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Pearl Millet and Cowpea Yields as Influenced by Tillage, Soil Amendment and Cropping System in the Sahel of Burkina Faso

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Abstract: Sole cropped pearl millet and intercropped pearl millet with cowpea are the dominant cropping systems in the Sahelien agroecological zone of Burkina Faso with low and stagnant pearl millet and cowpea yields. Two experiments were conducted in randomized complete block designs with split plot arrangements and three replications. The main plot was tillage method in both experiments and the sub-plot was soil amendment (compost, fertilizer, and crop residues). The objective was to identify the best combination of tillage method, cropping system, and soil amendment to optimize sole and intercropped millet and intercropped cowpea yields. In Exp. 1, sole crop millet grain yield was increased by soil amendment application from 238 kg ha^{-1} to 450 to 768 kg ha^{-1}, and stover yields from 551 kg ha^{-1} to 1075 to 1813 kg ha^{-1}. In Exp. 2, zaï tillage increased sole cropped millet grain yield by 348 to 495 kg ha-$^{-1}$, and intercropped millet by 194 to 202 kg ha^{-1} over use of no till and scarify. Combined zaï with C + F application increased sole cropped millet grain yield from 288 to 777 kg ha^{-1} and intercropped millet from 114 to 502 kg ha^{-1} over zaï without soil amendment. Similar trends were observed for millet stover and intercropped cowpea grain and stover yields. Influence of soil amendment application on grain and stover yields was greatest for sole cropped millet with use of zaï in high rainfall years. This first documentation of differential soil amendment response of sole and intercropped pearl millet with zaï, scarify, and no till systems indicates that the greatest pearl millet grain and stover yield is obtained with application of plough or zaï in combination with C + F, F + CR or C + F + CR soil amendment.

Keywords: Compost, Fertilizer, No Till, Plough, Sole and Intercrop System, Scarify, Zaï

1. Introduction

In the Sahelian agroecological zone of the poor West African country of Burkina Faso, sole cropped pearl millet and intercropped pearl millet with cowpea are the dominant cropping systems (World Bank, 2019). The economy is agriculture-based, with 90% of the population involved in subsistence agriculture. In this agroecological zone, pearl millet and cowpea both have low and stagnant 17-yr. average yields of 708 kg ha^{-1} for sorghum and 635 kg ha^{-1} for cowpea (MAAH/DGESS, 2016), while soils are degrading with soil organic matter and nutrient levels declining, thereby reducing water and nutrient holding capacity (Sanchez et al., 1997; Mason et al., 2015a; Mason et al., 2015b). Climate change is projected to increase air temperatures and decrease precipitation further adversely affecting future pearl millet and cowpea yields in the future (Sultan et al., 2013).

Past research has largely focused on single management factors and has shown pearl millet grain yield to increase without long-term soil deterioration due to tillage. Ploughing has been shown to increase soil porosity, rooting depth, soil water storage, and reduce evaporation (Nicou et al., 1993; Ouattara et al., 2006). Klaij and Hoogmoed (1993) indicated an improved use of fertilizer and crop residues, stand establishment, and water use efficiency due to tillage. Harrowing and scarification increases early season rainfall infiltration resulting in yield increases from zero to 15% (Nicou and Charreau, 1985). Use of zaï, consisting of small pits dug before planting with compost applied in the pit before planting, increases yield and helps reclaim degraded land (Yaméogo et al., 2013; Fatondji et al., 2001; Fatondji et al., 2006; Ouattara et al., 1999). Leaving crop residue as a mulch on the soil surface increases soil organic matter concentration (Klaij and Hoogmoed, 1993), soil nutrient levels (Michels et al., 1995) and catches

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aeolian material containing nutrients (Michels et al., 1995). Mulching the soil surface increases water infiltration into soils (Nicou and Charraeu, 1985). Mulching also reduces soil temperature and water evaporation from the soil surface (Stroosnijder et al., 2001), and increases fertilizer response and pearl millet grain yield (Suzuki et al., 2016; Fatondji et al., 2018; Dicko et al., 2018). Compost application increases pearl millet grain yield (Fatondji et al., 2006, Garba et al., 2018) as does fertilizer application rate (Garba et al., 2018; Dicko et al., 2018; Fatondji et al., 2018) and placement (Bagayoko et al., 2011; Fatondji et al., 2018). Studies have shown additive pearl millet grain yield to using a crop residue mulch, compost and fertilizer (Garba et al., 2018; Fatondji et al., 2018; Bationo et al., 1993), and greater pearl millet grain and stover responses in higher rainfall years (Bationo et al., 1990).

Sole crop pearl millet and cowpeas yield more grain and stover but intercropped pearl millet with cowpea often has greater system productivity as measured by land use ratio (Reddy et al., 1992). Yamoah et al. (2003) found greater pearl millet plus cowpea grain and stover yields than sole crop pearl millet in high rainfall year, but lower intercrop yields than sole crop in dry years. Further, they found that the intercrop was more profitable due to the higher price of cowpea grain and stover than for pearl millet. Mason et al. (2015b) and Maman et al. (2017) recently summarized individual management factors on sole and intercropped pearl millet and cowpea to optimize grain and stover yield. Similarly, Maman et al. (2017) found biological and economic advantage of pearl millet and cowpea intercropping over pearl millet sole crops.

