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Poultry Litter and Pig slurry Applications in an Integrated Crop-Livestock System

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ABSTRACT: Organic fertilizers derived from poultry litter and pig slurry are alternatives to mineral fertilizers in increasing soil nutrient availability. The aim of this study was to evaluate soil response, through characterization of organic C and available N, P, and K contents, and corn yield response to increasing amounts of poultry litter, pig slurry, and mineral fertilizers in an integrated crop-livestock production system (ICL) from 2011 to 2013. The experimental design consisted of randomized blocks in a 4 × 3 + 1 factorial arrangement with four replicates. The treatments consisted of four types of fertilizer, two organic (poultry litter and pig slurry) and two mineral, balanced with the same amounts of N, P and K as the organic fertilizers, one of which corresponded to the levels in the pig slurry (M1) and the other to the levels in the poultry litter (M2) in combination with three .increasing application rates of N (100, 200, and 300 kg ha^{-1} N) and control without fertilizer. For two years after implementing the ICL system, the application of the different rates of N using organic (pig slurry and poultry litter) or mineral (M1 and M2) fertilizers increased corn yields and K and P availability in the soil; these results were accompanied by small changes in organic C and total N content. There are similar efficiencies between the treatments pairs (pig slurry/M1 and poultry litter/M2).

Keywords: mineral fertilizers, organic carbon, nitrogen.

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INTRODUCTION

The practice of fertilization, when necessary, can result in a yield up to three times greater than when not adopting the practice (IFDC, 2012) and is responsible for preserving 67 million hectares in Brazil (FAO, 2013). Such activity helps explain Brazil's position as the world's fourth largest consumer of mineral fertilizers; however, 75 % of these products are imported (ANDA, 2013), which places undo risk on agribusinesses, which account for 27 % of the Gross Domestic Product.

The development of sustainable production technologies aimed at improving nutrient availability in soil-plant systems following fertilizer applications is important in this scenario (Fancelli, 2010). Furthermore, research is needed on reuse of the nutrients available in organic waste (Grohskopf et al., 2015) and the use of highly productive conservation systems, such as integrated crop-livestock production systems (ICL), which place particular importance on soil fertility (Tormena et al., 2012).

To ensure that fertilization using organic fertilizers is sustainable and provides adequate nutrient availability to the soil-plant system, technical recommendation criteria are needed. Specific recommendations include the development of critical P limits (Gatiboni et al., 2015) to obtain the expected benefits from the chemical, physical, and biological properties of the soil and subsequent crop yield (Mafra et al., 2014; Grave et al., 2015). The concept has been adopted that organic fertilizers help promote system sustainability and should not be regarded as a potential source of environmental pollutants (Lourenzi et al., 2013).

Fertilization practices using organic fertilizers in ICL systems often result in economic and environmental gains because the diversity of the integrated system is enhanced such that new nutrient-cycling pathways are created and new ecosystem processes emerge (Anghinoni et al., 2011). Our knowledge of fertilization in ICL systems is based on mineral fertilizers and can be used to predict the increased export of nutrients generated by high-yield potential (Costa et al., 2015). However, organic fertilizers make different nutrients available to plants than mineral fertilizers (Scherer and Nesi, 2009; Scherer et al., 2010), and fertilizer recommendation studies should therefore be conducted on organics in ICL systems.

The hypothesis of this study is based on the premise that organic fertilizer is equal to or better than the mineral fertilizers in ICL systems when the same criteria for N, P, and K applications to the soil are adopted. Thus, the aim of this study was to evaluate soil response, based on the organic C content and N, P, and K availability in the soil, and corn yield response to different amounts of poultry litter, pig slurry, and mineral fertilizers in an ICL system.

MATERIALS AND METHODS

The experiment was conducted during the 2011-2013 growing seasons at the Instituto Federal Catarinense - IFC (Santa Catarina Federal Institute), Concordia *Campus*, in the municipality of Concordia, with geographical coordinates of latitude 27° 12′ 0.08″ and longitude 52° 4′ 58.22″ and an altitude of 569 m. The production system adopted was ICL, which included the cultivation of Syngenta Celeron LT hybrid corn (*Zea mays* L.) intercropped with brachiaria (*Urochloa brizantha* (Hochst. ex A. Rich) RD Webster), cultivar MG-5, during the summer and dual-purpose rye (*Secale cereale* L.), cultivar BRS Serrano, during the winter.

The climate is classified as humid subtropical (Cfa) according to the Köppen classification system, where the colder months (June and July) have mean temperatures of approximately 15 °C, and the mean annual temperature is 23 °C. The rains are regular and well distributed with a total annual rainfall greater than 1,500 mm, sufficient to ensure there are no water deficits. The relief is predominantly undulating with an 8 % slope.

