmental risks and reduces conflicts for the use of natural resources (FAO, 2014; Sanfo et al., 2015; Kiéma et al., 2019).

The availability of feed resources in the hot dry season is the main constraint of this livestock system. The distances traveled for pasture by livestock are becoming longer because of the decline in pasture productivity and larger livestock herds (Boote et al., 2021). This induces a systematic use of crop residues as feed (Zampaligré et al., 2013; Amole & Ayantunde, 2016; Duncan et al., 2016). These crop residues are either directly grazed on farms after grain harvest or are collected and stored for later use during the hot dry season (Sanou et al., 2011; Cuvelier & Dufresne, 2014; FAO, 2014; Kiéma et al., 2019). Cereal straw (sorghum [*Sorghum bicolor* (L.) Moench], millet [*Pennisetum glaucum* (L.) R. Br.], and maize [*Zea mays* L]) have low crude protein concentrations (2-9%) compared to legume haulms such as cowpea [*Vigna unguiculata* (L.) Walpers], groundnut [*Arachis hypogaea* L], and Bambara bean [*Vigna subterranea* (L.) Verdc.] (Nantoumé et al., 2000; Palé, 2017; Zampaligré et al., 2021). The use of cereal straw and legume haulms respectively at 40% straw and 10 to 60% legume haulm in local and hybrid sheep diets provided a daily weight body gain of 92 to 206 g/day (Somda, 2001; Kiéma, 2008).

Forage crop production for livestock feed has been sparsely adopted by farmers despite the efforts of extension and research (Bayala et al., 2014; Boote et al., 2021). This reflects the lack of farmers' interest in those forages due to land tenure, cropping calendar, lack of technical skills, and seed availability issues (Kagoné, 2001; Bayala et al., 2014). Urbanization and demographic pressure on croplands favor food-feed cereal and legume cropping to the detriment of strict forages. This risk management strategy for small crop-livestock farmers benefits from crop residues as livestock feed and grains for food using the same unit of area (Sanfo et al., 2015). The majority of these crop residues used by farmers are from local cultivars with low nutritive value, in addition to their poor preservation causing a loss of nutritive value over time (Feyissa et al., 2014; Akakpo et al., 2020). Research on crop breeding has enabled improved food-feed cultivars that have good grain yield and fodder biomass with better quality (Cesar and Guiro, 2004). A recent study by Zampaligré et al. (2021) identified Sarioso16 for Sorghum and

KVX74511P for cowpea to be among the best bet food-feed cultivars for Burkina Faso's different agro-ecologies. Their introduction of appropriate cropping systems among the smallholder farmers is key for their adoption. Due to a lack of land area and poor soil fertility, smallholder farmers are increasing the use of intercropping of legumes and cereals for their crop production.

Intercropping is an arrangement of crops on the same plot and at the same time for complementarity in order to make the system more resilient to physico-chemical soil conditions (Matusso et al., 2014). Cereal and legume intercropping is more suitable for agro-pastoralists and sedentary crop-livestock farmers because of this dual need for food and feed for human beings and livestock, respectively (Nasir et al., 2019). The use of improved food-feed cultivars, which can fit into smallholder farmer's cropping calendar, is likely to provide greater benefits both for grains and fodder biomass (Mbaye et al., 2014; Louarn et al., 2016; Abera et al., 2021; Sanfo et al., 2023). Previous studies revealed that intercrop of maize-cowpea-sorghum-cowpea led to an increase in grain yield and fodder biomass in the range of 30-60% with better weed control (Matusso et al., 2014; Obulbiga et al., 2015; Coulibaly et al., 2017; Sanfo et al., 2023), and land equivalent ratios were greater in cowpea-maize intercropping systems (Sanfo et al., 2023). Considering the multiple benefits of using improved cultivars and appropriate cropping systems, we hypothesized that intercropping of best-bet sorghum and cowpea cultivars will provide greater grain yield and fodder biomass as well as quality fodder in smallholder farming systems in Burkina Faso. Thus, this study was conducted to assess the agronomic performance and fodder quality of sorghum Sarioso16 and cowpea KVX74511P in intercrop by comparison to monoculture in the crop-livestock system.

2 Materials and methods

2.1 Site description: location, rainfall, soil, vegetation, crop, and livestock systems

The mother study was conducted in Burkina Faso (Figure 1). A central trial was established at INERA (Institut de l'Environnement et de Recherches Agricoles) research station, Saria, located in Boulkiemde province and Nandiala commune located 80 km southwest of Ouagadougou with coordinates 12° 15' 57" N, 2° 08' 47" W. On-farm trials were conducted in four other communes, namely, Koudougou, Poa, Nandiala, and Kokologo within 40 km maximum radius from the Saria research station (Figure 1).

The climate is part of the Köppen climate zone B classification (Beck et al., 2018). The annual rainfall is 600-900 mm/year with 6 to 7 months of dry season lasting from November to May, with the rainy season occurring from June to October and the number of rainy days ranging from 60 to 68 a year. The monthly rainfall recorded in 2019 and 2020 in the study site is indicated in Figure 2. The average annual temperature in Saria is approximately 28°C, with a low temperature (12°C) occurring in December-January and a high temperature (40°C) in March-April.

Soils in the study sites are classified as Ferric Lixisol (Traoré, 2012). They are sandy-silty textured and have acid with low nitrogen, organic matter, available phosphorus, and available potassium contents (Table 1). The vegetation is dominated by agroforestry parklands and annual grasses. Main woody species are *Vitellaria paradoxa* C.F.Gaertn, *Faidherbia albida*, *Parkia biglobosa* Jacq, *Tamarindus indica* L., *Combretum nigricans* Lepr, and *Piliostigma reticulatum* (DC.) Hochst. The dominant grasses are *Andropogon gayanus* Kunth, *Loudecia togoensis* Hubb, and *Dactyloctenium aegyptium* Beauv (Ouédraogo, 2019; Zampaligré et al., 2021).

The cropping system is mainly rain-fed, extensive subsistence agriculture with small farms averaging 2 to 5 ha. It is dominated by cereal-based systems that integrate crops and livestock. The main crops are sorghum for cereals and groundnut and cowpea for legumes, accounting for 61, 69, and 56% of the national area sown for each crop type, respectively (MA, 2015). The dominant livestock systems are the integrated sedentary crop-livestock and agro-pastoral systems with local breeds of cattle, sheep, and goats (Mulumba et al., 2008). The livestock population in this zone is estimated at approximately 11,836,020 for small ruminants and 3,683,125 for large ruminants which represent 50 and 40% of the national flock, respectively (MRA, 2015).

