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Strategies for fertilization with pig and cattle slurry in wheat crop

Júnior M. Damian[1], Dionei S. Muraro[2], Claudir J. Basso[3], Alieze N. da Silva[2], Marlo A. B. Pinto[2] & Antônio L. Santi[3]

[1] Universidade de São Paulo/Escola Superior de Agricultura "Luiz de Queiroz". Piracicaba, SP. E-mail: damianjrm@usp.br (Corresponding author) - ORCID: 0000-0002-1692-6751
[2] Universidade Federal de Santa Maria. Santa Maria, RS. E-mail: dioneimuraro@gmail.com - ORCID: 0000-0003-1476-3108; alieze.agro@rocketmail.com - ORCID: 0002-0003-3253-0885; marlo.bison@gmail.com - ORCID: 0002-0003-1567-8490
[3] Universidade Federal de Santa Maria/Campus de Frederico Westphalen. Frederico Westphalen, RS. E-mail: claudirbasso@gmail.com - ORCID: 0000-0002-3013-5702; santi_pratica@yahoo.com.br - ORCID: 0000-0002-4773-4912

Key words:
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A B S T R A C T

This study aimed to evaluate the effect of different managements with pig slurry (PS) and cattle slurry (CS) on wheat dry matter and grain yields, and the potential to estimate this variation with the NDVI (normalized difference vegetation index) and NDRE (normalized difference red edge index) vegetation indices. The experiment was conducted in Frederico Westphalen-RS, Brazil, in a randomized block experimental design, in a 2 x 7 factorial scheme with four replicates and seven forms of surface and subsurface application, with and without the use of the dicyandiamide (DCD) nitrification inhibitor, distributed as follows: control without application of slurry and DCD; control without application of slurry and DCD, but scarified only with the injection machine; surface application; surface application with DCD; subsurface injection; subsurface injection with DCD; and application of NPK in mineral form. At flowering of the wheat crop, dry matter was collected and readings of NDVI and NDRE were taken, and finally grain yield was quantified. For PS and CS, best results of dry matter and grain yields were found in managements with subsurface injection and subsurface injection with DCD, respectively. Among the vegetation indices, only NDVI was efficient to estimate variations in the management using CS for wheat dry matter and grain yields.

Palavras-chave:
Triticum aestivum L.
resíduos orgânicos
NDVI
NDRE

Estratégias para adubação com dejeto líquido de suíno e de bovino na cultura do trigo

R E S U M O

Este estudo teve como objetivo avaliar o efeito de diferentes manejos com dejeto líquido de suíno (DLS) e bovino (DLB) na produtividade de matéria seca e de grãos da cultura do trigo e o potencial de estimativa dessa variação com os índices de vegetação NDVI (índice de vegetação da diferença normalizada) e NDRE (índice de vegetação da diferença normalizada pelo red-edge). O experimento foi conduzido em Frederico Westphalen, RS, no delineamento experimental blocos ao acaso, em esquema fatorial 2 x 7, com quatro repetições, sendo duas fontes (DLS e DLB) e sete formas de aplicação superficial e subsuperficial, com e sem o uso de dicianodiamida (DCD), ficando assim distribuídos: testemunha sem aplicação de dejetos e DCD; testemunha sem aplicação de dejetos e DCD, porém apenas escarificada com a máquina de injeção; aplicação dos dejetos em superfície; aplicação dos dejetos em superfície com DCD; injeção dos dejetos em subsuperfície; injeção dos dejetos em subsuperfície com DCD; e aplicação de NPK na forma mineral. No florescimento da cultura do trigo, realizou-se a coleta de matéria seca e as leituras de NDVI e NDRE, e por fim, quantificou-se a produtividade de grãos. Constatou-se que, para DLS e DLB, os melhores resultados em produtividade de matéria seca e de grãos foram para os manejos com injeção em subsuperfície e com injeção em subsuperfície com DCD respectivamente. Dos índices de vegetação, apenas o NDVI foi eficiente em estimar as variações no manejo para a fonte DLB para a produtividade de matéria seca e de grãos do trigo.

