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Original Research

Sorghum Grain and Stover Nutrient Concentrations as Influenced by Tillage and Soil Amendment in Semi-Arid Burkina Faso

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Abstract

Sorghum [Sorghum bicolor (L) Moench) is a major grain crop in Burkina Faso. Two three-year experiments were conducted in the Sudanian and Sudano-Sahelian zones to determine how plant nutrient concentrations are affected by tillage methods (T) and soil amendments (SA). In both locations, T and SA had little effect on grain and stover nutrient concentrations with some cases of inconsistency across years. Some nutrient concentrations differed by year. The grain nutrient concentrations of N, P, Mg, S, Zn, and Fe were adequate for human nutrition at both locations, but deficient for K, Ca, Mn and Cu. Sorghum nutrient concentrations for feeding cattle were adequate for K, Ca, Mg, S, Mn, and Zn in most cases at both locations but low for N, P, and Cu. The stover N and P concentrations also appeared to be deficient for optimal plant growth. In both agroecological zones, nutrient applications or genetic enhancement to improve deficient nutrient concentrations, or use of diverse foodstuffs, or biofortified sorghum to provide deficient nutrients in human and cattle diets is needed to meet dietary requirements. In addition to grain and stover yield, studies need to evaluate grain nutrient and stover nutrient concentrations to meet human and cattle dietary requirements. **Keywords:** Zaï; Tied ridges; Crop residues; Compost; Fertilizer; Human and cattle nutrition.

1. Introduction

Population growth [1], soil degradation and climate change [2] are forcing farmers to adopt sustainable intensification of production systems to meet human and livestock nutrition needs while maintaining soil quality in West Africa. Grain sorghum *[Sorghum bicolor (L)* Moench) is one of the most important crops grown in West Africa [3]. It is widely produced as a sole crop using a variety of tillage methods and with or without soil amendment application.

In West Africa, sorghum grain is primarily consumed by humans as whole-grain products and nutritional value is influenced by the quantity, concentration and bioavailability of nutrients [4]. Malnutrition in Burkina Faso has been found to be related to inadequate food consumption, lack of dietary diversity and the consequent low intake of essential nutrients [5]. Literature review indicated that recommended human dietary concentrations have been previously published [6, 7] and average sorghum grain nutrient concentrations have been presented for Mali, Niger, Nigeria, and Tanzania [8], Burkina Faso [9] and South Africa [10]. Location and year [8], genotype [10-12], water stress [11] and fertilizer application [12] have been shown to influence grain nutrient concentrations. Previous research has indicated that reductions in grain nutrient concentrations are commonly associated with increased cereal yield [13].

Typical sorghum stover nutrient concentrations have been published for West Africa [14] and the United States [15]. Current nutrient requirements for cattle have been published by Gadberry [16], but little research has been published relating stover nutrient concentrations to cattle dietary needs. Literature indicated that sorghum and pearl millet stover research had primarily focused on animal performance, metabolizable energy and stover N concentrations [17]. Nutrient concentrations of plant tissue can be useful to determine sufficiency of nutrient levels for optimal crop growth and nutritional status. The best sufficiency level data for sorghum in Sub-Saharan Africa

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CC BY: Creative Commons Attribution License have been estimated in Wortmann, *et al.* [18]. Research to determine the nutrient concentration variations in crop growth indicated that 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 growth stage [15].

A better understanding of variation in nutrient concentrations of stover and grain and implications for cattle and human nutrition is needed. Palé *et al.* [9, 19] found that T and SA application had only small effects on sorghum and pearl millet (Pennisetum glaucum (L) R. Br.) nutrient concentrations. Pearl millet grain nutrient concentrations in Burkina Faso have been found limiting for Mn, Ca and P in humans [19] while sorghum grain has been found limiting for K, Mn and Cu [9]. Pearl millet stover was found to be limited for N and P, and N [19], while limitations in sorghum stover were for P and Cu [9]. Sorghum grain and stover yields can be increased with the use of zaï combined with applications of compost and fertilizer for sandy loam soil of low organic matter in the SudanoSahelian and Sudanian agroecological zones [20-22].

The study was conducted with the hypothesis that interaction of tillage method and soil amendment would influence sorghum grain and stover 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 relates these results to growing grain sorghum plant critical nutrient levels that should be included as quality parameters in evaluating sorghum management systems.

2. Materials and Methods

2.1. Study Sites

2.1.1. Sudanian Site

The Sudanian site was at the Nadion Mini Agricultural Research Station (11.131 latitude, -2.205 longitude and 340 m elevation) in the agroecological zone of Burkina Faso with more than 900 mm yr⁻¹ rainfall, of which approximately 700 mm occurs during the July to October growing season (Fig. 1). The total rainfall of the site was 592 mm in 2011, 872 mm in 2012, 839 mm in 2013 and 379 mm in 2014. The soil order in the area is Lixisol (FAO-UNESCO), sandy loam with 66.4% sand, 26.9% silt and 6.8% clay, relatively low water holding capacity and a hardpan at 54 cm depth. The surface horizon had 6.0 pH, 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 [23]. The history of the field indicated that it was fallowed for 20 years.

