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Sorghum and Groundnut Yields as Influenced by Tillage, Cropping System and Soil Amendment in the Sudanian Agroecological Zone of Burkina Faso

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ABSTRACT

Experiments were conducted under rainfed conditions in the Sudanian Agroecological Zone (SAZ) of Burkina Faso from 2012 to 2014 to identify the best package of practices that will increase sorghum yields in sole cropping (Exp.1) and sorghum and groundnut yields in intercropping (Exp.2). Split plot design was used. The main plot was tillage method (T) in both studies. Sub-plot treatment was soil amendment (SA) with compost (C), mineral fertilizer (F) and crop residues (CR) in Exp.1. In Exp.2, subplot was cropping system (CS) with soil amendment (SA) of C and/or F. T and SA responses were greatest in the high rainfall year. Compared to no-till, tied-ridging produced additional grain yield of 668 kg ha^{-1} in Exp.1 and 250 kg ha^{-1} in Exp.2. Intercropped groundnut produced the highest yields with use of scarifying or no-till. SA produced the highest yields in both cropping systems, but sorghum grain yield in sole crop was 353 kg ha^{-1} higher than when intercropped with groundnut. The greatest sole crop sorghum yields occurred with C + F and C + F + CR application, particularly in high rainfall years. Yield increase due to C + F was 176% for grain and 120% for stover. C + F + CR increased grain yield by 174% and stover by 118%. Tied-ridging in intercropping produced highest sorghum yields but lowest groundnut yields. In conclusion good soil amendment with efficient water management can be recommended for sustainable sorghum and groundnut production in the SAZ of Burkina Faso.

Keywords: Compost, Crop residues, Mineral fertilizer, No-till, Scarifying, Tied-ridging.

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INTRODUCTION

Sole cropped sorghum and intercropped sorghum with groundnut are the dominant cropping systems of the Sudanian Agroecological Zone of southern Burkina Faso (Chianu et al., 2012; World Bank, 2018). The Burkina Faso economy is poor, agricultural-based, with 90% of the population involved in subsistence agriculture. In this agroecological zone, grain sorghum and groundnut have low and stagnant 17 year average yields of 1165 kg ha^{-1} for sorghum and 879 kg ha^{-1} for groundnut (MAAH, 2016) while soils are degrading with soil organic matter and nutrient levels declining, thereby reducing water and nutrient holding capacity (Ouattara et al., 2006). Changing climate is predicted to increase air temperatures and decrease precipitation in the future, thereby adversely influencing sorghum and groundnut yields in the future (Zougmoré, 2018). Past research has largely focused on single management factors. Research has shown that sorghum grain yield in West Africa increases or decreases with no-till (Ouédraogo et al., 2007; Obalum et al., 2011), and by tied-ridging (Palé et al., 2009). In addition, sorghum yield increases with scarifying or shallow harrowing (Nicou et al., 1993), or ploughing (Kanton et al., 2000; Ouattara et al., 2006). Leaving crop residue on the soil surface or mulching (Mando et al., 2005; Obalum et al., 2011; Mason et al., 2015) increases sorghum grain and stover yield. Application of compost or manure (Maman et al., 2017; Garba et al., 2018), and application of the recommended rate/method of mineral fertilizer (Maman et al., 2017; Garba et al., 2018; Traoré et al., 2018; Ouattara et al., 2018) increases sorghum grain and stover yields.

The most common studies of two factors have been with compost or manure application in combination with