2.2 Methodology

2.2.1 Conceptual framework

This research used the participatory “Mother and Baby trials” approach (Snapp, 2002). It has two steps which are central

(Mother) and on-farm (Baby) trials. The central trial is conducted in a village with a leader and innovative farmer or in a nearby research station. On-farm trials are farmers’ individual tests conducted by themselves under the research team’s supervision (Rusike et al., 2004; Gonsalves et al., 2005). Each farmer is a replication and linked to the central trial in order to compare a subset of innovations from the central trial (Snapp, 2002; Gonsalves et al., 2005). This approach allows farmers to evaluate the innovations that are most appropriate for their production system and resource endowment. It is an approach that initiates dialogue and collaboration between farmers, extension workers, policymakers, and researchers. In this way, rapid transformation and dissemination of the innovation are achieved through the snowball effect (Snapp, 2002).

2.2.2 Sampling method and plant materials

In 2018 - 2019, prior to the start of the experiment, a baseline survey with 250 farmers in the same four communes was conducted on fodder production in crop-livestock systems. A reasoned and stratified sampling approach was used regarding these criteria: (i) farmers’ willingness to conduct food-feed trials on at least 0.1 ha, (ii) farm accessibility, (iii) a minimum of three sheep availability for fattening trials, and (iv) gender with at least 30% of women participation. Based on the results of this study, 30 farmers (20 men and 10 women) were selected for a second survey on the evaluation of their preferences for crop species, cultivars, cropping systems, and fodder conservation methods (Sanfo et al., 2020). Following the results of these surveys, the same 30 farmers were chosen for this participatory research on food-feed crop production

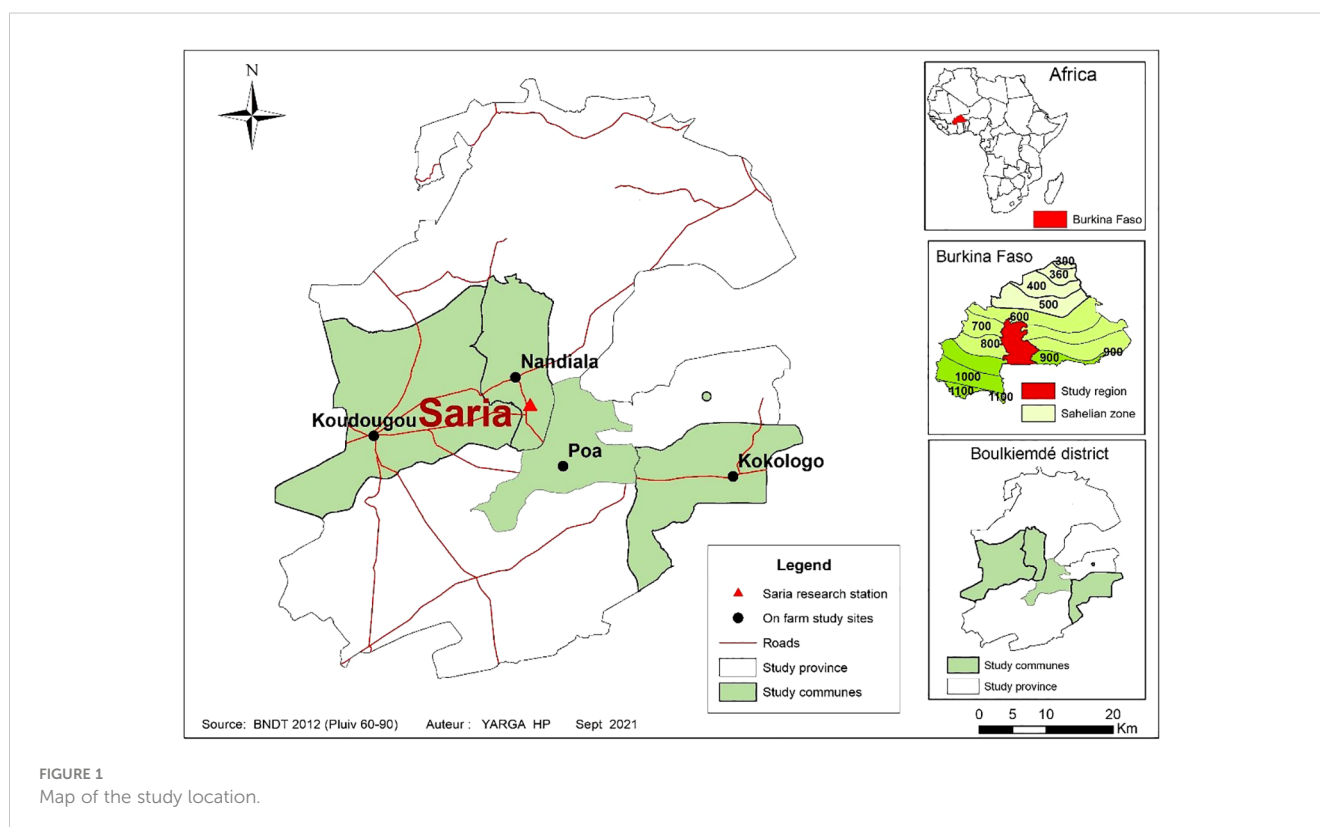


FIGURE 1
Map of the study location.

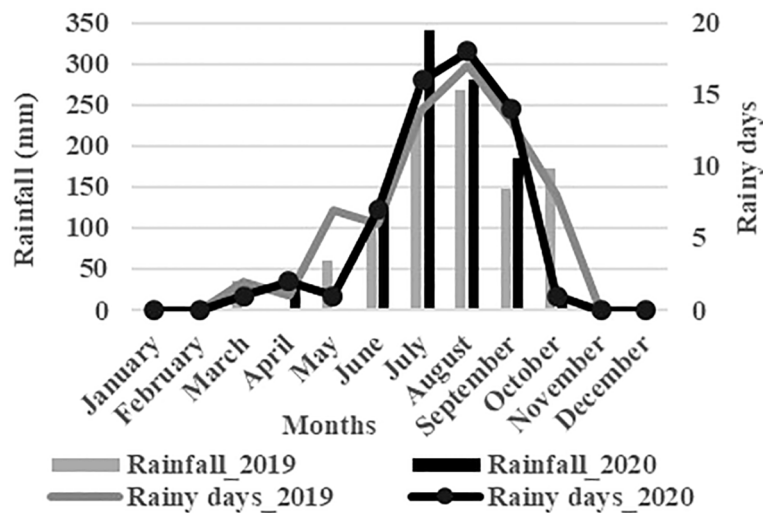


FIGURE 2 Monthly rainfall recorded in the study site in 2019 and 2020. Source, INERA FARAKOBA Pluviométries de l'année 2019 et 2020.

based on improved cultivars of sorghum and cowpea in intercropping systems.

