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Sorghum and Cowpea Yields as Influenced by Tillage, Soil Amendment and Cropping System in the Sudano-Sahelian Agroecological Zone of Burkina Faso

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ABSTRACT

Grain sorghum and cowpea yields are decreasing in the Sudano-Sahelian agroecological zone of Burkina Faso due to soil nutrient levels declination. Sole cropped grain sorghum (Exp. 1) and sorghum intercropped with cowpea (Exp. 2) were conducted in a randomized complete block design with split plot arrangement of treatments and three replications. The main plot was tillage method in both studies and the sub-plot was soil amendment (compost, crop residues and mineral fertilizer) in Exp. 1 and cropping system with soil amendment (compost and mineral fertilizer) in Exp. 2. The objective was to identify the best combination of tillage method, soil amendment type and cropping system to optimize sorghum and cowpea yields. For both experiments, averaged across years, yields were greater with scarifying and zaï, particularly in the higher rainfall season. Yields were lower in the lower rainfall year. In Exp. 1, zaï and scarifying produced greater grain yields. In Exp. 1 greater yield was obtained with compost + fertilizer + crop residues (C + F + CR) than no soil amendment. Yield increases ranged from 74 to 170% according to year. In Exp. 2, greater sorghum grain yields occurred with the use of zaï. Lower cowpea yields occurred in 2014 with grain yield of 424 ha^{-1} and stover yield of 644 kg ha^{-1}. Averaged across tillage methods, soil amendments showed higher grain yield in all tillage methods with C + F. In conclusion, zaï technique with C + F can be recommended for the Sudano-Sahelian Burkina Faso.

Keywords: Compost, Mineral fertilizer, Crop residues, Sole and intercrop, Scarifying, Zaï.

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INTRODUCTION

Sorghum is the main cereal crop grown in Burkina Faso, with more than 1.5 million hectares. Along with pearl millet, it is the staple diet of rural populations in the Sub-Sahelian regions (World Bank, 2019). Sorghum intercropped with cowpea is a common cropping system in the Soudano-sahelian zone of Burkina Faso. Grain sorghum and cowpea yields are decreasing (MAAH, 2016) due to soil nutrient levels declination (Ouattara et al., 2006). Past research has largely focused on single management factors and has shown sorghum grain yield to increase due to no-till (Nicou et al., 1993), ploughing (Kanton et al., 2000; Wolf et al., 2015), hand or animal scarifying of the soil surface (Serme et al., 2015), and use of zaï (Pale et al., 2009; Fatondji et al., 2001). Leaving crop residues on the soil surface has been shown to increase crop yields in most cases (Mason et al., 2015), although incorporation sometimes leads to greater yield (Rebafka et al., 1994). Composting crop residue (Ouédraogo et al., 2007) and fertilizer application rate also increase sole and intercropped sorghum (Maman et al., 2017a; Garba et al., 2018) and intercropped cowpea (Maman et al., 2017b) grain yields. Composting methods influence the magnitude of these yield responses (Traoré et al., 2018; Ouattara et al., 2018). The most common studies of two factors have been with compost or manure application in combination with mineral fertilizer. These studies have shown additive sorghum yield advantage to using compost and fertilizer together (Garba et al., 2018), but some exceptions have been documented (Youl et al., 2018; Garba et al., 2018). Sole crop sorghum yields more grain and stover than intercrops, but intercropped sorghum with cowpea often has greater system productivity and economic value (Oseni, 2010; Maman et al., 2017a; 2017b). Chianu et al. (2012), Mason et al. (2015), Partey et al. (2018), and Wolka et al. (2018) have recently summarized individual management factors on sorghum grain and stover yield. Given the present state of knowledge, research is needed to integrate individual management factors into a "package" producing optimal grain and stover yields