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Introduction

Pork is the most consumed meat in the world, representing more than 36% of the global meat consumption, and beef also has a significant share, corresponding to 22% of the total meat consumption in the world (FAO, 2016). However, with the increasing environmental concern in the most varied sectors of economy, in cattle and pig livestock activities an adequate destination has been required for the residues generated, especially the wastes.

The main destinations include the use of these wastes as organic fertilizers, and studies have reported that they can promote numerous benefits of physical, chemical and biological nature in the soil. Silva et al. (2006) report benefits in the increments of soil organic matter, water retention, contents of phosphorus and potassium and corn yield, with the use of these wastes. Nevertheless, although it is an alternative for these wastes, their use as organic fertilizer requires caution in the management, especially due to environmental problems. The main environmental concerns regarding the use of animal wastes as organic fertilizers particularly include losses of nitrogen (N) through leaching of nitrate (NO_3^-) and volatilization of ammonia (NH_3) and nitrous oxide (N_2O) (Meade et al., 2011). Thus, studies still frequently aim to clarify issues regarding the doses of wastes (Maia Filho et al., 2013), methods and forms of application (Schröder et al., 2015), as well as ways to minimize N losses in the environment with the use of these wastes (Ekpo et al., 2016).

Strategies such as waste incorporation into the soil, besides splitting the recommended dose, may result in significant reduction of NH_3 volatilization (Dell et al., 2012). Recently, nitrification inhibitors have been used during waste application, which may act in the reduction of N_2O emissions, and dicyandiamide is among the most used (Zaman et al., 2009).

In this context, when the objective is to optimize and quantify the efficiency of the management with pig and cattle wastes as source of nutrients, it is recommended to use technologies that are efficient in rapidly meeting these goals (Gebrezgabher et al., 2015). Thus, vegetation indices can be useful tools to assist the decision-making regarding the use of wastes in agricultural crops that are demanding in the nutritional management, such as the wheat crop. The normalized difference vegetation index (NDVI) and the normalized difference red-edge index (NDRE) are widely recommended for this purpose, due to their simplicity and close relationship with crop yield, and also for being indicators of anomalies caused by water stress, attack of pests and diseases, and nutritional stress (Tian et al., 2015).

Given the above, this study aimed to evaluate the effect of different managements with pig slurry (PS) and cattle slurry (CS) on wheat dry matter and grain yields. In addition, the study aimed to verify the potential of the NDVI and NDRE vegetation indices to estimate the variations in wheat dry matter and grain yields caused by the managements with PS and CS.

Material and Methods

The study was carried out at the experimental area of the Federal University of Santa Maria, Campus of Frederico Westphalen-RS, Brazil (27º 23' 58" S; 53º 25' 22" W; 566 m) from July to November 2015. The climate of the region is humid subtropical with hot summer, Cfa, with maximum temperatures equal to or higher than 22 °C, minimum temperature between -3 and 18 °C, and mean annual rainfall from 1,900 and 2,200 mm (Alvares et al., 2013).

Two experiments were installed in the same experimental area and under the same conditions of climate, relief and soil: one using pig slurry (PS) and the other using cattle slurry (CS). Both areas had been under waste application for two years. The soils of the areas were characterized as typic alumino-ferric Red Latosol (Santos et al., 2013), cultivated under direct planting system (DPS) for 12 years, basically with wheat, soybean and corn (last crops before installing the experiments). Prior to the experiments, the soils of both areas were characterized physically and chemically, according to the recommendations of the Soil Chemistry and Fertility Commission for the states of Rio Grande do Sul and Santa Catarina (CQFS, 2004), (Table 1).

