AGRONOMIC AND ENVIRONMENTAL QUALITY ASSESSMENT OF TREATED MANURES APPLICATION TO THE SOIL

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1 INTRODUCTION

Livestock manure processing (e.g. solid/liquid separation, anaerobic digestion) alters physical, chemical and biological characteristics of manures, affecting the agronomic and the environmental effect of their application to the soil. Solid/liquid separation may improve manure management, field spreading and the agronomic value of both fractions. Anaerobic digestion allows using the labile fraction of organic matter for producing bio-energy and the more recalcitrant fraction for sequestration into the soil organic matter. The study of the post application dynamics of carbon (C) and nitrogen (N) fractions of manures (Fangueiro et al., 2007; Bechini and Marino, 2009) is important to have a comprehensive analysis of the environmental effects of the different treatment options. This may also improve the emission coefficients foreseen by environmental impact assessment tools as LCA (Hansen et al., 2006). In the present work, we present the results of a laboratory quantification of the early carbon dioxide (CO_2) and nitrous oxide (N_2O) emissions and soil N availability after the application to soil of solid and liquid fractions from non-treatement, anaerobic digestion and codigestion of cattle slurry.

2 MATERIALS AND METHODS

Two laboratory experiments were set up as 36 day aerobic incubations of manured soil carried out in a climatic chamber (20° C). The two soils utilized in the experiment were a sub-acid silty loam (*Poirino*) and a sub-alkaline loam (*TettoFrati*) soils collected from the tilled layer of two arable fields in Piemonte. They were both poor in soil organic C and total N contents: 8.4 and 8.3 g C kg^{-1} and 0.81 and 0.83 g N kg^{-1} for Poirino and TettoFrati, respectively. A first experiment was conducted on the following treatments: non-treated cattle slurry, solid and liquid fractions of non-treated cattle slurry and solid and liquid fractions of digested cattle slurry, for a total of 5 different treatments. Fresh cattle slurry was directly collected from the storage facilities of a dairy farm and anaerobic digestion was carried out in laboratory reactors simulating the process at the real scale under mesophilic conditions (Mantovi et al., 2010). Solid/liquid separation of non-treated and digested manures were performed using a laboratory centrifuge. Manures were then stored in tanks for 90 days under controlled ambient conditions. Before the experiment start, manures were analyzed for their main properties (Table 1) and for organic matter (total extractable C) and fibrous (Van Soest's method) characterization (Table 2). 180 one-liter glass jars were filled with 600 g of dry soil wetted with deionized water to reach 60% of water filled pore space and were fertilized with the incorporation of 125 mg kg^{-1} of total manure-N, corresponding approximately to 170 kg N ha^{-1} in 20 cm of soil (EU Nitrate Directive threshold for Vulnerable zones). An unfertilized treatment was also prepared. CO_2 and N_2O emissions from manured soil samples were measured in three replicates with a photo-acoustic infrared gas analyzer following the method described by Bertora et al. (2008). Soil inorganic N was extracted with KCl at five different dates (1, 3, 8, 15 and 36 days after fertilization) destroying 3 replicates per treatment per date. A second experiment was set up according to the same protocol using solid and liquid fractions of cattle slurry codigested with chopped silage maize.

3 RESULTS AND DISCUSSION

3.1 Manures characteristics.

Manure processing and storage deeply changed the composition of the different fractions. The three types of liquid fractions showed different pH, dry matter (DM), total organic C and ammonium N, but a similar total N content.