The choice of cultivars was done according to the farmers' preferences (Sanfo et al., 2020) and included improved cultivars of sorghum (Sariaso16 and Ponta Negra) and cowpea (KVx745-11P and Tiligré). These cultivars were released by INERA (Institut de l'Environnement et de Recherches Agricoles) and EMBRAPA (Brazil) research. The INERA cultivars are the ones currently being promoted in Burkina Faso (Zampaligré et al., 2021). These cultivars are described in Table 2 (MRSI, 2014; Palé, 2017; Ramdé, 2019; Zampaligré et al., 2021).

2.2.3 Experimental design

The on-station trials were laid out as a completely randomized block design with eight treatments and four replications: two

sorghum cultivars, two cowpea cultivars, and two cropping systems (monocultures versus intercropping). The size of each subplot was 35 m² (7 m x 5 m). Below are the treatments:

- (T1) Sorghum Ponta Negra only;
- (T2) Sorghum Sariaso16 only;
- (T3) Cowpea Tiligré only;
- (T4) Cowpea KVx745-11P only;
- (T5) Sorghum Ponta Negra intercropped with cowpea Tiligré;
- (T6) Sorghum Ponta Negra intercropped with cowpea KVx745-11P;
- (T7) Sorghum Sariaso16 intercropped with Cowpea Tiligré; and
- (T8) Sorghum Sariaso16 intercropped with Cowpea KVx745-11P.

The on-farm trials involved 30 farmers with 0.1 ha as individual plot size. The farmers were all trained on farm agricultural practices and management on 14 and 15 June 2019 at Saria and Kokologo,

TABLE 1 Study sites soils' chemical characteristics.

Sample	pH H ₂ O	pH KCl	OM (%)	N (%)	C/N	Total P	P Bray1	Total K	K Av.	Clay (%)	Silt (%)	Sand (%)
						mg/kg						
A	4.78	4.06	0.46	0.02	10.5	90	3.9	1012	43	16.4	21.3	62.3
B	5.00	4.19	0.49	0.03	10.9	99	5.2	1063	45	17.2	19.4	63.5
C	4.73	4.33	0.43	0.02	10.4	94	4.9	952	37	15.4	20.8	63.7
D	4.95	4.07	0.53	0.03	10.7	99	6.2	1049	42	17.2	19.6	63.2
E	5.01	4.14	0.49	0.03	10.4	85	4.1	1011	41	17.4	17.7	64.9
F	4.90	4.12	0.43	0.02	10.6	83	4.3	975	42	16.7	19.1	64.2
G	5.01	4.18	0.39	0.02	10.4	88	3.5	976	43	16.4	17.2	66.4
H	5.09	4.22	0.43	0.02	10.5	87	4.7	1123	38	19.4	16.2	64.5
Mean	4.93	4.16	0.46	0.02	10.6	91	4.6	1020	41	17.0	18.9	64.1

OM, Organic Matter; N, Nitrogen; C, Carbon; P, Phosphorus; K, Potassium; Av, Available. *(Soils samples from study site in 2019. NB: Composite samples from 3 sampling points on the diagonal of each plot.

TABLE 2 Plant materials characteristics.

Species	Cultivar	Origin	Cycle (days)	Grain yield (t/ha)	Biomass (t DM/ha)	CP (%)	IVOMD (%)
Sorghum (<i>Sorghum bicolor</i> L. Moensh)	Ponta Negra Sariaso16	EMBRAPA INERA	130	0.4 - 3	5.3 - 10	5 - 5.5	48 - 49
			105-110	1.5 - 4.4	3 - 4.7	3.9 - 4.2	49 - 50
Cowpea (<i>Vigna unguiculata</i> L. Walpers)	Tiligré KVx745-11P	INERA INERA	70	1.5 - 2.3	2.5 - 3	13 - 15.4	64 - 65
			75	0.8 - 2.1	3 - 5	16 - 21.6	64 - 65

CP, Crude protein; IVOMD, In vivo organic matter digestibility (Source: Ramdé, 2019 and Ilboudo, 2020).

respectively. Then, they were provided with seed, fertilizer, and pest control products by the research team. Trial implementation was facilitated by a team of extension workers (crop and livestock agents) under the supervision of the research team. Three treatments/options were selected from the on-station trial and tested by 10 farmers per treatment, each farmer representing a replicate for each option:

(T1) *Sorghum Sariaso16* only;

(T4) *Cowpea KVx745-11P* only; and

(T8) *Sorghum Sariaso16* intercropped with *Cowpea KVx745-11P*.

The study was done during two consecutive rainy seasons in 2019 and 2020 on-farm and on-station.

2.2.4 Trial establishment and agronomic management

2.2.4.1 Mother trial established at Saria research station

The trial was implemented on fallow land that had cowpea as the previous crop after soil analysis (Table 1). Flat plowing with a tractor followed by leveling was done after rainfall prior to sowings from 5 to 12 July. These sowings were done manually from 15 to 19 and 18 to 22 July for sorghum in the 2019 and 2020 cropping seasons, respectively. For cowpea, they were done from 25 to 30 July and 28 July to 3 August in 2019 and 2020, respectively. Cowpea sowings were shifted approximately 10 days later from those of sorghum in order to optimize its grain yield and biomass (Mbaye et al., 2014). Spacing was 80 cm between rows and 40 cm between plants within rows for all cultivars. Thinning was done 15-20 days after sowing (DAS) to obtain the needed densities: 62,500 plants/ha for sorghum and cowpea in monocultures plots; and 20 833 plants/ha for cowpea and 41 666 for sorghum in the intercropping plots.

Weeding was done twice (15-20 and 25-35 DAS) followed by hoeing at 40-45 DAS. Cattle manure was applied in the first year at the rate of 5 t/ha before planting. Mineral fertilization was done annually with NPK (14-23-14) at a rate of 100 kg/ha for all sorghum and cowpea crops at 15-20 DAS, corresponding to 14 kg of nitrogen, 10 kg of potassium, and 12 kg of phosphorus (Zampaligré et al., 2021). In addition to NPK, only sorghum plots received 50 kg/ha of urea annually at 40-45 DAS (23 kg of nitrogen). For pest control, two treatments were done on cowpea plots with *Acetamiprid* 16g/l + *Indoxacarb* 30g/l at the rate of 1 l/ha at flowering and pod formation stages. Sorghum plots were treated specifically with *Lambda-cyhalothrin* 15 g/l + *Acetamiprid* 20 g/l against armyworm (*Spodoptera frugiperda*) attack.

2.2.4.2 On-farm trials (baby trials)

At the on-farm plots, previous crops included cowpea, Bambara bean, millet, and sorghum. Flat plowing with animal traction was done after rainfall followed by sowings. Plantings were done manually by farmers themselves in lines from 14 to 25 July for sorghum and from 22 July to 5 August for cowpea in 2019 and 2020. Planting spacing and thinning were performed following the method described above for the mother trial. Weeding and hoeing were done similarly as in the mother trial.

