

## Effects of composted swine manure on nutrient content in grains of *Panicum miliaceum* L.

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### Abstract

The aim of this work was to evaluate the effect of different doses of composted swine manure on protein and macronutrient contents of proso millet grains and in nutrient export by the crop. The experiment was carried out in the years 2013 and 2014 in a randomized block design, with four replications and five treatments, composed of four doses of composted swine manure (0, 4.0, 8.0 and 12.0 Mg ha<sup>-1</sup>) and one dose of mineral fertilization (NPK 100-60-40 kg ha<sup>-1</sup>). Compost and mineral fertilizers were applied manually in each plot after the sowing of the crop, according to the established doses. After the harvesting, grain samples were taken to determine protein, N, P, K, Ca, Mg and S contents, as well as the amount of macronutrients exported by the crop. The data were submitted to analysis of variance. The means of the variables related to the compost doses were compared to the control plot (absence of fertilization) and to the mineral fertilization plot using the Tukey' test ( $P \leq 0.05$ ), and the effects of CSM doses were assessed by regression analysis, adopting as selection criteria the model and the magnitude of the regression coefficients at 5% of significance. The export of nutrients from the field by *P. miliaceum* grains at the dose of 4.0 Mg ha<sup>-1</sup> of compost was equal to the mineral fertilization recommended for the crop, justifying the use of swine manure as a substitute for mineral fertilization. The use of compost provides protein content in *P. miliaceum* grains similar to the use of mineral fertilizer.

**Keywords:** organic fertilizer, proso millet, pig slurry, composting, nutrient export, macronutrients.

**Abbreviations:** CSM\_composted swine manure; NPK\_nitrogen phosphorus potassium; ASL\_above sea level.

### Introduction

Proso millet (*Panicum miliaceum* L.) is a short cycle grass (Lu et al., 2009) native to East Asia (Bettinger et al., 2007) and well adapted to warm climates (Baltensperger et al., 1995; Berglund, 2007). The grass has emerged as an alternative to crop rotation under no-tillage system in the USA (Habiyaemye et al., 2017), where it is grown mainly in the spring. Though still sparsely cultivated in Brazil, *P. miliaceum* has attracted the attention of growers as an alternative for wheat cultivation during the winter, since its short cycle allows the subsequent sowing of soybean within its optimum sowing window (Basso et al., 2015). The crop presents low production costs and high straw formation rate, one of the basic premises in the no-tillage system (Basso et al., 2015; Muraro et al., 2016). Proso millet grains can be used to feed poultry (Guglieri et al., 2004) and

produce beer (Zarnkow et al., 2010) and ethanol (Rose and Santra, 2013).

The use of swine waste as a nutritional source for agricultural crops has gradually increased in recent years (Meade et al., 2011) due to the resulting improvement in the chemical properties of the soil (Brito et al., 2005; Oliveira et al., 2014) and the lack of alternatives for the disposal of liquid swine waste in Brazil (Makara and Kowalsky, 2015; De Conti et al., 2016). Among the chemical elements typically present in swine waste, nitrogen (N) stands out in importance, since it is directly related to the grain yield of most crops and is usually required in large quantities (El-Shaarawi et al., 2011). Composted swine manure (CSM) is obtained from the mixture of liquid swine manure (LSM) and sawdust substrate, resulting in an organic fertilizer with high dry matter content (53%) and N in organic form. The

