

**SORGHUM GRAIN AND STOVER NUTRIENT CONCENTRATIONS AS  
INFLUENCED BY TILLAGE, CROPPING SYSTEM AND SOIL AMENDMENT**

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**ABSTRACT**

Grain sorghum intercropped with cowpea or sole cropped are common cropping systems in the Sudano-sahelian agroecological zone of Burkina Faso. A two-year experiment was conducted on the influence of tillage and cropping system with soil amendment (CS/SA) on sorghum grain and stover nutrient concentrations. Tillage had no influence on grain nutrient concentrations. Year and cropping with soil amendment slightly influenced the grain P, K, and Mg concentrations. Stover Mg and S concentrations were influenced by year, tillage, and CS/SA, while other nutrient concentrations were not. Nitrogen (N), P, K, Mg, and Zn concentrations ( $R = 0.22$  to  $0.44$ ) were positively associated with grain yield, but only K ( $R = 0.41$ ) and N ( $-0.22$ ) were associated with stover yield. Nutrient concentration of sorghum grain met human nutritional requirements for N (2.15%), P (0.34%), Mg (0.28%), Zn (34 ppm) and Fe (69 ppm) but deficient for K (0.45%), Mn (23 ppm), and Cu (6 ppm). Sorghum stover nutrient concentrations exceeded requirements for cattle feed except for N (1.6%), P (0.23%), and Cu (7 ppm). Genetic and management research to increase sorghum grain K, Mn, Cu concentrations, and stover N, P, and Cu concentration to meet human and cattle nutritional needs is merited.

**Keywords:** Compost, human and cattle nutrition, intercrop, scarifying, Sudano-sahelian agroecological zone.

**1. INTRODUCTION**

Population growth (World Bank, 2021), soil degradation and climate change (Mason et al., 2015) are forcing farmers to adopt intensive but more sustainable production systems to meet human food and livestock feed needs while maintaining soil quality in West Africa. Grain sorghum [*Sorghum bicolor* (L) Moench] is the most important crop grown in the Sudano-sahelian agroecological zone of West Africa (FAO, 2021). It is widely produced either by intercropping with cowpea [*Vigna unguiculata* (L.) Walp] or as a sole crop using a variety of tillage methods and with or without soil amendment application. Sorghum grain and stover yields for this study were published previously, and found that in the Sudano-sahelian agroecological zone in a sandy loam, low organic matter soil that grain and stover yields increased with use of zaï combined with applications of compost and fertilizer (Palé et al., 2020).

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 (Kruger et al., 2012). Malnutrition in Burkina Faso was found to be related to inadequate food

consumption, lack of dietary diversity and the consequent low intake of essential nutrients (Taylor et al., 2012). Literature review indicated that recommended dietary concentrations have been previously published (National Academy of Science, 2019a; 2019b) and average sorghum grain nutrient concentrations have been presented for Mali, Niger, Nigeria, and Tanzania (Wortmann et al., 2018) and South Africa. (Mabelebele et al., 2015). Location and year (Wortmann et al., 2018), genotype (Mabelebele et al., 2015; Kumar et al., 2017; Liboreiro Paiva et al., 2017), water stress (Liboreiro Paiva et al., 2017), and fertilizer application (Kumar et al., 2017) 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 (Buerkert et al., 1998).

Typical sorghum stover nutrient concentrations have been published for West Africa (Van Duivenbooden, 1992) and the United States (Cox and Unruh, 2000). Current nutrient requirements for cattle have been published (Gadberry, 2018), but little research has been published relating stover nutrient concentrations to cattle dietary needs. Literature indicated that sorghum and pearl millet (*Pennisetum glaucum* (L) R. Br.) stover researches had primarily focused on animal performance, metabolizable energy and stover N concentration (Bidinger and Blümmel, 2007). 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 pearl millet in Sub-Saharan Africa have been estimated in recent study (Wortmann et al., 2019). Results from an investigation to understand the nutrient concentration variations in crop growth indicated sufficiency levels of nutrients in the United States as crop growth progresses with decreases at physiological maturity/harvest, thus showing the relationship between critical concentrations for optimizing growth and producing high yield (Cox and Unruh, 2000).