Research to integrate individual management factors into a "package" is needed to produce optimal grain and stover yields, thereby leading to greater farmer adoption and increased income, and to improved sustainability. The objective of this study was to identify the best combination of tillage method, soil amendment (compost and/or fertilizer), and cropping system to optimize pearl millet and cowpea grain and stover yields in the Sahelien agroecological zone of Burkina Faso. This would increase integration of production practices helping to optimize production to meet producer needs and consumer demands.

2. Materials and methods

Two experiments were conducted from 2011 to 2014 at the Katchari/Dori Agricultural Research Station (14^o 3' 11'' N lat; 0^o 08' 0.7'' W long) in the Sahelian agroecological zone of Burkina Faso with 407 mm 10-yr average rainfall (Fig. 1; Table 1) falling between July and Oct. Monthly seasonal rainfall and temperature for years of the experiments are presented in Table 1.

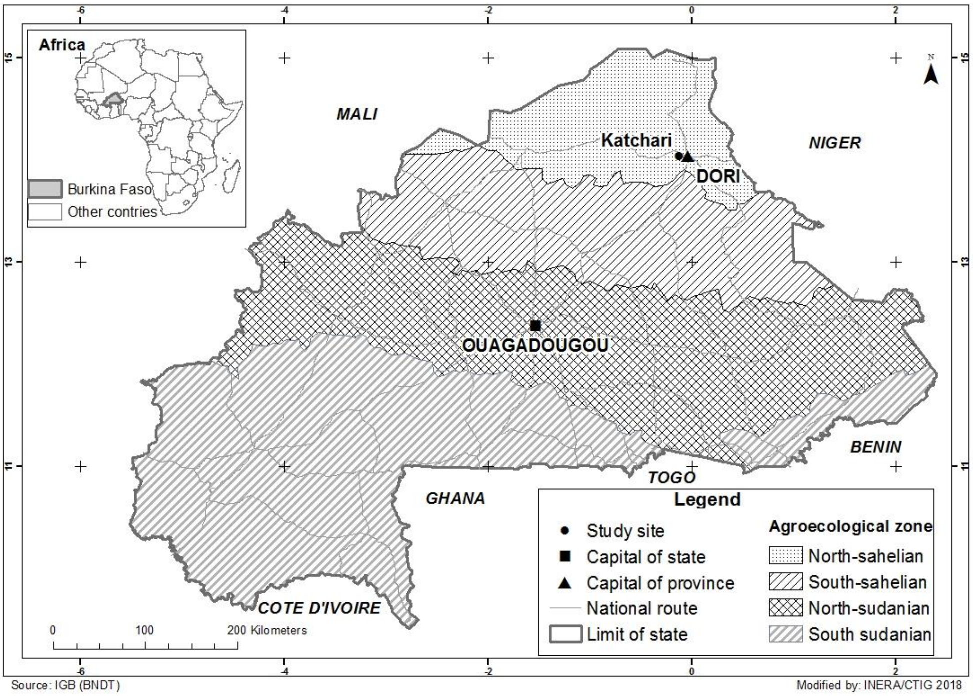

Fig. 1. Map of Burkina Faso showing the Sahelian agro-ecological zone and Katchari (study site) [*Source*: Geography Institute of Burkina Faso; rivized by the Remote Sensing and Geographical Information Unit (CTIG) at the Institute of Environment and Agricultural Research (INERA), Burkina Faso, 2018].

Table 1. Seasonal and monthly rainfall and temperatures in Katchari (Dori), Burkina Faso, 2011 to 2014.

	Seasonal rainfall					Seasonal temperatures				
Month	2011	2012	2013	2014	10-yr ave	2011	2012	2013	2014	10-yr ave
	---------------- mm --------------------					------------------- ºC -------------------				
July	148	160	102	115	117	30.0	28.8	29.6	30.4	29.7
Aug	209	272	250	138	189	28.2	28.0	27.4	28.8	28.3
Sept	129	96	39	122	80	29.7	29.2	29.8	29.2	29.5
Oct	0	10	31	5	21	31.8	30.8	30.5	30.9	31.1
Ave						29.9	29.2	29.3	29.8	29.7
Total	486	537	422	380	407					

Both experiments were conducted in a deep Little Leached Ferruginous Tropical Soil with stains and/or concretions, and sand texture with low water holding capacity. The surface horizon had a pH of 7.4, organic matter concentration of 2.3 g kg^{-1}, and 0.2 g kg^{-1} total N, 11.1 mg kg^{-1} Mehlich-3P, and 0.2 $Cmol^{(+)}$ kg^{-1} exchangeable K (Barro and Ouattara, Institut de l'Environnement et de Recherches Agricoles, Burkina Faso, personal communication, 2011). The fields had been fallowed for 13 years prior to 2011. The pearl millet variety used in both studies was SOSAT C88 with maturity rating of 90 days, and the cowpea variety was "Gorom local" with maturity rating of 70 days was intercropped with pearl millet 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 was soil amendment (compost, mineral fertilizer, crop residues or combination of these soil amendments) in Exp. 1, and cropping system with soil amendment (compost and/or mineral fertilizer) in Exp. 2 (Table 2). The treatments presented in Table 2 were applied to the same plots each year in both studies.

