MAIZE NITROGEN USE EFFICIENCY IS AFFECTED BY PIG SLURRY COMPOSTING AND ANAEROBIC DIGESTION

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ABSTRACT: We assessed the nitrogen use efficiency of maize amended with mineral and organic N sources in a Nitisol from Southern Brazil under contrasting soil tillage systems: conventional tillage (CT) and no-tillage (NT). The tested N sources were: 140 kg N ha^{-1} (total N input) either as mineral fertilizer (urea; MIN), pig slurry (PS), anaerobically digested pig slurry (ADS) and composted pig slurry (CS), besides a control without fertilization (CTR). The N-based application of PS and ADS supplied less than 74% of the maize requirements for P_2O_5 (115 kg ha^{-1}), while CS exceeded P_2O_5 demand by up to 109%. PS and ADS promoted maize N uptake, biomass production and grain yield similar or higher than maize receiving mineral fertilizer (urea). However, CS promoted significantly lower N agronomic efficiency (AE_N) and recovery efficiency (RE_N) than other fertilizers. CS should be primarily used as a source of P and K or as an amendment to recover SOM stocks in degraded soils.
Keywords: swine slurry, biodigestion, co-composting.

INTRODUCTION

The use of pig slurry as fertilizer for agricultural soils can supply lower cost nutrients for crop production replacing mineral fertilizers and is the main manure management practice in Brazilian pig farms (Miele et al., 2015). Anaerobic digestion and composting are emerging technologies for manure treatment in Brazil (Kunz et al., 2009) although little is known about the quality of anaerobically digested slurry (ADS) or composted slurry (CS) as nutrient sources for grain crops. Differences on organic matter quality (recalcitrance) and nutrient composition due to anaerobic digestion or composting (Vivan et al., 2010; Angnes et al., 2013; Grave et al., 2015) could also impact nitrogen use efficiency and the recommendation of ADS and CS as organic fertilizers. In order to test this hypothesis, we assessed the N Agronomic Efficiency (AE_N) and Recovery Efficiency (RE_N) of different organic N sources for maize in a Nitisol from Southern Brazil under contrasting soil tillage systems.

MATERIAL AND METHODS

This study took place on a Rhodic Nitisol (FAO, 1998) located in Concordia-SC, Brazil (27º18'53"S; 51º59'25"O). The site was previously cultivated with maize and wheat crops. The clay, silt and sand contents of the 0-10 cm soil layer were 250, 460 and 290 g kg^{-1}, respectively, and the chemical characteristics as sampled in March/2012 were: pH-$H_2O_{(1:1)}$ 5.3, pH-SMP 5.8, Al^{3+} 0.3 cmol$_c$ dm^{-3}, organic matter 39.0 g kg^{-1}, $P_{Mehlich-I}$ 6.6 mg dm^{-3}, $K_{Mehlich-I}$ 249.6 mg dm^{-3}, Ca 7.5 cmol$_c$ dm^{-3}, Mg 3.3 cmol$_c$ dm^{-3}, CEC 11.9 cmol$_c$ dm^{-3} and base saturation of 68%. The local climate is humid subtropical (Cfa) based on the Köppen classification system (Embrapa, 2004). Lime was applied at the soil surface (2 Mg ha^{-1}) in order to increase pH at the 0-10 cm soil layer to 5.5 (CQFS-RS/SC, 2004).

The experiment was initiated in October/2012 and was arranged in a split-plot randomized blocks with four replications in plots with maize (*Zea mays* L.) during spring/summer and black oats (*Avena strigosa* Scherb) during autumn/winter. The tillage systems were the main plots (25 m x 10 m; W x L) and the N sources were the sub-plots (5 m x 10 m). The tillage systems were conventional tillage (CT) and no-tillage (NT). The CT consisted of disk plowing followed by offset disking in the spring and offset disking in the autumn, while NT consisted of planting directly through the crop residues with minimal soil disturbance. The disk plow and offset disking operations were performed to an average depth of 25 and 10 cm, respectively. The N sources were applied just before maize planting: 140 kg N ha^{-1} (total N input) either as mineral fertilizer (urea; MIN), pig slurry (PS), anaerobically digested pig slurry (ADS) and composted pig slurry (CS), besides a control without fertilization (CTR). The PS was collected from deep storage tanks, while the ADS was collected from an anaerobic lagoon composed of effluent from a covered lagoon biodigester (Vivan et al., 2010). The CS consisted of a mixture of pig slurry with sawdust and wood shavings composted for 150 days (Angnes et al., 2013). Mineral P and K were applied as requested in order to supply 115 kg P_2O_5 ha^{-1} and 77 kg K_2O ha^{-1} for an expected maize grain yield of 8.7 Mg ha^{-1} (CQFS-RS/SC, 2004).