Mineral fertilization was done annually with NPK (14-23-14) at a rate of 100 kg/ha for all crops at 15 - 20 DAS. In addition to NPK, sorghum plots received 50 kg/ha of urea annually at 40 - 45 DAS. For pest control, two (02) treatments were done on cowpea plots with *Acetamiprid* 16g/l + *Indoxacarb* 30g/l at the rate of 1 l/ha at flowering and pod formation stages. Sorghum plots were treated specifically with *Lambda-cyhalothrin* 15 g/l + *Acetamiprid* 20 g/l against armyworm attack.

2.3 Data collection

2.3.1 Grain yield and fodder biomass evaluation

Grain yield (GY) was evaluated at sorghum panicle and cowpea pod maturity stages using the yield square method in 1m². Three yield squares were placed along the diagonal of each plot; sorghum panicles and cowpea pods were harvested separately and sun-dried for 10 days before being shelled/threshed and winnowed. The obtained grains were further sun-dried to constant weight and then weighed using a small scale (2 kg ± 5 g) to get grain yield for each crop. The fodder biomass was evaluated right after grain harvest (same day) using the same three yield squares. Fresh fodder weight in each square was taken using a 10 kg ± 10 g sensitive scale; a sample of 500 g from each square was collected and oven-dried at 105°C for 24 hours to determine fodder biomass on a dry matter basis (kg DM/ha).

2.3.2 Intercropping efficiency assessment

Three (03) parameters were used to assess the intercropping efficiency: (i) Weed Control (WC) based on Weed Density (WD) and Weed Biomass (WB), (ii) Land Equivalent Ratio (LER), and (iii) System Productivity Index (SPI).

WD was assessed at 70-80 DAS using three (03) yield squares of 1m² in each plot along the diagonal and all weeds within the square were counted.

>WB was evaluated using the same three yield squares and all the weeds in the square were collected and weighed. Then, samples were oven-dried at 105°C for 24 h. After dry matter determination, weed biomass was calculated by extrapolation (kg DM/ha).

>LER is the relative land area under sole crops required to produce the yield achieved in intercropping and determined by the following formula (Wiley, 1979 in N'Goran et al., 2011):

$$LER = (Y_a / Y_A) + (Y_b / Y_B)$$

Y_a and Y_b are the yields of sorghum and cowpea in intercropping, respectively. Y_A and Y_B are also the yields of sole cultures of sorghum and cowpea on a similar unit area, respectively.

SPI is the standardization of the yields of the secondary crop "b" into those of the main crop "a" in intercropping according to the formula (Agegehu et al., 2008; Khan et al., 2020): =

$$SPI = (R_s / R_c) \times Y_c + Y_s$$

R_s and R_c are the average yields of sorghum and cowpea in monoculture, respectively. Y_s and Y_c are also the average yields of sorghum and cowpea in intercropping, respectively.

The indexes WC, LER, and SPI were used to identify the relative advantages of intercropping, and their appropriate spatial arrangement is described in Table 3.

2.3.3 Fodder nutritive value assessment

Two composite samples of 500 g of the whole plant (stems + leaves) were taken in each plot replication from the three yield squares on the same day of fodder biomass and grain yield assessment. Samples were pre-dried and then shade-dried and ground at 1 mm size. The Near Infrared Spectrometry (NIRS)

method was used for nutritive value analysis. Sample spectra were collected using the NIRS FOSS DS 2500 F and the *International Livestock Research Institute (ILRI) Global Mixed Feed* calibration was used to predict the nutritional quality. Nutritive value parameters assessed were: Dry Matter (DM), ash, Crude Protein (CP), Neutral Detergent Fiber (NDF), Acid Detergent Fiber (ADF), Acid Detergent Lignin (ADL), Metabolizable Energy (ME), and *In Vitro* Organic Matter Digestibility (IVOMD).

2.4 Data analysis

Data entry as well as tables and graphs were created using Excel. The general linear model of SPSS Statistic 20.0 was used for performing an analysis of variance considering all factors as fixed effects. Three-way ANOVA (year, cultivar, and cropping system) was applied to the on-station trial data and two-way ANOVA (cropping system and year) for on-farm trial data. One-way ANOVA was performed for fodder nutritive value analysis. Mean comparisons for significant effects were done using the LSD (Least Significant Difference) test and significance was declared at $p \leq 0.05\%$.

3 Results and discussion

3.1 Results

3.1.1 Grain yield, fodder biomass, weed density, and biomass

On-station (mother trial) data analysis of variance (ANOVA) showed that the cultivar effect was significant for fodder biomass, weed density, and biomass of cowpea, while it was only significant for grain yield and fodder biomass of sorghum (Table 4). The cropping system effect was significant for grain yield and fodder biomass for cowpea and sorghum but was significant for only weed density and biomass for sorghum (Table 4).

For the on-farm trial, only the cropping system effect was significant for sorghum grain yield and fodder biomass (Table 4).

3.1.2 Cropping systems and weed control

Low weed density (12 plants/m²) and low weed biomass (36.2 kg DM/ha) were obtained with cowpea KVx74511P in monoculture (Table 5). In addition, regardless of sorghum cultivar, weed density and biomass were lower in the intercropping system than in monoculture except for Sarioso16 weed biomass in its intercropping with Tiligré (Table 5).

3.1.3 Grain yield and fodder biomass of tested cultivars

Sorghum Sarioso16 had the greatest grain yield for the on-station trial (4415 kg/ha) and also had a high yield in the on-farm trials (3458 kg/ha) across two rainy seasons (2019 and 2020) (Table 6). Ponte Negra had the highest fodder biomass yield (10051 kg DM/ha). For

TABLE 3 Description of indexes used for intercropping efficiency assessment.

Index	Definition	Interpretation	Reference
WC	Weed density (WD) and biomass (WB) per unit area of land	Comparison of different weed densities and biomass regarding cropping systems	Ekeleme et al., 2019
LER	Land area under sole crops required to produce the yields achieved in intercropping	An LER of 1 indicates equal advantages for intercropping and monoculture; a value more than 1 means more advantage for intercropping than for monoculture; and an LER less than 1 means less advantage for intercropping than for monoculture	N'Goran et al., 2011
SPI	Standardization of the yields of the secondary crop "b" into those of the main crop "a" in the intercropping	Comparison between yields of the main crop in monoculture and the one in intercropping after standardization	Khan et al., 2020

TABLE 4 ANOVA results for grain yield, fodder biomass, weeds density, and biomass for cowpea and sorghum (2019 and 2020).