Table 2. Cropping system, tillage and soil amendment treatments for Exp. 1 and 2 in Katchari (Dori), Burkina Faso, 2011 to 2014.

Treatments	Experiment 1	Experiment 2
Cropping system	Sole cropped pearl millet	Sole and intercropped pearl millet, intercropped cowpea
Tillage methods	1.Plough	1. No till
	2.Zaï	2. Zaï
	3.Scarify	3. Scarify
Soil amendments	1. No soil amendment	1. Sole pearl millet 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. Sole pearl millet 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. Sole pearl millet 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 1.5 t ha^{-1}	4. Sole pearl millet with compost and mineral fertilizers.
	5. Compost and fertilizer	5. Pearl millet/cowpea with no soil amendment
	6. Compost and crop residues	6. Pearl millet/cowpea with recommended compost and mineral fertilizer rates.
	7.Fertilizer and crop residues	7. Pearl millet/cowpea with mineral fertilizers
	8. Compost, fertilizer and crop residues	8. Pearl millet/cowpea with compost and mineral fertilizers.

The zaï system is a traditional system used in Burkina Faso and consists of digging small pits 20 to 30 cm in diameter and 10 to 20 cm deep, and in the bottom of the pits either manure or compost is placed and seeds planted. Thus, such a system combines the effects of tillage to capture water and supply nutrients (Fig. 2).

Fig. 2. Zaï pit with pearl millet plants at Dori, Burkina Faso, 2011.

The scarify method consists of a shallow cultivation of the field using a Manga hoe, which is an animal drawn tool.

Plots consisted of six rows, 10-m long. Pearl millet planting was done at the recommended spacing of 80 cm between rows and 80 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 between plants within the row for cowpea , with 1 to 2 plants per hill after thinning. Intercrop planting was done alternating two rows of pearl millet with two rows of cowpea, giving a total of four rows of pearl millet and two rows of cowpea per plot. Simultaneous planting of pearl millet and cowpea were on 10 July 2012, 18 July 2013, and 22 July 2014. Weed control was accomplished by hand hoeing as needed. In all years, 1 L ha^{-1} of Decis® 12 EC containing the active ingredient deltamethrine was mixed with 50 L of water ha^{-1} and sprayed on the cowpea plants at flower budding and pod establishment growth stages to control cowpea aphid (*Aphis craccivora* Koch).

Harvest was done in the middle of each plot and the harvested area was 24.32 m^2 for pearl millet in both experiments and 32 m^2 for cowpea in Exp. 2. Pearl millet panicles, cowpea pods and stover from both crops were hand-harvested, air-dried, threshed, weighted, and recorded as dry weight. Grain and stover subsamples were ground to pass through a 1-mm mesh screen. An automatic combustion method was used for N analysis (Miller et al., 1997), and digestation and inductively coupled plasma spectrometry for P, K, Ca, Mg and micronutrient concentrations (Wolf et al, 2003; Kovar, 2003).

Grain and stover yields were analyzed using standard analysis of variance and pair-wised comparisons by the General Linear Model Procedure on the software SAS version 9.2/STAT®, version 9.2 (SAS Institute, 2010). Results were considered significant at the $P \leq 0.05$ level. Tillage system and cropping system/soil amendment combinations were considered fixed effects.

3. Results and discussion

3.1. Seasonal climatic and plant nutrient concentrations

Seasonal annual rainfall was near the 10-yr average in 2013, while being 27 mm below average in 2014, 79 mm above average in 2011, and 130 mm above average in 2012 (Table 1). Monthly rainfall deviated from the average in all years, likely influencing pearl millet and cowpea yields. Monthly average rainfall in 2012 was 16 to 83 mm 10-yr average in July, Aug and Sept. while in 2011 it was 20 to 49 mm above average. In 2013, monthly rainfall was 15 mm less in July, 61 mm greater in Aug., and 41 mm less in Sept than the 10-yr average. In 2014, monthly rainfall was 51 mm less in Aug., 42 mm greater in Sept., and 16 mm less in Oct. than the 10-yr average. These monthly rainfall difference likely influenced crop growth at the critical times of pollination and early grain fill growth stages of pearl millet in 2014 (Winkel et al., 1997) and late season growth of cowpea for stover (Dingkuhn et al., 2006), especially in the below-average 2014 year. Seasonal and monthly temperatures were near 10-yr average in all years and months with temperatures within ±1.1º C indicating that climatic differences influence on grain and stover yield were largely due to seasonal rainfall differences.

Sole and intercrop pearl millet, and intercropped cowpea nutrient concentrations of grain and stover at harvest were not influenced by tillage method, soil amendment or year in this study (data not presented). This suggests that plant nutrient levels did have an influence on pearl millet and cowpea grain and stover yield in this study.

