



Division - Soil Use and Management | Commission - Soil Fertility and Plant Nutrition

Residual and immediate effect after 16 applications of organic sources on yield and nitrogen use efficiency in black oat and corn

Alessandra Bacca^{(1)*} , Carlos Alberto Ceretta⁽¹⁾ , Matheus Severo de Souza Kulmann⁽¹⁾ , Rodrigo Otavio Schneider Souza⁽¹⁾ , Paulo Ademar Avelar Ferreira⁽²⁾ , Lucas Antonio Telles Rodrigues⁽³⁾ , Carina Marchezan⁽¹⁾ , Luana Paula Garlet⁽¹⁾  and Gustavo Brunetto⁽¹⁾ 

⁽¹⁾ Universidade Federal de Santa Maria, Departamento de Ciência do Solo, Programa de Pós-Graduação em Ciência do Solo, Santa Maria, Rio Grande do Sul, Brasil.

⁽²⁾ Universidade Federal de Santa Maria, Departamento de Ciência do Solo, *Campus Cachoeira do Sul*, Rio Grande do Sul, Brasil.

⁽³⁾ Universidade Federal do Rio Grande do Sul, Departamento de Ciência do Solo, Programa de Pós-Graduação em Ciência do Solo, Porto Alegre, Rio Grande do Sul, Brasil.

ABSTRACT: Soils with a long-term history of animal manure application exhibit higher residual effects of nitrogen (N) in soil and can affect the efficiency with which N will be used. This study aimed to evaluate how the immediate and residual effect of 16 applications of animal manure reflects on yields of black oat and corn rotation system, as well as N use efficiency. The study was carried out in no-tillage from 2004 to 2016 in Brazil. The treatments were pig slurry (PS), dairy slurry (DS), pig deep-litter (PL), mineral fertilizer (MF), and control (C). Prior to the sowing of black oat, in which 16 animal manure applications had already been made, an area of the soil was delimited where the treatments were not applied. This area was referred to as unfertilized (U) soil. Applications were carried out in the remaining area and were referred to as fertilized (F) soil. The highest dry matter yield and N accumulation in black oat and corn were found in F soils treated with DS and PL, respectively. In corn, the highest grain yield and N accumulation in grains were found with DS and PS. In U soil, the 16 applications (of DS especially) resulted in yields and N accumulation greater than the control and MF, but lower than those in F. The highest N use efficiency was found with DS. The history of animal manure applications was not enough to rule out additional applications in the following years.

Keywords: animal manure, mineralization, soil residual N pool, application history.

*** Corresponding author:**

E-mail: alessandrabacca@gmail.com

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INTRODUCTION

Continuous applications of animal manure over several years may significantly change soil nitrogen (N) dynamics (Mallory and Griffin, 2007) and availability to plants (Müller et al., 2011). Studies show an increase in the organic N pool in soils with a long history of animal manure application, which may increase the residual effect of N in soil. This could reduce the need for additional applications of nitrogen sources (Zhang et al., 2012).

The availability of manure N is different from that of mineral fertilizers because N from mineral sources is readily available to crops (Gutser et al., 2005). Part of the manure N is present in organic fractions and gradually made available over time (Petersen et al., 2012). There are variations in N availability among the different types of manure. Liquid manure (slurry) contains most total N in ammonium form (NH_4^+) (Webb et al., 2013), some of which may be immobilized and become part of the residual organic pool and only available to subsequent crops (Suarez-Tapia et al., 2017). On the other hand, up to 90 % of N in solid manure is in organic form (Oliveira, 2000). Consequently, the use of manures containing more recalcitrant organic N may intensify the process of N availability of the residual pool in subsequent crops over time.

Although the effect of the use of manure on increasing crop yield is well reported, little is known about how the residual effect of the application history affects yield in subtropical conditions. Typically, little residual N may be available in the year after application. The study of Sørensen and Amato (2002) with ^{15}N -labeled pig manures showed that barley plants recovered only 1 to 5 % of the total N applied to the previous crop. However, the effect may be greater when the area has an intensive history of applications because the mineralization rate is enhanced in these areas due to the added organic N, affecting the residual N pool. Studies on the long-term use of animal manure have shown great influence on N availability and the ability of these areas to supply N to crops, even years after the end of the applications. This is especially due to changing the dynamics of NO_3^- (Mallory and Griffin, 2007; Müller et al., 2011).

The effect of the application history on N use efficiency is also an important parameter to help predict the economic return, considering the need for additional applications of N in these areas. However, few studies have attempted to evaluate these parameters in conditions of long-term manure applications. In an experiment with 15 years of application of manure and manure combined with other nutrients, Duan et al. (2011) found greater effect of manure on yield and N use efficiency (NUE), especially when there was phosphorus (P) addition. Duan et al. (2014) also found similar results regarding agronomic N use efficiency. Thus, considering the effect of application history on the need for additional applications of N may be an important strategy to increase N use efficiency in plants and reduce N losses to the environment (Hernández et al., 2013).

This study is based on the hypothesis that areas with a long-term history of animal manure applications, especially those with higher levels of organic N such as DS and PL, exhibit higher residual effects of N in soil and positively affect N use efficiency, reducing losses to the environment. The study aimed to evaluate how the immediate and residual effect of 16 applications of animal manure reflects on yields of black oat and corn, as well as N use efficiency.

