Comissão 3.2 - Corretivos e fertilizantes

CROP RESPONSE TO ORGANIC FERTILIZATION WITH SUPPLEMENTARY MINERAL NITROGEN[1]

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SUMMARY

Animal manure is applied to the soil as a nutrient source, especially of nitrogen, to plants. However, manure application rates can be reduced with the use of N fertilizer in topdressing. The aim of this study was to evaluate crop responses to different application rates of animal manure sources, used alone and supplemented with mineral N topdressing, in a no-tillage system. The study was carried out from 2005 to 2008 on a Hapludalf soil. The treatments consisted of rates of 10, 20 and 30 m^3 ha^{-1} of pig slurry (PS), and of 1 and 2 t ha^{-1} of turkey manure (TM), applied alone and supplemented with topdressed N fertilizer (TNF), as well as two controls, mineral fertilization (NPK) and one control without fertilizer application. Grain yield in common bean and maize, and dry matter yield and nutrient accumulation in common bean, maize and black oat crops were evaluated. Nitrogen application in topdressing in maize and common bean, especially when PS was used at rates of 20 and 30 m^3 ha^{-1}, and TM, at 2 t ha^{-1}, proved effective in increasing the crop grain yields, showing the viability of the combined use of organic and industrialized mineral sources. Nitrogen accumulation in maize and common bean tissues was the indicator most strongly related to grain yield, in contrast with the apparent nutrient recovery, which was not related to the N, P and K quantities applied in the organic sources. No clear residual effect of N topdressing of maize and common bean was observed

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on the dry matter yield of black oat grown in succession to the main crops with PS and TM applications.

Index terms: animal manure, crop rotation, no-tillage cropping system.

RESUMO: *RESPOSTA DE CULTURAS À ADUBAÇÃO ORGÂNICA COM COMPLEMENTAÇÃO DE NITROGÊNIO MINERAL*

Os dejetos de animais são aplicados no solo como fonte de nutrientes, especialmente nitrogênio, às plantas. Entretanto, as doses dos dejetos podem ser diminuídas com a aplicação de fertilizante nitrogenado em cobertura. Este trabalho objetivou avaliar a resposta de culturas à aplicação de diferentes doses de fontes de dejetos de animais, utilizadas de maneira isolada e complementadas com N mineral em cobertura, sob sistema plantio direto. O trabalho foi realizado no período de 2005 a 2008, sob um Argissolo Vermelho distrófico arênico. Os tratamentos foram: doses de 10, 20 e 30 m^3 ha^{-1} de dejeto líquido de suínos (DLS) e 1 e 2 t ha^{-1} de dejeto de peru (DP), aplicadas isoladamente e complementadas com adubação nitrogenada em cobertura (ANC), além de dois controles, adubação mineral (NPK) e testemunha, sem aplicação. Foram avaliadas a produtividade de grãos, nas culturas do feijoeiro e milho; a produção de matéria seca; e o acúmulo de nutrientes, nas culturas do feijoeiro, milho e aveia-preta. A aplicação de N em cobertura nas culturas de milho e feijoeiro, especialmente, quando foram utilizados DLS, nas doses de 20 e 30 m^3 ha^{-1}, e DP, na dose de 2 t ha^{-1}, se apresentou eficiente no aumento da produtividade de grãos das culturas, demonstrando a viabilidade do uso associado de fontes orgânicas e minerais industrializadas. O acúmulo de N no tecido das culturas de milho e feijoeiro foi o indicador que mais se relacionou com a produtividade de grãos, ao contrário da recuperação aparente de nutrientes que não apresentou relação com as quantidades aplicadas de N, P e K das fontes orgânicas. A aplicação de N em cobertura no milho e no feijoeiro, cultivados com a aplicação de DLS e DP, não evidenciou claramente efeito residual na produção de matéria seca de aveia, cultivada em sucessão.

Termo de indexação: resíduos animais, rotação de culturas, sistema plantio direto.

INTRODUCTION

Crop and livestock production are of great economic and social importance in the South of Brazil, especially on small rural properties. This region is responsible for 54 % of domestic pork production (ABIPECS, 2011) and 77 % of turkey production (Silva, 2008). The normally used livestock production system is the confinement of the animals, which generates a large amount of manure. As the manure has high nutrient quantities in its composition, producers often apply the manure on the soil as a nutrient source for plants, especially the nutrients N, P and K (Adeli et al., 2008; Scherer et al., 2010; Lourenzi et al., 2013). This is a way of disposing of the waste and making nutrient cycling as well as savings with industrial fertilizers possible.

The application of pig slurry (PS) represents the addition of nutrients readily available to plants because this waste has a low dry matter content (Lourenzi et al., 2013) and low C/N ratio (Aita et al., 2006a), which facilitates decomposition and reduces the immobilization rate of nutrients, such as N, by soil microorganisms. In contrast, for the solid waste sources applied to the soil, such as turkey manure (TM), there may be immobilization of N by soil microorganisms, depending on the C/N ratio (>30) of these sources. There may thus be a reduction in the availability of N forms to plants in development stages with higher nutrient demands, which may decrease the quantity of N accumulated in the plants, resulting in lower grain yields or lower dry matter production in the aerial part of the crops (Giacomini & Aita, 2008).

