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Performance of food–feed maize and cowpea cultivars under monoculture and intercropping systems: Grain yield, fodder biomass, and nutritive value

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Livestock feeding in Burkina Faso is characterized by a recurrent deficit in both the quality and the quantity of fodder during the dry season, which affects animal performance. To overcome this, quality fodder/forage production is an alternative. Therefore, this study evaluated food- and feed-improved cultivars of maize and cowpea in intercropping trials using the "mother and baby trials" approach with crop–livestock farmers. The mother trial comprised a randomized block design with eight treatments and four replicates: two cowpea (KVx745-11P and Tiligré) and two maize cultivars (Barka and Espoir), and grown under two cropping systems (monoculture and intercropping). Baby trials were established on-farm and involved 30 farmers during two seasons (2019 and 2020) in four villages in the South Sudan zone of Burkina Faso. Data were collected on (1) weed density and biomass, (2) grain yield and fodder biomass, (3) intercropping efficiency, and (4) fodder nutritive value. Data were analyzed using ANOVA and the least significant difference (LSD) means separation at a 5% threshold. The results revealed that maize and cowpea intercropping significantly reduced weed biomass ($p \leq 0.05$). In monoculture, the maize cultivar Barka produced a greater grain yield (4980 kg/ha) and fodder biomass [6259 kg dry matter (DM)/ha] than the cultivar Espoir, which produced a grain yield of 2581 kg/ha and fodder biomass of 4952 kg DM/ha. The cowpea cultivars, KVx745-11P and Tiligré, were similar ($p \geq 0.05$) in terms of fodder biomass (2435–2820 kg DM/ha) and grain yield (1152–1163 kg/ha). For the intercropping system, land equivalent ratios for fodder biomass (1.18:1.41) and grain yield (1.02:1.44) were greater than 1; intercropping also had better productivity system indexes than the monoculture cropping system. The crude protein concentration of fodder was greater for Barka maize (9.5%–

9.8%) than for Espoir maize (8.5%–8.7%). The crude protein concentration was greater for cowpea KVx745-11P (19%–21.8%) than for cowpea Tiligré (15%–17%). Intercropping both Barka maize and cowpea KVx745-11P was the most productive cropping system for maximizing grain and fodder production for crop–livestock farmers in the South Sudan zone of Burkina Faso.

KEYWORDS

crop–livestock system, food–feed crops, intercropping, improved crop cultivars, Burkina Faso

1 Introduction

Livestock feeding in Burkina Faso uses mostly natural pastures and crop residues and is characterized by a recurrent deficit in fodder during the dry season that leads to a decrease in livestock productivity (Tamini et al., 2014). The three main livestock production systems are extensive, semi-intensive, and intensive systems (Kristjanson et al., 2012). The semi-intensive system involves integrating mixed-crop and livestock systems with two groups of actors, namely agropastoralists and sedentary crop–livestock farmers, who together manage about 70% of the national animal numbers (MRA, 2015). This system is a low-cost investment, with 10%–50% of household gross income coming from livestock activities (Sangaré et al., 2005). Livestock do not move far from the production site and their manure is used for soil amendment. Animals graze on natural pastures and are supplemented during the dry season with cereal stover and legume haulms (Mulumba et al., 2008; Kiéma et al., 2014). The dominant livestock species are local cattle (*Bos taurus* Linnaeus), sheep (*Ovis aries* Linnaeus), and goats (*Capra hircus* Linnaeus). The integrated crop and livestock system serves multiple roles, and benefits and strengthens farmers' resilience to risks related to the use of natural resources (Sanfo et al., 2015).

The major constraint of this production system is the scarcity of feed resources, especially in the dry season, when grazing distances become longer owing to the decline in pasture productivity and the growth of the livestock herd (Boote et al., 2021). This leads to the increased systematic use of crop residues as feed. These residues are cereal straws [sorghum, *Sorghum bicolor* (Linnaeus) Moench], millet [*Pennisetum glaucum* (Linnaeus) R Brown], and maize [*Zea mays* (Linnaeus)], as well as legume haulms [cowpea, *Vigna unguiculata* (Linnaeus) Walpers], groundnut [*Arachis hypogaea* (Linnaeus)], and Bambara beans [*Vigna subterranea* (Linnaeus), Verdc.]. They are used directly for livestock on a farm, collected and stored, or sold for livestock supplementation in the dry season (Sanou et al., 2011; Kiéma et al., 2014). The main cereal residues are maize, sorghum, and millet; these have a low crude protein concentration (2%–9%) compared with legumes (groundnut, cowpea, and Bambara bean) (9%–22%) (Nantoumé et al., 2000; Savadogo, 2000; Zampaligré et al., 2021). The incorporation of cereal and legume residues at 40% and 60%, respectively, in the diet of local sheep has been reported to give an average daily weight gain of 92–206 g/day (Kiéma et al., 2008).

The use of strictly forage-type crops remains limited despite extension and research efforts to improve adoption by farmers into their cropping systems (Cesar & Guiro, 2004). The rate of adoption has remained very low, reflecting the farmers' lack of interest in these forage-type crops due to land tenure, cropping calendar, and seed multiplication issues (Coulibaly et al., 2012). The low availability of cropland favors cereal planting to the detriment of forage plots. In an uncertain environment, the risk management strategy requires that small farmers give priority to dual-purpose crops over strict forage species so that they benefit from crop residues (feed) and grain (food) by cultivating the same unit of area. These residues, although systematically used, are generally from local cultivars and are often poorly preserved and lose their nutritive value over time. Akakpo et al. (2020) reported that crop residue preservation methods by farmers in the Sudan zone led to a loss of 14%–35% of dry matter and 15%–50% of crude protein (CP) because of a decrease in the leaf-to-stem ratio, which was linked to strong winds and intense sunshine. Improved feed–food cultivars of maize (i.e., Barka, Espoir, SR21, and Wari) and cowpea (i.e., KVx745-11P and Tiligré) have the advantage of having greater yield and quality fodder (Palé, 2017; Zampaligré et al., 2021). A better choice of cropping system could solve the problem of both arable land scarcity and soil fertility with a gain in energy and protein sources. Therefore, intercropping based on improved cultivars of maize and cowpea is proposed.

