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Pearl Millet Grain and Stover Nutrient Concentrations as Influenced by Tillage, Cropping System and Soil Amendment

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Abstract: A two-year experiment was conducted in a randomized complete block designs with split plot treatment arrangements and three replications in the Sahelian agroecological zone of Burkina Faso. The main plot was tillage method and the sub-plot was cropping system/soil amendment (compost and mineral fertilizer) combinations. The objective of this study was to determine the influence of tillage and cropping system/soil amendment on pearl millet grain and stover concentrations, and relate these to nutritional needs of humans, cattle and for pearl millet plant growth. The cropping system/soil amendment combinations had little influence on nutrient concentrations, significant only for Mg with concentrations varying from 0.16 to 0.39%, and Fe with concentrations varying from 70 to 119-ppm in grain, and P in stover with concentrations varying from 0.06 to 0.18%. Year and tillage more frequently influenced nutrient concentrations, except for grain K, Ca, S, and Zn and stover S, Zn, Fe and Cu. Pearson's correlations-indicated that high yields due to year and tillage were often associated with lower nutrient concentration, and low yields with higher nutrient concentrations. Nutrient concentration of pearl millet grain was adequate to meet human nutritional requirements except for Mn, Ca for females, and P in some circumstances. Stover nutrient concentrations exceeded requirements for cattle feed and critical nutrient concentrations for the yield levels produced in this study except for N and P. Results indicates that the combination of good in presence of judicious cropping systems and soil amendment that positively affected pearl millet grain and stover nutrient concentrations should be recommended for use in the Sudano-Sahelian zone of Burkina Faso. However, management of Mn, Ca and P concentrations in grain and N and P concentration in stover requires further research.

Keywords: Compost, Fertilizer, No Till, Scarifying, Zaï, Human Nutrition, Cattle Nutrition, Critical Nutrient Concentration

Abbreviations: N: nitrogen; P: phosphorus; K: potassium; S: sulfur; Ca: calcium; Zn: zinc; Fe: iron Cu: copper; Mn: manganese.

1. Introduction

Pearl millet [*Penisetum glaucum* (L.) R.Br.] is the most important crop grain crop gown in the Sahelien Zone in West Africa (FAO, 2021). It is widely produced in sole crop and intercropping with cowpea [Vigna unguiculate (L.) Walp] systems with a variety of tillage methods and soil amendments ~~used~~. In West Africa, human population growth (World Bank, 2021), soil degradation, and climate changes (Mason et al., 2015a; 2015b) are forcing farmers to adopt intensive but more sustainable production systems to meet human and livestock food needs and maintain the soil environment. Most research has focused on pearl millet grain and stover yield with little attention given to nutrient concentrations of stover and grain that influence human and animal nutrition. Pearl millet grain and stover yields for this study were published previously (Palé et al., 2019), and found that in the Sahelien zone in a sandy, low organic matter soil that grain and stover yields increased with use of ploughing or zaï combined with applications of two or three of the soil amendments compost, fertilizer, and/or crop residues. Rengel et al. (1999) and Buerkert et al. (1998) indicated that increased yield often leads to a reduction in grain nutrient concentrations.

Pearl millet grain is primarily produced for human consumption in West Africa. Current recommended dietary allowances have been published by the National Academy of Science (2019a; 2019b). Average pearl millet grain nutrient concentrations for West Afeica (van Duivenbooden, 1992), Mali, Niger, Nigeria, and Tanzania (Wortmann et al., 2018), the United States (Kering and Broderick (2018), and worldwide (Kumar et al., 2018) have been published.

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Location (Wortmann et al., 2018), cropping system (Sharma and Gupta, 2002), genotype (Abdalla et al, 1998; Zerbini and Thomas, 2003), bio-fortification, and P and Zn fertilization (Singh et al., 2017) have been shown to influence grain nutrient concentrations. Buerkert et al. (1998) indicated that the emphasis on increasing pearl millet grain yield with applications of fertilizer macronutrients may lead to micronutrient deficiencies, especially for Fe and Zn. Further, they found that P fertilizer application decreased N and Zn concentrations in pearl millet grain due to nutrients dilution from increased yield. Sharma and Gupta (2002) found that N and P fertilizer application increased grain N and P concentration.