mineralization of organic N occurs slowly and gradually, increasing the synchronism between demand and availability of N to the crops (Barrena et al., 2011) and avoiding environmental problems related to nitrogen loss (Prapasongsa et al., 2010), such as eutrophication (Vitousek et al., 2009; MacDonald et al., 2011) and enhanced emission of NH<sub>3</sub>, CO<sub>2</sub> and N<sub>2</sub>O to the atmosphere (Thu et al., 2012). Therefore, CSM efficiency as a source of N to the plants is higher than that provided by liquid waste (Barrena et al., 2011) and even by mineral fertilizers (Sieling et al., 2014). The use of CSM as fertilizer to *P. miliaceum* plants is known to increase dry mass production, number of grains per plant and grain yield (Silva et al., 2016), but there is scarcity of data concerning the effects CSM on grain composition and nutrient export in proso millet and other crops. Seidel et al. (2010) and Alves et al. (2017) evaluated the contents of N, P and K in maize leaves and grains, respectively, and observed no difference between organic and mineral fertilizers. Silva et al. (2015), on the other hand, verified that the use of swine manure resulted in significant increases in protein, N, P, Ca and Mg levels in *Brachiaria decumbens* plants. Abrantes et al. (2011) found that the moment of nitrogen application did not affect significantly the export of macronutrients by proso millet grains, though variations were observed in the N, P, K, Ca, Mg and S export levels according to the dose of N used. The controversy observed between the existing data, therefore, justifies further studies on the subject.

The aim of this work was to evaluate the effect of different doses of composted swine manure (CSM) on protein and macronutrient contents of proso millet grains and in nutrient export by the crop.

## Results and Discussion

### Nutrient content in the grains

Protein and nitrogen contents in *P. miliaceum* grains varied according to the treatments used (Table 1), but no significant difference was observed for protein (Figure 1) and nitrogen (Figures 2A and 2B) content in the two cropping seasons, in relation to the different CSM doses supplied to the crop. Similar results were obtained by Abrantes et al. (2011) and Muraro et al. (2016), who also did not observe significant differences in the protein content of proso millet grains when using different doses of inorganic-release nitrogen. According to Kelling and Fixen (1992), when the demand of N for plant growth and grain production is satisfied, further additions of N are directed by the plant to increase the protein content of the grains. In this sense, it is possible that the doses of N provided to the crop (both in organic and inorganic form) did not exceed the minimum levels required for plant growth and development, since protein content in the grains from the control plots (absence of fertilization) was statistically similar to the treatments with mineral fertilization and with the highest dose of CSM (Table 1, Figure 1).

Phosphorus content in the proso millet grains varied among the treatments. In the first year, the treatment without fertilization (control) presented data statistically similar to the treatments with 4 and 8 t ha<sup>-1</sup> of CSM, and these differed only from the treatments with 12 t ha<sup>-1</sup> of CSM and with mineral fertilization (NPK). Similarly, the control treatment did not differ from any other treatment in the second year,

indicating that the accumulation of phosphorus in the grains was not influenced by the phosphorus supplied to the crop (Table 1).

Potassium content in the proso millet grains was also not influenced by fertilization in the first year, since the highest potassium content was observed in the treatment without fertilization (control). In the second year, however, the highest potassium content was observed when the crop received mineral fertilization (NPK), even though the CSM fertilizer contained potassium in a much larger concentration than that provided by mineral fertilization. No statistical difference was observed in the second year among the treatments with 0, 4 and 12 t ha<sup>-1</sup> of CSM, all of which presented an intermediate level of potassium; the lower level was observed when 8 t ha<sup>-1</sup> of CSM were supplied to the crop (Table 1).

Calcium content in the proso millet grains was not significantly influenced by the fertilizing treatments. In the 2013 cropping season, magnesium levels were higher in the treatment without fertilization and with 4 t ha<sup>-1</sup> of CSM, while in 2014 the treatment with 8 t ha<sup>-1</sup> of CSM differed only from the treatments without fertilization (control) and with mineral fertilization (NPK). Sulfur content in the grains varied considerably among the treatments in 2013, with the highest levels observed in the treatments without fertilization (control), with mineral fertilization (NPK) and with 4 t ha<sup>-1</sup> of CSM; in 2014, however, there was no significant difference among the treatments (Table 1).

The comparison of nutrient levels from the first year indicates that phosphorus, potassium, magnesium and sulphur contents in the proso millet grains were linearly reduced by increased doses of CSM, while nitrogen and calcium levels were not significantly affected (Figure 2A). In 2014, on the other hand, there was no influence of the CSM doses in the nitrogen, phosphorus, potassium, calcium, magnesium and sulphur levels of the proso millet grains (Figure 2B).

