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Nitrogen fertilizer replacement value of undigested liquid cattle manure and digestates

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ABSTRACT

Accurate estimation of animal manure nitrogen (N) availability is required to maximize crop N use efficiency and reduce environmental N losses. Many field and laboratory experiments have shown that first-year net mineralization of manure organic N is often negligible, which often causes crop available N to approximate the ammonium N content of the manure. Anaerobic digestion increases the ammonium share and reduces the C to organic N ratio of animal manures, potentially increasing their N fertilizer value.

In 2011, we undertook a three-year field experiment in Northern Italy to estimate the N fertilizer value of four manures: undigested cattle slurry, digested cattle slurry-maize mix, and liquid and solid fractions of the digested slurry-maize mix. The experiment also allowed us to test if ammonium recovery was similar among manures, and between manures and ammonium sulphate. Fertilizers were applied annually to plots before silage maize cultivation that was followed by an unfertilized Italian ryegrass crop.

Results showed that the recovery of ammonium from manure in maize did not differ significantly compared to ammonium sulphate among all the fertilizers in 2013; however, in 2011 and 2012 it was significantly lower for all manures except digested slurry-maize mix and its liquid fraction in 2011.

The increased recovery of applied N in 2012 and 2013 for solid fraction and undigested manure were likely due to the residual effect of previously applied organic N.

1. Introduction

The efficiency of plants to take up nitrogen (N) from undigested manures and anaerobic digestion by-products (digestates) is usually assessed through apparent N recovery (ANR) and N fertilizer replacement value (NFRV) calculations. The ANR represents the fraction of applied total N that can be taken up by the crop in addition to what is taken up by an unfertilized control in a single season after fertilizer application. NFRV – also known as the mineral fertilizer equivalency – equals the organic fertilizer ANR divided by the mineral fertilizer ANR (Schröder, 2005). Both indices can also be calculated for ammonium-N (NH_4-N) provided by different manures.

Many laboratory incubations (Bechini and Marino, 2009; Morvan et al., 2006; Van Kessel and Reeves, 2002) and field experiments involving untreated (Reijs et al., 2007; Schröder et al., 2005, 2013; Sørensen et al., 2003) and digested manures (Chantigny et al., 2008; de Boer, 2008; Herrmann et al., 2013; Möller et al., 2008; Saunders et al., 2012; Sieling et al., 2013; Schröder et al., 2007) have shown that first-year crop available N often approximates the NH_4-N content of manure (Möller and Müller, 2012; Webb et al., 2013), and thus NFRV approximately equals the manure NH_4-N to total N ratio. The relevance of the contribution of manure organic N to plant nutrition becomes more important when manure is applied repeatedly to the soil during consecutive years. In such cases, the slow mineralization of previously applied organic N, and the remineralization of immobilized manure NH_4-N, can substantially increase the NFRV of manures during subsequent years (Gutser et al., 2005; Schröder et al., 2005, 2007; Nevens and Reheul, 2005; Hernández et al., 2013).

Digestates typically have high NH_4-N to total N ratios that raise their potential N availability for crops (Gutser et al., 2005; Möller and Müller, 2012). Nowadays, digestates often consist of animal manures co-digested with other biomasses used to increase

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methane production (Holm-Nielsen et al., 2009). Moreover, to facilitate the fertilizer use of both digested and raw manures, their liquid and solid fractions are separated (Burton, 2007; Hjorth et al., 2010; Møller et al., 2000; Möller and Müller, 2012). In fact, separation makes export of the solid fraction off the farm easy, which permits an efficient strategy to reduce N and phosphorus loads per unit of land area where it is high. Both co-digestion and solid–liquid separation can influence digestate N availability for crops (Möller and Müller, 2012).

Experiments that evaluate the NFRVs of unseparated digested and co-digested manures and their solid or liquid fractions are still scarce (Chantigny et al., 2008; Grigatti et al., 2011); further research is needed to better assess their N supply for crop, as well as across years. To this end, we established a field experiment in 2011 (Cavalli et al., 2014) to measure the NFRV of undigested and digested cattle manure named SINBION-field, in which silage maize was fertilized with ammonium sulphate (AS), untreated cattle slurry (US), unseparated digestate from a mix of cattle slurry and maize (DSMM), and the liquid (LF) and solid (SF) fractions of DSMM. In this experiment we measured ANR and NFRV of the applied manures and tested several hypotheses regarding the effects during the first year after their application:

i) applied NH_4-N recovery is similar among manures;
ii) applied NH_4-N recovery is similar for manures and AS;
iii) first-year NFRV of manures can be approximated by their NH_4-N to total N ratio (i.e., most manure ammonium is available in the first year after application; part of the inevitable N loss is compensated for by mineralized N from the easily decomposable N fraction of the manure).

Cavalli et al. (2014) found that ammonium applied to the soil with US, SF, and LF was less available for maize than that of AS. They also observed that recovery of applied N with SF and US increased in the second year, suggesting that N residual effects contributed to maize N uptake. Herein we report the third-year results of data with in-season measurements of maize biomass, maize N uptake, and soil mineral N. Our aims are: to enhance the understanding of N dynamics in a soil-crop system, and to discuss the cumulative effects of repeated treatments.