Pearl millet stover is used largely as cattle feed (Zerbini and Thomas, 2003) either through grazing or stockpiling and feeding to corralled animals. The nutrients Na, Ca, P, Cu and Zn have been reported to often be deficient in West Africa (Friot and Calvet, 1971), and van Duivenbooden (1992) showed great variation across locations and years. Genotype differences in stover quality have been documented (Blümmel et al., 2007; Abdalla et al, 1998). N fertilizer application has been shown to increase crude protein (Blümmel et al., 2007; Powell and Fussell, 1993), and P fertilizer application to increase the P concentration with no effect on crude protein. Grain and stover yield and stover quality have been shown to be unrelated (Blümmel et al., 2007). Little research attention has been focused on stover nutrient levels to meet cattle nutrient needs, but typical stover nutrient concentrations have been published for the United States (Kering and Boderick, 2018) and India (Choudhary et al., 2019). Sharma and Gupta (2002) found that N and P fertilizer application increased N and P concentration in pearl millet stover, while Singh et al. (2017) found that found that P and Zn fertilizer application increased the N, P, K and Zn concentration. Current nutrient requirements for cattle have been published by Gadberry (2018).

The best sufficiency level data for pearl millet in Sub-Saharan Africa are estimated by Wortmann et al. (2019), but these have not been fully developed and tested nor widely used. Nutrient concentrations decrease as crop growth progresses, and at physiological maturity/harvest relationship critical concentrations for producing growth and high yield are not well understood.

This manuscript addresses the influence of tillage method and soil amendment on sole and intercropped pearl millet grain and stover nutrient concentrations, and relates these results to human and cattle nutrition, and growing pearl millet plant critical nutrient levels. Nutrient concentration should be considered in addition to grain and stover yield, and other quality parameters in evaluating pearl millet management systems.

2. Materials and methods

2.1. Study site

The experiment was conducted from 2012 to 2014 at the Katchari/Dori Agricultural Research Station (14° 3’ 11’’ N lat; 0° 08’ 0.7’’ W long) in the Sahelian agroecological zone of Burkina Faso (Fig. 1) with 407 mm 10-yr average rainfall falling between July and Oct. The total rainfall of the site during the experiment years was 537 mm in 2012, 422 mm in 2013 and 380 mm in 2014.

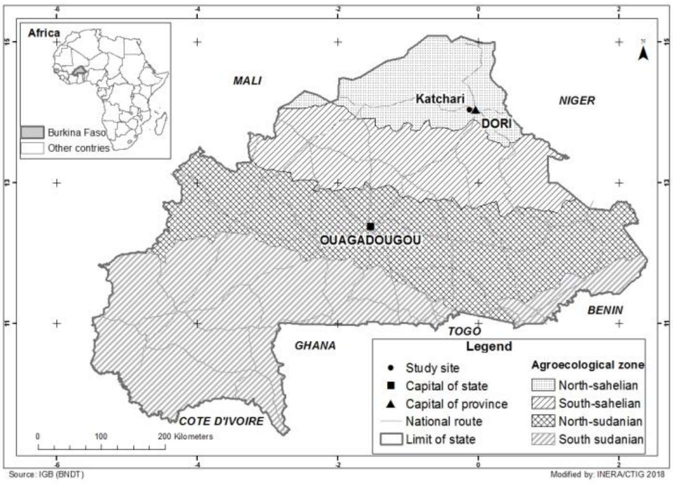

Fig. 1. Map of Burkina Faso showing the Sahelian agro-ecological zone and Katchari (study site) [*Source*: Geography Institute of Burkina Faso; rivized by the Remote Sensing and Geographical Information Unit (CTIG) at the Institute of Environment and Agricultural Research (INERA), Burkina Faso, 2018].