### Nutrient export by the crop

Nitrogen export by *P. miliaceum* grains in the two cropping seasons was not significantly influenced by N supply, either through CSM or mineral fertilization (Table 2). However, evaluation of export values according to the CSM doses revealed an increasing line until the calculated doses of 8.9 and 11.3 t ha<sup>-1</sup> of CSM for the years 2013 and 2014, respectively, with a reduction in export values above these doses (Figures 3A and 3B).

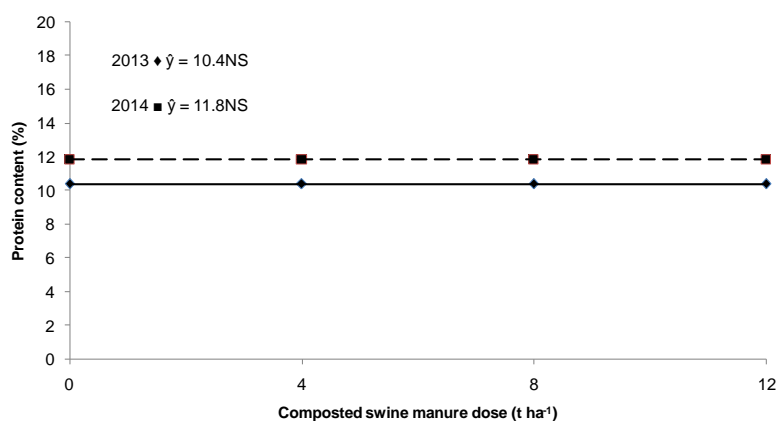
Phosphorus export by proso millet grains varied significantly among the treatments. The highest export values were obtained in the treatments with 4 and 8 t ha<sup>-1</sup> of CSM, in the first year, and with 12 t ha<sup>-1</sup> of CSM and mineral fertilization, in the second year (Table 2). The effect of the CSM doses in 2013 displayed a quadratic behaviour (with the highest export provided by the calculated dose of 5.8 t ha<sup>-1</sup>), while in 2014 there was a linear increase on exported phosphorus levels according to the CSM doses (Figures 3A and 3B).

The amount of potassium exported in the first year was higher in the treatment that received 8 t ha<sup>-1</sup> of CSM, differing from all other treatments except 4 t ha<sup>-1</sup> of CSM. In the second year, however, the application of 8 t ha<sup>-1</sup> of CSM resulted in the lowest export level, differing significantly only from the treatment with mineral fertilization (Table 2).

**Table 1.** Protein, nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulphur (S) contents in *P. miliaceum* grains in relation to composted swine manure (CSM) and mineral fertilization (NPK) doses. Cropping seasons 2013 and 2014.

Treatment (fertilizer dose)	Protein (%)	g kg <sup>-1</sup>					
		N	P	K	Ca	Mg	S
2013							
0	10.9 ab*	17.5 ab	3.3 a	4.8 a	1.6 a	0.8 a	2.5 a
4 t ha <sup>-1</sup> (CSM)	9.9 b	15.9 b	3.4 a	4.4 a	1.5 a	0.9 a	2.0 ab
8 t ha <sup>-1</sup> (CSM)	10.2 ab	16.4 ab	3.2 a	4.7 a	1.9 a	0.5 b	1.6 bc
12 t ha <sup>-1</sup> (CSM)	10.5 ab	16.7 ab	1.8 b	3.4 b	2.0 a	0.3 b	1.2 c
100-60-40 kg ha <sup>-1</sup> (NPK)	11.6 a	18.5 a	2.0 b	4.0 ab	1.7 a	0.3 b	2.6 a
CV (%)	5.9	5.8	17.7	10.1	19.2	29.9	14.8
2014							
0	12.1 ab	19.5 ab	3.0 abc	4.9 b	1.6 a	0.9 a	2.5 a
4 t ha <sup>-1</sup> (CSM)	11.2 b	18.0 b	2.1 bc	3.9 b	1.8 a	0.7 ab	1.8 a
8 t ha <sup>-1</sup> (CSM)	12.7 a	20.3 a	1.6 c	2.1 c	2.0 a	0.3 b	2.0 a
12 t ha <sup>-1</sup> (CSM)	11.3 b	18.2 b	3.6 a	4.4 b	2.0 a	0.7 ab	1.7 a
100-60-40 kg ha <sup>-1</sup> (NPK)	13.1 a	21.0 a	3.3 ab	6.4 a	1.8 a	1.2 a	2.1 a
CV (%)	4.8	4.8	23.2	14.5	12.9	31.8	19.5

\*Means followed by the same lowercase letter in the column do not differ among themselves by the Tukey test (P≤0.05).

