



International Fertiliser Society

CROP AVAILABLE NITROGEN SUPPLY FROM FOOD-BASED DIGESTATE

by
Anne Bhogal¹, Fiona Nicholson¹, Matt Taylor¹, Alison Rollett¹
and John Williams²

¹ ADAS Gleadthorpe, Meden Vale, Mansfield, UK.

² ADAS Boxworth, Cambridge, UK.

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SUMMARY.

Anaerobic digestion is the controlled biological decomposition of biodegradable materials (e.g. food waste, livestock manures or purpose-grown crops) in the absence of oxygen, releasing biogas that can be used as a source of heat and/or power. The process also produces a nutrient-rich digestate which is a potentially valuable source of crop available nitrogen (N) together with phosphate and potash. As with any 'new' material being recycled to agricultural land it is important to understand the crop N supply characteristics of digestate applications and to develop best management practices that maximise crop N utilisation, whilst minimising emissions to the environment.

Approximately 90% of the total N content of digestate derived from food waste is present in a readily available N form (i.e. ammonium-N), compared to c.65% for digestate derived from livestock manures and purpose grown crops, and 45% for a typical cattle slurry. This, together with a high pH means the potential for N loss via ammonia volatilisation following digestate applications can be considerable. The DC-*Agri* experimental programme aimed to quantify the crop available N supply from digestate application at 15 sites across the UK. Additional measurements to quantify ammonia emissions to air and nitrate leaching losses to water were carried out at 3 of the sites. Ammonia losses were higher from digestate (40% of total N applied) than from livestock slurry (30% of total N applied) applications reflecting the higher ammonium-N content and pH of the digestate. Bandspreading was effective at reducing ammonia emissions but only where the food-based digestate stayed in a band and rapidly infiltrated into the soil. Nitrate leaching losses following autumn application of food-based digestate to a sandy soil were similar in magnitude to those from livestock slurry at c.15-20% of the total N applied, demonstrating that digestate poses a similar threat as livestock slurries in terms of nutrient leaching to water bodies. Over all 15 sites, spring application timings of food-based digestate resulted in a crop (winter and spring cereals, potatoes and grass) nitrogen use efficiency (NUE) of c.55% compared to just 15% from autumn applications, due to a low crop N uptake and overwinter nitrate leaching losses following autumn applications.

The DC-*Agri* experimental programme has demonstrated the value of food-based digestate as a source of crop available nitrogen, but also highlighted the potentially high environmental cost of mismanaging these materials due to losses of N via overwinter nitrate leaching and ammonia volatilisation. These findings have directly fed into the development of best practice guidelines which provide a framework for the responsible use of digestates and composts.

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1. INTRODUCTION.

The application of organic materials to agricultural soils is generally considered to be the best practical environmental option for utilising the valuable nutrient supply and soil conditioning properties of these materials. At around 12 million hectares, agricultural land in the UK provides a large potential landbank for the recycling of organic materials. Indeed, around 93 million tonnes (fresh weight) of farm manures (Nicholson *et al.*, 2008), 1.1 million tonnes of biosolids dry solids (Water UK, 2010) and 1.3 million tonnes (fresh weight) of compost (WRAP, 2009) are currently applied annually to agricultural land in the UK. With increasing pressure to divert biodegradable 'waste' from landfill, a wide range of 'new' organic materials are becoming available for recycling to land. Notably, the anaerobic digestion of source-segregated food waste is an area of significant growth, with an estimated 5 million tonnes of food-based digestate predicted to be produced by 2020 (DECC and Defra, 2011). With any 'new' material being recycled to agricultural land it is important to provide robust information on the crop nutrient supply characteristics and to develop best management practices that maximise crop utilisation of these nutrients, whilst minimising environmental emissions to the air (e.g. ammonia, nitrous oxide) and to water (e.g. nitrate and phosphorus).