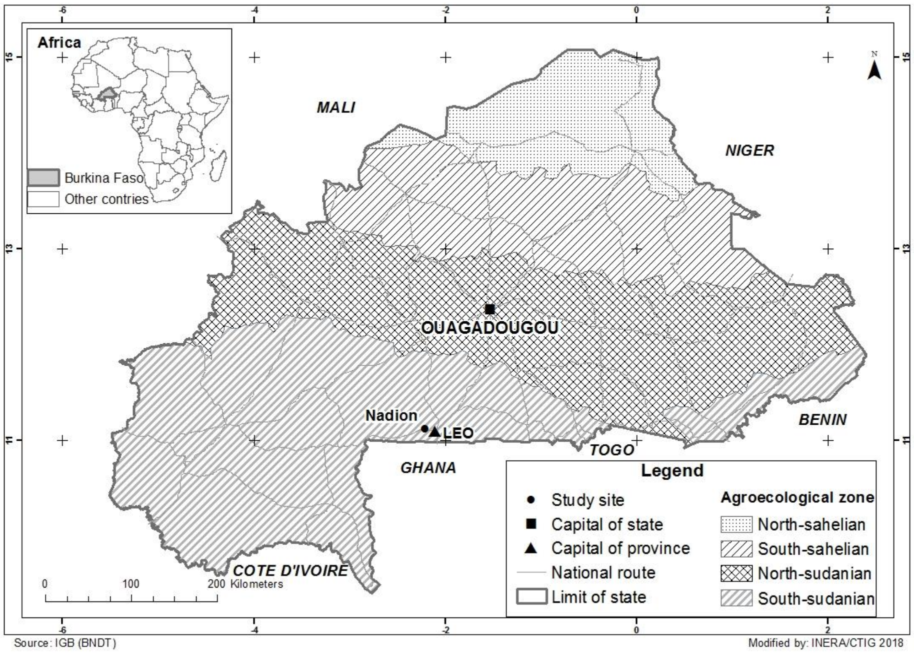

Figure 1. Map of Burkina Faso showing the Sudanian Agro-ecological Zone and Nadion (study site) [(*Source*: Geography Institute of Burkina Faso; rivized by the Remote Sensing and Geographical Information Unit (CTIG) at the Institute of Environment and Agricultural Research (INERA), Burkina Faso, 2018)].

Table 1. Seasonal and monthly rainfall and temperatures for Nadion (Léo), Burkina Faso, 2011 through 2014.

Month	Seasonal Rainfall					Seasonal Temperatures				
	2011	2012	2013	2014	26 Year Average	2011	2012	2013	2014	10 Year Average
	---------------- mm --------------------					-------------------- ºC --------------------				
July	186	272	290	173	193	NA†	25.2	NA‡	26.5	NA†
Aug	219	272	243	76	272	NA	24.9	24.6	38.9	NA
Sept	152	300	279	77	161	NA	25.4	25.6	30.1	NA
Oct	36	28	27	53	57	NA	26.8	26.9	27.6	NA
Average							25.6		30.8	
Total	592	872	839	379	683					

† Long-term weather station 12 km from experimental site only had 2011 and long-term rainfall information. Weather station installed in the experimental site in 2012 provided seasonal rainfall and temperature for 2012 through 2014. ‡ Not available due to dead batteries in weather station at the experimental site.

mineral fertilizer. These studies have shown sorghum grain yield advantage to using compost and fertilizer together (Garba et al., 2018; Youl et al., 2018) and use of rock bunds or grass strips increases response to mineral fertilizer application (Zougmoré et al., 2010). Sole crop sorghum and groundnut response are greater to mineral fertilizer application than intercropped sorghum or groundnut (Maman et al., 2017). Sole crop sorghum yields more grain and stover than intercrop, but intercropped sorghum with groundnut often has greater system productivity and economic value (Maman et al., 2017). 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. Research to combine individual management factors into a "package" producing optimal grain and stover yields thereby increasing the probability of farmer adoption, improved sustainability and greater farmer income is needed. The objective of this study was to identify the best combination of tillage method and soil amendment in sorghum sole cropping, tillage method and cropping system with soil amendment in sorghum/groundnut intercropping to optimize grain sorghum and groundnut yields in the Sudanian Agroecological Zone of Burkina Faso.

MATERIALS AND METHODS

Two experiments were conducted from 2011 to 2014 at the Nadion Mini Agricultural Research Station (11° 7' 50'' N lat; 2° 12' 18'' W long) in the Sudanian agroecological zone of Burkina Faso with more than 900 mm per year, of which approximately 700 mm occurs during the growing season months between July and Oct (Figure 1 and Table 1). Long-term air temperatures are not available for the experimental site.

