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Nitrogen losses to the environment following food-based digestate and compost applications to agricultural land☆

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ABSTRACT

The anaerobic digestion of food waste for energy recovery produces a nutrient-rich digestate which is a valuable source of crop available nitrogen (N). As with any 'new' material being recycled to agricultural land it is important to develop best management practices that maximise crop available N supply, whilst minimising emissions to the environment. In this study, ammonia (NH_3) and nitrous oxide (N_2O) emissions to air and nitrate (NO_3^-) leaching losses to water following digestate, compost and livestock manure applications to agricultural land were measured at 3 sites in England and Wales. Ammonia emissions were greater from applications of food-based digestate (*c*.40% of total N applied) than from livestock slurry (*c*.30% of total N applied) due to its higher ammonium-N content (mean 5.6 kg/t compared with 1–2 kg/t for slurry) and elevated pH (mean 8.3 compared with 7.7 for slurry). Whilst bandspreading was effective at reducing NH_3 emissions from slurry compared with surface broadcasting it was not found to be an effective mitigation option for food-based digestate in this study. The majority of the NH_3 losses occurred within 6 h of spreading highlighting the importance of rapid soil incorporation as a method for reducing NH_3 emissions. Nitrous oxide losses from food-based digestates were low, with emission factors all less than the IPCC default value of 1% (mean 0.45 ± 0.15%). Overwinter NO_3^- leaching losses from food-based digestate were similar to those from pig slurry, but much greater than from pig farmyard manure or compost. Both gaseous N losses and NO_3^- leaching from green and green/food composts were low, indicating that, in these terms, compost can be considered as an 'environmentally benign' material. These findings have been used in the development of best practice guidelines which provide a framework for the responsible use of digestates and composts in agriculture.

1. Introduction

The United Kingdom generates around 14 million tonnes of food waste each year, the highest rate in the European Union, which in total generates nearly 90 million tonnes; the quantity produced by the different member states depends on numerous factors such as cultural practices, climate, diet and socio-economic conditions (EC, 2010). A large proportion of this waste is disposed of to landfill, with the UK sending around 8 million tonnes of biodegradable municipal waste (including food waste) to landfill every year (Defra, 2016). Redirecting this material away from landfill will significantly reduce greenhouse gas (GHG) emissions, in particular methane (CH_4), which has a global warming potential around 25-fold greater than carbon dioxide (CO_2), thereby contributing to GHG reduction targets. To this end, the EU Landfill Directive states that by 2020 the amount of biodegradable municipal waste disposed of in landfill sites must be reduced by 65%, compared with 1995 levels (EC, 1999).

As part of the UK's commitment to reduce GHG emissions and to meet EU renewable energy targets, policies and strategies have been implemented (DECC/Defra, 2011) to increase the treatment of food waste through anaerobic digestion (AD; Styles et al., 2016)

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which, as well as providing renewable energy, generates a nutrient-rich digestate or 'biofertiliser'. The most recent estimates suggest that by 2020 around 5 Mt of the 7 Mt of food waste currently sent to landfill could be available for digestion annually in the UK (DECC/Defra, 2011). However, AD is not without its problems. In a recent study of the UK biogas sector, Styles et al. (2016) found that whilst biogas energy has a lower GHG intensity than fossil fuels, it can increase acidification and eutrophication burdens. Life-cycle assessment (LCA) studies have highlighted the fact that the environmental outcomes are very sensitive to factors such as feedstock type, fugitive emissions, biomethane use, energy conversion efficiency and digestate management. Nevertheless, Styles et al. (2016) concluded that to maximise the potential for GHG abatement, climate change policies should encourage digestion of food waste whilst restricting digestion of crop inputs and wastes that could be used as animal feed.

The AD sector in the UK has been developing rapidly, with a 34% increase in the total number of operational AD plants between 2012 and 2013, and an increase of 51% in the tonnage of organic material processed (WRAP, 2014). Over 2 million tonnes of digestate were applied to agricultural land in the UK in 2013, supplying a total of 92 kt nitrogen (N). Although this is only half the total N supplied by composts, *c.*80% of the total N within food-based digestate is readily available (WRAP, 2016) i.e. in the form of ammonium-N (NH_4-N). A regular survey of the organics processing industry has been undertaken since the mid-1990s; in 2012 the survey indicated that there had been little year-on-year change in the UK composting sector, with a total of 3.5 million tonnes (fresh weight) produced in 2012, 68% of which was recycled to agricultural land, supplying 192 kt N.