The experiment was conducted in a deep Little Leached Ferruginous Tropical Soil with stains and/or concretions, and sand texture with low water holding capacity. The surface horizon had a pH of 7.4, organic matter concentration of 2.3 g kg^{-1}, and 0.2 g kg^{-1} total N, 11.1 mg kg^{-1} Mehlich-3P, and 0.2 $Cmol^{(+)}$ kg^{-1} exchangeable K (Barro and Ouattara, personal communication, 2011). The fields had been fallowed for 14 years prior to 2012.

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 was cropping system with soil amendment (compost and/or mineral fertilizer) combinations. The treatments were applied to the same plots each year.

The three tillage methods allocated to the main plots were:

- no tillage;
- scarifying;
- zaï.

The scarifying method consists of a shallow cultivation of the field using a Manga hoe, which is an animal drawn tillage tool. 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 rainwater and supply nutrients (Fig. 2).

Fig. 2. Zaï pit with pearl millet plants at Dori, Burkina Faso, 2012.

The eight soil amendment levels allocated to the sub-plots were:

- Sole cropped pearl millet with no soil amendment;
- Sole cropped pearl millet with recommended compost rate of 2500 kg ha^{-1} /year broadcasted zaï pits;
- Sole cropped pearl millet with recommended mineral fertilizer at the rate of 10.5 kg N ha^{-1} + 17 kg P_2O_5 ha^{-1} + 10.5 kg K_2O ha^{-1} as complete fertilizer broadcasted at planting or within one week after planting, and 23 kg N ha^{-1} as urea, applied 45 days after planting;
- Sole cropped pearl millet with compost and mineral fertilizers;
- Intercropped pearl millet with cowpea with no soil amendment;
- Intercropped pearl millet with cowpea + compost;
- Intercropped pearl millet with cowpea + mineral fertilizer;
- Intercropped pearl millet with cowpea + compost + mineral fertilizer;

Plots consisted of six rows, 10-m long. Pearl millet planting was done at the recommended spacing of 80 cm between rows and 80 cm within the row with 1 or 2 plants per hill after thinning. Cowpea planting was done at the recommended density of 80 cm between rows and 40 cm between plants within the row for cowpea , with 1 to 2 plants per hill after thinning. Intercrop planting was done alternating two rows of pearl millet with two rows of cowpea, giving a total of four rows of pearl millet and two rows of cowpea per plot. Simultaneous planting of pearl millet and cowpea was in July of each year. Weed control was accomplished by hand hoeing as needed. The pearl millet variety used was SOSAT C88 with maturity rating of 90 days and was intercropped with cowpea variety “Gorom local” with maturity of 70 days.

2.3. Data collection

Pearl millet grain and stover harvest was done in the middle of each plot and the harvested area of 24.32 m^2. Pearl millet panicles and stover were hand-harvested, air-dried, threshed (for panicles), weighted, and recorded as dry weight. Experiment was conducted from 2012 through 2014, and grain and stover samples used for the determination of nutrient concentrations were 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 (Miller et al., 1997), and digestion and inductively coupled plasma spectrometry for phosphorus (P), potassium (K), sulfur (S), calcium (Ca), magnesium (Mg), zinc (Zn), iron (Fe), manganese (Mn) and copper (Cu) concentrations (Wolf et al, 2003).

2.4. Data analysis

Grain and stover yields were analyzed using standard analysis of variance and pair-wised comparisons by the General Linear Model Procedure on the software SAS version 9.2/STAT®, version 9.2 (SAS Institute, 2010). Results were considered significant at the $P \leq 0.05$ level. Pearson correlations between grain and stover yield and nutrient concentrations were conducted. Results were related to published sufficiency levels for humans (National Academy of Science, 2019a; 2019b), cattle (Gadberry (2018), and pearl millet plant critical nutrient levels (Wortmann et al., 2018).