Table 2. Cropping system, tillage and soil amendment treatments for Exp. 1 and 2, Nadion (Léo), Burkina Faso, 2011 through 2014.

Treatments	Exp. 1	Exp. 2
Cropping system	Sole cropped grain sorghum	Sole and intercropped grain sorghum/groundnut
Tillage methods	1. No till	1. No till
	2. Scarifying	2. Scarifying
	3. Tied ridging (Figure 2)	3. Tied-ridging
	4. Ploughing	
Soil amendments	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/groundnut with no soil amendment
	6. Compost and crop residues	6. Grain sorghum/groundnut with recommended compost
	7.Fertilizer and crop residues	7. Grain sorghum/groundnut 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/groundnut 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).

The experiments were planted in a Little to Medium Depth Leached Indurates type soil with a sandy-loam texture with relatively low water holding capacity, surface horizon pH of 6.0, organic carbon (C) concentration of 10.6 g kg^{-1}, 0.6 g kg^{-1} N, 3.1 g kg^{-1} P and 0.15 $cmol^{+}$ kg^{-1} K (Sermé et al., 2015). The soil has 66.4% sand, 26.9% silt and 6.8% clay. A hardpan was present at 54 cm depth. The plots were previously fallowed for 20 years. The sorghum variety used in both studies was Sariasso14 with a maturity rating of 90 days, and the groundnut variety CN94C with a maturity rating of 90 days was intercropped with sorghum in Exp. 2. 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 treatment was soil amendment (compost and/or fertilizer) in Exp.1 and cropping system with soil amendment (compost and/or fertilizer) in Exp. 2. The treatment combinations are presented in Table 2 and were applied to the same plots each year in both studies. The scarifying method consists of shallow cultivation of the field using a Manga hoe, which is an animal-drawn tool. The tied-ridging method consists of making ridges before planting along the planting rows using animal-drawn ridger (Figure 2). Ties were made at 1 m distance one month after planting, using a manual hoe.

The average height is 0.22 m for the ridges and 0.19 m for the ties, and the average width was 0.33 m for the main ridges and 0.25 m for the ties. 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. Groundnut was planted at 40 cm between rows and 15 cm within the row with 1 to 2 plants per hill after thinning. Intercrop planting was done alternating two rows of sorghum with three rows of groundnut. Simultaneous planting of sorghum and groundnut was done on 18 July 2012, 10 July 2013, and 10 July 2014. Weed control was accomplished by hand hoeing as needed. Harvest was done in the middle of each plot and the harvested area was 25.76 m^2 in both experiments and 36.8 m^2 for groundnut in Exp. 2. Grain sorghum panicles, groundnut pods and stover from both crops were hand-harvested, air-dried, threshed (for only sorghum), weighted, and recorded as dry weight. Grain and stover subsamples of sorghum were ground to pass through a 1-mm mesh screen. An automatic combustion method was used for N analysis (Miller et al., 1997), and digestion and inductively coupled plasma spectrometry for P, K, Ca, Mg and micronutrient concentrations (Wolf et al, 2003; Kovar, 2003). Soil physical properties and soil water were measured and reported previously by Sermé et al. (2015). Grain and stover yield data were analyzed by using standard analysis of variance and pair-wise comparisons by the General Linear Model Procedure on the software SAS/STAT®, version 9.2 (SAS Institute, 2010). Differences were declared significant at the $P \leq 0.05$ level. Tillage system, soil amendment and cropping

Figure 2. Tied-ridging technique (Ridge: made along the planting rows; Tie: made at 1 m distance and tying ridges) (Source: Palé et al., 2009).

Table 3. Year (Y) x soil amendment (SA) effects on sole crop sorghum grain yield and main effects of SA on stover yield in Exp. 1 in Nadion, Burkina Faso, 2011 through 2014 [Analyis of variance probability: Grain yield Y x SA P = 0.02, SA P < 0.01, Y P < 0.01; Stover yield SA P < 0.01].