Daily data for the maximum and minimum temperatures and rainfall throughout the two years of the experiment were collected at the weather station of Embrapa Suínos e Aves and are presented in figure 1. It should be noted that the rainfall and temperature conditions were adequate for crop development.

The soil in the experimental area was a *Nitossolo Vermelho Eutrófico* according to the Brazilian Soil Classification System (Santos et al., 2013). Soil chemical and physical properties are shown in table 1. The experimental area was previously managed with corn crops in the summer and black oats and turnips for vegetative cover in the winter from 1994 to 2011. During this period, there were two lime applications per year with 5 Mg ha^{-1} of dolomitic limestone, organic fertilization applications with pig slurry at 50 m^3 ha^{-1} yr^{-1}, based on the normative instructions of the state environmental agency of Santa Catarina (FATMA), and mineral fertilizer applications based on crop needs as defined by soil analysis; crop yields were also determined. Even with medium to high nutrient levels in the soil, increased production levels are expected from the amounts of organic and mineral fertilizers added to the soil to achieve the yield thresholds proposed by the study.

In setting up the experiment, cover crops were desiccated by applying glyphosate herbicide (2,160 g ha^{-1} a.i.), and then rye was planted. This agricultural practice was repeated 14 days prior to sowing the winter crops in 2011 and 2012, and prior to the 2011/12 and 2012/13 summer harvests.

The experiment was conducted under field conditions using a randomized block design with four replicates in a 4 × 3 + 1 factorial design, consisting of four fertilizers, three different amounts of N, and a control treatment without fertilization. The fertilizer treatments

