Nutritional Evaluation of Millet Plants Grown in Soils Fertilized With Organic Wastes From Different Sources

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Abstract

The losses of essential elements to crops make necessary to correct soil fertility to meet the nutritional requirements of plants, which can be achieved by increasing soil organic matter. The objective of this work was to evaluate the leaf nutritional conditions of millet plants grown in soils fertilized with organic wastes from different sources at different rates. Organic matter can make the soil more productive and suitable to agricultural crops. A randomized block experimental design with a 4×2 factorial arrangement was used with four replications, consisting of 32 experimental units. The treatments consisted of four organic matter sources (swine manure, sewage sludge, bovine manure, and poultry litter), and two organic matter rates (20% and 40% of the pot volume). Boron extraction was performed by dry digestion—the organic matter of the plant tissue was incinerated in an electric muffle furnace at 450-550 ºC, and the inorganic residue (ash) was dissolved in a dilute acid solution. N, K, Ca, Mg, S, Fe, Cu, Mn, and Zn was extracted through wet digestion—the organic matter of the leaf tissue was oxidized by concentrated mineral acids and by heat. N, P, S, B, Ca, Mg, Cu, Fe, Mn, and Zn was determined by spectrophotometry. K was determined by flame photometry. All macro and micronutrient contents in the millet leaves, and biometric parameters of the millet panicle were affected by the organic matter sources, organic matter rates, and the interaction between them.

Keywords: *Pennisetum glaucum,* swine manure; sewage sludge

1. Introduction

The use of lands for agricultural purposes contributes to soil nutrient loss due to crop harvest (Galvão et al., 2008; Santos et al., 2010). Moreover, nutrients are lost through volatilization, inadequate fertilization, and fertilizer runoff (Novais et al., 2007). The losses of essential elements to crops make necessary to correct soil fertility to meet the nutritional requirements of plants, agricultural crops, and native species for recovery of degraded areas, which can be achieved by increasing soil organic matter, since organic matter is a great soil conditioner that generates physical, chemical, and biological improvements (Alcântara & Madeira, 2008).

Organic matter can make the soil more productive and suitable to agricultural crops. The most used organic fertilizers for supplying organic matter to soils are bovine manure, chicken litter, swine manure, and more recently, sewage sludge (Morais, 2016).

Bovine manure and poultry litter are low moisture residues and are, therefore, known as solid wastes. However, wastes may vary in concentration of nutrients depending on the dilution, handling, and storing (Oliveira, 1993). Effluent or sewage sludge are residues with plenty moisture. All residues must undergo a previous treatment of composting before incorporated into the soil to avoid damage to crops by phytotoxicity. Organic fertilization is important for agriculture, especially for millet crops.

Millet is an important annual crop for animal feed; this crop can replace maize and other grains. This species does not present dhurrin, which is found in sorghum plants, thus, it is not toxic to animals at any vegetative stage, and can be used as grazing, hay, silage, and grain feed (Fontaneli et al., 2012). The objective of this work was to evaluate the leaf nutritional conditions of millet plants grown in soils fertilized with organic wastes from different sources at different rates.

2. Materials and Methods

The experiment was conducted in a greenhouse at the Federal Institute of Goiás, Rio Verde campus, southwest of the state of Goiás, Brazil (17º47′53″ N, 51º55′53″S, and altitude of 743 m). The soil was characterized as Dystroferric Red Latossolo (Oxisol) (Embrapa, 2013).

A randomized block experimental design with a 4 × 2 factorial arrangement was used with four replications, consisting of 32 experimental units. The treatments consisted of four organic matter sources (swine manure, sewage sludge, bovine manure, and poultry litter), and two organic matter rates (20% and 40% of the pot volume).

Fifty-liter pots filled with an agricultural soil that is predominant in the region were used. The pots were filled with 80% of soil and 20% of organic matter; and with 60% of soil and 40% of organic matter. The soil chemical analysis after the treatments is shown in Table 1. The soil analysis was performed according to Silva et al. (2009).