2. WHAT IS ANAEROBIC DIGESTATE?

Anaerobic digestion - AD (also referred to as biogas production or bi-methanation) is the controlled biological decomposition of biodegradable materials in the absence of oxygen. In addition to the generation of renewable energy or 'biogas' (used to generate electricity and provide a source of heat), the AD process generates a nutrient-rich digestate, which is a good source of plant available nitrogen (Taylor *et al.*, 2010). Feedstocks include domestic and commercial food waste, animal manures and purpose-grown (energy) crops, although it can also be used for sewage sludges and industrial organic wastes. AD is widely used on farm manures across Europe, with more than 4,000 farm-scale digesters in Germany alone (Nkoa, 2014). In the UK, AD has predominantly been used for the processing of sewage sludge. However, as part of the UK's commitment to meet EU Renewable Energy Targets by 2020, UK governments have put in place policies and strategies to increase the generation of renewable energy and treatment of food waste through AD. Key drivers are the Renewable Energy Directive, which requires that 15% of the energy delivered to UK consumers comes from renewable sources by 2020, and the EU Landfill Directive which states that by 2020 the amount of biodegradable municipal waste disposed of in landfill sites must be reduced by 65%, compared with 1995 levels. As a result, there has been a rapid expansion of AD in the UK, with currently over 300 operational AD plants outside the sewage treatment sector (compared to c.10 plants in 2010), and a further 450 projects under development (NNFCC, 2016). Approximately a third of these process food wastes, with the remaining two thirds 'farm-fed' using crops (e.g. maize, grass silage) and livestock manures as feedstocks.

2.1. Quality assurance.

The British Standards Institution Publicly Available Specification 110 (PAS 110; BSI, 2014) provides a baseline quality standard for digestate, ensuring that it is consistent, safe and reliable to use to supply nutrients to agricultural land. In addition, the Quality Protocol for Anaerobic Digestate (ADQP) provides a clear framework for the production and supply of quality (PAS110) digestate in England, Wales and Northern Ireland derived from both waste and non-waste inputs (EA and WRAP, 2014). This builds on BSI PAS 110 by clarifying feedstocks and identifying specific market sectors where quality digestates can be used, with an emphasis on traceability throughout the process through to the final market. ADQP-compliant digestate is classed as a product, not a waste, and therefore does not require an environmental permit/exemption for transport or application to agricultural land. However, the ADQP does not apply in Scotland, where PAS110 digestates can be used without further regulation in accordance with a Regulatory Position Statement obtained from the Scottish Environmental Protection Agency (SEPA).

The Biofertiliser Certification Scheme (BCS) is an independent, third-party quality assurance and certification scheme, which combines PAS110, the ADQP and specific Scottish requirements into a single process. Digestates certified under the scheme are referred to as quality digestates or 'biofertilisers'. The scheme is not compulsory, but the application of un-certified materials to agricultural land would require a permit under EU legislation, as implemented through the Environmental Permitting (England and Wales) Regulations 2010 SI 2010/675.

2.2. Digestate composition.

The feedstock used in the AD process and configuration of the digester will have a significant impact on the nutrient content of the resultant digestate (Nkoa, 2014). The digestate produced can be used 'whole' (with typically <5% dry matter) or can be further separated into liquor (1-4% dry matter) and fibre (20-40% dry matter) fractions to reduce storage, handling and transportation costs. The digestion process converts organic nitrogen (N) into soluble inorganic N which, as the environment is anaerobic, remains in the ammonium-N form or its equilibrium partner, ammonia (the equilibrium relation being dependent largely on temperature and pH). Nkoa (2014) reviewed the biochemical properties of digestates and reported pH values in the range 7.3-9.0, total N contents ranging from 0.12-1.5% (fresh weight) and ammonium-N contents between 35 and 81% of the total N content.

In a recent review of the UK Fertiliser Manual (RB209), Williams *et al.* (2016), collated data on the nutrient composition of c. 1,300 food-based digestates (food waste feedstocks) and c. 800 farm-sourced digestates (livestock manure and crop feedstocks), comprising samples of whole, separated liquor and separated fibre fractions (Table 1). Digestate derived from food waste had higher N and phosphate (P_2O_5) contents than those where manure and crops were used as feedstocks, whereas the latter tended to have higher potash (K_2O) contents. The data confirmed the value of whole (and liquor) digestate

Table 1. *Indicative nutrient content of food and farm-based digestates (Williams et al., 2016).*

	Food-based digestate			Farm-sourced digestate		
	Whole	Separated liquor	Separated fibre	Whole	Separated liquor	Separated fibre
	(n= 849)	(n= 146)	(n=266)	(n= 462)	(n= 17)	(n=274)
Dry matter (%)	4.1	3.8	26	5.6	3.0	24
Nutrient content (kg/t or kg/m ³)						
Total N	4.8	4.5	8.9	3.6	1.9	5.6
RAN	4.2	3.8	2.6	2.3	1.3	1.2
Total P ₂ O ₅	1.1	1.0	8.9	1.4	0.6	4.3
Total K ₂ O	2.4	2.8	2.9	4.0	2.5	6.0
Total MgO	0.2	0.2	2.2	0.6	0.4	1.8
Total SO ₃	0.7	1.0	4.0	0.8	<0.1	2.0

