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On-Farm Evaluation on Yield and Economic Performance of Cereal-Cowpea Intercropping to Support the Smallholder Farming System in the Soudano-Sahelian Zone of Mali

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Abstract: Cereal-cowpea intercropping has become an integral part of the farming system in Mali. Still, information is lacking regarding integrated benefits of the whole system, including valuing of the biomass for facing the constraints of animal feedings. We used farmers' learning networks to evaluate performance of intercropping systems of millet-cowpea and sorghum-cowpea in southern Mali. Our results showed that under intercropping, the grain yield obtained with the wilibali (short maturing duration) variety was significantly higher than the yield obtained with the sangaranka (long maturing duration) variety whether with millet (36%) or sorghum (48%), corresponding, respectively, to an economic gain of XOF (West African CFA franc) 125 282/ha and XOF 142 640/ha. While for biomass, the yield obtained with the sangaranka variety was significantly higher by 50% and 60% to that of wilibali with an economic gain of XOF 286 526/ha (with millet) and XOF 278 516/ha (with sorghum). Total gain obtained with the millet-cowpea system was significantly greater than that obtained with the sorghum-cowpea system by 14%, and this stands irrespective of the type of cowpea variety. Farmers prefer the grain for satisfying immediate food needs instead of economic gains. These results represent an indication for farmer's decision-making regarding cowpea varieties selection especially for addressing household food security issues or feeding animals.

Keywords: intercropping; cropping systems; Sub-Saharan Africa; millet and sorghum; diversification

1. Introduction

In Mali, millet (*Pennissetum glaucum* (L.) R. Br.) and sorghum (*Sorghum bicolor* (L.) Moench) represent 1/3 of all crops and contribute mainly to the food security of the population, especially in rural areas [1,2]. Cowpea (*Vigna unguiculata* (L.) Walp.) is largely produced by farm households as a staple food crop, and with 22 to 30% protein content, it has become a major source of low-cost nutrition for the urban and rural poor who cannot afford meat and milk products [3]. Cowpea varieties are divided into early- (wilibali variety) or medium-maturing types (korobalen variety); highly grain-productive and late-maturing types; and high fodder production types (sangaranka variety). The planting date and pattern of cowpea plants vary from farmer to farmer, and the plants occupy 30 to 50% of the land area in each field [4].

Major constraints for farming systems in the region are related to high inter- and intra-annual rainfall variability resulting in recurrent droughts [5] and secondly to years of crop nutrient-mining and limited organic or inorganic resupply [6]. A high diversity of farming systems between agro-ecological and socioeconomic environments [7] and poor resource endowments of households limit options and opportunities to address specific production constraints [8]. Furthermore, many projections on West Africa's future climate prognosticate adverse impacts that are likely to lead to productivity crises unless sustainable solutions are in place. It is estimated that crop growing periods in West Africa may shorten by an average of 20% by 2050, causing a 40% decline in cereal yields and a reduction in cereal biomass for livestock [9].

Crop diversification including intercropping in this region reduces the risk of crop failure for smallholder farmers [10] by improving productivity per unit of land when compared with those of sole cropping systems [11]. This is especially true within low input, subsistence-oriented, agro-pastoral land use systems in the Sudano-Sahelian zone of West Africa [12].

Cereal-cowpea intercropping has long been practiced by smallholder farmers and has become part of the common cropping system. The traditional system of intercropping consists of mixing and planting cereals and cowpea seeds on the same hill, resulting in important inter-specific competition and low yields of the component crops. Although sole cropping of cowpea is profitable, farmers grow cowpea within a mixed cropping system because it fits well into the low input labor-intensive tradition of growing crops in the region [13] and favors greater yield on a given piece of land [14].

The land equivalent ratio index (LER) of cereal-cowpea intercropping in the region usually has a value greater than 1, indicating no detrimental competition between both crops [15].

However among several studies comparing sole cereals cropping [16], sole cowpea cropping [17], or cereal-cowpea intercropping [18], there are limited results that take into account the integrated benefits of the system, including valuing of the biomass, which has become important and widespread in the cities. Information on the monetary value of biomass in the system is scanty and less informative for supporting traders. From that perspective, whether with cereals or with cowpea, biomass has become as important as grain for human consumption.

In this study, we used the farmers' learning networks in partnership with researchers to evaluate the performance of intercropping systems of millet-cowpea and sorghum-cowpea in southern Mali. Our specific objectives were to: (i) evaluate cereal-cowpea system performance, (ii) analyze the rotation effect of cereal-cowpea intercropping, and (iii) identify economic benefits of cereal-cowpea intercropping.

2. Materials and Methods

2.1. Study Area

The study was conducted in the Soudano-Sahelian zone of southern Mali, covering the commune of Tominian (13.2857° N, 4.5908° W) and Yorosso (12.3548° N, 4.7782° W). The rainy season lasts from June to October with rainfall peaks in August. In 2016, mean seasonal rainfall in the region was 1005 mm while in 2017 seasonal rainfall was 861 mm. The number of rainy days was 51 in 2016 compared to 45 in 2017. The dry season includes a relatively cold period from November to February and a hot period lasting from March to May. The mean maximum temperature is 34 °C during the rainy season and 40 °C during the hot dry period.

