DIGESTATE QUALITY AND FERTILISER VALUE

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Abstract

Anaerobic digestion (AD) involves the breakdown of biodegradable materials (such as household food waste, livestock slurry and waste from food processing plants) in the absence of oxygen. During the AD process methane is released that can be used to provide heat and power, and a digestate is produced. Whole digestates from three plants (two food-based and one manure-based) were analysed for a wide range of chemical, physical, biological and microbiological properties. The analyses showed that digestate contains valuable quantities of major plant nutrients (*e.g.* nitrogen, phosphate, potash and sulphur), which are all essential for plant growth. In particular, digestate was shown to be a valuable source of readily available N (*c.*80% of total N for the food-based digestates) that can be used to replace manufactured fertiliser N use, as well as useful amounts of organic matter. Notably, the digestate samples had a significant biochemical oxygen demand, indicating that care is needed when applying these materials to land in order to minimise any water pollution risks and to maximise their fertiliser value.

Key words

Anaerobic digestate, biochemical oxygen demand, digestate, fertiliser, nitrogen, plant nutrient, organic matter, soil conditioner.

Introduction

The recycling of organic materials to land is regarded as the best practicable environmental option in most circumstances, completing both natural nutrient and carbon cycles. Organic materials are valuable sources of major plant nutrients (*i.e.* nitrogen – N, phosphate – P_2O_5, potash – K_2O and sulphur – SO_3), which are essential for plant growth and therefore sustainable crop production. Organic materials also provide a valuable source of organic matter, which improves soil water holding capacity, workability and structural stability *etc*.

Anaerobic digestion (AD) involves the breakdown of biodegradable materials (such as household food waste, livestock slurry and waste from food processing plants) in the absence of oxygen. During the AD process methane is released that can be used to provide heat and power, and a digestate is produced. In the UK, the quantity of digestate (from source-segregated biodegradable materials) currently recycled to agricultural land is relatively small (around 100,000 tonnes fresh-weight), when compared with livestock manures (around 90 million tonnes), biosolids (3-4 million tonnes) or compost (2 million tonnes). This quantity is expected to increase to over 2 million tonnes (fresh-weight) in the next 10 years, as the drive to remove organic materials from landfill increases and the need to generate gas/electricity from renewable sources grows. The EC Landfill Directive (EC, 1999) sets strict limits on the amount of biodegradable municipal waste that can be disposed of via landfill; the amounts must be reduced by 65% in 2020 compared with 1995 levels (EC, 1999). Defra's Vision Statement identifies anaerobic digestion as making "*a significant and measurable contribution to climate change and wider environmental objectives….in diverting organic waste, especially food waste, from landfill"* (Defra, 2009).

In addition to the legislative drivers, there is increasing agricultural demand for organic materials (*e.g.* digestate, compost, *etc.*) as sources of crop-available nutrients. This is largely due to recent dramatic (3 to 4-fold) increases in the price and also availability of manufactured fertilisers, as a consequence of the growing demand for food as the world's population continues to grow. As a result, farmers and growers are becoming increasingly interested in and reliant on organic materials to supply crop nutrient requirements. Additionally, as the importance placed on carbon footprinting increases, farmers and land managers will be encouraged to reduce the carbon footprint of their products, for example, through using organic materials to offset the use of manufactured fertilisers.

BSI PAS110 (BSI, 2010) for the processing and production of digestate, and the Quality Protocol for Anaerobic Digestate (WRAP/EA, 2009) have recently been published. PAS110 requires producer's to undertake Hazard Analysis and Critical Control Point (HACCP) planning to ensure digestate meets minimum requirements for microbial pathogens, heavy metals, stability and physical contaminants, and is fit for purpose. The Quality Protocol sets out criteria for the recovery/production of quality digestate from source-segregated biodegradable waste (which includes compliance with PAS110). Adherence with the Quality Protocol means that though 'waste' feedstocks are used as an input to the process, the resultant digestate can be used as a product, and hence is not subject to Environmental Permitting Regulations (SI, 2010) when applied to land in England, Wales and Northern Ireland.

Methodology

Triplicate digestate samples were taken from three facilities on two occasions: firstly in November 2009 and secondly in March 2010 (18 samples in total). Standard methodologies were followed (Chambers *et al*., 2001; Defra/EA, 2009; EA, 2006) to obtain representative samples. Each sample was analysed for a range of physical, chemical, biological and microbiological properties. Feedstocks at two of the sites were largely food waste-based and at the third site manure-based (including some crop residues).