3.2. Pearl millet

Analysis of variance indicated that the soil amendment main effect influenced on pearl millet grain and stover yields in Exp. 1 (Table 3). In Exp. 2, grain and stover yields for pearl millet were influenced by the interaction effect of Year and Cropping system with soil amendment (Y x CS/SA) (Table 4). Also, the Tillage method and Cropping system with soil amendment (T x CS/SA) interaction influenced the grain and stover yields for pearl millet in Exp. 2 (Table 5). Year x Tillage method interaction (Y x T) had an influence on grain yield for pearl millet in Exp. 1 and stover yield in Exp. 2 (Table 6). The Year x Tillage x Cropping System/Soil Amendment (Y x T x CS/SA) three-way interaction was declared significant for pearl millet stover yield, but is not presented nor discussed as only small magnitude and variable responses occurred, and this interaction presented little useful information beyond that contained in two-way interactions. Further, the analysis of variance indicated that, in either experiment, the T main effect had no influence on pearl millet grain ($P_{Exp1} = 0.93$; $P_{Exp2} = 0.12$) and stover yields ($P_{Exp1} = 0.92$; $P_{Exp2} = 0.07$) in contrast to other tillage research in West Africa (Nicou et al., 1993; Ouattara et al., 1999; Ouattara et al., 2006; Fatondji et al., 2001; Fatondji et al., 2006).

The soil amendment main effect in Exp. 1 indicated the highest grain yield for C + F + CR and F + CR applications, and lowest for zero soil amendment (Table 3). The greatest pearl millet stover yield was for C + F + CR > two soil amendment combinations > single soil amendment application > zero soil amendment across years.

Table 3. Soil amendment influence on grain yield (P <0.01) and stover yield (P <0.01) for pearl millet in Katchari (Dori) in Exp. 1, Burkina Faso, 2011-2014.

Soil amendment	Grain yield	Stover yield
	----------- kg ha^{-1}	------------
Zero	238^{d}	551^{d}
Compost (C)	450^{c}	1113^{c}
Fertilizer (F)	466^{bc}	1075^{c}
Crop residues (CR)	474^{bc}	1101^{c}
C + F	608^{b}	1420^{b}
C + CR	590^{bc}	1230^{bc}
F + CR	682^{ab}	1433^{b}
C + F + CR	768^{a}	1813^{a}

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

The Y x CS/SA interaction effects in Exp. 2 indicated that sole pearl millet grain and stover yields were higher than for intercrop (Table 4) as previously found (Lithourgidis et al., 2011; Maman et al., 2017; Giana et al., 2017), and that soil amendment application increased grain and stover yield in both systems (Maman et al., 2017). Giana et al. (2017) indicated that this reduction in grain yield of pearl millet under pearl millet + cowpea intercropping could probably de attributed to competitive effects of intercrop.

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

Cropping system	Soil amendment	Grain				Stover			
		2012	2013	2014	Mean	2012	2013	2014	Mean
		-------------------------------------				kg ha^{-1} -----------------------------------			
Sole cropped	Zero	409^{Acd}	242^{Bab}	56^{Cb}	236^{c}	1316^{Ac}	493^{Bb}	196^{Ba}	668^{c}
	Compost (C)	576^{Abc}	372^{Ba}	119^{Cab}	356^{b}	1544^{Abc}	758B^{ab}	183^{Ca}	828^{bc}
	Fertilizer (F)	640^{Ab}	279^{Bab}	170^{Bab}	363^{b}	1809^{Ab}	726B^{ab}	402^{Ba}	979^{b}
	Compost + Fertilizer (C + F)	902^{Aa}	365^{Ba}	220^{Bab}	496^{a}	2495^{Aa}	1037^{Ba}	411^{Ca}	1314^{a}
Intercropped	Zero	226^{Ad}	86^{Ab}	64^{Ab}	125^{d}	691^{Ad}	265^{Bb}	151^{Ba}	369^{d}
	Compost (C)	281^{Ad}	133^{Ab}	194^{Aab}	203^{cd}	1064^{Acd}	365^{Bb}	338^{Ba}	589^{c}
	Fertilizer (F)	411^{Acd}	176^{Bb}	196^{Bab}	261^{c}	1476^{Abc}	343^{Bb}	397^{Ba}	739^{c}
	Compost + Fertilizer (C + F)	461^{Ac}	320^{ABab}	259^{Ba}	347^{bc}	1608^{Abc}	699^{Bab}	324^{Ca}	877^{bc}
	Mean	488^{A}	247^{B}	160^{C}		1500^{A}	586^{B}	300^{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.

Pearl millet grain and stover yields were highest in the high rainfall 2012 growing season and lowest in the driest 2014 year (Table 4), consistent with results of Bationo et al. (1990). Averaged across years, the lowest grain yields were without soil amendment, intermediate for C or F application, and greatest for combined C + F application. This was also the case for sole cropped pearl millet stover, while C, F, and C + F produced similar yields to no sole amendment for intercropped pearl millet stover. Without soil amendment application, grain and stover yields were similar for sole and intercropped pearl millet in all years except for stover in the high rainfall 2012 year (Table 1), when sole crop stover yield was 90% greater than intercrop (Table 4). However, with soil amendment application, sole crop pearl millet grain and stover yields were generally greater than for intercrop yields in 2012 and 2013, but not in the dry 2014 year (Table 1). In the low rainfall year of 2014 and the intermediate rainfall year of 2013, pearl millet grain and stover yields with soil amendment were similar to zero soil amendment, and only greater than the grain or stover yield without soil amendment for intercrop stover (Table 4). In contrast, in the high rainfall year of 2012 pearl millet grain yield was greatest for application of C + F. These results indicate that production of sole cropped pearl millet in higher rainfall years with C + F or C + F + CR applications will maximize grain and stover yields across years. In dry production years, cropping system and soil amendment application had little influence in pearl millet grain and stover yields in this study. Clear assessment of the soil and expected climate conditions is required to decide on the appropriate cropping system and soil amendment application for pearl millet in the Sahelian agroecological zone.

