ISSN 1807-1929
Revista Brasileira de Engenharia Agrícola e Ambiental
v.21, n.10, p.686-690, 2017
Campina Grande, PB, UAEA/UFCG – http://www.agriambi.com.br

DOI: http://dx.doi.org/10.1590/1807-1929/agriambi.v21n10p686-690

Maize yield after long-term application of pig slurry

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Key words:
organic fertilizer
sustainable waste disposal
swine

A B S T R A C T

Organic wastes produced in large quantities in pig farms, such as liquid swine manure (LSM), can become a good alternative source of nutrients for agriculture, thus enabling total or partial replacement of mineral fertilizers in agricultural crops. The aim of this study was to evaluate the use of LSM as a substitute of mineral fertilizer in the maize crop under Cerrado soil conditions. The treatments consisted of using mineral fertilization recommended for the maize crop; without fertilization; and LSM doses (25, 50,100 and 200 m^3 ha^{-1}). Maize grain yield was evaluated in the 2004/2005, 2005/2006, 2006/2007, 2007/2008, 2009/2010, 2011/2012 and 2013/2014 crop seasons. The mineral fertilization in maize can be replaced by pig slurry doses from 100 m^3 ha^{-1} in a Cerrado soil (dystroferric Red Latosol with clayey texture) with no loss of yield components.

Palavras-chave:
adubação orgânica
disposição sustentável dos resíduos
suinocultura

Produtividade da cultura do milho após a aplicação em longo prazo de dejetos de suínos

R E S U M O

Os resíduos orgânicos produzidos em grandes quantidades nas granjas suinícolas, como os dejetos líquidos de suínos (DLS), podem tornar-se alternativa de fonte de nutrientes na agricultura. O descarte desses resíduos de forma racional possibilita a substituição total ou parcial da adubação mineral nos cultivos agrícolas. O objetivo com este trabalho foi avaliar a utilização de DLS como substituição da adubação mineral na cultura do milho em condições de solo de Cerrado. Os tratamentos consistiram na utilização de adubação mineral recomendada para a cultura do milho; sem adubação e doses de DLS (25; 50; 100 e 200 m^3 ha^{-1}). A produtividade de grãos de milho foi avaliada nas safras agrícolas de 2004/2005; 2005/2006; 2006/2007, 2007/2008; 2009/2010; 2011/2012 e 2013/2014. A adubação mineral na cultura do milho pode ser substituída por doses de dejetos líquidos de suínos a partir de 100 m^3 ha^{-1} em um solo de Cerrado (Latossolo Vermelho distroférrico de textura argilosa), sem que haja prejuízos dos componentes de rendimento.

Ref. 199-2016 – Received 1 Dec, 2016 • Accepted 14 Apr, 2017 • Published 25 Aug, 2017

Introduction

In Brazil, pig farming has great social and economic importance, but the wastes generated by the animals raised in confinement continue to be potential contaminants, even with their use as fertilizers in crops.

Liquid swine manure (LSM) is a mixture of feces, urine and other organic materials, such as food leftovers, residues from the stalls and animal hair, besides a variable amount of water waste from drinking facilities and from sanitation (Giacomini & Aita, 2008).

For being a waste with high contents of organic matter and relevant contents of nitrogen, phosphorus, potassium, copper and zinc, swine waste can improve physical properties and chemical and biological characteristics of the soil, which allows its use in agriculture as a supplier of nutrients and elements that are beneficial to plant development and production (Scherer et al., 2007; Lourenzi et al., 2014; Sediyama et al., 2014; Sousa et al., 2014).

Chemical fertilizers can be formulated specifically for each type of crop and soil; simultaneously, animal wastes have various minerals that are found in unbalanced proportions in relation to the absorption capacity of the plants. Because of that, prolonged and/or excessive use may result in chemical imbalances, and many of these impacts have already been observed in various regions of Brazil (Seganfredo, 2004; Oliveira, 2007).

Various reports in the literature mention improvements in soil fertility and increase in crop yield when swine wastes are used as organic fertilizer (Sediyama et al., 2009; Seidel et al., 2010; Santos et al., 2012; Lourenzi et al., 2014; Moraes et al., 2014; Sediyama et al., 2014; Sousa et al., 2014; Basso et al., 2016; Bócoli et al., 2016). Thus, the use of this waste as fertilizer in the soil presents itself as a viable alternative for its final destination, because it promotes reduction in production costs, besides improving the biological quality of the soil. However, it must be adequately managed to avoid the expression of its high polluting power.

The objective of this study was to evaluate the utilization of LSW as a substitute of mineral fertilization in the maize crop under Cerrado soil conditions.