Vegetation in the region is savannah with trees and shrubs, mainly from a natural regeneration system, and cultivated lands are mainly characterized by parks of Vitellaria paradoxa (shea nut tree), Parkia biglobosa (néré), and Adansonia digitata (baobab). The mean population density is 16.4 inhabitants per km^2 with a mean of 8 persons per household [19].

Cropping land is spatially dispersed and the largest share is allocated to cereal production. Sorghum (*Sorghum bicolor* (L.) Moench) and millet (*Pennisetum glaucum* (L.) R.Br.) are the main crops, representing, respectively, 38% and 32% of the cultivated area, but maize (*Zea mays* L.) is also important, covering 12%. Cereals are grown in a two- or three-year rotation with cotton (*Gossypium hirsutum* L.). Fertilizer and pesticides are mainly applied to cotton and maize. Millet and sorghum usually do not receive fertilizer but benefit in the crop rotation from previous fertilizer applications to cotton or maize.

Cattle is a key component of the mixed crop-livestock farming systems in the study area. Eighty per cent of farmers own at least one pair of oxen, a cultivator, and a seeder, and use animal traction for soil preparation, weeding, and sowing [3].

The soils are mainly Ferric Lixisols with low clay content (<10%) in the topsoil. Soils are in general moderately acidic with a pH of around 5–6 [20] and with low nutrient holding capacity and low organic matter content [21]. The fertilizer application rates recommended by agricultural research and extension services have generally proven too costly for smallholder farmers. In addition, they involve a high financial risk, which is a major factor driving decision making for smallholder farmers [22].

2.2. Field Experimentation

Experimentation was the last phase in a series of four activities focusing mainly on biophysical characterization of farm fields, farmer's dialogue on the cereal-cowpea intercropping system, technical organization, and cropping system selection by the respective farmers.

A total of 159 trials including 76 with millet and 83 with sorghum, both intercropped with cowpea, were conducted in 2016 and 2017 in 108 villages. The experimental design for each trial was arranged in a randomized block design with 4 treatments based on 3 improved cowpea varieties and the farmers' local cowpea variety. The selection of cowpea varieties was oriented towards the farmers' objectives, which were mainly based on earliness of production and availability of biomass for animal feeding. The same varieties were simultaneously tested at all sites.

The intercropping system was designed by the community based on a previous study [15] and on the farmers' experience. The implemented intercropping system consisted of 2 rows of cereals (millet or sorghum) followed by 2 rows of cowpea varieties (Table 1). Each farmer selected either millet or sorghum in combination with cowpea varieties.

Table 1. System characterization.

Crop	Variety	Time to Maturity (days)	Duration
Cowpea	Wilibali	60–65	Short
Cowpea	Korobalen	70–75	Medium
Cowpea	Sangaranka	90–100	Long
Cowpea	Local	60–70 and 90–100	Short and long
Sorghum	Jakumbè (CSM63E)	90–100	Medium
Millet	Toroniou	90–100	Medium

Field plot size for each treatment was 100 m^2. For cereals (millet and sorghum) and cowpea varieties (wilibali and korobalen), the inter-row distance was 0.75 m, with a within-row plant distance of 0.4 m because of erected stem character and small space occupation rate. For sangaranka and local varieties, within-row plant distance was 0.8 m and the inter-row distance was 0.75 m. These varieties are creeping crops with large space occupation rates. The distance between adjacent cereal and cowpea rows was 0.75 m. All crops were thinned (2 plants/hole) at 15 days after planting to achieve the recommended planting densities.

Planting dates mostly occurred in June. Weeding was carried out before 20 days after planting and again between 30 and 40 days after planting (Table 2), i.e., weeding was completed twice for each field.

Based on the national recommendation and the farmers' common practice, an average of 100 kg/ha of diammonium phosphate (18-46-0) was applied between 15 and 20 days after planting. To protect crops from enemies, particularly cowpea, water-based Neem [23] was spread between 35 and 45 days after planting (DAP) for the first application and between 50 and 55 DAP for second application.

Table 2. Cropping management (days after planting, DAP) under cowpea intercropping with millet and sorghum in southern Mali.

Crop	Year	Planting Date	1st Weeding (DAP)	2nd Weeding (DAP)	Fertilizer Application (DAP)	Biopesticide Treatment 1 (DAP)	Biopesticide Treatment 2 (DAP)
Millet	2016	12/07 ± 8.2	19.0 ± 6.6	34.3 ± 7.9	21.9 ± 5.7	36.0 ± 6	53.8 ± 15
Sorghum		15/07 ± 6.7	19 ± 10.6	35.83 ± 13.5	21.56 ± 9.5	46.30 ± 18.7	58.00 ± 22
Millet	2017	13/07 ± 7.3	18.0 ± 6.4	35.5 ± 8.4	18.3 ± 6.8	35.4 ± 10.6	49.7 ± 9.6
Sorghum		12/07 ± 6	17.8 ± 12.6	34.54 ± 12.3	16.34 ± 5.8	40.60 ± 19.1	55.88 ± 19.2

Rotation effect was determined based on the crop cultivation calendar for the previous three years. In total, the effects of three types of rotation, i.e., cereal-cereal, cereal-legume, and cereal-cotton, on yield were analyzed using an unbalanced design regression model. The cereal consisted of millet, sorghum, or maize while the legume consisted of groundnut or cowpea.