The organic fertilizers used in this study were sampled and analyzed for characterization of these materials following standard protocols (APHA, 2005) for total solids (TS) or dry matter (DM), total organic carbon (TOC), total kjeldahl nitrogen (TKN), ammonium-nitrogen (NH_4-N), nitrate- and nitrite-nitrogen (reported as NO_3-N), phosphorous as phosphorus pentoxide equivalent (P_2O_5), potassium as potassium chloride equivalent (K_2O). Total nitrogen (TN) was calculated by the sum of TKN and NO_3-N contents and organic nitrogen (Org-N) was calculated by subtracting NH_4-N from TKN (Angnes et al., 2013). All samples were analyzed in triplicate and the results presented as average. Maize was sampled at the grain maturation to assess aboveground biomass production and grain yield in each subplot. Samples were dried at 65ºC, weighed and the grain yield was adjusted to 13% of moisture content. The maize biomass and grain samples were finely grounded and analyzer for N content (Tedesco et al., 1995). The N agronomic efficiency (AE_N) and recovery efficiency (RE_N) were calculated as following (Baligar et al., 2001):

AE_N, kg kg^{-1} = (Yield F, kg – Yield C, kg) / N applied, kg (Equation 1)

RE_N, % = (N uptake F, kg – N uptake C, kg) / N applied, kg X 100 (Equation 2)

where, F are treatments receiving fertilizer and C is the control treatment without fertilizer.

Two-way analysis of variance (ANOVA) was performed to assess differences on N uptake by maize, aboveground biomass production, grain yield, NAE, and ANRE considering the effects of soil tillage systems as the main plots and N sources as the subplots. We used the Fisher´s LSD test to assess the differences between soil tillage systems and N sources. All analyses were performed by soil depth using SigmaPlot v12.5 (Systat Software, San Jose, CA). All results were considered statistically significant at $p<0.05$.

RESULTS AND DISCUSSION

The ADS used in this study have lower TN content (Table 1) than other organic fertilizers, thus increasing ADS application rates (27.7 – 75.5 m^3 ha^{-1}) in relation to PS (24.7 – 46.9 m^3 ha^{-1}) and CS (12.5 – 29.9 Mg ha^{-1}) in order to achieve the same TN input for maize crop (140 kg ha^{-1}). Although N inputs were the same, higher volumes would ultimately raise the costs and viability for transportation and distribution of the organic fertilizers (Miele et al., 2015). The application of PS and ADS supplied, on the average of four years, 73 and 74%, respectively, of the maize requirements for P_2O_5 (115 kg ha^{-1}), considering an expected grain yield of 8.7 Mg ha^{-1} (CQFS-RS/SC, 2004). PS and ADS also supplied 96 and 88%, respectively, of the projected K_2O demand for the same grain yield of maize (77 kg ha^{-1}). CS had higher P_2O_5 and K_2O contents than the others organic fertilizers and exceeded maize requirements for these nutrients by 109 and 41%, respectively. Considering the environmental impacts related with the long-term and excessive accumulation of P at the soil surface (Gatiboni et al., 2015), it is reasonable that application of CS should meet soil and crops requirements for P rather than N.