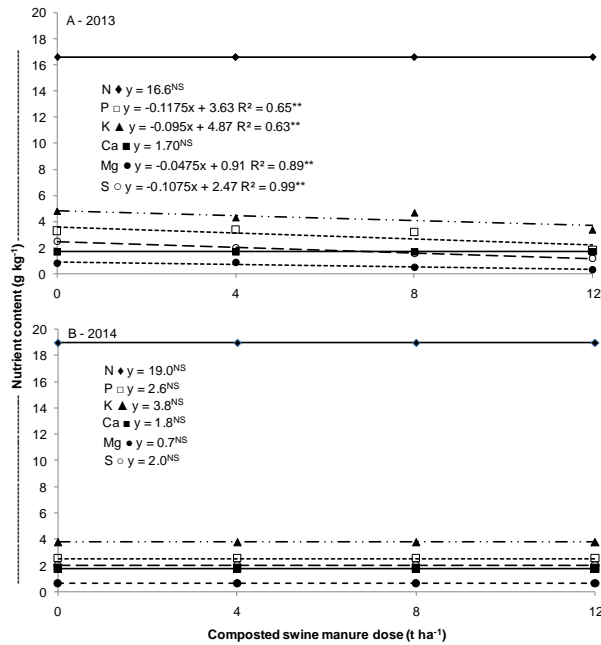


**Fig 1.** Protein content in *P. miliaceum* grains (%) in relation to composted swine manure (CSM) doses (t ha<sup>-1</sup>). Cropping seasons 2013 and 2014.

**Table 2.** Nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulphur (S) amounts exported by *P. miliaceum* grains in relation to composted swine manure (CSM) and mineral fertilization (NPK) doses. Cropping seasons 2013 and 2014.

Treatment (fertilizer dose)	kg ha <sup>-1</sup>					
	N	P	K	Ca	Mg	S
2013						
0	38.5 b*	7.2 bc	10.7 b	3.5 b	2.0 ab	5.5 a
4 t ha <sup>-1</sup> (CSM)	44.7 ab	9.7 ab	12.2 ab	4.7 ab	2.7 a	5.5 a
8 t ha <sup>-1</sup> (CSM)	62.5 a	12.2 a	18.0 a	7.2 a	1.7 abc	5.7 a
12 t ha <sup>-1</sup> (CSM)	52.7 ab	5.5 c	11.0 b	6.5 ab	1.0 bc	3.7 a
100-60-40 kg ha <sup>-1</sup> (NPK)	44.2 ab	4.7 c	9.2 b	4.0 ab	0.7 c	6.2 a
CV (%)	19.6	23.1	21.5	30.4	32.3	24.7
2014						
0	20.8 b	3.2 b	5.2 ab	1.7 b	1.0 a	2.7 a
4 t ha <sup>-1</sup> (CSM)	27.7 ab	3.5 b	6.0 ab	3.0 ab	1.2 a	3.2 a
8 t ha <sup>-1</sup> (CSM)	38.3 a	3.2 b	4.5 b	4.0 a	0.75 a	3.7 a
12 t ha <sup>-1</sup> (CSM)	36.5 a	7.0 a	8.7 ab	4.0 a	1.5 a	3.5 a
100-60-40 kg ha <sup>-1</sup> (NPK)	30.7 ab	5.2 ab	9.7 a	3.0 ab	1.7 a	3.5 a
CV (%)	19.2	34.4	32.3	24.2	55.6	32.9