MATERIALS AND METHODS

Description of the experimental area and treatments

The study was conducted in the 2015/2016 crop season of a long-term experiment installed in 2004 in the experimental area of the Department of Soil Science at the Federal University of Santa Maria (29° 42' 50.97" S, 53° 42' 25.10" W), located in the state of Rio Grande do Sul, Brazil. The climate of the region is classified as humid subtropical

(Cfa2), with an average annual temperature of 19.3 °C, rainfall of 1561 mm, and relative humidity of 82 %. The soil is classified as *Argissolo Vermelho Distrófico arênico* according to Brazilian Soil Classification System (Santos et al., 2018), which corresponds to Typic Hapludalf in the US Soil Taxonomy (Soil Survey Staff, 2014). The chemical properties of the soil prior to the installation of the experiment and the weather conditions during the conduction of the experiment are shown in table 1 and figure 1, respectively.

The treatments consisted of four organic sources and one mineral source of nutrients: (i) control (no fertilization); (ii) mineral fertilizer (MF) (urea + triple superphosphate +

Table 1. Chemical characterization of the soil at the layer of 0.00-0.10 m in each treatment before the start of this study in June 2015

Property	Control	MF ⁽¹⁾	PS	PL	DS
pH(H ₂ O) ⁽²⁾	4.2	4.3	4.6	5.2	4.7
Al ³⁺ (cmol _c dm ⁻³) ⁽³⁾	0.7	1.2	0.4	0.3	0.5
CEC _{pH 7.0}	5.5	7.3	6.4	8.0	6.2
Base saturation (%)	29.9	15.5	38.6	51.1	43.6
Total C (g kg ⁻¹) ⁽⁴⁾	7.63	8.63	9.23	15.42	11.46
Total N (g kg ⁻¹) ⁽⁴⁾	0.85	0.92	0.92	1.31	1.15
NO ₃ ⁻ (kg ha ⁻¹) ⁽⁵⁾	7.2	8.4	14.3	11.3	11.9
NH ₄ ⁺ (kg ha ⁻¹) ⁽⁵⁾	12.2	16.6	14.5	24.2	19.7
C/N	9.3	9.5	10.1	9.9	11.9
Clay (g kg ⁻¹) ⁽⁶⁾	108				
Silt (g kg ⁻¹)	183				
Sand (g kg ⁻¹)	709				

⁽¹⁾ MF: mineral fertilizer; PS: Pig Slurry; PL: pig deep-litter; DS: Dairy Slurry. ⁽²⁾ pH(H₂O) in a soil:solution ratio of 1:1, according Tedesco et al. (1995). ⁽³⁾ Extracted from the soil with KCl 1 mol L⁻¹, according Tedesco et al. (1995). ⁽⁴⁾ Determined by dry combustion using an elemental analyzer. ⁽⁵⁾ Extracted from the soil with KCl 1 mol L⁻¹ solution and quantified according to Tedesco et al. (1995). ⁽⁶⁾ Determined by densimeter method.

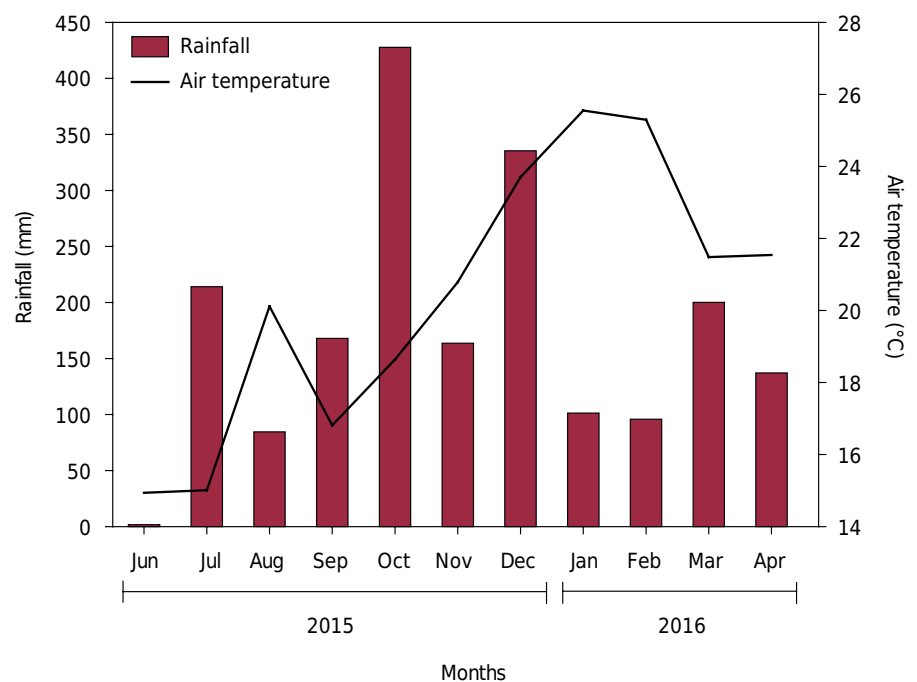


Figure 1. Average rainfall and air temperature during the cultivation of black oat (2015) and corn (2016).

potassium chloride); (iii) pig slurry (PS); (iv) dairy slurry (DS); and (v) pig deep-litter (PL). The liquid organic sources (PS and DS) applied were composed of urine, washing water from installations, feces, and food remain, which were stored in anaerobic tanks, while the PL was composed of rice husk, urine, feces, and food remain. From 2004 to 2009, the treatments were applied before the sowing of corn (*Zea mays* L.), in succession with black oat (*Avena strigosa* Schreb.) and radish (*Raphanus sativus* L.). As of 2010, applications were carried out twice a year, prior the sowing of the summer and winter crops, with the following successions: corn (*Zea mays* L.) and black oat (*Avena strigosa* Schreb.) in 2010/2011 and 2011/2012, corn (*Zea mays* L.), and common bean (*Phaseolus vulgaris* L.) in 2012/2013, and wheat (*Triticum* spp.) and corn (*Zea mays* L.) in 2013/2014. By the winter of 2015, 16 applications of each source were carried out. The design used in the experiment was randomized blocks and each plot has 25 m² (5 × 5 m), but for this study, an area of 4 m² (2 × 2 m) was delimited to evaluate the residual effect, remaining 21 m² to the analysis of the immediate effect of treatments on black oat and corn.