The experimental design used was randomized blocks, and treatments were arranged in a 2 x 7 factorial scheme, with four replicates, set in 36 m² plots (6 x 6 m). The first factor consisted in sources of wastes (PS and CS), whereas the second consisted in managements with surface and subsurface application of the wastes, with and without the use of the dicyandiamide (DCD) nitrification inhibitor, distributed as follows: T1 - control without application of waste and DCD; T2 - control without application of waste and DCD, but only scarified with the injection machine; T3 - application of the wastes on surface; T4 - application of the wastes on surface with DCD; T5 - injection of the wastes in subsurface; T6 - injection of the wastes in subsurface with DCD; and T7 - application of N, P_2O_5 and K_2O in the mineral form. In treatments with both injection and application on surface, the doses of the wastes were established based on their total N content and on the recommendation of the Soil Chemistry and Fertility Commission for the states of Rio Grande do Sul and Santa Catarina (CQFS, 2004), for an expected grain yield of 3.5 Mg ha^{-1}.

The treatment with NPK received 60 kg N ha^{-1} (urea), 75 kg P_2O_5 ha^{-1} (triple superphosphate) and 60 kg K_2O ha^{-1} (potassium chloride), also one day before sowing. The rest of N (90 kg N ha^{-1}), in the form of urea, was applied as top-dressing in the tillering stage. In the treatments with waste application on surface, the application was manually performed using watering cans, while subsurface injection was performed using a tractor-pulled injector, with a 4000 L metal tank. The

Table 1. Results of chemical and physical analysis of the soils of both experiments with pig slurry (PS) and cattle slurry (CS)

Source	P[1]	K[2]	Ca[3]	Mg[4]	(H + Al)[5]	Al[6]	CEC[7]	OM[8]	Clay[9]	SMP	pH[10]	V[11]	m[12]
	mg dm^{-3}		cmol$_c$ dm^{-3}					%		Index	H_2O	%	
PS	5.5	64.80	5.50	2.10	6.90	0.20	8.10	2.84	65.40	5.60	5.10	57.22	2.50
CS	7.0	93.68	6.10	2.50	5.80	0.10	8.50	2.51	71.30	5.10	5.00	60.31	2.70

[1]P-Mehlich; [2]Potassium-Mehlich; [3]Calcium; [4]Magnesium; [5]Potential acidity; [6]Exchangeable aluminum; [7]Cation exchange capacity; [8]Organic matter; [9]Clay content; [10] pH in water (1:1); [11]Base saturation; [12]Aluminum saturation

nitrification inhibitor used was dicyandiamide (DCD), present in the product Agrotain Plus®, at 81.4% concentration. Agrotain Plus®, in the form of powder and at dose of 10.0 kg ha^{-1} (8.14 kg ha^{-1} of DCD), was manually added and mixed with the wastes at the moment of their application in the soil.

The PS, from animals in the finishing phase, composed by feces, urine, food leftovers, water from the drinkers, rainwater, hair and dust, was collected in anaerobic pond, transported to the experimental area and placed in 1000 L polypropylene boxes. The CS came from milking and feeding rooms, and was stored under the same conditions as the PS. For both wastes, a sample of approximately 1 L was collected in each box for characterization (dry matter and contents of total N and ammoniacal N), according to the methodology proposed by Tedesco et al. (1995). The composition of each waste is presented in Table 2.

The wheat cultivar TBIO Sinuelo was sown on July 28, 2015, for both experiments, one day after applying the wastes. The sowing date did not correspond to the agricultural zoning for the wheat crop because of the rainfalls that had occurred previously. The spacing between rows was 0.17 m and sowing density was adjusted to obtain 300 to 330 plants m^2. Figure 1 details the rainfall and maximum and minimum temperatures along the wheat cycle.

At full flowering of the wheat crop, a 0.5 m^2 area was sampled to evaluate the dry matter. The samples were dried in a forced-air oven at temperature of 65 °C until constant weight and weighed, and the values were extrapolated to kilograms per hectare (kg ha^{-1}). Along with the dry matter evaluation at full flowering, the NDVI and NDRE vegetation indices were evaluated using the OptRx® sensor (Ag Leader), which calculates the indices using Eqs. 1 and 2, respectively.