Trial	Source of variation	Cowpea				Sorghum			
		Grain Yield (kg ha ⁻¹)	Fodder Biomass (kg DM ha ⁻¹)	Weed Density (plant/m ²)	Weed Biomass (kg ha ⁻¹)	Grain Yield (kg ha ⁻¹)	Fodder Biomass (kg DM ha ⁻¹)	Weed Density (plant/m ²)	Weed Biomass (kg ha ⁻¹)
Mother trial (On Station)	Year	NS	NS	NS	NS	NS	NS	NS	NS
	Cultivar	NS	*	**	*	*	*	NS	NS
	Cropping system	***	***	NS	NS	***	***	*	*
	Year*cultivar	NS	NS	NS	NS	NS	NS	NS	NS
	Year*cropping system	NS	NS	NS	NS	NS	NS	NS	NS
	cultivar*cropping system	NS	*	NS	NS	***	**	NS	NS
	Year*cultivar*cropping system	NS	NS	NS	NS	NS	NS	NS	NS
Baby trials (On Farm)	Year	NS	NS	-	-	NS	NS	-	-
	Cropping system	NS	NS	-	-	***	***	-	-
	Year* Cropping system	NS	NS	-	-	NS	NS	-	-

*=p ≤ 0.05, **=p ≤ 0.01, ***=p ≤ 0.001, NS, Not significant at p ≤ 0.05. DM, Dry Matter.

cowpea cultivars in the on-station trials, KVx745-11P and Tiligré had similar grain yield (2116-2169 kg/ha), while KVx745-11P fodder biomass (4721 kg DM/ha) was higher than Tiligré (3283 kg DM/ha). In the on-station trials, greater fodder biomass was obtained for monoculture of sorghum cultivars compared to intercropping with cowpea. This appeared to repeat for the on-farm trials but was not significant because of large farm-to-farm variability. For intercropping in the on-station trial, the fodder biomass of Ponte Negra was greater than for Sarioso16 regardless of cowpea cultivars used, but Sarioso16 had greater grain yield regardless of cowpea cultivars. For cowpea cultivars tested on-station, grain yield and

fodder biomass were greater in monoculture than for intercropping. However, no significant differences were found between the two cultivars for grain yield and fodder biomass in intercropping.

3.1.4 Intercropping efficiency for land use, grain yield, and fodder biomass

LER and SPI were used to assess land use, grain yield, and fodder biomass efficiencies regarding cropping systems (Table 7). Sorghum and cowpea intercropping LERs for fodder biomass (1.01-1.37) and grain yield (1.02-1.65) were greater than one. Sorghum Sarioso16 intercropped with cowpea Tiligré had the greatest LER for fodder biomass, while the highest LER was obtained for Ponta Negra intercropped with Tiligré for grain yield.

Intercropping SPIs were higher than those of the corresponding sorghum cultivar (main crop) monoculture evaluated. The highest SPI values for fodder biomass were obtained by Ponta Negra intercropped with either cowpea cultivar (10539 and 12587). In terms of grain yield, Sarioso16 intercropped with cowpea had the highest index (4517 - 5438) regardless of the cowpea cultivar.

3.1.5 Sorghum straw and cowpea haulm nutritive value

Sarioso16 had greater fodder DM, NDF, and ADL, and lower fodder ME and IVOMD compared to Ponta Negra regardless of the cropping system (monoculture and intercropping) and cowpea cultivar used in intercropping (Table 8). Nevertheless, the two sorghum cultivars had similar CP (4.1 - 5.1%) concentrations regardless of the cropping system and cowpea cultivar used in intercropping. There were differences between the nutritive value of sorghum fodder in monoculture and intercropping. Sarioso16 intercropped with cowpea KVx745-11P had lower fodder ADF compared to Sarioso16 in monoculture. Ponta Negra intercropped with Tiligré had greater ME than in monoculture.

TABLE 5 Effect of cropping systems on weeds biomass and density for the mother trial (average of 2019 and 2020).

Cropping system	Cultivar	Density (plant/m ²)	Biomass (kg DM/ha)
Monoculture	Ponta Negra	60 ^a ± 41	115.2 ^a ± 97
	Sarioso16	67 ^a ± 52	137.0 ^a ± 63
	Tiligré	46 ^{ab} ± 47	76.5 ^{ab} ± 44
	KVx745-11P	12 ^c ± 10	36.2 ^c ± 40
Intercropping	Ponta Negra and Tiligré	32 ^b ± 12	80.7 ^{ab} ± 40
	Ponta Negra and KVx745-11P	28 ^{bc} ± 22	40.7 ^c ± 22
	Sarioso16 and Tiligré	58 ^{ab} ± 26	117.3 ^a ± 24
	Sarioso16 and KVx745-11P	32 ^b ± 9	87.3 ^{ab} ± 80
Statistic	F	2.84	3.28
	P-Value	0.013	0.005

Values with the same letters in the same column are equal (LSD; P = 0.05).

TABLE 6 Sorghum and cowpea grain yield and fodder biomass regarding the interaction between cropping systems and cultivars across two years.

	Cropping system	Fodder biomass (kg DM/ha)		Grain yield (kg/ha)	
		Sorghum	Cowpea	Sorghum	Cowpea
Mother trial (On-station)	Sorghum Ponta Negra monoculture	10051 ^a ± 1169	–	1863 ^c ± 934	–
	Sorghum Sariasso16 monoculture	4447 ^{bc} ± 407	–	4415 ^a ± 593	–
	Cowpea Tiligré monoculture	–	3283 ^{ab} ± 556	–	2116 ^a ± 457
	Cowpea KVx745-11P monoculture	–	4721 ^a ± 1550	–	2169 ^a ± 341
	Ponta Negra intercropped with Tiligré	5735 ^b ± 838	2238 ^b ± 405	2015 ^c ± 325	1193 ^b ± 391
	Ponta Negra intercropped with KVx745-11P	6230 ^b ± 1276	2025 ^b ± 517	1345 ^d ± 309	834 ^b ± 224
	Sariasso16 intercropped with Tiligré	2832 ^c ± 388	2420 ^b ± 380	2365 ^{bc} ± 145	1207 ^b ± 241
	Sariasso16 intercropped with KVx745-11P	2313 ^c ± 434	2288 ^b ± 386	2315 ^{bc} ± 457	1082 ^b ± 475
Baby trials (On-farm)	Sariasso16 only	6414 ^b ± 2817	–	3458 ^{ab} ± 1175	–
	KVx745-11P only	–	3860 ^{ab} ± 1888	–	1268 ^b ± 635
	Sariasso16 intercropped with KVx745-11P	3084 ^{bc} ± 1232	3251 ^{ab} ± 1265	2394 ^{bc} ± 1089	1116 ^b ± 401
Statistic	F	2.21	2.21	4.48	3.58
	P-Value	0.035	0.039	0.000	0.002

Values with the same letters in the same column are equal (LSD; P = 0.05).