Intercropping is a combination of several crops on the same land area at the same time (Reddy et al., 1980). A complementarity of species is sought to make the system more resilient to soil physicochemical conditions (Matusso et al., 2014). Cereal and legume intercropping is suitable for small crop–livestock farmers for food and feed needs, with better land management (Nasir, 2019). An intercropping system based on improved cultivars compatible with the agricultural calendars of farmers would be a good alternative (Sangaré et al., 2005) to improve grain yield and fodder biomass (Baudron et al., 2009; Mbaye et al., 2014), as well as fodder protein (Louarn et al., 2016). The overall production (fodder plus grain) of maize–cowpea and sorghum–cowpea intercropping has been reported to increase grain yield and fodder biomass by 30%–60% compared with a monoculture of each crop (Obulbiga et al., 2015; Coulibaly et al., 2017). This cropping system improves soil fertility (Coulibaly et al., 2017) with better weed control (Matusso et al., 2014). To gain the multiple advantages of improved cultivars and intercropping, it is necessary to identify the best feed–food cultivars and suitable intercropping systems and adapt these to crop–livestock farmers' needs. It is in this context that the current study is conducted, with the objective of optimizing grain and fodder production under monoculture and intercropping among small-holder farmers using improved feed–food crop cultivars of maize and cowpea in Burkina Faso.

2 Materials and methods

2.1 Study site description: location, rainfall, soils, vegetation, animal husbandry, and farming characteristics

The study was conducted in southern Burkina Faso. The on-station trial was conducted at the Institut de l'Environnement et de Recherches Agricoles (INERA) in Farakoba, Bobo Dioulasso (11°07′00.0′′N 4°25′00.0"W), and the on-farm trials were conducted in Koumbia, Kongolikan, Sébédougou, and Makognadougou villages, with 90 km as the maximum radius from Farakoba (Figure 1). The INERA research station is located on the national road (NR1) Bobo-Dioulasso–Banfora, and 15 km from Bobo-Dioulasso.

The annual rainfall of the study site ranged from 900 to 1200 mm/year, with a 5- to 6-month dry season (from November to April). The annual rainfall recorded in 2019 (1308 mm) and 2020 (1210 mm) at the research station was greater than the long-term average of 1990–2020 (Figure 2), and the long-term mean temperature is 26°C–27°C. The rainy season typically spans May to October, with 67–69 rainy days (Figure 2).

Soils are mostly tropical ferruginous with low nitrogen, phosphorus, and organic matter content, and require fertilizer application for better crop production (Zampaligré et al., 2021). Soil analyses for the 0- to 30-cm horizon show that the study soils are acid and low in nitrogen, available phosphorus, and available potassium (Table 1).

The vegetation in this region consists of trees and shrubs, savanna, wooded savanna, and gallery forests. The climate zone is part of zone A of the Köppen climate classification (Beck et al., 2018). The dominant woody species are *Parkia biglobosa* Jacq., *Detarium microcarpum* Guill. et Perr, *Vittelaria paradoxa* CF Gaertn, *Gmelina arborea* Roxb, *Mangifera indica* Linnaeus, *Khaya senegalensis* A Juss., and *Tamarindus indica* Linnaeus, while the grass species are *Andropogon* spp, *Indigofera* spp, *Loudetia togoensis* Pilg., *Eragrostis tremula* Hochst., and *Urochloa* spp (Zampaligré et al., 2021).

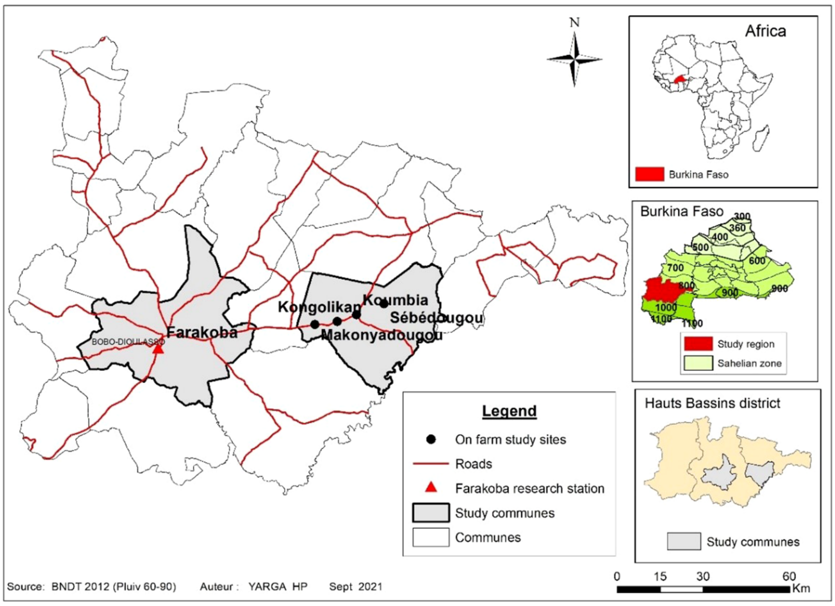

FIGURE 1
Map of the study location in Burkina Faso.

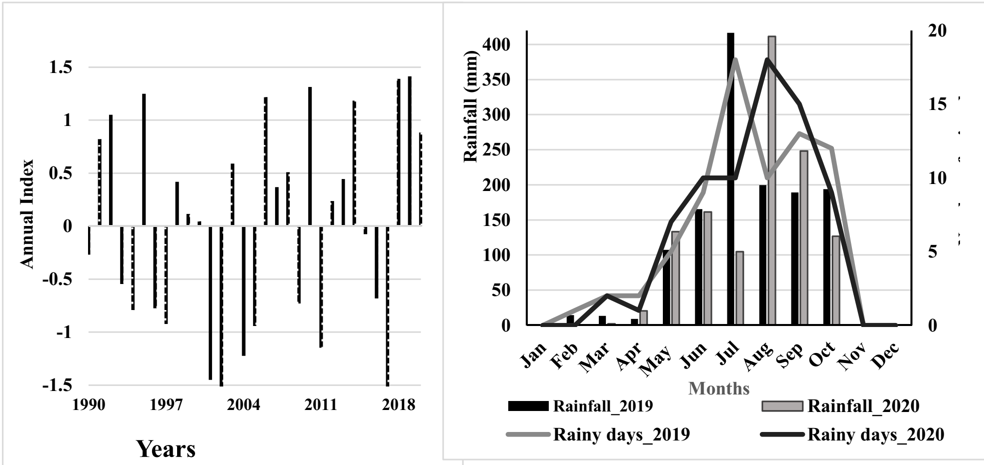

FIGURE 2
Annual rainfall indexes from 1990 to 2020 (left), and rainfall variation in 2019 and 2020 (right).