The dose of each organic source used in the study was determined based on crop N requirement and N use efficiency, according to the official recommendation of the CQFS-RS/SC (2004). As a result, 80 kg N ha⁻¹ was applied to black oat and 120 kg N ha⁻¹ to corn. Nitrogen use efficiency is the percentage of N that will be available in the first two crops after application. Prior to application, a sample of each manure was collected for chemical characterization. Nitrogen content was determined by the Kjeldahl method (Tedesco et al., 1995). Carbon content in manure was determined by dry combustion in an autoanalyzer (Flash EA 1112, Thermo Finnigan, Milan, Italy). Dry matter content of each manure each was obtained by drying manure in an oven with air forced circulation at 65 °C until reaching constant weight. The main characteristics of each source in each crop are shown in table 2. The treatments were applied to the soil surface without incorporation, as the soil management used in the study was no-tillage.

Management of black oat and corn in 2015/2016

Two crops were grown in crop season 2015/2016 (black oat in winter and corn in summer). Prior to the planting of black oat, an area of 4 m² (2 × 2 m) was delimited within each of the 25 m² that was not treated during the cultivation of black oat and corn. This area of 4 m² was referred to as unfertilized (U) soil in which we evaluated the residual effect of the 16 applications made since 2004. All nutrient sources were reapplied on the remaining area (21 m²) in both crops. This area was referred to as fertilized (F) soil, totaling 17 applications in the cultivation of black oat and 18 applications in corn,

Table 2. Characteristics and application rate of animal manure applied to black oat and corn

Manure	DM	Total C	Total N	TAN ⁽¹⁾	C/N	TAN-N	Nitric N	Rate
	g kg ⁻¹				% total N	g kg ⁻¹	m ³ ha ⁻¹	
Black oat								
PS	17.6 (628.3) ⁽²⁾	5.2 (185.6)	2.7 (96.4)	1.6 (57.1)	1.9	59.3	-	35.7
DS	40.5 (2385.5)	13.8 (812.8)	1.4 (82.5)	0.3 (17.7)	9.8	23.6	-	58.9
PL	718.0 (11135.1)	122.8 (1903.0)	5.9 (91.5)	0.1 (1.6)	20.8	1.9	0.5 (7.8)	15.5 ⁽³⁾
Corn								
PS	19.1 (412.6)	6.0 (112.3)	5.7 (123.1)	2.6 (56.1)	1.1	45.6	-	21.6
DS	22.8 (3388.1)	14.2 (2110.1)	1.4 (214.0)	0.4 (59.4)	10.1	27.7	-	148.6
PL	719.0 (15314.7)	121.8 (2594.3)	8.32 (177.2)	0.2 (4.26)	14.6	2.4	1.9 (40.47)	21.3 ⁽³⁾

⁽¹⁾ Nitrogen as total ammoniacal nitrogen. PS: pig slurry; DS: dairy slurry; PL: pig deep-litter. ⁽²⁾ Values in parentheses represent the application rate (kg ha⁻¹). ⁽³⁾ Application rate in Mg ha⁻¹ in the PL.

respectively. Black oat was sown on July 20, 2015 (19 days after manure application) in an amount equivalent to 120 kg ha⁻¹ of seeds. The seeds were broadcast by hand on the soil surface without incorporation. Corn was sown by hand on November 16, 2015 (six days before manure application), with a row spacing of 0.60 m.

Evaluation of black oat and corn in 2015/2016

In October 2015, when black oat was at the stage of full flowering, plant shoots were cut close to the soil surface in areas of 0.5 and 0.25 m² in F and U soils, respectively. At the stage of physiological maturation in April 2016, five plants in F soil and three plants in U soil were collected to determine dry matter yield. Corn grains were collected in plants located in a useful area of 11.9 m² and the entire area (4 m²) in F and U soils, respectively. The above-ground biomass of black oat and corn as well as the grains of corn were dried in an oven with forced air circulation at 65 °C until a constant weight was reached. Samples of dry grain and shoot dry matter were ground. The tissue was prepared and subjected to total N analysis by dry combustion in an autoanalyzer (Flash EA 1112, Thermo Finnigan, Milan, Italy).

Estimation of the residual effect of organic sources and mineral fertilizer

The residual effect (RE) (Equation 1) of organic sources and mineral fertilizer on DM yield of black oat and grain yield of corn was estimated by equation 1, proposed by Cela (2011):

$$RE (kg ha^{-1}) = Y - Y_0 \quad \text{Eq. 1}$$

in which Y is the yield with fertilization and Y₀ is the yield without fertilization.