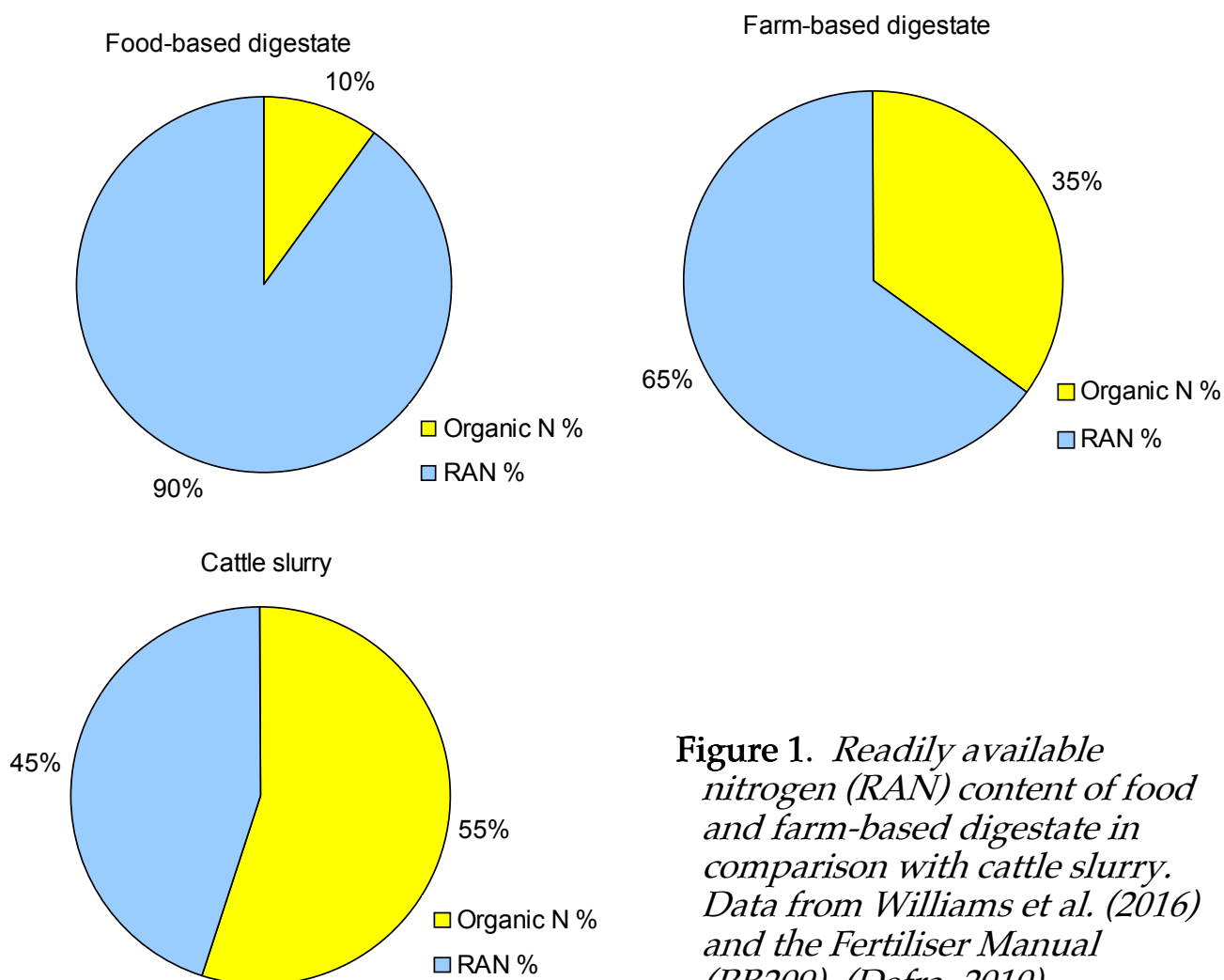


Figure 1. *Readily available nitrogen (RAN) content of food and farm-based digestate in comparison with cattle slurry. Data from Williams et al. (2016) and the Fertiliser Manual (RB209), (Defra, 2010).*

as a good source of readily available N (RAN, i.e. ammonium-N), particularly that derived from food waste where *c.*90% of its total N content was RAN, with *c.*65% of the total N in farm-sourced digestates as RAN compared to 45% for a typical cattle slurry (Figure 1). The separated fibre from both the farm-sourced and food-based digestate had elevated total N and total P₂O₅ contents, but reduced RAN contents compared with the whole and separated liquor fractions. These results confirm the findings of Nkoa (2014) who concluded that a) the liquor fraction had a greater potential as a N fertiliser than the fibre fraction, with the latter more useful as a soil conditioner due to its greater organic matter content, and b) the feedstock is one of the major determinants of the potential value and use of the digestate. Given the potential variability in AD feedstocks (particularly the wide range of different food wastes) it is recommended that a laboratory analysis of the nutrient content is obtained for each batch of digestate before it is applied to agricultural land (WRAP, 2016).