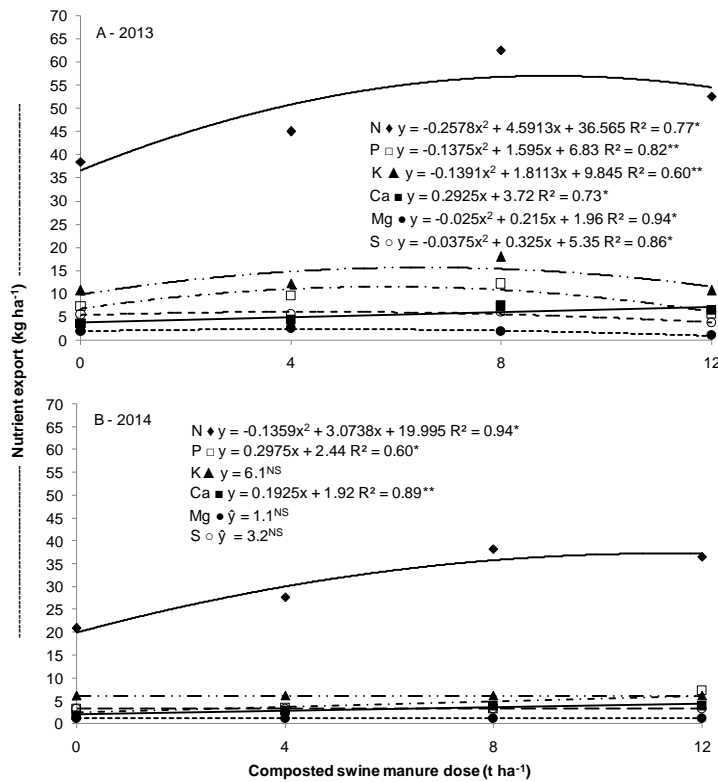
\*Means followed by the same lowercase letter in the column do not differ among themselves by the Tukey test (P≤0.05).



**Fig 2.** Nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulphur (S) contents in *P. miliaceum* grains ( $g\ kg^{-1}$ ) in relation to composted swine manure (CSM) doses ( $t\ ha^{-1}$ ). Cropping seasons 2013 and 2014.

**Table 3.** Chemical characteristics of the composted swine manure (CSM) in each of the doses used.

	N	P	K	Ca	Mg
	$g\ kg^{-1}$				
	29.4	4	24.7	17.8	5.6
Mg $ha^{-1}$	$kg\ ha^{-1}$ added				
4	117.6	16	98.8	71.2	22.4
8	235.2	32	197.6	142.4	44.8
12	352.8	48	296.4	213.6	67.2



**3.** Nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulphur (S) amounts exported by *P. miliaceum* grains ( $kg\ ha^{-1}$ ) in relation to composted swine manure (CSM) doses ( $t\ ha^{-1}$ ). Cropping seasons 2013 and 2014.

Regarding the effect of CSM doses, the amount of potassium exported in 2013 increased until the calculated dose of 6.5 t ha<sup>-1</sup>, while in 2014 there was an initial decrease followed by an increase (Figures 3A and 3B).

Export levels for calcium in 2013 differed only between the application of 8 t ha<sup>-1</sup> of CSM and the control treatment, which presented the lowest value. In 2014, the only significant difference was between the control and the applications of 8 and 12 t ha<sup>-1</sup> of CSM (Table 2). The export of this nutrient by proso millet grains increased with higher doses of CSM in the two cropping seasons (Figures 3A and 3B).

The amount of magnesium exported in 2013 varied significantly among the treatments with 4 t ha<sup>-1</sup> of CSM, 12 t ha<sup>-1</sup> of CSM and mineral fertilization. In 2014, on the other hand, no difference was observed among the treatments (Table 2). Regarding the effect of CSM doses, there was a quadratic increase in magnesium export in 2013 (with a maximum value provided by the calculated dose of 4.3 t ha<sup>-1</sup>), while in 2014 no significant difference was observed (Figures 3A and 3B). The same quadratic behaviour and maximum point were found for the sulphur content in proso millet grains, whose exported amounts in the two years were not statistically influenced by the treatments (Table 2).

