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Sorghum and cowpea productivity as influenced by tillage, cropping system with soil amendment in Centre-West Region of Burkina Faso

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Abstract

Improving crop productivity requires integrated management of soil fertility. This study aimed to assess the effects of tillage and the cropping system with soil amendment on the productivity of sorghum and cowpea. The experimental design was a completely randomized block with the treatments arranged in a split plot and three repetitions. Four tillage methods were allocated to the main plots and four cropping systems combined with four types of soil amendment were allocated to the sub plots. The results showed that ploughing and tied-ridging generated higher grain yields of sorghum than minimum tillage and manual zaï. The two cropping systems 1) 2 rows of sorghum alternated with 2 rows of semi-erect habit cowpea and 2) 1 or 2 row(s) of sorghum alternated with 1 or 2 row(s) of creeping habit cowpea in interaction with soil amendments generated higher grain yields for sorghum ranging from 895 to 1097 kg ha^{-1} and stover yields ranging from 1913 to 2370 kg ha^{-1} in the third year of study. Minimum tillage and ploughing proved to be more efficient in improving cowpea grain yields in the cropping system of 1 row of sorghum alternated with 1 row of creeping cowpea with soil amendment. These results show that tillage and crop association with soil amendments are likely to optimize agricultural productivity.

Keywords: Burkina Faso; Compost; Crop association; Yield of sorghum and cowpea

1 Introduction

Burkina Faso is an agricultural country whose agriculture occupies an important place in the national economy. The primary sector, and particularly agriculture, employs 56.2% of people in the country [1] even though the performance of this sector has decreased these recent years. Thus, the contribution of crop production to the Gross domestic product (GDP) formation had fallen from 21% in 2018 to 16.2% in 2021 [2]. This poor agricultural performance is the main cause of food insecurity in the country [3]. Sorghum [*Sorghum bicolor* (L) Moench)] and cowpea [*Vigna unguiculata* (L.) Walp] occupy an important place in the crop rotation systems used by farmers. Sorghum is one of the most important cereals grown in West Africa, ranking second among cereal crops grown in Burkina Faso in terms of total grain production in 2020 and 2021 [4]. This crop is very often produced using sole cropping system or intercropped with cowpea which is increasingly constituting the main cash crop for women.

However, production of sorghum and cowpea faces many global constraints such as the precariousness of the agroecosystem due to the continuous degradation of the soil [5], land pressure, climate change and the non-adoption of

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good farming practices thus leading to the low soil fertility status [6-12]. In addition, the security crisis in the country these recent years is negatively affecting the agricultural sector. Indeed, farmers in rural areas are being forced to abandon their arable land and move to more secured areas mainly in big cities, therefore leading to overpopulation of cities and more land pressure. In addition, the irregularity and poor distribution of rainfall affect crop productivity resulting in a decrease in quantitative crop production [12]. Thus, the intensification of the agricultural sector while insuring sustainable preservation of natural resources becomes a must. Past investigations have shown the contribution of tillage, cropping systems that associate cereal and legume crops to improving crop yields (sorghum, millet, maize and cowpea). For example, Palé *et al*. [13] pointed out that, in the sudano-sahelian zone of Burkina Faso, the use of ploughing as a tillage method resulted in an increase of pearl millet grain yield from 266 to 635 kg ha^{-1} and stover yield from 381 to 601 kg ha^{-1}. In addition, Ouédraogo *et al.* [12] showed from on-farm study that a technological package composed of stone bunds, zaï and NPK+ Urea generated sorghum grain yield increase ranging from 5.66% to 44.45% in 2018 and from 25.15% to 53.80% in 2019 compared to farmer practice. Furthermore, Zongo *et al*. [14] reported a significant increase of +10 to 58% in total grain yields of sorghum and cowpea compared to sole sorghum with high efficiency in nutrient acquisition by sorghum in sorghum/cowpea system.

The objective of this investigation was to assess the effects of tillage, cropping system with soil amendment on sorghum and cowpea productivity and recommend practices that will help improve grain and stover yields for the two crops. Achieving such an objective will allow small household farmers in the sudano-sahelian zone of Burkina Faso to improve their food security and incomes.

2 Material and methods

2.1 Study site

The study was conducted at the Saria Environmental and Agricultural Research Station (12° 16' N lat; 2° 09' W long) in the province of Boulkiemdé located 80 km West of Ouagadougou, the capital of Burkina Faso (Figure 1). Experiment was laid out in 2020, 2021 and 2022 under rainfed conditions. The site is located in the sudano-sahelian climate zone with a short rainy season from May to October and a dry season from November to April. The climate is characterized by large variations in temperature, wind, rainfall, humidity and evaporation. The inter-season variation in annual rainfall over the last ten years (2013 to 2022) was observed in the area with an average of 887.80 mm (meteorological data from the Saria Environmental and Agricultural Research Station for the period 2013 to 2022; Source: Saria Station). The annual total rainfalls recorded in the study area were 1045.8 mm in 2020, 719.5 mm in 2021 and 1174.8 mm in 2022. A drop in annual cumulative rainfall of 31.20% was observed in 2021 compared to 2020 and 38.75% compared to 2022.

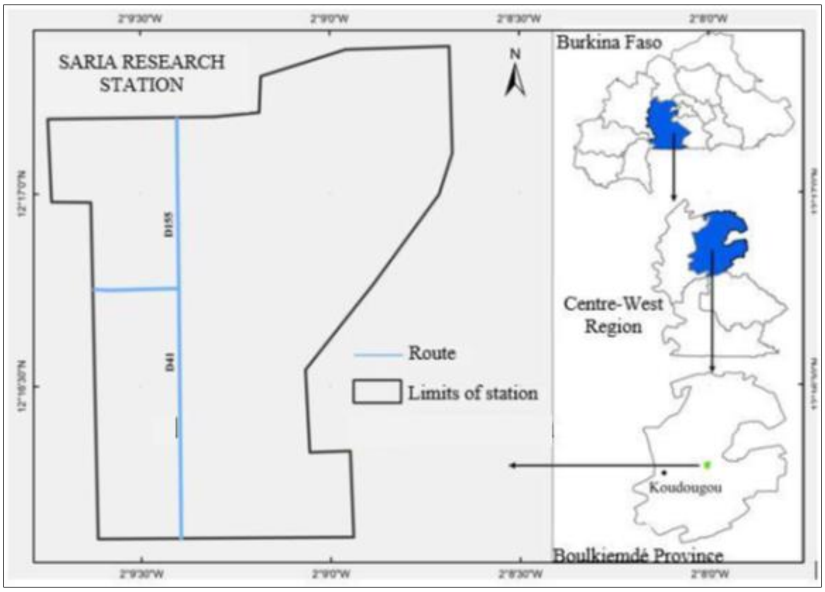

Figure 1 Map showing the Saria Research Station (drawn by Abdel Kader DRAME, 2021)