The two main livestock systems are the integrated mixed crop and livestock system and the agropastoral system; however, transhumant herders are welcomed every year during the dry season (Mulumba et al., 2008). The main animal species kept are local cattle, sheep, and goats. The national number of livestock in 2015 was estimated to be 33,455,000, with 69% of this total being small ruminants; this zone had 20% of this total number of livestock, with 13% being small ruminants (MRA, 2015). The main cereal and legume crops are maize and cowpea, respectively, and are grown by 70% of farmers in an extensive system (SP-CPSA, 2008). Plots sown for maize and cowpea represent 49.7% and 26% of the national area, respectively. Maize and cowpea are dominant staple food crops in the study area, representing about 58% and 19% of the national production, respectively, in 2015 (MA, 2015).

Agricultural systems are dominated by the small-holder farming and commercial crops, such as cotton, cashew, and mangoes.

2.2 Methodology

2.2.1 Conceptual framework

This research followed the "mother and baby trials" approach (Figure 3), and is a study of an on-farm participatory approach to introduce and test a range of technology suitable for heterogeneous communities, with two main steps (Snapp, 2002; Gonsalves et al., 2005):

The mother trial is a central test located in a village or at a nearby research station and is replicated at the site (i.e., three or four replications). The trial is designed, set up, and supervised by a research team to find the best-adapted technologies for farmers' conditions.

Baby trials are conducted on-farm and each farmer represents a replicate, comparing a subset of technologies (i.e., treatments) according to their choice from the mother trial, without replication on their farm, and are directly managed by them.

Farmers in Burkina Faso are a diverse group of individuals with distinct challenges and priorities, which has repercussions on their adaptation and adoption of new practices and technologies. In most cases, classical research approaches do not take into account this diversity. Therefore, technologies generated are not often applicable on-farm (Snapp, 2002). The "mother and baby trials" approach is a demonstration of alternative technologies and is the starting point to facilitate dialogue and collaboration among farmers, policymakers, extension, and researchers (Kerr et al., 2007). In our study, the mother trial was conducted at the Farakoba research station and the baby trials were conducted on farmers' plots in four villages

TABLE 1 Average soil chemical characteristics for two sites in Burkina Faso.

Site	pH (H_2O)	pH (KCl)	N[1] (%)	C/N[2]	Total P (mg/kg)	P-av. (mg/kg[3])	Total K (mg/kg)	K-av. (mg/kg)[4]
Farakoba research station	4.60	4.01	0.02	10.80	52.39	1.85	1263	68
On-farm	5.04	4.52	0.04	11.65	96.77	6.75	563	49

N, nitrogen; C, carbon; P,phosphoru; K, potassium; KCl, potassium chloride; av., available.

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within a maximum radius of 90 km from the research station center (Figure 1).

2.2.2 Sampling methods and plant materials

A baseline survey was conducted in 2018–19 on forage production in crop–livestock systems involving 250 farmers in four (04) villages using a reasoned and stratified sampling approach with the following criteria: (1) farmers' willingness to engage in dual-purpose crop trials, with a plot size of at least 0.1 ha; (2) physical accessibility to farmers' plots; and (3) availability of at least three adult sheep for feeding trials, and a minimum of 30% of farmers being women. Following this survey, 30 farmers (20 men and 10 women) were selected to participate in a second study on the evaluation of their crops, cultivars, cropping systems, and fodder preservation method preferences (Sanfo et al., 2020). The same 30 farmers were then targeted to conduct this participatory research on fodder production using improved cultivars of dual-purpose maize and cowpea intercropping. The choice of plant material was based on farmers' preferences (Sanfo et al., 2020). Plant material was improved cultivars released by INERA that are currently being promoted in Burkina Faso. These cultivars are described in Table 2 (MRSI, 2014; Sanou, 2017a; Palé, 2017; Zampaligré et al., 2021).

2.2.3 Experimental design

The on-site mother trial followed a completely randomized block design with eight treatments in four replications. The size of each plot was 35 m² (7 × 5 m) and the treatments were:

- Treatment 1: Barka maize only.
- Treatment 2: Espoir maize only.
- Treatment 3: Tiligré cowpea only.
- Treatment 4: KVx745-11P cowpea only.
- Treatment 5: Barka maize intercropped with cowpea Tiligré.
- Treatment 6: Barka maize intercropped with cowpea KVx745-11P.
- Treatment 7: Espoir maize intercropped with cowpea Tiligré.
- Treatment 8: Espoir maize intercropped with cowpea KVx745-11P

The on-farm trials involved 30 farmers with individual plots of 1000 m². They were all trained in the agricultural practices and management of the farm on 12 June 2019, at Koumbia. Seeds, fertilizers, and pesticides were provided to the farmers by the project team. Field implementation was facilitated by extension workers (livestock and crop agents) under the supervision of the research team. Three treatments were selected from the central trial and were tested with 10 farmers per treatment: (1) Barka maize only, (2) KVx745-11P cowpea only, and (3) Barka maize intercropped with cowpea KVx745-11P. The study was conducted over two consecutive years (i.e., 2019 and 2020) during the rainy season both on-station and on-farm.

2.2.4 Trial establishment and agronomic management

Before trial implementation, information about cropping history was collected for each farmer's field. The intercropping system was the system most preferred by farmers: two rows of maize for one row of cowpea (Sanfo et al., 2020). The spacing for all the crops was 80 × 40 cm. Soils were plowed after rainfall by animal traction followed by sowing: 6–15 July for maize and 13–23 July for cowpea during the 2 years. Cowpea planting was shifted (7–10 days) later to optimize yield and fodder biomass (Mbaye et al., 2014). Seedlings were thinned at 15–20 days after sowing (DAS) to obtain the desired densities: 6.25 plants/m² in monoculture of maize and cowpea, and 4 plants/m² and 2.25 plants/m² for maize and cowpea intercropping, respectively. All the plots received compost made of cattle manure and crop residues (5 t/ha) in the first year, followed annually by mineral fertilization with nitrogen, phosphorous, and potassium (NPK; 14:23:14) at a rate of 100 kg/ha for cowpea and 200 kg/ha for maize between 15 and 20 DAS. In addition, maize plots received annually 150 kg/ha of urea (100 kg/ha between 25 and 35 DAS and 50 kg/ha between 40 and 45 DAS) in accordance with INERA recommendations (Sanou, 2017a). Weeding was carried out manually twice (15–20 and 25–35 DAS) followed by hoeing (40–45 DAS). Cowpea plots were treated twice (16 g/l of acetamiprid plus 30 g/l indoxacarb: 1 L per hectare) against parasites at flowering and pod formation. Specific treatment (15 g/l of lambda-cyhalothrin plus 20 g/l of acetamiprid) was carried out for other plots against armyworms (*Spodoptera frugiperda).* During the heading–flowering period (25–30 September), guided tours were organized for scouting and checking for insects.