In addition, N is one of the main constituents of PS, and approximately 50 % of its total amount is found in ammonia forms (NH_4^+-N and NH_3 -N) (Joshi et al., 1994; Aita et al., 2006a; Scherer et al., 2007). Thus, after manure application to the soil, part of the N is lost by ammonia volatilization (N-NH_3) (Basso et al., 2004) and part of it that remains on the soil can be nitrified to nitrate (NO_3^--N). In soils with manure application, nitrification rates vary from 0.98 to 1.53 kg ha^{-1} per day (Aita et al., 2006b) and all N in ammonia forms present in the waste may be nitrified in up to 10 days following application (Chantigny et al., 2001). This rapid transformation of N from ammonia forms to NO_3^--N considerably increases the content of this nutrient form in the soil (Loria & Sawyer, 2005), which may be transferred through runoff (Smith et al., 2001; Ceretta et al., 2010a) or through percolation (Daudén et al., 2004; Basso et al., 2005; Bergström & Kirchmann, 2006; Girotto et al., 2013), especially in soils with low organic matter content and a sandy-texture surface horizon.

Based on the foregoing, the use of industrialized N fertilizers in topdressing of crops may be a strategy for decreasing the application rates of animal manure and also for increasing synchronism between N release and uptake by plants, increasing biological activity and reducing the possibility of N transfer to surface and/or underground waters (Basso et al., 2005; Ceretta et al., 2010a; Girotto et al., 2013). In addition, the differences in the manure composition and plant requirements show that the use of organic sources associated with industrialized mineral nutrients may mean a more rational use of nutrient sources for plants. In a study evaluating different application PS rates in combination with N fertilization in topdressing, Cela et al. (2011) observed that the use of lower manure rates supplemented by mineral N in topdressing may promote large grain yields and a good residual effect of the nutrient in the soil for the subsequent crop. However, studies in this regard are still scarce in Brazil. Therefore, the aim of this study was to evaluate crop responses to different application rates of animal manure used separately and in combination with topdressing of mineral N in a no-tillage system.

MATERIAL AND METHODS

The experiment was carried out in the experimental area of the Soil Department of the Universidade Federal de Santa Maria (UFSM) (latitude 29º 45' S, longitude 53º 42' W and altitude of 95 m) in Santa Maria (RS), Brazil, in the physiographic region of the Central Lowlands of the State, from December 2005 to August 2008. The soil of the experimental area is an Hapludalf (Soil Survey Staff, 1999) with the following characteristics in the 0-20 cm layer prior to experiment: pH in water (1:1) 5.5; 15 g kg^{-1} organic matter; 34.6 and 88 mg dm^{-3} available P and exchangeable K, respectively (both extracted by Mehlich-1); 0.0, 3.8 and 1.3 $cmol_c$ dm^{-3} exchangeable Al, Ca and Mg, respectively (extracted by 1 mol L^{-1} KCl); 2.2 $cmol_c$ dm^{-3} H+Al; 5.4 $cmol_c$ dm^{-3} $CEC_{effective}$; 6.6 $cmol_c$ dm^{-3} $CEC_{pH7.0}$; and base saturation of 71 %. Mean temperature and rainfall in the experimental period are shown in figure 1.

A randomized block design with 12 treatments and four replications was used, with 5 × 4 m (or 20 m^2) plots. The treatments consisted of: T1 - without application (WA); T2 - 10 m^3 ha^{-1} of PS; T3 - 10 m^3 ha^{-1} of PS + topdressed nitrogen fertilization (TNF); T4 - 20 m^3 ha^{-1} of PS; T5 - 20 m^3 ha^{-1} of PS + TNF; T6 - 30 m^3 ha^{-1} of PS; T7 - 30 m^3 ha^{-1} of PS + TNF; T8 - 1 t ha^{-1} of turkey manure (TM); T9 - 1 t ha^{-1} of TM + TNF; T10 - 2 t ha^{-1} of TM; T11 - 2 t ha^{-1} of TM + TNF; T12 - mineral fertilization (NPK). The N application rate in topdressing and of NPK was established based on the recommendations proposed by CQFSRS/SC (2004). The manure and mineral fertilizer were broadcast over the soil surface before sowing each commercial crop (summer crop). Nitrogen was broadcast 20 days after plant emergence over common bean and maize when the plants had six fully developed leaves (CQFSRS/SC, 2004). The crops were planted in a succession of black bean (*Phaseolus vulgaris* L.) and black oat (*Avena strigosa* Schreb.) in the 2005/2006 growing season, and maize (*Zea mays* L.) and black oat in the 2006/2007 and 2007/2008 growing seasons. The manure characteristics are shown in table 1 and the quantities of N, P and K applied to each crop in table 2.

At full flowering of common bean and maize, five plants were collected per plot, and black oat plants were collected in a useful area of 0.25 m^2 per plot. The plant tissue of each crop was dried in an air circulation oven at 65 ºC to constant weight and then weighed for determination of dry matter (DM) per hectare. Part of the residue was ground and prepared for analysis of total N, P and K (Tedesco et al., 1995). At common bean and maize harvest, fully grown plants were collected in a 12 m^2 area per plot and, subsequently, the harvested grains weighed and corrected to 13 % moisture. Yield per hectare was then estimated.

Recovery of N, P and K by common bean and maize grown in the soil subjected to the application of manure with or without N topdressing was estimated by subtracting the amount of N, P and K accumulated in the plants grown in the soil of the WA treatment. With this method, it was assumed that the mineralization rate of N and P of the soil organic matter was not affected by N and P applied in manure and with the N and P in the mineral fertilizer. Therefore, this estimate was designated as "apparent" recovery of the N, P and K applied, as proposed by Mitchell & Teel (1977) (Equation 1):

$$RaN = \left[\frac{(NAPf - NAPsf)}{Naf} \right] \times 100 \quad (1)$$

where RaN is the apparent recovery of nutrients (N, P and K) by the crops in %, NPAf is the quantity of N, P and K accumulated in the crops in the treatments with the application of nutrients; NAPsf is the quantity of N, P and K accumulated by the crops in the treatment without the application of nutrients; and Naf is the quantity of N, P and K applied through the manure or mineral fertilizer.