During the growing seasons (May to October) from 2020 to 2022, monthly rainfall variations were observed depending on the year (Figure 2). The heaviest rainfall was recorded in the months of July (341.2 mm) and August (281.5 mm) during the growing season of year 2020. In 2021, it was recorded in June (139.5 mm) and August (272.9 mm). Rainfall was higher in August (341.1 mm) and September (316.7 mm) for the year 2022. Minimum monthly temperatures ranged from 15.21 to 27.53 °C in 2020 with an annual average of 21.58 °C, while the maxima ranged from 30.74 to 40.43 °C in 2020 with an annual average of 35.42 °C. In 2021, monthly minimum temperatures ranged from 14.61 to 27.25 °C with an annual average of 21.66 °C, while the maxima were between 31.18 and 41.16 °C with an annual average of 36.21 °C. In 2022, these monthly minimum temperatures ranged from 10.94 to 27.99 °C with an annual average of 21.96 °C. The maxima of the temperature in the 2022-year ranged from 31.01 to 45.06 °C, with an annual average of 37.48 °C. The experiment was conducted on a Lixisol [15] with a shell at a depth of about 50 cm, sandy-silty texture on the surface (59.2% sand, 31.4% silt and 9.4% clay), low water holding capacity and a pH of 5.4.

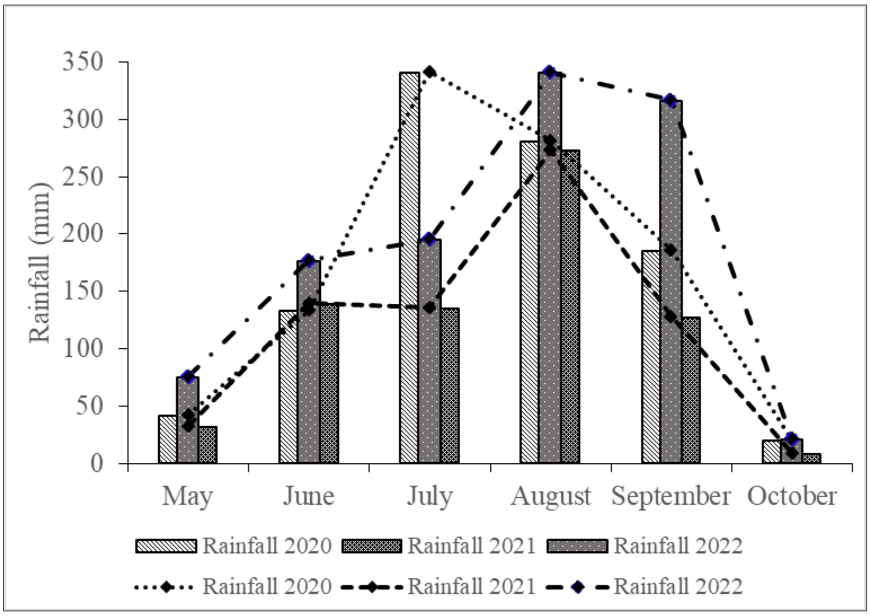

Figure 2 Monthly rainfall recorded from May through October in 2020, 2021 and 2022 at Saria Research Station, Burkina Faso

2.2 Plant material

The plant material used was composed of a sorghum variety named Sariaso 14 and two cowpea varieties which are Nerwaya (or KVX 780-6) and Moussa Local. The Sariaso 14 is a dual-purpose sorghum variety (grain and fodder) developed by the Institute of Environment and Agricultural Research (INERA) with a 110-day vegetative cycle and recommended for the sudano-sahelian zone. The cowpea variety Nerwaya was also developed by INERA. It is a semi-erect variety with a 70-day cycle and a lower soil coverage rate than Moussa Local. The cowpea variety Moussa Local is also developed by INERA from a variety traditionally used by farmers and which has the same morphological traits as the traditional local varieties. It is a creeping variety with a vegetative cycle of 75 to 80 days and a very high soil coverage index which explains its use in this study.

2.3 Fertilizers

The compost produced at the Saria research station was the organic fertilizer used in the experiment. This compost contained 15.27% total carbon (Ctot), 1.40% total nitrogen (Ntot), 2.98% total phosphorus (Ptot), 0.64% total potassium (Ktot) and a pH of 8.1. Mineral fertilizers were NPK (14N-23P-14K-6S-1B) and urea (46% N).

2.4 Experimental design, treatments and field management

The experiment was conducted in 2020, 2021 and 2022. A randomized complete block design with split plot arrangement of treatments and three replications was used to conduct the experiment. Four (04) tillage methods (TM) were allocated to the main plots and four (04) cropping systems (CS) combined with four (04) different soil amendments (SA) allocated to the subplots (Table 1). The elementary plot size was six (06) m long and four (04) m wide and plots were separated by a 1-m wide alley. The compost was broadcasted on the plots receiving the organic fertilizer before minimum tillage, ploughing and tied-ridging methods. In the manual zaï plots, compost was applied in the pits.

For all tillage methods, compost was applied in the plots before planting. Planting was done in alternate rows of sorghum and cowpea at a recommended spacing of 80 cm between rows and 40 cm within rows for both crops. Plantings were done during the second week of July in 2020, last week of July in 2021 and last week of June in 2022.