2.3. Measurement

The timing of different operations including planting, weeding, harvesting, and fertilizing was recorded by field technicians. Crop physiology status such as flowering and maturity dates was also collected. At crop maturity, farmers harvested the total area of the plot with the assistance of the researchers. Mature millet and sorghum plants were harvested following the local practice of cutting the panicles and bagging. Legume pods were harvested when mature. Biomass of all crops was weighed at the plot, and a sub-sample was taken for weighing. Millet ears, sorghum panicles, and legume pods were dried on a clean floor at the homestead and were threshed and hand-winnowed; legume pods were shelled by hand. Grains were weighed and grain sub-samples were taken and weighed as well. All sub-samples (grain and biomass) were dried and re-weighed to determine dry weights in kg/ha.

2.4. Statistical Analysis

Because of the varied number of experiments per village, across villages, and per year, we used an unbalanced design using the GenStat regression model for the variables mean separation. Firstly, ANOVA was performed to separately evaluate the simple effect of cowpea grain yield with cowpea biomass yield under intercropping with millet and sorghum. Secondly, for the purpose of economic analysis, we compared yield of grain to biomass under intercropping with each of the two cereals and their respective interactions with varieties. Treatment structure consisted of either grain or biomass variables for varieties per crop and their respective interactions with the year, representing the annual rainfall effect. Villages were considered as replicate. Significant means were separated using average standard error of difference (SED). We also used Box plots for capturing the distribution of variables.

2.4.1. System Gain

To determine system economic gain per hectare, we used a gross margin (GM) analysis model that is equal to the difference between total revenue (TR) and total variable cost (TVC) and is expressed as follow:

$$GM\ (\pi) = \sum TR - \sum TVC \quad (1)$$

Total revenue means the total market price of production per hectare multiplied by the crops' yields (grain or biomass) while TVC includes mainly input costs such as insecticide, fertilizer, and ploughing. The system economic gain was expressed in West African CFA franc (XOF).

2.4.2. Farmers' Ranking of Cowpea Varieties

A total of 30 farmers (18% of the total) participated to the prioritization of the cereal-cowpea intercropping systems using a paired comparison scaling method. Each farmer was requested to provide a weighted score for cowpea grain, biomass, and total income. The respective scores were multiplied by the number of scores for each cowpea variety to obtain a total weighted score that was then divided by the total number of respondents to obtain the weighted mean score (WMS). Rank order was given according to the WMS values.

3. Results

3.1. Yield of Grain and Biomass of Cowpea under Intercropping with Millet and Sorghum

Grain yield distribution of cowpea varieties under intercropping with millet showed that in the 25% trial, yields of korobalen and sangaranka were less than 100 kg/ha while in the 75% trial, yields were below 400 kg/ha (Figure 1). In contrast, in the 25% trial for wilibali, yields of korobalen and sangaranka were less than 200 kg/ha while in the 75% trial, yields were below 500 kg/ha. Grain yield distribution for the local variety varied from 100 kg/ha to 500 kg/ha. Statistical analysis of cowpea grain yield showed that the best yield was obtained with the wilibali variety, which was significantly higher than that of the the sangaranka variety with a difference of + 150 kg/ha (Table 3). This result did not change over years or with varieties.

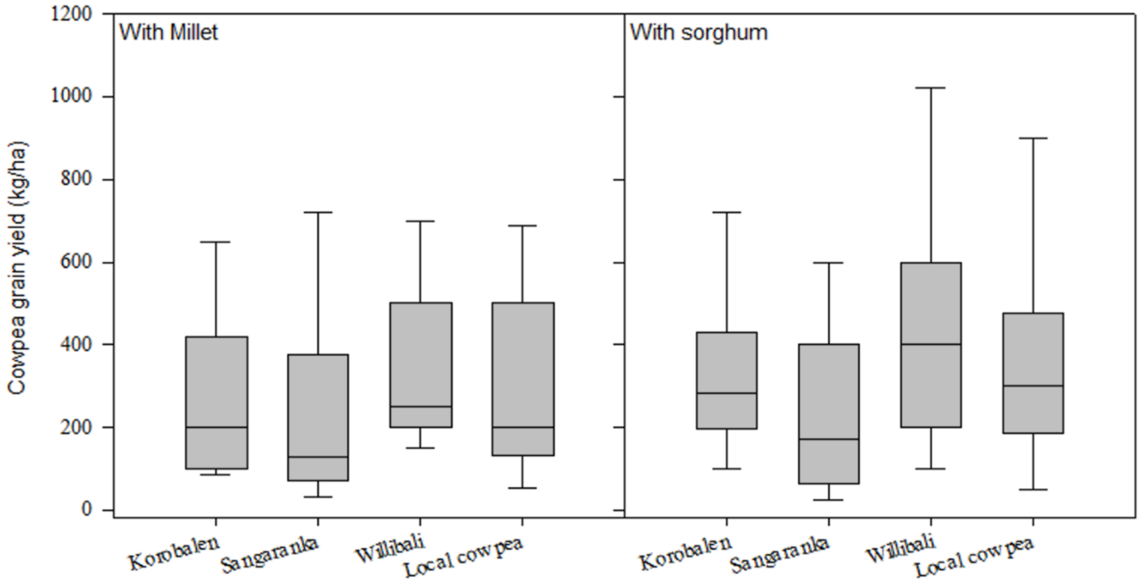

Figure 1. Cowpea grain yield under intercropping with millet and sorghum in southern Mali.