Material and Methods

The study was carried out during seven crop seasons (2004/2005; 2005/2006; 2006/2007, 2007/2008; 2009/2010; 2011/2012 and 2013/2014) in the experimental area of the University of Rio Verde, located at the 'Fontes do Saber' Farm, municipality of Rio Verde, GO (29º 43' 12" S, 53º 43' 12" W), in dystroferric Red Latosol with clayey texture (470 g kg^{-1}) and declivity of 4% (EMBRAPA, 2006). The chemical characteristics in the 0-20 cm layer prior to the experiment (1999/2000 season), according to the methodology described in Tedesco et al. (1995) were: pH = 4.0; OM = 23 g kg^{-1}; P = 3.0 mg dm^{-3}; K = 55 mg dm^{-3}; Ca, Mg, Al and H+Al = 1.6; 0.6; 0.13 and 8.8 $cmol_C$ dm^{-3}, respectively.

The climate of the region is classified as Aw (tropical), according to Köppen's classification, with a long dry season (April to October), mean annual rainfall of 1,550 mm and mean annual temperature of 23.3 ºC (Alvares et al., 2013).

The soil was plowed and its acidity was corrected with limestone (2.242 t ha^{-1}) so that pH increased to 5.5-6.0 and base saturation reached 60%, as commonly performed in opening areas in the Cerrado (Sousa & Lobato, 2004). After these interventions, the no-till farming system was adopted in all crop seasons.

The experimental design was randomized blocks with three replicates and the treatments consisted of: T1 - control (without LSW application and mineral fertilization); T2 - mineral fertilization (400 kg ha^{-1} of the 8-20-20 formulation and 100 kg ha^{-1} of N as top-dressing in the form of urea); T3 - 25 m^3 ha^{-1} of LSW; T4 - 50 m^3 ha^{-1} of LSW; T5 - 50 m^3 ha^{-1} of LSW plus 100 kg ha^{-1} of N as top-dressing in the form of urea; T6 - 100 m^3 ha^{-1} of LSW and T7 - 200 m^3 ha^{-1} of LSW. From October 2000 on, the wastes were manually applied using these same treatments. Each plot was 10 m wide x 15 m long, with an area of 150 m^2.

The utilized swine waste came from an SVT (vertical finishing system) farm, where they remained for 30 days in an anaerobic stabilization pond with capacity for 120 m^3. After this period, the wastes were applied in the experimental area 20 to 30 days before sowing the maize crop and distributed broadcast on soil surface on the residues of the previous crops through the jet of a hose connected to a pressurized tank, without incorporation.

The liquid swine waste was chemically analysed according to Pavan et al. (1992) in all years of the study, at the moment of its application in the soil, to determine pH, Ca, Mg, K, P, N total, S and density. The analyses were made according to the methodologies described by Silva et al. (1999). Table 1 illustrates the mean nutritional value of the LSW applied in the experimental area.

Mineral fertilizations calculated for the 0-20 cm layer were based on the recommendations of Souza & Lobato (2004). Soil samples were collected before applying the treatments in the plots that received annual applications of the mineral fertilizer. Chemically fertilized plots received the fertilizers at planting, and the application was made broadcast on soil surface on the residues of the previous crop. Top-dressing fertilization with nitrogen was performed 15 days after maize sowing, using 100 kg ha^{-1} of N in the form of urea.

Maize sowing was performed between 20 and 30 days after applying the treatments, usually in the second week of November. In all seasons, maize was sown using a no-till seed drill, composed of frontal cut disc and furrowing by mismatched double disc. During the cycle, all cultivation

Table 1. Mean contents of nutrients in the liquid swine wastes of a vertical finishing system of the region of Rio Verde, GO

N total	P	K	Ca	Mg	S
kg m^{-3}					
0.79	0.16	0.94	0.57	0.25	0.11
OM	DM	Density	pH	Cu	Zn
%		kg m^{-3}		g m^{-3}	
1.05	1.49	1008	7.8	2.34	6.03

OM – Organic matter, DM – Dry matter

practices were carried out according to crop need and the technical recommendations.

Maize was manually harvested always in March of each year, when the grains reached moisture content of 18%. The ears of each plot were threshed, the grains were weighed on digital scale and the moisture of the grains from each plot was determined, adjusted to 13%.

The obtained results were subjected to joint analysis of variance between treatments and seasons. When there was significance, Tukey test at 0.05 probability level was applied; for the effects of the applied doses, regression analysis was adopted using the statistical program SISVAR 5.3 (Ferreira, 2011).

Results and Discussion

The contents of N, P and K and doses of liquid swine waste and mineral fertilizers applied in the plots were used to estimate the amounts of N, P_2O_5 and K_2O added to the soil in each treatment (Table 2).