Table 1 Levels of tillage method, cropping system and soil amendment in 2020, 2021 and 2022, Saria, Burkina Faso

Tillage method (TM)						
TM1 = *Minimum tillage*						
TM2= Ploughing using oxen drawn plough called CH9 that penetrates the soil beyond 15 cm soil depth						
TM3= Tied-tied-ridging. Ridges were made before planting along the planting rows using oxen drawn ridger; ties were made manually at 100 cm distance using manual hoes one month after planting						
TM4= Manual Zaï (traditional) with holes made along the planting rows with 10 to 15 cm depth and 20 to 40 cm diameter for the pit						
Cropping system (CS)						
CS1 = 2 rows of sorghum alternated with 2 rows of semi-erect cowpea						
CS2 = 2 rows of sorghum alternated with 2 rows of creeping cowpea						
CS3 = 1 row of sorghum alternated with 1 row of semi-erect cowpea						
CS4 = 1 row of sorghum alternated with 1 row of creeping cowpea						
Soil amendment (SA)	**N**	**P_2O_5**	**K_2O**	**S**	**B**	**Compost**
	-------------------kg ha^{-1}-----------------------					
SA1 = No amendment	0	0	0	0	0	0
SA2 = 2500 kg compost ha^{-1}yr^{-1}	-	-	-	-	-	2500
SA3 = 100 kg NPK (14-23-14-6S-1B) ha^{-1}+ 50 kg Urea (46% N) ha^{-1}	37	23	14	6	1	0
SA4 = 2500 kg compost ha^{-1} yr^{-1} + 100 kg NPK (14-23-14-6S-1B) ha^{-1}+ 50 kg Urea (46% N) ha^{-1}	37	23	14	6	1	2500
Combinations of cropping systems with soil amendments (CS/SA) CS1/SA1 = 2 rows of sorghum alternated with 2 rows of semi-erect cowpea with no amendment CS1/SA2 = 2 rows of sorghum alternated with 2 rows of semi-erect cowpea+ compost CS1/SA3 = 2 rows of sorghum alternated with 2 rows of semi-erect cowpea+ NPK +Urea CS1/ SA4 = 2 rows of sorghum alternated with 2 rows of semi-erect cowpea+ compost + NPK + Urea CS2/SA1 = 2 rows of sorghum alternated with 2 rows of creeping cowpea with no amendment CS2/SA2 = 2 rows of sorghum alternated with 2 rows of creeping cowpea+ compost CS2/SA3 = 2 rows of sorghum alternated with 2 rows of creeping cowpea+ NPK +Urea CS2/SA4 = 2 rows of sorghum alternated with 2 rows of creeping cowpea+ compost + NPK + Urea CS3/SA1 = 1 row of sorghum alternated with 1 row of semi-erect cowpea with no amendment CS3/SA2 = 1 row of sorghum alternated with 1 row of semi-erect cowpea+ compost CS3/SA3 = 1 row of sorghum alternated with 1 row of semi-erect cowpea+ NPK +Urea CS3/SA4 = 1 row of sorghum alternated with 1 row of semi-erect cowpea+ compost + NPK + Urea CA4/SA1 = 1 row of sorghum alternated with 1 row of creeping cowpea with no amendment CS4/SA2 = 1 row of sorghum alternated with 1 row of creeping cowpea+ compost CS4/SA3 = 1 row of sorghum alternated with 1 row of creeping cowpea+ NPK +Urea CS4/SA4 = 1 row of sorghum alternated with 1 row of creeping cowpea+ compost + NPK + Urea						

The two crops were simultaneously planted with thinning done to 1 to 2 plants per hill after emergence. In each year, NPK was applied 14 days after planting (DAP) using the micro dose technique consisting of placing the fertilizer close to the plant. Urea was also brought to sorghum plants, 35 to 40 DAP using this micro dose technique. Mineral fertilizer rates were 100 kg ha^{-1} NPK + 50 kg ha^{-1} urea (46% N). The applied compost rate was 2500 kg ha^{-1} per year. The traditional hoe or "daba" was used for weeding the plots when necessary. K-Optimal [Lambda-cyhalothrin (15 g/L) + Acetamiprid (20 g/L)] at a dose of 1 L ha^{-1} mixed with 300 L of water was used every year, at flower bud and pod formation stages, to control cowpea aphids (*Aphis craccivora* Koch).

2.5 Data collection

Data collection concerned grain and stover yields for both crops, 1000-seed weight for sorghum and 100-seed weight for cowpea. Harvests were done at physiological maturity of the crops. Each year, sorghum panicles and stover, cowpea pods and stover from each plot were hand harvested, dried, threshed (sorghum panicles and cowpea pods) and weighted for yield determination. Sorghum 1000-seed and cowpea 100-seed weights were also determined.

2.6 Statistical analysis of data

A Microsoft Excel spreadsheet was used to record the data collected over the three years. Statistical analysis of the data collected was performed using SAS/STAT® software, version 9 [16]. Effects were declared significant at probability value ≤ 0.05. Pearson correlation analysis was done on yield data and rainfall to detect possible linkages.

3 Results

3.1 Effects of the tested factors on the measured parameters

Analysis of variance (ANOVA) of the effects of the tested factors showed that sorghum grain and stover yields were affected by the interactive effects of year and tillage ($P < 0.01$). Moreover, the ANOVA showed a remarkable influence of the interactive effect of year and cropping system with soil amendment (CS/SA) ($P < 0.01$) on these yields. The 1000-seed weight of sorghum was influenced by year ($P < 0.01$) and CS/SA ($P < 0.01$). Results also indicated that the influence of the tested factors on cowpea yields was similar to that on sorghum yields. Indeed, cowpea grain and stover yields were significantly affected by the year and tillage interaction ($P < 0.01$) and year by CS/SA interaction ($P < 0.01$). The 100-seed weight for cowpea was also affected by the year and tillage interaction ($P < 0.01$), year by CS/SA interaction ($P < 0.01$). Interactive effects of year by tillage, year by CS/SA ($P < 0.01$ for the two interactions) were observed on the 100-seed weight for cowpea.

3.2 Interactive effect of year and tillage on sorghum grain and stover yields

Table 2 Year (Y) x tillage method (TM) effects on grain (Gr) and stover (St) yields of sorghum produced in 2020, 2021 and 2022, Saria, Burkina Faso. [Analysis of variance probability (P): $Gr_{Y*TM} < 0.01$; $Gr_{Y} < 0.01$; $Gr_{TM} = 0.27$; $St_{Y*TM} < 0.01$; $St_{Y} < 0.01$; $St_{TM} = 0.30$]

Tillage method	2020	2021	2022	Mean
	---------------- Grain yield (kg ha^{-1}) ----------------			
Minimum tillage	132 ^{bB}	44 ^{aB}	386 ^{cA}	187 ^{b}
Ploughing	188 ^{abB}	23 ^{aC}	747 ^{aA}	320 ^{a}
Tied-ridging	279 ^{aB}	28 ^{aC}	632 ^{bA}	313 ^{a}
Manual zaï	176 ^{abB}	27 ^{aC}	636 ^{abA}	280 ^{a}
Mean	194 ^{B}	31 ^{C}	600 ^{A}	
Stover yield (kg ha^{-1})				
Minimum tillage	621 ^{bB}	287 ^{aC}	949 ^{cA}	619 ^{b}
Ploughing	671 ^{bB}	296 ^{aC}	1719 ^{aA}	895 ^{a}
Tied-ridging	938 ^{aB}	223 ^{aC}	1471 ^{bA}	877 ^{a}
Manual zaï	654 ^{bB}	315 ^{aC}	1560 ^{abA}	843 ^{a}

Mean	721 B	280 C	1425 A	

† Values followed by the same small letter in a column and capital letter in a row are not significantly different at P ≤ 0.05.

