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Nitrogen availability and indirect measurements of greenhouse gas emissions from aerobic and anaerobic biowaste digestates applied to agricultural soils

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ABSTRACT

Recycling biowaste digestates on agricultural land diverts biodegradable waste from landfill disposal and represents a sustainable source of nutrients and organic matter (OM) to improve soil for crop production. However, the dynamics of nitrogen (N) release from these organic N sources must be determined to optimise their fertiliser value and management. This laboratory incubation experiment examined the effects of digestate type (aerobic and anaerobic), waste type (industrial, agricultural and municipal solid waste or sewage sludge) and soil type (sandy loam, sandy silt loam and silty clay) on N availability in digestate-amended soils and also quantified the extent and significance of the immobilisation of N within the soil microbial biomass, as a possible regulatory mechanism of N release. The digestate types examined included: dewatered, anaerobically digested biosolids (DMAD); dewatered, anaerobic mesophilic digestate from the organic fraction of municipal solid waste (DMADMSW); liquid, anaerobic co-digestate of food and animal slurry (LcoMAD) and liquid, thermophilic aerobic digestate of food waste (LTAD). Ammonium chloride (NH_4Cl) was included as a reference treatment for mineral N. After 48 days, the final, maximum net recoveries of mineral N relative to the total N (TN) addition in the different digestates and unamended control treatments were in the decreasing order: LcoMAD, 68%; LTAD, 37%, DMAD, 20%; and DMADMSW, 11%. A transient increase in microbial biomass N (MBN) was observed with LTAD application, indicating greater microbial activity in amended soil and reflecting the lower stability of this OM source, compared to the other, anaerobic digestate types, which showed no consistent effects on MBN compared to the control. Thus, the overall net release of digestate N in different soil types was not regulated by N transfer into the soil microbial biomass, but was determined primarily by digestate properties and the capacity of the soil type to process and turnover digestate N. In contrast to the sandy soil types, where nitrate (NO_3^-) concentrations increased during incubation, there was an absence of NO_3^- accumulation in the silty clay soil amended with LTAD and DMADMSW. This provided indirect evidence for denitrification activity and the gaseous loss of N, and the associated increased risk of greenhouse gas emissions under certain conditions of labile C supply and/or digestate physical structure in fine-textured soil types. The significance and influence of the interaction between soil type and digestate stability and physical properties on denitrification processes in digestate-amended soils require urgent investigation to ensure management practices are appropriate to minimise greenhouse gas emissions from land applied biowastes.

1. Introduction

Biowastes represent a diverse range of organic materials produced by a variety of commercial, industrial as well as municipal sources and are increasingly applied to land to divert biodegradable waste from landfill disposal and for resource recovery (Defra, 2011a). They may also be treated to varying extents by different process technologies, such as anaerobic digestion, for public health and environmental reasons, and to produce biorenewable energy (Defra, 2011b).

Land application of biowastes is controlled and managed to protect soil quality and the environment and has to be demonstrably beneficial. Under the UK Environmental Permitting Regulations (SI, 2010), for instance, the use of biowastes on land must provide agricultural benefit or lead to ecological improvement. Rates of application are also limited by total N (TN) addition and must not exceed crop requirements for nitrogen (N) (CEC, 1991; Defra, 2009).

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However, insufficient is known of the N dynamics of digestates of commercial/industrial or municipal solid wastes to be able to define either their fertiliser properties or potential environmental impact. It is essential, for instance, to correctly manage organic N applications to prevent N leaching and water pollution, or atmospheric impacts through denitrification or ammonia volatilisation.

Recent research demonstrates the varying capacity of different soil types to turnover and release plant available N from organic N sources (Smith et al., 1998a; Breedon et al., 2003; Rigby et al., 2009). Coupled with the intrinsic properties of the biowastes themselves, and the effects of digestion treatments on organic N stability, these factors are likely to have a profound influence on the kinetics of N release in biowaste-amended soil (Bustamante et al., 2010; Sanchez-Monedero et al., 2004). Fundamentally, the soil microbial biomass has a critical role in processing and modulating the release of organic N into plant available forms (Pierzynski and Gehl, 2005). However, few measurements have quantified the dynamics of microbial biomass N (MBN) in soils treated with different biowaste types.

The objectives of this laboratory incubation study were therefore to: (1) investigate the effects of waste type, digestion process (aerobic or anaerobic) and soil type on N availability in amended soils under controlled temperature and moisture conditions, and (2) study immobilisation of N within the soil microbial biomass, the subsequent influence on N release and the implications for N availability and crop production. Four digestate types were investigated in addition to a mineral N and unamended control, in combination with three contrasting agricultural soil types.