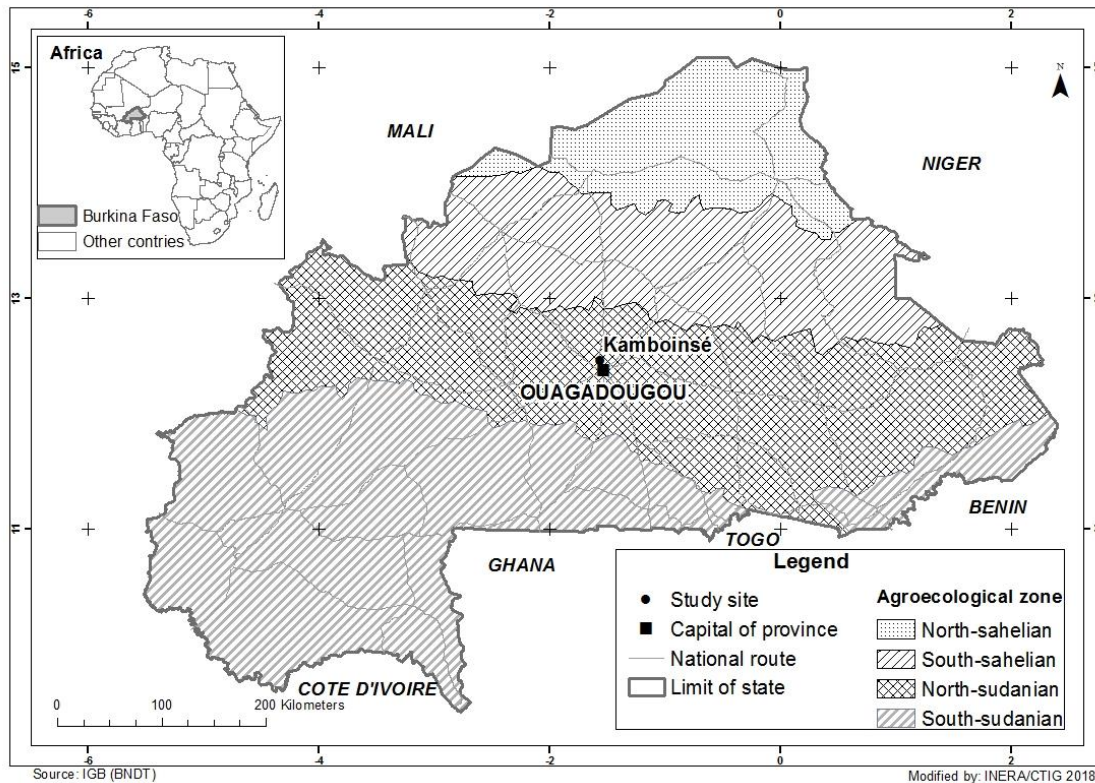
This manuscript addresses the influence of tillage method, cropping system with soil amendment, and year on sole and sorghum intercropped with cowpea on grain and stover nutrient concentrations, and relates these results to human and cattle nutrition, and growing grain sorghum plant critical nutrient levels.

## **2. MATERIALS AND METHODS**

### **2.1 Study site**

The experiment was conducted from 2011 to 2014 at the Kamboinsé Agricultural Research Station (12° 28' 29'' N lat; 1° 33' 5.5'' W long) in the Sudano-sahelian agroecological zone of Burkina Faso (Figure 1) with total rainfall of 409 mm in 2011, 626 mm in 2012, 433 mm in 2013, and 542 mm in 2014 for the growing season months of July to Oct.

The soil in the experiment site was a Little Evolved Hydromorphic Alluvial Soil with sandy loam textured surface horizon and low water holding capacity, surface horizon pH of 7.4, organic carbon (C) concentration of 2.7 g kg<sup>-1</sup>, 0.08g kg<sup>-1</sup> N, 1.6 mg kg<sup>-1</sup> P and 105mg kg<sup>-1</sup> K (Barro and Ouattara, 2011, personal communication). The fields had been fallowed for 10 years previous to 2011.



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

## 2. 2 Experimental design

A randomized complete block design with a split-plot arrangement of three tillage methods as main plots and eight cropping system with soil amendment treatments allocated in the sub-plots with three replications was used (Table 1).

**Table 1. Tillage methods and soil cropping system with soil amendment treatments for sole intercrop sorghum experiment in Kamboinsé, Burkina Faso, 2012 to 2014.**

Tillage methods	Cropping system with soil amendment (CS/SA)
1. No till	1. Sole cropped sorghum with no soil amendment applied
2. Scarifying	2. Sole cropped sorghum with recommended compost rate of 2500 kg ha <sup>-1</sup> /year broadcasted in no-zaï-plots at planting. The 2500 kg ha <sup>-1</sup> were divided equally and applied in each zaï pit at planting
3. Zaï	<p>3. Sole cropped sorghum with recommended mineral fertilizer (so-called fertilizer) at the rate of 10.5 kg N ha<sup>-1</sup> + 17 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> + 10.5 kg K<sub>2</sub>O ha<sup>-1</sup> as complete fertilizer broadcasted at planting or within one week after planting, and 23 kg N ha<sup>-1</sup> as urea, applied 45 days after planting</p> <p>4. Sole cropped sorghum with recommended compost and fertilizers applied</p> <p>5. Sorghum intercropped with cowpea and with no soil amendment</p> <p>6. Sorghum intercropped with cowpea and with recommended compost application at planting</p> <p>7. Sorghum intercropped with cowpea and with recommended fertilizer applications (same rates of NPK complete fertilizer for both crops, 23 kg N ha<sup>-1</sup> as urea for grain sorghum at boot stage, no urea for cowpea)</p> <p>8. Sorghum intercropped with cowpea and with recommended compost and recommended fertilizers applied at planting (same rates of NPK complete fertilizer for both crops, 23 kg N ha<sup>-1</sup> as urea for grain sorghum at boot stage, no urea for cowpea)</p>