Soil Amendment	Grain Yield					Stover
	2011	2012	2013	2014	Mean	2011-2014
	------------ kg ha^{-1} ------------					
Zero fertilizer	233^{Bb}	862^{ABbc}	1273^{Ad}	427^{Bc}	699^{d}	2701^{d}
Compost (C)	488^{Cb}	1175^{Bb}	1997^{Ac}	870^{BCbc}	1132^{c}	3711^{c}
Mineral fertilizer (F)	787^{Cab}	1453^{Bab}	2577^{Ab}	893^{Cbc}	1428^{b}	4909^{b}
Crop residues (CR)	329^{Bb}	601^{ABc}	1038^{Ad}	548^{Bc}	629^{d}	2627^{d}
C + F	1073^{Ca}	1739^{Ba}	3199^{Aa}	1708^{Ba}	1930^{a}	5930^{a}
C + CR	567^{Cb}	1112^{Bb}	1899^{Ac}	1077^{Bb}	1164^{c}	3716^{c}
F + CR	940^{Cab}	1363^{BCab}	2608^{Ab}	1159^{Cb}	1518^{b}	5098^{b}
C + F + CR	1185^{Ca}	1690^{Ba}	2953^{Aab}	1825^{Ba}	1913^{a}	5884^{a}
Mean	700^{D}	1249^{B}	2193^{A}	1063^{C}		4322

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

system with soil amendment combinations were considered fixed effects.

RESULTS AND DISCUSSION

Seasonal Climatic Conditions

Seasonal annual rainfall was 91 mm above 26-year average in 2011, 189 mm above in 2012 and 156 mm above average in 2013, while being 304 mm below long-term average in 2014 (Table 1). Monthly rainfall deviated from the 26 year average in all years, likely influencing sorghum and groundnut yields, especially in 2014 in August and September. In 2012 and 2013, monthly rainfall was above the long-term average in July and September. Monthly temperatures were similar in 2012 and 2013. Table 1 shows air temperatures in 2014 being much hotter in August and September than in 2012 and 2013.

Sorghum in Sole Crop Experiment

In sole crop sorghum experiment (Exp.1), analysis of variance indicated that the tillage method had no influence on sorghum grain (P = 0.61) or stover yield (P = 0.94) even though tillage reduced soil bulk density, increased soil porosity, and increased soil water present four weeks after planting (Sermé et al., 2015). Analysis of variance indicated that the soil amendment (SA) main effect influenced sorghum grain and stover yields (P < 0.01), and the year x soil amendment (Y x SA) interaction effect influenced sorghum grain yield (P =

Table 4. Year (Y) x cropping system with soil amendment (CS/SA) influence on grain and stover yields for intercropped grain sorghum in Exp. 2 in 2012, 2013 and 2014 in Nadion (Léo), Burkina Faso [Analysis of variance probability: Grain yield Y x CS/SA P = 0.02, CS/SA P < 0.01, Y P = 0.03; Stover yield Y x CS/SA P < 0.01, CS/SA P < 0.01, Y P < 0.01].

Cropping System	Soil Amendment	Grain Yield				Stover Yield			
		2012	**2013**	**2014**	**Mean**	**2012**	**2013**	**2014**	**Mean**
		kg ha^{-1}							
Sole Cropped	Zero	603^{Bcd}	1218^{Ac}	603^{Bc}	808^{d}	4226^{Ab}	2572^{Bbc}	854^{Ccd}	2551^{c}
	Compost	804^{Bbc}	1432^{Abc}	663^{Cc}	966^{c}	4477^{Ab}	2805^{Bbc}	896^{Ccd}	2726^{c}
	Fertilizer	900^{Bb}	1668^{Ab}	1056^{Bb}	1208^{b}	7173^{Aa}	3239^{Bab}	1978^{Cb}	4130^{b}
	Compost + fertilizer	1316^{Ba}	2385^{Aa}	1432^{Ba}	1711^{a}	8098^{Aa}	3998^{Ba}	2403^{Ca}	4833^{a}
Intercropped	Zero	306^{Ae}	477^{Ae}	254^{Ad}	346^{e}	2079^{Ac}	1019^{Bf}	283^{Be}	1127^{d}
	Compost	306^{Be}	749^{Ade}	416^{Bcd}	490^{e}	1958^{Ac}	1229^{ABf}	480^{Bde}	1222^{d}
	Fertilizer	560^{Bd}	1122^{Acd}	608^{Bc}	763^{d}	3838^{Ab}	2065^{Bcd}	1023^{Cc}	2309^{c}
	Compost + fertilizer	690^{Bbcd}	1055^{Acd}	663^{Bc}	803^{d}	4192^{Ab}	1796^{Bde}	1138^{Bc}	2375^{c}
	Mean	686^{B}	1263^{A}	712^{B}		4505^{A}	2340^{B}	1132^{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 5. Tillage (T) x cropping system with soil amendment (CS/SA) influence on grain yields for intercropped sorghum in Exp. 2 in Nadion, 2012 through 2014, Burkina Faso [Analysis of variance probability: Grain yield T x CS/SA P <0.01, T P = 0.01, CS/SA P < 0.01].