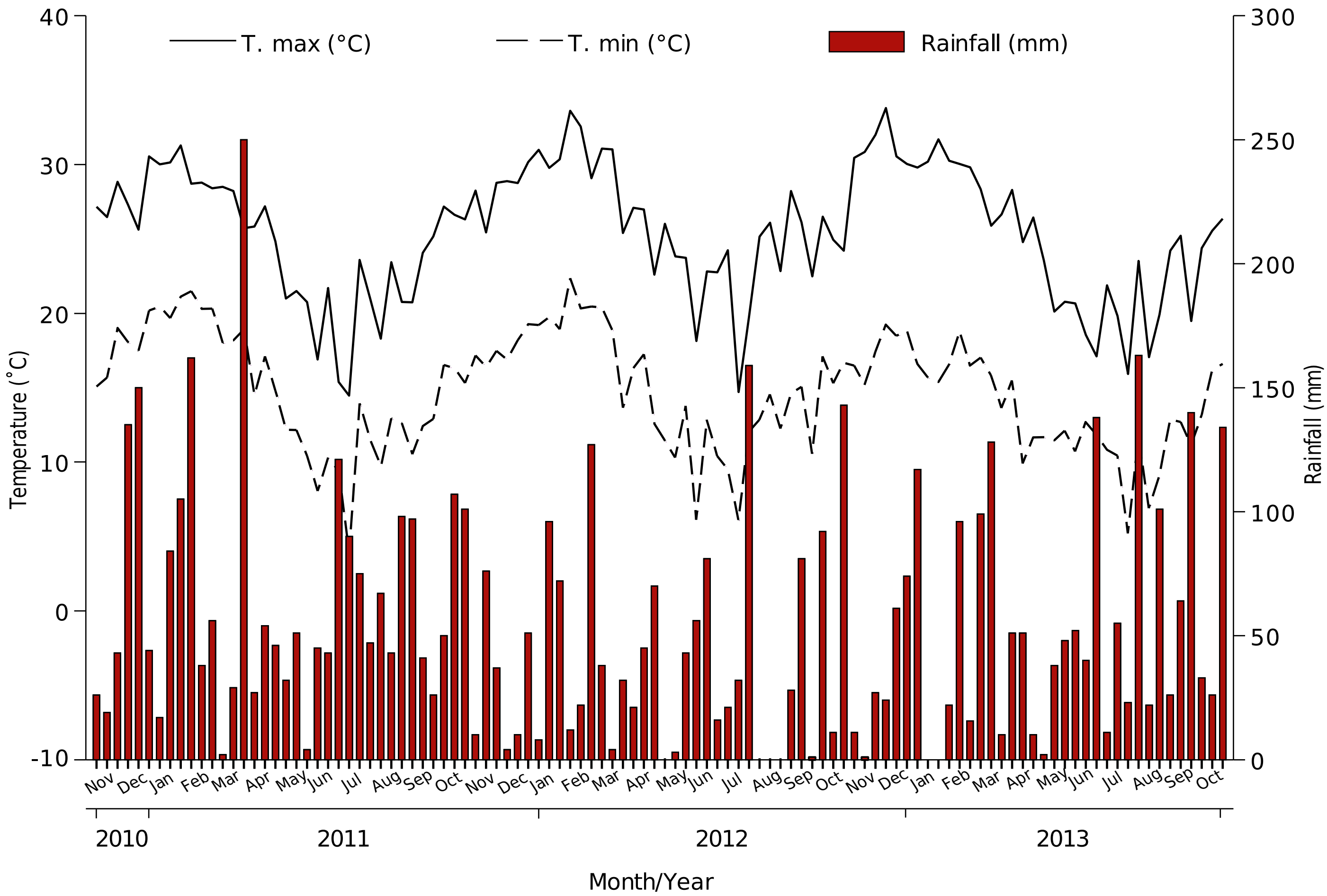

Figure 1. Rainfall and maximum and minimum temperature recorded in the experiment during the 2011/2013 crop seasons in Concordia, SC, Brazil. Temperature and rainfall were reported as the average and sum of values registered during consecutive 10 days periods, respectively.

consisted of two organic fertilizers (poultry litter and pig slurry), two mineral fertilizers (M1 and M2) and a control (no fertilizer) in combination with 100, 200, and 300 kg ha^{-1} N applied in each treatment. The experimental units were formed by 5 × 5 m plots (25 m^2) with 2.5 m between blocks.

The fertilizer was applied on the surface next to the plant row for both the winter and summer crops. The pig slurry and poultry litter were obtained from production systems at the IFC, Concórdia *Campus*. The chemical properties of each organic fertilizer for each crop are shown in table 2 and were analyzed according to official methods (Rice et al., 2012) to determine the N, P, and K content.

Information on the N, P, and K concentrations in the organic fertilizer were used to establish the mineral fertilizer formulations from the following sources: urea for N, triple superphosphate for P, and potassium chloride for K, such that the M1 treatment contained the same levels of these nutrients as the pig slurry, and the M2 treatment, the same as the poultry litter (slurry/M1 and litter/M2).

Table 1. Soil chemical and physical properties prior to fertilizer application in 2011

Property	0.00-0.05 m	0.05-0.10 m	0.10-0.20 m	0.20-0.40 m
N (mg kg^{-1})	1,885	1,707	1,543	1,203
Cu (mg kg^{-1})	4.7	5.46	4.4	3.9
K (mg kg^{-1})	590	406	346	232
Mg (mg kg^{-1})	588	488	508	452
Ca (mg kg^{-1})	1,676	1,344	1,912	1,496
H+Al (mmol$_c$ kg^{-1})	57	60	58	54
CTC (mmol$_c$ kg^{-1})	205	178	205	172
V (%)	72	66	72	69
P (mg kg^{-1})	100	80	70	24
Zn (mg kg^{-1})	5.1	4.4	3.6	1
Organic C (g kg^{-1})	18	17	17	14
pH(H_2O)	5.8	5.6	5.5	5.3
Clay (g kg^{-1})	680	680	700	700

N, Cu, K, Mg, Ca, H+Al, P, Zn, Organic C, pH(H_2O): in according to Tedesco et al. (1995). Clay: in according to Claessen (1997).

Table 2. Nitrogen, phosphorus, and potassium contents in poultry litter (PL) and pig slurry (PS) and phosphorus and potassium inputs in cropping systems

	Content of nutrients in fertilizer residue			P input			K input		
				N application rate (kg ha^{-1})					
	N	P	K	100	200	300	100	200	300
				Rye crop 2011					
	g kg^{-1} (PL) or g L^{-1} (PS)			kg ha^{-1}					
Poultry litter	20.3	11.6	26.9	57	114	171	132	265	397
Pig slurry	4.20	0.42	2.43	10	20	30	58	116	174
				Maize crop 2011/12					
Poultry litter	20.7	13.4	12.8	64	128	192	62	124	186
Pig slurry	3.72	1.43	1.54	39	78	117	41	82	123
				Rye crop 2012					
Poultry litter	19.3	36.1	46.2	190	380	570	242	484	726
Pig slurry	2.9	0.85	1.14	29	58	87	38	76	114
				Maize crop 2012/13					
Poultry litter	21.8	13.3	13.4	61	122	183	61	122	183
Pig slurry	3.85	0.99	4.23	26	52	78	109	218	327

Determinations carried according to Rice et al (2012).

Dual-purpose BRS Serrano rye was used for pasture formation during the winter at a sowing density of 250-350 viable seeds m^{-2} (40 to 60 kg ha^{-1}), with a 0.17 m spacing between the rows. Syngenta single hybrid Celeron TL corn was the summer crop, with a 0.80 m row spacing and eight seeds per meter, intercropped with brachiaria MG-5, which was manually seeded between rows at a density of 4 kg ha^{-1}.