Compared with the NPK fertilization recommended for maize (Souza & Lobato, 2004): the LSW dose of 200 m^3 ha^{-1} exceeded in relation to N; none of the doses met the requirements of P; and LSW doses above 100 m^3 ha^{-1} were superior in relation to K. Swine wastes can be considered as unbalanced fertilizers, since they have nutrients in disproportionate amounts in relation to the requirements of the plants (Berwanger, 2006), as opposed to mineral fertilizers, which can be specifically formulated, according to the conditions of cultivation and soil. Hence, excessive or successive fertilizations with swine waste can cause alterations in soil chemical attributes (Scherer et al., 2010; Lourenzi et al., 2013) and lead to undesirable environmental impacts, such as pollution of surface and subsurface waters (Carneiro et al., 2012; Sørensen & RubÆk, 2012; Sweeney et al., 2012). Table 3 shows the results of maize grain yield as a function of the fertilizations (doses of swine waste and mineral fertilization - NPK).

The interaction Fertilization (B) versus Crop seasons (A) was significant (Table 4). It was observed that the LSW doses influenced maize grain yield in the seasons 2009/2010,

Table 2. Mean amounts of N, P_2O_5 and K_2O supplied to the soil according to the treatments

Treatments	N	P_2O_5	K_2O
		kg ha^{-1}	
Control	-	-	-
25 m^3 ha^{-1} of LSW	19.7	9.3	28.3
50 m^3 ha^{-1} of LSW	39.5	18.5	56.5
100 m^3 ha^{-1} of LSW	79.0	37.0	113.0
200 m^3 ha^{-1} of LSW	158.0	74.0	226.0
Mineral Fertilization[1]	132.0	80.0	80.0

[1] Chemical fertilization varied according to soil fertility and expected crop yield in each season

Table 3. Mean values, F value, least significant difference (LSD), coefficient of variation (CV) as a function of seasons and fertilization (mineral and liquid swine waste) for maize grain yield

Season (A)	Yield (kg ha^{-1})
2004/2005	6783.9
2005/2006	5756.1
2006/2007	5640.7
2007/2008	8097.3
2009/2010	7804.3
2011/2012	7616.6
2013/2014	7458.5
2015/2016	9987.6
LSD	1063.5
Fertilization (B)	
Mineral	7831.70
Control	5756.60
25 m^3 ha^{-1} LSW	6971.20
50 m^3 ha^{-1} LSW	7843.00
100 m^3 ha^{-1} LSW	7707.20
200 m^3 ha^{-1} LSW	8249.30
LSD	1308.90
CV (%)	17.06
F value	
Block	1.83^{ns}
Season (A)	12.316**
Fertilization (B)	21.935**
A x B	1.702*

*Significant at 0.01 probability by F test; *Significant at 0.05 probability by F test

2011/2012, 2013/2014 and 2015/2016 (Table 4).

The increment in grain yield (Table 4) occurred from the LSW dose of 25 m^3 ha^{-1} on, in comparison to the treatment without fertilization. In general, all LSW doses promoted significant increments in grain yield.

Mineral fertilization led to increments of 39.5, 77.3, 106 and 39.7% in the yield, compared with the control (without fertilization) in the seasons 2009/2010, 2011/2012, 2013/2014, 2015/2016, respectively, demonstrating the need of using a source of nutrients for adequate development and yield of the maize crop under the soil conditions of the present study.

Comparing the grain yields between the treatments, it is noted that, in the first crops (2004/2005 to 2007/2008), the yields were similar. However, from the fifth crop on with successive LSW application (2008/2009), the highest yields were obtained with the highest LSW dose in relation to the control, but always equivalent to the grain yields with mineral fertilization (Table 4).

There was a significant effect of the interaction Season x Doses for maize grain yield (Table 5).

The variable grain yield showed quadratic increase as a function of the increment in LSW doses in the seasons 2011/2012 and 2013/2014 and linear increase in the seasons 2009/2010 and 2015/2016 (Table 6).

Table 4. Follow-up analysis of the significant interaction between seasons and fertilizations for maize grain yield (kg ha^{-1})

Treatments	2004/2005	2005/2006	2006/2007	2007/2008	2009/2010	2011/2012	2013/2014	2015/2016
Mineral	6973a	5539a	5539a	7787a	8490 ab	8506 ab	8879 ab	10939 a
0 m^3 ha^{-1}LSW	5897a	5460a	5211a	6476a	6086 b	4797 c	4295 c	7830 b
25 m^3 ha^{-1}LSW	6933a	5800a	5399a	9172a	6230 ab	6239 bc	5954 bc	10042 ab
50 m^3 ha^{-1}LSW	6654a	5962a	5987a	8607a	7581 ab	7619 bc	9874 a	10458 ab
100 m^3 ha^{-1}LSW	6973a	6079a	6378a	7430a	9209 a	9246 ab	7159 abc	9182 ab
200 m^3 ha^{-1}LSW	7272a	5695a	5329a	9112a	9230 a	9292 a	8590 ab	11474 a
LSD	3008							

Table 5. Mean square and significance level of maize grain yield as a function of the doses of liquid swine waste (LSW)

Source of variation	DF	Yield (kg ha^{-1})
Block (Season)	16	1948398.2^{ns}
Season	7	23110945.3**
Dose	4	26547450.4**
Season x dose	28	3019859.9*
Error	64	1600739.5

^{ns}Not significant; **Significant at 0.01 and *Significant at 0.05 probability level by F test

The maximum technical efficiency of grain yield was obtained with the LSW doses of 152 m^3 ha^{-1} (2011/2012) and 137 m^3 ha^{-1} (2013/2014).