Plots consisted of six rows, 10-m long. Treatments were applied to the same plots each year. Sorghum planting was done at the recommended spacing of 80 cm between rows and 40 cm within the row with 1 or 2 plants per hill after thinning. Cowpea planting was done at the recommended density of 80 cm between rows and 40 cm within hills in the row, with 1 to 2 plants per hill after thinning. Planting was done alternating two rows of sorghum with two rows of cowpea, giving a total of four rows of sorghum and two rows of cowpea per plot. Sorghum and cowpea were simultaneously planted in July of each year. Weed control was done by hand

hoeing as needed. The sorghum variety used in the experiment was Sarioso 11 with a maturity rating of 100 to 105 days and intercrop plots planted with the cowpea variety K VX 396-5-2D with a maturity rating of 65 to 70 days.

### **2.3 Data collection**

The middle of each sorghum plot was harvested and the harvested area was 25.76 m<sup>2</sup>. Grain sorghum panicles and stover were hand-harvested, air-dried, threshed (for panicles), weighed, and recorded as dry weight. The experiment was conducted from 2012 through 2014 but nutrient concentrations of grain and stover samples were only collected in 2012 and 2013. Grain and stover sub-samples of sorghum were ground to pass through a 1-mm mesh screen. An automatic combustion method was used for N digestion and analysis (Miller, 1997), and inductively coupled plasma spectrometry for P, K, Ca, Mg, S, Zn, Fe, Mn and Cu concentrations (Wolf, 2003). Calcium and Fe concentrations were omitted for both grain and stover concentrations due to either a sampling or laboratory error that led to unrealistic values.

### **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 (SAS Institute, 2010). Mean separation was done using pair-wise comparisons of significant interaction and main effects. Pearson correlations between grain and stover yields and nutrient concentrations at harvest were conducted. Results were considered significant at  $P \leq 0.05$ .

## **3. RESULTS**

### **3.1 Sorghum grain nutrient concentrations – N, P, K, Mg, S, Zn, Fe, Mn and Cu**

The tillage method or cropping system with soil amendment combinations (CS/SA) had no influence on the N (2.15%), S (0.14%), Zn (34 ppm), Fe (69 ppm), Mn (23 ppm), and Cu (6 ppm) concentrations of the sorghum grain (data not shown). However, the N concentration of 2.35% in 2012 was greater than the 1.95% in 2013.

The tillage method had no influence on sorghum grain concentrations for P and Mg, however both nutrients were influenced by the year by CS/SA combination interactions. and the grain K concentration was influenced by the CS/SA main effect (Table 2). Both P and Mg grain concentrations were greater in the higher seasonal rainfall and higher grain yield year of 2012 than in the lower grain yield year of 2013. Averaged across years, the sorghum grain P concentrations were 0.06 to 0.07% higher for sole cropped sorghum with either fertilizer or compost application than for sole cropped sorghum without soil amendment and intercropped sorghum with compost plus fertilizer applied, very similar to results in 2012. In 2013, the grain P concentration for intercropped sorghum with fertilizer applied was 0.08 to 0.12% higher than for intercropped sorghum with compost and compost plus fertilizer application. Averaged across years, the sorghum grain Mg concentrations were 0.02 to 0.03% higher for sole cropped sorghum with either compost or fertilizer applied and intercropped sorghum with fertilizer applied than for sole cropped sorghum without soil amendment, and intercropped sorghum with either compost or compost plus fertilizer applied. The sole cropped sorghum grain Mg without soil amendment was 0.03 to 0.05% lower than other treatments in 2012, while in 2013, sole cropped sorghum

with compost and with fertilizer, and intercropped sorghum with fertilizer were 0.03 to 0.05% higher than for intercropped sorghum with compost and with compost plus fertilizer applications. Averaged across year and tillage methods, the grain K concentration for sole cropped sorghum with fertilizer applied was 0.04 to 0.06% higher than sole cropped without soil amendment, and intercropped sorghum with compost and with compost plus fertilizer applications.