Concerning the ratio between ammonium and total N in the liquid fractions, values were higher for codigested, intermediate for digested and lower for non-treated cattle slurry. Solid fractions mainly differed for the C to N ratio, which was higher for codigestion. Treatments also greatly differed for the main parameters resulting from organic matter and fiber characterization

TABLE 1 **Main properties of the cattle slurry included in the experiment (all the percentages are expressed on a fresh weight basis) (Mantovi et al. 2010).**

Type of manure	pH	Dry matter	Total organic carbon	Total N	NH_4^+-N	C/N
		%	%	%	% of total N	
Non-treated	6.7	5.9	2.6	0.26	54.5	10.1
Non-treated (liquid fraction)	7.3	2.5	1.1	0.19	64.3	5.6
Non-treated (solid fraction)	8.0	13.4	5.6	0.40	29.5	14.1
Digested (liquid fraction)	7.9	1.8	0.8	0.20	70.4	3.9
Digested (solid fraction)	8.5	13.7	5.9	0.42	34.6	14.0
Codigested (liquid fraction)	8.5	1.6	0.5	0.21	77.0	2.4
Codigested (solid fraction)	8.7	13.0	5.6	0.50	32.5	11.2

TABLE 2 **Organic matter and fiber (Van Soest's method) characterization of the manures included in the experiment (all the percentages are expressed on a dry matter weight basis).**

Type of manure	Total organic carbon	Total extractable carbon	Humic carbon	C soluble compounds (Organic matter-NDF)*	Hemicellulose NDF-(ADF)*	Cellulose (ADF - ADL)*	Lignin (ADL)*
				%			
Non-treated	44.8	22.6	5.1	40.5	15.7	14.7	9.9
Non-treated (liquid fraction)	43.4	33.3	14.1	57.4	4.1	0.4	1.0
Non-treated (solid fraction)	42.0	29.5	10.1	24.6	21.7	27.1	13.0
Digested (liquid fraction)	42.7	29.9	13.7	46.0	10.9	0.5	1.8
Digested (solid fraction)	42.8	17.4	4.6	17.1	23.4	21.4	19.0
Codigested (liquid fraction)	32.7	24.8	16.8	47.9	4.2	0.2	1.3
Codigested (solid fraction)	42.9	18.6	13.9	17.0	20.7	19.4	22.8

* Fiber fractions followed Van Soest method: NDF: Neutral detergent fiber, ADF: acid detergent fiber, ADL: acid detergent lignin.

3.2 Comparison among treatments

The results of the laboratory incubations are synthesized in table 3a and 3b. For the first laboratory experiment, the increase with respect to unfertilized soil in the total CO_2–C emissions was the highest for the solid fraction of the non-treated cattle slurry (0.682 g kg^{-1} of C), and the lowest for the liquid fraction of the digested slurry (0.140 g kg^{-1} of C). If the amount of CO_2-C emitted is expressed as percentage of the C applied, the rank of the treatments changed and the liquid fraction of non-treated slurry showed the highest value (46.1%). Anaerobic digestion reduced CO_2 emissions with respect to non-treated cattle slurry for both liquid and solid fractions. Treatment and treatment * soil interaction affected total cumulative N_2O emissions. In both soils, the highest values of N_2O emissions were measured for the liquid fraction of non-treated cattle slurry (3.092 mg N_2O-N kg^{-1} $soil^{-1}$, on average) and the lowest for the solid fraction of digested cattle slurry (-0.007 mg N_2O-N kg^{-1} $soil^{-1}$, on average). Soil inorganic N recovery at the end of the experiment was affected by treatment and soil effect. From 38.3 to 108.5 % of the applied total manure-N was recovered as soil inorganic N at the end of the experiment. Solid fraction of digested slurry showed a soil N recovery 1.6 times higher than solid fraction of untreated cattle slurry. The results of the second laboratory experiment (Table 2b) showed that the fertilization with codigested fractions have a different effect on CO_2 and N_2O emissions depending on soil type, since soil * treatment interaction was highly significant. Comparing the two experiments, total CO_2 and N_2O emissions were similar for codigested fractions compared with digested fractions, while codigested fractions showed a lower soil inorganic N recovery. The results of total CO_2 emissions after manure application was calculated as the percentage of the initial C content in the non-treated cattle slurry (Table 4). Anaerobic digestion followed by solid/liquid separation reduced early CO_2 emissions after fertilization in both soils.