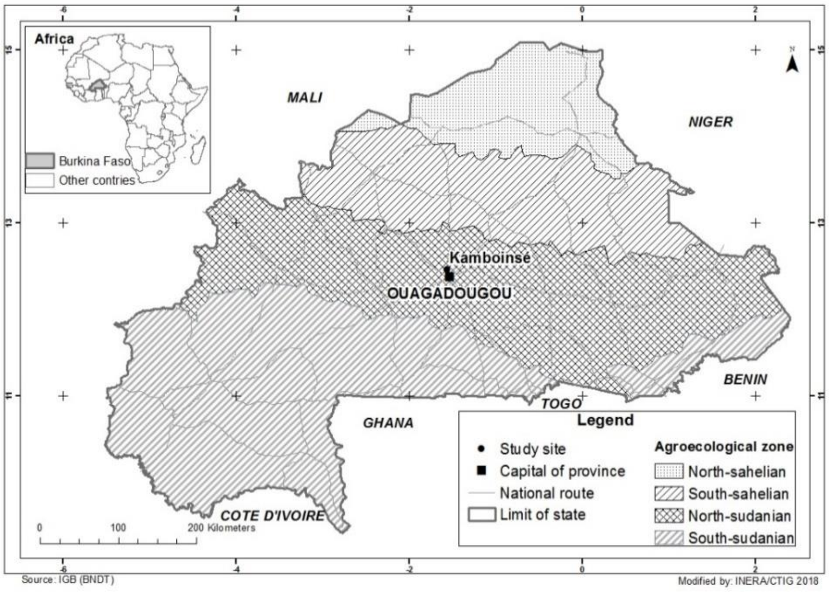

Figure 1. Map of Burkina Faso showing the Sudano-sahelian ecological zone and Kamboinsé (study site) [(*Source*: Geography Institute of Burkina Faso; rivized by the Remote Sensing and geographical Information Unit (CTIG) at the Institute of Environment and Agricultural Research (INERA), Burkina Faso, 2018).

thus leading to farmer adoption, improve sustainability and greater farmer income. The objective of this study was to identify the best combination of tillage method and cropping system with soil amendment (mineral or organic fertilizer) to optimize grain sorghum and cowpea yields in the Sudano-Sahelian agro-ecological zone of Burkina Faso. This would increase the integration of production practices helping grain sorghum and cowpea to optimize productivity to meet producer and consumer demands in Burkina Faso.

MATERIALS AND METHODS

Study Site

The study was conducted from 2011 to 2014 at the Kamboinsé Agricultural Research Station (12° 28’ 29’’ N lat; 1° 33’ 5.5’’ W long) in the Sudano-Sahelian agroecological zone of Burkina Faso (Figure 1) with total rainfall of 409 mm in 2011, 626 mm in 2012, 433 mm in 2013 and 542 mm in 2014 for months of the experiments falling between July and October. The two experiments were planted in a Little Evolved Hydromorphic Alluvial Soil with sandy loam textured surface horizon and low water holding capacity, surface horizon pH of 7.4, organic carbon (C) concentration of 2.7 g kg^{-1}, 0.08g kg^{-1} N, 1.6 mg kg^{-1} P and 105 mg kg^{-1} K (Barro and Ouattara, Institut de l’Environnement et de Recherches Agricoles, Burkina Faso, personal communication, 2011). The soil has 35% sand, 32% silt and 33% clay. The fields had been fallowed for 10 years previous to 2011.

Experimental Design

A randomized complete block design with a split-plot arrangement of treatments was used in both studies with three replications. The main plot was tillage method in both studies and the sub-plot was soil amendment (zero, compost, crop residues and mineral fertilizer) in Exp. 1 and sole and intercrop system with soil amendment (zero, compost and/or fertilizer) in Exp. 2. The treatments are presented in Table 1 and were applied to the same plots each year in both studies. Plots consisted of six rows, 10-m long. Sorghum planting was done at the recommended spacing of 80 cm between rows and 40 cm within the row with 1 or 2 plants per hill after thinning. Cowpea planting was done at the recommended density of 80 cm between rows and 40 cm within hills in the row, with 1 to 2 plants per hill after thinning. Intercrop planting was done alternating two rows of sorghum with two rows of cowpea, giving a total of four rows of sorghum and two rows of cowpea per plot. In both experiments, planting was done in July of each year. Sorghum and cowpea were simultaneously planted in Exp. 2. Weed control was done by hand hoeing as needed. In all years, 1 L ha^{-1} of Decis$^{®}$ 12 EC containing deltamethrin as the active ingredient was mixed with 50 L of water ha^{-1} and sprayed to cowpea at flower budding and pod establishment growth stages on the cowpea plants to control cowpea aphid (*Aphis craccivora* Koch).