No significant differences on cumulative N uptake and biomass production by maize were observed among CT and NT treatments (Table 2). However, cumulative maize grain yield was 5.2% higher in CT than NT soil. The mineralization of soil organic matter (SOM) due to intensive soil disturbance (Wuaden et al., 2016) probably promoted higher N availability to sustain higher grain yield in CT soil. However, the exhaustion of nutrient storage due depletion of SOM stocks in CT soil would ultimately restrain grain yield in the long-term (Lal, 2010). N uptake by maize fertilized with MIN, PS and ADS were similar and higher than the maize receiving CS, which in turn did not differed from the CTR treatment. The higher recalcitrance (Grave et al., 2015) and proportion of Org-N (91-99%) in the CS in comparison with PS (22-42%) and ADS (17-49%) would have limited N availability in the soil and N uptake by maize plants. Maize biomass production followed a similar pattern being higher in treatments receiving PS, ADS and MIN. However, the biomass production of maize plants fertilized with CS was in turn similar to ADS and MIN treatments but also did not differed from CTR treatment. The application of PS increased maize grain yield by 7.6% in relation to plants receiving mineral fertilization (MIN). Maize grain yield in ADS treatment was intermediary to PS and MIN treatments. The mineralization of Org-N from PS and ADS would have sustained soil N availability during the period of higher demand by maize plants increasing grain yield in relation to the soil receiving MIN. CS had the lower maize grain yield among the treatments receiving fertilization not differing from CTR treatments which corroborates the low N availability of the fertilizer.

The AE_N indicates the efficiency of maize plants to recover the applied N through mineral or organic fertilizers and use each additional unit of N for grain production (Baliga et al., 2001). The RE_N for instance indicates how much of the applied N was recovered in plant biomass and grains and is dependent of the synchronicity between maize N demand and N released from fertilizers (Baliga et al., 2001). Typical AE_N and RE_N values are 10-30 kg grain kg^{-1} N and 30-50%, respectively, but could be higher in well-managed fertilization systems, low N use rates or low soil N supply (Dobermann, 2005). The average AE_N and RE_N values observed in or study (8.3 kg grain kg^{-1} N and 24.8%, respectively) are lower than the expected range, mostly because all fertilizers where applied in a single time just before planting (Table 3). Although usual by most farmers from Southern Brazil applying organic fertilizers for maize production, this practice increases N losses as most of N is released from fertilizers and available in the soil when there is no or low demand for N by maize crop. The relatively high maize grain yield averaging 7.6 Mg ha^{-1} yr^{-1} in CTR treatments without fertilization also decreased the AE_N and RE_N values observed in our experiment, since SOM mineralization was enough to supply an expressive amount of N to maize (average of 142 kg N ha^{-1}). Nonetheless, AE_N was not significantly affected either by soil tillage and fertilization treatments. However, AE_N for CS treatment was just 39 and 24% of MIN and PS treatments, respectively. Soil tillage systems had no effect on RE_N although this index was sensitive to fertilization treatments. Again, RE_N for CS treatments (RE_N = 8.4%) was substantially lower (24-31%) than the values observed for other fertilizers (MIN, PS, and ADS), which not differed among then (RE_N = 27-35%). Although further research is needed to assess AE_N and RE_N of the tested organic fertilizers in soils with low N supply our results indicate that the CS should be primarily used as a source of P and K for crops or as an amendment to recover SOM stocks in degraded soils (Wuaden et al., 2016).

CONCLUSION

The application of PS and ADS promoted maize N uptake, biomass production and grain yield similar or higher than maize receiving mineral fertilizer (urea). The N agronomic efficiency (AE_N) and recovery efficiency (RE_N) of CS was lower than 39 and 31% of AE_N and RE_N of the other fertilizers tested in this study. CS should be primarily used as a source of P and K for crops or as an amendment to recover SOM stocks in degraded soils.

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Table 1. Application rate and characteristics of the organic fertilizers used in this study.