Results and Discussion

Nutrient concentrations

The mean total N concentration in the food-based digestate samples was 7.4 kg/m^3 compared with 4.4 kg/m^3 in the manure-based digestate. These values compare with typical total N concentrations in pig and cattle slurries of 3.6 and 2.6 kg/m^3, respectively (Table 1).

Table 1: Mean nutrient concentrations in food and manure-based digestate samples (kg/m^3 fresh weight)

Nutrient (kg/m^3)	Food-based digestates+ (n=12)	Manure-based digestate++ (n=6)	Pig slurry* (4% dry matter)	Cattle slurry* (6% dry matter)
Total N	7.4	4.4	3.6	2.6
Readily available N (NH_4 + NO_3-N)	5.9	2.6	2.5	1.2
Total P_2O_5	0.5	1.4	1.8	1.2
Total K_2O	1.8	3.5	2.4	3.2
Total MgO	0.05	0.8	0.7	0.6
Total SO_3	0.4	1.3	1.0	0.7

+ *4.3% dry matter*
++ *7.5% dry matter*
* *'Typical' slurry values taken from the "Fertiliser Manual (RB209)" (Defra, 2010)*

Readily available nitrogen – RAN (*i.e.* the ammonium-N content of digestates) is the nitrogen that is potentially available for rapid crop uptake. Livestock slurries and poultry manures are 'high' in readily available-N (typically in the range 35-70% of total N) compared with farmyard manure that is 'low' in readily available-N (typically in the range 10-25% of total N). In contrast, organic-N is the nitrogen contained in organic forms; which will be slowly released and become potentially available for crop uptake over a period of months/years.

The food-based digestates had 81% of their total N content present as RAN and the manure-based digestate 59%. These values compare with typical RAN contents of pig slurry at 70% and cattle slurry at 45% of total N (Defra, 2010), Figure 1.

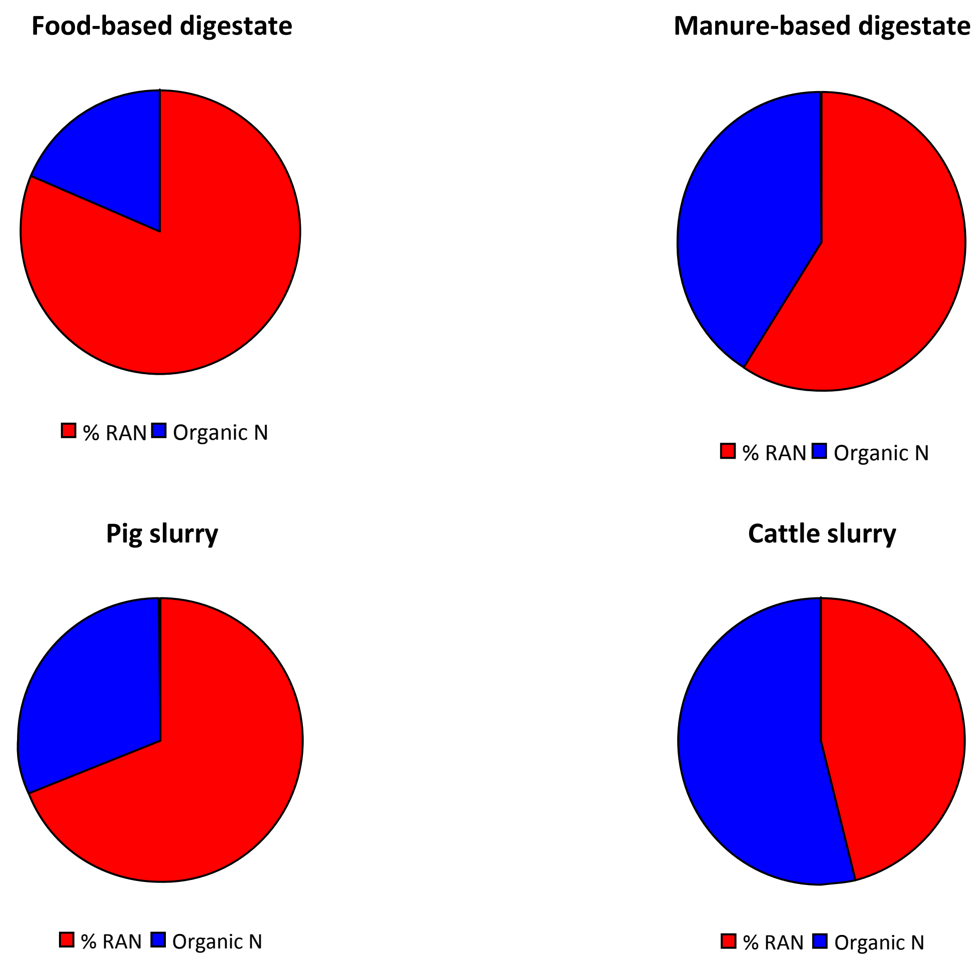

Figure 1: Readily available N (RAN) contents of food and manure-based digestates in comparison with typical values for pig and cattle slurries.