TABLE 3 **The cumulative CO_2 and N_2O emissions and the soil inorganic N recovery at the beginning and at the end of the experiment [(soil inorganic N of treatment - soil inorganic N of the control)/(total N applied)] for the first (a) and the second (b) experiment.**

a)	**CO_2–C cumulative emissions**		**N_2O-N cumulative emissions**	**Soil inorganic N recovery**	
				Initial	Final
	g CO_2-C kg^{-1} $soil^{-1}$	% of applied C	mg N_2O-N kg^{-1} $soil^{-1}$	% of applied total N	
Treatment					
Non-treated cattle slurry	0.390b	30.8b	0.263	48.2	71.6bc
Unfertilized	0.099f	-	-0.060	-	-
Non-treated (liquid fraction)	0.317bc	46.1a	3.092	63.4	90.7ab
Non-treated (solid fraction)	0.682a	24.3bc	0.406	42.7	38.3d
Digested (liquid fraction)	0.140e	28.7b	0.418	85.8	108.5a
Digested (solid fraction)	0.277cd	18.2c	-0.007	46.8	61.0c
Soil					
Poirino	0.315	29.3	0.881	44.0	68.1
TettoFrati	0.320	29.9	0.490	70.6	80.0
Source of variation					
Treatment	**0.000**	**0.000**	0.000	0.000	**0.000**
Soil	ns	ns	ns	0.000	**0.004**
Treatment * soil	ns	ns	**0.015**	**0.031**	ns

b)	**CO_2–C cumulative emissions**		**N_2O-N cumulative emissions**	**Soil inorganic N recovery**	
				Initial	Final
	g CO_2-C kg^{-1} $soil^{-1}$	% of applied C	mg N_2O-N kg^{-1} $soil^{-1}$	% of applied total N	
Treatment					
Unfertilized	0.105	-	0.011	-	-
Codigested (liquid fraction)	0.196	70.0	0.482	85.6	78.8
Codigested (solid fraction)	0.288	21.4	0.085	51.5	46.2
Soil					
Poirino	0.145	30.6	0.118	66.4	57.9
TettoFrati	0.248	60.7	0.268	70.7	67.0
Source of variation					
Treatment	0.000	0.000	0.000	**0.001**	**0.000**
Soil	0.000	0.000	ns	ns	**0.036**
Treatment * soil	**0.000**	**0.011**	**0.001**	ns	ns

* Different characters denote statistically significant differences based on log-trasformed data.

TABLE 4 **Total CO_2 emissions of the manure treatments after the application to the soil, expressed as percentage of initial C and N amounts in the non-treated cattle slurry**.

Manure treatment process	**CO_2-C emitted after fertilization (% of C as non-treated)**	
	Poirino	Tettofrati
Non-treated cattle slurry	28.3	33.3
Solid/liquid separation of non-treated slurry	28.5	27.0
Digestion followed by solid/liquid separation	15.2	14.4

4 CONCLUSIONS

The different manures were applied to soils at the same total N level. Early CO_2 losses due to manure application ranged from 0.39 to 1.91 Mg CO_2-C ha^{-1}, for digested liquid fraction and non-treated solid fraction, respectively. On the contrary, the different manures supplied a different amount of total C: from 18.2 to 70.0% of this C was lost as CO_2. Nitrous oxide emissions were high only for liquid fractions, where they represented, on average, 2.0% of the N applied. During the experimental interval, soil inorganic N recovery increased, on average, from 78.3 to 92.6% of total N applied with liquid fractions of manure, confirming the high N availability to crops of this type of manures.
Moreover, results showed that manure treatment options reduce the amount of CO_2 losses after application to soils by 10 (solid/liquid separation) and 52% (anaerobic digestion followed by solid/liquid separation).

On average, 65% and 100% of CO_2 and N_2O was emitted within the first two weeks, respectively. A steady-state CO_2 respiration rate was reached within the end of the experiment. These results confirm that, in several cases, longer laboratory incubations of amended soils are not necessary for early decomposition and basic respiration measurement. The effect of long-term application of treated manure on soil CO_2 respiration level and the relative contribution of early CO_2 and N_2O emissions after application on total emission levels need to be investigated.

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