Although the tillage method main effect had no influence on pearl millet grain (P = 0.12) and stover yields in either experiment (P = 0.07), tillage method interacted with cropping system/soil amendment (T x CS/SA) to influence grain and stover yield in Exp. 2 (Table 5).

Table 5. Tillage (T) x cropping system with soil amendment (CS/SA) influence on grain and stover yields for pearl millet in Exp. 2 in Katchari (Dori), Burkina Faso, 2012-2014 [Analysis of variance probability: Grain yield T x CS/SA P < 0.01, T P = 0.12, CS/SA P < 0.01; Stover yield T x CS/SA P < 0.01, T P = 0.07, CS/SA P < 0.01].

		Grain				Stover			
Cropping system	Soil amendment	No till	Scarify	Zaï	Mean	No till	Scarify	Zaï	Mean
		---------------- kg ha^{-1} ----------------							
Sole cropped	Zero	297^{Aa}	122^{Bb}	288^{Ac}	236^{c}	736^{Aab}	557^{Ab}	713^{Ac}	669^{c}
	Compost (C)	167^{Bab}	196^{Bb}	704^{Aa}	356^{b}	471^{Bb}	553^{Bb}	1462^{Ab}	829^{bc}
	Fertilizer (F)	318^{Aa}	325^{Aab}	446^{Abc}	363^{b}	758^{Bab}	1042^{ABa}	1138^{Abc}	979^{b}
	Compost + Fertilizer (C + F)	282^{Bab}	429^{Ba}	777^{Aa}	496^{a}	790^{Bab}	1005^{Ba}	2147^{Aa}	1314^{a}
Intercropped	Zero	114^{Ab}	148^{Ab}	114^{Ad}	125^{d}	420^{Ab}	429^{Ab}	257^{Ad}	369^{d}
	Compost (C)	133^{Ab}	201^{Ab}	274^{Acd}	203^{cd}	562^{Aab}	507^{Ab}	699^{Ac}	589^{c}
	Fertilizer (F)	297^{ABa}	148^{Bb}	338^{Ac}	261^{c}	817^{Aab}	544^{Ab}	854^{Ac}	738^{c}
	Compost + Fertilizer (C + F)	283^{Bab}	254^{Bb}	502^{Ab}	346^{bc}	868^{Aa}	731^{Aab}	1033^{Ac}	877^{bc}
	Mean	236^{B}	228^{B}	430^{A}		678^{B}	671^{B}	1038^{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.

Averaged across T, pearl millet grain and stover yields responses to CS/SA were similar to those found across years (Table 4) except for yields with C being higher than F application for sole cropped pearl millet (Table 5) but lower for intercropped pearl millet. On average, the zaï tillage method greatly increased pearl millet grain and stover yields in this low water holding capacity sand soil than with no till and scarifying with a manga hoe, similar to previous research (Ouattara et al., 1999; Fatondji et al., 2001; Fatondji et al., 2006). However, differences among tillage methods were less evident, likely due to decreased df in the statistical analysis and relatively high variability in the study. Pearl millet grain and stover yields were maximized with use sole cropping combined with zaï tillage and application of compost + fertilizer. Although intercrop pearl millet grain and stover yields were lower than for sole crops, pearl millet grain and stover yields were maximized with zaï tillage and application of C + F. These results are consistent with less competition for soil water in sole crops, and greater sole cropped pearl millet grain and stover response to soil amendment application in higher rainfall years (Bationo et al., 1990). In addition, the zaï tillage method acted as a micro-catchment also increasing the sole crop pearl millet response to soil amendment application likely due to increased soil water availability (Ouattara et al., 1999; Fatondji et al., 2001; Fatondji et al., 2006)

Tillage method interacted with year for grain yield in Exp. 1 and stover yield in Exp. 2 (Table 6). In Exp. 1, the plough and zaï systems resulted in the greatest pearl millet grain yields in all years except the high rainfall 2012 year when ploughing produced the highest grain yield, similar to previous results (Nicou et al., 1993; Ouattara et al., 2006). In Exp. 2, averaged across years, the zaï tillage method resulted in the greatest pearl millet stover yield (Table 6), likely the result of increased soil water availability (Ouattara et al., 1992; Fatondji et al., 2001; Fatondji et al., 2006). On average, pearl millet grain and stover yields were greatest in high rainfall 2012 year (Table 1), and lower in 2011, 2013 and 2014 (Table 6).

Table 6. Year (Y) x Tillage method (T) influence on grain yield in Exp. 1 and stover yield in Exp. 2 for pearl millet in 2011, 2012, 2013, and 2014 in Katchari (Dori), Burkina Faso [Analysis of variance probability: Grain yield in Exp. 1 Y x T P = 0.05, Y P < 0.01, T P = 0.93; Stover yield in Exp. 2 Y x T P = 0.02, Y P < 0.01, T P = 0.07].