2.3 Data collection

2.3.1 Grain yield (GY) and fodder biomass (FB) assessment

Grain yield was assessed at the grain maturity stage using three squares of 1 m² along the diagonal of each plot. Maize ears and cowpea pods were harvested separately and sun-dried for 10 days before the grain was shelled/threshed and winnowed. The

1 Kjeldahl procedure.

2 Walkley–Black procedure for carbon extraction.

3 Bray –[I] method.

4 Acetate ammonium solution.

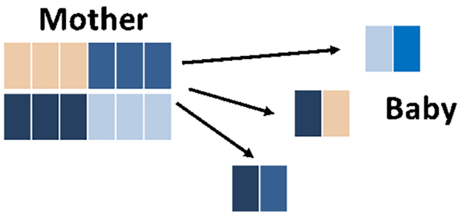

FIGURE 3
Illustration of the mother and baby approach.

resulting grains were further sun-dried to a constant weight and then weighed using a small scale of 2 kg ± 5 g to obtain a grain yield for each crop. Fodder biomass was also assessed after grain harvest on the same day and in the same area using the same three yield squares. Fresh biomass weight was measured using a 10 kg ± 10 g sensitive scale. A sample of 500 g of each square was then taken and oven-dried at 105°C for 48 hours to determine the dry matter concentration before fodder dry biomass (kg DM/ha) was computed.

2.3.2 Intercropping efficiency evaluation

Three parameters were used to evaluate the intercropping efficiency. These were weed control (WC), land equivalent ratio (LER), and system productivity index (SPI). WC describes weed density (WD) and weed biomass (WB):

WD was recorded between 75 and 80 DAS using yield square at three replicates in each plot along the diagonal.

WB was assessed using the same three yield squares. All the weeds in the squares were harvested and weighed; samples were oven-dried at 105°C for 48 hours to determine weed biomass (kg DM/ha).

LER is defined as the area of land under monoculture required to produce yields per ha achieved in intercropping (Wiley, 1979) and determined by Equation 1:

$$LER = \sum_{n=1}^{N} YN/SN \tag{1}$$

YA +............+ YN = yield of each component in the intercropping

SA + ... + SN = yield of each component in monoculture

SPI is an index used to evaluate the performance of the two crops in the intercropping treatment. It gives an overview of whole-system performance as both crop yields are standardized to allow comparison. Initially developed by Odo in 1991 (Khan et al., 2020), SPI has been successfully used in cereal and legume intercrop studies (Khan et al., 2020). The formula used for SPI calculation is as follows:

$$\mathbf{SPI} = (\mathbf{My} / \mathbf{Cy \ x \ Yc}) + \mathbf{Ym}$$

where My and Cy are the mean yields of maize and cowpea in monoculture, respectively, and Ym and Yc are the mean yields of maize and cowpea in intercropping, respectively.

These indexes were used to evaluate the relative advantages of intercropping compared with monocultures. The value in their appropriateness of use in our context comes from the fact that we used two crop types (i.e., cereal and legume) in a spatial arrangement. Table 3 summarizes the indices used for intercropping efficiency evaluation.

2.3.3 Fodder nutritive value assessment

For the fodder nutritive value assessment, two composite samples of the whole plant (stems plus leaves) from the three yield squares were taken in each plot, after biomass evaluation. The samples were first air-dried, then shade-dried, and finally ground at 1 mm. The near-infrared reflectance spectrometry (NIRS) method was used. The spectra of the samples were taken using the NIRS FOSS DS2500 F feed analyzer at the International Livestock Research Institute (ILRI). Global mixed-model calibrations were used. The following parameters were determined: dry matter (DM), crude protein (CP), ash, neutral detergent fiber (NDF), acid detergent fiber (ADF), acid

TABLE 2 Characteristics of crop cultivars used.

Cultivar	Cycle (day)	Seed color	Grain yield (t/ha)	Fodder biomass (t DM/ha)	CP (%)	IVOMD (%)
Maize Barka	88	White	2.7–5.5	3–7.3	8.7–9.4	52
Maize Espoir	97	Yellow	2.1–6.5	2.2–6.8	7.8–8.6	51
Cowpea Tiligré	70	White	1.5–2	2.5–3	13.–15.4	64
Cowpea KVx745-11P	75	White	0.8–1.6	3–4.5	16–21.6	65

CP, crude protein; DM, dry matter; IVOMD, in vitro organic matter digestibility.

detergent lignin (ADL), metabolizable energy (ME), and *in vitro* organic matter digestibility (IVOMD).

2.4 Statistical analysis

Microsoft Office Excel™ 2013 (Microsoft Corporation, Redmond, WA, USA) was used for data entry and for the preparation of tables and graphs. Statistical analysis was performed using IBM SPSS Statistics version 20.0 software (IBM Corp., Armonk, NY, USA).

Analysis of variance (ANOVA) (three-way ANOVA for on-station and two-way ANOVA for on-farm) was performed for a randomized complete block design (RCBD), followed by means comparisons for significant effects using the least significant difference (LSD) test. Significance was declared at a *p*-value of ≤ 0.05.

3 Results

3.1 Weather conditions during the two years

The 2-year period of the study received better rainfall than the mean of the last 20 years. The quantity of rain received was 1308 and 1210 mm in 2019 and 2020, respectively. These conditions were appropriate for maize production and allowed the cultivars to express their performance in the trials both on-farm and on-station. Details about the weather conditions are shown in Figure 2.

3.2 Statistical analyses of grain yield, fodder biomass, weed density, and weed biomass

For on-station trials, the year and cropping systems have significant effects on grain yield, fodder biomass, weed density, and biomass of maize (Table 4). The cultivar effect was significant only for the grain yield of maize. For cowpea, the year had a significant effect on grain yield, fodder biomass, weed density, and fodder biomass. The cultivar was significant only for fodder biomass, weed density, and weed biomass. The cropping system was also significant for grain yield and fodder biomass of cowpea. For on-farm trials, the year had a significant effect on maize grain yield only. The cropping system had a significant effect on the grain yield and fodder biomass of maize. For cowpea, the effect was significant for fodder biomass only.

3.3 Intercropping efficiency for weed control

Cropping systems did not affect weed density but did affect weed biomass (Table 5). Weed biomass in cowpea monoculture (124–328 kg DM/ha) was lower than that in maize (675–725 kg DM/ha), regardless of cultivar. In addition, cowpea and maize intercropping reduced weed biomass (261–343 kg DM/ha) compared with maize monoculture (675–725 kg DM/ha). The highest weed biomass was obtained with Barka maize monoculture (725 kg DM/ha), whereas the lowest value was observed with cowpea KVx745-11P monoculture (124 kg DM/ha) (Table 5).