Fig-1. Map of Burkina Faso showing Kamboinsé in the Sudano-sahelian agro-ecological zone and Nadion in the Sudanian agro-ecological zone of Burkina Faso



Source: Geography Institute of Burkina Faso; rivised by the Remote Sensing and Geographical Information Unit (CTIG) at the Institute of Environment and Agricultural Research (INERA), Burkina Faso, 2021

2.1.2. Sudano-Sahelian Site

The Sudano-Sahelian site was at the Kamboinsé Agricultural Research Station (12.475 latitude, -1.585 longitude, and 310 m) (Fig. 1). The total rainfall during the July to October season was 409 mm in 2011, 626 mm in 2012, 433 mm in 2013, and 542 mm in 2014. The soil order in the area is Luvisol (FAO-UNESCO), sandy loam with 35% sand, 32% silt and 33% clay and had low water holding capacity. The surface horizon had 7.4 pH, organic carbon (C) concentration of 2.7 g kg⁻¹, N concentration of 0.08g kg⁻¹, P concentration of 1.6 mg kg⁻¹ and K concentration of 105 mg kg⁻¹. The history of the field indicated that it was fallowed fallowed for 10 years previous to 2011.

2.2. Experimental Design

The research was conducted during 2011-2014 on the same sites using a randomized complete block design with a split-plot arrangement and three replications. The four main plots had tillage treatments repeated each year including: no-till, scarifying, tie-ridging at Nadion or zaï at Kamboinsé, and ploughing. The scarifying method consists of a 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. 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. 3).



Fig-2. Tied-ridging technique (Ridge: made along the planting rows; Tie: made at 1 m distance and tying ridges)

Source: Photo by S. Pale, 2009



Source: Photo by S. Pale, 2009

The eight sub-plots had soil amendment treatments that included 1) no amendment, 2) 2.5 t ha⁻¹ yr⁻¹ compost (13.95 g kg⁻¹ N, 29.80 g kg⁻¹ P and 6.35 g kg⁻¹ K) applied before tillage and planting, 3) fertilizer broadcast application at planting or within one week of planting with 10.5 kg N ha⁻¹ yr⁻¹, 17 kg P₂O₅ ha⁻¹ yr⁻¹, and 10.5 kg K₂O ha⁻¹ yr⁻¹, and another 23 kg N ha⁻¹ yr⁻¹ as urea at 45 days after planting; 4) 3 t ha⁻¹ yr⁻¹ of sorghum crop residues applied before tillage.; 5) compost plus fertilizer as in treatments 2 and 3; 6) compost plus crop residue as in treatments 2 and 4; 7) fertilizer plus crop residues as in treatments 3 and 4; and 8) compost, fertilizer plus crop residues as in treatments 2, 3 and 4 (Table 1). Treatments were applied to the same plots each year.

Plots consisted of six rows of 10-m length spaced at 80 cm. Sorghum was thinned to 1 or 2 plants per hill space at 40 cm within rows. Sorghum was planted in July of each year. The sorghum varieties were Sariaso14 of 90-day maturity at Nadion and Sariaso 11 at Kamboinsé of 100 to 105 days maturity. Weed control was done by hand hoeing as needed, including for no-till treatments.

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

Soil Amendmer	nt (SA) for Both	Sites
Nadion	Kamboinsé	
1. No till	1. No till	1. No soil amendment
2. Scarifying	3. Scarifying	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
4. Tied-ridging (Fig. 2)	2. Zaï (Fig. 3)	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 ₂ O 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
5. Plough	3. Plough	4. Recommended surface applied sorghum crop residues of 3.0 T ha ⁻¹
		5. Recommended compost and fertilizer
		6. Recommended compost and surface applied crop residues
		7. Recommended fertilizer and crop residues applied
		8. Recommended compost, fertilizer and crop residues applied

2.3. Data Collection

Panicles and stover were hand-harvested from 25.76 m² in the middle of each plot, air-dried with threshing of the panicles, and weighed for air-dry weight. Grain and stover subsamples of sorghum were collected in 2011, 2012 and 2013 at Kamboinsé. At Nadion, grain samples were collected in 2011, 2012 and 2013, but stover samples were only collected in 2012 and 2013. Samples were ground to pass through a 1-mm mesh screen. An automatic combustion method was used for N analysis [24], and digestion and inductively coupled plasma spectrometry for P, K, S, Ca, Mg, Zn, Fe, Mn and Cu concentrations [25]. Fe was omitted from sorghum stover concentration data due to erratic concentration levels likely resulting from sampling or laboratory errors.

2.4. Data Analysis

Grain and stover nutrient concentrations were analyzed using standard analysis of variance using the General Linear Model Procedure on the software SAS/STAT[®], version 9.2 [26]. Pearson correlations between grain and stover yields and nutrient concentrations at harvest were determined. Results were considered significant at $P \le 0.05$.

3. Results

3.1. Sorghum Grain Nutrient Concentrations

Tillage method and SA application had no influence on grain N, P, K, Ca and Fe concentrations at both locations, and on Zn and Fe concentrations at Kamboinsé. When differences were present for grain nutrient concentration, the differences were small and erratic across tillage methods and soil amendments. In contrast to T and SA effects, Y influenced grain N, P and K concentrations at Nadion (Table not shown), and grain N, P, K, Ca, S, Zn, Fe and Cu concentrations at Kamboinsé (Table 2). At Nadion, grain N and P concentrations were 1.94% in 2012 and 2.03 to 2.06% in 2011 and 2013, P was 0.32% in 2012 and 0.36 to 0.38 in 2011 and 2013, while K was 0.40 to 0.41% higher in in 2011 and 2012 and 0.43% in 2013. At Kamboinsé, the grain N, Ca, S, Zn and Cu were highest in 2013, with lower and similar concentrations in 2011 and 2012. Both the grain P and K concentrations at Kamboinsé were highest in 2012 and 2013, and lowest in 2011 while the Fe concentration was highest in 2013 and lowest in 2011.