Parameters of N use efficiency and N balance

Partial Factor Productivity (PFP) (Equation 2), agronomic N use efficiency (ANUE) (Equation 3), apparent N recovery efficiency (ANRE) (Equation 4), physiological N use efficiency (PNUE) (Equation 5), and nitrogen harvest index (NHI) (Equation 6) were calculated according to Kurai et al. (2015):

$$PFP (kg kg N^{-1}) = \frac{Y}{F} \quad \text{Eq. 2}$$

in which Y is the grain yield with fertilization and F is the amount of N applied;

$$ANUE (kg kg N^{-1}) = \frac{(Y - Y_0)}{F} \quad \text{Eq. 3}$$

in which: Y is the grain yield with fertilization; Y₀ is the yield of the control treatment; and F is the amount of N applied;

$$ANRE (\%) = \frac{(U - U_0)}{F} \times 100 \quad \text{Eq. 4}$$

in which U is the total N in shoots with fertilization; U₀ is the total N in shoots of the control treatment; and F is the amount of N applied;

$$PNUE (kg kg N^{-1}) = \frac{(Y - Y_0)}{(U - U_0)} \quad \text{Eq. 5}$$

in which: Y is the grain yield with fertilization; Y₀ is the yield of the control treatment; U is the total N in shoots with fertilization; and U₀ is the total N in shoots of the control treatment;

$$NHI (\%) = \frac{TNG}{TNG + G} \quad \text{Eq. 6}$$

in which TNG is total N in grains and TNS+G = total N in shoots plus grains.

Nitrogen surplus and N balance (Equations 7 and 8) were calculated according to Zhang et al. (2016):

$$N \text{ surplus } (kg \text{ ha}^{-1}) = N_F + N_A \quad \text{Eq. 7}$$

$$N \text{ balance } (kg \text{ ha}^{-1}) = (N_F + N_{RIN}) - (N_A + N_{ROUT}) \quad \text{Eq. 8}$$

in which N_F is fertilized N; N_A is N uptake; N_{Rin} is N contained in residues of the previous crop; and N_{Rout} is N contained in crop residues of the year.

Statistical analysis

Data of PNUE, NHI, ANUE, ANRE, N surplus and N balance, RE, and yield, dry matter yield, and N accumulation were submitted to analysis of variance in SISVAR software, version 4.0 165 (Ferreira, 2008). Means of the treatments were compared by the Scott-Knott test at 5 %.

RESULTS

Dry matter yield, N accumulation, grain yield, and residual effect

The parameters of productivity of black oats and corn were changed by treatments and application methods (F and U) (Table 3). The DS provided increases in dry matter yield of black oat of 39 and 31 % in F and U soils compared to both soils treated with MF. The highest dry matter yield of corn was found in plants grown in F soil with PL, which was 1.43 times greater than those grown in F soil with MF. In U soil, dry matter yield of corn did not differ statistically among the organic sources (Table 4). The highest accumulations of N were found in shoots of black oat grown in F and U soils treated with DS. On the other hand, the highest accumulations of N in corn were found in plants grown in both soils with PL and DS. The highest corn yields were found in F and U soils treated with PS and DS. The fertilization of soil with PS and DS provided increases in yield of 140 and 151 % in comparison to the control treatment. The PS and DS in U soil promoted increased corn yields of 2.03 and 1.92 times in relation to the control treatment, respectively. The highest accumulations of N in grains were found in F soil treated with DS and U soil with DS and PS.

Parameters of N use efficiency in corn and black oat

The highest values of PFP, ANUE, and ANRE were found in black oat grown in F soil treated with DS. In corn, the highest values of PFP and ANUE were found in F soil with DS and PS. In U soil, DS also stood out in regards to the residual effect (RE) on DM yield and N accumulation in shoots of both crops, although it did not differ from U soil treated with PS in corn (Table 5). The residual effect of DS on DM yield and N accumulation in shoots was 2.70 and 3.14 times greater than the soil treated with MF. The values of PNUE in black oat did not differ statistically between treatments in F and U soils (Figure 2a). However, the treatments DS and PL presented, respectively, the highest values of PNUE in F soil when compared to U soil (Table 3). In comparing each treatment in F and U soils in the cultivation of corn, we found the highest values of PNUE with the application of PS in F soil and of MF in U soil. In F soil in corn, the values of the PNUE ranged from 35.8 to 51.4 kg N, in which the highest value was found in plants grown in F soil treated with PS (Figure 2b). On the other hand, in U soil, the highest value of PNUE was found in plants grown with MF. The PNUE values did not differ between the plants grown in F and U soils with DS. The nitrogen harvest index (NHI) of corn showed that plants grown in soil treated with PS and DS had higher NHI values and were more efficient in transferring N absorbed during growth to the grains (Figure 3).

Table 3. Analysis of variance (ANOVA) for treatments and application methods (fertilized and unfertilized) and the interaction in the black oat and corn crops

Variable	Effects		
	Treatment (T)	Application mode (A)	T × A
Black oat			
<i>Production parameters</i>			
Dry matter	*	*	*
N accumulation in shoots	*	*	*
<i>Parameters of N use efficiency</i>			
PNUE	ns	*	ns
Corn			
<i>Production parameters</i>			
Dry matter	*	*	*
N accumulation in shoots	*	*	*
Grain yield	*	*	*
N accumulation in grain	*	*	*
<i>Parameters of N use efficiency</i>			
PNUE	*	*	*
HNI	*	ns	*

 ns: not significant. *: significant at $p < 0.05$.