Plant Material

The sorghum variety used in both experiments (Exp. 1 and 2) was Sariasso 11 with a maturity rating of 100 to 105 days. In sole intercrop experiment (Exp. 2), Sariasso 11 was intercropped with cowpea variety KVX 396-5-2D with a maturity rating of 65 to 70 days.

Data Collection

Harvest was done in the middle of each plot and the harvested area was 25.76 m^2 for grain sorghum in both experiments and 36.8 m^2 for cowpea in Exp. 2. Grain sorghum panicles, cowpea pods and stover from both

Table 1. Cropping system, tillage and soil amendment treatments for Experiment 1 and 2 in Kamboinsé, Burkina Faso.

Experiment 1	Experiment 2
Cropping system	
Sole cropped grain sorghum	Sole and intercropped grain sorghum and cowpea
Tillage methods	
1. No till	1. No till
2. Scarifying with Manga hoe	2. Scarifying
3. Zaï	
4. Plough	3. Zaï
Soil amendment	
1. No soil amendment	1. Grain sorghum with no soil amendment
2. Recommended compost rate of 2500 kg ha^{-1} /year broadcasted in no-zaï-plots. These 2500 kg ha^{-1} were divided by the number of zaï pits and applied.	2. Grain sorghum with recommended compost rate of 2500 kg ha^{-1} /year broadcasted in no-zaï-plots. These 2500 kg ha^{-1} were divided by the number of zaï pits and applied.
3. Recommended mineral fertilizer at the rate of 10.5 kg N ha^{-1} + 17 kg P_2O_5 ha^{-1} + 10.5 kg K_2O ha^{-1} as complete fertilizer broadcasted at planting or within one week after planting, and 23 kg N ha^{-1} as urea, broadcasted 45 days after planting.	3. Grain sorghum with recommended mineral fertilizer at the rate of 10.5 kg N ha^{-1} + 17 kg P_2O_5 ha^{-1} + 10.5 kg K_2O ha^{-1} as complete fertilizer broadcasted at planting or within one week after planting, and 23 kg N ha^{-1} as urea, applied 45 days after planting.
4. Recommended surface applied crop residues of 3.0 t ha^{-1}	4. Grain sorghum with compost and mineral fertilizers.
5. Compost and fertilizer	5. Grain sorghum/cowpea with no soil amendment
6. Compost and crop residues	6. Grain sorghum/cowpea with recommended compost
7.Fertilizer and crop residues	7. Grain sorghum/cowpea with mineral fertilizers (same rates of NPK for both crops, 23 kg N ha^{-1} as urea for grain sorghum, no urea for cowpea)
8. Compost, fertilizer and crop residues	8. Grain sorghum/cowpea with compost and mineral fertilizers (same rates of NPK for both crops, 23 kg N ha^{-1} as urea for grain sorghum, no urea for cowpea).

crops were hand-harvested, air-dried, threshed, weighted, and recorded as dry weight.

Data Analysis

Grain and stover yields were analyzed using standard analysis of variance with the General Linear Model Procedure on the software SAS/STAT®, version 9.2 (SAS Institute, 2010). Mean separation was done using pair-wise comparisons of significant interaction and main effects. Results were considered significant at $P \le 0.05$.

RESULTS AND DISCUSSION

Sorghum Grain Yield Variation

In Exp. 1, analysis of variance indicated that sorghum grain yield differences were caused by the interaction effects of Year x Tillage (Y x T) ($P < 0.01$; Table 2), Tillage Method x Soil Amendment (T x SA) ($P < 0.01$; Table 3), and Year x Soil Amendment (Y x SA) ($P < 0.01$; Table 4). Averaged across years, the scarifying with manga hoe and zaï tillage systems produced the greatest sorghum grain yield, with ploughing being intermediate, and no-till producing the lowest grain yield. Previous results indicated that sorghum grain yield in West Africa decreases with no-till (Ouédraogo et al., 2007; Obalum et al., 2011). On average, the use of the zaï tillage system produced grain yield of 279 kg ha^{-1} greater than no till and 81 kg ha^{-1} greater than the plough tillage system. On average, use of the scarifying tillage system produced a grain yield of 296 kg ha^{-1} greater than no-till and 98 kg ha^{-1} greater than ploughing. However, year variation indicated that tillage methods had no influence on grain yield in year of 2014 growing season with rainfall of 542 mm, scarifying with manga hoe and the zaï led to the highest yields in the very dry 2011 growing season with rainfall of 409 mm, scarifying with manga hoe and ploughing led to the greatest yield in the dry 2013 growing season with 433 mm, and scarifying with manga hoe and ploughing led to the greatest yield in the higher rainfall of 2012 growing season with 626 mm. These results corroborate the findings documented by Nicou et al. (1993), indicating the positive effect of scarifying on sorghum yield. Increases in sorghum yield due to the use of ploughing was shown by Kanton et al. (2000) and Ouattara et al. (2006). Sorghum grain yield across tillage systems closely followed seasonal rainfall,