**Table 2. Year (Y) x Cropping system with soil amendment (CS/SA) effect on sorghum grain nutrient concentrations in Kamboinsé, 2012 through 2013, Burkina Faso. [Analysis of variance probability: P  $P_Y \times CS/SA = 0.03$ ,  $P_Y = 0.01$ ,  $P_{CS/SA} = 0.10$ ; Probability of CS/SA main effect on K = 0.05; Mg  $P_Y \times CS/SA = 0.04$ ,  $P_Y = 0.23$ ,  $P_{CS/SA} = 0.02$ ].**

Cropping system with soil amendment (CS/SA)	Phosphorus (% P)			Potassium (% K)	Magnesium (% Mg)		
	2012	2013	Mean	2012-2013	2012	2013	Mean
	Sole cropped + without soil amendment	0.33 <sup>ba</sup>	0.35 <sup>abA</sup>	0.34 <sup>b</sup>	0.42 <sup>b</sup>	0.16 <sup>ba</sup>	0.18 <sup>abA</sup>
Sole cropped + Compost	0.45 <sup>aA</sup>	0.36 <sup>abB</sup>	0.40 <sup>a</sup>	0.47 <sup>ab</sup>	0.21 <sup>aA</sup>	0.19 <sup>aA</sup>	0.20 <sup>a</sup>
Sole cropped + Fertilizer	0.45 <sup>aA</sup>	0.36 <sup>abB</sup>	0.41 <sup>a</sup>	0.48 <sup>a</sup>	0.20 <sup>aA</sup>	0.19 <sup>aA</sup>	0.19 <sup>a</sup>
Sole cropped + Compost + Fertilizer	0.41 <sup>abA</sup>	0.34 <sup>abA</sup>	0.37 <sup>ab</sup>	0.44 <sup>b</sup>	0.19 <sup>aA</sup>	0.17 <sup>abA</sup>	0.18 <sup>ab</sup>
Intercropped + without soil amendment	0.45 <sup>aA</sup>	0.32 <sup>abB</sup>	0.38 <sup>ab</sup>	0.47 <sup>ab</sup>	0.21 <sup>aA</sup>	0.18 <sup>abB</sup>	0.19 <sup>a</sup>
Intercropped + Compost	0.42 <sup>aA</sup>	0.29 <sup>bbB</sup>	0.35 <sup>ab</sup>	0.44 <sup>b</sup>	0.19 <sup>aA</sup>	0.15 <sup>bbB</sup>	0.17 <sup>b</sup>
Intercropped + Fertilizer	0.39 <sup>abA</sup>	0.37 <sup>aA</sup>	0.38 <sup>ab</sup>	0.45 <sup>ab</sup>	0.19 <sup>aA</sup>	0.20 <sup>aA</sup>	0.19 <sup>a</sup>
Intercropped + Compost + Fertilizer	0.43 <sup>aA</sup>	0.25 <sup>bbB</sup>	0.34 <sup>b</sup>	0.44 <sup>b</sup>	0.19 <sup>aA</sup>	0.16 <sup>bbB</sup>	0.17 <sup>b</sup>
Mean	0.41 <sup>A</sup>	0.33 <sup>B</sup>			0.19 <sup>A</sup>	0.18 <sup>B</sup>	

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

**3.2 Sorghum stover nutrient concentrations – N, P, K, Mg, S, Zn, Mn, and Cu**

Stover differences for P (0.23%), K (1.13%), and Mn (55 ppm) concentrations differences were not found across tillage, and CS/SA combinations in this study (data not presented). However, P average concentrations of 0.39% in the higher stover yield of year2012were higher than the 0.07% obtained in the low stover yield year of 2013 (Palé et al., 2020).

Stover differences in N, Mg, and Cu concentrations were caused by the Year x Tillage interaction effect (Table 3). Averaged across years, the stover N concentrations were similar across tillage methods, but 1.29% higher in 2013than in 2012. Sorghum produced with the zaï, had 0.16 to 0.24% higher stover N concentration than other tillage methods in 2012, but not in 2013.