3.4 Grain yield and fodder biomass

During the evaluation of the two cropping seasons, Barka grain yield (4980 kg/ha) and fodder biomass (6259 kg DM/ha) were greater than those of Espoir in monocultures. In intercropping, the best maize grain yields were obtained by Barka and KVx745-11P. The best maize fodder biomass in intercropping were Barka and KVx745-11P. Grain yield (1153–1162 kg/ha) and fodder biomass (2435–2821 kg DM/ha) were similar in monocultures of KVx745-11P and Tiligré cowpea. However, Tiligré had the least fodder biomass in intercropping. As expected, grain yield and fodder biomass from monocultures were greater than those from intercropping both on-station and

TABLE 3 Characteristics of the parameters for evaluating the efficiency of the crop association.

Parameter	Definition	Interpretation	Reference
Weed control	Weed density and biomass per unit of area	Intercropping and monoculture values comparison	Ekeleme et al., 2019
LER	Relative land area required by sole crops to produce the yields achieved in intercropping	LER = 1: equal advantages for intercropping and sole cropping TSE > 1: more advantage for intercropping than for sole cropping TSE < 1: less advantage for intercropping than for sole cropping	N'Goran et al., 2011
SPI	Standardization of the yield of the secondary crop "b" into the primary crop "a" Standardization of cowpea yield on maize yield for comparison purposes	Comparison between yields of the main crop in monoculture and the secondary crop in intercropping after standardization as indicated in the formula: a = b: yield of the primary and secondary crops are equal a > b: yield of the primary crop is greater than that of the secondary crop a < b: yield of the primary crop is less than that of the secondary crop	Khan et al., 2020

LER, land equivalent ratio; SPI, system productivity index; TSE, taux de surface equivalente.

on-farm. Barka maize fodder biomass was the best on-station for monoculture. However, cowpea KVx745-11P fodder biomass and grain yield were greater on-farm than on-station, regardless of the cropping system (Table 6).

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

Land equivalent ratio (LER) and SPI were used to evaluate intercropping efficiency in terms of land use, grain yield, and fodder biomass (Table 7). Maize and cowpea intercropping all had an LER for biomass (1.18:1.41) and yield (1.02:1.44) greater than 1 (the value of monocultures). Intercropping gave a greater SPI than monocultures for each of the maize cultivars evaluated (Table 7). The greatest SPI value for biomass was observed in Barka maize intercropped with KVx745-11P (7906). In terms of grain yield, Barka maize monoculture and Barka maize intercropped with KVx745-11P had the best SPI (4854–8787).

3.6 Fodder nutritive value

The effect of cultivar and cropping system on maize and cowpea fodder nutritive value is presented in Table 8. For the on-station trial, the main effect of the cultivar was significant only for maize CP. The main effect of cultivar was also significant for ash concentration and CP of cowpea, while only ash for their cropping system.

The nutritive value of cowpea fodder is presented in Table 8. Cowpea KVx745-11P fodder had higher CP levels than that of Tiligré (21.5% and 16.3%, respectively), with similar *in vitro* organic matter digestibility (56.8%–57.5%). Cowpea KVx745-11P fodder in intercropping had the greatest ash concentration, ranging from 14.7% to 15%. On-farm cowpea KVx745-11P fodder had a lower ash concentration than that of on-station cowpea KVx745-11P fodder (Table 9).

Barka maize fodder had higher CP levels (9.5%–9.8%) than that of Espoir (7.5%–8.5%). On-farm Barka maize fodder had a lower NDF concentration than on-station Barka maize fodder, regardless of the cropping system (Table 10).

4 Discussion

4.1 Effect of intercropping on weed control

The effect of cropping systems on weed control showed that cowpea monocultures and their intercropping with maize, regardless of cultivar used, reduced weed biomass in all the plots. Cover crops, such as cowpea, tend to occupy all the available space, resulting in a reduction in light, water, and mineral elements for weed development. Cowpea KVx745-11P is a creeping cultivar and would be the most effective in controlling these weeds in both monoculture and intercropping. The smothering of weeds inducing the reduction of their biomass would be linked to competition for light and the allelopathy phenomenon (Cordeau and Moreau, 2017). Competition for water, mineral elements, and light associated with allelopathy would affect the photosynthetic process of weeds, leading to a decrease in their development and growth (Cordeau et al., 2015). Ekeleme et al. (2019) showed that legume monocultures and their intercropping with cereals

TABLE 4 Statistical analyses of grain yield, fodder biomass, weed density, and weed biomass for cowpea and maize.

Trial	Source of variation	Cowpea				Maize			
		Grain yield (kg/ha)	Fodder biomass (kg DM/ha)	Weed density (plant/m^2)	Weed biomass (kg/ha)	Grain yield (kg/ha)	Fodder biomass (kg DM/ha)	Weed density (plant/m^2)	Weed biomass (kg/ha)
On-station	Year	***	***	***	***	*	***	***	***
	Cultivar	NS	*	*	**	***	NS	NS	NS
	Cropping system	***	***	NS	NS	***	***	***	***
	Year*cultivar	NS	**	*	*	NS	NS	NS	NS
	Year*cropping system	***	NS	NS	*	NS	**	NS	***
	Cultivar*cropping system	NS	NS	NS	NS	**	*	NS	NS
	Year*cultivar*cropping system	NS	NS	NS	NS	*	NS	NS	NS
On-farm	Year	NS	NS	–	–	*	NS	–	–
	Cropping system	NS	**	–	–	***	*	–	–
	Year*system	NS	NS			*	NS		

*p ≤ 0.05, **p ≤ 0.01, ***p ≤ 0.001; NS, not significant at p ≤ 0.05.
DM, dry matter.

TABLE 5 Weed density and weed biomass (mean and standard deviation) from 2019 and 2020 under maize and cowpea monocultures and intercrops (on-station trial).

Cropping system		Weed density (plant/m^2)	Weed biomass (kg DM/ha)
Monoculture	Maize Barka	1084 ± 430	725^{a} ± 682
	Maize Espoir	943 ± 367	675^{ab} ± 585
	Cowpea Tiligré	1074 ± 129	328^{bc} ± 282
	Cowpea KVx745-11P	434 ± 237	124^{c} ± 90
Intercropping	Maize Barka and cowpea Tiligré	740 ± 390	343^{bc} ± 302
	Maize Barka and cowpea KVx745-11P	587 ± 326	260^{bc} ± 268
	Maize Espoir and cowpea Tiligré	561 ± 476	327^{bc} ± 336
	Maize Espoir and cowpea KVx745-11P	577 ± 341	261^{bc} ± 220
Statistic	*F*-value	1.54	2.30
	p-value	0.17	0.04

DM, dry, matter; LSD, least significant difference.
Values with the same letters in the same column are equal (LSD; p = 0.05).

reduced weediness and weed biomass compared with cereal monocultures and hoe-weeded plots. Chikoye et al. (2001) also found that cereal and legume intercropping reduced weed density by creating unfavorable conditions for their germination. The non-significant effect on weed density could be partly related to some short-cycle weeds having completed their life cycle, becoming dry and disappearing from the plots (Muhammad et al., 2013). In addition, in 2020, the sowing date of cowpea coincided with a dry spell, which did not allow their rapid growth (and, therefore, soil cover), which would, in turn, have had an impact on the germination of weed seeds (Ekeleme et al., 2019).

