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Tillage, sole and intercrop systems and soil amendment influence on sorghum grain and stover nutrient levels

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Abstract

Sorghum [*Sorghum bicolor* (L) Moench) is a major grain crop in Burkina Faso. A three-year experiment was conducted in the Sudanian zone to determine the combined effects of tillage methods (T) and cropping systems with different soil amendments (CS/SA) on plant nutrient concentrations and related this to human and cattle nutrient requirements. The analysis of variance indicated that tillage, soil amendment nor cropping system affected the stover nutrient concentration of grain sorghum. Nitrogen, P, K, S, Ca, Mg, Zn, Mn and Cu concentrations in grain were all influenced by the Y x T interaction largely due to increased nutrient concentrations for no-till in 2012 and tied ridges in 2013. As grain yield increased, grain N, Ca, Mg and Mn concentrations decreased while P and Zn increased. Grain N, P, Mg, S, Fe and Zn concentrations met human nutritional requirements, while K, Ca, Mn and Cu were deficient and merited supplementation. Nutrient gross means indicated that cattle nutrient requirements were met for N, P, Mg, Fe and Zn, but low for K, Ca, S, Mn and Cu. Tillage, CS/SA and Y had no or small effects on the nutrient concentrations of sorghum grain and stover. The agroecological zones in 2012 and 2013 indicated most nutrients to be adequate for human and cattle diets, but not for K, Ca, Mn and Cu.

Keywords: Compost; Fertilizer; No till; Scarifying; Tied-ridging; Crop production systems

1. Introduction

The growing population [1], soil degradation and climate change [2] are forcing farmers to adopt more intensive and sustainable cropping systems to meet human food needs while improving soil productivity in West Africa. Grain sorghum [*Sorghum bicolor* (L) Moench) is produced either by intercropping with groundnut (*Arachis hypogaea L*) or as a sole crop using various tillage methods often combined with different soil amendments in the Sudanian agro-ecological zone of West Africa [3]. Results from a previous study conducted in the Sahelian, Sudano-sahelian and Sudanian agroecological zone in a sandy or sandy loam, low organic matter soil [4] indicated that pearl millet [*Pennisetum glaucum* (L.) R. Br.] and sorghum grain and stover yields increased with use of zaï or tied ridges combined with compost and fertilizer application [4-6]. Tillage and soil amendment has been shown to have only a small influence on sole and intercropped pearl millet and sorghum grain nutrient concentrations [7-9].

In most West African countries, sorghum grain is primarily consumed by humans as whole-grain products and nutritional value is influenced by the quantity, concentration, and bioavailability of nutrients [10]. Taylor *et al.* [11] reported that malnutrition in Burkina Faso was related to inadequate food consumption, lack of dietary diversity and the consequent low intake of essential nutrients. Previous research reported recommended dietary concentrations for humans and cattle [12-14] and average sorghum grain nutrient concentrations for Mali, Niger, Nigeria and Tanzania

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[15], and for South Africa [16]. Location and year [15], genotype [16-18], fertilizer application [17] and water stress [18] have been shown to influence grain nutrient concentrations.

Typical sorghum stover concentrations have been published for West Africa [19], Botswana [20] and the United States [21]. Wortmann *et al.* [22] is the best source for sorghum nutrient sufficiency levels for West Africa and [23] determined that the sufficiency level of nutrients in sorghum is highest during vegetative growth and then decreases until physiological maturity/harvest, thus critical concentrations for optimizing growth and producing high yield vary with sorghum growth stage.

The study was conducted with the hypothesis that interaction of tillage method and soil amendment would influence sole and intercropped sorghum grain and stover nutrient concentrations. The objective of the present manuscript is to determine the best tillage and soil amendment that will help improve the grain and stover nutritional quality to meet human and cattle nutrition requirements and relate these results to growing grain sorghum plant critical nutrient levels that should be included as quality parameters in evaluating sorghum cropping systems.