The data of grain yield, dry matter production and nutrient accumulation in the aerial part (N, P and K) were subjected to analysis of variance, using the statistical analysis system Sisvar, version 4.0 (Ferreira, 2008). When analysis of variance was significant, the mean values of the treatments were compared by the Scott-Knott test at 5 %.

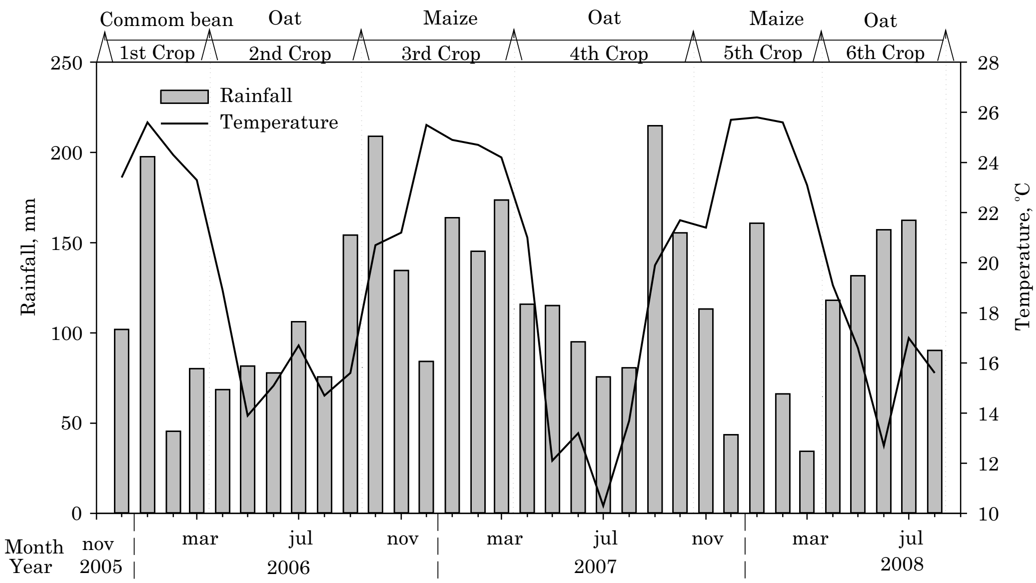

Figure 1. Mean values of temperature and rainfall in the experimental period.

Table 1. Characteristics of pig slurry and turkey manure applied in the 2005 to 2008 growing seasons

Growing season	Crop	Dry matter	N	P	K
		%			
			Pig slurry		
2005/06	Common bean	4.34	0.28(1)	11.11(2)	3.32(2)
2006/07	Maize	6.30	0.25	2.41	3.97
2007/08	Maize	1.92	0.17	5.78	7.79
			Turkey manure		
2005/06	Common bean	75	10.64(2)	3.17(2)	4.24(2)
2006/07	Maize	75	10.67	3.30	3.63
2007/08	Maize	75	11.01	3.39	3.63

(1) Analysis on a wet base; (2) Analysis on dry base.

Table 2. Nutrient amounts applied with pig slurry and turkey manure in the 2005 to 2008 growing seasons

Treatment	Common bean 2005/06			Maize 2006/07			Maize 2007/08		
	N	P	K	N	P	K	N	P	K
	kg ha^{-1}								
Without application	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10 m^3 ha^{-1} PS	28.0	48.2	14.4	25.0	15.1	25.0	17.0	11.0	14.9
10 m^3 ha^{-1} PS+TNF	58.0	48.2	14.4	85.0	15.1	25.0	77.0	11.0	14.9
20 m^3 ha^{-1} PS	56.0	96.4	28.8	50.0	30.2	50.0	34.0	22.1	29.9
20 m^3 ha^{-1} PS+TNF	86.0	96.4	28.8	110.0	30.2	50.0	94.0	22.1	29.9
30 m^3 ha^{-1} PS	84.0	143.3	42.8	75.0	45.3	75.0	52.0	33.2	44.8
30 m^3 ha^{-1} PS+TNF	116.0	143.3	42.8	135.0	45.3	75.0	112.0	33.2	44.8
1 t ha^{-1} TM	107.7	32.9	38.3	107.7	32.9	38.3	107.7	32.9	38.3
1 t ha^{-1} TM+TNF	137.7	32.9	38.3	167.7	32.9	38.3	167.7	32.9	38.3
2 t ha^{-1} TM	215.4	65.7	76.6	215.4	65.8	76.6	215.4	65.8	76.6
2 t ha^{-1} TM+TNF	245.4	65.7	76.6	275.4	65.8	76.6	275.4	65.8	76.6
NPK	50.0(1)	40.0	50.0	90.0(1)	45.0	30.0	90.0(1)	45.0	30.0

(1) Nitrogen was divided into two applications, one at sowing and the other in topdressing, as recommended by the CQFSRS/SC (2004). Nutrient amounts were applied based on 100 % dry matter.

RESULTS AND DISCUSSSION

Grain yield, dry matter production and nutrient accumulation in common bean and maize

Common bean grain yield in the 2005/06 growing season was greater in the soils subjected to the application of 30 m^3 ha^{-1} PS + TNF and of 2 t ha^{-1} TM + TNF, with values of 2.31 and 2.08 Mg ha^{-1} (Figure 2), representing increases of 28.1 and 15.1 % in relation to the soil without application. This was probably the case because greater nutrient quantities were applied in manure in these treatments, especially of N and K (Table 2), which are required in large quantity by the plants. In addition, the application of organic waste can improve the parameters related to acidity, such as increase in pH values and reduction of CEC saturation by Al^{3+} (Chantigny et al., 2004; Lourenzi et al., 2011), and increase the nutrient availability in the soil (Adeli et al., 2008; Scherer et al., 2010; Lourenzi et al., 2013), favoring crop development.