In cereal- and legume-based cropping systems for crop–livestock farmers, the use of legumes, such as cowpea, in either monoculture or intercropping presents advantages in terms of weed control that could increase yield and fodder biomass, and be time-saving for crop establishment (Muhammad et al., 2013). Odhinambo and Ariga (2001) showed that maize and cowpea intercropping for *Striga* control increased grain yield from 51% to 61%. In this study, the KVx745-11P cowpea cultivar would be the most suitable for weed control for crop–livestock farmers; therefore, this can be recommended to the farmers for better-integrated weed management in their production system instead of using chemical products.

4.2 Grain yield and fodder biomass improvement

Barka maize had the greatest fodder biomass and grain yield in monoculture, with greater fodder biomass in on-station trials than in on-farm trials. The cowpea cultivars KVx745-11P and

TABLE 6 Grain yield and fodder biomass of maize and cowpea in two cropping systems in on-station and on-farm experiments (mean from 2019 and 2020 cropping seasons).

	Cropping system	Grain yield (kg/ha)		Fodder biomass (kg DM/ha)	
Mother trial: research station		Maize	Cowpea	Maize	Cowpea
	Maize Barka monoculture	4980^{a} ± 1118	–	6259^{a} ± 1985	–
	Maize Espoir monoculture	2582^{b} ± 1466		4953^{ab} ± 2223	–
	Cowpea KVx745-11P monoculture	–	1162^{a} ± 445	–	2821^{b} ± 1281
	Cowpea Tiligré monoculture	–	1153^{a} ± 428	–	2435^{b} ± 587
	Barka and cowpea KVx745-11P intercropping	2842$^{bc=}$ ± 1360	744^{b} ± 234	3173^{bc} ± 1338	2147^{bc} ± 1055
	Barka and cowpea Tiligré intercropping	2095^{c} ± 1216	696^{b} ± 270	2736^{c} ± 1400	1804^{bcd} ± 723
	Espoir and cowpea KVx745-11P intercropping	2079^{c} ± 1261	753^{b} ± 253	2855^{c} ± 1081	2303^{bc} ± 1002
	Espoir and cowpea Tiligré intercropping	2261^{c} ± 1195	564^{b} ± 143	3471^{bc} ± 1335	1726^{bcd} ± 402
Baby trials: on farm	Maize Barka monoculture	5646^{a} ± 895	–	4840^{ab} ± 1153	–
	Cowpea KVx745-11P monoculture	–	1152^{a} ± 627	–	5352^{a} ± 1807
	Barka and cowpea KVx745-11P intercropping	3659^{bc} ± 1362	913^{ab} ± 391	3324^{bc} ± 1663	3149^{ab} ± 1048
Statistic	*F*-value	11.65	3.08	5.23	11.41
	p-value	0.0001	0.008	0.0001	0.0001

DM, dry matter; LSD, least significant difference.
Values with the same letters in the same column are equal (LSD; p = 0.05).

TABLE 7 Land equivalent ratio (LER) and system productivity index (SPI): monoculture versus intercropping.

Trial	Treatment	LER for forage biomass	LER for grain yield	SPI for forage biomass	SPI for grain yield
On-station	Cowpea Tiligré monoculture	1.00	1.00	2435	1153
	Cowpea KVx745-11P monoculture	1.00	1.00	2821	1162
	Maize Barka monoculture	1.00	1.00	6259	4980
	Maize Espoir monoculture	1.00	1.00	4952	2581
	Maize Barka and cowpea Tiligré intercropping	1.18	1.02	6974	4052
	Maize Barka and cowpea KVx745-11P intercropping	1.27	1.21	7907	4854
	Maize Espoir and cowpea Tiligré intercropping	1.41	1.36	6227	3450
	Maize Espoir and cowpea KVx745-11P intercropping	1.39	1.45	7046	4288
On-farm	Cowpea KVx745-11P monoculture	1.00	1.00	5352	1152
	Maize Barka monoculture	1.00	1.00	4839	5646
	Maize Barka and cowpea KVx745-11P intercropping	1.27	1.44	7021	8787

Tiligré also had similar grain yield and fodder biomass in monocultures. These results could be explained by genetic, agroclimatic, and cropping system factors (Coulibaly et al., 2012; Alidu et al., 2013; Coulibaly et al., 2020).

Barka and Espoir maize were identified as the best cultivars, performing well in the South Sudan zone of Burkina Faso for grain yield and fodder biomass, despite those performances being relatively low (Zampaligré et al., 2021). Cowpea KXv745-11P and Tiligré have been also identified as the best cultivar for grain yield and fodder biomass, respectively (Palé, 2017; Lalsaga and Drabo, 2017; Ramdé, 2019). These cultivars could have performed differently for grain yield and fodder biomass depending on the agro-ecological conditions of the site of production (Obulbiga et al., 2015; Ouattara, 2016; Sanou, 2017b; Traoré et al., 2020). Water and soil fertility influencing genetic potential are the most limiting factors for crop production, while the two cropping years of evaluation were wet seasons (Alidu et al., 2013; Kihindo et al., 2015). Zampaligré et al. (2021) reported less grain yield and fodder biomass for Barka and Espoir maize cultivars at Farakoba (INERA) research station in a 2-year experiment. This could be due to the level of fertilization. They used 50 kg/ha urea in addition to NPK, whereas we used 150 kg/ha urea. In addition, maize Espoir may be more sensitive to acidity, low levels of soil organic matter, and low concentrations of mineral elements, which are major causes of low maize productivity (Temegne et al., 2015; Coulibaly et al., 2017). According to the national statistics for staple crop production metrics, total maize production in the South Sudan zone of Burkina Faso is estimated at 1,124,824 t DM (MA, 2015) using approximately 367,504 ha, which represents approximately half (49.7%) of the national cropping areas dedicated to maize production (MA, 2015). In fact, this production is mainly carried out using traditional cultivars with lower grain yields and fodder biomass. The results of this study indicated that the use of this improved Barka maize cultivar in an appropriate crop management system would lead to an increase in maize biomass production up to 2,205,024–2,572,528 t DM. This represents an increase of 51% of the current maize biomass production in the country.