3. Results and discussion

3.1. Pearl millet grain macronutrient concentration variations – N, P, K, Ca, Mg, and S

Pearl millet grain N concentrations were influenced by the tillage ($P = 0.02$) and P concentration by the year x tillage method interaction ($P = 0.03$), but neither by the cropping system/soil amendment combinations (Table 1). Neither tillage method or cropping system/soil amendment influenced the K (0.9%), Ca (0.15%), or S (0.17%) concentrations. In contrast, the year x tillage interaction (P = 0.03) and the tillage x cropping system/soil amendment interaction (P = 0.04; Table 2) influenced the pearl millet grain Mg concentration.

Table 1. Year (Y) x Tillage method (T) effect and T main effect on pearl millet grain nutrient concentrations in sole and intercropped pearl millet with cowpea in Katchari (Dori). 2012 through 2013. Burkina Faso [Analysis of variance probability: P P_{YxT} = 0.03, P_Y = 0.37, P_T = 0.77; Mg P_{YxT} = 0.03, P_Y = 0.43, P_T = 0.12; Fe P_{YxT} = 0.05, P_Y = 0.55, P_T = 0.80; Cu P_{YxT} = 0.03, P_Y = 0.03, P_T = 0.30; Probability of Tillage main effect on N = 0.02].

Tillage Method	Phosphorus (% P)			Magnesium (% Mg)			Nitrogen (% N)
	2012	2013	Mean	2012	2013	Mean	2012-2013
No till	0.30 $^{ab A}$	0.18 $^{a B}$	0.24 ^{a}	0.14 ^{aB}	0.35 ^{bA}	0.24 ^{b}	1.87 ^{a}
Scarifying	0.27 ^{bA}	0.16 ^{abB}	0.21 ^{b}	0.13 ^{aB}	0.32 ^{bA}	0.23 ^{b}	1.86 ^{ab}
Zaï	0.31 ^{aA}	0.13 ^{bB}	0.22 ^{ab}	0.14 ^{aB}	0.44 ^{aA}	0.29 ^{a}	1.73 ^{b}
Mean	0.29 ^{A}	0.16 ^{B}		0.14 ^{B}	0.37 ^{A}		
	Iron (ppm Fe)			Copper (ppm Cu)			
No till	65 ^{aB}	110 ^{aA}	87 ^{a}	7.9 ^{aA}	6.4 ^{aB}	7.2 ^{a}	
Scarifying	62 ^{aB}	114 ^{aA}	88 ^{a}	8.0 ^{aA}	7.1 ^{aA}	7.5 ^{a}	
Zaï	73 ^{aA}	834 ^{bA}	78 ^{a}	6.8 ^{bA}	7.2 ^{aA}	7.0 ^{a}	
Mean	67 ^{B}	103 ^{A}		7.56 ^{A}	6.9 ^{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 2. Tillage (T) x Cropping system with soil amendment (CS/SA) effect and CS/SA main effect on pearl millet grain nutrient concentrations in sole and intercropped pearl millet with cowpea in Katchari (Dori). 2012 through 2013. Burkina Faso [Analysis of variance probability: Mg $P_{TxCS/SA}$ = 0.04, P_T = 0.12, $P_{CS/SA}$ = 0.37; Probability of CS/SA main effect on Fe = 0.02].

Cropping system with soil amendment	Magnesium (% Mg)				Iron (ppm Fe)
	No till	Scarifying	Zaï	Mean	2012-2013
Sole cropped with Zero amendment	0.23 ^{aA}	0.25 ^{abA}	0.26 ^{bA}	0.24 ^{a}	75 ^{b}
Sole cropped with compost (C)	0.24 ^{aA}	0.16 ^{bA}	0.21 ^{bA}	0.20 ^{a}	78 ^{b}
Sole cropped with mineral fertilizer (F)	0.24 ^{aA}	0.28 ^{aA}	0.36 ^{abA}	0.29 ^{a}	87 ^{b}
Sole cropped with C + F	0.27 ^{aA}	0.24 ^{abA}	0.23 ^{bA}	0.25 ^{a}	70 ^{b}
Intercropped with zero soil amendment	0.30 ^{aA}	0.20 ^{abA}	0.24 ^{bA}	0.24 ^{a}	71 ^{b}
Intercropped with C	0.22 ^{aA}	0.30 ^{aA}	0.22 ^{bA}	0.25 ^{a}	94 ^{ab}
Intercropped with F	0.24 ^{aB}	0.19 ^{abB}	0.39 ^{aA}	0.27 ^{a}	84 ^{b}
Intercropped with C + F	0.21 ^{aB}	0.22 ^{abB}	0.39 ^{aA}	0.27 ^{a}	119 ^{a}
Mean	0.24 ^{B}	0.23 ^{B}	0.29 ^{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.