Table 2. Year (Y) x tillage method (T) effects on sorghum grain yields in Exp. 1 and on grain and stover yields in Exp. 2, Kamboinsé, Burkina Faso [Analysis of variance probability in Exp. 1: Grain yield Y x T P < 0.01, Y P < 0.01, T P = 0.05. (Analysis of variance probability in Exp. 2: Grain yield Y x T P < 0.01, Y P = 0.02, T P = 0.10; Stover yield Y x T P = 0.02, Y P = 0.03, T P = 0.21).

Tillage Method	**Experiment 1**					**Experiment 2**							
	Grain					**Grain**				**Stover**			
	2011	**2012**	**2013**	**2014**	**Mean**	**2012**	**2013**	**2014**	**Mean**	**2012**	**2013**	**2014**	**Mean**
							kg ha^{-1}						
No till	275^{Bb}	679^{Ac}	423^{Bc}	818^{Aa}	549^{c}	560^{Ab}	260^{Bc}	254^{Bc}	358^{b}	2790^{Aa}	1569^{Bb}	1077^{Cb}	1812^{b}
Scarifying	692^{Ba}	946^{Ab}	862^{ABa}	880^{Aa}	845^{a}	881^{Aa}	616^{Ba}	437^{Cb}	654^{a}	3009^{Aa}	2701^{Aa}	1606^{Ba}	2439^{a}
Zaï	692^{BCa}	1132^{Aa}	644^{Cb}	843^{Ba}	828^{ab}	1059^{Aa}	408^{Cb}	657^{Ba}	708^{a}	2886^{Aa}	2426^{Aa}	1830^{Ca}	2381^{a}
Plough	157^{Cb}	1068^{Aab}	791^{Bab}	972^{Aa}	747^{b}								
Mean	454^{C}	956^{A}	680^{B}	878A		833^{A}	428^{B}	449^{B}		2895^{A}	2322^{B}	1504^{C}	

† Values followed by the same small letter in a column and capital letter in a row are not significantly different at P ≤ 0.5.

Table 3. Tillage method (T) x soil amendment (SA) effects on sole crop sorghum grain yield in Exp. 1, Kamboinsé, Burkina Faso, 2011 to 2014 (Analysis of variance probability: Grain yield T x SA P < 0.01, T P = 0.05, SA P < 0.01).

Soil Amendment	**Tillage Method**				
	Minimum	**Scarifying**	**Zaï**	**Plough**	**Mean**
		-------------------------- **kg ha^{-1}**	------------------------		
Zero	204^{Bc}	446^{ABd}	469^{Ac}	404^{ABd}	381^{e}
Compost (C)	459^{Bbc}	728^{Ac}	725^{Abc}	576^{ABd}	622^{d}
Fertilizer (F)	453^{Bbc}	702^{ABcd}	476^{ABc}	718^{Abcd}	587^{de}
Crop residue (CR)	456^{ABab}	615^{Acd}	586^{Abc}	314^{Bd}	493^{e}
C + F	715^{Cab}	1168^{ABb}	1317^{Aa}	1000^{Babc}	1050^{b}
C + CR	645^{Bab}	776^{ABe}	835^{ABb}	1019^{Aab}	819^{c}
F + CR	689^{Aab}	802^{Ac}	796^{Ab}	641^{Abcd}	732^{cd}
C + F + CR	770^{Ba}	1524^{Aa}	1420^{Aa}	1304^{Aa}	1255^{a}
Mean	454^{C}	845^{A}	828^{AB}	747^{B}	

† Values followed by the same small letter in a column and capital letter in a row are not significantly different at P ≤ 0.5.