3. THE NITROGEN SUPPLY CHARACTERISTICS OF DIGESTATE.

3.1. The soil nitrogen cycle.

The principles and processes of the cycling of N within soils are well established (Figure 2). Inputs of N, in the form of mineral fertilisers, organic materials and crop residues are subject to a number of transformative processes which determine the amount of N that will subsequently be available for crop uptake, lost to the atmosphere and water environments or locked up (immobilised) within the soil organic matter pool. The majority of N within digestate is in mineral (ammonium-N) form and therefore readily available for immediate crop uptake. However, the amount of crop-available N (compared to readily available N) will depend on losses following spreading, most notably via ammonia volatilisation and nitrate leaching. Whilst nitrous oxide (N₂O) makes the single largest contribution to greenhouse gas (GHG) emissions from UK agriculture (Rees *et al.*, 2013), the amount of N lost via this route is relatively small in terms of its effect on crop available N. As with other organic materials applied to land, it is important to calculate the N use efficiency (NUE) of digestate applications (i.e. efficiency of N uptake by the crop, after accounting for losses), in order to be able to accurately account for the N applied within farm nutrient management plans, as well as seek ways in which to improve NUE.

3.2. DC-*Agri* experimental programme.

The DC-*Agri* experimental programme was commissioned by WRAP, WRAP Cymru and Zero Waste Scotland in 2010, and funded by Defra and the governments of Scotland and Wales, in order to provide a robust evidence base to support the confident use of digestates and composts by farmers and growers (www.wrap.org.uk/dc-agri). A principal focus of this work was to quantify the crop available N supply from digestate and measure losses to the environment (Nicholson *et al.*, 2016). Fifteen replicated field experiments were

undertaken on a variety of arable crops (including winter and spring cereals and potatoes) and grassland between 2010 and 2014. The experiments covered the major soil types and agro-climatic zones in Britain, with the aim of determining the NUE of whole digestate derived from foodwaste ('food-based digestate') and livestock manure ('manure-based digestate') feedstocks, compared to conventional livestock slurries. Autumn and spring applications were compared at all sites, with the digestates both surface broadcast and bandspread to evaluate the effect of these application techniques on NUE. Ammonia emissions were measured at three of the sites, with nitrate leaching losses following autumn applications measured at one site. The three sites also included farmyard manure (FYM) and green compost treatments as part of the experimental design.