Mean grain Mn was higher in 2013 > 2011 > 2012 at Nadion and higher in 2012 > 2013 > 2011 at Kamboinsé (Table 3) indicating increased Mn with more rainfall. The Y x T interaction affected grain Mn concentration at both locations. Compared with other tillage treatments, grain Mn was low with scarification at Nadion in 2012 and high with plough in 2013. At Kamboinsé, grain Mn with plough was especially low in 2011 while overall Mn was for no-till > zaï > plough.

At Nadion, the Y x T interaction effects indicated that on average across tillage methods that the S, and Zn grain concentrations were higher in 2011 and 2013 than in 2012 (Table 4). In contrast, the grain Cu concentration was greatest in 2011 and lowest in 2012. Averaged across Y, the no-till had 0.01 higher grain S concentration and 1 mg kg⁻¹ higher grain Cu concentrations than for other T methods, and along with tied ridging had 2 mg kg⁻¹ greater grain Mn concentration than for scarifying. Grain Zn was 2 to 6 mg kg⁻¹ greater and S was 0.1 to 0.2 g kg⁻¹ greater with no-till and scarifying than with plough in a low rainfall year of 2011 [21]. In 2012 with higher rainfall and grain yield, sorghum grain produced with no till had 0.02% S and 1 mg kg⁻¹ Cu concentrations than with scarifying and plough tillage. In 2011, T had no influence on grain Zn concentrations. In 2012, sorghum produced with no till had

the highest grain S and Cu concentrations. The T method had no influence on the grain Zn concentration in 2012. In 2013, sorghum produced with plough tillage had higher S, Zn and Cu grain concentrations than with most other T methods.

The grain S concentration at Nadion was also influenced by the Y x SA and T x SA interactions (Table 5). Differences were small, but 2011 and 2013 produced sorghum grain with higher S concentration than in 2012. Averaged across years and across tillage methods, sorghum with compost and compost plus fertilizer applications had 0.01% lowest S concentrations than with other soil amendments. Only very small and subtle grain S concentration differences were present for soil amendment in individual year or different tillage methods. In addition, grain Mg concentrations were 0.01 to 0.02% higher for compost, compost plus fertilizer, compost plus crop residues, fertilizer plus crop residues, and compost plus fertilizer and crop residues than for no soil amendment application. At Nadion, grain had higher Mg concentrations with most SA application than with no fertilizer application (Table 6).

At Kamboinsé, the T x SA interaction influenced the grain P and Mg concentrations (Table 6). Averaged across T, sorghum grain produced with compost plus fertilizer, compost plus crop residues and fertilizer with crop residues had higher P and Mg concentrations than with fertilizer alone applied. Averaged across SA, sorghum grain produced with no till and zaï had higher grain P concentration than with the plough, while for grain Mg concentration, concentrations were highest for sorghum produced with no till, scarifying and zaï and lowest for plough. The amendment x SA interaction was significant largely due to low P grain concentration for zaï with compost plus fertilizer applied, plough with crop residues applied, and high concentration for zaï with compost plus fertilizer applications. This interaction for grain Mg concentration appeared to largely be due to low sorghum grain Mg concentrations when produced with no till without amendment, scarifying with fertilizer applied, and plough with compost plus fertilizer plus crop residues and with compost plus fertilizer plus crop residues and with compost plus fertilizer plus crop residues applied.

The Y x T interaction effects were found for grain Ca, Mg and Mn concentrations at Kamboinsé (Table 7). Averaged across years, sorghum produced with plough had the lowest concentration for grain Ca and Mg with no difference among the other T methods for Mg concentrations. Averaged across tillage methods, sorghum grain Mg was highest in 2012 and 2013 and lowest in 2011, while the grain Ca concentration was greatest in 2013 and lowest in 2011 and 2012. The year by tillage method interaction was largely due to the low sorghum grain Mg and Ca concentrations with production using plough in 2011.

	Grain		Stover	Stover		
Nutrient	2011	2012	2013	2012	2013	
Nitrogen (%)	1.86 ^c	2.13 ^b	2.34 ^a	0.69 ^b	0.88 ^a	
Phosphorus (%)	0.34 ^b	0.41 ^a	0.41 ^a	0.06 ^a	0.06 ^a	
Potassium (%)	0.38 ^b	0.43 ^a	0.47 ^a	1.54 ^b	1.88 ^a	
Calcium (%)	0.06 ^b	0.06 ^b	0.07 ^a	0.33 ^b	0.38 ^a	
Sulfur (%)	0.14 ^b	0.15 ^b	0.18 ^a	0.11 ^b	0.18 ^a	
Zinc (mg kg ⁻¹)	38 ^b	36 ^b	47 ^a	31 ^b	41 ^a	
Iron (mg kg ⁻¹)	60 ^b	73 ^{ab}	87 ^a			
Copper (mg kg ⁻¹)	7 ^b	7 ^b	10 ^a	6 ^a	6 ^a	
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Table-2. Year effects on grain and stover nutrient concentrations at Kamboinsé, Burkina Faso

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

Table-3. Year (Y) x Tillage method (T) effects on grain Mn concentrations at Nadion and Kamboinsé, Burkina Faso. [Analysis of varianceprobability: Nadion Mn $P_{YxT} < 0.01$, $P_T < 0.23$; Kamboinsé Mn $P_{YxT} = 0.04$, $P_T < 0.01$, $P_T = 0.07$]