Grain from the no-till and scarify plots had similar N concentrations of 1.86 to 1.87% that were greater than for grain from zaï plots of 1.73% (Table 1). There were small differences in P concentration in 2012 while pearl millet grain produced in the zaï plots had 0.05% lower P concentration than with no-till in 2013. There was little difference in Mg concentrations across tillage methods in 2012, however, the Mg concentration when zaï was used in 2013 was 0.07 to 0.09% higher than with other tillage methods. Higher Mg concentrations was found with using the zaï in combination with fertilizer application when pearl millet was intercropped (Table 2). In addition, sole cropped pearl millet grain had higher Mg concentration with zaï in combination with fertilizer and lower Mg concentration with scarifying tillage in combination with compost application.

Grain P concentrations were higher in the higher yielding 2012 season (Palé et al., 2019) and higher in the lower yielding 2013, while the opposite was true for Mg concentrations and N concentrations were similar across years (Table 1). Grain yield correlated negatively with K (R = -0.24, P ≤ 0.01), Ca (R = -0.28, P ≤ 0.01), Mg (R = -0.25, P ≤ 0.01), and S (R = -0.27, P ≤ 0.01) indicating dilution of nutrient concentrations with higher grain yields as reported by Rengel et al. (1999) and Buerkert et al. (1998). In contrast, the grain N concentration (R = 0.16, ns) was not related to grain yield while the P concentration was positively related to grain yield (R = 0.30, P ≤ 0.01).

Pearl millet grain P and Mg concentrations (Table 1) were greater than required for human nutrition for 31 to 50-year-old male weighing 60 kg and non-pregnant female weighing 40 kg, N concentrations were greater than requirement by males and approximately equal to the N requirement of females, and Ca was nearly adequate for males but not females (National Academy of Science, 2019a). Adequacy of grain P concentrations varied with all tillage systems with P concentration being greater than male and female critical requirements in 2012, but only for grain in the low grain yielding no-tillage plots in 2013. These results suggest that pearl millet grain is adequate for human diets except Ca for females and P in some situations.

Concentrations of N (Table 1) were 0.3 to 0.4% lower than reported averages for Sub-Saharan Africa by Wortmann et al. (2018), van Duivenbooden (1992), and Abdalla et al. (1998), while grain P concentrations were near the averages cited by Wortmann et al. (2018) and van Duivenbooden (1992) in 2012, but much lower than in 2013. Potassium concentration were similar to those reported by Wortmann et al. (2018) and Abdalla et al. (1998) but lower than those of van Duivenbooden (1992), Buerkert et al. (1998), and Kumar et al. (2018). Grain Mg concentrations (Tables 1 and 2) were lower than the concentrations found by Wortmann et al. (2019), Abdalla et al. (1998), and van Duivenbooden (1992) in 2012, but much higher than in 2013. Calcium concentrations were lower than reported by Wortmann et al. (2018), Abdalla et al. (1998), Buerkert et al. (1998), and Kumar et al. (2018) while sulfur concentrations were higher than those of Wortmann et al. (2018) van Duivenbooden (1992). This study combined with reference citations show great variability in macronutrient concentrations in pearl millet grain in West Africa.