Soil samples were taken from the 0.00-0.05, 0.05-0.10, 0.10-0.20, and 0.20-0.40 m layers at the end of each summer growing season. Three simple samples were taken at random using a Dutch auger, one from the row and two from between the rows, to form a composite sample. The composite samples were analyzed to determine the C, N, P, and K content, as described by Tedesco et al. (1995).

In both crop years, the corn crop in each plot was harvested manually from two 2-m-long rows that were 0.8 m apart, for a total of 3.2 m^2. Manual husking, weighing, and drying; separation of the chaff and grain; and determination of the weight of the harvested grain for per-hectare grain-yield calculations, with subsequent corrections for 13 % humidity, were then performed.

The model used to analyze the variance inherent in a randomized block design considered the following factors: fertilizer, application rate, and blocks. After confirming the significance of the reference variable using the F test, means values of the treatments were compared using Student's t-test at a 5 % of probability. The linear and quadratic effects between the N levels were also tested in each fertilizer using the GLM procedure in SAS.

RESULTS AND DISCUSSION

Fertilization with organic and mineral fertilizers with increasing amounts of N in an integrated crop-livestock production system (ICL) system increased organic C content for the M2 at every soil layer, and at the application rate of 300 kg ha^{-1} N, the C content in the M2 was higher than in the poultry litter treatment at the 0.00-0.05, 0.05-0.10, and 0.10-0.20 m layers, higher than M1 at the 0.05-0.10 m layer, and higher than the pig slurry treatment at the 0.20-0.40 m layer (Table 3). A trend toward an increase in the organic C content was observed for the M1 and slurry treatments in the 0.20-0.40 m layer. Scherer et al. (2010), after 15 to 25 years of successive applications of pig slurry in a no-tillage system, observed that the organic C content in the soil did not change in *Neossolo Litólico*, *Cambissolo Háplico*, and *Latossolo Vermelho*.

Two years after implementation of the ICL system, higher organic C content found in soils at the 300 kg ha^{-1} levels of N in the M2 treatment was converted into organic C input, based on soil bulk density, reaching the order of 1.2 Mg ha^{-1} yr^{-1} in the 0.00-0.05 and 0.05-0.10 m surface layers, 2.4 Mg ha^{-1} yr^{-1} in the 0.10-0.20 m layer, and 6 Mg ha^{-1} yr^{-1} in the 0.20-0.40 m layer. These results are consistent with reports by Lovato et al. (2004) and Leite et al. (2009), who observed a mean input of 4.1 Mg ha^{-1} yr^{-1} of organic C in the surface layer and 10.4 Mg ha^{-1} yr^{-1} in the 0.10-0.20 m layer in a no-tillage system.

Soil under ICL potentially serves as a sink of atmospheric C and favors accumulation of soil organic matter (SOM) (Nicoloso et al., 2008). Input of C in the ICL system is provided by high production of plant residues (plant residues on the soil surface and roots in the soil profile) in both crops and pastures compared to conventional grain-only production systems (Souza et al., 2010; Anghinoni et al., 2011; Loss et al., 2012). Importantly, soils with high clay content have high capacity to store C because they have a higher specific surface area and better aggregation (Six et al., 2000).

The application of organic and mineral fertilizers in the ICL systems did not significantly change the total N content in the soil, with a trend toward decrease observed up to levels of 111 kg ha^{-1} in the M2 treatment in the 0.05-0.10 m layer and a trend toward linear increase observed for the pig slurry treatment in the 0.20-0.40 m layer. No differences were observed among treatments for the same application rate for each particular layer (Table 4). These results can be explained by a soil reservoir that contains from 1 to 10 Mg ha^{-1} of organic N in the 0.00-0.20 m layer depending on the type of soil (Phelan, 2009). The initial N levels in the soil (Table 1) were such that the treatment where no N was applied was just as effective as the other treatments; that is, the N was derived from the SOM and not exclusively supplied by the fertilizer.

The increasing levels of N in the system from the organic and mineral fertilizers were directly related to available P content (Table 5) due to the input of 121, 242, and 363 kg ha^{-1} P in the form of poultry litter and 49, 98, and 196 kg ha^{-1} P in the form of pig slurry in 2011 and 251, 502, and 753 kg ha^{-1} P in the form of poultry litter and 55, 110, and 165 kg ha^{-1} P in the form of pig slurry in 2012, with the same order of magnitude between litter/M2 and manure/M1 (Table 2).

The M2 treatment showed a trend toward an increase in available P content in all layers, which was linear for the 0.00-0.05 m layer and quadratic for the other layers; in contrast, the M1 treatment showed a trend toward a linear increase only for the 0.20-0.40 m layer. Among the organic fertilizers, the poultry litter showed a trend toward a linear increase in P in the 0.00-0.05 and 0.05-0.10 m layers and a trend toward a quadratic increase in the 0.20-0.40 m layer, whereas the manure showed a trend toward a linear increase in the 0.05-0.10 m layer and a quadratic increase in the deeper layers (Table 5). This significant input of P into the system increased the degree of saturation of the soil solution and promoted precipitation of orthophosphates with Fe, Al, and Ca ions for the formation of amorphous minerals with varying degrees of solubility (Reddy et al., 2005).