	Nadion	- Mn (m	g kg ⁻¹)		Kamboinsé- Mn (mg kg ⁻¹)			
Tillage method	2011	2012	2013	Mean	2011	2012	2013	Mean
No till	21 ^{aA}	21 ^{aA}	22 ^{bA}	21 ^a	27^{abB}	30^{aAB}	35 ^{aA}	31 ^a
Scarifying	21 ^{aA}	17 ^{bB}	21 ^{bA}	20 ^b	29 ^{aA}	27 ^{abA}	31 ^{abA}	28^{ab}
Tied ridging	21 ^{aA}	22 ^{aA}	21 ^{bA}	21 ^a	23 ^{bA}	27 ^{abA}	26 ^{bA}	25 ^b
Plough	19 ^{aB}	18 ^{bB}	26 ^{aA}	21 ^{ab}	11 ^{cB}	22 ^{bA}	22 ^{bA}	18 ^c
Mean	21 ^B	19 ^{°C}	22 ^A		23 ^B	26 ^A	28 ^A	

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

Table-4. Year (Y) x Tillage method (T) effects on grain S, Zn and Cu concentrations at Nadion, Burkina Faso. [Analysis of variance probability: S $P_{YxT} < 0.01$, $P_T = 0.08$; Zn $P_{YxT} = 0.04$, $P_T < 0.01$, $P_T = 0.03$; Cu $P_{YxT} = 0.01$, $P_T < 0.01$, $P_T = 0.00$; Probability of Year main effect on N < 0.01; Probability of Year main effect on P < 0.01]

Tillage	S (%)	S (%) Zn (mg kg ⁻¹)										
method	2011	2012	2013	Mean	2011	2012	2013	Mean	2011	2012	2013	Mean
No till	0.15 ^{aA}	0.14 ^{aA}	0.14 ^{abA}	0.14 ^a	36 ^{aA}	29 ^{aB}	35 ^{abA}	33 ^a	9 ^{aA}	7 ^{aB}	8 ^{aB}	8 ^a
Scarifying	0.14 ^{aA}	0.12 ^{bB}	0.13 ^{bA}	0.13 ^b	35 ^{aA}	27 ^{aB}	33 ^{abA}	32 ^a	8 ^{bA}	6 ^{bB}	7 ^{abA}	7 ^b
Tied ridging	0.13 ^{abA}	0.13 ^{abA}	0.13 ^{bA}	0.13 ^b	33 ^{abA}	30 ^{aB}	32 ^{bAB}	311 ^a	7 ^{bcA}	7 ^{abA}	6 ^{bA}	7 ^b
Plough	0.12 ^{bB}	0.12 ^{bB}	0.15 ^{aA}	0.13 ^b	31 ^{bB}	27 ^{aB}	36 ^{aA}	31 ^a	6 ^{cA}	6 ^{bA}	7 ^{abA}	6 ^b
Mean	0.14 ^A	0.13 ^B	0.14 ^A		34 ^A	28 ^B	34 ^A		7 ^A	6 ^B	7 ^{AB}	

Table-5. Year (Y) x Soil amendment (SA), Tillage method (T) x SA influences on grain S concentrations at Nadion, Burkina Faso. [Analysis of variance probability: S $P_{YxSA} < 0.01$, $P_Y < 0.01$, $P_{SA} = 0.54$; S $P_{TxSA} = 0.02$, $P_T = 0.08$, $P_{SA} = 0.54$]

Soil amendment	S (%)				S (%)				
	2011	2012	2013	Mean	No till	Scarifying	Tied ridging	Plough	Mean
Zero fertilizer	0.13 ^{bA}	0.14 ^{aA}	0.14 ^{abA}	0.14 ^a	0.12 ^{bB}	0.13 ^{aAB}	0.15 ^{aA}	0.14 ^{aA}	0.14 ^a
Compost (C)	0.15 ^{aA}	0.12 ^{aB}	0.13 ^{bB}	0.13 ^b	0.15 ^{aA}	0.14 ^{aAB}	0.12 ^{bB}	0.13 abab	0.13 ^b
Mineral fertilizer (F)	0.13 ^{bB}	0.13 ^{aB}	0.15 ^{aA}	0.14 ^a	0.15 ^{aA}	0.13 ^{aAB}	0.14 abAB	0.12 ^{bB}	0.14 ^a
Crop residues (CR)	0.15 ^{aA}	0.14 ^{aAB}	0.13 ^{bB}	0.14 ^a	0.15 ^{aA}	0.14 ^{aA}	0.14 ^{abA}	0.14 ^{aA}	0.14 ^a
C + F	0.13 ^{bAB}	0.12 ^{aB}	0.14 ^{abA}	0.13 ^b	0.14 ^{aA}	0.13 ^{aA}	0.13 ^{bA}	0.13 ^{abA}	0.13 ^b
C + CR	0.15 ^{aA}	0.13 ^{aB}	0.14 ^{abAB}	0.14 ^a	0.15 ^{aA}	0.13 ^{aA}	0.13 ^{bA}	0.13 ^{abA}	0.14 ^a
F + CR	0.14 ^{aA}	0.13 ^{aA}	0.13 ^{bA}	0.14 ^a	0.15 ^{aA}	0.13 ^{aB}	0.13 ^{bB}	0.14 ^{aAB}	0.14 ^a
C + F + CR	0.13 ^{bB}	0.13 ^{aB}	0.15 ^{aA}	0.14 ^a	0.14 ^{aA}	0.14 ^{aA}	0.14 ^{abA}	0.13 ^{abA}	0.14 ^a
Mean	0.14 ^A	0.13 ^B	0.14 ^A		0.14 ^A	0.13 ^B	0.13 ^B	0.13 ^B	

 \dagger 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.