The RAN content of digestate (>30% of total N) means that like cattle/pig slurry, digestate applications will be subject to mandatory closed spreading periods during autumn/winter in Nitrate Vulnerable Zones – NVZs (SI, 2008; SSI, 2008; WSI, 2008).

The mean phosphate concentration was 0.5 kg/m^3 in the food-based digestates and 1.1 kg/m^3 in the manure-based digestate, compared with typical concentrations of 1.8 and 1.2 kg/m^3 in pig and cattle slurries, respectively (Table 1). Both digestates contained sulphur and magnesium, but the food-based digestates only contained a small amount of magnesium. The digestates also contained valuable quantities of potash at 1.8 and 3.5 kg/m^3 in the food and manure-based digestates, respectively, similar to the potash concentrations in typical pig and cattle slurries (Table 1).

Organic matter

Based on an application rate of 250 kg total N/ha (the maximum field N rate permitted in NVZs), the organic matter loading from the food-based digestates was *c.*1 t/ha and *c.*3 t/ha from the manure-based digestate. By way of comparison, typical organic matter loadings from a cattle slurry application would be *c.*3 t/ha (Bhogal *et al*., 2008).

Heavy metal concentrations

The mean total zinc concentration in the food-based digestates was 104 mg/kg dry matter (dm) and in the manure-based digestate 200 mg/kg dm (Table 2); both concentrations were below the PAS 110 upper limit value of 400 mg/kg dm. By way of comparison, Nicholson *et al*. (2010) reported mean total zinc concentrations of 870 mg/kg dm in pig slurry (more than double the PAS110 upper limit value for digestate) and 196 mg/kg dm in cattle slurry.

Table 2: Mean digestate and slurry heavy metal concentrations (mg/kg) compared to PAS110 limit values.

Metal concentration (mg/kg dry matter)	Food-based digestate (n=12)	Manure-based digestate (n=6)	*PAS110*	Pig slurry*	Cattle slurry*
Total Zinc	104	200	*400*	870	196
Total Copper	21.5	127	*200*	279	137
Total Cadmium	0.9	0.6	*1.5*	0.3	0.1
Total Nickel	19.7	11.4	*50*	3.9	3.4
Total Lead	6.1	11.3	*200*	3.5	4.8
Total Chromium	10.0	10.4	*100*	2.3	2.9
Total Mercury	< 0.05	< 0.05	*1*	n.d	n.d

n.d. = not determined

**Metal concentrations in pig and cattle slurries from Nicholson et al. (2010)*

Mean total copper concentrations were also below the PAS110 limit value (200 mg/kg dm) in the food-based digestates (21.5 mg/kg dm) and manure-based digestate (127 mg/kg dm), Table 2. By way of comparison, Nicholson *et al.* (2010) reported mean total copper concentrations of 279 mg/kg dm in pig slurry (*c.*40% above the PAS110 upper limit for digestate) and 137 mg/kg dm in cattle slurry. The mean digestate total cadmium, nickel, lead, chromium and mercury concentrations were all below the PAS110 limits.

Based on an application rate of 250 kg total N/ha, zinc additions were *c.*0.14 kg/ha from the food-based digestates and *c.*0.8 kg/ha from the manure-based digestate. For copper, the corresponding figures were *c.*0.03 kg/ha and *c.*0.50 kg/ha from the food and manure-based digestates, respectively. By way of comparison, typical zinc additions from pig slurry are *c.*2.5 kg/ha and from cattle slurry *c.*1.3 kg/ha, and copper additions are *c.*0.8 kg/ha from both pig and cattle slurries, respectively (Nicholson *et al.* 2010). All other metal addition rates from the digestates were <0.05 kg/ha (Figure 2). The loadings for digestates and slurries are well below those which are annually permitted under the Sludge Use in Agriculture Regulations (SI, 1989), which allows 15 kg/ha zinc, 7.5 kg/ha copper, 3 kg/ha nickel, 0.15 kg/ha cadmium, 15 kg/ha lead and 0.1 kg/ha mercury to be applied per year (based on a 10 year average).