Table 4. Dry matter yield and N accumulation in shoots of black oat and corn, and grain yield and N accumulation in grains of corn grown in fertilized and unfertilized soils

Application	Control	MF	PS	PL	DS
Black oat					
Dry matter yield					
Fertilized (kg ha^{-1})	786	3294 aB	3608 aB	3389 aB	4581 aA
Unfertilized (kg ha^{-1})	-	1437 bB	1420 bB	1422 bB	1885 bA
Fertilized/Unfertilized (%)	-	129	154	138	143
N accumulation in shoots					
Fertilized (kg ha^{-1})	14.1	64.0 aC	68.1 aB	60.9 aC	74.7 aA
Unfertilized (kg ha^{-1})	-	28.2 bB	25.8 bB	28.2 bB	37.7 bA
Fertilized/Unfertilized (%)	-	128	161	117	97
Corn					
Dry matter yield					
Fertilized (kg ha^{-1})	3189	5697 aC	5594 aC	8202 aA	6606 aB
Unfertilized (kg ha^{-1})	-	3372 bB	4403 bA	4713 bA	4954 bA
Fertilized/Unfertilized (%)	-	69	27	74	33
N accumulation in shoots					
Fertilized (kg ha^{-1})	21.5	43.5 aC	44.9 aC	75.8 aA	54.0 aB
Unfertilized (kg ha^{-1})	-	23.8 bC	32.8 bB	48.0 bA	44.0 bA
Fertilized/Unfertilized (%)	-	83	37	58	23
Grain yield					
Fertilized (kg ha^{-1})	3042	6370 aB	7328 aA	6631 aB	7638 aA
Unfertilized (kg ha^{-1})	-	4075 bC	6169 bA	4901 bB	5836 bA
Fertilized/Unfertilized (%)	-	56	19	35	31
N accumulation in grain					
Fertilized (kg ha^{-1})	32.8	84.7 aC	99.2 aB	82.9 aC	114.2 Aa
Unfertilized (kg ha^{-1})	-	47.2 bC	79.3 bA	55.9 bB	78.4 bA
Fertilized/Unfertilized (%)	-	79	25	48	46

 Mean values followed by the same uppercase letters compare the treatments within fertilized soil as well as those within unfertilized soil, and lowercase letters compare the fertilized and unfertilized conditions in each treatment by the Scott-Knott test ($p < 0.05$). MF: mineral fertilizer; PS: pig slurry; PL: pig deep-litter; DS: dairy slurry.

Nitrogen surplus and N balance

Nitrogen surplus and N balance was only determined in F soil and were positive when using animal manure and MF, both in black oat and corn (Figure 4). In black oat, the highest N surplus was found in soil treated with PL, followed by MF, PS, and DS, while it was negative ($-14.03 \text{ kg N ha}^{-1}$) in the control soil. In corn, the highest N surplus values were found with PL and MF (37.1 and $35.2 \text{ kg N ha}^{-1}$, respectively), followed by PS and DS (20.7 and 5.8 kg N ha^{-1}). The highest value of N balance in black oat was found in soil

Table 5. Parameters of N use efficiency and residual effect on dry matter (DM) yield and N accumulation in shoot DM after the use of organic sources and a mineral fertilizer in the cultivation of black oat and corn

Source	Fertilized			Unfertilized	
	PFP	ANUE	ANRE	RE	
	kg kg ⁻¹		%	DM	N in DM
			kg ha ⁻¹		
Black oat					
MF	41.2 b	31.4 b	62.4 c	652 b	14.2 b
PS	45.1 b	35.3 b	67.5 b	635 b	12.0 b
PL	42.4 b	32.5 b	58.5 d	636 b	14.1 b
DS	57.3 a	47.4 a	75.5 a	1099 a	24.0 a
Corn					
MF	53.1 b	27.8 b	43.3 c	1033 c	14.5 c
PS	62.8 a	37.4 a	55.5 b	3126 a	46.3 a
PL	55.3 b	29.9 b	41.8 c	1859 b	23.2 b
DS	63.7 a	38.3 a	67.8 a	2794 a	45.6 a

Means followed by the same letters do not differ from each other by the Scott-Knott test ($p < 0.05$). MF: mineral fertilizer; PS: pig slurry; PL: pig deep-litter; DS: dairy slurry; PFP: partial factor productivity; ANUE: agronomic nitrogen use efficiency; ANRE: apparent nitrogen recovery efficiency; RE: residual effect.