For cowpea biomass, there was great variability depending on varieties (Figure 2). Distribution showed that 75% of the biomass yield of korobalen and the local variety was below 1400 kg/ha, while for the sangaranka yield, distribution was higher and varied from 900 kg/ha to 2200 kg/ha. Cowpea biomass yield obtained with wilibali varied less (500 kg to 1000 kg/ha). Statistical analysis indicated that the best biomass yield was obtained with sangaranka, which was significantly higher than that obtained with korobalen, wilibali, or the local variety, with a difference of 482 kg/ha, 820 kg/ha, and 721 kg/ha, respectively (Table 3). Comparing grain yield to biomass showed that biomass yield of cowpea was statistically higher than that of grain yield ($p < 0.05$). Interaction between grain and biomass yield with cowpea varieties was significant, indicating that performance of grain or biomass yield depends on cowpea varieties. Thus, under intercropping with millet, the cowpea grain yield obtained with the wilibali variety was statistically higher to that with sangaranka while its biomass yield was significantly higher compared to that of wilibali.

Table 3. Cowpea yield (kg/ha) under intercropping with millet and sorghum in southern Mali.

	Cowpea Yield with Millet Intercropping				Cowpea Yield with Sorghum Intercropping			
	DF	Grain	DF	Biomass	DF	Grain	DF	Biomass
Village	36	-	39	-	38	-	38	-
Cowpea variety	3	-	3	-	3	-	3	-
Korobalen		310.3		1154		382.6		1125
Sangarakan		261.1		1637		253.2		1592
Wilibali		417.6		815		475.5		659
Local cowpea		317.2		913		386.1		1012
v.r		2.69		13.58		4.38		17.78
p-value		0.04		0.001		0.003		0.001
SED		54.53		140.6		66.79		126.9
Year 2016	1	337.9		1171	1	416.8		1212
Year 2017		319.5		1068		331.9		964
P-value Year		0.79		0.57		0.22		0.10
Interaction of cowpea and Year	3	0.78		0.95	3	0.23		0.51
p-value cowpea grain vs. biomass			0.001			0.001		

DF: Degrees of Freedom.

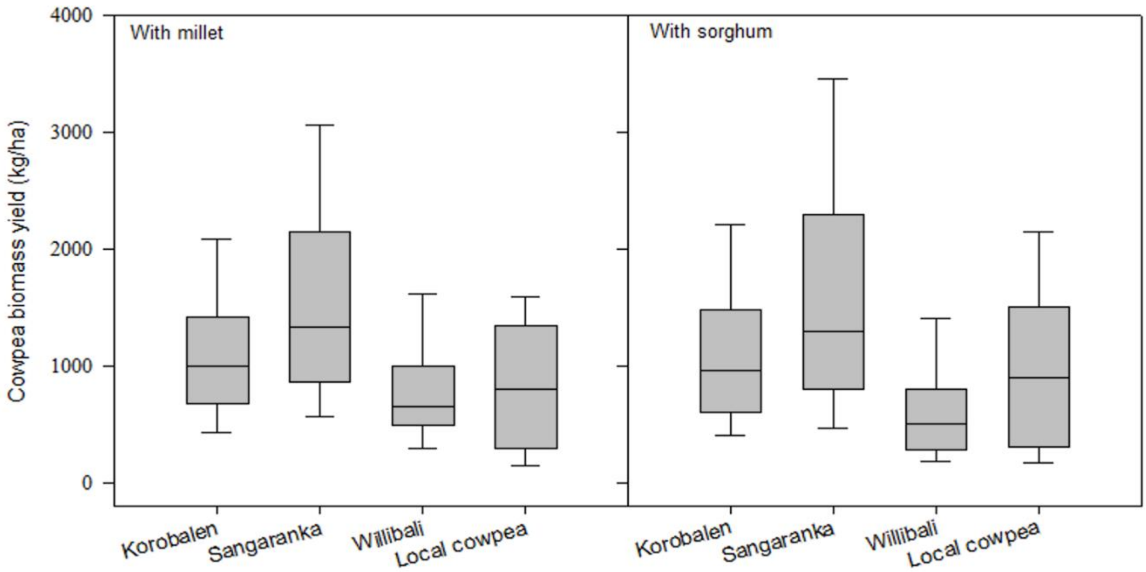

Figure 2. Cowpea biomass yield (kg/ha) under intercropping with millet and sorghum in southern Mali.

With sorghum intercropping (Figure 1), cowpea yield distribution was similar to that with millet except in the 75% trial, where the yield of wilibali was lower, 600 kg/ha, compared to 500 kg/ha with millet. Grain yield obtained with the wilibali variety was 25% and 15% significantly higher than the yields obtained with the sangaranka and local varieties (Table 3). Interaction effect of cowpea yield under intercropping with sorghum and year was not significant. For cowpea biomass (Figure 2) when intercropped with sorghum, the yield obtained with sangaranka was significantly higher by 30% and 25%, respectively, for wilibali and korobalen and by 45% for the local variety. Interaction effect of year with cowpea varieties was not significant, indicating that difference in cowpea biomass is not related to a particular year.