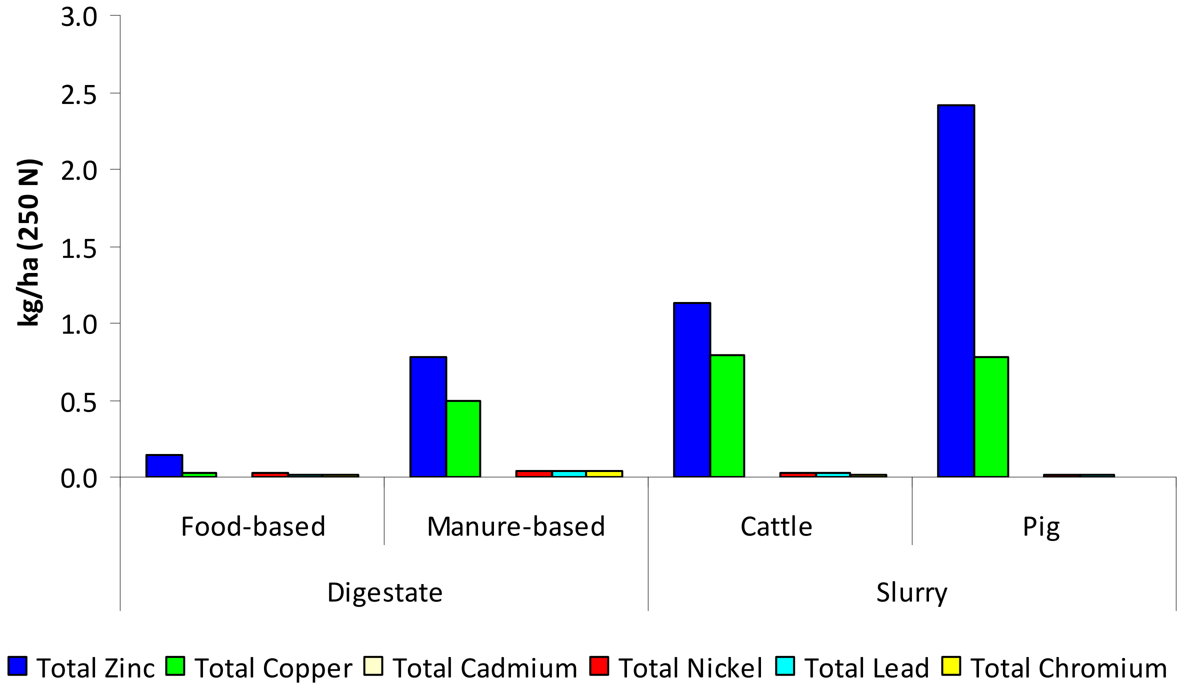

Figure 2: Mean heavy metal loading rates (at an application rate of 250 kg total N/ha).

Residual biogas potential

Digestate stability was assessed by measuring the residual biogas potential (RBP). For digestate to meet PAS110 the RBP must be below 0.25 l/g of volatile solids; at this point the rate of biological activity is considered to have slowed to an acceptably low level and the material can be considered sufficiently stable for landspreading. The mean RPB was 0.22 l/g of volatile solids for the food-based digestates and 0.11 g/l of volatile solids for the manure-based digestate.

Biochemical oxygen demand

Biochemical oxygen demand (BOD) is a measure of the oxygen used by microorganisms to decompose organic materials. The BOD of the food-based digestates was *c.*9,000 mg/l and the manure-based digestate *c.*5,000 mg/l. By way of comparison, pig slurry typically has a BOD level of 20,000-30,000 mg/l, cattle slurry between 10,000-20,000 mg/l and dirty water 1,000-5,000 mg/l (MAFF, 1998). Treated sewage effluent must typically have a BOD of ≤20 mg/l before entering a surface water system. As with livestock slurry management, the digestate BOD values indicate that care is needed when applying digestate to land to minimise water pollution risks.

Physical contaminants

The PAS110 limit for total physical contaminants (>5mm) in digestate is 0.5% dm. All digestate samples were within this limit and no glass, metal or stone contamination was found in any of the samples. Incidental levels of plastic were measured in nine of the twelve food-based digestate samples, with a mean of 0.15% dm; no physical contaminants were measured in the manure-based digestate.