Table 1. Analysis of macronutrients and micronutrients of soils treated with organic wastes and used for the planting of millet

Treatments	Macronutrients[1]							pH
	Ca	Mg	Al	K	K	S	P (mol)	
	------------------ cmol$_c$ dm^{-3} --------------------				-------------- mg dm^{-3} --------------			
SM 20%	4.44	1.14	0.00	0.32	126.0	114.9	33.40	6.2
SM 40%	4.43	1.15	0.01	0.34	133.0	116.8	23.35	5.5
SS 20%	3.20	0.94	0.05	0.32	126.0	101.2	21.85	4.9
SS 40%	3.28	0.83	0.10	0.30	119.0	161.3	20.79	4.7
BM 20%	2.33	1.18	0.00	0.91	356.0	12.5	28.39	7.1
BM 40%	3.76	2.35	0.00	1.67	652.0	20.1	87.70	7.3
PL 20%	1.92	2.06	0.00	0.00	1.3	72.1	154.49	8.1
PL 40%	1.44	3.06	0.00	0.01	2.4	181.1	263.09	8.3
Treatments	Micronutrients						OM	CEC
	Na	Fe	Mn	Cu	Zn	B		
	-------------------------------- mg dm^{-3} ----------------------------------						g dm^{-3}	cmol$_c$ dm^{-3}
SM 20%	19.00	13.85	53.74	5.59	19.54	0.16	35.7	7.69
SM 40%	18.00	12.07	54.41	2.20	10.33	0.28	39.6	8.32
SS 20%	37.00	69.91	96.20	5.09	18.16	0.29	34.1	8.04
SS 40%	45.00	90.36	118.05	3.26	21.01	0.23	39.0	8.10
BM 20%	33.00	12.39	47.70	3.04	5.75	0.18	30.3	5.59
BM 40%	55.00	15.05	110.07	3.09	11.27	0.31	49.8	9.01
PL 20%	360.00	12.10	111.89	8.17	10.78	1.94	31.0	6.25
PL 40%	240.00	8.66	127.61	5.60	14.40	2.49	51.3	6.21

Note. [1]Macronutrients and Micronutrients. Treatments: swine manure (SM); sewage sludge (SS); bovine manure (BM); poultry litter (PL); organic matter (OM); cation exchange capacity (CEC).

Millet seeds of the cultivar BRS 1501 (Brazilian Agricultural Research Company Embrapa) were sown in April 2016. Chemical analysis of the millet leaves was performed to determine the nutritional status of the plants at 80 days after sowing (DAS).

Green leaves were washed with tap water and later with distilled water, dried in a forced-air circulation oven at 60 ºC to a constant weight, crushed in a Wiley mill and passed through a 1.0-mm mesh sieve.

Boron extraction was performed by dry digestion—the organic matter of the plant tissue was incinerated in an electric muffle furnace at 450-550 ºC, and the inorganic residue (ash) was dissolved in a dilute acid solution. N, K, Ca, Mg, S, Fe, Cu, Mn, and Zn was extracted through wet digestion—the organic matter of the leaf tissue was oxidized by concentrated mineral acids and by heat.

N, P, S, B, Ca, Mg, Cu, Fe, Mn, and Zn was determined by spectrophotometry. K was determined by flame photometry. The chemical analysis of the plant tissue was performed according to the methodology described by Miyazawa et al. (2009).

The data of each variable were subjected to analysis of variance using the SISVAR program (Ferreira, 2011). Significant means by the F test were subjected to the Tukey's test at 5% probability for the organic matter sources and rates.

3. Results and Discussion

Leaf macronutrients and micronutrients are important to evaluate the nutritional status of the plant. The interaction between the organic matter sources (OMS) and rates (OMR), and the isolated effects of OMS and OMR were significant for all macronutrient contents (N, P, K, Ca, Mg, and S) (Table 2), except the effect of OMR on N and K.

Table 2. ANAVA to evaluate the significance of the sources of variation of macronutrient contents in millet leaves

| SV | DF | Mean square[1] | | | | | |
		N	P	K	Ca	Mg	S
OMS	3	122.95**	2.23**	325.30**	48.71**	2.35**	0.10**
OMR	1	2.26ns	1.62**	0.17ns	33.62**	8.00**	0.25**
OMS × OMR	3	64.33**	0.67**	13.94**	6.42**	1.37**	0.05**
Block	3	21.73**	0.27**	4.63**	0.70**	0.21**	0.04**
Residual	21	0.71	0.009	0.26	0.03	0.01	0.002
CV (%)		1.85	1.60	1.21	2.17	2.53	1.64

Note. [1]Source of variation (SV); degree of freedom (DF); organic matter source (OMS); organic matter rate (OMR); coefficient of variation (CV); * significant at 5% by the F test; ** significant at 1% by the F test and ns not significant at 5% by the F test.

Usually, the interactions between soil characteristics and nutrient elements contribute negatively to the available level of nutrients in millet, however, organic matter in the soil is related positively to an increase of nutrient availability favoring to grains yield and quality (Tisdale et al., 1993; Koukoulakis et al., 2000, 2013).