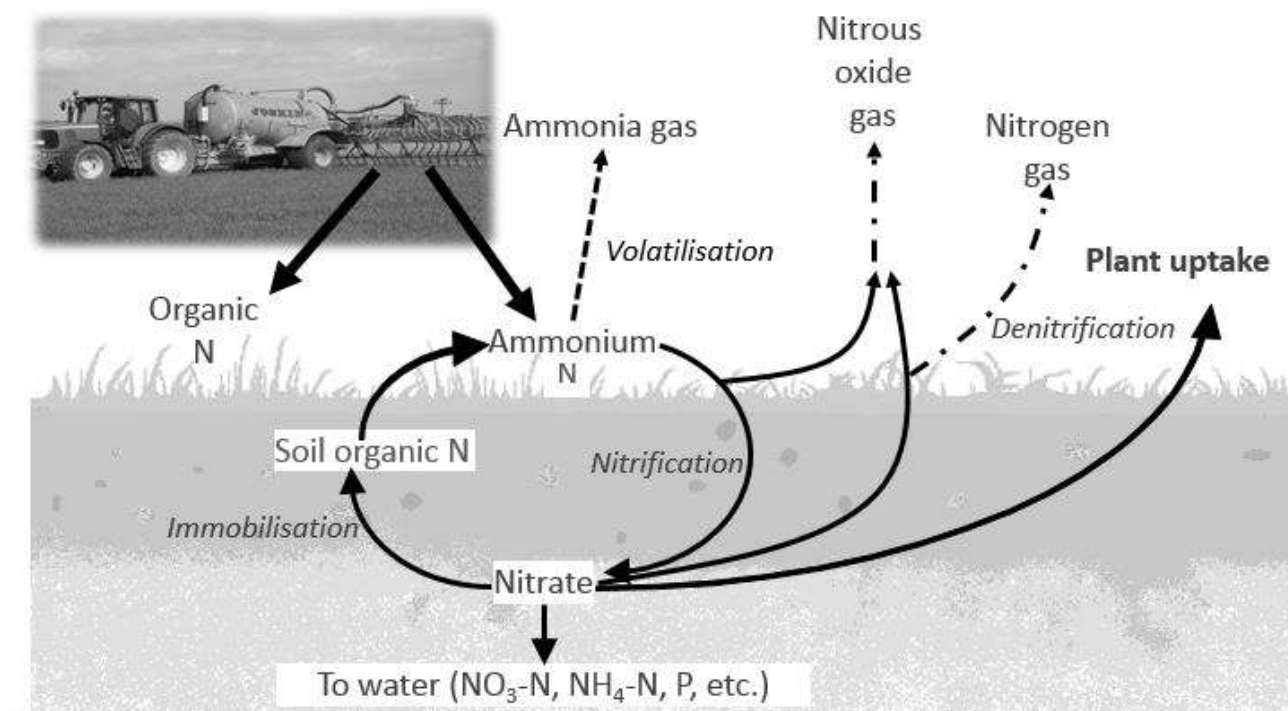


Figure 2. *The cycling of nitrogen in soils following the application of organic materials*

3.2.1. Ammonia emissions following digestate applications.

Since digestate has both a high ammonium-N content and high pH, the potential for N loss via ammonia volatilisation can be considerable (Nkoa, 2014). Indeed, higher ammonia volatilisation has been measured following the application of digested livestock slurries compared to their undigested counterparts (Moller *et al.*, 2008). Likewise DC-Agri found that about 40% of the total N applied could be lost by surface broadcasting food-based digestate to arable and grassland soils, compared to *c.*30% from cattle slurries and less than 5% from FYM and compost (Figure 3).

The food-based digestate used in these experiments had a higher ammonium-N content (mean 5.6 kg/t) compared with the livestock slurries (mean 2.2 kg/t for pig slurry and 1.3 kg/t for cattle slurry). Additionally, the mean pH of the

food-based digestate was 8.5 compared with 7.8 for pig slurry and 7.6 for cattle slurry; pH values greater than 8 are particularly conducive to elevated ammonia emissions from digestates (Hoeksma *et al.*, 2012). Over the three sites, bandspreading was effective at reducing ammonia emissions from livestock slurry, but not from food-based digestate (Figure 3). Bandspreading of liquid organic materials (such as food-based digestate) is now a common practice, with the majority of contractor-spread digestate applied using bandspreaders. In this study, the failure to observe a reduction in ammonia emissions when bandspreading food-based digestate (in comparison with surface broadcast applications) was most probably due to soil and/or organic material properties that meant that the digestate did not rapidly infiltrate into the soil or did not stay in a narrow band on the soil surface.