3.2. Grain and Biomass Yield of Millet and Sorghum under Intercropping with Cowpea Varieties

Grain yield of millet and sorghum varied similarly irrespective of cowpea varieties. With cowpea varieties, in the 25% trial, millet and sorghum grain yield was less than 300 kg/ha while 50% of yield was between 300 kg/ha and 900 kg/ha (Figure 3). Millet grain yields were statistically similar with a mean of 577 kg/ha regardless of intercropping with cowpea varieties (Table 4). For millet biomass (Figure 4), 50% of the biomass yield varied from 1500 kg/ha to 6300 kg/ha with a mean of 4033 kg/ha. The biomass yield difference within cowpea varieties was not significantly different while the year effect was significant ($P < 0.05$) whether with grain or with biomass yield. In 2016, millet grain yield was 636 kg/ha and was higher by 20% to that of 2017, while biomass yield was 5415 kg/ha in 2016 and was higher by 48% to that of 2017. For sorghum, grain yield was 621 kg/ha and yield difference under intercropping with cowpea varieties were not statistically significant ($P > 0.05$) (Table 4). For sorghum biomass, mean yield was 2923 kg/ha and differences under cowpea varieties was statistically significant. However, year effect was significant for biomass yield. In 2016, mean sorghum biomass yield was 4298 kg/ha and higher by 63% to that obtained in 2017.

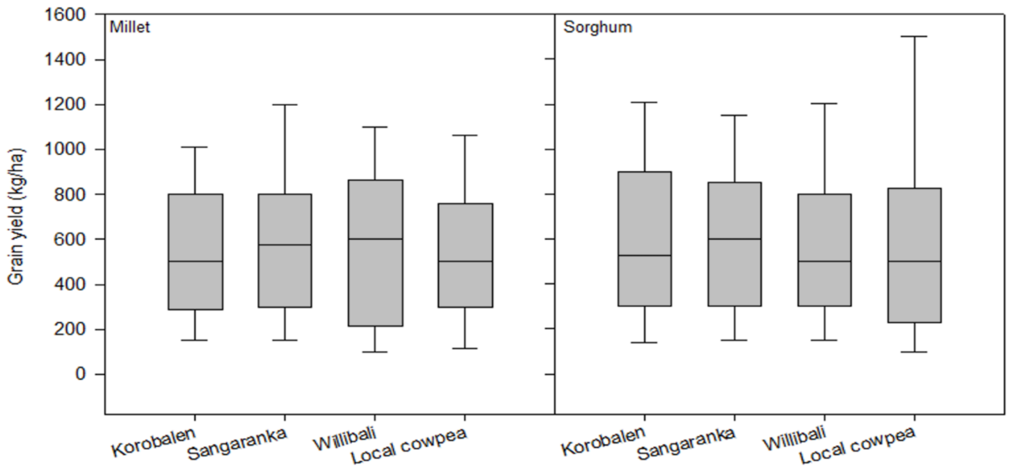

Figure 3. Grain yield of millet and sorghum under intercropping with different varieties of cowpea in southern Mali.

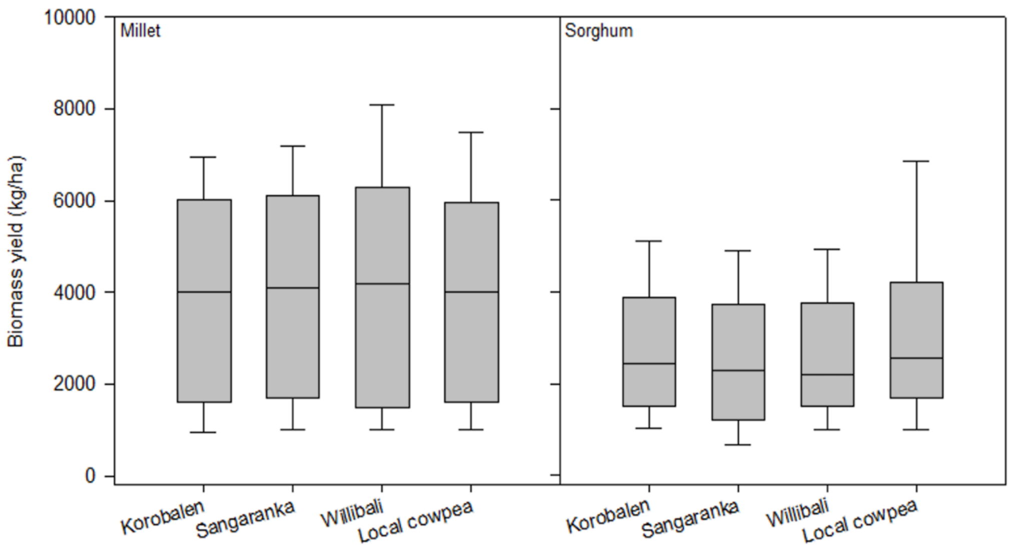

Figure 4. Biomass yield (kg/ha) of millet and sorghum under intercropping with different cowpea varieties in southern Mali.

Table 4. Yield (kg/ha) of millet and sorghum under intercropping with cowpea varieties in southern Mali.

	Millet Yield with Cowpea Intercropping				Sorghum Yield with Cowpea Intercropping			
	DF	**Grain**	**DF**	**Biomass**	**DF**	**Grain**	**DF**	**Biomass**
Village	37	-	31	-	37	-	37	-
Cowpea variety	3	-	3	-	3	-	3	-
Korobalen		561.5		3916		616.7		2793
Sangarakan		612.9		4061		638.8		2821
Wilibali		596.5		4117		617.3		2773
Local cowpea		538.9		4040		612		3308
v.r		1.33		0.28		0.09		3.02
p-value		0.27		0.84		0.96		0.03
SED		40.98		228		57.01		206
Year 2016	1	635.7		5415	1	632.9		4298
Year 2017		511.5		2795		610.3		1563
p-value Year		0.01		0.001		0.75		0.001
Interaction of crop and Year	3	0.37		0.44	3	0.64		0.678
p-value grain vs. biomass			0.001				0.001	

DF: Degrees of Freedom.