Cropping System	Soil Amendment	Grain yield			
		No Till	**Scarifying**	**Tied-ridging**	**Mean**
		kg ha^{-1}			
Sole Cropped	Zero	482^{Ccd}	839^{Bbc}	1108^{Ac}	810^{d}
	Compost	765^{Bbc}	875^{Bbc}	1259^{Abc}	966^{c}
	Fertilizer	1042^{Bab}	991^{Bb}	1599^{Ab}	1211^{b}
	Compost + fertilizer	1206^{Ca}	1727^{Ba}	2200^{Aa}	1711^{a}
Intercropped	Zero	322^{Ad}	391^{Ad}	324^{Ad}	346^{e}
	Compost	530^{Acd}	489^{Acd}	452^{Ad}	490^{e}
	Fertilizer	448^{Bcd}	896^{Abc}	946^{Ac}	763^{d}
	Compost + fertilizer	512^{Ccd}	804^{Bbc}	1092^{Ac}	803^{d}
	Mean	663^{C}	877^{B}	1123^{A}	

† Values followed by the same small letter in a column and capital letter in a row are not significantly different at P ≤ 0.

0.02). Grain sorghum stover yield was influenced by SA (P < 0.01) and the Y main effect (P = 0.02). Sorghum nutrient concentrations of grain and stover at harvest were not influenced by tillage method, soil amendment or year in this study (data not presented). There was no influence of SA on soil physical properties or soil water, with tillage method having a small influence on soil physical properties (Sermé et al., 2015). Tied-ridging and ploughing had greater soil water storage four weeks after planting than no-till and scarifying methods, but not at other sampling dates. Averaged across year, Compost (C) + Mineral fertilizer (F) and C + F + Crop residues (CR) applications resulted in the highest sorghum grain yield (Table 3). Compared to zero fertilizer, grain yield increases due to C + F was 176% and C + F + CR was 174%.

In all four years of the experiment, C + F and C + F + CR applications produced the highest grain yields, while the lowest grain yields were obtained with no soil amendment. Stover yield was also greater in plots receiving either C + F or C + F + CR (Table 3) and compared to plots with no soil amendment, yield increases were 120% for C + F and 118% for C + F + CR. These results support Garba et al. (2018) and Youl et al. (2018) who documented the synergistic effect of C and F on sorghum grain and stover yield. Stromberg et al. (1994) indicated that sorghum residue decomposition is relatively slow and especially when residues were left on the soil surface as was done in this study. Further, these authors indicated that nutrients contained in crop residues and released during decomposition can be temporally immobilized in the soil by the microbial biomass, especially in low yield environments. These factors may account for the fact that mulching with crop residues tended to be less effective than use of compost and mineral fertilizer in this study. The year main effect on sorghum stover led to greater yield of 5193 kg ha^{-1} in the higher rainfall year of 2012 and intermediate yield of 4592 kg ha^{-1} in the intermediate rainfall year of 2013. Lower yields for stover occurred in the lower rainfall year in 2011 with yield of 3924 kg ha^{-1} and in 2014 with yield of 3579 kg ha^{-1}. No year variation among soil amendments was present for sorghum stover, while averaged across SA,

Table 6. Year (Y) x tillage (T) influence on intercropped sorghum stover, and intercropped groundnut pod and stover yields in Exp. 2 in 2012, 2013 and 2014 in Nadion, Burkina Faso [Analysis of variance probability: Sorghum stover yield Y x T P = 0.04, Y P = 0.03, T P = 0.01; Groundnut pod yield Y x T P < 0.01, Y P = 0.01, T P < 0.01; Groundnut stover yield Y x T P = 0.05, Y P = 0.01, T P = 0.01].