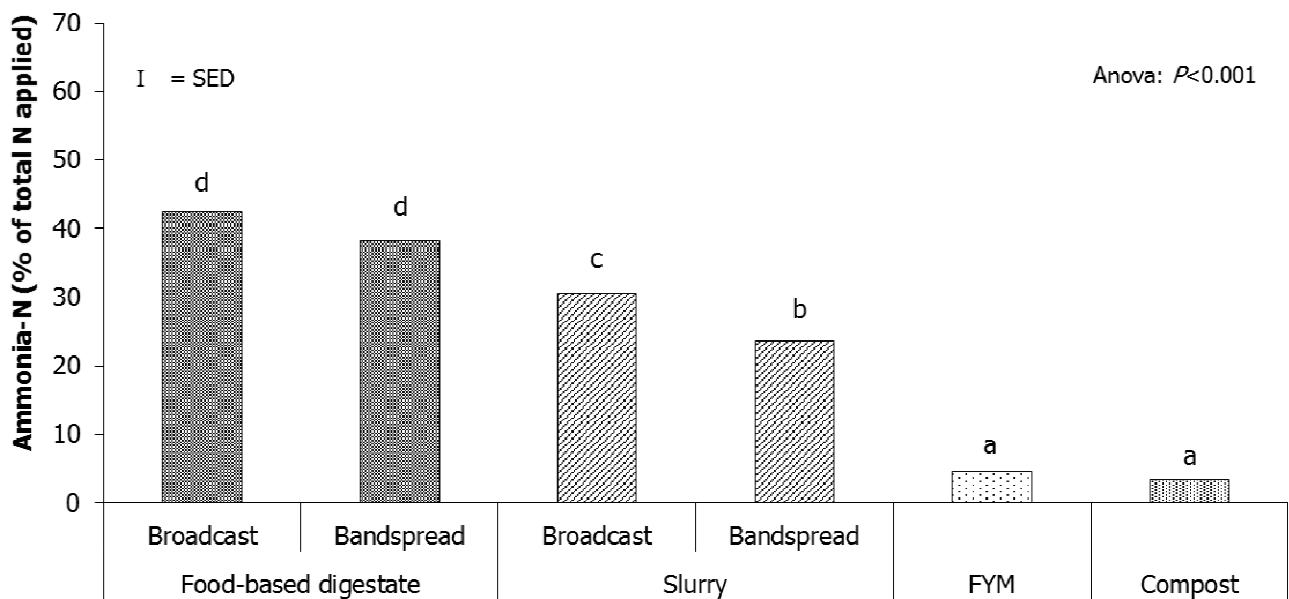


Figure 3. Average ammonia emissions measured across three DC-Agri experimental sites following autumn (one site only) and spring organic material applications, expressed as a percentage of the total N applied. Columns labelled with different letters are significantly ($P < 0.05$) different from each other. SED = standard error of differences of means

Under the EU National Emissions Ceiling Directive, the UK has a proposed target to reduce ammonia emissions by 8% (relative to a 2005 baseline) between 2020 and 2029, and by 21% from 2030 (with this target currently under review as part of the Clean Air Policy; <http://naei.defra.gov.uk/>). Therefore, as well as the loss of a valuable resource, ammonia emissions from digestate applications present a challenge to the UK meeting these targets, particularly given the number of AD plants currently under development.

3.2.2. Nitrate leaching losses following digestate applications.

Overwinter nitrate leaching losses were measured at one site on a sandy arable soil with a high risk of nitrate leaching. Here, cumulative nitrate leaching losses following the autumn application of food-based digestate were

similar in magnitude to those from pig slurry at c.15-20% of the total N applied (equivalent to 25-35 kg/ha N loss), and significantly greater ($P<0.05$) than those from applications of pig FYM and compost (at $< 5\%$ of the total N applied, equivalent to 5-10 kg/ha N loss). There was no difference in leaching losses as a result of the different application methods. Nkoa (2014) reviewed a number of studies comparing N leaching after applications of digested and undigested livestock slurries and also concluded that digestate posed at least a similar threat to livestock slurries in terms of nutrient leaching to water bodies. Digestate should therefore only be applied when there is a crop N requirement, and to maximise its N fertiliser value it is important to apply in the spring to minimise overwinter nitrate leaching losses.

3.2.3. Nitrogen use efficiency (NUE) of digestate.

The fertiliser replacement value and NUE of digestate can be calculated by direct comparison with the amount of manufactured N fertiliser needed to produce the same yield (Schröder *et al.*, 2007). Therefore at each of the 15 DC-Agri experimental sites, 5 rates of manufactured fertiliser N were applied to replicated plots, together with a nil-N control in order to produce a yield response curve from which fertiliser replacement values and NUE could be calculated. Results from the 15 sites indicated that for spring applications approximately 55% of the total N applied was taken up by the crops (cereals, potatoes and grass), compared to just 15% from autumn applications (Figure 4).