The OMR was not significant for N only for swine manure (SM) (Table 3). Plants in soils with poultry litter (PL), and bovine manure (BM) had higher leaf N contents than those in soils with sewage sludge (SS), when applying OMR of 40%. Plants in soils with the OMR of 20% had the highest leaf N contents in the treatments with PL, SM, and BM. The plants in soils with the OMR of 40% had the highest leaf N contents in the treatments with SS, and the lowest in the treatments with SM. Younger leaves contain more N than elder due to the effective N uptake of young leaves, consequently, the changing of N content of leaves is more remarkable in the initial phase, what requires the fast availability of this nutrient (Nagy & Holb, 2006).

Table 3. Significance of the interaction between organic matter sources (OMS) and organic matter rates (OMR) for macronutrients in millet leaves

OMR (%)	OMS[1]			
	PL	SM	BM	SS
N (g kg⁻¹)				
20	49.6aA	40.13aC	46.80aB	46.80bB
40	42.9bB	41.00aC	43.90bB	53.40aA
P (g kg⁻¹)				
20	6.30aB	6.50aA	5.70aC	6.20aB
40	6.40aA	6.40aA	5.10bB	5.00bB
K (g kg⁻¹)				
20	45.00bB	42.50aC	46.53bA	34.50aD
40	48.00aA	40.30bB	48.30aA	32.50bC
Ca (g kg⁻¹)				
20	5.70aD	10.00aB	8.90aC	10.60aA
40	2.90bD	10.20aA	7.30bB	6.60bC
Mg (g kg⁻¹)				
20	3.80aA	5.10aB	4.90aB	5.10aB
40	3.40bC	4.60bA	4.00bB	2.90bD
S (g kg⁻¹)				
20	3.30aAB	3.20aB	3.20aB	3.40aA
40	3.30aA	2.90bC	3.10bB	3.10bB

Note. [1] Means followed by the same lowercase letter in the columns and uppercase letter in the rows do not differ by the Tukey's test at 5% probability. Organic matter source (OMS); organic matter rate (OMR); poultry litter (PL); swine manure (SM); bovine manure (BM); sewage sludge (SS); 20 = 20% of organic matter; 40 = 40% of organic matter.

The OMR affected the P contents of plants in soils with BM and SS; and the plants had the highest P contents when using the OMR of 20%. The highest P contents with the OMR of 20% were found in plants in soils with SM, and the lowest in plants in soils with BM; and the highest P contents with the OMR of 40% were found in plants in soils with PL, and SM (Table 3). According to Sobrado (2014) the N and P are co-limiting macronutrients in the crops that growing in oxisol soil.

The OMR affected the leaf K contents of plants, regardless the OMS used (Table 3). The highest leaf K contents were found in plants in soils with SM, and SS. The highest K contents with the OMR of 20% were found plants in soils with BM, and the lowest with SM. The highest K contents with the OMR of 40% were found in plants in soils with PL, and BM, and the lowest with SS. Bouhafa et al. (2018) observed very highly significant differences were found between the leaf N and K levels measured at different sampling periods, indicating the high N and K needs of crops.

The OMR affected the leaf Ca contents of plants in soils with PL, BM, and SS (Table 3). The highest Ca in the leaves were found with the OMR of 20%. The highest leaf Ca contents with the OMR of 20% were found in plants in soils with SS, and the lowest with PL. The highest leaf Ca contents with the OMR of 40% were found in plants in soils with SM, and the lowest with PL. Miljković and Vrsaljko (2009) noted that the leaf had higher N and K, and lower Ca levels.

The OMR affected the leaf Mg contents, regardless the OMS used. Plants in soils with the OMR of 20% had higher Mg contents than those in soils with 40%. The highest Mg contents with the OMR of 20% were found in plants in soils with PL. The highest Mg contents with the OMR of 40% were found in plants in soils with SM, and the lowest with SS. The status that leaf Mg is in excessive range when leaf K is in deficiency due to a consequence of lower K competition (Nachtigall & Dechen, 2006; T. Milošević & N. Milošević, 2015), however, in this study were observed lower Mg levels.

The OMR only affect the leaf S contents of plants in soils with PL. Plants in soils with SM, BM, and SS had the highest leaf S contents at OMR of 20%. The highest S contents with the OMR of 20% were found in plants in

soils with SS. The highest S contents with the OMR of 40% were found in plants in soils with PL, and the lowest with SM.

Araújo et al. (2008) evaluated the effects of natural and composted tannery sludges combined with phosphate on maize production components, soil fertility, and chromium accumulation in the soil and found higher N, P, K, Ca, Mg, and S contents for treatments containing sewage sludge. The highest contents of these elements with the OMR of 20% were found, in general, in plants in soils with SS, and PL. The highest macronutrient contents with the OMR of 40% were found, in general, in plants in soils with PL, and SM.