Cowpea fodder ME and IVOMD were lower in intercropping than their monoculture regardless of sorghum cultivar used for the intercropping. Cowpea Tiligré fodder ash, ADF, and ADL were greater in intercropping than in monoculture regardless of the companion sorghum cultivar in intercropping (Table 9). Cowpea KVx745-11P intercropped with sorghum Sariasso16 had greater fodder CP than in monoculture, while Tiligré intercropped with Ponta Negra had lower CP compared to monoculture. For cowpea cultivars, KVx745-11P had greater ash (10.6-12.5%) and CP (17-20%) regardless of the cropping system.

3.2 Discussion

3.2.1 Sorghum and cowpea intercropping reduced weed density and biomass

Cowpea and sorghum intercropping reduced weed density and biomass compared to sorghum monocultures. KVx745-11P was the most effective cowpea cultivar to improve weed control. Cowpea Tiligré was less effective, possibly because it is a semi-erect plant that also exhibits defoliation in the later stages of the reproductive period. This cultivar may be more sensitive to dry spells explaining

TABLE 7 Cropping systems System Productivity Index and Land Equivalent Ratio (mother and baby trials).

Trial	Treatment	LER For forage biomass	LER For grain yield	SPI For forage Biomass	SPI For grain yield
Mother trials (On- station)	Tiligré monoculture	1.00	1.00	3283	2116
	KVx745-11P monoculture	1.00	1.00	4721	2169
	Ponta Negra monoculture	1.00	1.00	10051	1863
	Sariasso16 monoculture	1.00	1.00	4447	4415
	Ponta Negra intercropped with Tiligré	1.25	1.65	12587	3064
	Ponta Negra intercropped with KVx745-11P	1.05	1.11	10539	2061
	Sariasso16 intercropped with Tiligré	1.37	1.11	6110	4883
	Sariasso16 intercropped with KVx745-11P	1.01	1.02	4468	4517
Baby trials (On-farm)	KVx745-11P monoculture	1.00	1.00	3860	1268
	Sariasso16 monoculture	1.00	1.00	6414	3458
	Sariasso16 intercropped with KVx745-11P	1.32	1.57	8486	5438

TABLE 8 Proximate composition and *in vitro* digestibility of the dry matter of sorghum straws from the mother trial.

Cropping system		DM (%)	Ash (%)	CP (%)	NDF (%)	ADF (%)	ADL (%)	ME (MJ/kg)	IVOMD (%)
Monoculture	Ponta Negra	91.7 ^b ± 0.3	5.7 ^b ± 0.9	4.1 ± 1.5	65 ^b ± 2	37 ^c ± 2	4.7 ^b ± 0.1	7.8 ^{ab} ± 0.2	51 ^a ± 2
	Sariasso16	92.3 ^a ± 0.3	6.2 ^b ± 1.0	4.5 ± 0.8	68 ^{ab} ± 2	40 ^{ab} ± 3	6.4 ^a ± 0.4	7.3 ^b ± 0.3	48 ^b ± 1
	Sariasso16*	92.3 ^a ± 0.2	8.6 ^a ± 1.0	4.4 ± 1.1	70 ^a ± 2	43 ^a ± 2	6.3 ^a ± 0.7	6.9 ^{bc} ± 0.3	46 ^b ± 2
Intercropping	Ponta Negra and KVx745-11P	91.7 ^b ± 0.8	5.5 ^b ± 0.9	5.1 ± 1.5	65 ^b ± 3	37 ^c ± 5	5.2 ^b ± 1.4	7.6 ^{ab} ± 1.0	51 ^a ± 3
	Sariasso16 and Tiligré	92.6 ^a ± 0.3	6.6 ^b ± 1.5	4.8 ± 0.6	68 ^{ab} ± 3	41 ^{ab} ± 2	6.2 ^a ± 0.4	7.2 ^b ± 0.4	47 ^b ± 2
	Sariasso16 and KVx745-11P	92.4 ^a ± 0.1	7.6 ^{ab} ± 1.17	5.4 ± 1.2	66 ^{ab} ± 1	40 ^b ± 1	6.1 ^a ± 0.6	7.2 ^b ± 0.2	48 ^b ± 1
	Ponta Negra and Tiligré	91.7 ^b ± 0.4	5.1 ^b ± 0.9	5.1 ± 0.7	64 ^b ± 2	35 ^c ± 1	4.7 ^b ± 0.9	8.1 ^a ± 0.2	52 ^a ± 1
	Sariasso16 and KVx745-11P*	92.2 ^a ± 0.4	8.8 ^a ± 1.1	4.9 ± 1.1	67 ^{ab} ± 4	42 ^a ± 4	6.1 ^a ± 0.6	7.0 ^{bc} ± 0.3	47 ^b ± 2
Statistic	F	4.26	10.10	0.73	3.69	7.34	4.56	5.30	3.94
	P-Value	0.002	0.000	0.64	0.004	0.000	0.001	0.000	0.003

*= On-farm trials. Values with the same letters in the same column are identical (LSD; p ≤ 0. 05).

DM, Dry Matter; CP, Crude Protein, NDF, Neutral Detergent Fiber; ADF, Acid Detergent Fiber; ADL, Acid Detergent Lignin; EM, Metabolizable Energy; IVOMD, In Vitro Organic Matter Digestibility.

the loss of leaves unfavorable to the process of smothering weeds (Ekeleme et al., 2019). Both sorghum cultivars were effective in controlling weeds, but Ponta Negra was somewhat more effective in relation to its great capacity to produce aerial biomass with large and long leaves that could play the role of smothering weeds. Allelopathy associated with competition for light, water, and mineral elements would influence weed photosynthesis, inducing a decrease in their growth (Kruk et al., 2006; Cordeau et al., 2015). Crop shading also creates unfavorable conditions for weed seed germination (Barro et al., 2016; Benider, 2018). Other authors also showed that cowpea intercropping with sorghum or maize reduced weed density and biomass compared to cereal monocultures and manual weeding (Bybee and Ryan, 2018; Ekeleme et al., 2019). Better weed control would lead to increased grain yield and fodder biomass and save time for plot weeding (Odhinambo and Ariga,

2001; Muhammad et al., 2013). Intercropping could therefore be an acceptable biological weed control approach in cropping systems instead of using chemical weed management strategies.