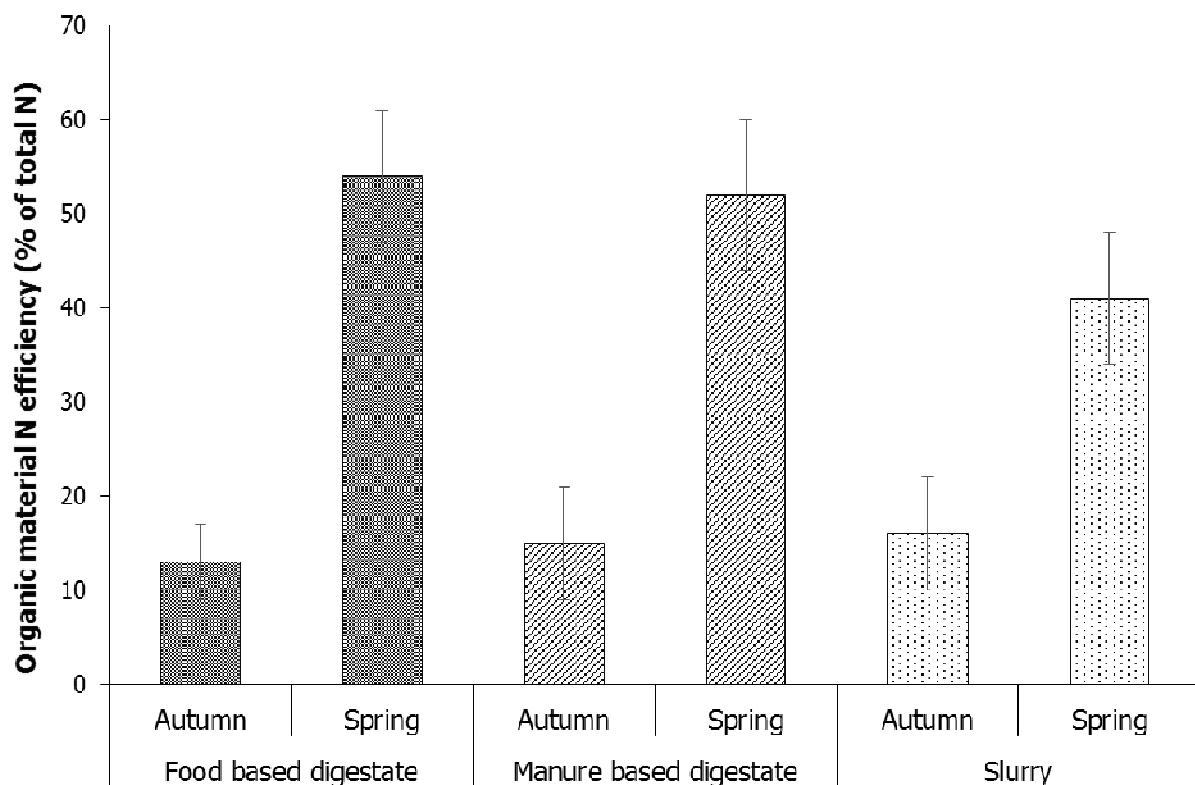


Figure 4. Nitrogen use efficiency (NUE as % of total N applied) following the application of digestate and livestock slurry in the autumn and spring (average for 15 experimental sites, with 95% confidence intervals).

The lower NUE from autumn application timings reflected a low crop N requirement at this time and losses of N via overwinter nitrate leaching, again confirming the need for spring applications to maximise digestate N fertiliser value (note: autumn applications to responsive crops, such as oilseed rape were not conducted). There was no difference between the NUE of the food and manure-based digestates, which were higher than the NUE of the livestock slurries, reflecting the higher RAN contents of the digestates.

4. BEST PRACTICE GUIDELINES.

The DC-*Agri* experimental programme has demonstrated the value of food-based digestate as a source of crop available N, but also highlighted the potentially high environmental cost of mismanaging these materials due to loss of N via overwinter nitrate leaching and via ammonia volatilisation. These have directly fed into the development of best practice guidelines which provide a framework for the responsible use of digestate and compost (WRAP, 2016).

4.1. Planning digestate applications.

It is important to understand the nutrient value of digestate applications and given the potential variability in the N content of digestate as a result of variation in feedstocks, it is recommended that an up-to-date analysis of a representative sample of the digestate is obtained using an accredited laboratory before calculating application rates. Nutrient management tools, such as the MANNER-NPK model (Nicholson *et al.*, 2013), can then be used to predict the amount of crop available N in order to adjust manufactured fertiliser N rates accordingly. This model includes both food-based and manure-based digestate, and allows users to input their own N analysis results, but currently uses the algorithms for pig slurry to calculate losses and predict final crop N availability. Further work is required to update this model, using results from DC-*Agri* to improve the accuracy of predictions.

The DC-*Agri* programme has also shown that in order to maximise the NUE of digestate, it should be applied accurately and evenly using precision application machinery (e.g. trailing shoe/hose or shallow injection) and only when there is a crop N demand (ideally in the spring to minimise overwinter nitrate leaching losses).

4.2. Nitrate Vulnerable Zones.

Nitrate Vulnerable Zones (NVZs) are areas designated as being at risk from agricultural nitrate pollution. About 62% of farmland in England falls within a NVZ and farmers within these areas have to follow mandatory rules to manage nitrate loss from agriculture. As the readily available N content of digestate exceeds 30% of its total N content (Table 1), applications within NVZs are subject to mandatory closed spreading periods during autumn and winter depending on the soil type (Defra, 2013). Additionally, following the end of the closed period to the 1st March, applications of whole and liquor

digestate are restricted to a maximum of 30m³/ha in a single application. Digestate suppliers therefore need to also ensure that they have adequate storage available to cover these closed periods.