### **Implications on fertilization programs**

Phosphorus, potassium and sulphur contents in the proso millet grains and export values for N, P, K, Ca, Mg and S were overall higher than those observed by Abrantes et al. (2011) in the same cultivar, while protein, nitrogen, calcium and magnesium contents in the grains were similar. The protein content found was also similar to the values observed by Kalinova and Moudry (2006) in different cultivars of *P. miliaceum*.

Fertilization with CSM provided export values for N, P, K, Ca, Mg and S equal or higher than those obtained with mineral fertilization (NPK), indicating that composted swine manure can be as efficient as mineral fertilization in the supply and export of nutrients in the proso millet crop. Alves et al. (2017) also did not find significant differences between the use of swine manure and mineral fertilizer for the accumulation of N, P and K in maize grains.

Regardless of the treatment used, nutrient export values followed the order N > K > P > S > Ca > Mg, differing from Abrantes et al. (N > P > Ca > S > K > Mg) in their evaluation of doses and moments of N supply to *P. miliaceum*. This result indicates that export order is influenced by the amount of nutrients supplied to the crop as well as its availability in the soil, since the experimental area used by the aforementioned authors presented lower availability of nutrients than the soil of this experiment. Teruel and Smiderle (1999) also state that differences in plant species, crop varieties and amounts of nutrients in the soil or supplied through fertilization can cause divergence between the results.

Regarding the effect of different CSM doses, nutrient export responses varied considerably among macronutrients, and the responses observed in the first cropping season were not maintained in the second; for some nutrients the doses were not significant, and for others increased doses resulted in lower concentration in the grains. Animal waste is known to present an exceptionally variable chemical composition, with certain nutrients in disproportionate amounts to the plants' needs; mineral fertilizers, on the other hand, are

formulated according to soil and crop conditions, and these characteristics certainly influenced the large variation in export responses among the macronutrients in the two agricultural years.

The yield of agricultural crops is directly related to the balance of elements available in the soil, since both insufficient and excessive amounts are detrimental to the growth and development of the plants. This relation was discussed by Voisin (1965), who stated that insufficiency (law of the minimum) or excess (law of the maximum) of a nutrient element in the soil reduces the efficiency of the others and decreases the yield of crops in general. The use of composted swine manure, therefore, requires particular attention on the physical and chemical properties of the soil and the extraction capacity of the plants, in order to avoid imbalance of nutrients and its detrimental effects on grain yield of proso millet and other crops.

## **Materials and Methods**

### **Experimental site**

The experiment was carried out during the years 2013 and 2014, in the experimental area of the Federal University of Santa Maria, campus of Frederico Westphalen - RS (27°23'59" S, 53°25'16" W, 566 meters a.s.l.). The climate of the site is defined as subtropical humid (Cfa) according to Köppen's classification (Alvares et al., 2013). The soil of the site is classified as Typical Distrophic Red Latosol, with medium clayey texture (EMBRAPA, 2013). A chemical analysis of the soil was carried out, in which the following chemical characteristics were observed in the 0-20 cm depth layer: pH (in water) = 4.6; SMP index = 5.1; clay content = 650 g kg<sup>-1</sup>; organic matter content = 2.7 g kg<sup>-1</sup>; phosphorus (Mehlich extractor) = 7.2 mg dm<sup>-3</sup>; potassium = 137 mg dm<sup>-3</sup>; calcium = 2.1 cmol<sub>c</sub>dm<sup>-3</sup>; magnesium = 1.2 cmol<sub>c</sub>dm<sup>-3</sup>; hydrogen + aluminum = 8.0 cmol<sub>c</sub>dm<sup>-3</sup>; aluminium = 2.1 cmol<sub>c</sub>dm<sup>-3</sup>; cation exchange capacity (CTC) = 11.6 cmol<sub>c</sub>dm<sup>-3</sup>; saturation by bases = 31.3%; saturation by aluminum = 36, 5%. Six months prior to the experiment setting, limestone was applied to raise the pH of the soil to 6.0, following the recommendation from the Commission for Soil Chemistry and Fertility (CQFS-RS/SC, 2004).