**Table 3. Year (Y) x Tillage method (T) effect on sorghum stover nutrient concentrations in sorghum/cowpea intercropped in Kamboinsé, 2012 through 2013. Burkina Faso [Analysis of variance probability: NP<sub>YxT</sub> = 0.01, P<sub>Y</sub> = 0.08, P<sub>T</sub> = 0.39; Mg P<sub>YxT</sub> = 0.02, P<sub>Y</sub> = 0.04, P<sub>T</sub> = 0.19; Cu P<sub>YxT</sub> = 0.05, P<sub>Y</sub> = 0.09, P<sub>T</sub> = 0.57].**

Tillage Method	Nitrogen (% N)			Magnesium (% Mg)			Copper (ppm Cu)		
	2012	2013	Mean	2012	2013	Mean	2012	2013	Mean
No till	0.88 <sup>bB</sup>	2.23 <sup>aA</sup>	1.55 <sup>a</sup>	0.21 <sup>bA</sup>	0.18 <sup>aB</sup>	0.20 <sup>b</sup>	10 <sup>aA</sup>	6 <sup>aB</sup>	8 <sup>a</sup>
Scarifying	0.80 <sup>bB</sup>	2.22 <sup>aA</sup>	1.51 <sup>a</sup>	0.23 <sup>bA</sup>	0.19 <sup>aB</sup>	0.21 <sup>b</sup>	7 <sup>bA</sup>	6 <sup>aA</sup>	7 <sup>b</sup>
Zaï	1.04 <sup>aB</sup>	2.17 <sup>aA</sup>	1.60 <sup>a</sup>	0.26 <sup>aA</sup>	0.19 <sup>aB</sup>	0.23 <sup>a</sup>	9 <sup>abA</sup>	6 <sup>aB</sup>	7 <sup>ab</sup>
Mean	0.91 <sup>B</sup>	2.20 <sup>A</sup>		0.23 <sup>A</sup>	0.19 <sup>B</sup>		9 <sup>A</sup>	6 <sup>B</sup>	

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

Stover Mg concentration was 0.04% higher in 2012 than 2013 (Tables 3 and 4), and stover Cu concentration was 3 ppm higher (Table 3). In 2012 and averaged across years, the stover Mg concentrations were highest for use of zaï, with scarifying and no till having the lowest and similar Mg concentrations. In 2012, the sorghum stover Cu concentration was highest with use of no-till and lowest for scarifying tillage. The tillage method had no effect on Mg and Cu concentrations in 2013.

**Table 4. Year (Y) x Cropping system with soil amendment (CS/SA) effect on sorghum stover nutrient concentrations in sorghum/cowpea intercropped in Kamboinsé, 2012 through 2013. Burkina Faso [Analysis of variance probability: Mg  $P_{Y \times CS/SA} = 0.01$ ,  $P_Y = 0.04$ ,  $P_{CS/SA} < 0.1$ ; S  $P_{Y \times CS/SA} = 0.01$ ,  $P_Y = 0.34$ ,  $P_{CS/SA} = 0.07$ ; Zn  $P_{Y \times CS/SA} = 0.02$ ,  $P_Y = 0.84$ ,  $P_{CS/SA} = 0.50$ ].**

Cropping system with soil amendment (CS/SA)	Magnesium (% Mg)			Sulphur (% S)			Zinc (ppm Zn)		
	2012	2013	Mean	2012	2013	Mean	2012	2013	Mean
Sole cropped without amendment	0.22 <sup>bcA</sup>	0.19 <sup>aB</sup>	0.21 <sup>b</sup>	0.10 <sup>bB</sup>	0.15 <sup>aA</sup>	0.12 <sup>b</sup>	31 <sup>bA</sup>	37 <sup>aA</sup>	34 <sup>ab</sup>
Sole cropped Compost	0.24 <sup>bA</sup>	0.18 <sup>aB</sup>	0.21 <sup>b</sup>	0.11 <sup>bB</sup>	0.13 <sup>aA</sup>	0.12 <sup>b</sup>	37 <sup>abA</sup>	39 <sup>aA</sup>	34 <sup>ab</sup>
Sole cropped Fertilizer	0.27 <sup>aA</sup>	0.19 <sup>aB</sup>	0.23 <sup>a</sup>	0.11 <sup>bB</sup>	0.15 <sup>aA</sup>	0.13 <sup>b</sup>	30 <sup>bA</sup>	37 <sup>aA</sup>	33 <sup>b</sup>
Sole cropped Compost + Fertilizer	0.26 <sup>abA</sup>	0.20 <sup>aB</sup>	0.23 <sup>a</sup>	0.11 <sup>bB</sup>	0.15 <sup>aA</sup>	0.13 <sup>b</sup>	32 <sup>bA</sup>	35 <sup>aA</sup>	33 <sup>b</sup>
Intercropped without amendment	0.20 <sup>cA</sup>	0.18 <sup>aA</sup>	0.19 <sup>b</sup>	0.15 <sup>aA</sup>	0.14 <sup>aA</sup>	0.15 <sup>a</sup>	46 <sup>aA</sup>	34 <sup>aB</sup>	40 <sup>a</sup>
Intercropped Compost	0.25 <sup>abA</sup>	0.20 <sup>aB</sup>	0.23 <sup>ab</sup>	0.10 <sup>bB</sup>	0.15 <sup>aA</sup>	0.12 <sup>b</sup>	34 <sup>bA</sup>	36 <sup>aA</sup>	35 <sup>ab</sup>
Intercropped Fertilizer	0.24 <sup>bA</sup>	0.18 <sup>aB</sup>	0.21 <sup>b</sup>	0.11 <sup>bB</sup>	0.14 <sup>aA</sup>	0.12 <sup>b</sup>	36 <sup>bA</sup>	32 <sup>aA</sup>	34 <sup>ab</sup>
Intercropped Compost + Fertilizer	0.19 <sup>cA</sup>	0.19 <sup>aA</sup>	0.19 <sup>b</sup>	0.12 <sup>bA</sup>	0.13 <sup>aA</sup>	0.13 <sup>b</sup>	39 <sup>abA</sup>	32 <sup>aA</sup>	36 <sup>ab</sup>
Mean	0.23 <sup>A</sup>	0.19 <sup>B</sup>		0.11 <sup>B</sup>	0.14 <sup>A</sup>		36 <sup>A</sup>	33 <sup>A</sup>	