Maize grain yields were highest when the plants were grown in soil treated with 30 m^3 ha^{-1} PS + TNF in the 2006/07 growing season, and 20 and 30 m^3 ha^{-1} PS + TNF in the 2007/08 growing season (Figure 2). With the application of 30 m^3 ha^{-1} PS + TNF, an average of 123, 39 and 60 kg ha^{-1} of N, P and K were added to the soil, respectively. Grain yield ranged from 1737 to 4243 kg ha^{-1} in the 2006/07 growing season, and reached 5102 kg ha^{-1} in the 2007/08 growing season (Figure 2), within the mean range of yield values for the State of Rio Grande do Sul (CONAB, 2010). The application of 30 m^3 ha^{-1} PS + TNF led to increases in grain yield of 43 and 2441 % over the treatment without application, and of 54 and 83 % in relation to the NPK treatment in the 2006/07 and 2007/08 growing seasons, respectively. Since maize is highly nutrient-demanding, the addition of high nutrient quantities favors greater grain and dry matter production, as observed by Ceretta et al. (2005) in a study with different PS rates. These authors observed that the application of 80 m^3 ha^{-1} of PS increased maize grain yield up to 1171 % in comparison to the soil without addition of the waste product. Moreover, Ceretta et al. (2005) also observed that with the application of 20 and 40 m^3 ha^{-1} of PS, rates similar to those used in this study, the increases in maize grain yield were 292 and 585 %, respectively.

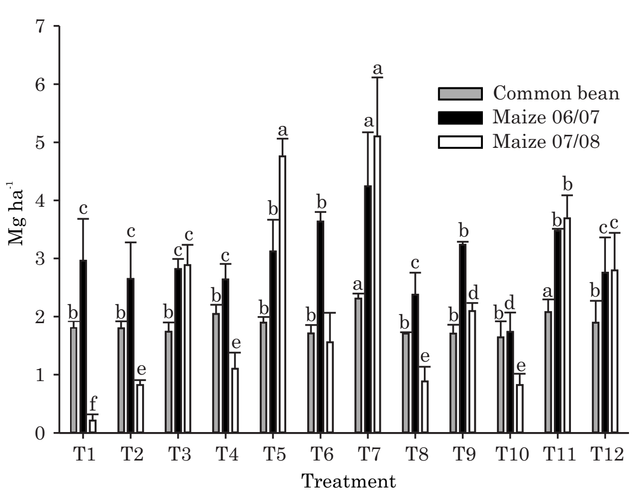

Figure 2. Grain yield of common bean (2005/06) and maize (2006/07 and 2007/08) crops subjected to organic and mineral fertilization. T1 - without application; T2 - 10 m^3 ha^{-1} PS; T3 - 10 m^3 ha^{-1} PS+TNF; T4 - 20 m^3 ha^{-1} PS; T5 - 20 m^3 ha^{-1} PS+TNF; T6 - 30 m^3 ha^{-1} PS; T7 - 30 m^3 ha^{-1} PS+TNF; T8 - 1 t ha^{-1} TM; T9 - 1 t ha^{-1} TM+TNF; T10 - 2 t ha^{-1} TM; T11 - 2 t ha^{-1} TM+TNF; T12 - NPK.

It is noteworthy that the nutrient quantities applied in the waste were more important than the manure application rate since the manures have large variations in nutrient concentrations (Ceretta et al., 2010a). It is noteworthy that although the application of TM provides a greater quantity of nutrients than the other treatments (Table 2), this was not reflected in greater maize grain yields (Figure 2), in contrast with what was seen in common bean, where the grain yield of the plants subjected to the application of 2 t ha^{-1} TM + TNF and 30 m^3 ha^{-1} PS + TNF was equal (Figure 2). This may probably be attributed, in part, to the low mineralization rate of organic matter in the soil due to the high dry matter contents, hampering microbial activity in the short term, as observed by Giacomini & Aita (2008) in a study evaluating PS and pig deep litter as N source for maize. These authors observed that the availability of N in the soil that received application of pig deep litter was less than that of the soil that received PS and they attributed the results to the low mineralization rate of organic N present in pig deep litter. In addition, factors such as the low amount of rainfall, as observed over the maize cycle in the 2007/08 growing season (Figure 1), and low temperature may have contributed to reduce the soil microbial activity, decreasing mineralization of organic N from TM (Moreira & Siqueira, 2006). Nevertheless, variations in the relationships between the N and P quantities added in PS and TM showed the importance of knowing the manure composition to improve the management and efficiency of the fertilization plan for the crops (Table 2).