Table 2. Composition of pig slurry (PS) and cattle slurry (CS) and quantities of dry matter and N applied in the wheat crop

Source	Dose	Waste composition			Quantity added		
	m^3 ha^{-1}	DM	N_{Total}	$N\text{-}NH_4^+$	DM	N_{Total}	$N\text{-}NH_4^+$
		kg m^{-3}			kg ha^{-1}		
CS	88.8	23.10	0.93	0.38	2079	82.58	33.74
PS	75.0	16.60	2.10	1.40	1245	157.50	105.00

PS - Pig slurry; CS - Cattle slurry; DM - Dry matter; N_{Total} - Total nitrogen; $N\text{-}NH_4^+$ - Ammoniacal nitrogen

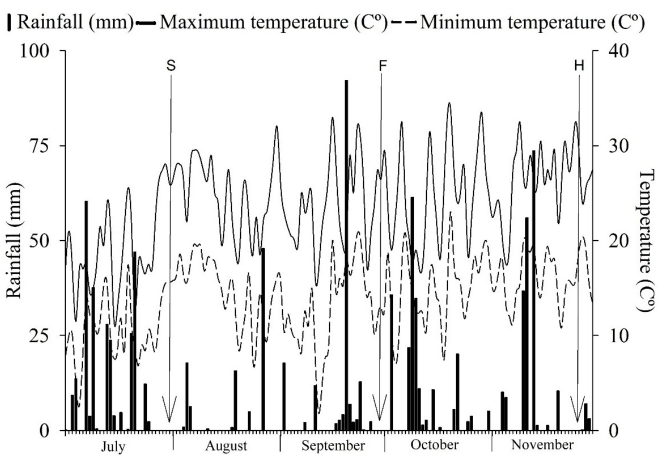

Figure 1. Rainfall, maximum temperature and minimum temperature, along the experiments in 2015 and the dates of sowing (S), flowering (F) and harvest (H)

$$\text{NDVI} = \frac{(\text{NIR} - \text{RD})}{(\text{NIR} + \text{RD})} \quad (1)$$

$$\text{NDRE} = \frac{(\text{NIR} - \text{RE})}{(\text{NIR} + \text{RE})} \quad (2)$$

where:

RD - red band (630-685 nm);

RE - red-edge band (690-730 nm); and,

NIR - near infrared band (760-850 nm).

The device was positioned at 0.8 to 1.0 m height, above and parallel to the soil surface (Grohs et al., 2009), and readings were randomly taken in the plot. The representative index of each treatment corresponded to the average of five readings per plot. Plants were harvested on November 26, 2015, using 3.06 m^2 of the evaluation area. Grain yield was corrected to 13% moisture content and the values were extrapolated to kilograms per hectare (kg ha^{-1}).

The results were subjected to analysis of variance (ANOVA) and, when significant difference was found between treatments, means were compared by Tukey test at 0.05 probability level. The analyses were carried out using the software suite Statistical Analysis System - SAS 8.0 (SAS Inc, Cary, USA).

Results and Discussion

Based on the results obtained with the analysis of variance (Table 3), the management had significant effect only for NDVI and wheat dry matter ($p < 0.01$). For the sources, the NDRE did not show significant difference ($p > 0.05$). Nonetheless, for all variables evaluated, there was significant difference caused by the interaction between factors, Management x Source.

The follow-up analysis of the interaction between management and sources of waste for NDRE and NDVI (Table 4) showed that, for the NDRE index, there were no significant differences of managements between sources, and of PS between managements. The difference was observed in CS between managements, and highest NDRE was found for the injection in subsurface with DCD (0.24), whereas lowest NDRE was found in the control without application of waste and DCD (0.16).

The results obtained for NDVI were similar to those for NDRE, in which no significant difference only occurred for PS between managements (Table 4). For CS, significant difference was found between managements; the highest value was found for the injection of waste with DCD (0.68), whereas the lowest value occurred in the scarified control treatment (0.36).