3.3. *Effect of Crop Rotation on Intercropping*

Separation of the effects of crop rotation and/or inter-cropping from continuous cereal showed that there are additional benefits to crop yield if crops are rotated with cash crop or at least intercropped with legume crops. For sorghum, the yield obtained after cereal-legume and cotton-cereal rotation was significantly higher than the yield obtained with cereal-cereal rotation (Table 5). For the systems with millet and sorghum biomass, the yield obtained after cotton-cereal and cereal-legume rotation was significantly higher than the yield obtained after the cereal-cereal rotation.

Table 5. Performance of millet and sorghum under intercropping with cowpea and according to type of rotation in 37 villages.

Rotation	**Millet Yield from Intercropping with Cowpea**		**Sorghum Yield from Intercropping with Cowpea**	
	Grain	**Biomass**	**Grain**	**Biomass**
Cereal-Cereal	529.3	4808	448	2445
Cereal-Legume	624.8	5359	694.6	2871
Coton-Cereal	588.1	6470	711.9	3689
P-value	0.227	0.001	0.001	0.001
SED	72.69	504.5	82.18	335.3

3.4. *Economic Gains*

3.4.1. Gains with Cowpea Grain and Biomass under Intercropping with Millet and Sorghum

Results showed that grain gain per hectare with cowpea varieties under intercropping with millet varied accordingly. Higher gain with cowpea grain was obtained with millet-wilibali system (XOF 125 282/ha) which was significantly higher than gain obtained with korobalen, sangaranka and local variety by respectively 26%, 37% and 24% (Table 6).

For cowpea biomass under intercropping with millet, gain obtained was statistically different ($p < 0.05$). Mean biomass gain obtained (XOF 286 526/ha) with sangaranka was significantly higher than those obtained with the korobalen, wilibali and local variety respectively by 30%, 50% and 44 % (Table 6).

Table 6. Gain /ha from grain and biomass of cowpea under intercropping with millet and sorghum. The values are expressed in actual currency of West African, the Franc CFA (XOF).

	Cowpea Gain with Millet Intercropping				**Cowpea Gain with Sorghum Intercropping**			
	DF	**Grain**	**DF**	**Biomass**	**DF**	**Grain**	**DF**	**Biomass**
Village	36	-	39	-	38	-	38	-
Cowpea variety	3	-	3	-	3	-	3	-
Korobalen		93,085		201,908		114,782		196,880
Sangarankan		78,341		286,526		75,972		278,516
Wilibali		125,282		142,559		142,640		115,284
Local cowpea		95,160		159,726		115,821		177,179
v.r.		2.69		13.58		4.38		17.78
p-value		0.04		0.001		0.005		0.001
SED		16,683		24,851		20,038		21,658
Year 1	1	101,371	1	204,889	1	125,027	1	212,039
Year 2		95,839		186,971		99,561		168,648
p-value year		0.79		0.58		0.22		0.10
Interaction of cowpea and Year	3	0.78	3	0.62	3	0.23	3	0.51
p-value grain vs. biomass			0.001				0.001	
p-value inter. grain and biomass cowpea variety			0.001				0.001	

DF: Degrees of Freedom.

By comparing gain obtained with cowpea grain to that of biomass under intercropping with millet, results show that gain with biomass (XOF 195 791/ha) was significantly greater than that of grain by 49%, corresponding to a difference of XOF 95 480/ha. However, this difference varied according to the intercropping systems which is due to the significant effect of interaction between gain from grain and biomass according to cowpea varieties. As consequence, greater biomass gain was obtained with the system millet-sangaranka while it has low gain from grains and alternatively best gain from grains was obtained with the system mil-wilibali while it has low biomass gain.

With sorghum, greater grain gain was obtained with the system sorghum-wilibali (XOF 142 640/ha) which was significantly higher ($p < 0.05$) than the gains obtained with the sorghum-sangaranka, sorghum-korobalen and local variety by 47%, 20%, and 19%, respectively (Table 6). On the other hand, with the biomass, greater gain was obtained with the sorghum-sangaranka which was statistically higher than the gain obtained with the sorghum-wilibali, sorghum local variety and sorghum-korobalen, by 59%, 36% and 29%, respectively.

By comparing the two variables grain and biomass under intercropping with sorghum, results showed that mean gain of XOF 187 649/ha obtained with biomass was significantly greater than that obtained with grain by 38% corresponding to a difference of XOF 71 025 /ha.

As with millet system, there was a significant effect of the interaction between grain and biomass gains based on cowpea varieties under intercropping with sorghum. Thus, greater biomass gain was obtained with the sorghum-sangaranka while it has the lowest gain from grains. Moreover, greater gain from grain was obtained with the sorghum-wilibali system while it has the lowest biomass gain.

3.4.2. Gain with Millet and Sorghum in Intercropping with Cowpea

Results showed that gain obtained with millet grain as well biomass in intercropping with cowpea was not statistically significant whatever cowpea variety (Table 7). However, gain obtained with biomass was significantly greater than that obtained with the grain by 75%, regardless cowpea variety. With regards to sorghum, yield was not significant unlike for biomass where system sorghum-wilibali had lowest gain. Gain obtained with biomass was greater than that obtained with the grain by 74% and this stands whatever cowpea varieties.