3.2.2 Grain yield and fodder biomass improvement

Sorghum Sariasso16, being a genetically improved grain type, had the greatest grain yield as expected. By comparison, Ponta Negra being a forage-type sorghum had the greatest fodder biomass. Those cultivars were selected as the best bet for this experiment based on prior research in Burkina Faso (Zampaligré et al., 2021). For cowpea, KVx745-11P and Tiligré had similar grain yield, while KVx745-11P fodder biomass was greater than for Tiligré, which is consistent with its spreading vegetative growth habit (Ramdé, 2019). The results are influenced by the combined effect of genetic, agro-climatic factors and various steps

TABLE 9 Proximate composition and *In vitro* digestibility of the dry matter of cowpea haulms tested from the mother trial.

Cropping system		DM (%)	Ash (%)	CP (%)	NDF (%)	ADF (%)	ADL (%)	ME (MJ/kg)	IVOMD (%)
Monoculture	Tiligré	91.1 ± 0.1	8.8 ^c ± 1.7	15 ^{bc} ± 0.8	36 ^{bc} ± 2	23 ^c ± 2	4.6 ^c ± 0.3	10.0 ^a ± 1.0	67 ^a ± 0.5
	KVx745-11P	91.1 ± 0.3	10.6 ^b ± 0.7	17 ^b ± 1.4	36 ^{bc} ± 1	28 ^b ± 1	5.1 ^{bc} ± 0.1	9.8 ^a ± 1.0	67 ^a ± 0.7
	KVx745-11P*	91.1 ± 0.2	12.5 ^a ± 1.3	18 ^b ± 1.6	41 ^a ± 4	37 ^a ± 4	6.5 ^a ± 0.9	8.7 ^c ± 0.4	59 ^c ± 2.6
Intercropping	KVx745-11P and Ponta Negra	91.3 ± 0.3	11.1 ^b ± 1.0	17 ^b ± 2.2	35 ^{bc} ± 2	30 ^b ± 1	5.4 ^{bc} ± 0.4	9.5 ^b ± 0.1	65 ^{ab} ± 0.8
	Tiligré and Sariasso16	91.4 ± 0.2	9.9 ^{bc} ± 0.3	15 ^{bc} ± 0.2	34 ^c ± 4	27 ^{bc} ± 3	5.4 ^{bc} ± 0.7	9.7 ^b ± 0.2	66 ^{ab} ± 1.5
	KVx745-11P and Sariasso16	91.2 ± 0.2	10.6 ^b ± 0.2	20 ^a ± 2.6	37 ^b ± 2	31 ^b ± 1	5.8 ^{bc} ± 0.3	9.6 ^b ± 0.4	66 ^{ab} ± 2.4
	Tiligré and Ponta Negra	91.1 ± 0.1	9.9 ^{bc} ± 1.5	13 ^c ± 1.0	37 ^b ± 2	28 ^b ± 2	5.5 ^b ± 0.3	9.5 ^b ± 0.2	64 ^{ab} ± 1.1
	KVx745-11P and Sariasso16*	91.2 ± 0.3	13.2 ^a ± 0.8	19 ^a ± 1.5	39 ^{ab} ± 2	38 ^a ± 2	6.1 ^a ± 0.5	8.6 ^c ± 0.3	60 ^c ± 1.6
Statistic	F	1.53	9.23	7.93	4.18	21.12	6.05	22.41	18.05
	P-Value	0.19	0.001	0.001	0.002	0.001	0.001	0.001	0.001

*= On-farm trials. Values with the same letters in the same column are identical (LSD; p ≤ 0. 05).

DM, Dry Matter; CP, Crude Protein, NDF, Neutral Detergent Fiber; ADF, Acid Detergent Fiber; ADL, Acid Detergent Lignin; EM, Metabolizable Energy; IVOMD, In Vitro Organic Matter Digestibility.

of crop management (Coulbaly et al., 2012; Alidu et al., 2013; Coulbaly et al., 2020; Ouédraogo et al., 2021). Some authors identified Sariaso16 and Ponta Negra as the best cultivars performing well in the North Sudan zone of Burkina Faso respectively for grain yield and fodder biomass even though yields were lower compared to the results presented in this study (Zampaligré et al., 2021).

These results highlight that the choice of cultivar by farmers would depend on their primary production objective (grain or biomass). Sariaso16 and cowpea KVx745-11P cultivars were locally developed at Saria (North Sudan zone of Burkina Faso) by INERA for food and food-feed purposes, respectively, even though Sariaso16 has acceptable fodder biomass (Kondombo, 2001; Palé, 2017; Zampaligré et al., 2021). Sorghum Ponta Negra (EMBRAPA-Brazil) and cowpea Tiligré (INERA) cultivars were released for fodder production and grain purposes, respectively, with more or less intermediate performances for food (Palé, 2017; Zampaligré et al., 2021).

This study was performed in the 2019 and 2020 cropping seasons which were wet years (rainfall deviating from the 1990-2020 series) (Figure 3). The genetic effect and pedo-climatic conditions influenced crop cultivar performance. Indeed, water and soil fertility which were the most limiting factors of crop production affected crop genetic potential (Alidu et al., 2013; Lalsaga and Drabo, 2017). Greater grain yield and fodder biomass were associated with rainy years, moderate temperatures, and normal rainfall distributions with better soil fertility conditions (Ishiyaku and Aliyu, 2013; Kihindo et al., 2015; Obulbiga et al., 2015). Hence, location-specific characteristics and production objectives were important in cultivar selection and recommendation (Zampaligré et al., 2021).

3.2.3 Sorghum and cowpea intercrop improves grain and fodder biomass yield

Sorghum and cowpea intercropping LERs for fodder biomass and grain yield were usually greater than one. This showed an

advantage in terms of total production for intercropping. The capacity production of one sorghum stand grown with cowpea was higher than the one of sorghum or cowpea stands grown in monoculture. Thus, sorghum and cowpea intercropping would save 1 to 65% of land use for the overall production (grain and biomass) compared to the monoculture of each crop. This would lead to an increase in grain yield and fodder biomass in the same order of magnitude (Obulbiga et al., 2015; Akanza & N'guessan, 2017; Diatta et al., 2019). The SPI values for sorghum-cowpea intercropping were also higher than those of the corresponding sorghum monocultures in the intercropping (main crop). Then, the conversion of grain yield and fodder biomass of the secondary crop (cowpea) to the main crop (sorghum) in the intercropping are all higher than those of the corresponding sorghum monocultures. The best fodder biomass indexes (10539 and 12587) were obtained by the intercropping of Ponta Negra and KVx745-11P, respectively; Ponta Negra and Tiligré. For grain yield, the best values of SPI (4517 and 4883) are recorded respectively by the intercropping of Sariaso16 and KVx745-11P; Sariaso16 and Tiligré. These results showed the advantages of grain yield and fodder biomass production with sorghum-cowpea intercropping and were corroborated by other authors (Agegnehu et al., 2008; Khan et al., 2020). These comparative advantages can be explained by the beneficial relationships of complementarity between the two associated crops for the use of nitrogen resources, space (very different aerial architectures), and growth peaks (Justes et al., 2014; Barro et al., 2016; Louarn et al., 2016). Shifting the sowing date between the two associated crops reduces the interspecific competition (Mbaye et al. (2014). Indeed, the symbiotic fixation of atmospheric nitrogen by cowpeas limits its competition with sorghum, which uses mineral nitrogen in the soil. In addition, a greater interception of radiation and a reduction in weed incidence by intercropping