Tillage Method	Sorghum Stover Yield				Groundnut Pod Yield				Groundnut Stover Yield			
	2012	2013	2014	Mean	2012	2013	2014	Mean	2012	2013	2014	Mean
	kg ha^{-1}											
No till	3718^{Ac}	1994^{Bb}	903^{Cb}	2205^{c}	366^{Aa}	220^{Ca}	285^{Bb}	290^{b}	617^{Aa}	490^{Ba}	408^{Cb}	505^{a}
Scarifying	4542^{Ab}	2244^{Bb}	1064^{Cb}	2617^{b}	372^{Ba}	181^{Cb}	490^{Aa}	348^{a}	659^{Aa}	409^{Cb}	527^{Ba}	532^{a}
Tied-ridging	5255^{Aa}	2782^{Ba}	1429^{Ca}	3155^{a}	255^{Ab}	138^{Bc}	211^{Ac}	201^{c}	458^{Ab}	328^{Bc}	359^{Bb}	382^{b}
Mean	4505^{A}	2340^{B}	1132^{C}		331^{A}	180^{B}	329^{A}		578^{A}	409^{B}	431^{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.

sorghum grain yields in 2013 were> 2012 > 2014 > 2011, consistent with seasonal rainfalls except for that in 2011 (Table 1). Grain yields were lowest in 2011 except equal yields to 2014 for Zero, F, CR, and F + CR soil amendment applications.

Sorghum And Groundnut In Sole Intercrop Experiment

Grain Sorghum

In the sole intercrop sorghum/groundnut experiment (Exp. 2), analysis of variance indicated that the two-way interactions Year x Cropping system and soil amendment (Y x CS/SA) (P = 0.02), and Tillage (T) x CS/SA (P < 0.01) influenced sorghum grain yield, while Y x CS/SA (P < 0.01) and the Y x T interaction effects influenced sorghum stover yield (P = 0.04). Sole cropped sorghum produced the greatest grain yields in the high rainfall 2013 year, intermediate yield in 2012, and lowest yields in the dry 2014 year (Tables 1 and 4). Sole cropped sorghum produced the highest yields with C + F application in both experiments in all years (Tables 4 and 5), and for stover yield in the dry 2014 year (Table 1) and averaged across years (Table 4). Fertilizer application led to greater grain and stover yields than C application except for stover yield in dry 2014 year (Table 1) and for scarifying tillage (Table 5). Compost and zero tillage led to similar grain and stover yields in all years (Table 4) and all tillage systems (Table 5). Tied ridging led to the highest sorghum stover yield in all years while no-till produced lower sole sorghum stover yield than other tillage systems on average and in the dry 2014 year (Table 1). However, no till and scarifying led to similar sorghum stover yield (Table 6) in both the high rainfall 2012 year and near average rainfall 2013 year (Table 1). Intercropped sorghum had lower grain and stover yields than sole cropped sorghum (Tables 4 and 5), and was less responsive to soil amendment application than sole cropped sorghum. In general, intercropped sorghum grain and stover yields were similar for F and C + F application and greater than the Zero and C applications for most years and tillage systems. However, sorghum grain yields for C, F, and C + F were similar in the dry 2014 year (Table 4) and in no-till plots (Table 5). Differences in harvested grain and stover nutrient concentrations were declared for Y x T and Y x CS/SA interactions but nutrient differences were small and appeared unrelated to sorghum grain and stover nutrient concentrations (data not reported).