Table-6. Tillage x Soil amendment (SA) influence on grain P and Mg concentrations at Kamboinsé and main effect on Mg concentrations at Nadion, Burkina Faso. [Analysis of variance probability: Kamboinsé P $P_{TxSA} = 0.04$, $P_{T} = 0.26$, $P_{SA} = 0.23$; Mg $P_{TxSA} = 0.04$, $P_T = 0.27$, $P_{SA} = 0.15$; Nadion Probability of SA main effect on Mg = 0.02]

Soil amendment	Kamboinsé- P (%)					Kamboinsé- Mg (%)					Nadion- Mg (%) 2012-2013
	No till	Scarifying	Zaï	Plough	Mean	No till	Scarifying	Zaï	Plough	Mean	
Zero	0.31 ^{bA}	0.35 ^{abA}	0.43 ^{abA}	0.38 ^{abA}	0.37 ^{ab}	0.14 ^{bA}	0.18 ^{abA}	0.20 ^{abA}	0.16 ^{abA}	0.17 ^{ab}	0.16 ^b
Compost (C)	0.42 ^{abA}	0.40^{abA}	0.31 ^{bA}	0.37 ^{abA}	0.37 ^{ab}	0.19 ^{abA}	0.19 ^{abA}	0.14 ^{bA}	0.16 ^{abA}	0.17 ^{ab}	0.18 ^a
Fertilizer (F)	0.33 ^{bA}	0.27 ^{bA}	0.35 ^{bA}	0.35 ^{abA}	0.33 ^b	0.15 ^{bA}	0.14 ^{bA}	0.16 ^{bA}	0.16 ^{abA}	0.15 ^b	0.17 ^{ab}
Crop residue (CR)	0.50^{aA}	0.39 ^{abA}	0.43 ^{abA}	0.21 ^{bB}	0.38 ^{ab}	0.22 ^{aA}	0.19 ^{abA}	0.20 ^{abA}	0.09 ^{bB}	0.17 ^{ab}	0.17 ^{ab}
C + F	0.47^{abAB}	0.37 ^{abB}	0.54 ^{aA}	0.25 ^{bB}	0.41 ^a	0.21 ^{aA}	0.18 ^{abA}	0.23 ^{aA}	0.12 ^{bB}	0.18 ^a	0.18 ^a
C + CR	0.45 ^{abA}	0.39 ^{abA}	0.40^{abA}	0.45 ^{aA}	0.42 ^a	0.22 ^{aA}	0.19 ^{abA}	0.19 ^{abA}	0.19 ^{aA}	0.20 ^a	0.18 ^a
F + CR	0.42 ^{abA}	0.47^{aA}	0.42 ^{abA}	0.34 ^{abA}	0.41 ^a	0.19 ^{abA}	0.20 ^{aA}	0.21 ^{abA}	0.15 ^{abA}	0.19 ^a	0.18 ^a
C + F + CR	0.47^{abA}	0.40^{abAB}	0.37 ^{bAB}	0.30 ^{bB}	0.39 ^{ab}	0.19 ^{abA}	0.18 ^{abA}	0.17 ^{abA}	0.15 ^{abA}	0.17 ^{ab}	0.18 ^a
Mean	0.42 ^A	0.38 ^{AB}	0.41 ^A	0.33 ^B		0.19 ^A	0.18 ^Å	0.19 ^A	0.15 ^B		

 \dagger 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.

 $\begin{array}{l} \textbf{Table-7. } Year \ x \ Tillage \ influence \ on \ sorghum \ grain \ Ca \ and \ Mg \ concentrations \ at \ Kamboinsé, \ Burkina \ Faso. \ [Analysis \ of \ variance \ probability: \ Ca \ P_{YxT} < 0.01, \ P_{T} = 0.02; \ Mg \ P_{YxT} = 0.04, \ P_{T} = 0.02, \ P_{T} = 0.04, \ P_{$

Tillage method	Ca (%)				Mg (%)			
	2011	2012	2013	Mean	2011	2012	2013	Mean
No till	0.07^{aB}	0.07^{aB}	0.09 ^{aA}	0.07^{a}	0.17^{aB}	0.19^{aAB}	0.21 ^{aA}	0.19 ^a
Scarifying	0.07^{aA}	0.06^{abA}	0.07^{abA}	0.07 ^a	0.18^{aA}	0.18^{aA}	0.19 ^{aA}	0.18 ^a
Zaï	0.06b ^A	0.06^{abA}	0.06^{bA}	0.06^{b}	0.17^{aA}	0.20^{aA}	0.19 ^{aA}	0.19 ^a
Plough	0.03 ^{cB}	0.05^{bA}	0.05^{bA}	0.04 ^c	0.10^{bB}	0.17^{aA}	0.18^{aA}	0.15 ^b
Mean	0.06^{B}	0.06^{B}	0.07 ^A		0,15 ^B	0,18 ^A	0,19 ^A	

Table-8. Year main effect on sorghum stover N, P, K, Ca, Mg and Mn concentrations at Nadion, Burkina Faso. [Analysis of variance probability: P for N < 0.01; P for P < 0.01; P for K < 0.01; P for Ca < 0.01; P for Mg < 0.01; P for Mn < 0.01]

Nutrient	2012	2013
Nitrogen (% N)	0.53 ^b	0.62 ^a
Phosphorus (% P)	0.07 ^a	0.06 ^b
Potassium (% K)	1.99 ^a	1.72 ^b
Calcium (% Ca)	0.18 ^b	0.28 ^a
Magnesium (% Mg)	0.17 ^b	0.21 ^a
Manganese (mg kg ⁻¹ Mn)	55 ^b	72 ^a

[†] Values followed by the same small letter in a row are not significantly different at $P \le 0.5$.