### **Plant material**

Cultivation of *P. miliaceum* was carried out under no-tillage system. In both years, soybean crop (*Glycine max*) preceded the cultivation of proso millet, with the area left fallow after soybean harvest for a period of three months. Prior to sowing the area was sprayed with glyphosate (3 L ha<sup>-1</sup> of commercial product). Sowing was carried out on September 14<sup>th</sup> (2013) and August 22<sup>th</sup> (2014), using the cultivar AL Tibagi, spaced 0.45 m between rows and with a density of 120 seeds m<sup>-2</sup>. Plant emergence occurred at 10 days after sowing for both years, with the cycle duration being 87 and 93 days for the years 2013 and 2014, respectively.

### **Composted swine manure**

Composted swine manure (CSM) is obtained from the mixture of liquid swine manure (LSM) and sawdust substrate with a high C/N ratio, resulting in a dry, solid organic fertilizer. The mixture is constantly revolved to promote water evaporation from animals' urine and feces (Fukumoto

et al., 2011). The manure/substrate ratio must be equal or higher than 8:1, to increase the concentration of manure nutrients and reduce the volume of waste generated. The compost used in both experimental years was obtained in the city of Concordia - SC, Brazil, where the liquid waste resulted from pig farming activity is treated and converted into CSM, according to the process described above. A sample of the compost was sent to laboratory for chemical analysis and macronutrient quantification, in which the following chemical characteristics were observed: N = 29.4 g kg<sup>-1</sup>; P = 4 g kg<sup>-1</sup>; K = 24.7 g kg<sup>-1</sup>; Ca = 17.8 g kg<sup>-1</sup>; Mg = 5.6 g kg<sup>-1</sup> (Table 3). The amount of nutrients added per hectare, according to each dose of compost, are also shown in Table 3.

#### **Experimental design and treatments evaluated**

The experimental design was a randomized block design, with five treatments and four replicates, and an area of 14.4 m<sup>2</sup> per plot (4.0 x 3.6 m). The treatments were comprised of four composted swine manure (CSM) doses (0, 4.0, 8.0 and 12.0 Mg ha<sup>-1</sup>) and one dose of mineral fertilization NPK (100-60-40 kg ha<sup>-1</sup>), using as minerals sources urea (100 kg ha<sup>-1</sup> of N), single superphosphate (60 kg ha<sup>-1</sup> of P<sub>2</sub>O<sub>5</sub>) and potassium chloride (40 kg ha<sup>-1</sup> of K<sub>2</sub>O). Compost and mineral fertilizers were applied manually in each plot after the sowing of the crop, according to the established doses.

#### **Traits measured**

After harvesting, grain samples (100 g) were taken to a forced air oven (60 °C, 72 hours), grounded and submitted to chemical analysis. Crude protein content was determined by multiplying the total N value by the 6.25 factor (AOAC, 1995), and the levels of N, P, K, Ca, Mg and S were quantified following the methodology described by Malavolta et al. (1997). The amounts of macronutrients exported by the crop (i.e. nutrient removal per hectare) were calculated by multiplying the nutrient contents in the grains (g kg<sup>-1</sup>) by the grain yield (dry basis) of the crop (kg ha<sup>-1</sup>), with subsequent conversion of the values to kg ha<sup>-1</sup>.

#### **Statistical analysis**

The data were submitted to analysis of variance. The means of the variables related to the CSM doses were compared to the control plot (absence of fertilization) and to the mineral fertilization plot using the Tukey' test (P≤0.05), and the effects of CSM doses were assessed by regression analysis, adopting as selection criteria the model and the magnitude of the regression coefficients at 5% of significance. The software Genes® (Cruz, 2013) was used for the statistical analyses.

#### **Conclusion**

Composted swine manure at a dose of 4.0 Mg ha<sup>-1</sup> provides an export of nutrients by *P. miliaceum* grains equal to the obtained with the recommended mineral fertilization for the crop, and can replace mineral fertilization in soil conditions similar to those used in this study. The use of composted swine manure as fertilizer provides protein content in *P. miliaceum* grains similar to the obtained with the use of mineral fertilization.

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