3.2. Pearl millet grain micronutrient concentration variations – Zn, Fe, Mn, Cu

Neither tillage method or cropping system/soil amendment influenced the Zn (43 ppm), and Mn concentrations (26 ppm) in the pearl millet grain. The year x tillage interaction (Table 1; P = 0.05) and cropping system/soil amendment main effect (Table 2; P = 0.02) influenced grain Fe concentrations. In the high grain yield year of 2012 (Palé et al., 2019), tillage methods had no influence on grain Fe concentrations. However, pearl millet grain Fe concentrations were higher in the lower yielding 2013, and lower when the zaï was used rather than no till or scarifying tillage (Table 1). Averaged across tillage method and year, Fe concentration in grain were higher in grain from intercropped pearl millet combined with compost and fertilizer treatments than with fertilizer or no soil amendment application (Table 2). The year x tillage interaction showed that differences in grain Cu concentration were small across tillage methods and years, with the zaï in 2012 and no till in 2013 producing 0.6 to 1.1 ppm lower Cu concentrations that other tillage method and year combinations (Table 1). Iron (R = -0.20, P ≤ 0.01) and Mn (R = -0.30, P ≤ 0.01) were lower when higher pearl millet grain yield was produced as reported by Rengel et al. (1999) and Buerkert et al. (1998). Zinc (R = 0.12, ns) and Cu (R = -0.04, ns) concentrations were not related to pearl millet grain yield.

Concentrations of Zn, Fe, and Cu (Table 1 and 2) in pearl millet grain met the dietary requirement for 31 to 50-year-old males weighing 60 kg and non-pregnant females weighing 40 kg, ns (National Academy of Science, 2019b). Manganese concentrations were inadequate and need to be supplemented by other foods in the diet. Grain Fe and Cu concentrations were much lower than average concentrations reported by Wortmann et al. (2018) but similar to those of Abdalla et al. (1998), while Zn concentrations were higher than reported by Buerkert et al. (1998), but lower than those of Wortmann et al. (2018) and Abdalla et al. (1998). Manganese concentrations were similar to those reported by Abdalla et al. (1998) but much lower than reported by Wortmann et al. (2018). This study combined with reference citations show great variability in micronutrient concentrations in pearl millet grain in West Africa.

3.3. Pearl millet stover macronutrient concentration variations – N, P, K, Ca, Mg and S

Tillage and cropping system/soil amendment did not influence stover K (1.8%), Mg (0.38%), and S (0.17%), and both were positively associated with stover yield (R for K = 0.33, P ≤ 0.01; R for S = 0.37, P ≤ 0.01). Differences in pearl millet stover N concentrations (P = 0.02) were found for the tillage (Table 3), with no differences across soil amendment/cropping system combinations or years. Pearl millet produced using the scarify and no-till tillage had the highest stover N concentration, and zaï the lowest. Stover N concentrations were not associated (R = -0.16, ns) with stover yields (Palé et al., 2019).

Table 3. Year (Y) x Tillage method (T) effect on pearl millet stover calcium and manganese concentrations, T main effect on stover nitrogen and Y main effect on stover magnesium concentrations in pearl millet/cowpea intercropped in Katchari (Dori). 2012 through 2013. Burkina Faso [Analysis of variance probability: Ca P_{YxT} = 0.01, P_Y = 0.28, P_T = 0.67; Mn P_{YxT} = 0.01, P_Y = 0.51, P_T = 0.59; Probability of T main effect on N = 0.02].

Tillage Method	Calcium (% Ca)			Manganese (ppm Mn)			Nitrogen (% N)
	2012	2013	Mean	2012	2013	Mean	2012-2013
No till	0.46 ^{abA}	0.18 ^{bB}	0.32 ^{a}	77 ^{abA}	44 ^{bB}	60 ^{a}	1.37 ^{a}
Scarifying	0.51 ^{aA}	0.18 ^{bB}	0.34 ^{a}	83 ^{aA}	39 ^{bB}	61 ^{a}	1.51 ^{a}
Zaï	0.43 ^{bA}	0.26 ^{aB}	0.34 ^{a}	64 ^{bA}	62 ^{aA}	63 ^{a}	1.16 ^{b}
Mean	0.46 ^{A}	0.21 ^{B}		75 ^{A}	49 ^{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.