Table-9. Year x Soil amendment (SA) on stover S and Zn concentrations at Nadion, Burkina Faso. [Analysis of variance probability: S $P_{YxSA} = 0.04$, $P_Y = 0.02$, $P_{SA} = 0.03$; Zn $P_{YxSA} < 0.01$, $P_Y = 0.01$, $P_{SA} < 0.01$]

	S (%)			Zn (mg kg ⁻¹)			
Soil amendment	2012	2013	Mean	2012	2013	Mean	
Zero fertilizer	0.12 ^{aA}	0.12 ^{abA}	0.12 ^a	58 ^{aA}	32 ^{bB}	45 ^{ab}	
Compost (C)	0.12 ^{aA}	0.12 ^{abA}	0.12 ^a	55 ^{aA}	47^{abA}	51 ^a	
Mineral fertilizer (F)	0.08 ^{bB}	0.11 ^{abA}	0.09 ^b	27 ^{bA}	34 ^{bA}	30 °	
Crop residues (CR)	0.12 ^{aA}	0.12 ^{abA}	0.12 ^a	62 ^{aA}	42 ^{abB}	52 ^a	
C + F	0.09 ^{bB}	0.10 ^{abA}	0.09 ^b	32 ^{bA}	28 ^{bA}	30 °	
C + CR	0.12 ^{aA}	0.09 ^{bA}	0.11 ^{ab}	57 ^{aA}	36 ^{bB}	47 ^{ab}	
F + CR	0.09 ^{bB}	0.13 ^{aA}	0.11 ^{ab}	31 ^{bB}	48 ^{aA}	40 ^b	
C + F + CR	0.09 ^{bB}	0.12 ^{abA}	0.10^{ab}	33 ^{bA}	44 ^{abA}	38 ^{bc}	
Mean	0.10 ^B	0.11 A		44 ^A	39 ^B		

 \dagger 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.

 $\begin{array}{l} \textbf{Table-10. Year x Tillage influence on stover Mg and Mn concentrations and Year x Soil amendment (SA) influence on stover Zn concentrations and at Kamboinsé. [Analysis of variance probability: Mg P_{YxT} = 0.01, P_{T} = 0.45; Mn P_{YxT} < 0.01, P_{Y} < 0.01, P_{T} = 0.33; Zn P_{YxSA} = 0.01, P_{Y} < 0.01, P_{SA} = 0.29]. \end{array}$

Tillage method	2012	2013	Mean	2012	2013	Mean
	Mg (%)			$Mn (mg kg^{-1})$		
No till	0.25 ^{aB}	0.54^{aA}	0.40^{a}	93 ^{aA}	57 ^{bB}	75 ^a
Scarifying	0.24^{aB}	0.38 ^{bA}	0.31 ^b	83 ^{abA}	77 ^{aA}	80^{a}
Zaï	0.21a ^B	0.35 ^{bA}	0.28 ^b	77 ^{bA}	66 ^{abA}	72 ^a
Plough	0.22^{aB}	0.40^{bA}	0.31 ^b	72 ^{bA}	74 ^{aA}	73 ^a
Mean	0.25 ^B	0.42 ^A		81 ^A	68 ^B	
Soil amendment	Zn (m	ng kg-1)				
Zero	31 ^{aA}	37 ^{bA}	34 ^{ab}			
Compost (C)	26^{aB}	56 ^{aA}	41 ^a			
Fertilizer (F)	33 ^{aA}	41 ^{bA}	37 ^{ab}			
Crop residue (CR)	35^{aA}	32 ^{bA}	34 ^{ab}			
C + F	32^{aB}	50 ^{abA}	41 ^a			
C + CR	30^{aA}	33 ^{bA}	32 ^b			
F + CR	32^{aA}	39 ^{bA}	36 ^{ab}			
C + F + CR	33 ^{aA}	43 ^{bA}	38 ^{ab}			
Mean	31 ^B	41 ^A				

 \dagger 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.

Table-11. Tillage (T) x Soil amendment (SA) influence on sorghum stover P concentrations and SA main effect on stover K concentrations at Nadion, Burkina Faso. [Analysis of variance probability: $P P_{TxSA} = 0.02$, $P_T = 0.72$, $P_{SA} = 0.01$; Probability of SA main effect on K < 0.01]

		P (%)								
Soil amendment	No till	Scarifying	Tied ridging	Plough	Mean					
Zero fertilizer	0.06^{aA}	0.06 ^{bA}	0.05 ^{bA}	0.05 ^{bA}	0.05 ^b	1.66 ^b				
Compost (C)	0.07 ^{aA}	0.07 ^{bA}	0.06 ^{abA}	0.07^{aA}	0.07 ^a	1.95 ^{ab}				
Mineral fertilizer (F)	0.05 ^{aA}	0.06 ^{bA}	0.06 ^{abA}	0.05 ^{bA}	0.05 ^b	1.63 ^b				
Crop residues (CR)	0.05^{aB}	$0.07 ^{\mathrm{bAB}}$	0.08 ^{aA}	0.05 ^{bB}	0.06^{ab}	2.05 ^a				
C + F	0.06^{aA}	0.06 ^{bA}	0.06 ^{abA}	$0.06^{\text{ abA}}$	0.06^{ab}	1.70 ^b				
C + CR	0.07^{aB}	0.10 ^{aA}	$0.06^{\text{ abB}}$	0.05 ^{bB}	0.07 ^a	2.06 ^a				
F + CR	0.05 ^{aA}	0.06 ^{bA}	0.06 ^{abA}	0.05 ^{bA}	0.05 ^b	1.77 ^b				
C + F + CR	0.05^{aB}	$0.08 ^{\mathrm{bAB}}$	0.04 ^{bB}	0.09 ^{aA}	0.06^{ab}	1.98 ^{ab}				
Mean	0.06 ^B	0.07 ^A	0.06 ^B	0.06 ^B						

 \dagger 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.