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

Sorghum stover Mg, S and Zn concentrations were influenced by the year by CS/SA combinations (Table 4). The S concentration was 0.03% higher in 2013 than in 2012, and there was no difference across years for the Zn concentration. There were no CS/SA combination differences for Mg, S and Zn in 2013. However, in 2012, the intercropped sorghum with no soil amendment applied stover Mg concentration was 0.3 to 0.05% higher than sole cropped, and sole crop sorghum with compost application and intercropped sorghum with compost plus fertilizer application. Sorghum stover Mg concentration for these treatments were 0.04% greater than for these treatments than for intercropped sorghum without soil amendment and intercropped sorghum with compost plus fertilizer application. The stover S concentration for intercropped



sorghum without soil amendment was 0.04 to 0.05% higher than all other cropping system and soil amendment combinations. The stover Zn concentration for intercropped sorghum without soil amendment was 0.10 to 0.16% higher than sole and intercropped sorghum with fertilizer application, intercropped sorghum with compost application, and sole cropped sorghum with compost plus fertilizer application.

Sorghum stover S and Mg concentrations were also influenced by the tillage method by cropping system with soil amendment combination interaction (Table 5). Averaged across years and CS/SA combinations, sorghum using the zaï had greater stover Mg concentration than with other tillage methods, while the stover S concentration was similar across years. Averaged across years and tillage methods, the sole cropped sorghum with fertilizer and with compost plus fertilizer and intercropped sorghum with compost application had stover Mg concentrations 0.02 to 0.04% higher than for other cropping systems and soil amendment applications. However, for no till sorghum had 0.04 to 0.08% higher stover Mg concentration for sole crop without soil amendment and with fertilizer application than for intercropped sorghum without soil amendment, with fertilizer, and with compost plus fertilizer applications. Sorghum with scarifying tillage had 0.04 to 0.05% higher stover Mg concentration for sole cropped sorghum with compost plus fertilizer application and for intercropped sorghum with fertilizer applied. In contrast, with zaï sole cropped sorghum with compost and fertilizer applied and intercropped sorghum with compost application was 0.05 to 0.06% higher than intercropped sorghum without soil amendment and with compost applied and intercropped sorghum with compost plus fertilizer applied. The stover S concentration was 0.02 to 0.03% higher for intercropped sorghum without soil amendment than all other cropping system with soil amendment combinations. Sorghum stover S concentrations were similar with scarify and zaï, but for no till, intercropped sorghum without soil amendment was 0.06 to 0.08% higher than other cropping system with soil amendment combinations.

**Table 5. Tillage method (T) x Cropping system with soil amendment (CS/SA) effect on sorghum stover nutrient concentrations in sorghum/cowpea intercropped in Kamboinsé, 2012 through 2013. Burkina Faso [Analysis of variance probability: Mg  $P_{T \times CS/SA} < 0.1$ ,  $P_T = 0.19$ ,  $P_{CS/SA} < 0.1$ ; S  $P_{T \times CS/SA} = 0.02$ ,  $P_T = 0.36$ ,  $P_{CS/SA} = 0.07$ ].**