2. Material and methods

2.1. Study site

The experiment was conducted in 2012, 2013 and 2014 at the Nadion agricultural research station (11.131 latitude, -2.205 longitude and 340 m elevation) in the Sudanian agro-ecological zone of Burkina Faso with more than 900 mm yr^{-1} mean rainfall, of which approximately 700 mm occurs during the July to October growing season (Fig. 1). The total rainfall of the site was 872 mm in 2012, 839 mm in 2013 and 379 mm in 2014. The soil was Lixisol with a sandy loam texture (FAO-UNESCO), low water holding capacity and a hardpan at 54 cm depth. The surface horizon had pH of 6.0, 10.6 g kg^{-1} organic C, 0.6 g kg^{-1} total N, 3.1 g kg^{-1} P, and 0.15 $cmol^{+}$ kg^{-1} K [24]. The field was fallowed for the previous 20 years before the experiment was initiated.

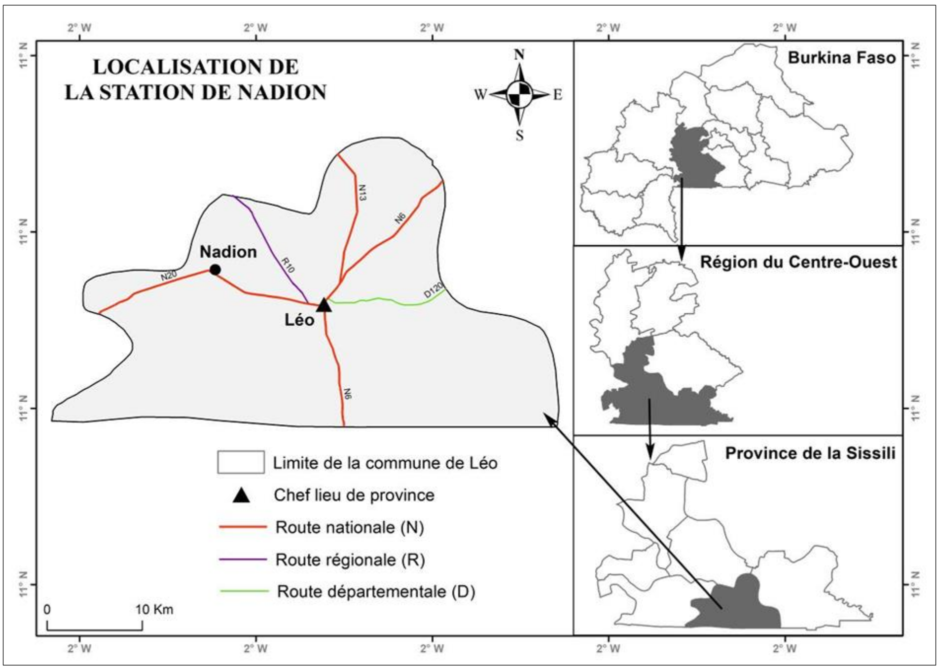

Figure 1 Map of Burkina Faso showing Nadion (study site) [(Map produced by Abdoul Kader DRAME, 2022)]

2.2. 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 and the sub-plot treatment was cropping system with soil amendment (compost and/or fertilizer) (Table 1). Treatments were applied to the same plots each year.

The tied-ridging method consisted of making ridges before planting along the planting rows using animal drawn ridger (Fig. 2). Ties were made at 1 m distance one month after planting, using a manual hoe. The average height was

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 in July of each year. Weed control was accomplished by hand hoeing as needed.