3.2. Sorghum Stover Concentration Variations - N, P, K, Ca, Mg, S, Zn, Mn and Cu

Sorghum stover nutrient concentrations were influenced by Y main or interaction effects, the exception being Cu at Nadion (6 mg kg⁻¹) (Tables 2 and 8). Stover N, Ca, Mg and Mn concentrations were higher in the higher rainfall, higher yield year of 2013 [21] at both locations that was also present for stover K, S and Zn concentrations at Nadion, the opposite was found for stover P and K concentrations at Nadion and stover Mn concentrations at Kamboinsé.

A Y x SA interaction effect for stover Zn concentration were found at both locations (Tables 9 and 10). The year by soil amendment interaction effect at Nadion for stover Zn concentrations was largely due to having the highest stover Zn concentrations for no soil amendment and compost plus crop residue applications in 2012 but the lowest in 2013 (Table 9). Averaged across years at Kamboinsé, the stover Zn concentration was higher for sorghum with compost and compost plus fertilizer applied than for sorghum with fertilizer and compost plus crop residues applied (Table 10). Tillage method had no influence on the stover Zn concentrations in the higher rainfall year of 2012, while in 2013, sorghum stover receiving compost had higher Zn concentrations than sorghum receiving most other soil amendment applications.

The Y x SA interaction at Nadion indicated that the stover S concentrations were 0.01% higher in 2013 than in 2012 and stover Zn 5 mg kg⁻¹ higher in 2012 than in 2013 (Table 9). Averaged across years, the zero fertilizer, compost, and crop residue applications led to sorghum stover S concentrations being 0.03% higher than for fertilizer and compost plus fertilizer applications. Compost and crop residue applications led to 20 mg kg⁻¹ higher stover Zn concentrations than with fertilizer application, and 11 mg kg⁻¹ greater than with fertilizer plus crop residue applications. The year by soil amendment interaction for stover S concentration was largely due to the lowest S concentration when fertilize and crop residues were applied in 2012, while having the highest stover S concentration in 2013.

No Y x T interaction effect was found at Nadion. A year x tillage method interaction for stover Mg and Mn concentrations occurred at Kamboinsé (Table 10). The Y x T interaction indicated that averaged across years, stover Mg concentrations were higher for no till and lower for other tillage methods, but stover Mg concentrations averaged

across tillage methods were lower in 2012 than 2013. Averaged across years, stover Mn concentrations were similar for all tillage methods, but stover Mn concentrations averaged across tillage methods were lower in 2013 than 2012.

At Nadion, the T x SA interaction effect was found for P concentration, which indicated that averaged across soil amendment treatments, sorghum produced with scarifying tillage had 0.01% higher stover P concentration than for other T methods (Table 11). Averaged across T, the application of compost and compost plus crop residues resulted in 0.02% higher stover P concentrations than with no soil amendment, fertilizer and fertilizer plus crop residue applications. The interaction effect appeared to be largely due to high stover P concentrations for sorghum produced with scarifying tillage and compost plus crop residue application, and plough with compost and compost plus fertilizer and crop residues application. The main effect of SA indicated that sorghum produced with crop residue and compost plus crop residue had 0.39 to 0.40% great stover K concentration than sorghum produced under no soil amendment, fertilizer, compost plus fertilizer, and fertilizer plus crop residue application.

3.3. Correlations Between Grain and Stover Yields and Nutrient Concentrations

Grain yield [21] was largely not associated with grain nutrient concentrations at Nadion, with only Cu concentration being negatively correlated (R = -0.23, P \leq 0.01). Similarly, association between sorghum grain yield and grain nutrient concentrations was limited, with only S (R = -0.19, P \leq 05) and Cu (R = -0.19, P \leq 0.05) found to be correlated with sorghum stover yield. At Kamboinsé, grain yield [22] was negatively association with grain N (R = -0.25, P \leq 0.01), K (R = -0.21, P \leq 0.01); Ca (R = -0.24, P \leq 0.01), Mg (R = -0.17, P \leq 0.05), S (R = -0.33, P \leq 0.01), Zn (R = -0.35, P \leq 0.01), Mn (R = -0.22, P \leq 0.01) and Cu (R = -0.30, P \leq 0.01). Stover yield was only positively associated with stover K concentration (R = 0.41, P \leq 0.01) and negatively associated with stover N concentration (R = -0.22, P \leq 0.05). Possible nutrient dilution was only found for grain at Kamboinsé.

4. Discussion

4.1. Sorghum Grain Nutrient Concentration Variations- N, P, K, Ca, Mg, S, Zn, Fe, Mn and Cu

Although often declared significant, most sorghum grain nutrient levels were influenced only by small amounts by T and SA applications at both locations. Tillage method had no influence on grain N, P, K, Ca, Mg and Fe grain concentrations at Nadion and had no influence on grain N, P, K, S, Zn and Cu concentrations at Kamboinsé, and had only a small influence on other nutrients. Soil amendment had no influence on grain N, P, K and Ca concentrations at Nadion, and no influence on grain N, Ca, Mn and Cu at Kamboinsé, with only small differences for other nutrients. When responses to T or SA were found, they were inconsistent across locations. Grain N, P, K, S, Mn, Zn and Cu concentrations were influenced to a small degree by year at Nadion, and grain N, P, K, Ca, S, Zn, Fe and Cu concentrations at Kamboinsé, much more frequently influenced by year than by tillage and soil amendment. It was concluded that tillage, and soil amendment combinations had only minor effect on sorghum grain concentrations for yield levels produced in these studies.