The accumulated grain production in the three crops was greatest with the application of 30 m^3 ha^{-1} PS + TNF, achieving 11.66 Mg ha^{-1} (Figure 3). This represents an increase of 134.3 % in relation to the WA treatment. It is worth mentioning that the application of 20 m^3 ha^{-1} PS + TNF and 2 t ha^{-1} TM + TNF resulted in similar yields, with values of 9.78 and 9.24 Mg ha^{-1} (Figure 3), representing an increase of 96.5 and 85.8 % in relation to the WA soil, respectively. Results show that the use of N fertilization in topdressing was effective when combined with organic fertilization, resulting in greater grain yields. This may be attributed to greater

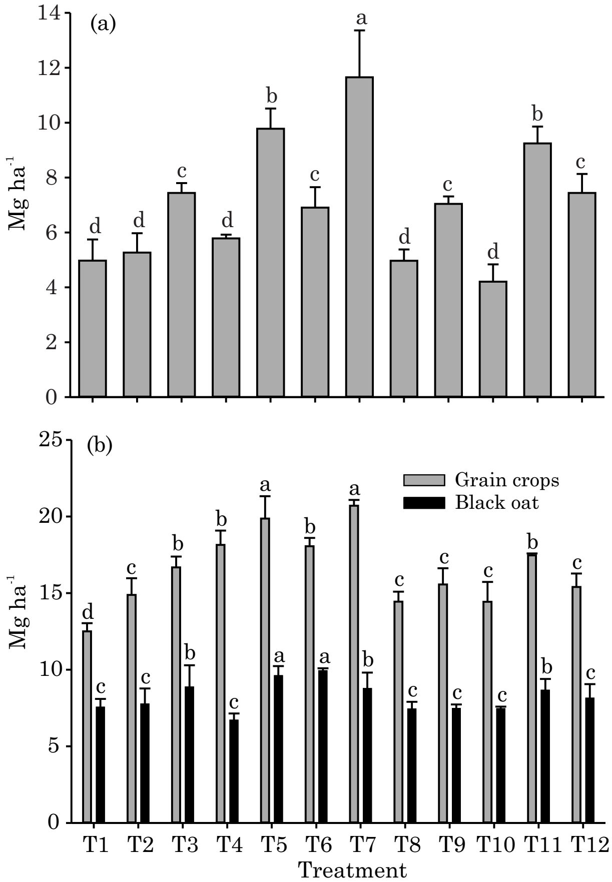

Figure 3. Accumulated grain yield (a) of common bean (2005/06) and maize (2006/07 and 2007/08) crops, and accumulated dry matter production (b) of the grain crops and black oat of the crops grown in the 2005 to 2008 growing seasons. T1 - without application; T2 - 10 m³ ha⁻¹ PS; T3 - 10 m³ ha⁻¹ PS+TNF; T4 - 20 m³ ha⁻¹ PS; T5 - 20 m³ ha⁻¹ PS+TNF; T6 - 30 m³ ha⁻¹ PS; T7 - 30 m³ ha⁻¹ PS+TNF; T8 - 1 t ha⁻¹ TM; T9 - 1 t ha⁻¹ TM+TNF; T10 - 2 t ha⁻¹ TM; T11 - 2 t ha⁻¹ TM+TNF; T12 - NPK.

availability of N at times of higher crop demands because the N present in the manures, after soil application, is subject to losses through volatilization of NH_3-N (Basso et al., 2004; Nyord et al., 2012), surface runoff and percolation of NO_3^--N (Daudén & Quílez, 2004; Smith et al., 2007; Ceretta et al., 2010a; Carneiro et al., 2012; Girotto et al., 2013), reducing N availability to the crops.

The accumulated dry matter productions of maize and common bean were greatest with the application of 20 and 30 m^3 ha^{-1} PS + TNF, resulting in 19.87 and 20.71 Mg ha^{-1} (Figure 3), which represents an increase of 58.9 and 65.6 % in relation to the WA treatment; this was observed in all three crops (Table 3). The reason was the greater nutrient quantity added to the soil in this treatment, leading to increases in soil available P and K contents (Adeli et al., 2008; Scherer et al., 2010; Lourenzi et al., 2013), but especially of mineral N (Scherer et al., 2007; Giacomini & Aita, 2008). In addition, it was observed that the application of 2 t ha^{-1} of TM + TNF on the soil over the two maize crops caused greater dry matter production and N, P and K accumulation in the plant tissue, with values similar to that of plants grown with the application of 30 m^3 ha^{-1} of PS separately and supplemented with TNF. These results show that because of the great input of dry matter, the TM mineralization in the soil is slow (Giacomini & Aita, 2008). On the other hand, with successive applications under conditions that favor mineralization, such as adequate moisture and temperature, these waste products constitute an important nutrient source for the crops, increasing crop yield and reducing production costs for farmers in the acquisition of, for example, phosphate and potassium mineral fertilizers.

Apparent recovery of N, P and K by plants

The plants grown in the soil subjected to PS application, regardless of the rate used or presence or absence of TNF in topdressing, exhibited greater apparent recovery of N, P and K in comparison to the other treatments (Table 3). The greatest recoveries of nutrients by common bean were 68 % of the N applied on the soil with the addition of 20 m^3 ha^{-1} of PS, 10 % of the P and 103 % of the K applied on the soil with the application of 10 m^3 ha^{-1} of PS + TNF. For maize, in the 2006/07 growing season, the greatest recoveries were 73 % of the N applied with the addition of 20 m^3 ha^{-1} of PS, 33 % of the P applied with 10 m^3 ha^{-1} of PS and 40 % of the K applied with 20 m^3 ha^{-1} of PS + TNF. In the 2007/08 growing season, the apparent recovery of N, P and K were 66, 71 and 146 % with the application of 20 m^3 ha^{-1} of PS, respectively. According to Giacomini & Aita (2008), maize plants recovered 22 and 11 % of the 140 kg ha^{-1} of N applied via PS and pig deep litter, respectively. In contrast, Lourenzi et al. (2014), evaluating 13 crops over five growing seasons, observed an average of apparent recovery of 73, 63 and 55 % of the total N applied at rates of 20, 40 and 80 m^3 ha^{-1} of PS, respectively.