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

Table 1 Tillage methods and soil cropping system with soil amendment treatments for sole intercrop sorghum experiment at Nadion, Burkina Faso

Tillage methods	Cropping system with soil amendment (CS/SA)
No till	1. Sole-cropped grain sorghum with no soil amendment
Scarifying	2. Sole-cropped grain sorghum with recommended compost rate of 2500 kg ha^{-1} /year broadcasted in no-zaï-plots applied before tillage and planting. These 2500 kg ha^{-1} were divided by the number of zaï pits and applied.
Tied-ridging (Fig. 2)	3. Sole-cropped 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. Sole-cropped grain sorghum with compost and mineral fertilizers.
	5. Grain sorghum intercropped with groundnut and no soil amendment
	6. Grain sorghum intercropped with groundnut with recommended compost
	7. Grain sorghum intercropped 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. Grain sorghum intercropped /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).

2.3. Plant material

The sorghum variety used was Sariaso14 with a maturity rating of 90 days, and the groundnut variety CN94C with a maturity rating of 90 days was intercropped with sorghum.

2.4. Data collection

Harvest was done in the middle of each plot leaving the two sorghum border rows at the end of the plot. Grain sorghum panicles and stover were hand-harvested, air-dried, threshed, weighted, and recorded as dry weight. Experiment was conducted in 2012, 2013 and 2014 but grain and stover samples used for the determination of nutrient concentrations were only collected in 2012 and 2013. 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 [25] and digestion and inductively coupled plasma spectrometry for P, K, Ca, Mg and micronutrient concentrations [26].

2.5. Data analysis

Grain and stover nutrient concentrations data were analyzed by using standard analysis of variance and pair-wised comparisons by the General Linear Model Procedure on the software SAS/STAT®, version 9.2 [27]. Differences were declared significant at the $P \leq 0.05$ level. Tillage system and cropping system with soil amendment combinations were considered fixed effects.

3. Results

The analysis of variance indicated that tillage, soil amendment nor cropping system affected the stover nutrient concentration of grain sorghum (N = 2.15%, P = 0.33%, K = 0.49%, Ca = 0.06%, Mg = 0.16%, S = 0.14%, Fe = 61 g kg^{-1}, Zn = 37 g kg^{-1}, Mn = 16 g kg^{-1} and Cu = 7 g kg^{-1}). As grain yield increased, the N (R = -0.27, P < 0.01), Ca (R = -0.35, P < 0.01), Mg (-0,59, P < 0.01) and Mn (R = -0.43, P < 0.01) concentrations decreased while the P (R = 0.54, P < 0.01) and Zn (R = 0.42, P < 0.01) increased. Results indicated that N, P, K, S, Ca, Mg, Zn, Mn and Cu concentrations in grain were all influenced by the Year (Y) x Tillage method (T) interaction (Tables 2, 3 and 4). The grain N and P concentrations were also affected by the Y x cropping system with soil amendment CS/SA interaction (Table 5).

Table 2 Year (Y) x Tillage method (T) effect and on sorghum grain nutrient concentrations in sorghum/groundnut intercrop system at Nadion (Léo), Burkina Faso. [Analysis of variance probability: N PY x T = 0.02, PY = 0.18, PT = 0.05; P PYxT< 0.01, PY= 0.07, PT= 0.51; K PY x T< 0.01, PY = 0.89, PT = 0.68]

Tillage Method	N (%)			P (%)			K (%)		
	2012	2013	Mean	2012	2013	Mean	2012	2013	Mean
No till	2.14^{aA}	1.88^{aB}	2.01^{a}	0.43^{aA}	0.20^{abB}	0.32^{a}	0.48^{aA}	0.42^{bB}	0.45^{a}
Scarifying	2.06^{abA}	1.90^{aB}	1.98^{a}	0.37^{bA}	0.17^{bB}	0.27^{b}	0.43^{bA}	0.44^{bA}	0.44^{a}
Tied ridging	1.92^{bA}	1.95^{aA}	1.94^{a}	0.34^{bA}	0.25^{aB}	0.29^{ab}	0.43^{bB}	0.49^{aA}	0.46^{a}
Mean	2.04^{A}	1.91^{B}		0.38^{A}	0.21^{B}		0.45^{A}	0.45^{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.