In general, NDVI was efficient to differentiate managements with CS. It was possible to observe with greater detail the differences between NDVI values due to the variation in the management with CS. Putra & Soni (2017), in tests using cameras to capture red band (used in NDVI calculation) and red-edge band (used in NDRE calculation), report that the red-edge band is more sensitive to small changes in the green. In the present study, since the readings were taken at the flowering stage, in which the color degree stabilizes, the NDRE

Table 3. Analysis of variance for the vegetation indices (NDRE and NDVI) and wheat dry matter and grain yields under different managements and sources of waste

Factor of variation	Mean square				
	DF	NDRE	NDVI	Dry matter (kg ha^{-1})	Grain yield (kg ha^{-1})
Management	6	0.0023^{ns}	0.0527**	2607281.28**	27260.84^{ns}
Source	1	0.0014^{ns}	0.0269*	1355089.38*	176011.52*
Manag. * Source	6	0.0046*	0.0175*	675132.01**	199956.89**
Block	3	0.0004^{ns}	0.0037^{ns}	193386.59^{ns}	74459.78*
Residual	39	0.0017	0.1617	3942949.26	18868.46
CV (%)		18.52	12.13	13.47	19.95

^{ns};**;*Not significant, significant at $p < 0.01$ and $p < 0.05$, respectively; DF - Degrees of freedom; CV - Coefficient of variation

Table 4. Follow-up analysis of the interaction between managements and sources of wastes for the indices normalized difference red edge index (NDRE) and normalized difference vegetation index (NDVI) in the wheat crop

Managements	Sources PS	Sources CS	Mean
	NDRE		
T1	0.16 a A	0.16 a B	0.19
T2	0.14 a A	0.17 a B	0.18
T3	0.20 a A	0.18 a B	0.19
T4	0.21 a A	0.17 a B	0.17
T5	0.17 a A	0.18 a B	0.18
T6	0.20 a A	0.24 a A	0.18
T7	0.21 a A	0.16a B	0.22
Mean	0.18	0.19	
	NDVI		
T1	0.56 a A	0.38 b C	0.47
T2	0.53 a A	0.36 b C	0.45
T3	0.49 a A	0.48 a B	0.49
T4	0.48 a A	0.46 a B	0.47
T5	0.60 a A	0.56 a B	0.63
T6	0.62 a A	0.68 a A	0.65
T7	0.59 a A	0.55 a B	0.57
Mean	0.55	0.51	

PS - Pig slurry; CS - Cattle slurry; Means followed by the same lowercase letters in the rows and the same uppercase letters in the columns do not differ statistically by Tukey test at 0.05 probability level; T1 - Control without application of waste and DCD; T2 - Control without application of waste and DCD, but only scarified with the injection; T3 - Application of wastes on surface; T4 - Application of wastes on surface with DCD; T5 - Injection of wastes in subsurface; T6 - Injection of wastes in subsurface with DCD; T7 - Application of N, P_2O_5 and K_2O in the mineral form

Table 5. Follow-up analysis of the interaction between managements and sources of wastes for wheat dry matter and grain yields wastes for wheat dry matter and grain yields

Managements	Sources PS	Sources CS	Mean
	Dry matter (kg ha^{-1})		
T1	1,237.10 b C	2,125.40 a B	1,681.25
T2	1,490.35 a C	2,222.75 a B	1,856.55
T3	2,559.05 a B	2,577.00 a B	2,568.02
T4	2,608.55 a B	2,917.65 a B	2,813.10
T5	2,891.00 a A	2,937.20 a B	2,914.10
T6	2,387.60 b B	3,205.45 a A	2,796.52
T7	2,593.00 a B	2,859.00 a B	3,226.00
Mean	2,395.23	2,706.35	
	Grain yield (kg ha^{-1})		
T1	1,090.68 bC	1,880.75 a C	1,485.72
T2	2,780.19 a C	4,020.14 a B	3,400.17
T3	3,490.68 a B	5,001.96 a B	4,246.32
T4	3,330.50 a B	5,560.79 a B	4,445.65
T5	5,710.82 a A	5,120.35 a B	5,415.59
T6	3,670.55 a B	6,020.87 a A	4,845.71
T7	4,610.06 a B	4,093.52 a B	4,351.79
Mean	3,526.21	4,528.34	