with the greatest yield in the highest rainfall years of 2012 and 2014, lowest in the very dry 2011 season, and intermediate in 2013 (Table 2). Averaged across soil amendment, scarifying with manga hoe and zaï tillage systems produced the greatest yield, ploughing intermediate, and no till the lowest yield (Table 3).The scarifying with manga hoe, zaï, plough tillage systems produced similar and the greatest sorghum grain yield with all soil amendments except for the leaving crop residue on the soil surface and compost + fertilizer soil amendments. No-till produced similar

Table 4. Year (Y) x soil amendment (SA) effects on sorghum grain and stover yields in Exp. 1, Kamboinsé, Burkina Faso (Analysis of variance probability: Grain yield Y x SA $P < 0.01$, Y $P < 0.01$, SA $P < 0.01$; Stover yield Y x SA $P < 0.01$, Y $P < 0.01$, SA $P < 0.01$).

Soil Amendment	Grain					Stover				
	2011	2012	2013	2014	Mean	2011	2012	2013	2014	Mean
						kg ha $^{-1}$				
Zero	223^{Bd}	566^{Ae}	382^{ABd}	352^{ABd}	381^{e}	1666^{Be}	3106^{Ae}	1860^{Bd}	1640^{Bc}	2068^{e}
Compost (C)	398^{BCbde}	906^{Ac}	466^{Bd}	718^{Abc}	622^{d}	1957^{Bcde}	4044^{Acd}	2475^{Bcd}	2668^{Bc}	2786^{d}
Fertilizer (F)	272^{Bdc}	825^{Acd}	514^{Bd}	738^{ABbc}	587de	2006^{Bcde}	3575^{Acde}	2750^{Bc}	2399^{Bcd}	2683^{d}
Crop residues (CR)	421^{Abdc}	598^{Ade}	498^{Ad}	^{453Acd}	493^{e}	1925^{Bde}	3316^{Ade}	2669^{ABcd}	1879^{Bde}	2447^{d}
C + F	560^{Cab}	1310^{Ab}	919^{Bb}	1410^{Aa}	1050^{b}	2523^{Cabc}	5144^{Ab}	3979^{Bab}	4623^{ABa}	4067^{b}
C + CR	550^{Bab}	1035^{Ac}	800^{Abc}	890^{Ab}	819^{c}	2264^{Cbcd}	4189^{Ac}	3316^{Bbc}	3065^{Bbc}	3209^{c}
F + CR	501^{Babc}	841^{ABc}	628B^{cd}	958^{Ab}	732^{cd}	2669^{Bab}	4238^{Ac}	2620^{Bcd}	3529^{Ab}	3264^{c}
C + F + CR	708^{Ca}	1569^{Aa}	1233^{Ba}	1508^{Aa}	1255^{a}	2911^{Ca}	5977^{Aa}	4488^{Ba}	4424^{Ba}	4440^{a}
Mean	454^{C}	956^{A}	680B	878A		2240^{C}	4199^{A}	3015^{B}	3028^{B}	

† Values followed by the same small letter in a column and capital letter in a row are not significantly different at $P \leq 0.5$. C: Compost; F: Fertilizer; CR: Crop residues.

sorghum grain yield to the Zaï and scarifying with manga hoe system when crop residues were left on the soil surface with other soil amendment application. Averaged across tillage systems the compost + fertilizer + crop residue and compost + fertilizer soil amendments resulted in the greatest sorghum grain yield, with zero soil amendment having the lowest crop yield. Compared to no soil amendment, compost + fertilizer + crop residue resulted in grain yield increases of 277% with no-till, 242% with scarifying tillage, 203% with zaï, and 228% with ploughing. Combinations of two or three soil amendments resulted in higher grain yield than that with single soil amendment. Mando et al. (2005), Obalum et al. (2011) and Mason et al. (2015) have shown that when crop residues were left on the soil surface or mulching, sorghum grain and stover yield significantly increased. Previous results indicated that application of compost or manure (Maman et al., 2017b; Garba et al., 2018), and application of the recommended rate of mineral fertilizer increased sorghum grain and stover yield (Traoré et al., 2018; Ouattara et al., 2018).