Table 7. Gain of grain and biomass/ha for millet and sorghum under intercropping with cowpea varieties. The values are expressed in actual currency of West African, the Franc CFA (XOF).

	Millet Gain/ha under Intercropping with Cowpea				Sorghum Gain/ha under Intercropping with Cowpea			
	DF	**Grain**	**DF**	**Biomass**	**DF**	**Grain**	**DF**	**Biomass**
Village	37	-	24	-	37	-	37	-
Cowpea variety	3	-	3	-	3	-	3	-
Korobalen		88,874		301,989		96,825		349,087
Sangarankan		96,490		299,626		100,286		352,600
Wilibali		94,299		276,184		96,923		346,667
Local cowpea		85,150		286,654		96,092		413,483
v.r		1.28		0.40		0.09		3.02
p-value		0.28		0.75		0.96		0.03
SED		6503		25,811		8951		25,806
Year 2016	1	100,419		263,817	1	99,367	1	537,295
Year 2017		80,832		297,775		95,814		195,343
p-value year		0.02		0.78		0.75		0.001
Interaction of cowpea and Year	3	0.34	3	0.08	3	0.64	3	0.67
p-value grain vs. biomass		0.001				0.001		

DF: Degrees of Freedom.

3.4.3. Total Economic Gain per System

By comparing the two systems, total gain obtained with millet-cowpea system was significantly greater than that obtained with sorghum-cowpea system by 14% corresponding to a difference of XOF 123 676/ha and this stands irrespective the type of cowpea variety (Table 8). For both systems millet and sorghum, total gain varied significantly from year to year. In 2016, for millet-cowpea system, mean gain was XOF 1124389/ha and was 39% higher than that obtained in 2017. For sorghum-cowpea system mean gain in 2016 was XOF 954 739/ha and was 49% higher than that of 2017.

Table 8. Total gain/ha of the system millet-cowpea and sorghum-cowpea. The values are expressed in actual currency of West African, the Franc CFA (XOF).

	DF	Total Gain/ha (Millet and Cowpea)	DF	Total Gain/ha (Sorghum and Cowpea)
Village	28	-	36	-
Cowpea variety	3	-	3	-
Korobalen		879,428		737,843
Sangaranka		994,643		800,579
Wilibali		863,508		691,568
Local cowpea		853,056		737,606
v.r		1.95		2.13
p-value		0.12		0.09
SED		63,516		49,408
Year 2016	1	1124,389	1	954,739
Year 2017		686,145		484,574
p-value Year		0.001		0.001
Interaction of crop and Year	3	0.19	3	0.29
p-value total gain of millet vs. sorghum	1		0.009	
p-value inter. income of millet and sorghum and cowpea variety	3		0.81	

DF: Degrees of Freedom.

4. Discussion

4.1. Yield Variation under Intercropping with Cereal

Although cowpea is of vital importance to the livelihoods of most Malian farmers, we found that whether with millet or sorghum, cowpea yields were low, and 75% of the yields were less than 500 kg/ha. This result is similar to that of [24], supporting that cowpea grain yields in farmers' fields can be below 300 kg/ha.

In the study area, soil fertility is low, including low organic carbon and especially P deficiency, which may limit cowpea yield through growth limitation and impaired pod formation and N fixation [25]. We found high variability in yield whether with millet, sorghum, or cowpea varieties. This can be due to agricultural practices variability, which may depend on farm resource endowment status. A farm with appropriate equipment can benefit more from the first rain for earlier planting, while a delay in planting, especially with a low resource farm type, may result in significant yield penalty. Furthermore, variability in soil fertility management across the region can also result in yield variations as can biotic factors such as the presence of trees, which varied from 10 to 40 trees per farm ha depending on field topographic position [26].

4.2. Cowpea Varieties under Intercropping

By comparing cowpea varieties under intercropping, the best yield was obtained with the wilibali variety, whether with millet or sorghum and whatever the year, and this was mainly due to the shortness of time to crop maturity. This variety can be harvested in as little as 60–80 days and therefore can avoid the seasonal late water-stress that mostly occurs in September.

With the potential of a short growing season, the wilibali variety enables households to have grains for consumption or sale during the "hungry period", especially when grain reserves from the previous cereal harvests were reduced and current crops are still not ready to be harvested. On the other hand, the best biomass yield was obtained with sangaranka, because the long duration of maturity time maximized the thermal temperature sum. With the high biomass yielding potential, the sangaranka variety offers opportunities for animal feeding, especially in the zones where grazing has become increasingly rare due to the expansion of cropping fields [27] and the poor quality of grazing [27].

Given local farming constraints, each of the two products grain or biomass offers opportunities for each farmer. Thus, farmers with less sufficient financial or technical means (land, equipment, etc.) for farming and whose primary objective is for food for their families can select the wilibali variety. In contrast, farmers with sufficient technical background, means for farming, and with many animals can select the sangaranka variety because of the high potential biomass production for animal feeding.