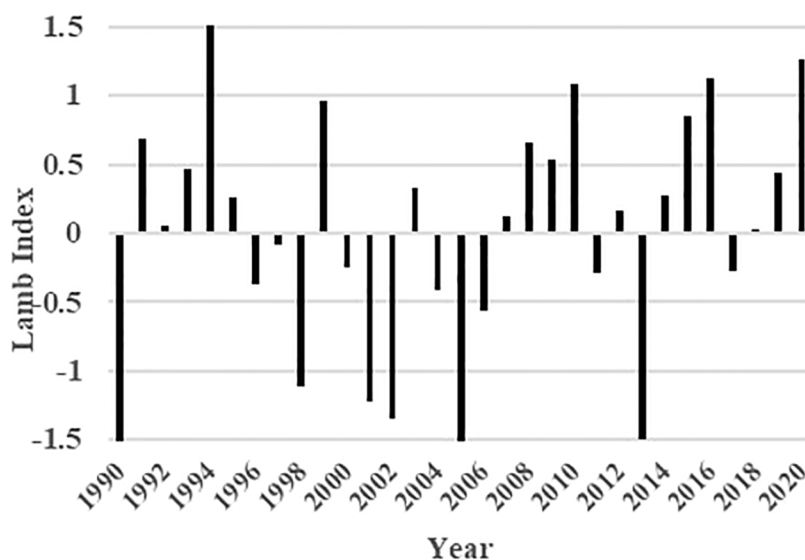


FIGURE 3
Saria rainfall Lam Index (1990-2020).

could further explain these advantages (Muhammad et al., 2013). Sorghum and cowpea intercropping is a very efficient and appropriate cropping system to optimize fodder biomass production and grain yield for crop-livestock farmers.

3.2.4 Sorghum and cowpea nutritive value as fodder

Sorghum Sariaso16 fodder content of two anti-nutritional factors NDF and ADL was greater than those of Ponta Negra, implying a slightly better nutritive value for Ponta Negra. Sariaso16 and Ponta Negra both had similar CP regardless of the cropping system. The fodder of Ponta Negra had higher IVOMD than Sariaso16, regardless of the cropping system, confirming its higher nutritive value. In addition, fodder of sorghum Ponta Negra intercropped with Tiligré had greater ME content. For cowpea cultivars, KVx745-11P had the greatest content of ash and CP regardless of cropping systems. Intercropping also differentially affected cowpea fodder's nutritive value for ash, ME, CP, and IVOMD. Finally, on-farm sorghum Sariaso16 and cowpea KVx745-fodder concentration in ash and ADF were greater than those on-station with the lowest content being ME. These results could be explained by the combined effect of genetic, agro-climatic factors and cropping systems (Cesar et al., 2009; Python and Boessinger, 2012; Mehdadi et al., 2013; Schlegel and Wyss, 2013; Louarn et al., 2016).

Cowpea KVx745-11P has better *stay-green attributes* at pod maturity with low leaf losses, resulting in greater CP content than many cultivars, which do not have these genetic characteristics (Obulbiga et al., 2015; Simian, 2017). Many cultivars of sorghum fodder showed variation of their CP content with ranges between 4.3 to 10.2%, (Simian, 2017; Zampaligré et al., 2021). This variability is mostly correlated to the harvest period; better CP concentration occurs during the heading phase and the CP begins to decline as the grains continue their maturation process (Simian, 2017). However, fodder cultivars such as Sariaso16 are more lignified with high concentrations of ADF and ash (Cesar et al., 2009). Some authors have shown that agro-ecological conditions and the duration time between fodder sample collection at farms and their pre-drying or drying would influence ash and crude cellulose content (Python and Boessinger, 2012; Mehdadi et al., 2013; Schlegel and Wyss, 2013). It has also been shown that cereal-legume intercropping would improve their total fodder quality in terms of protein and energy (Louarn et al., 2016). Sorghum fodder cultivars with CP concentration lower than 7% can be intercropped with cowpea in order to obtain an improved diet for livestock. Sorghum Ponta Negra intercropped with cowpea KVx745-11P would be the most appropriate cropping system for agro-pastoralists in Burkina Faso (livestock production as the main goal); whereas for crop-livestock farmers, it would be sorghum Sariaso16 intercropped with cowpea KVx745-11P (food production as the main goal).

For the extension of quality and quantity fodder production based on food-feed crops to meet human and livestock needs in Burkina Faso northern Sudan zone, we suggested emphasizing sorghum cultivar Ponta Negra and cowpea cultivar KVx745-11P intercropping and adoption of best fodder conservation techniques in order to preserve fodder nutritive value for dry season utilization in Burkina Faso.

4 Conclusions

Sorghum and cowpea intercropping with improved cultivars resulted in optimized grain and fodder biomass production while effectively controlling weeds when compared to monoculture of either sorghum or cowpea. For intercropping systems, sorghum cultivar Ponta Negra and cowpea cultivars had the greatest fodder production whereas sorghum cultivar Sariaso16 and cowpea cultivars had the greatest grain yields. The two cultivars of sorghum had similar fodder nutritive value in terms of ash, CP, and ME although Ponta Negra had higher IVOMD and lower ADF. Cowpea KVx745-11P fodder nutritive value was the best for ash, CP, and ADF content. Sorghum-Cowpea intercropping differentially affected fodder nutritive value in terms of ash, ME, CP, and IVOMD. In summary, intercropping was more efficient and appropriate for fodder biomass and grain yield compared to monoculture with equivalent or better fodder quality.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material. Further inquiries can be directed to the corresponding author.

Author contributions

SA: Contribution to study's conceptual and methodological design, as well as first manuscript drafting, revision, and editing. ZN: Contribution to study's conceptual and methodological design, as well as first manuscript drafting, revision, editing, and country project coordination. KA: Contribution to study's conceptual and methodological design, as well as manuscript revision and editing; this PhD research supervisor. DJ and OA: Contributed to data collection and curation. RF, DJ, JB, and BK: Contributed to the study's conceptual and methodological design, as well as manuscript revision and editing. AA: Contributed to manuscript revision and editing, project coordination, and fundraising. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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