Grain nutrient concentrations were not associated with grain yield [21] and nutrient dilution was not present at Nadion as also found by Palé, *et al.* [20]. In contrast, at Kamboinsé, grain yield was correlated with nutrient concentrations and there was evidence of nutrient dilution as found by Palé, *et al.* [20] and Buerkert, *et al.* [13].

Assuming that bioavailability was not an issue [4, 27], the grain nutrient concentrations were adequate for 31 to 50-year-old human males weighing 60 kg and non-pregnant females weighing 49 kg for N, P, Mg, S, Zn and Fe at both locations, but deficient for K, Ca, Mn and Cu [6, 7]. Improvement of deficient nutrients through genetic improvement [10-12] and/or targeted fertilizer application [12, 17] to improve sorghum grain nutrient concentrations or to supplement with diverse foodstuffs in the diet or use biofortified grain [5] are likely needed to meet human dietary needs in Burkina Faso.

Grain N, S and Zn concentrations were similar to values cited by multiple studies conducted worldwide [8, 10, 14, 20]. Sorghum grain concentrations for P, K, Mn and Cu were similar to multiple reports [10, 11, 14, 20] but P and K were somewhat lower and Fe and Mn were much lower than those reported by Wortmann, *et al.* [8]. Sorghum grain nutrient concentrations in this study and in reference citations show great variability worldwide.

4.2. Sorghum Stover Nutrient Concentrations – N, P, K, Mg, S, Zn, Mn and Cu

Seldom did T and SA influence the nutrient concentration of sorghum stover at both locations, and when this did occur, the differences in sorghum stover nutrient concentrations were small with no logical reason for these differences to be present. Soil amendment application had a greater influence on sorghum stover nutrient concentrations than T, with only a small tillage difference found for stover S concentrations at Nadion and for stover Mg and Mn at Kamboinsé. All sorghum stover nutrient concentrations, stover N, Ca and Mg concentrations were in higher rainfall, higher stover yield year of 2013 [6, 21] while stover P, K, S and Mn concentrations were also higher in 2013 in Kamboinsé.

At both locations, sorghum stover concentrations for Mg and Cu were similar to other worldwide reports [14, 20], but lower than their reports for stover N, P and Ca concentrations. Stover concentrations for K were similar to values from Van Duivenbooden [14] and Youngquist, *et al.* [28], but higher than Maw, *et al.* [27]. The stover S concentration was similar to Youngquist, *et al.* [28] but lower than Maw, *et al.* [27]. The stover Zn concentration was similar to Youngquist, *et al.* [28] but higher than Maw, *et al.* [27].

than reported by Maw, *et al.* [27] but lower than that of Youngquist, *et al.* [28]. Considerable variability in sorghum stover nutrient concentrations occurs across years and locations.

Sorghum nutrient concentrations for feeding cattle were adequate for stover K, Ca, Mg, S, Mn and Zn concentrations in most cases at both locations [16, 20] but low for stover N, P and Cu. Results from a study conducted with pearl millet in the Sahelian agroecological zone of Burkina Faso also indicated a stover deficiency for N and P [29]. These results indicate the need to apply fertilizer to raise stover N, P and Cu concentrations in sorghum stover or supplement cattle rations with N, P and Cu sources to meet cattle nutrient requirements. the results also indicated that the stover K, Ca, Mg, S, Zn and Mn concentrations at physiological maturity were adequate to meet the critical levels for growth of grain sorghum under the production situation present in this study [15, 16, 23]. The stover N, P and Cu concentrations were deficient, and suggests the possible need to apply fertilizer to optimize grain yield, similar to results of Palé, *et al.* [19] for pearl millet in the Sahelian agroecological zone and Palé, *et al.* [20] for sorghum in the Sudano-Sahelian agroecological zone.

5. Conclusions

Sorghum grain and stover nutrient concentrations were measured at physiological maturity to assess the influence of T and SA effects on nutrient concentrations and suitability for human food, livestock feed, and nutritional adequacy for yield produced in the Sudano-Sahelian and Sudanian agroecological zones of Burkina Faso. Only small and erratic influences of T and SA on grain and stover nutrient concentrations were found, and little relationship between grain and stover yield and nutrient concentrations were found. Limited nutrient dilution was present in grain and stover. This study combined with other cited sources, indicate that much variation in grain and stover nutrient concentrations are present worldwide.

In both agroecological zones of Burkina Faso in this study, 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, Zn, S and Zn, but deficient for K, Ca, Mn and Cu. Sorghum stover nutrient concentrations for feeding cattle were adequate for K, Ca, Mg, S, Zn and Mn but low for N, P and Cu. These results indicate the need to apply fertilizer to raise grain K, Ca, Mn and Cu concentrations for human dietary needs and stover N, P and Cu concentrations for cattle, or supplement human and cattle diets with other food sources or biofortified grain and stover to meet dietary needs.

This is the first documentation of the influence of tillage methods and soil amendment applications on solecropped sorghum grain and stover nutrient concentrations and that relates results to human and cattle nutrition, and growing grain sorghum plant critical nutrient levels. It is concluded that the need to apply fertilizer to raise grain K, Ca, Mn and Cu concentrations for human dietary needs, and stover N, P, K and Cu concentrations for cattle diets, or supplement human and cattle diets with other feedstuffs that include the needed deficient nutrients is required in this Semi-Arid Burkina Faso.

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