Table 3. Soil organic carbon content (OC) according to organic and mineral fertilizer application in integrated crop-livestock systems in 2013

ICL	N application rate (kg ha^{-1})				Equation
	0	100	200	300	
				OC (0.00-0.05 m)	
		g kg^{-1}			
Poultry litter	19	20	20	20 b	$\bar{y} = 20.0$
Pig slurry	19	19	19	21 b	$\bar{y} = 20.0$
M1	19	21	21	21 b	$\bar{y} = 21.0$
M2	19	19	20	23 a	$\hat{y} = 20 - 0.014^{*} x + 0.00009^{*} x^2$ $R^2 = 0.97$
				OC (0.05-0.10 m)	
Poultry litter	18	20	19	18 b	$\bar{y} = 18.6$
Pig slurry	18	18	20	20 ab	$\bar{y} = 18.9$
M1	18	18	20	19 b	$\bar{y} = 18.5$
M2	18	19	19	21 a	$\hat{y} = 17.8 + 0.013^{**} x$ $R^2 = 0.78$
				OC (0.10-0.20 m)	
Poultry litter	17	18	18	16 b	$\bar{y} = 16.9$
Pig slurry	17	18	18	19 a	$\bar{y} = 17.8$
M1	17	15	17	19 a	$\bar{y} = 17.2$
M2	17	16	19	20 a	$\hat{y} = 15.9 + 0.013^{**} x$ $R^2 = 0.79$
				OC (0.20-0.40 m)	
Poultry litter	13	15	16	16 ab	$\bar{y} = 15.0$
Pig slurry	13	17	17	15 b	$\hat{y} = 13.3 + 0.044^{**} - 0.0001^{**} x^2$ $R^2 = 0.99$
M1	13	14	15	18 a	$\hat{y} = 12.8 + 0.015^{**} x$ $R^2 = 0.92$
M2	13	14	14	18 a	$\hat{y} = 12.8 + 0.015^{**} x$ $R^2 = 0.75$

Means followed by different letters in columns at the same depth are different according to Student's t-test ($p \leq 0.05$). Significance level ** ($p \leq 0.01$) and * ($p \leq 0.05$). M1: mineral treatment contained the same levels of these nutrients as the pig slurry, and the M2 mineral treatment, the same as the poultry litter.

Table 4. Total nitrogen content (TN) in soil according to organic and mineral fertilizer application in integrated crop-livestock systems in 2013

ICL	N application rate (kg ha^{-1})				Equation
	0	100	200	300	
			TN (0.00-0.05 m)		
		g kg^{-1}			
Poultry litter	1.9	2.0	2.3 a	1.9	$\bar{y}$ = 2.0
Pig slurry	1.9	1.9	1.8 b	1.9	$\bar{y}$ = 1.9
M1	1.9	1.8	1.9 b	1.8	$\bar{y}$ = 1.8
M2	1.9	1.7	1.8 b	2.1	$\bar{y}$ = 1.9
			TN (0.05-0.10 m)		
Poultry litter	1.7	1.8	1.7	1.7	$\bar{y}$ = 1.7
Pig slurry	1.7	1.7	1.6	1.8	$\bar{y}$ = 1.7
M1	1.7	1.7	1.7	1.8	$\bar{y}$ = 1.7
M2	1.7	1.6	1.7	1.9	$\hat{y} = 1.6 - 0.002^{*} x + 0.000009^{*} x^2$ $R^2 = 0.99$
			TN (0.10-0.20 m)		
Poultry litter	1.6	1.7	1.4	1.5	$\bar{y}$ = 1.6
Pig slurry	1.6	1.6	1.6	1.7	$\bar{y}$ = 1.6
M1	1.6	1.6	1.6	1.6	$\bar{y}$ = 1.6
M2	1.6	1.6	1.6	1.7	$\bar{y}$ = 1.6
			TN (0.20-0.40 m)		
Poultry litter	1.4	1.6	1.5	1.5	$\bar{y}$ = 1.5
Pig slurry	1.4	1.5	1.5	1.8	$\hat{y} = 1.38 + 0.001^{*} x$ $R^2 = 0.71$
M1	1.4	1.6	1.5	1.6	$\bar{y}$ = 1.5
M2	1.4	1.5	1.5	1.7	$\bar{y}$ = 1.5

Means followed by different letters in columns at the same depth are different according to Student's t-test ($p<0.05$). Significance level ** ($p\leq0.01$) and * ($p\leq0.05$). M1 mineral treatment contained the same levels of these nutrients as the pig slurry, and the M2 mineral treatment, the same as the poultry litter.