	Grain in Experiment 1					Stover in Experiment 2			
Tillage method	2011	2012	2013	2014	Mean	2012	2013	2014	Mean
	----------------kg ha^{-1}----------------								
No till						1240^{Ab}	473^{Bb}	320^{Bab}	678^{b}
Scarify	308^{Ca}	856^{Ab}	518^{Ba}	360^{BCa}	510a	1365^{Ab}	523^{Bb}	125^{Cb}	671^{b}
Zaï	405^{Ba}	787^{Ab}	412^{Ba}	439^{Ba}	511a	1895^{Aa}	762^{Ba}	456^{Ca}	1038^{a}
Plough	452^{Ba}	1080^{Aa}	435^{Ba}	361^{Ba}	582a				
Mean	388^{B}	908^{A}	455^{B}	387^{B}		1500^{A}	586^{B}	300^{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.

In 2012 and 2013, pearl millet stover yields were highest with the zaï tillage method and lowest for scarify and no till, while in the dry 2014 year the pearl millet stover yield of the zaï and no till systems were equal. These results indicate that the plough or zaï tillage system should be used in the sand soils in northern Burkina Faso to optimize pearl millet grain and stover yields.

3.3. Cowpea

Analysis of variance indicated that intercropped cowpea grain yields were different across years ($P < 0.01$) with higher yield of 986 kg ha^{-1} in the intermediate rainfall year of 2013 (Table 1), intermediate yield of 598 kg ha^{-1} in the dry rainfall year of 2014, and lower yield of 426 kg ha^{-1} in the high rainfall year of 2012 year. Intercropped cowpea grain and stover yields were influenced by the tillage method x cropping system/soil amendment interaction (T x CS/SA) effects (Table 7).

Table 7. Tillage (T) x Cropping system with soil amendment (CS/SA) influence on cowpea grain and stover yields in Exp. 2 in Katchari (Dori), Burkina Faso, 2012-2014 [Analysis of variance probability: Grain yield T x CS/SA P = 0.02, T P = 0.24, CS/SA P < 0.01; Stover yield T x CS/SA P = 0.04, T P = 0.52, CS/SA P < 0.01].

	Grain				Stover			
Soil amendment	No till	Scarify	Zaï	Mean	No till	Scarify	Zaï	Mean
	kg ha^{-1}							
Zero	262^{Bb}	627A^{ab}	455^{ABb}	448^{b}	786^{Ab}	632^{Aa}	1111^{Ab}	843^{b}
Compost (C)	451^{Bab}	734^{ABa}	864^{Aa}	683^{a}	1696^{Aa}	1052^{Ba}	1182^{ABb}	1310^{a}
Fertilizer (F)	654^{Ba}	406^{Bb}	1063^{Aa}	708^{a}	1432^{Ba}	731^{Ca}	2076A^{a}	1413^{a}
Compost + Fertilizer (C + F)	627^{Ba}	755^{Ba}	1142^{Aa}	841^{a}	1224^{Aab}	870^{Aa}	1328^{Ab}	1141^{ab}
Mean	499^{B}	631^{B}	881^{A}		1285^{A}	821^{B}	1424^{A}	

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

On average, application of soil amendment increased intercropped cowpea and stover yield similar to fertilizer response of Maman et al. (2017) in Niger and manure response of Garba et al. (2018) in northern Burkina Faso. However, there was yield response variability across tillage systems, especially for cowpea grain yield. This yield response was also found for the no till and zaï tillage systems, but for unknown reasons, fertilizer application in the scarify system produced lower yield than with the zero-soil amendment. The zaï tillage system combined with soil amendment application produced the greatest cowpea grain and stover yield, similar to results for pearl millet for sandy soils in northern Burkina Faso (Tables 5 and 6).

Conclusions

This study found that sole cropped and intercropped pearl millet grain and stover, and intercropped cowpea yield was greatest in high rainfall years. The use of the zaï pit technique combined with the application of C + F maximized sole crop pearl millet and intercrop cowpea grain and stover yields. In contrast, when intercropping with cowpea, pearl millet grain and stover yields were greatest when zaï tillage was used while soil amendment had small and variable effects across years. Although pearl millet grain and stover yields were greater in sole crop, the intercrop of pearl millet and cowpea produced a total of 890 kg ha^{-1} grain and 1827 kg ha^{-1} of stover compared to 363 kg ha^{-1} grain and 948 kg ha^{-1} stover for sole cropped pearl millet. This indicated that the intercrop was more biologically efficient than pearl millet sole crop as also found by Maman et al. (2017) and Yamoah et al. (2003). It was concluded that the zaï or plough tillage method is recommended for both sole and intercrop production of pearl millet and intercropped cowpea on low water holding capacity, sandy soils in the Sahelien agroecological zone of Burkina Faso. Soil amendments increase pearl millet and cowpea grain and stover yields, especially in sole pearl millet crops produced during high rainfall years and with zaï tillage. This is the first documentation of differential soil amendment response of sole and intercropped pearl millet with zaï, scarify with manga hoe, and no till systems. Further, this research documents that the greatest pearl millet grain and stover yield occurred with the plough or zaï tillage method in combination of C + F, F + CR or C + F + CR soil amendment applications.