The highest N content (53.40 g kg^{-1}) were found when using SS at OMR of 40%, and the lowest (40.13 g kg^{-1}) when using SM at OMR of 20%. The soil with SM at OMR of 20% had the highest P content (6.50 g kg^{-1}), and that with SS at OMR of 40% had the lowest P content (5.00 g kg^{-1}). The soil P contents when using SM at OMR of 20%, and SS at OMR of 40% were 33.40, and 20.79 mg dm^{-3}, respectively.

The highest K content (48.30 g kg^{-1}) was found when using BM at OMR of 40%, and the lowest (32.50 g kg^{-1}) when using SS at OMR of 40%. The soil K contents when using BM at OMR of 40%, and SS at OMR of 40% were 652.0, and 119.0 mg dm^{-3}, respectively.

According to Pitta et al. (2012) the nutrient release rate was highest during the first 60 days of decomposition and after 150 days of litter incubation in the field, 54, 51, 100, and 52 % of N, P, K and Ca had become available to the soil, and also reported the residual effects of and nutrient release from organic matter source decomposition can last longer than a year.

The highest Ca content (10.60 g kg^{-1}) was found when using SS at OMR of 20%, and the lowest (2.90 g kg^{-1}) when using PL at OMR of 40%. The soil Ca contents when using SS at OMR of 20%, and PL at OMR of 40% were 3.20, and 1.44 cmol$_c$ dm^{-3}, respectively. Calcium concentration increases with age as a high proportion in the plant tissue is located in the cell walls (Marschner, 1995). The highest Mg content (5.10 g kg^{-1}) was found when using SM, and SS at OMR of 20%, and the lowest (2.90 g kg^{-1}) when using SS at OMR of 40%. The soil Mg contents when using SM, and SS at OMR of 20%, and SS at OMR of 40% were 1.14, 0.94, and 0.83 cmol$_c$ dm^{-3}, respectively.

The highest S content (3.40 g kg^{-1}) were found when using SS at OMR of 20%, and the lowest (2.90 g kg^{-1}) when using SM at OMR of 40% (Table 3). The soil S contents when using SS at OMR of 20%, and SM at OMR of 40% were 101.2, and 116.8 mg dm^{-3}, respectively.

The isolated effects of OMS and OMR, and their interaction were significant for the micronutrients Fe, Mn, Cu, Zn, and B (Table 4).

Table 4. ANAVA to evaluate the significance of the sources of variation of micronutrient contents in millet leaves

SV	DF	Mean square[1]				
		Fe	Mn	Cu	Zn	B
OMS	3	111356.87**	198755.01**	128.05**	5739.03**	1438.21**
PMO	1	18542.57**	26450.00**	16.68**	378.13**	19.22**
OMS × OMR	3	34237.16**	26537.76**	88.18**	1289.58**	42.31**
Block	3	3673.25**	896.14**	6.68**	25.23**	4.94**
Residual	21	86.86	8.97	0.24	1.83	0.14
CV (%)		2.10	1.35	2.47	2.17	1.90

Note. [1] Source of variation (SV); degree of freedom (DF); organic matter source (OMS); organic matter rate (OMR); coefficient of variation (CV); * significant at 5% by the F test; ** significant at 1% by the F test and [ns] not significant at 5% by the F test.

The OMR affected the leaf Fe contents of plants, regardless the OMS used; plants in soils with the OMR of 20% had higher Fe contents when using PL, and BM, when compared to the OMR of 40% (Table 5). The highest Fe contents with the OMR of 20% were found in plants in soils with BM, and the lowest with PL. The highest Fe contents with the OMR of 40% were found in plants in soils with SM, and the lowest with PL.

Table 5. Significance of the interaction between organic matter sources (OMS) and organic matter rates (OMR) for micronutrients in millet leaves

OMR (%)	OMS			
	PL	SM	BM	SS
Fe (mg kg⁻¹)				
20	314.63aD	368.80bC	543.93aA	454.33bB
40	227.83bD	576.20aA	518.73bC	551.50aB
Mn (mg kg⁻¹)				
20	311.80aB	98.70bD	109.80aC	483.50aA
40	108.10bC	173.20aB	80.70bD	411.80bA
Cu (mg kg⁻¹)				
20	31.20aA	14.70bD	17.40bC	20.00bB
40	20.03bA	18.50aB	18.20aB	20.80aA
Zn (mg kg⁻¹)				
20	63.90aC	67.40aB	27.20bD	77.40bA
40	53.40bB	53.10bB	38.50aC	118.40aA
B (mg kg⁻¹)				
20	42.80aA	10.50bD	12.50aC	12.50bB
40	37.00bA	15.10aB	11.70bD	16.70aC

Note. [1] Means followed by the same lowercase letter in the columns and uppercase letter in the rows do not differ by the Tukey's test at 5% probability. Organic matter source (OMS); organic matter rate (OMR); poultry litter (PL); swine manure (SM); bovine manure (BM); sewage sludge (SS); 20 = 20% of organic matter; 40 = 40% of organic matter.