The soil amendment influence on sorghum grain yield in Exp. 1, varied across years (Table 4). On average across years, the compost + fertilizer + crop residues combination of soil amendments always produced the highest yields, followed by compost + fertilizer. Compared to no soil amendment, application of compost + fertilizer + crop residues resulted in grain increases of 217% in 2011, 177% in 2012, 223% in 2013, and 328% in 2014 (Table 4). The lowest sorghum grain yields were produced with no soil amendment and crop residue soil amendment, with the single soil amendment treatments producing lower yield than the two soil amendment combinations. When comparing soil amendments within years, the treatments with three soil amendments produced greater yield than other treatments in 2012 and 2013, and along with the compost + fertilizer soil amendment in 2014. In contrast, in the very low rainfall year of 2011, all two and three soil amendment combinations produced similar grain yields that were greater than the no soil amendment and single soil amendment applications. In the low-rainfall years of 2011 and 2013, no soil amendment produced similar sorghum grain yields to applications of single soil amendments, while in higher rainfall years of 2012 and 2014, leaving crop residues on the soil surface did not increase grain yield. Grain yield levels closely followed annual season rainfall, with greatest yield in the above-average 2012 season, second in near-average 2014 season, third in the dry 2013 season, and lowest in the very dry 2011 season. Leaving crop residues on the soil surface had more yield benefit in dry-growing seasons, and combined with other soil amendments less effectively than compost and fertilizer applications in average and high-rainfall years. These results corroborate those of Palé et al. (2009, 2019) who documented that microdose or placement of 4 g NPK + additional N and P, compost + mineral fertilizer and compost + mineral fertilizer and crop residues, releasing more nutrients for sorghum plant growth, resulted in higher sorghum yields. In Exp. 2, analysis of variance indicated that sorghum grain yield differences were due to Year x Tillage interaction ($P < 0.01$, Table 2) and Cropping System with soil amendment main effects ($P < 0.01$, Table 5).

The yield of sorghum grain was lowest in all three years when the no-till system was used. The zaï system produced the highest sorghum grain yield in the near-average rainfall year of 2012 and scarifying in the low-

Table 5. Main effects of cropping system with soil amendment (CS/SA) on sorghum grain yield in 2012-2014 and year (Y) x cropping system with soil amendment (CS/SA) effects on stover yields in Exp. 2, Kamboinsé, Burkina Faso (Analysis of variance probability: Grain yield CS/SA main effect P < 0.01; Stover yield Y X CS/SA P = 0.03, Y P = 0.03, CS/SA P < 0.01).

Cropping System	**Soil Amendment**	**Grain**	**Stover**			
		2012 to 2014	**2012**	**2013**	**2014**	**Mean**
		kg ha^{-1}				
	Zero	497^{c}	2842^{Abc}	2070^{Bcd}	1304^{Cb}	2072^{b}
Sole Cropped	Compost	627^{bc}	3580^{Aab}	2545^{Bbc}	1281^{Cb}	2469^{b}
	Fertilizer	853^{a}	4335^{Aa}	3084^{Bab}	2187^{Ca}	3202^{a}
	Compost + fertilizer	855^{a}	3774^{Aa}	3580^{Aa}	2519^{Ba}	3291^{a}
	Zero	280^{d}	2178^{Acd}	884^{Be}	970^{Bb}	1344^{c}
Intercropped	Compost	407^{cd}	1876^{Ad}	1661^{ABde}	1057^{Bb}	1531^{c}
	Fertilizer	405^{cd}	1984^{Acd}	1531^{ABde}	1165^{Bb}	1560^{c}
	Compost + fertilizer	637^{b}	2588^{Acd}	2502^{Abc}	1553^{Bb}	2214^{b}
	Mean		2895^{A}	2232^{B}	1505^{C}	

† Values followed by the same small letter in a column and capital letter in a row are not significantly different at P ≤ 0.5.

Table 6. Tillage method (T) x Cropping system and soil amendment (CS/SA) effects on intercropped cowpea grain and stover yield in Exp. 2, Kamboinsé, Burkina Faso, 2012 to 2014 (Analysis of variance probability: Grain yield T x CS/SA P = 0.02, T P= 0.19, CS/SA P < 0.01; Stover yield T x CS/SA P < 0.01, T P = 0.10, CS/SA P < 0.01).