Table 5. Phosphorus content in soil according to organic and mineral fertilizer application in integrated crop-livestock systems in 2013

ICL	N application rate (kg ha^{-1})				Equation
	0	100	200	300	
			P (0.00-0.05 m)		
		mg kg^{-1}			
Poultry litter	64.3	101.0 a	124.0 a	140.0 a	$\hat{y} = 70.33 + 0.25^{**} x$ $R^2 = 0.97$
Pig slurry	64.3	59.4 b	72.5 b	85.1 b	$\bar{y}$ = 70.3
M1	64.3	52.3 b	60.8 b	63.4 b	$\bar{y}$ = 60.2
M2	64.3	69.8 b	85.6 b	133.0 a	$\hat{y} = 54.99 + 0.22^{**} x$ $R^2 = 0.84$
			P (0.05-0.10 m)		
Poultry litter	61.3	76.9 a	108.0	111.0 a	$\hat{y} = 62.33 + 0.18^{**} x$ $R^2 = 0.92$
Pig slurry	61.3	58.6 ab	89.4	79.4 b	$\hat{y} = 59.39 + 0.08^{*} x$ $R^2 = 0.56$
M1	61.3	44.6 b	99.4	49.4 c	$\bar{y}$ = 63.7
M2	61.3	45.0 b	85.0	112.0 a	$\hat{y} = 57.78 - 0.13^{*}x + 0.001{*} x^2$ $R^2 = 0.91$
			P (0.10-0.20 m)		
Poultry litter	48.1	55.0	54.4 b	49.1 b	$\bar{y}$ = 51.6
Pig slurry	48.1	61.9	72.5 a	50.9 b	$\hat{y} = 46.67 + 0.28^{**}x - 0.0009^{**} x^2$ $R^2 = 0.89$
M1	48.1	41.3	51.1 b	56.0 b	$\bar{y}$ = 49.1
M2	48.1	52.0	32.9 c	108.0 a	$\hat{y} = 54.01 - 0.38^{*}x + 0.002^{**} x^2$ $R^2 = 0.79$
			P (0.20-0.40 m)		
Poultry litter	31.6	42.7 b	53.0 a	44.6	$\hat{y} = 30.65 + 0.19^{**}x - 0.0005^{**} x^2$ $R^2 = 0.93$
Pig slurry	31.6	41.0 b	53.6 a	43.8	$\hat{y} = 30.27 + 0.19^{**}x - 0.0005^{**} x^2$ $R^2 = 0.87$
M1	31.6	38.7 b	39.1 b	43.1	$\hat{y} = 32.83 + 0.03^{**} x$ $R^2 = 0.89$
M2	31.6	60.6 a	35.0 b	39.4	$\hat{y} = 35.78 + 0.18^{*}x - 0.00062^{*} x^2$ $R^2 = 0.30$

Means followed by different letters in columns at the same depth are different according to Student's t-test ($p<0.05$). Significance level ** ($p\leq0.01$) and * ($p\leq0.05$). M1 mineral treatment contained the same levels of these nutrients as the pig slurry, and the M2 mineral treatment, the same as the poultry litter.

Management practices that include organic fertilizers have positive effects on nutrient availability, making nutrients available to plants and microorganisms in the first year after application (Schomberg et al., 2009), and these practices are especially effective at making available those nutrients that are preferentially displaced through the process of diffusion, such as with P (Dao, 2014). Successive applications of organic fertilizers at amounts that exceed crop demand can lead to P movement in the soil profile (Hesketh and Brookes, 2000). Cassol et al. (2012) applied 200 m^3 ha^{-1} of manure and observed an increase in the extractable P content in the deeper layers, up to 0.40 m, showing evidence of the transfer of this element into deeper layers in a *Latossolo Vermelho*.

Thus, the results reported herein suggest that organic P in the poultry litter and in the pig slurry, due to higher soil inputs, allowed for different P availability dynamics compared to the paired mineral fertilizers, thus contributing more effectively to P availability in the soil.

The application of increasing amounts of N from organic and mineral fertilizers in the ICL system increased K content in the soil (Table 6), explained by the input of 194, 389, and 583 kg ha^{-1} K in the form of poultry litter and 99, 198, and 297 kg ha^{-1} K in the form of pig slurry in 2011 and by the input of 303, 606, and 909 kg ha^{-1} K from poultry litter and 147, 294, and 441 kg ha^{-1} K from pig slurry in 2012 (Table 2). The same amounts of K were applied through mineral fertilizers (M1 and M2) in the form of potassium chloride.