Results from ANOVA indicated that the use of tied-ridging (TM3) significantly increased sorghum grain and stover yields in 2020 compared to minimum tillage (TM1) (Table 2). In 2020 (or year of intermediate rainfall), the additional gains generated by TM3 compared to TM1 were 111.36% for grain and 51.05% for stover. In 2021 (or year of lower rainfall) grain and stover yields were low but similar no matter the tillage method used. In 2022 (or year of higher rainfall), ploughing (TM2) was more efficient, allowing a significant increase in sorghum grain and stover yields, compared to TM1 and TM3. The gaps in sorghum yields in 2022 due the use of TM2, when compared to TM3, were 18.20% for grain and 16.86% for stover. In addition, compared to TM1, results indicated that TM2 generated additional grain yield of 93.52% and stover yield of 81.14% in 2022. The effects of manual zaï (TM4) on yields varied depending on the growing seasons. Considering globally the average grain and stover yields of sorghum from the three growing seasons, TM2, TM3 and TM4 performed better than TM1 with significant increases in sorghum yields. However, these yields varied largely from year to year and were significantly higher in 2020 and 2022 than in 2021. The 2021 growing season was particularly affected by drought at the beginning and end of the season.

3.3 Interactive effect of year and cropping system with soil amendment on sorghum grain and stover yields

Results showed that among the cropping systems with soil amendment treatments, CS4/SA4 (1 row of sorghum alternated with 1 row of creeping cowpea + compost + NPK + Urea) was more efficient in sorghum production, resulting in a significant increase in grain yield and stover yield for sorghum no matter the growing season. In 2022, the application of CS1/SA4 (2 rows of sorghum alternated with 2 rows of semi-erect cowpea + compost + NPK + urea) and CS2/SA4 (2 rows of sorghum alternated with 2 rows of creeping cowpea + compost + NPK + Urea) resulted in similar yields with CS4/SA4. These combinations generated the highest sorghum grain yields ranging from 895 to 1097 kg ha^{-1} compared to the other combinations with yields of 272 to 880 kg ha^{-1} (Table 3). Results had also indicated higher stover yields generated by CS1/SA4, CS2/SA4 and CS4/SA4 which ranged from 1913 to 2370 kg ha^{-1} compared to the other CS/SA producing yields of 684 to 1657 kg ha^{-1}(Table 4). These increases in sorghum yields are on average 87.25% for grain and 69.36% for stover compared to the thirteen other CS/SA. Also, in 2022, fertilization that excluded combined NPK + urea and compost had a depressing effect on sorghum grain and stover yields. For all three growing seasons, despite the rainfall variation (succession of low and high rainfall), CS1/SA4, CS2/SA4 and CS4/SA4 greatly contributed to production of higher sorghum grain yields ranging from 399 to 509 kg ha^{-1} and stover yield from 1056 to 1309 kg ha^{-1}.

Table 3 Year (Y) x cropping system with soil amendment (CS/SA) effects on sorghum grain yield produced in 2020, 2021 and 2022, Saria, Burkina Faso. [Analysis of variance probability (P): $P_{Y*CS/SA} < 0.01$; $P_{Y} < 0.01$; $P_{CS/SA} < 0.01$]

Cropping System	Soil amendment	2020	2021	2022	Mean
		-------------------------- Kg ha^{-1}--------------------------			
CS1	SA1	156 bAB	24 aB	326 cA	168 c
	SA2	133 bB	21 aB	656 bA	270 bc
	SA3	131 bB	15 aB	491 bcA	212 c
	SA4	282 abB	19 aC	895 aA	399 ab
CS2	SA1	91 bAB	20 aB	272 cA	128 c
	SA2	166 abB	16 aB	602 bA	261 bc
	SA3	348 abA	35 aB	548 bcA	310 bc
	SA4	307 abB	76 aC	901 aA	428 ab
CS3	SA1	43 bB	12 aB	277 cA	111 c
	SA2	238 abB	18 aB	567 bA	274 bc
	SA3	79 bB	29 aB	468 bcA	192 c
	SA4	162 bB	45 aB	880 abA	363 b
CS4	SA1	176 abB	20 aB	485 bcA	227 c

	SA2	200 ^{abB}	26 ^{aB}	654 ^{bA}	294 ^{bc}
	SA3	202 ^{abB}	73 ^{aB}	475 ^{bcA}	250 ^{bc}
	SA4	387 ^{aB}	43 ^{aC}	1097 ^{aA}	509 ^{a}
Mean		194 ^{B}	31 ^{C}	600 ^{A}	

† Values followed by the same small letter in a column and capital letter in a row are not significantly different at P ≤ 0.05.

Table 4 Year (Y) x cropping system with soil amendment (CS/SA) effects on sorghum stover yield produced in 2020, 2021 and 2022, Saria, Burkina Faso. [Analysis of variance probability (P): $P_{Y*CS/SA} < 0.01$; $P_{Y} < 0.01$; $P_{CS/SA} < 0.01$]

Cropping System	Soil amendment	2020	2021	2022	Mean
		-------------------------- Kg ha^{-1}-------------------------			
CS1	SA1	422 ^{bcAB}	197 ^{aB}	843 ^{dA}	487 ^{d}
	SA2	564 ^{bcB}	259 ^{aB}	1657 ^{bcA}	827 ^{bc}
	SA3	778 ^{abB}	226 ^{aC}	1235 ^{cdA}	746 ^{c}
	SA4	972 ^{abB}	284 ^{aC}	1913 ^{bcA}	1056 ^{b}
CS2	SA1	419 ^{bcAB}	156 ^{aB}	747 ^{dA}	441^{d}
	SA2	581 ^{bcB}	154 ^{aB}	1543 ^{cA}	759 ^{c}
	SA3	1208 ^{aA}	404 ^{aB}	1392 ^{cdA}	1001^{b}
	SA4	1143 ^{aB}	545 ^{aC}	1987 ^{abA}	1225 ^{ab}
CS3	SA1	231 ^{cB}	149 ^{aB}	684 ^{dA}	355 ^{d}
	SA2	674 ^{bB}	246 ^{aB}	1308 ^{cdA}	743 ^{c}
	SA3	510 ^{bcB}	213 ^{aB}	1114 ^{cdA}	613 ^{cd}
	SA4	676 ^{bB}	335 ^{aB}	1932 ^{bA}	981 ^{bc}
CS4	SA1	551 ^{bcB}	233 ^{aB}	1058 ^{dA}	614 ^{cd}
	SA2	791 ^{abB}	213 ^{aC}	1652 ^{bcA}	886 ^{bc}
	SA3	878 ^{abB}	450 ^{aB}	1297 ^{cdA}	875 ^{bc}
	SA4	1135 ^{aB}	423 ^{aC}	2370 ^{aA}	1309 ^{a}
Mean		721 ^{B}	280 ^{C}	1425 ^{A}	

† Values followed by the same small letter in a column and capital letter in a row are not significantly different at P ≤ 0.05.