Fertilizer	Year	Rate	Characteristics[1]								
			TS/DM[2]	TOC	TN	Org-N	NH_4-N	NO_3-N	C/N	P_2O_5	K_2O
		$m^3\ ha^{-1}$	----------	----------	----------	----------	$kg\ m^{-3}$	----------	----------	----------	----------
PS	2012	31.7	119.1	29.0	4.4	1.7	2.7	N/D	6.6	1.7	2.5
	2013	31.4	N/D	15.6	4.1	0.9	3.2	N/D	3.8	2.7	1.8
	2014	46.9	52.2	9.3	3.0	1.0	2.0	N/D	3.1	1.5	2.0
	2015	24.7	266.1	51.5	5.7	2.4	3.3	N/D	9.0	4.7	2.4
ADS	2012	27.1	140.6	17.7	5.2	2.6	2.6	N/D	3.4	7.2	1.1
	2013	54.8	N/D	6.3	2.6	0.5	2.1	N/D	2.4	0.5	1.4
	2014	75.5	26.4	4.3	1.8	0.5	1.3	N/D	2.3	1.0	1.0
	2015	74.5	23.1	4.0	1.9	0.3	1.6	N/D	2.1	0.5	1.1
		$Mg\ ha^{-1}$	----------	----------	----------	----------	$g\ kg^{-1}$	----------	----------	----------	----------
CS	2012	29.0	29.1	317.0	16.6	15.1	1.2	0.3	19.1	25.0	22.8
	2013	12.5	47.3	249.6	23.6	23.5	0.1	0.0	10.6	51.7	11.6
	2014	14.8	43.8	378.0	21.6	19.8	0.8	1.0	17.5	24.1	13.4
	2015	18.2	42.0	325.1	18.3	18.2	0.1	0.0	17.8	39.7	11.4

PS: pig slurry; ADS: anaerobically digested pig slurry; CS: composted pig slurry; [1]Results are expressed on a fresh matter basis for PS and ADS and dry matter basis for the CS; [2]TS: total solids (PS/ADS); DM: dry matter (CS); TOC: total organic carbon; TN: total nitrogen; Org-N: organic nitrogen; NH_4-N: ammonium-nitrogen; NO_3-N: nitrate-nitrogen; C/N: total organic carbon/total nitrogen ratio; P_2O_5: phosphorus as phosphorus pentoxide equivalent; K_2O: potassium as potassium chloride equivalent.

Table 2. Nitrogen uptake, aboveground biomass production and grain yield of maize according to soil tillage and fertilization treatments (cumulative of four crop seasons).

Parameter	Tillage	Fertilization					Mean
		CTR	MIN	PS	ADS	CS	
		----------	----------	----------	$kg\ ha^{-1}$	----------	----------
N uptake	CT	599	759	751	741	647	700 **ns**
	NT	536	680	782	711	583	659
	Mean	567 **b**[1]	719 **a**	766 **a**	726 **a**	615 **b**	679
Biomass	CT	43,716	47,548	50,620	49,890	46,652	47,685 **ns**
	NT	39,808	46,794	51,004	49,901	43,393	46,180
	Mean	41,762 **c**	47,171 **ab**	50,812 **a**	49,895 **ab**	45,023 **bc**	46,932
Grain yield	CT	32,108	35,158	37,198	36,292	33,756	34,902 **A**
	NT	28,477	33,754	36,952	36,538	30,092	33,163 **B**
	Mean	30,293 **d**	34,456 **bc**	37,075 **a**	36,415 **ab**	31,924 **cd**	34,032

CTR: control without fertilization; MIN: mineral fertilization; PS: pig slurry; ADS: anaerobically digested pig slurry; CS: composted pig slurry; CT: conventional tillage; NT: no-tillage; ns: differences were not significant according to the F test ($p>0.05$); [1]Means followed by the same uppercase letter in the columns and lowercase letters in the lines are not different according to the Fisher's LSD test ($p<0.05$).

Table 3. Maize nitrogen use efficiency indexes according to soil tillage and fertilization treatments.

Parameter	Tillage	Fertilization				Mean
		MIN	PS	ADS	CS	
		----------	----------	$kg\ kg^{-1}$	----------	----------
N Agronomic efficiency (AE_N)	CT	5.4	9.1	7.5	2.9	6.2 **ns**
	NT	9.4	15.1	14.4	2.9	10.4
	Mean	7.4 **ns**	12.1	10.9	2.9	8.3
		----------	----------	%	----------	----------
N recovery efficiency (RE_N)	CT	28.7	27.1	25.4	8.5	22.4 **ns**
	NT	25.6	43.9	31.2	8.3	27.3
	Mean	27.1 **a**	35.5 **a**	28.3 **a**	8.4 **b**	24.8

CTR: control without fertilization; MIN: mineral fertilization; PS: pig slurry; ADS: anaerobically digested pig slurry; CS: composted pig slurry; CT: conventional tillage; NT: no-tillage; ns: differences were not significant according to the F test ($p>0.05$); [1]Means followed by the same lowercase letters in the lines are not different according to the Fisher's LSD test ($p<0.05$).