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Declaration of Conflicts of Interest:

- All authors have reviewed the manuscript and approved its submission to *International Journal of Sciences*.
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References

1. Bagayoko M., Maman, N., Palé, S., Sirifi, S., Taonda, S.J.B., Traore, S. and Mason, S.C. (2011). Microdose and P fertilizer application to pearl millet in West Africa. African Journal of Agricultural Research, 6:1141-1150.
2. Bationo, A., Christianson, C.B. and Baethgen, W.E. (1990). Plant density and nitrogen fertilizer effects on pearl millet production in Niger. Agronomy Journal, 82:290-295. https://doi:10.2134/agronj1990.00021962008200020023x
3. Bationo, A., Christianson, C.B. and Klaij, J.C. (1993). The effect of crop residue and fertilizer use on pearl millet production in West Africa. Fertilizer Research, 34:251-258. https://doi.org/10.1007/BF00750571
4. CTIG (Remote Sensing and Geographical Information Unit). (2018). Map of Burkina Faso showing the Sudano-sahelian ecological zone and Katchari (study site). INERA, Burkina Faso.
5. Dicko, M.K., Traoré, L., Kouyaté, Z., Koné, M., Sidibé, B., Kamissoko, N., Wortmann, C., Dioni, L. and Diakité, C.H. (2018). Response of rice, maize and millet to fertilization in Mali. P. 139-155, Chap. 8. In Baiono, A., Ngaradoum, D., Youl, S., Lompo, F., Fening J.O. (eds). Improving the profitability, sustainability and efficiency of nutrients though site specific fertilizer recommendations in West African agro-ecosystems. Vol. 1. Springer Nature, Cham, Switzerland. https://doi.org/10.1007/978-3-319-58789-9_8
6. Dingkuhn, M., Singh, B.B., Clerget, B., Chantereau, J. and Sultan, B. (2006). Past, present and future criteria to breed crops for water-limited environments in West Africa. Agricultural Water Management, 80:241-261. https://doi.org/10.1016/j.agwat.2005.07.01
7. Fatondji, D., Martius, C. and Vlek, P. (2001). Zaï - A traditional technique for land rehabilitation in Niger. *ZEF news* 8: 1 - 2. [Zentrum für Entwicklungsforschung, Universität Bonn, Bonn, Germany].
8. Fatondji, D., Martikus, C., Bielders, C.L., Vlek, P.L.G., Bationo, A. and Gerard, B. (2006). Effect of planting technique and amemdment type on pearl millet yield, nutrient uptake, and water use on degraded land in Niger. Nutrient Cycling in Agroecosystems, 76:203-217.
9. Fatondji, D., Tabo, R., Hash, T.C. and Bationo, A. (2018). Effect of hill placement of nutrients on millet productivity and characteristics of Sahelian soils of Niger: Analysis of yield trend after three years cropping. P. 62-79, Chap. 5. In Baiono, A., Ngaradoum, D., Youl, S., Lompo, F., Fening J.O. (eds). Improving the profitability, sustainability and efficiency of nutrients though site specific fertilizer recommendations in West African agro-ecosystems. Vol. 1. Springer Nature, Cham, Switzerland. https://doi.org/10.1007/978-3-319-58789-9_5
10. Garba, M., Serme, I., Maman, N., Korodjoujma, O., Gonda, A., Wortmann, C. and Mason, S. (2018). Crop response to manure and fertilizer in Burkina Faso and Niger. Nutrient Cycling In Agroecosystems, 111:175-188 (doi.org/10.1007/s10705-018-9921-y).
11. Giana G.K., Sharma, O.P., Shivran, A.C., Boori, P.K. and Meena, S.S. (2017). Productivity and nutrient uptake of pearl millet influenced by intercropping with legumes and fertility level. Research in Environment and Life Sciences, 10:209-212.
12. Klaij, M.C. and Hoogmoed, W.B. (1993). Soil management for crop production in the West African Sahel. II. Emergence, establishment and yield of pearl millet. Soil and Tillage Research, 25:301-315. https://doi.org/10.1016/0167-1987(93)90029-O
13. Kovar, J.L. (2003). Method 6.3 Inductively Coupled Plasma Spectroscopy, IN Peters, J (ed.). Recommended Methods of Manure Analysis. Pub. A3769, pp. 41-43. Univ. Wisconsin Coop. Ext. Service, Madison, WI.
14. Lithourgidis, A.S., Dordas, C.A., Danalas, C.A. and Vlachostergios, D.N. (2011). Annual intercrops: An alternative pathway for sustainable agriculture. Australian Journal of Crop Science, 5: :396-410.
15. MAAH/DGESS (Ministère de l'Agriculture et des Aménagements Hydro-agricoles /Direction Générale des Etudes et des Statistiques Sectorielles). (2016). Enquêtes permanentes agricoles. Ministère de l'Agriculture et des Aménagements Hydro-agricoles, Ouagadougou, Burkina Faso.
16. Maman, N., Dicko, M., Abdou, G., Kouyate, Z. and Wortmann, C. (2017). Pearl millet and cowpea intercrop response to applied nutrients in West Africa. Agronomy Journal, 109 : 2333-2342. https://doi.org/10.5061/dryad.4t0v127
17. Mason, S.C., Ouattara, K., Taonda, S.J.B., Palé, S., Sohoro, A. and Kaboré D. (2015a). Soil and cropping system research in semi-arid West Africa as related to the potential for conservation agriculture. International Journal of Agricultural Sustainability, 13:120-134. https://doi.org/10.1007/s10705-018-9921-y
18. Mason, S.C., Maman, N and Palé, S. (2015b). Pearl millet production practices in semi-arid West Africa: A review. Experimental Agriculture, 51:501-521.
19. Miller, R.O., Kotuby-Amacher, J. and Rodriguez, J.B. (1997). Total Nitrogen in Botanical Materials – Automated Combustion Method. Soil and Plant Analytical Methods, Version 4, pp 106-107. Western States Labortory Proficiency Testing Program. Soil Science Society of America, Madison, WI.
20. Nicou, R. and Charreau, J.G. (1985). Soil tillage and water conservation in semi-arid West Africa, p. 9-32. In Ohm, H.W., Magy, J.G. (eds.) Appropriate technologies for farmers in semi-arid West Africa.West Lafayette, IN.
21. Nicou, R., Charreau, C. and Chopart, J.L. (1993). Tillage and soil physical properties in semi-arid West Africa. Soil and Tillage Research, 27:125-147.
22. Ouattara, B., Hien, V. and Lompo, F. (1999). Development of water management technologies for rainfed crops in Burkina Faso. In van Duivenbooden, N., Pala, M., Studer, C., Bielders, C.L. (eds.). Efficient soil water use: the key to sustainable crop production in the dry areas of West Asia, and North and Sub-Saharan Africa. Proceedings of the 1998 (Niger) and 1999 (Jordan) workshops of the Optimizing Soil Water Use (OSWU) Consortium. Aleppo, Syria: ICARDA; and Patancheru, India: ICRISAT. pp. 265 – 281.
23. Ouattara, K., Ouattara, B., Assa, A. and Sédogo, P.M. (2006). Long term effect of ploughing, and organic matter input on soil moisture characteristics of a Ferric Lixisol in Burkina Faso. Soil and Tillage Research, 88 (1-2): 217-224. DOI: 10.1016/j.still.2005.06.003.
24. Sanchez, P.A., Shepard, K.D., Soule, M.J., Place, F.M., Buresh, R.J., Izac, A.M.N., Mokwunye, A.U., Kwesiga, R.K., Ndiritu, C.G. and Woomer, P.L. (1997). Soil fertility replemishment in Africa: an investment in natural resource capital, p. 1-46. In Buresh, R.J, Sanchez, P.A., Calhoun, F. Replenishing soil fertility in Africa. Soil Sci. Soc. Amer, Madison, WI. Lll
25. SAS Institute (2010). SAS/STAT®, version 9.2, Cary, North Carolina.
26. Stroosnijder, L., Ridder, N. and Kiepe, P. (2001). Nutrient balances in Sahelian villages. Advances in GeoEcology, 33 :213-264.
27. Sultan, B., Roudier, P., Quirion, P., Alhassane, A., Muller, B., Dingkuhn, M., Ciais, P., Guimberteay, M., Traore, S. and Baron, C. (2013). Assessing climate change impacts on sorghum and millet yields in the Sudanian and Sahelian savannas of West Africa. Environment Research Letters, 8 : 014-040 doi :10.1088/1748-9326/8/1/014040.
28. Suzuki, K., Matsunaga, R., Hayashi, K., Matsumoto, N., Tobita, S., Bationo, A. and Okada, K. (2016). Long-term effects of fertilizer and organic matter application on millet in Niger. Agron. J. 108:873-883. Winkel, T., Renno J.-F. and