Results from the ANOVA also indicated that the cropping systems integrating inorganic and organic fertilizers (NPK, urea and compost) had a positive influence on the 1000-seed weight regardless of the type of association (Figure 3). However, the cropping system composed of 2 rows of sorghum alternated with 2 rows of creeping cowpea with application of compost + NPK + urea largely increased yields compared to the CS/SA. Indeed, this combination generated higher 1000-seed weights compared to the combinations of 1 or 2 row(s) of sorghum alternated with 1 or 2 row(s) of cowpea without fertilizer (CS4/SA1, CS2/SA1, CS3/SA1 and CS1/SA1).

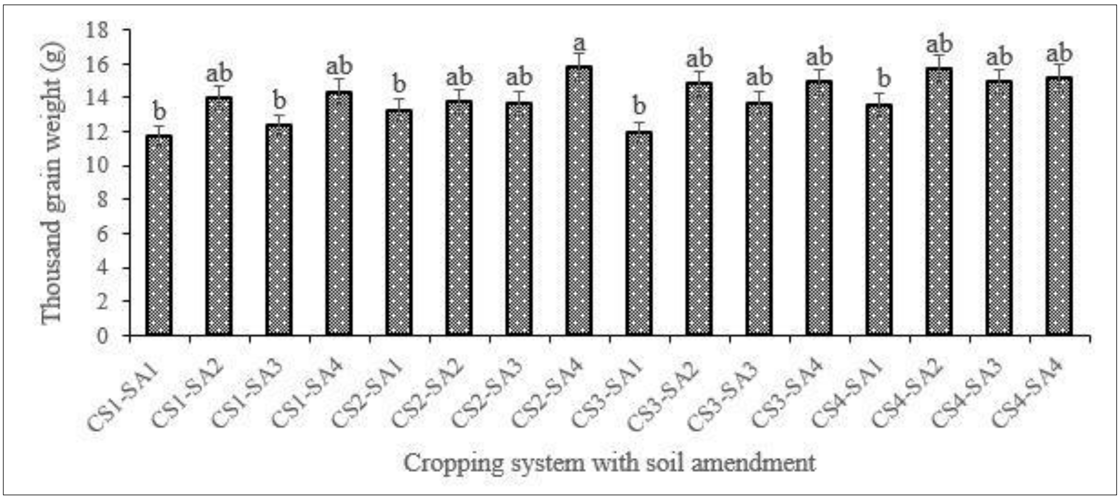

Figure 3 Effect of cropping system with soil amendment on sorghum 1000-grain weight, Saria, Burkina Faso, 2020, 2021 and 2022 ($P < 0.01$)

On average over all the combinations, the 1000-seed weights were higher in 2022 (year of higher rainfall) than in 2020 (year of intermediate rainfall and 2021 (year of lower rainfall).

Person correlations showed a strong and positive relationship between sorghum grain yields and annual and monthly rainfall as well. Thus, increases in yields were observed in years of higher rainfall than in 2021 which was short in terms of cumulative annual rainfall. However, only the correlations between monthly rainfall in May and grain yields ($P = 0.04$; $R = 0.998$) and between rainfall in September and grain yields ($P = 0.01$; $R = 0.999$) were significant.

3.4 Interactive effect of year and tillage on cowpea grain and stover yields, and 100-seed weight

Table 5 Year (Y) x tillage method (TM) effects on cowpea grain yield and 100-seed weight produced in 2020, 2021 and 2022, Saria, Burkina Faso. [Analysis of variance probability (P): $Gr_{Y*TM} < 0.01$; $Gr_{Y} < 0.01$; $Gr_{TM} = 0.01$; 100-seed weight $_{Y*TM} < 0.01$; 100-seed weight $_{Y} < 0.01$; 100-seed weight $_{TM} = 0.05$]

Tillage method	2020	2021	2022	Mean
	---------------- Grain yield (kg ha^{-1}) ---------------			
Minimum tillage	264 ^{abB}	205 ^{aB}	751 ^{aA}	407 ^{a}
Ploughing	206 ^{bB}	204 ^{aB}	732 ^{aA}	381 ^{ab}
Tied-ridging	294 ^{aB}	116 ^{bC}	628 ^{bA}	346 ^{b}
Manual zaï	106 ^{cB}	147 ^{abB}	633 ^{bA}	295 ^{c}
Mean	217 ^{B}	168 ^{C}	687 ^{A}	
	100-seed weigth (g)			
Minimum tillage	18.96 ^{aA}	17.75 ^{aB}	15.11 ^{aC}	17.27 ^{a}
Ploughing	18.77 ^{abA}	18.10 ^{aA}	14.95 ^{aB}	17.27 ^{a}
Tied-ridging	18.33 ^{abA}	16.02 ^{bB}	15.13 ^{aC}	16.50 ^{b}
Manual zaï	18.02 ^{bA}	17.73 ^{aA}	15.59 ^{aB}	17.11 ^{a}
Mean	18.52 ^{A}	17.40 ^{B}	15.20 ^{C}	

† Values followed by the same small letter in a column and capital letter in a row are not significantly different at $P \leq 0.05$.

The results showed that for each of the tillage methods, the highest grain yields occurred in 2022 (Table 5). In 2020, the use of tied-ridging resulted in higher cowpea grain yields than those obtained in ploughed and manual zaï plots. The additional yields generated by tied-ridging compared to ploughing were 42.72% and 177.36% compared to manual zaï. Tied-rigging method was followed by minimum tillage which generated intermediate yields.