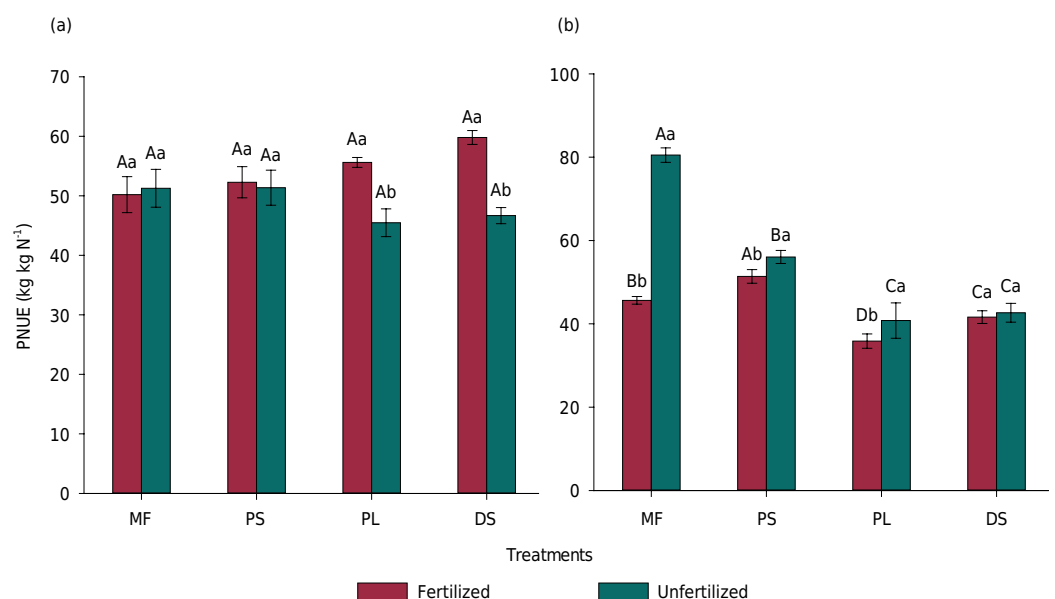


Figure 2. Physiological N use efficiency (PNUE) in black oat (a) and corn (b) grown with and without the application of organic sources and mineral fertilizer. Mean values followed by the same uppercase letters compare the treatments within fertilized soil as well as those within unfertilized soil, and lowercase letters compare the fertilized and unfertilized conditions in each treatment [Scott-Knott ($p < 0.05$)].

treated with PS, followed by PL, MF, DS, and the control soil (Figure 4). In corn, the highest values of N balance were found in soil treated with PL and MF, followed by PS and DS.

DISCUSSION

Dry matter yield, N accumulation, grain yield, and residual effect

The results of yield and N accumulation in shoots of black oat and corn as well as yield and N accumulation in grains of corn (Table 4) showed the need for additional

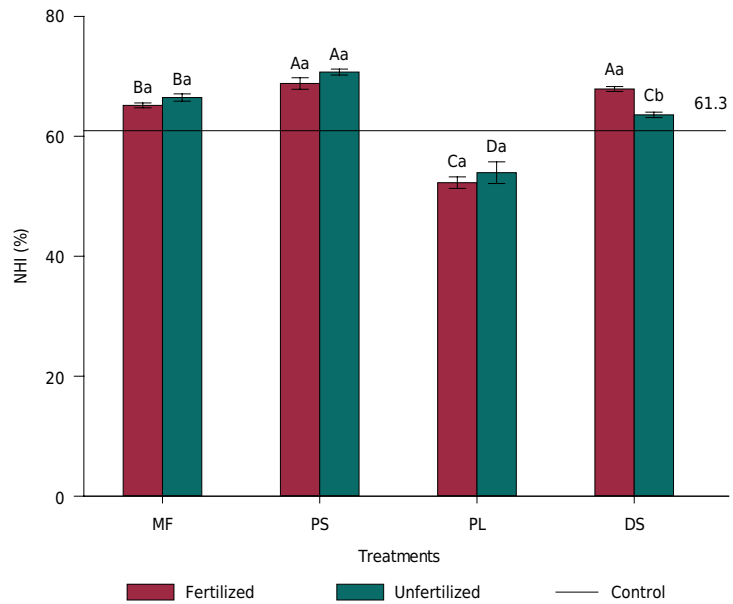


Figure 3. Nitrogen harvest index (NHI) in corn grown with and without the application of different organic sources and mineral fertilizer. Mean values followed by the same uppercase letters compare the treatments within fertilized soil as well as those within unfertilized soil, and lowercase letters compare the fertilized and unfertilized conditions in each treatment [Scott-Knott ($p < 0.05$)].

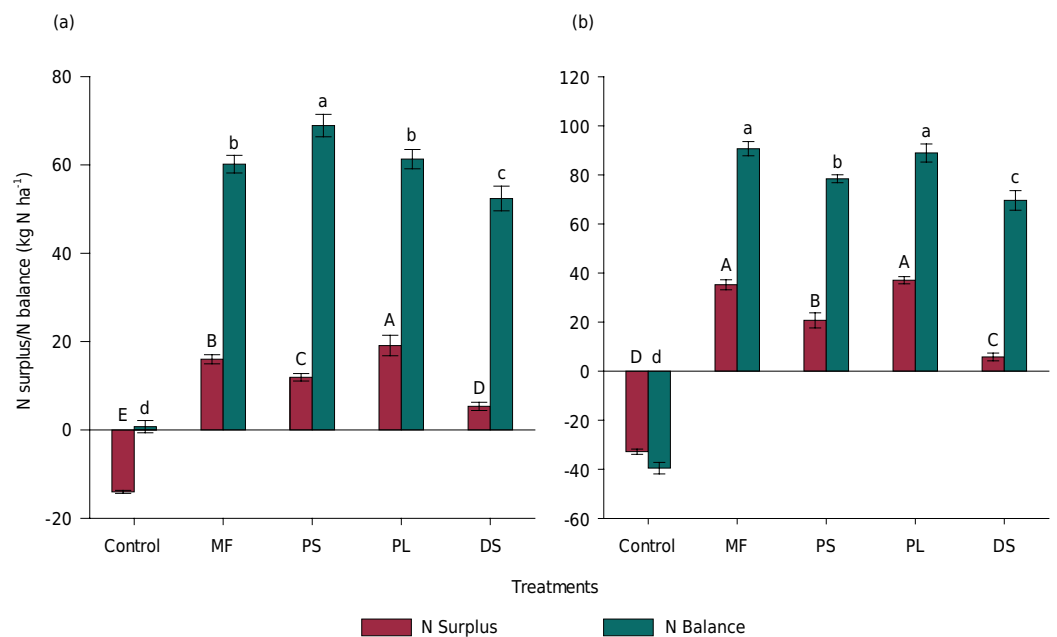


Figure 4. Nitrogen surplus and N balance in black oat (a) and corn (b) grown with the application of different organic sources and a mineral fertilizer. Means followed by the same uppercase or lowercase letters do not differ by the Scott-Knott test ($p < 0.05$).