Table 3 Year (Y) x Tillage method (T) effect and on sorghum grain nutrient concentrations in sorghum/groundnut intercrop system at Nadion (Léo), Burkina Faso. [Analysis of variance probability: S $P_{Y\,x\,T}$< 0.01, P_Y = 0.28, P_T = 0.01; Ca $P_{Y\,x\,T}$< 0.01, P_Y = 0.09, P_T = 0.28; Mg P_{YxT} = 0.02, P_Y= 0.02, P_T =0.18]

Tillage Method	S (%)			Ca (%)			Mg (%)		
	2012	2013	Mean	2012	2013	Mean	2012	2013	Mean
No till	0.12^{aA}	0.12^{bA}	0.13^{a}	0.05^{aA}	0.04^{aB}	0.04^{a}	0.20^{aA}	0.13^{aB}	0.17^{a}
Scarifying	0.12^{aB}	0.13^{abA}	0.13^{a}	0.05^{aA}	0.04^{aB}	0.05^{a}	0.17^{bA}	0.14^{aB}	0.15^{b}
Tied ridging	0.11^{bB}	0.14^{aA}	0.13^{a}	0.04^{bA}	0.04^{aA}	0.04^{a}	0.16^{bA}	0.13^{aB}	0.15^{b}
Mean	0.12^{B}	0.14^{A}		0.05^{A}	0.04^{B}		0.18^{A}	0.13^{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.

Table 4 Year (Y) x Tillage method (T) effect and on sorghum grain nutrient concentrations in sorghum/groundnut intercrop system at Nadion (Léo), Burkina Faso. [Analysis of variance probability: Zn $P_{Y\,x\,T} < 0.01$, $P_Y = 0.17$, $P_T = 0.31$; Mn $P_{Y\,x\,T} = 0.01$, $P_Y = 0.12$, $P_T = 0.38$; Cu $P_{Y\,x\,T} < 0.01$, $P_Y = 0.17$, $P_T = 0.97$; Iron $P_{Y\,x\,T} = 0.02$, $P_Y = 0.22$, $P_T = 0.65$]

Tillage Method	Zn (g kg^{-1})			Mn (g kg^{-1})		
	2012	2013	Mean	2012	2013	Mean
No till	32^{aA}	33^{bA}	32^{a}	20^{aA}	13^{aB}	17^{a}
Scarifying	29^{abB}	36^{bA}	32^{a}	18^{abA}	13^{aB}	15^{a}
Tied ridging	27^{bB}	42^{aA}	34^{a}	15^{bA}	15^{aA}	15^{a}
Mean	29^{B}	37^{A}		17^{A}	14^{B}	
	Cu (g kg^{-1})			Fe (g kg^{-1})		
No till	6^{aA}	6^{bA}	6^{a}	46^{aA}	44^{bA}	45^{a}
Scarifyinging	5^{bB}	6^{abA}	6^{a}	46^{aA}	49^{abA}	48^{a}
Zaï	5^{bB}	7^{aA}	6^{a}	43^{aB}	55^{aA}	49^{a}
Mean	5^{B}	6^{A}		45^{B}	49^{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.

Table 5 Year (Y) x Cropping system with soil amendment (CS/SA) effect on sorghum grain nitrogen and phosphorus concentrations in grain sorghum/groundnut intercrop at Nadion (Léo), Burkina Faso. [Analysis of variance probability: N $P_{YxCS/SA} = 0.01$, $P_Y = 0.18$, $P_{CS/SA} = 0.07$; P $P_{Y\,x\,CS/SA} = 0.05$, $P_Y = 0.07$, $P_{CS/SA} = 0.40$]