The results for the effect of OMR on Mn contents were similar to those found for Fe, in all OMS (Table 5). Plants in soils with SS had the highest Mn contents, regardless the OMR used, and plants in soils with SM at OMR of 20%, and BM at OMR of 40% had the lowest.

The OMR affected Cu contents of plants, regardless the OMS used. Only the plants in soil with PL had the highest leaf Cu contents with the OMR of 20%. The highest leaf Cu contents with the OMR of 20% was found in plants in soils with PL, and the lowest with SM. The highest leaf Cu contents with the OMR of 40% was found in plants in soils with PL, and SS, and the lowest with SM, and BM.

The OMR affected the leaf Zn contents of plants, regardless the OMS used. The highest Zn contents were found in plants in soils with PL, and SM at OMR of 20%. The highest Zn contents with the OMR of 20% and 40% were found in plants in soils with SS, and the lowest with BM.

The OMR affected the leaf B contents of plants, regardless the OMS used. The highest B contents were found in plants in soils with PL, and BM at OMR of 20% (Table 5). The highest B contents with the OMR of 20% and 40% were found in plants in soils with PL, and the lowest with SM (20%), and BM (40%).

Teixeira et al. (2008) evaluated content and accumulation of micronutrients in millet, jack bean, pigeon pea, and gramineous intercropped with legumes, and found the following results for millet plants: Fe (643.97 mg kg⁻¹), Mn (101.93 mg kg⁻¹), Cu (9.80 mg kg⁻¹), Zn (98.13 mg kg⁻¹) and B (11.70 mg kg⁻¹). The highest Fe contents in the present work (576 mg kg⁻¹) was found for SM at OMR of 40%, and the lowest (227.83 mg kg⁻¹) for PL at OMR of 40% (Table 5). These Fe contents were lower than those found by Teixeira et al. (2008). The soil Fe contents with SM at OMR of 40%, and PL at OMR of 40% were 12.07, and 8.66 mg dm⁻³, respectively.

The highest Mn contents (483 mg kg⁻¹) was found when using SS at OMR of 20%, and the lowest (80.70 mg kg⁻¹) when using BM at OMR of 40%. The highest Mn contents found were well above those found by Teixeira et al. (2008). The soil Mn contents when using SS at OMR of 20%, and BM at OMR of 40% were 96.20, and 110.07 mg dm⁻³, respectively. The highest Cu contents (31.20 mg kg⁻¹) were found in plants in soils with PL at OMR of 20% and the lowest (14.70 mg kg⁻¹) with SM at OMR of 20%. These results were above those found by Teixeira et al. (2008). The soil Cu contents when using PL at OMR of 20%, and SM at OMR of 20% were 8.17, and 5.59 mg dm⁻³, respectively.

The highest Zn content (118.40 mg kg^{-1}) was found when using SS at OMR of 40%, and the lowest (27.20 mg kg^{-1}) when using BM at 20 % (Table 5). The lowest Zn found is well below that found by Teixeira et al. (2008). The soil Zn contents when using SS at OMR of 40%, and BM at OMR of 20% were 21.01, and 5.75 mg dm^{-3}, respectively. The highest B content (42.80 mg kg^{-1}) was found when using PL at OMR of 20%, and the lowest (11.70 mg kg^{-1}) when using BM at OMR of 40% (Table 5). The lowest B content was similar to that found by Teixeira et al. (2008). The soil B contents when using PL at OMR of 20%, and BM at OMR of 40% were 1.94, and 0.31 mg dm^{-3}, respectively.

4. Conclusion

All macro and micronutrient contents in the millet leaves, and biometric parameters of the millet panicle were affected by the organic matter sources, organic matter rates, and the interaction between them.

Plants grown in soils with poultry litter, and swine manure had the highest macronutrient contents. The leaf tissue of millet plants grown in soils with sewage sludge had the highest micronutrient contents. Macronutrient and micronutrient contents, and biometric parameters of the millet panicles were better when the millet plants were grown in soils with an organic matter rate of 20%.

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