Payne, W.A. (1997). Effect of the timing of water deficit on growth, phenology and yield of pearl millet (*Pennisetum glaucum* (L.) R. Br.) grown in Sahelian conditions. Journal of Experimental Botany, 310:1001-1009.

29. Wolf, A., Watson, M. and Wolf, N. (2003). Method 5.4 Digestion and dissolution methods for P, K, Ca, Mg and trace elements, IN Peters, J (ed.). Recommended Methods of Manure Analysis. Pub. A3769, pp. 35-36. Univ. Wisconsin Coop. Ext. Service, Madison, WI.
30. World Bank (2019). Burkina Faso – Overview. Washington, D.C. Online athttp://www.worldbank.org/en/country/burkinafaso/overview . Accessed on 14 Jan 2019.
31. Yaméogo, J.T., Somé, A.N., Mette Lykke, A., Hien, M. and Nacro, H.B. (2013). Restauration des potentialités de sols dégradés à l'aide du zaï et des cordons pierreux à l'Ouest du Burkina Faso. Tropicultura, 31: 224-230.
32. Yamoah, C.F., Bationo, A. Shapiro, B. and Koala, S. (2003). Soil management practices to improve nutrient-use efficiencies and reduce risk in millet-based cropping systems in the Sahel. Tropicultura, 21:68-72.