The similarity of values with regard to N recovery obtained in this study and in the literature show the immediate effect of PS as N source to crops since PS has a large part of N in the form of ammonia (Joshi et al., 1994; Aita et al., 2006a; Scherer et al., 2007), which is rapidly oxidized to NO_3^--N after manure application on the soil (Chantigny et al., 2001; Aita et al., 2006b). This explains why one of the factors that may best explain the increases in crop dry matter production is N accumulation in dry matter because this was always greater after applications of 20 and 30 m^3 ha^{-1} PS + TNF. However, the apparent recovery by maize and common bean of N, P and K applied in manure was not related to dry matter production (Table 3) nor to grain yield (Table 3, Figures 2 and 3). Nevertheless, the lower recovery of N from TM by common bean and maize may be because a large part

Table 3. Dry matter, nutrient accumulation and apparent recovery of nutrients by the aerial part of common bean and maize subjected to organic and mineral fertilization

Treatment	Dry matter	Nutrient accumulation			Apparent recovery[(1)]		
		N	P	K	N	P	K
	$Mg\ ha^{-1}$	$kg\ ha^{-1}$			%		
Common bean (2005/06)							
Without application	2.46 b	53.60 e	11.65 b	58.95 d	-	-	-
$10\ m^3\ ha^{-1}$ PS	2.97 b	51.74 e	14.58 a	63.94 d	0.0	6.1	34,7
$10\ m^3\ ha^{-1}$ PS+TNF	3.74 a	81.07 c	16.35 a	73.79 c	47.4	9.8	103,1
$20\ m^3\ ha^{-1}$ PS	2.90 b	91.61 b	12.52 b	66.71 c	67.9	0.9	26,9
$20\ m^3\ ha^{-1}$ PS+TNF	2.92 b	70.60 d	12.94 b	60.65 d	19.8	1.3	5,9
$30\ m^3\ ha^{-1}$ PS	3.74 a	77.83 c	17.90 a	92.52 a	28.8	4.4	78,4
$30\ m^3\ ha^{-1}$ PS+TNF	3.63 a	118.04 a	16.53 a	73.07 c	55.6	3.4	33,0
$1\ t\ ha^{-1}$ TM	2.76 b	47.76 e	10.63 b	69.72 c	0.0	0.0	28,1
$1\ t\ ha^{-1}$ TM+TNF	2.96 b	90.00 b	13.13 b	57.77 d	26.4	4.5	0,0
$2\ t\ ha^{-1}$ TM	3.06 b	61.57 d	12.06 b	67.59 c	3.7	0.6	11,3
$2\ t\ ha^{-1}$ TM+TNF	3.05 b	60.16 d	13.83 b	80.57 b	2.7	3.3	28,2
NPK	2.83 b	71.34 d	11.89 b	66.47 c	35.5	0.6	15,0
CV (%)	11.83	12.15	14.33	11.46			
Maize (2006/07)							
Without application	5.08 d	54.47 c	14.36 b	78.21 b	-	-	-
$10\ m^3\ ha^{-1}$ PS	6.45 b	66.94 c	19.38 a	83.09 a	49.9	33.2	19,5
$10\ m^3\ ha^{-1}$ PS+TNF	6.02 c	85.32 b	15.70 b	60.88 b	36.3	8.9	0,0
$20\ m^3\ ha^{-1}$ PS	5.84 c	91.08 b	12.88 c	79.57 a	73.2	0.0	2,7
$20\ m^3\ ha^{-1}$ PS+TNF	7.30 a	122.62 a	15.77 b	98.42 a	62.0	4.7	40,4
$30\ m^3\ ha^{-1}$ PS	7.19 a	98.47 b	12.40 c	75.49 a	58.7	0.0	0,0
$30\ m^3\ ha^{-1}$ PS+TNF	7.63 a	74.28 c	20.16 a	85.42 a	14.7	12.8	9,6
$1\ t\ ha^{-1}$ TM	5.84 c	56.16 c	11.68 c	79.30 a	1.6	0.0	2,8
$1\ t\ ha^{-1}$ TM+TNF	5.03 d	74.66 c	7.50 c	46.01 b	12.0	0.0	0,0
$2\ t\ ha^{-1}$ TM	5.16 d	58.83 c	8.00 c	62.23 b	2.0	0.0	0,0
$2\ t\ ha^{-1}$ TM+TNF	6.02 c	90.57 b	13.42 c	87.86 a	13.1	0.0	12,6
NPK	5.06 d	68.58 c	10.20 c	59.67 b	15.7	0.0	0,0
CV (%)	8.19	16.26	17.56	12.40			
Maize (2007/08)							
Without application	4.95 d	39.48 d	10.49 d	50.52c	-	-	-
$10\ m^3\ ha^{-1}$ PS	5.46 d	37.23 d	14.50 d	59.90 c	0.0	36.5	63,0
$10\ m^3\ ha^{-1}$ PS+TNF	6.92 c	63.02 c	17.97 c	67.66 b	30.6	68.0	115,0
$20\ m^3\ ha^{-1}$ PS	9.40 a	61.75 c	26.09 a	94.16 a	65.5	70.6	146,0
$20\ m^3\ ha^{-1}$ PS+TNF	9.64 a	80.82 b	22.42 b	90.56 a	44.0	54.0	133,9
$30\ m^3\ ha^{-1}$ PS	7.13 c	48.63 d	18.73 c	90.82 a	17.6	24.8	90,0
$30\ m^3\ ha^{-1}$ PS+TNF	9.44 a	107.57 a	25.56 a	89.85 a	60.8	45.4	87,8
$1\ t\ ha^{-1}$ TM	5.85 d	46.26 d	13.67 d	75.63 b	6.3	9.7	65,6
$1\ t\ ha^{-1}$ TM+TNF	7.58 c	65.95 c	13.27 d	51.63 c	15.8	8.4	2,9
$2\ t\ ha^{-1}$ TM	6.22 d	45.21 d	15.92 c	69.78 b	2.7	8.3	25,1
$2\ t\ ha^{-1}$ TM+TNF	8.40 b	89.22 b	20.58 b	96.88 a	18.1	15.3	60,5
NPK	7.52 c	91.50 b	15.68 c	90.84 a	57.8	11.5	134,4
CV (%)	9.74	18.09	18.00	15.33			