During this intermediate rainfall year of 2020, the lowest yields were observed in the zaï plots. On the other hand, in 2021 or year of lower rainfall, cowpea grain yields obtained from the tied-ridging plots were similar to those in manual zaï plots but lower than those obtained with the use of minimum tillage and ploughing. In addition, two different groups were observed in 2022. The first group composed of minimum tillage and ploughing which significantly improved cowpea grain yields compared to the second group formed by tied-ridging and manual zaï. For all three years, the results indicated that minimum tillage and ploughing were the most successful tillage methods for cowpea grain production. The use of manual zaï resulted in lower yields throughout the three years of cultivation. On average, minimum tillage generated cowpea grain yield gaps of 17.63% compared to tied-ridging and 37.97% compared to manual zaï. The average yield increase due to ploughing was 29.15% compared to manual zaï.

Similar to the cowpea grain yields, the results showed lower 100-seed weights in the zaï and tied-ridging plots in 2020 (lower rainfall year). These grain yields were similar in the higher rainfall year of 2022. Throughout the three years, minimum tillage, ploughing and manual zaï produced similar but higher 100-seed weights compared to those obtained with the use of tied-ridging.

Regarding the variation in cowpea stover yields due to the interaction effects of year and tillage, the results showed that manual zaï had a depressive effect in 2020 with lower yields compared to minimum tillage, ploughing and tied-ridging (Table 6). The differences in yields were from 72.34 to 139.36%. In 2021, cowpea stover yields were also lower with the use of tied-ridging. In 2022, a significant increase in cowpea stover yields was observed in plots where minimum tillage and ploughing were applied compared to those of tied-ridging and manual zaï. In general, ploughing had a significant impact on cowpea stover yields during the three growing seasons. In addition, the 2022 year allowed more substantial cowpea grain and stover yields.

Table 6 Year (Y) x tillage method (TM) effects on cowpea stover yield produced in 2020, 2021 and 2022, Saria, Burkina Faso. [Analysis of variance probability (P): $P_{Y*TM} < 0.01$; $P_Y = 0.03$; $P_{TM} = 0.15$]

Tillage method	2020	2021	2022	Mean
	---------------- Stover yield (kg ha^{-1}) ----------------			
Minimum tillage	162 ^{aC}	228 ^{abB}	556 ^{aA}	315 ^{ab}
Ploughing	192 ^{aC}	271 ^{aB}	564 ^{aA}	343 ^{a}
Tied-ridging	225 ^{aB}	176 ^{bB}	464 ^{bA}	288 ^{b}
Manual zaï	94^{bC}	277 ^{aB}	413 ^{bA}	261 ^{b}
Mean	168 ^{C}	238 ^{B}	499 ^{A}	

† Values followed by the same small letter in a column and capital letter in a row are not significantly different at P ≤ 0.05.

3.5 Interactive effect of year and cropping system with soil amendment on cowpea grain and stover yields and 100-seed weight

Cowpea grain and stover yields varied according to years and CS/SA (Table 7). These variations showed that CS2 and CS4 [1 or 2 row(s) of sorghum alternated with 1 or 2 row (s) of creeping cowpea] with plots receiving compost + NPK + urea generated higher cowpea grain yields compared to CS1 and CS3 [1 or 2 row(s) of sorghum alternated with 1 or 2 row(s) of semi-erect cowpea] no matter the soil amendment types. The cropping systems CS4 with soil amendment SA2 (2500 kg of compost ha^{-1} year^{-1}) and CS4 with soil amendment SA4 (2500 kg of compost ha^{-1} year^{-1} + 100 kg of NPK ha^{-1} + 50 kg of urea ha^{-1}) allowed higher grain yields of 1219 and 1003 kg ha^{-1} in 2022. Depending on the soil amendment levels, the use of CS1 and CS3 resulted in lower cowpea grain yields ranging from 360 to 889 kg ha^{-1}.

Results indicated cowpea stover yields that were largely varying during the three years of the study (Table 8). Nevertheless, CS3/SA4 (1 row of sorghum alternated with 1 row of semi-erect cowpea + compost + NPK + urea) and CS4/SA2 (1 row of sorghum alternated with 1 row of creeping cowpea + compost) produced invariable stover yields.

As in cowpea grain and stover yields, the cowpea 100-seed weight varied one year to another and from one cropping system with soil amendment to another. Contrasting effects were observed regarding years and CS/SA. However, over all three years, the use of CS/SA without fertilizer led to the lowest 100-seed weight in this study (Table 9).

Table 7 Year (Y) x cropping system with soil amendment (CS/SA) effects on cowpea grain yield produced in 2020, 2021 and 2022, Saria, Burkina Faso. [Analysis of variance probability (P): $P_{Y*SC/AS} < 0.01$; $P_Y < 0.01$; $P_{CS/SA} < 0.01$]

Cropping System	Soil amendment	2020	2021	2022	Mean
		------------------------- Kg ha^{-1}---------------------------			
CS1	SA1	105 ^{bB}	100 ^{bB}	360 ^{eA}	188 ^{d}
	SA2	105 ^{bB}	162 ^{abB}	446 ^{eA}	238 ^{d}
	SA3	145 ^{bB}	145 ^{bB}	468 ^{deA}	253 ^{cd}
	SA4	237 ^{abB}	147 ^{bB}	598 ^{deA}	327 ^{c}
CS2	SA1	251 ^{abB}	86 ^{bC}	559 ^{deA}	299 ^{cd}
	SA2	284 ^{abB}	197 ^{abB}	764 ^{cA}	415 ^{b}
	SA3	198 ^{abB}	146 ^{bB}	751 ^{cA}	365 ^{bc}
	SA4	286 ^{abB}	207 ^{abB}	777 ^{cA}	423 ^{b}
CS3	SA1	134 ^{bB}	98 ^{bB}	457 ^{eA}	229 ^{d}
	SA2	204 ^{abB}	181 ^{abB}	777 ^{cA}	387 ^{bc}
	SA3	181 ^{abB}	137 ^{bB}	605 ^{dA}	307 ^{cd}
	SA4	201 ^{abB}	211 ^{abB}	889 ^{bcA}	434 ^{b}
CS4	SA1	264 ^{abB}	120 ^{bC}	561 ^{deA}	315 ^{cd}
	SA2	318 ^{aB}	251 ^{abB}	1219 ^{aA}	596 ^{a}
	SA3	263 ^{abB}	205 ^{abB}	762 ^{cA}	410 ^{bc}
	SA4	303 ^{aB}	298 ^{aB}	1003 ^{bA}	535 ^{a}
Mean		217 ^{B}	168 C	687 ^{A}	

† Values followed by the same small letter in a column and capital letter in a row are not significantly different at P ≤ 0.05.