4.3 Intercropping efficiency evaluation

Intercropping had an LER greater than 1, which means the production capacity of a maize stand grown with cowpea is higher than that of a maize or cowpea stand grown in monoculture. Maize and cowpea intercropping, therefore, reflects a saving of 2%–45% of land area. The same grain yield and fodder biomass obtained with cowpea or maize monocultures can be produced by their intercropping while reducing the area sown by 2% to 45%. For fodder production, the highest area saving was obtained with Espoir and Tiligré intercropping (41%), while for grain production this was on-farm Barka with KVx745-11P (44%) and Espoir with KVx745-11P (45%). That means the need for an area of 1.17–1.41 ha for biomass and 1.02–1.45 ha for yield in monocultures to obtain the same production with 1 ha of intercropping. SPI values corroborate these results with higher values for intercropping than for monocultures of each entity. The highest fodder biomass (7906) and yield (8787) indexes were obtained with Barka and KVx745-11P intercropping. That means if Barka maize monoculture fodder biomass production is 6259 kg DM/ha and grain yielded 4980 kg/ha, then its intercropping with KVx745-11P would produce 7906 kg DM/ha as fodder biomass and grain yield between 4854 kg/ha and 8787 kg/ha. These gains could be explained by the beneficial complementary relationships between the two associated species for resource use (Justes et al., 2014; Louarn et al., 2016). Shifting the

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TABLE 8 Statistical analyses of variation for cowpea and maize fodder nutritive value.

Trial	Source of variation	Cowpea DM (%)	Cowpea Ash (%)	Cowpea CP (%)	Cowpea NDF (%)	Cowpea ADF (%)	Cowpea ADL (%)	Cowpea ME (MJ/kg)	Cowpea IVOMD (%)	Maize DM (%)	Maize Ash (%)	Maize CP (%)	Maize NDF (%)	Maize ADF (%)	Maize ADL (%)	Maize ME (MJ/kg)	Maize IVOMD (%)
On-station	Cultivar	NS	**	***	NS	NS	NS	NS	NS	NS	NS	***	NS	NS	NS	NS	NS
	Cropping system	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	Cultivar*cropping system	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
On-farm	Cropping system	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

*=p ≤ 0.05, **=p ≤ 0.01, ***=p ≤ 0.001, NS, not significant at p ≤ 0.05.
ADF, acid detergent fiber; ADL acid detergent lignin; CP, crude protein; DM, dry matter; IVOMD, in vitro organic matter digestibility; ME, metabolizable energy; NDF, neutral detergent fiber.

sowing date between the two species reduces interspecific competition (Mbaye et al., 2014). Indeed, cowpea because it is a legume, has the capacity to fix nitrogen from the air, avoiding competition with maize for this resource. These results corroborate those obtained by N'Goran et al. (2011) and Diatta et al. (2019), who found an area saving of 30%–84% with cereal and legume intercropping. Considering the efficiency of intercropping in weed control, LER, and SPI, Barka maize and cowpea KVx745-11P or Tiligré intercropping would be the two most efficient systems.

4.4 Fodder nutritive value

Fodder nutritive values were affected by crop cultivar and cropping system. In fact, cowpea KVx745-11P had greater concentrations of ash and CP than Tiligré. Cowpea KVx745-11P fodder in intercropping had the highest ash concentration. Barka maize CP concentration was greater than that of Espoir, regardless of cropping systems. Cowpea KVx745-11P fodder content in ash was lower on-farm than on-station. However, Barka maize fodder was lower in NDF on-farm than on-station.

In total, 80%–90% of the stems and leaves of Cowpea KVx745-11P were green at the pod maturity stage (stay green), compared with 40–60% for Tiligré, which meant that better-quality fodder was obtained at harvest, including a higher CP concentration than many cultivars that do not have the same genetic characteristics (Obulbiga et al., 2015; Simian, 2017). However, the CP concentration of cowpea fodder for the two cultivars studied was higher than that obtained (11.9%) by Nantoumé et al. (2000), and was comparable to values recorded (13%–21%) by Gérad et al. (2001) using several cultivars. The concentration of CP in Barka maize fodder was similar to that of the cultivar studied by Zampaligré et al. (2021); however, in this study, Barka maize fodder had a greater concentrations of CP than Espoir. Nevertheless, both cultivars have greater concentrations of CP than those obtained by Nantoumé et al. (2000) and Savadogo (2000) with various maize cultivars fodders (4%–7%). In fact, once the maize grain is mature, there is rapid yellowing of its leaves. This could affect the nutritive value of its fodder if it is not harvested in time. For that reason, we recommend the timely harvest of maize and cowpea for fodder to maintain nutritive value.

Some authors have shown that agroecological conditions and the elapsed time between fodder sample collection at farms and their pre-drying or drying influence ash and CP content (Mehdadi et al., 2013; Schlegel and Wyss, 2013). It has been also shown that cereal–legume intercropping improves fodder nutritive value in terms of protein concentrations and levels of energy (Louarn et al., 2016). All cowpea and maize cultivar fodders at maturity have a CP level above the critical threshold of crude protein utilization, estimated at 7% (Van Soest, 1982), below which domestic ruminants' rumen microflora activity decreases. This would make it possible to avoid or reduce supplementation with an economic gain (Nantoumé et al., 2000). Thus, regarding agronomic and fodder performances of the cropping systems, Barka maize, and cowpea KVx745-11P intercropping would

TABLE 9 Nutritive value of cowpea haulms according to cropping systems: on-station and on-farm.