manure applications, even in a soil with a history of 16 applications of animal manure in 11 years. Manure applications in black oat and corn promoted better results than in soil treated with MF for all the variables evaluated in this study, both in F and U soils. This may have happened because, unlike MF, the use of animal manure promotes the addition of several soil nutrients (P, K, Ca, and Mg), which can be absorbed by plants, stimulating crop growth and yield (Duan et al., 2014). Moreover, animal manure increases total organic carbon (TOC) input in soils, which may increase cation exchange capacity (Lourenzi et al., 2011; Miller et al., 2016). As a result, there is an increase in nutrient adsorption, which increases availability and reduces losses by leaching (Miller et al., 2016). Manure applications increase mineral N forms such as NH_4^+ and NO_3^- in soils. These forms can be absorbed by plants, in addition to adding organic N, which can be mineralized and contributes to increasing mineral N forms in the soil solution over time (Müller et al., 2011; Hernández et al., 2013; Wang et al., 2017).

The results of dry matter yield and N accumulation in shoots were higher in corn than in black oat (Table 4). The fact that corn is grown in summer contributes to these results, because temperatures of the air and soil are higher. This increases the activity of the microbial population, which promotes the mineralization of soil organic matter and the availability of N forms to plants (Hartmann et al., 2014; Treat et al., 2016).

The lowest residual effect of PL on grain yield and N accumulation in corn grains (Tables 4 and 5) can be explained in part because, although more organic N and C were added to soil with 17 (black oat) and 18 (corn) applications of PL (Table 6), there was no increase in N use efficiency to promote greater grain yield and N accumulation in comparison to PS and DS. Yet, another explanation may be the fact that the total C added via PL was 148 and 588 % higher than with DS and PS from 2004 to 2014, respectively (Table 6). In addition, total C added via PL from 2004 to 2014 was 18.5 times higher than total N, while this ratio was 6.6 and 2.7 times higher with DS and PS, respectively. Therefore, due to its composition, PS adds a large amount of organic N and a low amount of mineral N. Consequently, there may have been an increase in soil C/N ratio after 16 applications. Thus, the presence of lignin in the rice husk may have promoted a high immobilization rate, decreasing the amount of N available to plants. This would affect N content in tissue and grains and consequently yield.

The values of yield and N accumulation, especially in corn, show that the organic sources were more efficient than MF (Table 4). The values found in MF treatment in F soil and the RE value calculated (Table 5) were lower than those found in U soil, which is in line with other studies (Petersen et al., 2012; Riley, 2016). Although the immediate application of animal manure has been positively represented in literature, studies using ^{15}N isotopes in manure have shown that most of the N absorbed by plants is derived from the soil and not from the N added to the crop (Nyiraneza et al., 2010; Gonzatto et al., 2016). Therefore, part of the ammonium N fraction of the manures and of the N added via MF during cultivation may be lost by volatilization (Basso et al., 2004;

Table 6. Total carbon, nitrogen, and dry matter added to each treatment from 2004 to 2014

Treatment	Urea and animal manure			Crop residue		
	Dry matter	Nitrogen	Carbon	Dry matter	Nitrogen	Carbon
	Mg ha ⁻¹					
Control	-	-	-	73.1	0.5	34.3
MF	-	1.31	-	115.8	0.8	53.4
PS	22.8	1.73	6.3	155.3	1.2	72.9
PL	162.9	2.24	43.5	139.9	1.1	65.0
DS	74.7	2.31	17.5	132.7	1.0	61.8

MF: mineral fertilizer; PS: pig slurry; PL: pig deep-litter; DS: dairy slurry.

Aita et al., 2015), nitrous oxide (N₂O) emission (Aita et al., 2015; Lazcano et al., 2016), leaching (Giroto et al., 2013), surface runoff (Ceretta et al., 2010), and/or immobilized in soil microbiota (Wang et al., 2017). In this study, it is likely that N losses by leaching may have been more significant in the cultivation of black oat. This is because the soil has a sandy texture and low organic matter content, and also because there was rainfall of 114 mm from the day of application of the treatments until sowing and of 100 mm one day after sowing. Moreover, more intense rainfall events were observed in the months of September and especially October (Figure 1). This may explain the higher response of black oat to the reapplication of treatments (Table 4). This situation shows the importance of better understanding N dynamics, especially in subtropical and tropical regions. The results found in the cultivation of corn showed that a total of 123 kg N ha⁻¹ was applied to F soil (Table 2) and there was a difference in yields between F and U soils with PS of only 1159 kg ha⁻¹. In other words, part of the N applied may have been lost and/or immobilized.