The results found in the present study of maize grain yield differ from those of Ceretta et al. (2005), who reported that maize grain yield increased in both cultivation years with the use of LSW, and found maximum technical efficiency with the application of 85 m^3 ha^{-1} of LSW in the first year of the study. The same was reported by Moraes et al. (2014), who found maximum technical efficiency of grain yield using 91 m^3 ha^{-1} of LSW. Pinto et al. (2014), compared LSW doses and mineral fertilization, for maize grain yield in both cultivation years, and observed that the LSW dose of 80 m^3 ha^{-1} was statistically equal to mineral fertilization. Lourenzi et al. (2014) reported increment in maize grain yield with LSW application at dose of 80 m^3 ha^{-1}, which may reach 11.6 t ha^{-1}. Basso et al. (2016) also reported satisfactory results for all evaluated variables using the dose of 80 m^3 ha^{-1} in the wheat/maize succession. However, Seidel et al. (2010), using urea and swine wastes at doses of 20, 30, 40 and 50 m^3 ha^{-1} in maize cultivation, observed no significant differences in grain yield. Bócoli et al. (2016), evaluating the potential of using LSW in the maize crop at doses of 40, 80,120, 160, 200 and 240 m^3 ha^{-1}, in an Oxisol, reported no effect on maize grain yield and its components (ear length, ear diameter, number of grains per ear and 1000-grain weight) under application of swine wastes.

The different performance regarding grain yield under fertilization with swine waste in these experiments is due to the concentration of nutrients in the wastes. According to Perdomo et al. (2003), the higher the content of dry matter, the lower the amount of water present in the waste and the better its fertilizing quality. However, it should be highlighted that the LSW composition is variable according to the swine production system, fattening or finishing (Gonçalves Júnior et al., 2008).

Therefore, in the present study it was observed that there were no yield losses in comparison to mineral fertilization, for the doses of 100 and 200 m^3 ha^{-1}; the mean values demonstrated that, under these conditions, the fertilization with LSW positively contributed to grain yield. Moraes et al. (2014) claimed that the use of LSW is a viable option for the farmer. These authors used, in the maize crop in a Red Latosol with very clayey texture, LSW doses of up to 100 m^3 ha^{-1} and concluded that mineral fertilization in the maize crop can be substituted by LSW doses from 50 m^3 ha^{-1} on, without compromising yield components.

The results in this study for a dystroferric Red Latosol with clayey texture demonstrate the effectiveness of using LSW as source of nutrients and, compared with mineral fertilization, it allows adequate grain yield of the maize crop under no-till system.

Conclusion

Mineral fertilization in the maize crop can be replaced by the dose of 100 m^3 ha^{-1} of liquid swine waste in Cerrado soil (dystroferric Red Latosol with clayey texture) with no losses of yield components.

Acknowledgments

To the Foundation for Research Support of the State of Goiás (FAPEG) and National Council for Scientific and Technological Development (CNPq), for granting the scholarship and supporting the research.

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Table 6. Maize grain yield (kg ha^{-1}) as a function of the seasons and doses of liquid swine waste (LSW)

Season	Doses of liquid swine waste (m^3 ha^{-1})							
	0	25	50	100	200	F	r^2	Equation
2004/2005	5897	6933	6654	6973	7272	0.244^{ns}		
2005/2006	5460	5800	5962	6079	5695	0.404^{ns}		
2006/2007	5211	5399	5987	6378	5329	1.749^{ns}		
2007/2008	6476	9172	8607	7430	9111	0.056^{ns}		
2009/2010	6086	6230	7581	9209	9230	13.637**	0.77	$y = 6388 + 17.06 x$
2011/2012	4797	6239	7619	9246	9292	7.290**	0.99	$y = 4770 + 67.07 x - 0.22 x^2$
2013/2014	4295	5953	9874	7159	8590	7.014**	0.50	$y = 4960 + 60.42 x - 0.22 x^2$
2015/2016	7830	10042	10458	9182	11474	7.345**	0.52	$y = 8858 + 12.52 x$

^{ns} Not significant; **Significant at 0.01 probability level by F test

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