2. Materials and methods

2.1. Soils

Three arable soils with contrasting physico-chemical characteristics were selected for the laboratory incubation investigation. Soils were collected from two sites at the Imperial College Farm in Wye, Kent: Brices Field (Ordnance Survey Reference 60500, 146500) and North Sidelands (Ordnance Survey Reference 606600, 146500). A third soil was collected from Silwood Park, the Imperial College Campus in Berkshire (Ordnance Survey Reference 606600, 146900). The soils were collected during January 2005, stored in a temperature controlled cold room at 4 °C, and used within 2 weeks. The soils were sampled at a depth of 5–15 cm and sieved in the field moist condition to <5.6 mm to remove stones and plant debris; any remaining plant material passing in the <5.6 mm fraction was removed by hand. The soil properties were measured by a National Accreditation of Measurement and Sampling (NAMAS) accredited laboratory (NRM Laboratories, Bracknell, Berkshire), with the exception of the WHC, which was measured following Harding and Ross (1964). Selected physicochemical properties of the soils are presented in Table 1. North Sidelands was an alkaline (pH 7.8), silty clay with twice the amount of OM (4% dry soil (ds)) compared to the acidic (pH 5.9) sandy loam from Silwood Park (2% OM ds) and the moderately acidic (pH 6.2) sandy silt loam from Brices Field (1.9% OM ds), and had the largest overall cation exchange capacity (*CEC*), reflecting the larger OM and clay contents of this soil type.

The soils were carefully air-dried, without allowing any part of the soil sample to fully desiccate, for 8 h to reduce the moisture content to approximately 50% of the WHC, which is within the range recommended for laboratory-based soil incubation experiments (Harding and Ross, 1964; Wiseman and Zibilske, 1988; Smith et al., 1998a,b,c).

Table 1
Selected physical and chemical properties of the soil types used in the investigation[a].

		Silwood Park	Brices Field	North Sidelands
pH (H_2O)		5.9	6.2	7.8
Electrical conductivity (mS cm^{-1})		2.0	1.7	2.0
Texture	Sand (%)	80	41	29
	Silt (%)	13	41	34
	Clay (%)	7	18	34
Organic matter (%)		2	1.9	4.0
Cation exchange capacity (meq 100 g^{-1})		5.7	12	13
Water holding capacity		38	45	65
Total N (%)		0.11	0.12	0.25

[a] Values on a dry soil (ds) basis.

2.2. Digestates

Four digestate types were investigated: (1) mechanically dewatered, mesophilic anaerobic digested biosolids, which was included as a reference material (DMAD); (2) mechanically dewatered, mesophilic anaerobic digestate of the organic fraction of municipal solid waste (DMADMSW); (2) liquid mesophilic anaerobic co-digestate of food and farm wastes (LcoMAD); and (4) liquid thermophilic aerobic digestate of food wastes (a mixture of bread, cooked meat, fruit and vegetables) (LTAD). Samples of each digestate type were collected and transported to the laboratory at Imperial College where they were stored in a temperature-controlled cold room at 4 °C and used within 2 weeks. Subsamples of each material, of approximately 1 kg each, were sent to a NAMAS accredited laboratory (NRM Laboratories, Bracknell, Berkshire) for physico-chemical analysis; selected properties of the digestates are given in Table 2.

The anaerobic co-digestate of food and farm waste (LcoMAD) contained the most TN overall compared to the other organic waste materials examined, equivalent to 11.3% in the dry solids (DS), with approximately 50% in mineral form. The digested sewage sludge, DMAD, sampled here contained 4.6% TN (DS) with 9% in a mineral pool. In comparison, DMADMSW had approximately half the amount of TN measured in DMAD, equivalent to 2.3% (DS); however, DMADMSW contained a larger mineral N fraction equivalent to 15.3% of TN. Total N in LTAD was 3.5% (DS) and the

Table 2
Selected chemical properties of the digestates investigated in the laboratory incubation[a].

	DMAD[b]	DMADMSW[c]	LcoMAD[d]	LTAD[e]
DS (%)	28.9	28.9	5.25	17.1
OM (%)	60.1	42.3	37.9	86.0
pH	7.2	8.8	8.2	4.4
Total P (g kg^{-1})	28.0	4.43	6.47	3.81
Total K (g kg^{-1})	1.94	5.06	37.6	5.44
Total Mg (g kg^{-1})	2.98	7.99	6.63	2.38
Total S (g kg^{-1})	11.5	7.97	6.36	3.22
Total N (%)	4.64	2.32	11.3	3.50
NH_4–N (mg kg^{-1})	3400	3360	52,500	2800
NO_3–N (mg kg^{-1})	<0.1	<0.1	<0.1	<0.1
NO_2–N (mg kg^{-1})	82.1	191	0.43	0.19
Organic N (%)	4.22	1.96	6.00	3.22
Mineral N (%)	9.09	15.3	46.6	8.01
C to N ratio[f]	7.5:1	11:1	4:1	14:1

[a] Values on a dry solids (DS) basis.
[b] Dewatered, mesophilic anaerobically digested biosolids.
[c] Dewatered, mesophilic anaerobically digested organic fraction of municipal solid waste.
[d] Liquid, anaerobic co-digestate of food and animal slurry.
[e] Liquid, thermophilic aerobically digested food waste.
[f] C content estimated from OM content using conversion factor of 1.73 (MAFF, 1986).