Cropping system with soil amendment	N (%)			P (%)		
	2012	2013	Mean	2012	2013	Mean
Sole crop with no soil amendment	1.92^{bA}	1.70^{bA}	1.81^{b}	0.35^{bA}	0.21^{abB}	0.28^{ab}
Sole crop + compost (C)	1.95^{abA}	1.98^{aA}	1.96^{ab}	0.40^{abA}	0.26^{aB}	0.33^{a}
Sole crop + mineral fertilizer (F)	2.05^{abA}	2.04^{aA}	2.04^{a}	0.32^{bA}	0.21^{abB}	0.26^{b}
Sole crop + C + F	2.04^{abA}	2.10^{aA}	2.07^{a}	0.38^{abA}	0.21^{abB}	0.29^{ab}
Intercrop with no soil amendment	2.05^{abA}	1.95^{abA}	2.00^{a}	0.34^{bA}	0.21^{abB}	0.27^{ab}
Intercrop + C	2.02^{abA}	2.05^{aA}	2.04^{a}	0.44^{aA}	0.14^{bB}	0.29^{ab}
Intercrop + F	2.12^{abA}	1.75^{bB}	1.93^{ab}	0.38^{abA}	0.24^{aB}	0.31^{ab}
Intercrop + C + F	2.16^{aA}	1.72^{bB}	1.94^{ab}	0.43^{abA}	0.20^{abB}	0.31^{ab}
Mean	2.04^{A}	1.91^{B}		0.38^{A}	0.21^{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. *C: compost; F: fertilizer.*

3.1. Y x T interaction influence on grain nutrient concentrations

Averaged across soil amendment and cropping system, sorghum grain concentrations were higher in 2012 than 2013 for N, P, Ca, Mg and Mn, and lower in 2012 than 2013 for S, Zn, Cu and Fe (Tables 2, 3 and 4). There were no grain K concentration differences across years. Averaged across years, concentrations showed no N, K, S, Ca, Zn, Cu, Mn, and Fe differences. The P concentration was highest for no-till and lowest for scarifying tillage while the Mg concentration was highest for no-till and lowest for scarifying and tied ridging. The Y x T interaction influence was largely due to no till having the highest concentration for N, P, K, S, Ca, Mg, and MN in 2012. In 2013, the highest concentrations for Fe, Zn, and Cu occurred in tied ridging plots.

3.2. Y x CS/SA influence on sorghum grain N and P concentrations

Y x CS/SA interaction on sorghum grain nutrients resulted in concentrations that varied from 1.70 to 2.16 % for N and 0.14 to 0.44% for P (Table 5). Averaged across CS/SA combinations, sorghum grain N and P concentrations were higher in 2012 than 2013. Averaged across years, the sole crop sorghum with F and with C and F along with the intercropped sorghum without soil amendments and with compost had higher N concentration than the sole cropped sorghum without soil amendment. The sole crop with compost application had higher P concentration than the sole crop sorghum with fertilizer application. The Y x CS/SA interaction for N concentrations was largely due to the intercrop with fertilizer and intercrop with compost and fertilizer was higher in 2012 than 2013, but similar for the other CS/SA combinations. For the grain P concentration, the P concentration was similar for years for all CS/SA combinations except for intercropped sorghum with compost that was much higher in 2012 than 2013.

4. Discussion

4.1. Sorghum stover nutrient concentrations

In contrast to previous studies [7-9], tillage, cropping system and soil amendment had no influence on the stover nutrient concentrations in spite of having influence on stover yields [4-6]. Mean stover nutrient concentrations indicated that N, P, Mg, Fe and Zn were adequate to meet cattle nutritional requirements, while K, Ca, S, Mn and Cu were inadequate [14]. Stover nutrient concentrations at physiological maturity were adequate for P, Mg, S, Fe, Zn, Mn, and Cu, but inadequate for N, K and Ca which may have been deficient earlier during reproductive growth [22, 23]. Stover N and P concentrations were higher than other world reports, but lower for K and Ca stover concentrations [7-9, 19-21]. Concentrations for stover Mg was lower than other reports except for Palé *et al.* [9]. Concentrations for S and Cu were similar to other world reports, while stover concentrations for Fe and Zn were similar for other reports except higher than by Maw *et al.* [21]. Stover concentration for Mn was similar to other world reports except lower by Youngquist et al. [20]. Stover nutrient concentrations are thus shown to vary worldwide across locations and years.