Cropping system with soil amendment (CS/SA)	Magnesium (% Mg)				Sulphur (% S)			
	No till	Scarifying	Zai	Mean	No till	Scarifying	Zai	Mean
Sole cropped + without soil amendment	0.23 <sup>aA</sup>	0.20 <sup>abA</sup>	0.19 <sup>bA</sup>	0.21 <sup>b</sup>	0.13 <sup>bA</sup>	0.13 <sup>aA</sup>	0.12 <sup>aA</sup>	0.12 <sup>b</sup>
Sole cropped + Compost	0.20 <sup>abA</sup>	0.21 <sup>abA</sup>	0.22 <sup>bA</sup>	0.21 <sup>b</sup>	0.11 <sup>bA</sup>	0.12 <sup>aA</sup>	0.12 <sup>aA</sup>	0.12 <sup>b</sup>
Sole cropped + Fertilizer	0.24 <sup>aAB</sup>	0.21 <sup>abB</sup>	0.25 <sup>abA</sup>	0.23 <sup>a</sup>	0.13 <sup>bA</sup>	0.12 <sup>aA</sup>	0.14 <sup>aA</sup>	0.13 <sup>b</sup>
Sole cropped + Compost + Fertilizer	0.21 <sup>abB</sup>	0.23 <sup>aAB</sup>	0.26 <sup>aA</sup>	0.23 <sup>a</sup>	0.13 <sup>bA</sup>	0.13 <sup>aA</sup>	0.14 <sup>aA</sup>	0.13 <sup>b</sup>
Intercropped + without soil amendment	0.16 <sup>bB</sup>	0.24 <sup>aA</sup>	0.18 <sup>bB</sup>	0.19 <sup>b</sup>	0.19 <sup>aA</sup>	0.13 <sup>aB</sup>	0.12 <sup>aB</sup>	0.15 <sup>a</sup>
Intercropped + Compost	0.21 <sup>abB</sup>	0.20 <sup>abB</sup>	0.26 <sup>aA</sup>	0.23 <sup>ab</sup>	0.13 <sup>bA</sup>	0.12 <sup>aA</sup>	0.12 <sup>aA</sup>	0.12 <sup>b</sup>
Intercropped + Fertilizer	0.19 <sup>bB</sup>	0.19 <sup>bB</sup>	0.25 <sup>abA</sup>	0.21 <sup>b</sup>	0.12 <sup>bA</sup>	0.12 <sup>aA</sup>	0.14 <sup>aA</sup>	0.12 <sup>b</sup>
Intercropped + Compost + Fertilizer	0.16 <sup>bB</sup>	0.20 <sup>abAB</sup>	0.21 <sup>bA</sup>	0.19 <sup>b</sup>	0.13 <sup>bA</sup>	0.13 <sup>aA</sup>	0.12 <sup>aA</sup>	0.13 <sup>b</sup>
Mean	0.20 <sup>B</sup>	0.21 <sup>B</sup>	0.23 <sup>A</sup>		0.13 <sup>A</sup>	0.12 <sup>A</sup>	0.13 <sup>A</sup>	

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

### 3.3 Correlations between grain and stover yields and nutrient concentrations

Sorghum grain yield (Palé et al., 2020) was positively associated with N ( $R = 0.35$ ,  $P \leq 0.01$ ), P ( $R = 0.39$ ,  $P \leq 0.01$ ), K ( $R = 0.44$ ,  $P \leq 0.01$ ), Mg ( $R = 0.22$ ,  $P \leq 0.05$ ), and Zn ( $R = 0.36$ ,  $P \leq 0.01$ ) concentrations while S, Ca, Fe, Mn and Cu concentrations were not associated with grain yield. In contrast, sorghum stover yield was only positively associated with stover K concentration ( $R = 0.41$ ,  $P \leq 0.01$ ) and negatively associated with N concentration ( $R = -0.22$ ,  $P \leq 0.05$ ) while P, S, Mg, Zn, Mn and Cu concentrations were not associated.

## 4. DISCUSSION

### 4.1 Sorghum grain nutrient concentrations – N, P, K, Mg, S, Zn, Mn and Cu

Most sorghum grain nutrient levels were not influenced by tillage method and/or CS/SA combinations. Tillage method had no effect on grain N, S, Zn, Fe, Mn, and Cu concentrations.

For sole cropped sorghum, soil amendment application generally increased the grain P concentration but not for intercropped sorghum. Grain Mg and K concentration differences were declared significant, but differences were quite small and of little practical importance. It was concluded that tillage, and cropping system and soil amendment combinations had only minor effect on sorghum grain concentrations. Unexpectedly, several nutrients had positive correlations with grain yield indicating increased sorghum grain yield rather than dilute nutrient concentrations in this study, in contrast to previous results reported by Buerkert et al. (1998).

Assuming that bioavailability was not an issue (Kruger et al., 2012), the grain nutrient concentrations were adequate for 31 to 50-year-old males weighing 60 kg and non-pregnant females weighing 40 kg for N, P, Mg, Zn and Fe, but deficient for K, Mn and Cu (National Academy of Science, 2019a; 2019b). Improvement of deficient nutrients through genetic improvement (Mabelebele et al., 2015; Kumar et al., 2017; Liboreiro Paiva et al., 2017) and/or targeted fertilizer application (Mabelebele et al., 2015; Bidinger and Blümmel, 2007) to improve sorghum grain nutrient concentrations or supplement diets with diverse foodstuffs, or use biofortified grain (Taylor et al., 2012) are likely needed to meet human dietary needs.