Table 8 Year (Y) x cropping system with soil amendment (CS/SA) effects on cowpea stover yield produced in 2020, 2021 and 2022, Saria, Burkina Faso. [Analysis of variance probability (P): $P_{Y*CS/SA} < 0.01$; $P_{Y} = 0.03$; $P_{CS/SA} < 0.01$]

Cropping System	Soil amendment	2020	2021	2022	Mean
		--------------------------- Kg ha^{-1}------------------------------			
CS1	SA1	141 ^{abB}	237 ^{bAB}	297 ^{dA}	225 ^{c}
	SA2	135 ^{abC}	278 ^{abB}	439 ^{cdA}	284 ^{bc}
	SA3	164 ^{abB}	263 ^{abAB}	328 ^{dA}	252 ^{c}
	SA4	227 ^{abB}	269 ^{abB}	496 ^{cdA}	331 ^{bc}
CS2	SA1	120 ^{abB}	150 ^{bB}	355 ^{dA}	208 ^{c}
	SA2	118 ^{bB}	192 ^{bB}	556 ^{bcA}	289 ^{bc}
	SA3	123 ^{abB}	151 ^{bB}	449 ^{cdA}	241 ^{c}
	SA4	203 ^{abB}	234 ^{bB}	668 ^{bA}	369 ^{ab}
CS3	SA1	170 ^{abB}	240 ^{bB}	396 ^{dA}	269 ^{c}
	SA2	212 ^{abB}	296 ^{abB}	533 ^{cA}	347 ^{b}
	SA3	139 ^{abB}	257 ^{abAB}	371 ^{dA}	256 ^{c}
	SA4	248 ^{aB}	375 ^{aB}	658 ^{bcA}	427 ^{a}

CS4	SA1	151 abB	180 bB	306 dA	212 c
	SA2	174 abB	247 abB	884 aA	435 a
	SA3	171 abB	231 bB	522 cdA	308 bc
	SA4	194 abB	210 bB	790 abA	398 ab
Mean		168 C	238 B	499 A	

† Values followed by the same small letter in a column and capital letter in a row are not significantly different at P ≤ 0.05.

Table 9 Year (Y) x cropping system with soil amendment (CS/SA) effects on cowpea stover yield produced in 2020, 2021 and 2022, Saria, Burkina Faso. [Analysis of variance probability (P): $P_{Y*CS/SA} < 0.01$; $P_Y < 0.01$; $P_{CS/SA} < 0.01$]

Cropping System	Soil amendment	2020	2021	2022	Mean
		---------------------------- Kg ha^{-1}-----------------			
CS1	SA1	17.42 bA	19.00 abA	14.40 bB	11.73 b
	SA2	17.92 abA	19.33 aA	14.78 abB	13.97 ab
	SA3	19.33 aA	18.75 abA	14.78 abB	12.39 b
	SA4	18.58 abA	19.08 abA	14.53 bB	14.35 ab
CS2	SA1	18.75 abA	16.42 bB	14.62 abC	13.27 b
	SA2	18.42 abA	16.50 bB	15.89 abB	13.74 ab
	SA3	18.67 abA	16.42 bB	15.76 abB	13.70 ab
	SA4	18.58 abA	16.83 bB	16.26 aB	15.79 a
CS3	SA1	18.17 abA	17.50 bA	14.56 bB	11.98 b
	SA2	18.92 abA	19.50 aA	14.73 abB	14.81 ab
	SA3	19.33 aA	19.00 abA	15.97 abB	13.72 ab
	SA4	18.67 abA	19.08 abA	15.29 abB	14.94 ab
CS4	SA1	18.17 abA	16.17 bB	14.20 bC	13.58 b
	SA2	18.58 abA	14.08 cB	15.31 abB	15.70 ab
	SA3	18.58 abA	14.17 cC	15.95 abB	14.96 ab
	SA4	18.25 abA	16.58 bB	16.22 aB	15.17 ab
Mean		18.52 A	17.40 B	15.20 C	

† Values followed by the same small letter in a column and capital letter in a row are not significantly different at P ≤ 0.05.

4 Discussion

4.1 Effects of the tested factors on the productivity of sorghum in association with cowpea

The effects of tillage in a sorghum-cowpea intercropping system with organo-mineral fertilization (100 kg ha^{-1} of NPK + 50 kg ha^{-1} of urea 46% N + 2500 kg ha^{-1} year^{-1} of compost) had an influence on sorghum production in the sudano-sahelian zone of Burkina Faso. Ploughing and tied-ridging coupled with organo-mineral fertilization was reported to improve the productivity of cereals (sorghum and millet) [13, 17, 18]. This improvement in productivity is related to the positive effect of these production practices on the chlorophyll content of cereals [18]. A substantial improvement in grain yield of sorghum obtained with the use of ploughing compared to minimum tillage (3 to 5 cm soil depth) was also observed on tropical ferruginous soil in the sudano-sahelian zone of Burkina Faso [19, 20]; which corroborates the results obtained in the present investigation which showed low yields in minimum tillage plots. The improvement of soil physical properties (structure, porosity) particularly through the use of ploughing favors the soil water functioning thus contributing to improve agricultural productivity [21 - 23].

In addition, above-ground biomass yields were very low in years with lower rainfall compared to growing seasons with higher rainfall. Therefore, the inter-seasonal rainfall variability, which is one of the major causes of the annual variability of crop yields [12], would explain the negative impact of this rainfall variability on sorghum yields in 2021 (lower rainfall year). Indeed, a drop of the annual cumulative rainfall of 31.20% was observed in 2021 compared to 2020 and 38.75% compared to 2022. Also, the occurrence of drought due to the poor distribution of precipitation would have played an important role in the variation. The occurrence of drought at the beginning of the rainy season can lead to difficult crop establishment which negatively impacts yields [24, 25]. The late planting (last week of July) of sorghum and cowpea in 2021 was due to a drought that did not allow ploughing and tied-ridging to be carried out on time leading to a late installation of the experiment and thereafter a negative impact on yields. These results corroborate those of Coulibaly *et al*. [26] who revealed the difficult construction of ploughing and tied-ridging under dry soil conditions due to pockets of drought at the beginning of the season, a situation that can considerably delay the setup of the trials. Toudou *et al*. [27] showed that on deep sandy soil in the sahelian zone of Niger, late planting which did not allow crops to benefit from optimal rainfall conditions resulted in very low pearl millet and cowpea yields when the two crops were associated.