Microbial pathogens

The digestate samples were analysed for *E. coli* and *Salmonella* (Table 3). *Salmonella* spps. were absent from the food-based digestates, but were detected in the manure-based digestate. To comply with PAS110, *Salmonella* spps. should be absent in 25g of fresh matter. By way of comparison, around 5% of pig and cattle slurries contain *Salmonella* (Hutchison *et al.*, 2002). *E. coli* numbers were lower in the food-based digestates (<10 colony forming units-CFU/g fresh weight-fw) than in the manure-based digestate (2,700 CFU/g fw); the PAS110 limit for *E. coli* is 1000 CFU/g fw. By way of comparison, pig and cattle slurries typically contain *c.*7 $\log_{10}$ CFU/g fw (Defra project WQ0111).

Herbicide residues

The digestate samples were analysed for clopyralid and aminopyralid residues, neither of which were detected in any of the samples.

Organic compound contaminants (OCCs)

The digestate samples were analysed for polychlorinated biphenyls (PCBs), chlorinated dibenzo-p-dioxins and chlorinated dibenzofurans (dioxins and furans – PCDD/Fs), polycyclic aromatic hydrocarbons (PAHs), phthalates, polybrominated diphenyl ethers (PBDEs), perfluorooctane sulfonate (PFOS), tributyl tin, triclosan and bisphenol A concentrations.

Mean PCB concentrations (sum of the seven indicator congeners 28, 52, 101, 118, 138, 153 and 180) were 3.51 µg/kg dm in the food-based digestates and 1.86 µg/kg dm in the manure-based digestate. To contextualise these figures, EU (2000) proposed a PCB limit (sum of the seven congeners 28, 52, 101, 118, 138, 153 and 180) of 800 µg/kg dm in sewage sludge and EU (2001) proposed 400 µg/kg dm in biowaste.

The measured PCDD/F concentrations (comprising 17 congeners) were assigned Toxic Equivalency Factors (TEFs), using those given by the World Health Organisation (2005), which relate to the extent of a specific toxicological effect in comparison with 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (2,3,7,8-TCDD), which has a TEF of 1 (Van den Berg *et al*., 2006). The concentration of each dioxin or furan was multiplied by its respective TEF and the TEFs summed to obtain a Toxic Equivalent (TEQ), which is the quantity of 2,3,7,8-TCDD it would take to equal the combined effect of the 17 congeners. Mean PCDD/F concentrations were 2.73 ng TEQ/kg dm in the food-based digestates and 1.93 ng TEQ/kg dm in the manure-based digestate. To contextualise these figures, EU (2000) proposed a PCDD/F TEQ limit of 100 ng TEQ/kg dm in sewage sludge.

Mean PAH concentrations for the nine congeners (acenaphthene, phenanthrene, fluorene, fluoranthene, pyrene, benzo(b+j+k)fluoranthene, benzo(a)pyrene, benzo(ghi)perylene, indeno(1,2,3-cd)pyrene) were 1.27 mg/kg dm in the food-based digestates and 1.36 mg/kg dm in the manure-based digestate. To contextualise these figures, EU (2000) proposed a PAH limit value of 6 mg/kg dm in sewage sludge and EU (2001) proposed 3 mg/kg dm in biowaste.

The mean Di (2-ethylhexyl) phthalate (DEHP) concentration in the food-based digestates was 2 mg/kg dm and in the manure-based digestate 0.1 mg/kg dm. To contextualise these figures, EU (2000) proposed a DEHP limit of 100 mg/kg dm in sewage sludge.

PFOS, PFOS derivatives, PBDEs, triclosan, tributyl tin and bisphenol A were not detected (above the limits of analytical detection) in any of the digestate samples.

Conclusions

The analyses showed that digestate contains valuable quantities of major plant nutrients (*e.g.* nitrogen, phosphate, potash and sulphur). In particular, digestate was shown to be a valuable source of readily available N (*c.*80% of total N for the food-based digestates) that can be used to replace manufactured fertiliser N use.
Heavy metal concentrations in the food-based and manure-based digestates were within the limits set in PAS110, and notably for zinc and copper were well below typical levels in pig slurry.
The digestate samples were compliant with PAS110 limits for physical contaminants and RBP, and *E. coli* and *Salmonella* levels for the food-based digestates.
Organic compound contaminants were only present at very low levels or below the limits of analytical detection, well below any proposed standards for organic materials.
In common with livestock slurries, the digestate samples had a significant biochemical oxygen demand, indicating that care is needed when recycling these materials to land in order to minimise water pollution risks and to maximise their fertiliser value.

Acknowledgements

Funding of the work by the Waste and Resources Action Programme in Wales (WRAP Cymru) is gratefully acknowledged.

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