Regarding millet and sorghum, we found that grain yields varied similarly whatever the cowpea variety and there was no difference among cereal grains and biomass yields due to cowpea varieties. In similar regions intercropped with a legume, cereal grain yields may increase up to 55% compared to cereal alone [28] through improvement of the soil moisture due to soil covering, which limits evapotranspiration [29]. However, research has demonstrated that in some cases, intercropping may reduce cereals yields by 10% due to increased competition for resources [30]. This points out challenges related to setting adapted management strategies, in particular, planting date offsets between the main and secondary crops depending on the start and variability of the seasonal rainfall.

4.3. Cereal-Cowpea Rotation

For farmers, selection of cereals to consider in the rotation depends on the current fertility level as of the soil as well as on the households' capacity to produce organic manure [31]. Beyond grain for human consumption and fodder for animals feeding, the cowpea system plays an important role in soil fertility by maintaining and improving nutrient availability [32]. We found that cereal grain and biomass yield obtained after cereal-legume and cotton-cereal rotation were higher compared to that obtained with cereal-cereal rotation. Enhanced cereal yield following legume planting can be attributed to enhanced phosphorus (P) nutrition for cereals through improving soil chemical P availability and microbiologically increased P uptake [32]. Cereal-legume rotation contributes to soil P restoration and nitrogen (N) availability, especially in acidic soils, which are found in most of Sahelian, where P was found to be a major constraint to crop growth [33]. With a crop rotation system, soil bacterial communities have greater species diversity than under continuous cultivation with the same crop [33].

Cotton-cereal rotation represents 35 to 40% of the cropping system in southern Mali [34]. In the study area, cotton was introduced as an alternative source of cash for farmers, but also to allow other crops to benefit from the system. Our results show greater yields of millet and sorghum after cotton-cereal rotation, which is certainly due to the residual fertilizer effects [35]. This result indicates the importance of cotton in achieving food security for smalholder farmers. Furthermore, cotton provides access to fertilizer through credit schemes from cotton companies, to which farmers would not have access otherwise, and which are crucial for sustained crop productivity [35]. The result also reflects the need of direct application of mineral fertilizer on millet or sorghum. With application of only 3 g as a microdose, the yield of millet and sorghum increased by 70% and 52%, respectively [36]. The onus is on policymakers and extension workers to promote the use of the microdosing technique under cereal cropping, especially in the regions where cotton is driving the system.

4.4. Economic Performance of the Cereal-Cowpea System and Farmers' Perceptions

We found that whether intercropping with millet or sorghum, the greatest gain for grain was obtained with the wilibali variety while greatest gain for biomass was obtained with the sangaranka variety. This is mainly due to the highest grain and biomass yield obtained, respectively, with wilibali and sangaranka varieties. However, this gain can be subject to variation depending particularly on market opportunities regarding the price variation from ± 20 to 30% across the same year for cereal and cowpea grain in the region [37].

The results represent an indication for farmer's decision-making regarding cowpea varieties selection, especially for addressing house food security issues or feeding animals. Furthermore, although cowpea biomass gain is greater than cowpea grain, the farmers' choice is usually geared towards grains for satisfying immediate food needs. This is supported by farmers' preferential classification (Table 9), under which grains and biomass come as a priority before immediate economic gain. Selling cowpea grain is not a priority for farmers, but it occurs, especially when there is surplus production because of a good rainfall pattern or when there is a social emergency requiring cash. Profitability of the cereal-cowpea production system depends mainly on farm size, family labor, seed access and quality, as well as fertilizer and crop protection strategies [38].

Table 9. Farmer's evaluation and selection of technology.

	Karobalen	Sangaranka	Willibaly	Local Cowpea	Noted	Rank for Grain and Biomass
Biomass	12.48	12.39	6.63	11.13	10.50	II
Grain	12.03	14.39	24.63	13.65	17.02	I
Gross margin	0.83	0.88	1.40	0.89	1.04	III
Total noted	25.35	27.67	32.66	25.66		
Rank	III	II	I	III		

Our results show that by comparing the two systems, the total gain obtained with the millet-cowpea system was significantly greater than that obtained with the sorghum-cowpea system, and this stands whatever the type of cowpea variety. This is explained by the millet biomass, which we found to be 28% greater than that of sorghum. However, variation of biomass between millet and sorghum may depend on the variety and the date of planting [16]. A variety with a long maturing duration with an earlier planting date may produce more biomass with higher revenue. While a short maturing duration variety may result in low biomass revenue even with an earlier planting date.

In the cereal system of southern Mali, attribution of crop per surface does not only depend on satisfying a household's food needs or revenue but may also rely on food preferences based on the cultural education [39].

5. Conclusions

Whether intercropping with millet or sorghum and whatever the seasonal rainfall, the best grain yield was obtained with the wilibali (short maturing duration) variety and the best biomass yield was obtained with the sangaranka variety, which is a long-maturing duration variety. The study revealed strong trade-offs between household food opportunity and animal feeding and economic gain regarding cereal-cowpea intercropping in southern Mali. The knowledge generated revealed opportunities for alleviating some of the trade-offs and achieving more promising farming decisions based on specific farm needs. Farmers selected cereal in intercropping with short maturing duration such as the wilibali variety to mainly address household food needs at specific periods corresponding to food shortages. While for those farmers prioritizing animal feeding, especially agro-pastoralists, the sangaranka variety was the best option. On the other hand, from an economic point of view, millet intercropping with cowpea is more profitable than sorghum intercropping with cowpea. Yield variability and low yields of both cereals and cowpea for all varieties combined indicates opportunities for improvement in both research and farming.

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