PS - Pig slurry; CS - Cattle slurry; Means followed by the same lowercase letters in the rows and the same uppercase letters in the columns do not differ statistically by Tukey test at 0.05 probability level; T1 - Control without application of waste and DCD; T2 - Control without application of waste and DCD, but only scarified with the injection; T3 - Application of wastes on surface; T4 - Application of wastes on surface with DCD; T5 - Injection of wastes in subsurface; T6 - Injection of wastes in subsurface with DCD; T7 - Application of N, P_2O_5 and K_2O in the mineral form

showed little difference, which explains its poor performance to differentiate the managements.

For wheat dry matter production, in the comparison of sources against managements, significant difference occurred only for the managements control without application of waste and DCD and injection of waste in subsurface with DCD. For both managements, the highest dry matter yields were found for the source CS, 2125.40 and 3205.45 kg ha^{-1}, respectively (Table 5). The positive result of wheat dry matter yield with CS application, although its total N and ammoniacal N contents are lower than those in the PS (Table 2), may occur because approximately 80% of CS is composed by amino acids that are easily mineralizable and undergo fast hydrolysis and ammonification, thus being more easily assimilated by plants (Zaman & Blennerhassett, 2010).

In the evaluation of the managements regarding the source PS, highest dry matter yield was observed in the treatment with injection of wastes in subsurface (2,891.00 kg ha^{-1}), whereas the lowest values were found in the control without application of waste and DCD (1,237.10 kg ha^{-1}) and in the control without application of waste and DCD, but scarified (1,490.35 kg ha^{-1}). These results indicate that wheat dry matter yield for the source PS is not influenced by DCD application, but instead by the form of application, in this case in subsurface.

For the source CS, highest dry matter yield occurred in the treatment with injection in subsurface with DCD (3,205.45 kg ha^{-1}), while the lowest yields were found in the managements control without application of waste and DCD (2,125.40 kg ha^{-1}) and control without application of waste and DCD, but scarified (2,222.75 kg ha^{-1}) (Table 5).

For wheat grain yield, no significant difference was found between managements for the different sources of wastes (Table 5), demonstrating that wheat grain yield is not influenced by PS or CS. This result may be due to the similar effect of these wastes on the soil, regarding the improvement in the activity of microbial enzymes, acid phosphatase and urease, caused by their addition (Katoh et al., 2015).

In the comparison of PS between managements, highest grain yield was found in the treatment with injection in subsurface (5,710.82 kg ha^{-1}) (Table 5). Lowest yields were found in the managements control without application of waste and DCD (1,090.68 kg ha^{-1}) and control without application of waste and DCD, but scarified (2,780.19 kg ha^{-1}). It should be highlighted that the increase of approximately two times in the grain yield obtained in the control without application of waste and DCD, but scarified, in comparison to the control without application of waste and DCD, may be associated with the greater mineralization of soil organic matter, besides the intensification of biochemical activities promoted by the turning of the soil.

For CS, highest grain yield was found in the treatment with injection in subsurface with DCD (6,020.87 kg ha^{-1}), whereas lowest yields were observed in the control without application of waste and DCD (1,880.75 kg ha^{-1}) and control without application of waste and DCD, but scarified (4,020.14 kg ha^{-1}) (Table 5). Higher grain yield found for CS in managements with application of DCD may be related to the fact that DCD delays the nitrification rate and, therefore, greater quantity of N is available for absorption by plants (Tao et al., 2008). In addition, Crusciol et al. (2011) report that the charges of soil colloids, which are normally negative, repel nitrate, thus favoring its leaching.

The results obtained for the correlations between NDVI and wheat dry matter and grain yields were significant for PS and CS, but only CS groupings showed reliable correlations (< 0.60). In the same way, the results obtained for NDRE were not reliable (< 0.60), but unlike the NDVI, it was not possible to obtain precise correlations for any of the sources of waste (PS and CS).