The treatments that significantly contributed to K content in the soil showed a trend toward a linear increase from poultry litter and pig slurry and a trend toward a quadratic increase from M1 in the 0.00-0.05 m layer, a trend toward a quadratic increase from M2 in the 0.05-0.10 and 0.20-0.40 m layers, and a trend toward a quadratic increase from manure and a linear increase from M1 in the 0.10-0.20 m layer (Table 6). Among the fertilizers at the same application rate, increased availability of K in the M2 and poultry litter treatments was present because of the higher initial levels of this nutrient applied to the system compared to the M1 and manure treatments (Table 2).

Table 6. Potassium content in soil according to organic and mineral fertilizers application in integrated crop-livestock systems in 2013

ICL	N application rate (kg ha^{-1})				Equation
	0	100	200	300	
					K_2O (0.00-0.05 m)
	mmol$_c$ kg^{-1}				
Poultry litter	14	16 b	19 a	20 a	$\hat{y} = 14.3 + 0.02^{**} x$ $R^2 = 0.95$
Pig slurry	14	10 c	10 c	9 c	$\hat{y} = 13.3 - 0.01^{**} x$ $R^2 = 0.80$
M1	14	9 c	13 b	14 b	$\hat{y} = 13 - 0.04^{*} x + 0.00014^{*} x^2$ $R^2 = 0.54$
M2	14	20 a	15 b	21 a	$\bar{y} = 17.5$
					K_2O (0.05-0.10 m)
Poultry litter	14	11 ab	20 a	14 b	$\bar{y} = 14.9$
Pig slurry	14	8 b	12 b	10 c	$\bar{y} = 11.2$
M1	14	10 b	14 b	13 b	$\bar{y} = 12.9$
M2	14	14 a	12 b	19 a	$\hat{y} = 15 - 0.05^{**} x + 0.0002^{**} x^2$ $R^2 = 0.83$
					K_2O (0.10-0.20 m)
Poultry litter	11	13 ab	12 ab	10 b	$\bar{y} = 11.5$
Pig slurry	11	7 c	8 c	10 b	$\hat{y} = 10 - 0.04^{**} x + 0.0001^{**} x^2$ $R^2 = 0.96$
M1	11	10 b	14 a	14 a	$\hat{y} = 10.30 + 0.01^{*} x$ $R^2 = 0.74$
M2	11	14 a	10 bc	14 a	$\bar{y} = 12.4$
					K_2O (0.20-0.40 m)
Poultry litter	9	11 b	13 c	10 c	$\bar{y} = 10.8$
Pig slurry	9	8 c	11c	9 c	$\bar{y} = 9.1$
M1	9	7 c	17 b	20 a	$\bar{y} = 13.2$
M2	9	16 a	22 a	14 b	$\hat{y} = 8.7 + 0.12^{**} x - 0.0004^{**} x^2$ $R^2 = 0.89$

Means followed by different letters in columns at the same depth are different according to Student's t-test (p<0.05). Significance level ** ($p \leq 0.01$) and * ($p \leq 0.05$). M1 mineral treatment contained the same levels of these nutrients as the pig slurry, and the M2 mineral treatment, the same as the poultry litter.

Increased K levels in the soil were observed by Scherer and Nesi (2009) when poultry litter or pig slurry was used, which added 117 and 55 kg ha^{-1} yr^{-1} of the nutrient, respectively. After 19 applications of manure, Lourenzi et al. (2013) observed an input of 303, 606, and 1212 kg ha^{-1} of K, and showed that the addition of increasing amounts of this organic fertilizer results in increases in the levels of K available in the 0.00-0.10 m layer. After 20 years of applying manure to an *Argissolo Vermelho*, Scherer et al. (2010) found increased levels of available K in both the surface and deeper layers. Similar results were observed by Adeli et al. (2008) and Ceretta et al. (2010), who emphasized that care that should be taken in the application of manure due to the mobility of K through percolation and runoff.

In comparisons of the organic and mineral fertilizers in the pairs (litter/M2 and manure/M1), increased P availability in the organic treatments and, conversely, increased K availability in the mineral treatments were often observed (Tables 5 and 6).

The application of increasing amounts of N from organic and mineral fertilizers in the ICL system increased corn yield in the 2011/12 and 2012/13 harvests (Table 7). These results can primarily be explained by increased P and K availability in the soil (Tables 5 and 6).

During the 2011/12 harvest, corn yields in the ICL system showed a linear increase for poultry litter and pig slurry and a quadratic increase for M1 and M2, where mineral fertilizers were superior to organic fertilizers at 100 and 200 kg ha^{-1} of N. As of 200 kg ha^{-1} of N, the pig slurry fertilizer was superior to the poultry litter fertilizer, and at 300 kg ha^{-1} of N, it was similar to the mineral fertilizers (Table 7).