Stover P concentrations were influenced by the tillage x cropping system/soil amendment interaction

(P = 0.04) (Table 4). In general, the stover P concentrations were higher when pearl millet was produced with the scarify tillage method rather than by no till or zaï. Stover P concentration was much greater for the sole crop pearl millet without soil amendment and the intercrop pearl millet with compost and fertilizer applied than other soil amendment/cropping system combination. Also, pearl millet stover produced with the zaï tillage method had much greater stover P concentration for intercropped pearl millet with compost, and much lower for intercropped pearl millet with fertilizer. Phosphorus concentrations were similar and low in no-tilled plots for all CS/SA combinations. The stover P concentration was negatively associated (R = -0.29, P ≤ 0.01) with the stover yield (Palé et al., 2019).

Table 4. Tillage method (T) x Cropping System with soil amendment (CS/SA) effect on Stover P concentration for pearl millet in pearl millet/cowpea intercropped in Katchari /Dori, 2012 through 2013, Burkina Faso [Analysis of variance probability: $P_{TxCS/SA} = 0.04$, $P_T = 0.21$, $P_{CS/SA} = 0.49$].

Cropping system with soil amendment	Phosphorus (% P)			
	No till	Scarifying	Zaï	Mean
Sole cropped with zero amendment	0.11 aA	0.18 aA	0.12 bcA	0.14 ab
Sole cropped with compost (C)	0.10 aA	0.12 abA	0.15 bA	0.12 ab
Sole cropped with mineral fertilizer (F)	0.13 aA	0.10 bA	0.14 bcA	0.12 ab
Sole cropped with C + F	0.12 aA	0.12 abA	0.13 bcA	0.13 ab
Intercropped with zero amendment	0.10 aA	0.09 bA	0.17 abA	0.12 ab
Intercropped with C	0.12 aB	0.12 abB	0.23 aA	0.16 a
Intercropped with F	0.11 aAB	0.15 abA	0.06 cB	0.11 b
Intercropped with C + F	0.09 aAB	0.16 abA	0.07 cB	0.11 b
Mean	0.11 A	0.13 A	0.13 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.

Stover Ca concentrations were influenced by the year x tillage interaction effect (P = 0.01). Pearl millet stover Ca concentration in the high rainfall year of 2012 was greater no matter the tillage method used (Table 3). There were similar Ca concentrations in all tillage systems in 2012, but much higher for the zaï tillage method than the no-till and scarify methods in 2013. Stover Mg concentrations were 0.57% in 2012 and 0.19% in 2013 (P = 0.05) with no other differences found. Both the stover Ca (R = 0.40, P ≤ 0.01) and Mg (R = 0.57, P ≤ 0.01) concentrations were positively associated with the stover yield.

No matter the tillage or cropping system/soil amendment combination, the K, S and Mg (not reported) and Ca (Table 3) concentrations were greater than critical nutrient concentrations to meet nutrient needs for 400 kg heifers, 480 kg gestating cow ad 480 kg lactating cow (Gadberry, 2018), while stover N and P concentrations were lower. Either the cattle diet requires N and P supplementation when grazing or feeding pearl millet stover, or application of a readily available N and P fertilization application to pearl millet is necessary to not only produce high grain and stover yields but also to improve the N and P nutritional value of stover (Singh et al.; 2017; Bidinger and Blümmel, 2007; Sharma and Gupta, 2002; Maman et al., 2000; Buerkert et al., 1998). Nutrient concentrations for P, K, S and Ca in 2012 were similar to van Duivenbooden (1992), but higher for N concentration, and lower for Mg and Ca in 2013.