2. Material and methods

2.1. Experimental site and design

The three-year field experiment started in spring 2011 on a flat area located in Montanaso Lombardo (Lodi), Italy (45°20′32″N, 9°26′43″E, altitude 80 m asl). The field had been cultivated with barley (*Hordeum vulgare* L.) and silage maize (*Zea mays* L.) prior to the start of the experiment. No organic fertilizers had been applied in the previous ten years.

The 0–30 cm soil profile of the field displayed the following characteristics: sand, 469 g kg^{-1}, silt, 394 g kg^{-1}, clay, 137 g kg^{-1}; pH (H_2O) of 5.8; total N, 1.01 and organic C, 8.44 (both g kg^{-1}); extractable P, 61 mg kg^{-1} per Bray and Kurtz method; exchangeable K, 167 mg kg^{-1}; bulk density, 1.49 t m^{-3}. The climate of the area (average 1993–2010) is characterized by an annual rainfall of 875 mm and an average annual mean air temperature of 13.4 °C (Fig. 1).

In spring 2011, an experiment was established in plots of 112 m^2 arranged in a randomized block design with four replicates, and involving six treatments: an unfertilized control (CON), ammonium sulphate (AS) and four manure varieties (Table 1).

Every year, at no more than a week before spreading, the manures were sampled to determine the correct application rate. To ensure that NH_4-N recovery across treatments could be compared later, the application rate was calculated to deliver the same amount of NH_4-N to all fertilized treatments. Furthermore, the amount of NH_4-N distributed to all treatments was set equal to that supplied by US when applied at 340 kg N ha^{-1}. Effective NH_4-N application rates deviated from intended rates (represented by those of AS in Table 2) mainly because estimated manure-N concentrations at the preliminary sampling and at the time of spreading were not equal. The CON and AS plots received triple superphosphate (40 kg P ha^{-1}) and potassium chloride (230 kg K ha^{-1}) fertilizers before sowing. On 31 May 2011, DSMM, LF, and US were

Table 2
Total N and NH_4-N (kg N ha^{-1}) applied before maize sowing in 2011–2013 with ammonium sulphate and manures.

Year	Treatment[a]				
	AS	DSMM	LF	SF	US
	Total N				
2011	159	264	218	643	200
2012	152	306	291	606	271
2013	131	250	213	703	214
	NH_4-N				
2011	159	120	111	151	106
2012	152	142	147	226	136
2013	131	125	109	190	111

[a] AS: ammonium sulphate; DSMM: unseparated digestate from a mix of cattle slurry and maize; LF: liquid fraction of DSMM; SF: solid fraction of DSMM; US: untreated cattle slurry.

Table 1
Chemical–physical characteristics of the manures used in the field experiment (average ± standard deviation).

Manure[a]	Year	DM[b] (g kg^{-1})	pH (water)	Organic C (g kg^{-1} DM)	Total N	NH_4-N	Organic C/organic N	NH_4-N/total N
DSMM	2011	65.1	8.0 ± 0.0	395.8 ± 5.8	55.9 ± 0.3	25.5 ± 0.3	13.0	45.6
	2012	61.3	8.2 ± 0.0	389.4 ± 0.3	61.3 ± 0.3	28.6 ± 0.1	11.9	46.6
	2013	57.8	8.1 ± 0.0	368.7 ± 0.2	64.2 ± 0.2	32.0 ± 0.2	11.5	49.9
LF	2011	47.9	8.0 ± 0.0	363.6 ± 2.2	67.0 ± 0.1	34.2 ± 0.0	11.1	51.1
	2012	53.6	7.9 ± 0.0	383.6 ± 4.3	65.2 ± 0.0	32.9 ± 0.1	11.9	50.5
	2013	40.8	8.3 ± 0.0	357.4 ± 1.9	67.0 ± 0.0	34.3 ± 0.5	10.9	51.3
SF	2011	256.5	9.6 ± 0.0	439.8 ± 5.5	21.9 ± 0.2	5.1 ± 0.0	26.2	23.4
	2012	296.3	9.0 ± 0.2	436.7 ± 4.5	20.9 ± 0.4	7.8 ± 0.3	33.3	37.3
	2013	276.0	9.8 ± 0.1	431.6 ± 5.2	22.9 ± 0.9	6.2 ± 0.3	25.8	27.0
US	2011	82.3	7.3 ± 0.0	436.4 ± 1.3	39.2 ± 0.2	20.8 ± 0.2	23.7	53.0
	2012	84.2	7.3 ± 0.0	427.7 ± 5.8	43.1 ± 0.3	21.7 ± 0.1	20.0	50.4
	2013	37.5	7.9 ± 0.0	407.0 ± 0.6	57.4 ± 0.1	29.7 ± 0.2	14.7	51.8

[a] DSMM: unseparated digestate from a mix of cattle slurry and maize; LF: liquid fraction of DSMM; SF: solid fraction of DSMM; US: untreated cattle slurry.
[b] Dry matter, single determination.