A direct relationship between poultry litter and pig slurry fertilization and corn plant yields due to the availability of N and P in the system when using this agricultural practice were reported by Oliveira et al. (2009) and Novakowiski et al. (2013). Hanish et al. (2009) also reported a positive effect of poultry litter fertilization on corn yield when they compared the use of poultry litter to topdressing with natural urea.

Table 7. Maize yield according to application rates of nitrogen with organic and mineral fertilizers in integrated crop-livestock systems in 2011/2012 and 2012/2013 harvests

ICL	N application rate (kg ha^{-1})				Equation
	0	100	200	300	
					Crop 2011/2012
	Mg ha^{-1}				
Poultry litter	6,184	8,567 b	8,698 c	11,153 b	$\hat{y} = 6,394 + 15.0^{**}\ x\ \ R^2 = 0.91$
Pig slurry	6,184	8,410 b	11,753 b	14,629 a	$\hat{y} = 5,942 + 28.7^{**}\ x\ \ R^2 = 0.99$
M1	6,184	12,666 a	14,925 a	14,118 a	$\hat{y} = 6,242 + 80.7^{**}\ x - 0.182^{**}\ x^2\ \ R^2 = 0.99$
M2	6,184	11,516 a	14,219 a	15,621 a	$\hat{y} = 6,250 + 60.5^{**}\ x - 0.098^{*}\ x^2\ \ R^2 = 0.99$
					Crop 2012/2013
Poultry litter	3,327	6,485 ab	7,382	7,812	$\hat{y} = 3,416 + 34.8^{**}\ x - 0.07^{*}\ x^2\ \ R^2 = 0.99$
Pig slurry	3,327	6,904 a	7,702	8,826	$\hat{y} = 3,482 + 35.7^{**}\ x - 0.06^{*}\ x^2\ \ R^2 = 0.97$
M1	3,327	7,940 a	8,859	8,646	$\hat{y} = 3,455 + 53.1^{**}\ x - 0.120^{**}\ x^2\ \ R^2 = 0.98$
M2	3,327	5,378 b	8,250	9,065	$\hat{y} = 3,491 + 20.1^{**}\ x\ \ R^2 = 0.96$
					Total grain yield in the system
Poultry litter	9,511	15,051 b	16,079 c	18,964 b	$\hat{y} = 9,830 + 49^{**}\ x - 0.07^{**}\ x^2\ \ R^2 = 0.92$
Pig slurry	9,511	15,313 b	19,455 b	23,454 a	$\hat{y} = 9,587 + 59^{**}\ x - 0.04^{**}\ x^2\ \ R^2 = 0.91$
M1	9,511	20,605 a	23,783 a	22,763 a	$\hat{y} = 9,697 + 134^{**}\ x - 0.30^{**}\ x^2\ \ R^2 = 0.93$
M2	9,511	16,893 b	22,469 ab	24,686 a	$\hat{y} = 9,434 + 90^{**}\ x - 0.13^{**}\ x^2\ \ R^2 = 0.96$

Means followed by different letters in columns at the same depth are different according to Student's t-test ($p<0.05$). Significance level ** ($p \leq 0.01$) and * ($p \leq 0.05$). M1 mineral treatment contained the same levels of these nutrients as the pig slurry, and the M2 mineral treatment, the same as the poultry litter.

In the second growing season (2012/13 harvest), the use of increasing amounts of N showed a quadratic increase in corn yield from poultry litter, pig slurry and M1, and a linear increase from M2, whereas, at the 100 kg ha^{-1} rate of N application, the pig slurry and M1 treatments were superior to the M2 treatment (Table 7).

The nutrients supplied by pig slurry and the other favorable chemical, physical, and biological effects that manure has on the soil generally increase corn grain yields (Ceretta et al., 2005; Scherer, 2011). According to Sartor et al. (2012), corn grain production increases at a linear rate with the application of manure, with an increase of 59.9 kg ha^{-1} for each m^3 of manure applied.

When the positive corn yield results for both harvest years are combined and expressed as total production of the ICL system, the need for fertilizer recommendations to achieve high production levels is more evident (Table 7). Chantigny et al. (2007), in a study analyzing the application of 130 kg ha^{-1} of N to corn crops in the form of ammonium nitrate and pig slurry over 4 years, achieved an average of 9.3 Mg ha^{-1}, with mean yields that were 22 and 4 % higher than the control and mineral fertilizer, respectively.

CONCLUSIONS

Two years after implementing the integrated crop-livestock production system, the application of different amounts of N using organic (pig slurry and poultry litter) or mineral (M1 and M2) fertilizers increased corn yields and soil K and P availability with few changes in organic C and total N content.

There are similar efficiencies between the treatments pairs (pig slurry/M1 and poultry litter/M2).

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