When applying organic materials such as digestate and compost to land, it is essential that their application, agricultural or otherwise, is not harmful to the environment (i.e. to soil, water and air quality) or human health. The European Nitrogen Assessment (Sutton et al., 2011) highlighted how the overall environmental costs of all N losses in Europe (estimated at €70–€320 billion per year at current rates) outweigh the direct economic benefits of N in agriculture, due largely to loss of air and water quality. The land application of organic materials therefore needs to be carefully managed to maximise their crop available nutrient value and minimise their impact on the wider environment. Food-based digestate is of particular interest being a new, less well understood material which will vary in its compositional characteristics depending on the type of food waste used to produce it (e.g. vegetable-based feed stocks produce digestate with lower N concentrations than those produced from mixed food wastes). It generally has a relatively high total N content of around 5 kg/m^3 (WRAP, 2016) compared with *c.*3 kg/m^3 for cattle slurry and *c.*4 kg/m^3 for pig slurry (Defra, 2010) and might therefore be expected to have the potential for greater N losses to the environment than livestock manures or manure-based digestates.

Ammonia (NH_3) emissions to air contribute to acid deposition and can cause eutrophication of sensitive ecosystems; in addition, NH_3 reacts with acids in the atmosphere to form particulate matter which may pose a threat to human health (Webb et al., 2004). The amount and rate of NH_3 release following land spreading depends on a range of organic material (e.g. pH, readily available N, dry matter), spreading (e.g. application rate, method and timing), soil (e.g. moisture content) and environmental (e.g. temperature, wind speed, rainfall) factors (Nicholson et al., 2013). There is an extensive body of research in the UK (and elsewhere) on NH_3 emissions following land application of livestock manures and slurries (see for example Pain et al., 1989; Chambers et al., 1997; Sommer et al., 1997; Huijsmans et al., 2001; Misselbrook et al., 2002; Webb et al., 2004), which has been used to populate the National Ammonia Emissions Inventory (Misselbrook et al., 2015) and provide guidance for farmers to minimise NH_3 emissions from manures in the UK (Defra, 2009) and elsewhere. Research has also been undertaken using manure-based and crop-based digestates applied to land (e.g. Rubaek et al., 1996; Wulf et al., 2002); however, very little information is available for food-based digestates produced and applied under conditions pertinent to the UK. A recent study by Tiwary et al. (2015) showed that surface applied food-based digestate applications led to NH_3 losses of 35–65% of the total N applied in the week following application, with an abatement of 85% achieved if the material was incorporated into the soil immediately following application. However, this study was undertaken at a field site in India and used digestates that may not be comparable with those currently produced in the UK. Composts produced from green wastes such as grass clippings and hedge trimmings (green compost) or from a mixture of green and food wastes (green/food compost) tend to be applied to agricultural soils for soil conditioning purposes (WRAP, 2016), although they also contain valuable amounts of plant available nutrients. The low readily available N content of composts (generally <5% of total N; Defra, 2010) would suggest that NH_3 losses following land spreading are also likely to be low, although there is little evidence currently available to support this assertion.

Nitrous oxide (N_2O) is a greenhouse gas with a global warming potential *c.*300-fold greater than carbon dioxide (IPCC, 2006). The UK Greenhouse Gas Emissions Inventory (2014) estimated that *c.*70% of N_2O produced in the UK comes from agriculture (Brown et al., 2016), of which the majority (75%) is emitted from soils following N applications/returns (e.g. manufactured fertiliser N, crop residue incorporation organic materials and urine from grazing returns) to land. Around 17% of agricultural N_2O is emitted indirectly from soils following re-deposition of emitted NH_3 and from leached nitrate (NO_3^-) (Brown et al., 2016). As with NH_3, there is little information available on N_2O losses following food-based digestate and compost applications to agricultural land. The current IPCC Tier 1 default emission factor (EF) for N_2O losses from animal manure, compost, sewage sludge and other organic N additions (e.g. digestates) is 1% of the total N applied (IPCC, 2006). By way of comparison, Tiwary et al. (2015) found that N_2O emissions from food-based digestate were 4–10% of the total N applied, which is much higher than the default IPPC EF of 1%, although these measurements were made in India under very different soil and climatic conditions from those in the UK. Measurements in Scotland showed that cumulative N_2O emissions following green compost applied at 35, 100 and 200 t/ha ranged from 0.32 to 4.54 kg N_2O-N/ha/yr, with the higher values measured following the 200 t/ha application in the wet spring of 2008 (Ball et al., 2014). Although compost application rates were very high in this experiment (35–200 t/ha compared with a more typical rate of 30 t/ha), the maximum N_2O EFs were still only around 1% of the total N applied.

There is still much uncertainty over the factors which control N_2O emissions from food-based digestates following application to agricultural land. For example, Pezzolla et al. (2012) found that applying food-based digestate to a UK grassland did not increase emissions compared to the untreated control, although measurements were made during an exceptionally dry growing season. In contrast, an incubation study showed much larger emissions from food-based digestate compared to ammonium sulphate applied under high soil moisture conditions (Köster et al., 2011). A later study under similar conditions found emissions were twice as high from cattle slurry than from food-based digestate (Köster et al., 2015). Following a laboratory incubation study using food-based and other digestates, Rigby and Smith (2013) concluded that "the significance and influence of the interaction between soil type and