[(1)] Apparent recovery = [(quantity of the nutrient taken up per rate - quantity of the nutrient taken up in the control without application)/quantity of the nutrient applied in organic and mineral fertilization] × 100. Mean values followed by the same letter in the column do not differ from each other by the Scott-Knott test at a 5 %. PS: pig slurry; TNF: topdressed nitrogen fertilization; TM: turkey manure.

of the N contained in this waste product is found in organic form and needs to be mineralized to become available to the crops (Giacomini & Aita, 2008). The decomposition of an organic waste product is determined by the quantity and quality of the waste product, as well as the activity of the biota, which is regulated by environmental factors, especially temperature and moisture conditions. In general, decomposition of organic waste is favored by waste with high contents of soluble material and particles of reduced size with a low C:N ratio, as well as the N content itself, and physical and chemical conditions of the soil that maximize biological activity, especially temperatures from 30 to 35 °C and moisture near field capacity (Moreira & Siqueira, 2006). In addition, decomposition of the organic fraction of the manure may result in immobilization of part of the N in ammonia forms applied by the microbial biomass, which may also have contributed to reduction in N recovery by the crops evaluated.

The low values of apparent recovery obtained for P, especially in common bean and maize in the 2006/07 growing season (Table 3), may be explained, in part, by the low demand of these crops for the nutrient (Ceretta et al., 2003). However, it may also be related to transfer of part of the P derived from the manure by surface runoff (Ceretta et al., 2010a; Sweeney et al., 2012; Wang et al., 2013) and percolation (Basso et al., 2005; Girotto et al., 2013). Lourenzi et al. (2014) observed apparent recovery of P, on average, of 23, 21 and 18 % for the application rates of 20, 40 and 80 m^3 ha^{-1} of PS, respectively.

The greatest values of apparent recovery by the crops were observed for K, especially for maize in the 2007/08 growing season (Table 3). This occurs because most K in the manure is found in mineral form (Kayser & Isselstein, 2005), readily available to plants. Thus, there is an increase in K in the exchangeable fraction, which may be taken up by the plants even beyond their needs (Kaminski et al., 2007). This explains apparent recovery values above 100 % for K (Table 3), which means that, in addition to the K applied through the manure, the plants took up the exchangeable K present in the soil (Ceretta et al., 2003; Lourenzi et al., 2013).

Residual treatment effects on black oat

The residual effect of the treatments was evaluated by the dry matter production and nutrient accumulation by black oat grown after common bean and maize (Table 4). The use of organic and mineral nutrient sources in the grain crops showed a significant effect on dry matter production and nutrient accumulation in black oat in all evaluated years (Table 4). Over the three years evaluated, the accumulated dry matter production was greater with the application of 20 m^3 ha^{-1} PS + TNF and 30 m^3 of PS (Figure 3), with increases of 27 and 32 %, respectively, in relation to soil WA. Nevertheless, if each crop is analyzed individually, the greatest dry

Table 4. Dry matter and nutrient accumulation in the aerial part of the black oat plants subjected to organic and mineral fertilization

Treatment	Dry matter	N	P	K
	Mg ha^{-1}	kg ha^{-1}		
		Black oat (2006)		
Without application	3.52 b	42.02 b	8.45 b	38.78 c
10 m^3 ha^{-1} PS	3.67 b	36.86 c	7.58 b	35.12 c
10 m^3 ha^{-1} PS+TNF	4.39 a	57.79 a	7.85 b	47.06 c
20 m^3 ha^{-1} PS	3.11 b	45.72 b	8.65 b	45.70 c
20 m^3 ha^{-1} PS+TNF	4.72 a	47.28 b	11.97 a	53.93 b
30 m^3 ha^{-1} PS	4.91 a	54.57 a	10.23 a	67.79 a
30 m^3 ha^{-1} PS+TNF	4.11 a	40.95 b	7.65 b	56.62 b
1 t ha^{-1} TM	2.76 b	31.41 c	6.88 b	40.62 c
1 t ha^{-1} TM+TNF	2.64 b	31.23 c	7.92 b	43.18 c
2 t ha^{-1} TM	2.96 b	23.59 d	10.20 a	42.47 c
2 t ha^{-1} TM+TNF	3.21 b	31.63 c	7.59 b	67.38 a
NPK	3.97 a	41.56 b	9.44 a	69.33 a
CV (%)	13.87	13.76	20.68	18.13
		Black oat (2007)		
Without application	1.23 b	20.28 b	6.79 b	37.45 b
10 m^3 ha^{-1} PS	1.43 b	23.87 b	7.11 b	38.49 b
10 m^3 ha^{-1} PS+TNF	1.99 a	28.06 a	9.25 a	58.40 a
20 m^3 ha^{-1} PS	1.40 b	20.91 b	7.30 b	40.25 b
20 m^3 ha^{-1} PS+TNF	2.29 a	30.22 a	10.11 a	41.35 b
30 m^3 ha^{-1} PS	1.63 b	23.94 b	7.55 b	46.84 b
30 m^3 ha^{-1} PS+TNF	2.06 a	32.27 a	10.19 a	53.98 a
1 t ha^{-1} TM	1.74 a	29.05 a	8.31 b	51.48 a
1 t ha^{-1} TM+TNF	1.83 a	29.65 a	8.46 b	45.67 b
2 t ha^{-1} TM	1.82a	28.09 a	7.93 b	56.18 a
2 t ha^{-1} TM+TNF	2.15 a	30.91 a	10.46 a	63.84 a
NPK	1.32 b	20.61 b	6.87 b	49.50 a
CV (%)	15.21	17.46	15.91	12.34
		Black oat (2008)		
Without application	2.80 b	34.69 c	7.17 b	67.37 a
10 m^3 ha^{-1} PS	2.67 b	30.87 c	7.98 a	51.29 b
10 m^3 ha^{-1} PS+TNF	2.50 b	40.38 b	7.46 b	52.43 b
20 m^3 ha^{-1} PS	2.20 b	28.29 c	6.68 b	49.91 b
20 m^3 ha^{-1} PS+TNF	2.60 b	31.37 c	8.71 a	54.67 b
30 m^3 ha^{-1} PS	3.40 a	32.26 c	8.21 a	49.20 b
30 m^3 ha^{-1} PS+TNF	2.60 b	25.35 c	7.11 b	43.97 b
1 t ha^{-1} TM	2.93 a	34.08 c	9.07 a	62.88 a
1 t ha^{-1} TM+TNF	3.00 a	44.09 a	7.59 b	53.79 b
2 t ha^{-1} TM	2.67 b	34.26 c	5.66 b	47.92 b
2 t ha^{-1} TM+TNF	3.30 a	49.07 a	9.60 a	61.18 a
NPK	2.85 b	38.02 b	7.30 b	58.22 a
CV (%)	14.56	14.65	15.15	15.81