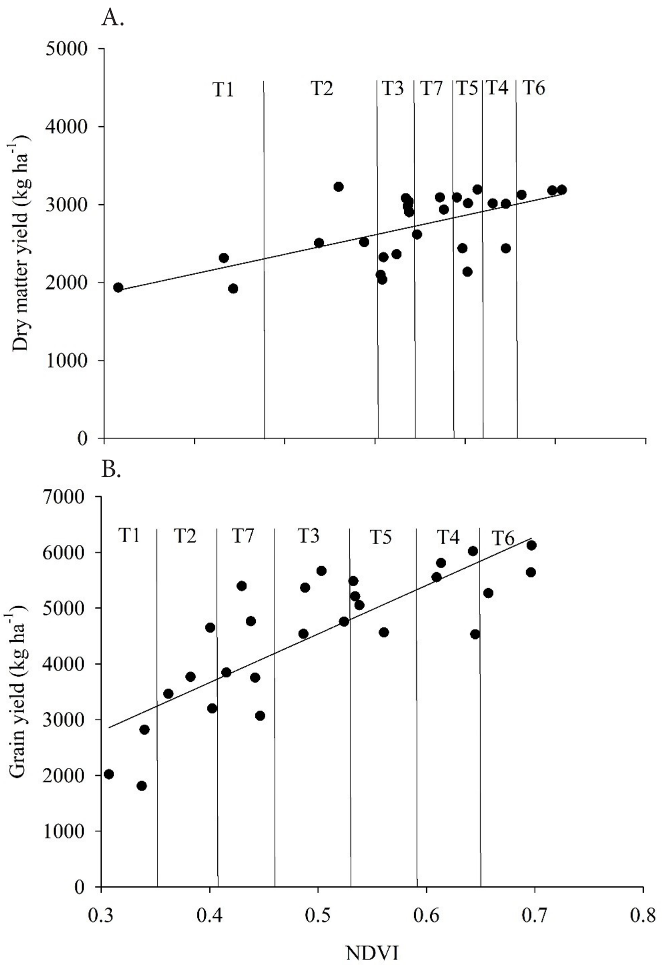

Figure 2. Pearson's correlation at 5% between normalized difference vegetation index (NDVI) and wheat dry matter for cattle slurry (A) and between NDVI and wheat grain yield for cattle slurry (B)

For CS, the correlations were 0.61 and 0.64 for the groupings of NDVI with dry matter yield and grain yield, respectively (Figure 2). The managements did not differ much between CS groupings, and only managements with application on surface and application of NPK in the mineral form showed the greatest differences. In general, highest and lowest values of dry matter and grain yields, as well as NDVI, were obtained in the control without application of waste and DCD, and in the treatment with injection in subsurface with DCD, respectively.

Although the results of the correlations between NDVI and dry matter and grain yields in the wheat crop exhibit differences of managements between the sources PS and CS (Figure 2), they point to a potential of NDVI to estimate wheat dry matter and grain yields. According to Tucker et al. (1980), up to 64% of the variability in grain yield can be explained by spectral data, which demonstrates the possibility of monitoring crop yield with this index (Peralta et al., 2016). In addition, studies have shown that NDVI is influenced by a great number of important factors, which influence the dry matter and grain yields of the crops (Hmimina et al., 2013; Lopresti et al., 2015; Damian et al., 2017). This fact can be better explored, in this case, in the management of pig and cattle wastes in annual crops, such as wheat.

Conclusions

1. Injection in subsurface led to the best results of wheat dry matter and grain yields with the pig slurry (PS).

2. For cattle slurry (CS), injection in subsurface with dicyandiamide (DCD) led to the best results of wheat dry matter and grain yields.

3. Between the normalized difference red edge index (NDRE) and normalized difference vegetation index (NDVI), NDVI showed higher potential to estimate the variation of the managements with CS in wheat dry matter and grain yields.

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