Soil Amendment	**Grain**				**Stover**			
	Minimum	**Scarifying**	**Zaï**	**Mean**	**Minimum**	**Scarifying**	**Zaï**	**Mean**
	kg ha^{-1}							
Zero	301^{Bb}	374^{ABb}	537^{Ab}	404^{c}	568^{Bab}	402^{Bc}	1350^{Aa}	773^{b}
Compost	411^{Bab}	694^{Aa}	468^{Bb}	524^{b}	504^{Cab}	1667^{Aa}	1063^{Ba}	1078^{a}
Fertilizer	408^{Bab}	468^{ABb}	604^{Aab}	493^{bc}	347^{Bb}	1102^{Ab}	951^{Aa}	800^{b}
Compost + fertilizer	528^{Ba}	785^{Aa}	785^{Aa}	699^{a}	640^{Ba}	1724^{Aa}	1543^{Aa}	1302^{a}
Mean	412^{B}	580^{A}	599^{A}		515^{B}	1224^{A}	1227^{A}	

† Values followed by the same small letter in a column and capital letter in a row are not significantly different at P ≤ 0.5.

rainfall year of 2013. Averaged across years, the zaï tillage system produced grain yield of 350 kg ha^{-1} greater than no-till and 296 kg ha^{-1} greater than scarifying tillage.In Exp. 2, sorghum grain yield was 39% greater in sole than when intercropped with cowpea (Table 6) similar to findings reported Oseni (2010). The response of the cropping system/soil amendment combinations was consistent across years and tillage systems (Table 5). Sole cropped sorghum produced the highest grain yield with compost + fertilizer application and fertilizer application, intermediate for compost application and lowest for no amendment application (Table 5). In contrast, intercropped sorghum similarly produced the highest grain yield with compost + fertilizer application, intermediate yield for compost or fertilizer application, and lowest with no soil amendment. Fertilizer application was of greater benefit for sorghum grain yield in sole cropped, being similar to that of compost + fertilizer application for intercropped sorghum.

This similarity in fertilizer response in sole cropped and intercropped sorghum could be related to the fact that mineral fertilizer is quickly available than organic materials being slow in releasing nutrients for plants.

Sorghum Stover Yield Variation

In Exp. 1, analysis of variance indicated that sorghum stover was influenced by the Year x Soil Amendment interaction (P < 0.01, Table 4), and that tillage system had no influence on sorghum residue production (P = 0.22). Sorghum residues are an important economic component of production systems as animal feed during the dry season (Maman et al., 2017b) and to maintain soil and grain yields (Mason et al., 2015). Averaged across years, when two soil amendments were applied, sorghum stover yield was greater than when single soil amendment were applied that was greater than with zero soil amendment. The greatest stover yield occurred with application of compost + fertilizer + crop residues, and second highest with compost + fertilizer as was also found for sorghum grain. Exceptions to these results when comparing soil amendment application between years include similar stover yields for the two and three soil amendments combinations. The the zero and single soil amendment applications in the very dry 2011 season and the compost + fertilizer application produced greater stover yield than the other two soil amendment applications in the dry 2013 season. These data suggest that soil amendment differences in sorghum stover production are less in dry years than in higher rainfall years. In the above-average rainfall year of 2012, the compost + fertilizer application led to greater sorghum stover yield than the other two soil amendment treatments. Results also indicated that the compost application led to greater stover yield than the fertilizer or crop residue applications in the above-average rainfall year of 2012.

In the 2013 low rainfall season, crop residue application alone did not increase stover production. Averaged across soil amendments, sorghum stover yields were greatest in above-average rainfall year of 2012, intermediate in near-average and dry years of 2012 and 2014, and lowest in the very dry 2011 season. Exceptions were greater stover yield in the near-average 2014 season than for the below-average rainfall 2013 season with compost, compost plus fertilizer, and fertilizer plus crop residue applications. Sorghum stover optimization required two or three concurrent soil amendment application, with the greatest stover yield when compost and mineral fertilizer (C + F) was applied (Garba et al., 2018; Youl et al., 2018) and crop residues were added to C + F. Compared to no soil amendment, stover yield increases due to application of C + F + CR were 74% greater in 2011, 92% greater in 2012, 141% greater in 2013, and 170% greater in 2014. If only two soil amendments could be applied, then the compost plus fertilizer led to higher yields in this study. This could be due to the additive effect of the application of mineral fertilizer and compost effect on sorghum yield as shown by Garba et al. (2018). In Exp. 2, analysis of variance indicated that sorghum stover yield was influenced by the interaction effects of Year x Tillage method (P = 0.02; Table 2) and Year x Cropping System/Soil Amendment combinations (P = 0.03; Table 5). The zaï and scarifying with manga hoe systems produced more sorghum stover than no-till, especially in below-average rainfall 2013 and average rainfall 2014 season. The above-average rainfall in 2012 apparently reduced the difference in sorghum stover production among tillage systems (Table 3). Sorghum stover production was greatest in the above-average rainfall 2012 season, intermediate for the below-average 2013 season and lowest for the average 2014 growing season. Averaged across soil amendments, sole crop sorghum produced 66% more stover than did intercropped sorghum. The soil amendment had no influence on intercropped sorghum stover yield in the above-average 2012 and near-average 2014 growing seasons. In the below-average 2013 growing season, compost + fertilizer produced the highest sorghum stover yield, compost or fertilizer the intermediate yield, and zero the lowest yield. In contrast, sole crop sorghum yield was greatest for fertilizer or compost + fertilizer yield in all three years, along with compost only in the above-average rainfall 2012 season. The higher rainfall in 2012 may have contributed to compost decomposing more rapidly releasing more nutrients for sorghum growth. The zero and compost only application had one of the lowest sorghums stover yields in all years. Long term experiment results in Africa have demonstrated that it takes several years for compost application only to significantly affect sorghum grain yield compared to combined mineral fertilizer and compost application (Bationo et al., 2012).