In addition, sorghum grain and stover yields and 1000-seed weight were significantly influenced by cropping system associating sorghum and cowpea with soil amendment. This result is similar to those from previous works that revealed the cereal-legume associations to be cropping systems that improve soil and crop productivity [14, 24, 28]. The cropping system consisting of 1 or 2 row(s) of sorghum alternated with 1 or 2 row(s) of creeping cowpea and that of 2 rows of sorghum alternated with 2 rows of semi-erect cowpea with the addition of compost, NPK and urea have been shown to perform well in the improvement of sorghum grain and stover yields. Cowpea, which is a cover crop helps protect the soil against water losses by evaporation and runoff [29, 30] thus contributing to the conservation and improvement of the agronomic potentialities of the soil. The creeping cowpea variety, with a much more interesting ground cover than the semi-erect variety, performed well no matter the planting method [1 or 2 row(s) of sorghum alternated with 1 or 2 row(s) of cowpea]. However, good performances of the semi-erect variety were observed in the cropping system consisting of 2 rows of sorghum alternated with 2 rows of cowpea which provides more ground cover. In addition, cowpea being a legume crop has the ability to fix atmospheric nitrogen which is a source for additional nitrogen for both legume crop (cowpea) and cereal crop (sorghum) when associated [28, 31, 32]. Such a complementary source of nitrogen added to mineral and organic fertilizers brought to crops have been decisive in improving the yield components. Results indicated greatest 1000-seed weights and highest yield that occurred when organic and mineral fertilizers were combined and applied to the plots. As reported by previous researchers, soils in the sudano-sahelian zones of Burkina Faso are deficient in nutrients such as nitrogen and phosphorus [33, 34] and organic matter [35, 36]. Organo-mineral fertilization is therefore necessary to improve crop yields [12, 37]. However, the exclusive, excessive and uncontrolled use of mineral fertilizers presents a risk of accelerating soil acidity [19]. This is why the use of a reasonable quantity of mineral fertilizers in localized placement close to plants (microdose) is recommended [12, 17, 37, 38]. Also, the use of organic matter which plays an important role in the improvement of soil physical, chemical and biological properties [39, 40] and legume crops that have the capacity to strengthen the soil nitrogen contents [32] has been strongly recommended in the literature. Similarly, Obulbiga *et al*. [25] reported that the sorghum-cowpea association in alternating rows proved to be interesting practice that more improve crop production compared to the farmers' practices consisting of planting the two crops in the same hill or in different hills in the same row. However, Obulbiga *et al*. [25] obtained relatively modest yields due to the climate changes and the variation in planting dates. One advantage of this alternated cereal-cowpea system was a better management of the farmer's land resulting in Land Equivalent Ratio greater than one (1) for both crops [25].

4.2 Effects of factors tested on the productivity of cowpea in association with sorghum

The use of minimum tillage and ploughing resulted in higher cowpea grain and stover yields than manual zaï and tied-ridging in all years. Hundred-seed weights were generally low in the tied-ridging plots. This result could be explained by the fact that the excess water observed in zaï pits and in tied-ridging plots had negatively affected the cowpea productivity, confirming the conclusions by Dugje *et al*. [41]. The variations in cowpea yields from one year to another could be related to the rainfall irregularity observed during the three years of experimentation, as reported by Obulbiga *et al.* [25] and Ouédraogo *et al*. [12]. Therefore, the year 2021 which was particularly deficient in terms of rainfall appeared to produce low grain and stover yields regardless of the tillage method used. Moreover, similar to sorghum, the results revealed a significant variation in cowpea yields depending on the year and the cropping system with soil amendment applied. The cropping system consisting of 1 row of sorghum alternated with 1 row of creeping cowpea with compost + NPK + urea or with compost alone generated higher grain yields. The creeping cowpea variety or Moussa local, used in this study, has longer vegetative cycle (75 to 80 days) than the semi-erect Nerwaya variety (70 days). Thus, with Nerwaya, the flowering time coincided with abundant rainfall that would have had a detrimental effect on the flowers. Indeed, the flowering stage is very sensitive to excess humidity as reported by Dugje *et al*. [41]. The better performance of Moussa Local variety with higher yields in the plots where the cropping system consisting of planting 1 row of sorghum alternated with 1 row of creeping cowpea amended with compost + NPK + urea or compost only could be then related to this sensitivity. In fact, this creeping variety of cowpea which had judiciously covered and explored the soil surface in the system of 1 row of sorghum alternated with 1 row of this variety had better performed. Indeed, Taffouo *et al*. [42] argued that a better occupation of the field offers a great opportunity for cowpea to optimize its productivity. The present investigation has confirmed the depressive effects of the cereal-legume association on yields for both species due to competition for light and nutrients previously reported [14, 24, 43, 44]. On the other hand, number of studies had shown that the cultivation of cereals in association with legume crops had these advantages of increasing and stabilizing total production (cereal plus cowpea) per hectare [3, 14, 24, 28, 45, 46]. Results showed that when plots were ploughed, planted using cropping system consisting of 1 row of sorghum alternated with 1 row of creeping cowpea and amended with 100 kg ha^{-1} of NPK + 50 kg $ha^{-1}$of urea 46% N + 2500 kg ha^{-1} $year^{-1}$ of compost, higher sorghum and cowpea grain yields were obtained. Thus, such cropping system with soil amendment type could be used to improve soil and crop productivities in the sudano-sahelian zone of Burkina Faso.

5 Conclusion

The effects of tillage and the cropping system with soil amendments on the productivity of sorghum and cowpea were assessed at the Environmental and Agricultural Research Station of Saria in 2020, 2021 and 2022. From this investigation, it appeared that ploughing and tied-ridging were agricultural practices that improved sorghum grain and stover yields in a cereal-legume cropping system in interaction with organo-mineral fertilization. Intercropping consisting of alternating two rows of sorghum with two rows of semi-erect or creeping cowpea varieties and also alternating one row of sorghum with one row of creeping cowpea generated the highest sorghum grain yields. In addition, minimum tillage and ploughing proved to be more effective in improving cowpea grain yields in the system of one row of sorghum alternated with one row of creeping cowpea with soil amendment. The organo-mineral fertilization applied in the ploughed plots where sorghum was associated with cowpea has improved total yields of sorghum and cowpea in the plots receiving the cropping system consisting of one row of sorghum alternated with one row of cowpea that has high potential coverage of soil. At the end of this study, the cropping system which combined sorghum and cowpea in the ratio of one row of sorghum followed by one row of creeping cowpea variety in ploughed plots, and amended with compost and mineral fertilizers can be recommended to farmers in the sudano-sahelian zone of Burkina Faso where cereal-legume systems are traditionally practiced.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors state that there is no conflict of interest.

Authors' Contributions

All the authors contributed to the realization of this manuscript.

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