Grain N, Mg, and S concentrations were similar to values reported in previous studies (Mabelebele et al., 2015; Liboreiro Paiva et al., 2017; Wortmann et al., 2018). Grain concentration for Zn and Cu were similar to findings reported in past researches (Mabelebele et al., 2015), but higher than values reported by other researchers (Mabelebele et al., 2015; Liboreiro Paiva et al., 2017). Sorghum grain concentrations for P, K, Mn, and Cu were found to be similar to values reported in past researches (Mabelebele et al., 2015; Liboreiro Paiva et al., 2017), but P and K were lower, and Fe and Mn were much lower than values found in recent study (Wortmann et al., 2018). Sorghum grain nutrient concentrations in this study and in reference citations indicated great variability worldwide.

#### **4.2 Sorghum stover nutrient concentrations – N, P, K, Mg, S, Zn, Mn, and Cu**

Tillage method influence on sorghum stover nutrient concentration was not uniform across years, but the zaï system did decrease sorghum stover N and increase Mg concentrations in the higher seasonal rainfall and higher grain yield year (Palé et al., 2020). Year x CS/SA interaction differences were declared significant for stover S and Mg concentrations, but differences were quite small. Stover Zn concentration differences due to year x CS/SA interaction were much greater than for S and Mg, but inconsistent across year and cropping system with soil amendment applications with no logical best cropping system or soil amendment. In contrast to grain nutrient concentrations, stover grain concentrations were largely not associated with stover yield.

Sorghum nutrient concentrations for feeding cattle were found to be adequate for Mg, K, S, Zn and Mn in most cases but low for Cu (Gadberry, 2018). Stover concentrations for N and P were inadequate in 2012 but adequate in 2013. These results indicate the need in some years to apply fertilizer to raise N, P and Cu concentrations in sorghum stover, or supplement cattle rations with Cu sources to meet cattle nutrient requirements, and N and P in certain years. In a similar study with pearl millet produced in the Sahelian agroecological zone of Burkina Faso, the need for either fertilizer to increase N and P concentrations of pearl millet stover or supplementation of ration was found necessary to meet cattle N and P needs (Palé et al., 2021).

The stover P, Mg, S, Zn, Fe, Mn, and Cu concentrations at physiological maturity were adequate to meet the critical levels for growth of grain sorghum under the production situation present in this study (Wortmann et al., 2019; Cox and Unruh, 2000). The results suggest that N concentrations may have been lower than the critical level for optimum plant growth, but the stover sample at physiological maturity was different than the upper-most leaves during reproductive growth that are commonly used to determine critical levels.

Previous studies had shown sorghum stover concentrations for N, and Cu to be similar to those reported in the present experiment (Youngquist, 1990; Van Duivenbooden, 1992; Maw, 2020). Previous results indicated that stover K concentrations were similar to those in the present study and other recent findings (Maw, 2020), but lower than values observed in some other studies (Youngquist, 1990; Van Duivenbooden, 1992). Stover concentrations for Zn and Mn were lower than those reported in some past researches (Youngquist, 1990) but higher in others (Maw, 2020). In contrast, the stover S concentration was shown to be similar to past value reported in the literature (Youngquist, 1990), but lower in some other studies (Maw, 2020). Stover nutrient concentrations varied widely across this study and in references cited.

## **5. CONCLUSION**

Sorghum grain and stover nutrient concentrations were measured at physiological maturity to assess the influence of tillage, and CS/SA combinations on sorghum grain and stover nutrient concentrations, and on suitability for human food, livestock feed, and nutritional adequacy for yield produced. The CS/SA combinations had no influence on grain nutrient concentrations while year and tillage had small influences. Most stover nutrient concentrations were affected by the year x tillage, year x cropping system with soil amendment, and tillage x cropping system with soil amendment interactions, but differences were small. Results also indicated that nutrient concentrations of sorghum grain were adequate to meet human nutritional requirements for N, P, Mg, Zn and Fe, but deficient for K, Mn and Cu. Sorghum nutrient concentrations exceeded requirements for cattle feed for the stover yield levels produced this study, except for Cu. Clearly, cattle fed sorghum stover requires Cu supplementation which could be obtained through management or cultivar selection. Management of sorghum grain and stover K, Mn and Cu concentrations merit research. Nutrient concentrations of grain and stover should be included along with yields as parameters to evaluate sorghum management systems.

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