Cropping system		DM (%)	Ash (%)	CP (%)	NDF (%)	ADF (%)	ADL (%)	ME (MJ/kg)	IVOMD (%)
Monoculture	Cowpea Tiligré	91.3 ± 0.5	12.5[b] ± 0.6	16.3[b] ± 1.5	42.5 ± 1.9	36.0 ± 1.6	7.2 ± 0.5	8.0 ± 0.0	56.8[b] ± 1.4
	Cowpea KVx745-11P	91.5 ± 0.6	13.5[ab] ± 1.3	21.5[a] ± 2.1	40.8 ± 3.3	37.7 ± 1.7	7.0 ± 0.0	8.3 ± 0.5	57.5[b] ± 1.0
	Cowpea KVx745-11P*	91.0 ± 0.0	12.0[b] ± 1.5	19.67[a] ± 2.7	42.0 ± 3.9	32.6 ± 4.1	6.2 ± 0.9	8.5 ± 0.5	61.2[a] ± 3.1
Intercropping	Cowpea Tiligré and maize Barka	91.3 ± 0.5	13.5[ab] ± 1.3	15.5[b] ± 2.5	42.7 ± 4.6	39.0 ± 4.7	7.7 ± 1.5	8.0 ± 0.0	56.0[b] ± 2.7
	Cowpea KVx745-11P and maize Barka	91.5 ± 0.6	14.7[a] ± 0.5	21.5[a] ± 1.0	39.7 ± 2.1	36.2 ± 2.8	6.7 ± 0.5	8.3 ± 0.5	58.5[b] ± 1.9
	Cowpea Tiligré and maize Espoir	91.5 ± 0.6	13.2[ab] ± 1.7	17.3[b] ± 1.0	41.3 ± 1.7	36.2 ± 1.3	7.0 ± 0.0	8.2 ± 0.5	57.8[b] ± 0.9
	Cowpea KVx74511P and maize Espoir	91.7 ± 0.5	15.0[a] ± 1.4	21.5[a] ± 2.6	40.0 ± 2.5	38.5 ± 4.5	6.7 ± 0.9	8.3 ± 0.5	57.8[b] ± 2.6
	Cowpea KVx745-11P and maize Barka*	91.2 ± 0.4	13.8[ab] ± 1.9	21.8[a] ± 1.6	40.6 ± 1.7	33.6 ± 2.5	6.4 ± 0.9	8.4 ± 0.5	60.2a ± 1.9
Statistic	*F*-value	1.17	2.42	6.94	0.61	2.33	1.61	0.67	3.07
	p-value	0.35	0.04	0.001	0.74	0.06	0.17	0.69	0.02

*on-farm trials.
ADF, acid detergent fiber; ADL acid detergent lignin; CP, crude protein; DM, dry matter; IVOMD, in vitro organic matter digestibility; ME, metabolizable energy; NDF, neutral detergent fiber.
Values with the same letters in the same column are identical (p ≤ 0.05).

be the most suitable for crop–livestock farmers for better food–feed supply.

5 Conclusion

This study showed that intercropping with improved cultivars of maize and cowpea optimized grain and fodder biomass production, with high-quality fodder and better weed control. Although intercropping systems are better than monocultures of each crop, Barka maize intercropped with cowpea KVx745-11P was even more efficient. This will improve the availability of quality fodder and grain for crop–livestock farmers. Intercropping and use of the improved cultivars over local cultivars is an alternative that could contribute to ensuring sustainable food–feed security for humans and livestock in an integrated crop–livestock system. Thus, for the promotion of fodder production in quantity and quality based on dual-purpose cereal and legume crops that can meet human and livestock food–feed needs in the South Sudan zone, we recommend:

✓emphasizing the promotion of Barka maize and cowpea KVx74511P intercropping
✓considering Barka and KVx745-11P for monocultures if some farmers prefer this system
✓exploring with farmers, timely harvest, and best preservation methods needed to maintain produced fodder quality.

TABLE 10 Nutritive value of maize stover as affected by cropping systems in on-station and on-farm trials.

Crop system		DM (%)	Ash (%)	CP (%)	NDF (%)	ADF (%)	ADL (%)	ME (MJ/kg)	IVOMD (%)
Monoculture	Maize Barka	93.2[a] ± 0.5	8.8 ± 1.7	9.8[a] ± 1.0	67.3[a] ± 1.5	40.0 ± 2.0	5.3 ± 0.5	7.3 ± 0.5	50.3 ± 1.5
	Maize Espoir	93.3[a] ± 0.5	8.3 ± 1.0	8.5[bc] ± 0.6	69.3[a] ± 1.0	40.5 ± 2.0	5.3 ± 0.5	7.0 ± 0.0	50.0 ± 0.8
	Maize Barka*	92.0[b] ± 0.0	11.7 ± 2.2	8.8[bc] ± 0.8	63.2[b] ± 3.0	40.3 ± 2.3	4.8 ± 0.8	7.3 ± 0.5	51.3 ± 3.1
Intercropping	Maize Barka and cowpea Tiligré	93.5[a] ± 0.6	7.5 ± 0.6	9.5[a] ± 1.0	72.3[a] ± 3.6	40.8 ± 1.9	5.5 ± 0.6	7.0 ± 0.0	48.0 ± 2.7
	Maize Barka and cowpea KVx745-11P	93.3[a] ± 0.5	10.5 ± 3.8	9.8[a] ± 1.0	69.3[a] ± 3.3	42.3 ± 3.8	5.3 ± 0.5	7.0 ± 0.1	48.3 ± 2.4
	Maize Espoir and cowpea Tiligré	93.3[a] ± 0.5	9.5 ± 4.4	7.5[c] ± 0.6	70.5[a] ± 2.9	43.3 ± 3.4	5.5 ± 0.6	7.3 ± 0.5	48.0 ± 2.6
	Maize Espoir and cowpea KVx74511P	93.0[a] ± 0.0	7.7 ± 1.0	7.8[c] ± 1.0	70.0[a] ± 2.6	41.3 ± 2.5	5.0 ± 0.0	7.0 ± 0.0	49.3 ± 1.3
	Maize Barka and cowpea KVx745-11P*	91.8[b] ± 0.5	11.0 ± 2.4	8.4[bc] ± 1.6	65.8[b] ± 1.8	41.6 ± 2.1	4.8 ± 0.5	7.4 ± 0.6	50.4 ± 2.0
Statistic	*F*-value	11.38	1.9	3.03	6.13	0.78	1.17	0.90	1.48
	p-value	0.00	0.10	0.01	0.00	0.61	0.35	0.52	0.22

*, on-farm trials.
ADF, acid detergent fiber; ADL acid detergent lignin; CP, crude protein; DM, dry matter; IVOMD, in vitro organic matter digestibility; ME, metabolizable energy; NDF, neutral detergent fiber.
Values with the same letters in the same column are identical (p ≤ 0.05).

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

AS: study concept and methodological design, data analysis, field work for data collection, and first draft of the manuscript, and its revision and editing. NZ: contributed to the study's concept and methodological design, data analysis, and first draft of the manuscript, and its revision and editing; was a PhD candidate adviser; and took part in country project co-ordination. AK: contributed to the study's concept and methodological design, manuscript revision and editing, and is a PhD research supervisor. SS and KT: contributed to data collection and curation. ER, JD, and KB: contributed to the study's concept and methodological design, manuscript revision, and manuscript editing. AA: contributed to manuscript revision and editing, project co-ordination and fundraising. All authors contributed to the article and approved the submitted version.

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Conflict of interest

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