Parameters of N use efficiency

The PFP, ANUE, and ANRE were higher in black oat and corn grown in F soil, which stresses the need for the reapplication of manure, as already observed in values of DM yield and N accumulation. The highest dry matter yield and N accumulation in shoots of black oat grown in F and U soils treated with DS can be attributed to the highest levels of N use efficiency (Table 5). This is true even if the total amount of N applied via DS in soil was somewhat lower than those applied via PS and PL (Table 2). In the cultivation of corn, DS also promoted higher values of dry matter yield compared to PS in most situations (Table 4). In this case, although the total amount of N applied via DS was 74 % higher than that of PS in the cultivation of corn, the amount of total C added by DS was 18.8 times higher than that of PS (Table 2). In fact, this can be seen in analyzing the residual effect (RE), because the amount of total N added via DS was 34 % higher than via PS, even if latter added 177 % more C (Table 6). This may have stimulated N immobilization in PS by the microbial population (Wang et al., 2017), but not enough to differentiate PS and DS in relation to PFP, ANUE, and ANRE in corn (Table 5). The ANUE is one of the main factors to evaluate the efficiency of the cropping system in making N available to plants. Values between 10-30 kg N kg⁻¹ have been found in literature, and cropping systems with 25-30 kg N kg⁻¹ are considered well managed, i.e., with great synchronicity between availability in soil and crop demand (Vanlauwe et al., 2011). In both black oat and corn, the use of DS showed the highest values of ANUE (47.4 and 38.3 kg N kg⁻¹, respectively). This indicates that the application history of DS produced adequate conditions for better use of N by plants. The highest dry matter yield, grain yield, and N accumulation in corn grown in soil with the highest residual effect after 16 applications of DS and PS can also be explained by the highest value of PFP. This is because this indicator shows that plants treated with DS and PS had greater efficiency in converting N absorbed, N added, and N accumulated in soil (Zhang et al., 2016).

The highest value of ANUE in black oat treated with DS shows that the plants were more efficient in recovering N, with an average value of 47.4 kg N kg⁻¹ (Table 5). Previous studies exhibit ANUE values of 10-30 kg N kg⁻¹ for cereals. Values above 30 kg N kg⁻¹ can be found in well-managed systems with conservation practices and adequate fertilization management (Vanlauwe et al., 2011). In soil treated with DS, we also found greater synchronicity between plant N demand and the amount available in soil. Therefore, it was the source that best allowed plants to recover N at the end of the crop cycle (Peng et al., 2012), because it had the highest ANRE value (Table 5).

In evaluating the balance between N inputs and outputs, black oat, and corn plants showed a better balance with the use of N derived from DS. This shows greater efficiency in the use of N, which ensured higher yields and consequently lower losses of N. This is because the values of N surplus and N balance were lower with the use of DS (Figure 4).

This is perhaps the reason NHI was higher with the use of DS, which shows that corn plants were efficient in transferring a large amount of the absorbed N to grains in U soil (Figure 3) (López-Bellido and López-Bellido, 2001; Ciampitti and Vyn, 2012). On the other hand, when corn was grown in soil treated with PL, a small amount of the absorbed N was transferred to grains (Figure 3). This result points to the fact that corn plants treated with PL exhibited the highest dry matter yield and N accumulation in tissue, but had the lowest grain yields and N accumulation in grains (Table 4). Therefore, it is likely that an application of mineral N in corn combined with the use of PL may provide a significant increase in grain yield and N accumulation in grains.

CONCLUSIONS

Reapplication of pig deep-litter, pig slurry, and dairy slurry is required for each new crop, even in areas with a history of 16 applications in 11 years.

The immediate and residual effects of dairy slurry and pig slurry stood out in relation to pig deep-litter, while there was no residual effect of MF on all the yield variables evaluated in this study, conducted on sandy soil. On the other hand, the cultivation of summer crops may benefit more from the residual effect of manure applications, because of the increase in the temperatures of the air and soil, and the activity of the microbial population, compared to winter crops.




Pig deep-litter was less efficient than pig slurry and dairy slurry in making N available to crops, because it has a high amount of C, resulting in lower mineral N content in the soil as a possible consequence of microbial immobilization. This suggests the need for a strategy to complement mineral N in cultivating grasses such as corn with an application of pig deep-litter.



The parameters of N use efficiency showed that there is a relationship of dependence between the amounts of N and C added via organic sources in soil. This shows that the addition of more N by the organic sources does not necessarily mean greater N accumulation in plant tissues and transport to grains.



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AUTHOR CONTRIBUTIONS

Conceptualization:  Alessandra Bacca (equal),  Carlos Alberto Ceretta (equal), and  Paulo Ademar Avelar Ferreira (equal).





Methodology:  Alessandra Bacca (lead) and  Paulo Ademar Avelar Ferreira (lead).

Formal analysis:  Alessandra Bacca (equal) and  Paulo Ademar Avelar Ferreira (equal).

Investigation:  Alessandra Bacca (lead),  Matheus Severo de Souza Kulmann (equal),  Rodrigo Otavio Schneider Souza (equal),  Paulo Ademar Avelar Ferreira (equal),  Lucas Antonio Telles Rodrigues (equal),  Carina Marchezan (equal), and  Luana Paula Garlet (equal).

Data curation:  Alessandra Bacca (lead).

Writing - original draft:  Alessandra Bacca (lead).

Writing - review and editing:  Alessandra Bacca (lead),  Carlos Alberto Ceretta (equal),  Paulo Ademar Avelar Ferreira (equal), and  Gustavo Brunetto (equal).

Visualization:  Alessandra Bacca (lead).

Funding acquisition:  Carlos Alberto Ceretta (lead) and  Gustavo Brunetto (lead).

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