4.2. Sorghum grain nutrient concentrations

The data indicates that grain N, Ca, Mg and Mn concentrations were diluted with increasing grain yield as found by Buerkert *et al.* [28]. Higher concentrations of grain N, P, Ca, Mg, and Mn in 2012 and higher grain concentration of S, Zn, Fe and Cu in 2013 (Tables 2, 3 and 4) do not appear to be related to the seasonal rainfall and distribution as these were similar in both years [6]. The differences across years for micronutrients were significant, but very small. Averaged across years, the concentrations for most nutrients were similar, and the interaction of Y and T with higher nutrient concentrations for no-till in 2012 and highest concentrations for tied ridges in 2013 does not appear to have a logical explanation.

Higher N and P grain concentrations in 2012 than 2013, and certain tillage methods with high N and P concentrations than the other treatments cannot be explained by the data collected. Nutrient concentrations for N, P, Mg, S, Fe and Zn were adequate to meet human nutritional requirements, while K Ca, Mn, and Cu were low [12, 13] and may need to be supplemented in human diets. Grain nutrient concentrations were similar to those reported by Pale *et al.* [7-9], Wortman *et al.* [15], Mabelebele *et al.* [16], Liboreiro Paiva *et al.* [18] and van Duivenbooden [19], except for (1) grain Ca being lower than for several references, (2) Fe being higher except for Pale *et al.* [7-9], (3) grain Zn concentration being much lower than Wortmann *et al.* [15], and (4) grain Cu concentration being higher than most references. Clearly, wide variation in sorghum grain concentration occurs across years and the world.

4.3. Abbreviations

N: Nitrogen; P: Phosphorus; K: Potassium; Ca: Calcium; Mg: Magnesium; S: Sulfur; Zn: Zinc; Fe: Iron; Mn: Manganese; Cu: Copper; SA: Amendment; T: Tillage Method; CS/SA: Cropping system with soil amendment; Y: Year

5. Conclusion

Sorghum grain and stover nutrient concentrations were measured at physiological maturity to assess the influence of T and CS/SA on nutrient concentrations and suitability for human food, livestock feed in the Sudanian agroecological zone of Burkina Faso. Tillage, cropping system and soil amendment had no influence on stover nutrient concentrations. The Y x T interaction indicated higher N, P, Ca, Mg and Mn concentrations in 2012 and for S, Zn and Cu in 2013. Most grain nutrient concentrations were similar across tillage system but variation across years indicated the no-till generally had the highest nutrient concentrations in 2012 and tied ridges in 2012.

In this Sudanian agroecological zone of Burkina Faso, the grain nutrient concentrations were adequate for 31 to 50-year-old males weighing 60 kg and non-pregnant females weighing 49 kg for N, P, Mg, S, Fe and Zn, but deficient for K, Ca, Mn and Cu while sorghum stover nutrient concentrations for feeding cattle were adequate for N, P, Mg, Fe but low for K, Ca, S, Mn and Cu.

It is concluded that Y and T had small influences on grain nutrient concentrations, but not on forage nutrient concentrations. Crop management to raise grain K, Ca, Mn and Cu concentrations to meet human and cattle dietary needs and S concentrations for cattle, or supplemented diets with other feedstuffs to meet nutrient requirements in this Sudanian agroecological zone of Burkina Faso.

Compliance with ethical standards

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Disclosure of conflict of interest

- All authors have reviewed the manuscript and approved its submission to the journal GSC Advanced Research and Reviews.
- The manuscript is not submitted elswhere.

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