Potassium (R = 0.33; P ≤0.01), Ca (R = 0.40, P ≤ 0.01), Mg (R = 0.57, P ≤ 0.01), and S (R = 0.37, P ≤ 0.01) stover concentrations were positively association with stover yield (Palé et al., 2019) while the stover P concentration was negatively associated (R = -0.29, P ≤ 0.01). No matter the tillage, soil amendment or cropping system used, pearl millet stover K, S and Mg (not reported) and Ca (Table 3) concentrations at physiological maturity were greater than critical level for upper leaves during early reproductive growth for the yield levels (Wortmann et al., 2019), thus in this study, these elements did not limit grain and stover yield. In contrast, the stover N and P concentrations were lower than the estimated cereal critical concentrations for plant growth (Wortmann et al., 2019) and limited grain and stover yields. The plant parts sampled and timing may have caused these values being less than the critical levels for plant growth, and further research of critical N and P levels of pearl millet is needed.

3.4. Pearl millet stover micronutrient concentration variations – Zn, Fe, Mn, and Cu

The tillage and cropping system/soil amendment did not influence the pearl millet stover Zn (42 ppm), Fe (448 ppm), or Cu (8 ppm) concentrations (data not shown). Stover Mn concentrations were influenced by the year x tillage interaction (P = 0.01; Table 3). The study showed greater stover Mn concentrations were greater in the higher yielding 2012 season than in 2013 (Palé et al., 2019). When averaged across years, no tillage method difference was found. In general, the scarify and no-till tillage methods had greater stover Mn concentrations than with the zaï. However, in the high stover yield season in 2012

(Palé et al., 2019), stover produced using the zaï had lower Mn concentrations than for other tillage methods, while the opposite was found in the lower yield 2013 season. The reason for these differences in stover Mn concentrations are not clear.

Stover concentrations for Zn (R = 0.08, ns), Fe (R = -0.07, ns) and Cu (-0.08, ns) were not associated with stover yield, while Mn (R = 0.26, P ≤ 0.01) was positively associated. The Zn, Fe, Mn, and Cu concentrations were greater than critical nutrient concentrations to meet nutrient needs for 400 kg heifers, 480 kg gestating cow ad 480 kg lactating cow (Gadberry, 2018) and to meet pearl millet critical concentrations for plant growth (Wortmann et al., 2019). Cattle diet supplementation and additional nutrient application for pearl millet production were not needed for micronutrients in this study.

Conclusions

Pearl millet grain and stover nutrient concentrations were measured at physiological maturity to assess the influence of tillage and cropping system/soil amendment effects, suitability for human food, livestock feed, and nutritional adequacy for yield produced. The cropping system/soil amendment combinations had little influence on nutrient concentrations, significant only for Mg and Fe in grain and P in stover. Year and tillage more frequently influenced nutrient concentrations, except for grain K, Ca, S, and Zn and stover S, Zn, Fe and Cu. Often high yields due to year and tillage were associated with lower nutrient concentration, and low yields with higher nutrient concentrations.

In general, nutrient concentration of pearl millet grain was adequate to meet human nutritional requirements. However, it was found that grain Mn concentration was lower than requirements, Ca was adequate for males but not females, and the P concentration adequacy varied across year and tillage methods. Balanced human diets with additional foodstuffs or supplementation usually should meet these nutritional needs.

Stover nutrient concentrations exceeded requirement for cattle feed and critical nutrient concentrations for the yield levels produced this study except for N and P. Clearly, cattle fed pearl millet stover requires N and P supplementation, or management or cultivar selection to increase the concentration of N and P in the animal diet. These results are less clear for N and P to meet critical plant needs for N and P, since the stage of sampling (physiological maturity rather than early reproductive) and the sampled part (stover rather than the upper leaves) were not consistent with common recommendations.

This study shows that in general that the tillage, cropping system and soil amendments used in this study meet most mineral nutrition requirements. Further, this research documents the beneficial effects of the combination of good tillage methods with judicious cropping systems and soil amendment which should be recommended to improve pearl millet grain and stover nutrient quality in the Sudano-Sahelian zone of Burkina Faso. However, management of Mn, Ca and P concentrations in grain merit increased study, as does N and P concentration in pearl millet stover. Further investigations on critical N and P levels of pearl millet is then needed, especially for late-season nutritional levels.

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