Groundnut

In Exp. 2, analysis of variance indicated that the Y x T interaction influenced intercropped groundnut pods (P < 0.01) and stover (P = 0.05) yields. ANOVA also indicated a Y x CS/SA interaction effect on groundnut pod yield (P = 0.01), and the main effect of CS/SA on groundnut stover yield (P <0.01). Intercropped groundnut pod and stover yields were higher in 2012 with the use of no-till and scarifying, in 2013 for no-till, and in 2014 in scarified plots (Table 6). In all three years, pod yield was lower with the use of tied-ridging rather than using no-till and scarifying. Averaged across years, groundnut pod and stover yields in scarified plots were> no-till > tied-ridging. Averaged across tillage methods, groundnut pod yields were greatest in the near-average rainfall of 2012 year, intermediate in the high rainfall 2013 year, lowest in the dry 2014 year. In contrast, the lowest groundnut stover yields were produced in the high rainfall 2013 season with similar stover yields in 2012 and 2014. Intercropped groundnut pod yields indicated greater yields that occurred with F and C + F in 2012, C, F and C + F in 2013, and similar pod yields for all soil amendments in the dry 2014 year (Table 7). Averaged across CS/SA, the greatest pod yields were obtained in 2012 and 2014 and the lowest in 2014. The main effect of CS/SA indicated that intercropped groundnut stover yield was greater in plots of sorghum/groundnut with F and with C + F, and lower in plots of sorghum/groundnut with no CS/SA or with C (Table 7). The low grain and stover yields and limited response of sorghum and groundnut to nutrient application in sorghum and groundnut intercropped in the Sudanian Agroecological Zone of Burkina Faso in this study were similar to results found by Maman et al. (2017) in the Sahelien Agroecological Zone in Niger.

CONCLUSION

Averaged across Y, T and SA, sole crop sorghum produced 353 kg ha^{-1} higher grain and 1802 kg ha^{-1} higher stover yield than when intercropped with groundnut. However, intercropped groundnut pods and

Table 7. Year (Y) x cropping system with soil amendment (CS/SA) influence on intercropped groundnut grain yield and main effects of CS/SA on stover yield for groundnut in Exp. 2 in Nadion, Burkina Faso, 2012 through 2014 [Analysis of variance probability: Grain yield Y x CS/SA P = 0.01, Y = 0.01, CS/SA P 0.02; Stover yield P < 0.01].

Cropping System with Soil Amendment	Pod Yield				Stover Yield
	2012	2013	2014	Mean	2012-2014
	------------------------ kg ha^{-1} ----------------------				
Zero	267^{Ab}	200^{Ba}	276^{Aa}	248^{b}	412^{b}
Compost	286^{Ab}	191^{Bab}	335^{Aa}	271^{ab}	453^{b}
Fertilizer	373^{Aa}	161^{Bb}	358^{Aa}	297^{a}	504^{ab}
Compost + fertilizer	397^{Aa}	167^{Bb}	345^{Aa}	303^{a}	523^{a}
Mean	331^{A}	180^{B}	329^{A}		473

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

stover were of greater economic value than sorghum, and thus the sorghum/groundnut intercrop was likely more economic. Sole crop sorghum response to SA was greater than for intercropped sorghum or groundnut. In general, F and C + F applications increased sorghum grain yield, groundnut pod and stover yields more than C that was greater than CR. The greatest yield response to soil amendment application occurred in high rainfall years when higher sorghum grain and stover yields were produced. Groundnut pod and stover yields were lowest in the high rainfall year and soil amendment responses were greatest in the intermediate rainfall year. Tied-ridging resulted in sole cropped grain yields 668 kg ha^{-1} higher and intercropped grain yields 250 kg ha^{-1} higher than no-till. Sorghum grain yields in scarified plots were intermediate. In contrast, intercropped groundnut produced the highest pod and stover yields with the use of scarifying or no-till. In conclusion, sole and intercropped sorghum amended with C and F is recommended in the Sudanian agroecological zone of Burkina Faso. Based on the results from this study, the use of scarifying, tied-ridging and ploughing with compost and mineral fertilizer can be recommended for grain sorghum production in a sole intercrop system in the Sudanian Agroecological zone of Burkina Faso, but when intercropping includes groundnut, the use of tied-ridging that reduces groundnut yields should be avoided.

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