Mean values followed by the same letter in the column do not differ from each other by the Scott-Knott test at a 5 %. PS: pig slurry; TNF: topdressed nitrogen fertilization; TM: turkey manure.

matter production by oat in 2006 was observed in the treatments with application of 10 m^3 ha^{-1} PS + TNF, 20 m^3 ha^{-1} PS + TNF, 30 m^3 of PS, 30 m^3 of PS + TNF and NPK. With regard to the crop in 2007, the greatest dry matter production of the aerial part of black oat was observed in the plants grown in soil treated with PS + TNF and TM (Table 4), and, in the black oat crop in 2008, the greatest residual effects on plants were observed with the addition of TM (Table 4). It may be observed that N topdressing in maize and common bean had no clear effect on the dry matter production of black oat grown in succession (Figure 3).

For N, accumulations in the aerial part were greatest in black oat in 2006, with the application of 10 m^3 ha^{-1} PS + TNF and 30 m^3 of PS (Table 4), with increases of 38 and 30 % in relation to the soil without application. In the 2007 growing season, as similarly observed for dry matter, greatest N accumulations were observed in the PS + TNF and TM treatments (Table 4), and, in black oat in 2008, accumulations were greatest in plants grown in soil treated with TM +TNF (Table 4). The lower N accumulations in black oat in 2007 and 2008 may be related to the occurrence of greater rainfall (Figure 1), which increased N transfer, especially in the form of NO_3^--N in surface runoff (Zhu et al., 2009; Ceretta et al., 2010a) and percolation (Basso et al., 2005; Girotto et al., 2013). For P and K, the greatest accumulations in the plants were normally observed in the treatments that received greater amounts of these nutrients (Table 4), but no characteristic behavior indicating better performance of some specific treatment was observed. This may be explained by the lower P demand by plants in relation to N and K, which may have led to an increase in nutrient availability in the soil where the manure rates were applied (Ceretta et al., 2010b; Guardini et al., 2012; Lourenzi et al., 2013) and also because K showed no residual effect in the manure (CQFSRS/SC, 2004).

Thus, PS application showed better residual effects in the first black oat crop (2006), while the application of TM showed better residual effects in the last two crops (2007 and 2008) (Table 4). These results may be related to the nutrient quantities applied to the soil and the mineralization rate. This is because 363, 222 and 163 kg ha^{-1} of N, P and K, respectively, were added to the soil with the application of 30 m^3 of PS + TNF in the three crops; while 796, 197 and 230 kg ha^{-1} of N, P and K, respectively, were added to the soil with the application of 2 t ha^{-1} of TM + TNF over the three applications. According to the CQFSRS/SC (2004), PS had only 10 % residual effect for P, and no residual effect for N and K, while TM had a residual effect of 20 % for N and P, and no residual effect for K. However, PS contains a large part of P already in mineral form at the time of application (Cassol et al., 2001) and the P not taken up by the plants can accumulate in plant-available forms in the soil (Chardon et al., 2007; Gatiboni et al., 2008; Ceretta et al., 2010b; Guardini et al., 2012; Lourenzi et al., 2013) and remain available for subsequent crops. Manures with greater dry matter contents, such as TM, although the amounts of nutrients added may be greater, need to be mineralized in the soil, which may be a slow process (Giacomini & Aita, 2008), and the residual effect may be lower in the first crops.

CONCLUSIONS

1. The application of nitrogen in topdressing in maize and common bean, especially when pig slurry was used at rates of 20 and 30 m^3 ha^{-1}, and turkey manure at 2 t ha^{-1}, proved to be effective in increasing the grain yield of the crops, showing the viability of a combined use of organic and industrialized mineral sources. As a result, the accumulation of N in the plant tissues of maize and common bean was the indicator that was most closely related to grain yield, in contrast with apparent recovery of nutrients, which showed no relation to the amounts of N, P and K applied in organic sources.

2. The application of nitrogen in maize topdressing and in common bean fertilized with pig slurry and turkey manure induced no clear residual effect on dry matter production of black oat grown in succession.

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