Variation of Intercropped Cowpea Grain and Stover Yields

Cowpea grain and stover yields were influenced by the year main effect (P_{Grain} = 0.01; P_{Stover} = 0.02), and the Tillage Method x Soil Amendment interaction effect (P_{Grain} = 0.02; P_{Stover} = 0.01) (Table 6). For both cowpea grain and stover yields, greater yields occurred in 2012 and 2013. In 2012 with higher rainfall of 626 mm, grain yield was 586 kg ha^{-1} and stover yield was 1110 kg ha^{-1}. In 2013 with lower rainfall of 433 mm grain yield was 581 kg ha^{-1} and stover yield 1212 kg ha^{-1}. Lower yields occurred in intermediate rainfall of in the year 2014 with an average rainfall of 542 mm leading to grain yield of 424 ha^{-1} and stover yield of 644 kg ha^{-1}. Compost, fertilizer and compost + fertilizer applications always produced the highest cowpea grain yield averaged across tillage methods as indicated by Palé et al. (2019), except for lower yield with compost application with the zaï tillage method (Table 6). Compared to no soil amendment plots, compost + fertilizer application resulted in grain yield increases of 75% in no-till, 110% in scarifying and 46% in zaï plots. The zaï and scarifying tillage methods produced the highest cowpea grain yield. With the zaï tillage method, soil amendment had no influence on cowpea stover production. Cowpea stover production was greatest for compost and compost + fertilizer applications with the scarifying with manga hoe tillage, and with zero, compost, and compost + fertilizer with no-till. Fertilizer application had a detrimental or less influence on cowpea stover production than compost application, while little difference was apparent for intercropped sorghum stover, and the opposite was true for sole crop sorghum stover (Table 6).

CONCLUSION

Sorghum and cowpea grain and stover production levels were closely related to the seasonal rainfall. Sole crop sorghum produced higher grain and stover yields than the intercrop. Sorghum and cowpea grain production was more sensitive to tillage method and soil amendment than stover production. The use of the zaï tillage method produced the highest sorghum grain yields in 2012, 2013, and 2014, while scarifying with Manga hoe led to the greatest yield in 2011. The zaï and scarifying tillage methods led to the greatest cowpea grain and stover yields. To optimize sole crop sorghum grain and stover production, two or three concurrent soil amendment combination of compost, fertilizer, and/or crop residues were required. Fertilizer and compost tended to give a bigger yield response to sole cropped sorghum that combinations with crop residues left on the soil surface. To produce optimal grain and stover yields of intercropped sorghum and cowpea, application of a combination of compost, fertilizer and crop residues was required. The zaï tillage system is recommended to optimize intercropped sorghum and cowpea grain and stover yields in the Sundano-Sahelian agroecological zone of Burkina Faso, while either the zaï or scarifying is recommended for soil cropped sorghum. Recommendation for soil amendment application varied depending upon the cropping system. Recommendation for optimal sorghum and cowpea intercropped sorghum and cowpea is application of compost + fertilizer, while either compost + fertilizer or compost + fertilizer + leaving crop residues on the surface is recommended for soil crop sorghum.

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