4.3. Renewable Fertiliser Matrix.

The renewable fertiliser matrix details when renewable fertilisers (i.e. digestates and composts), can be used to grow different crops, based on their potential risk to human and animal health from microbial contamination. It covers only BSI PAS 110 digestate (and PAS 100 compost), with restrictions for use of non-pasteurised products on crops that are typically eaten raw, and for non-graze/harvest intervals for grassland and forage (WRAP, 2016).

5. CONCLUSIONS.

Five years ago, food-based digestate was a little understood, little used 'novel' material being produced by a handful of commercial bio-energy companies. Today, over 1.5 million tonnes of food waste is processed by more than 100 AD operators. Not only does this provide a renewable energy source, it also produces valuable fertiliser in the form of digestate, which can be used to replace manufactured fertiliser sources as part of an integrated nutrient management plan. The research findings delivered by the DC-*Agri* experimental programme have provided a robust evidence base to support the confident use of digestate, so that farmers can maximise its N fertiliser value, whilst minimising losses to the environment.

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7. REFERENCES.

- BSI, (2014). PAS 110:2014 Specification for whole digestate, separated liquor and separated fibre derived from the anaerobic digestion of source-segregated biodegradable materials.
www.wrap.org.uk/content/bsi-pas-110-producing-quality-anaerobic-digestate.
- DECC and Defra, (2011). *Anaerobic Digestion Strategy and Action Plan*. Defra, London, UK.
www.defra.gov.uk/publications/files/anaerobic-digestion-strat-action-plan.pdf

- Defra, (2010). The Fertiliser Manual (RB209). The Stationary Office, Norwich, UK. ISBN 978-0-11-243286-9
- Defra, (2013). Guidance on complying with the rules for nitrate vulnerable zones in England for 2013 to 2016. www.gov.uk/defra.
- EA and WRAP, (2014). Quality Protocol – Anaerobic Digestate. End of waste criteria for the production and use of quality outputs from anaerobic digestion of source-segregated biodegradable waste. www.gov.uk/government/publications/quality-protocol-anaerobic-digestate
- Hoeksma, P., Mosquera, J. and Melse, R.W. (2012). *Monitoring Methane and Nitrous Oxide Reduction by Manure Treatment*. Report 627. Livestock Research, Wageningen UR, the Netherlands. www.mestverwerken.wur.nl/home/..%5CInfo%5CBibliotheek%5CPDF/Monitoring%20methane%20and%20nitrous%20oxide%20reduction%20by%20manure%20treatment_rappo.pdf
- Moller, K. and Stinner, W. (2009). Effects of different manuring systems with and without biogas digestion on soil mineral nitrogen content and on gaseous nitrogen losses (ammonia, nitrous oxides). *European Journal of Agronomy* **30**, 1–16.
- Nicholson, F.A., Anthony, S. and Chambers, B.J. (2008). *The National Inventory and Map of Livestock Manure Loadings to Agricultural Land: MANURE-GIS*. Final report, Defra project WQ0103.
- Nicholson, F.A., Bhogal, A., Chadwick, D., Gill, E., Gooday, R.D., Lord, E., Misselbrook, T., Rollet, A.J., Sagoo, L., Smith, K.A., Thorman, R.E., Williams, J.R. and Chambers, B.J. (2013). An enhanced software tool to support better use of manure nutrients: MANNER-NPK. *Soil Use and Management* **29**, 473-484.
- Nkoa, R. (2014). Agricultural benefits and environmental risks of soil fertilization with anaerobic digestate: a review. *Agronomy for Sustainable Development* **34**: 473-492.
- NNFCC, (2016). Anaerobic Digestion deployment in the UK. Third Annual report. <http://www.nnfcc.co.uk/>
- Nicholson, F.A. *et al.*, (2016). Field experiments for quality digestate and compost in agriculture – Work Package 2 Report Digestate Nitrogen Supply and Environmental Emissions. www.wrap.org.uk/content/digestate-and-compost-agriculture-dc-agri-reports.
- Rees, R.M, Baddeley, J.A., Bhogal, A., Ball, B.C., Chadwick, D.R., Macleod, M., Lilly, A. (2013). Nitrous oxide mitigation in UK agriculture. *Soil Science and Plant Nutrition* **59**, 3-15.
- Pappa, V.A., Thorman, R.E., Watson, C.A. and Williams, J.R. (2013). Nitrous oxide mitigation in UK agriculture. *Soil Science and Plant Nutrition*, **59**, 3-15.
- Schröder, J.J., Uenk, D. and Hilhorst, G.J. (2007). Long-term nitrogen fertilizer replacement value of cattle manures applied to cut grassland. *Plant and Soil* **299**, 83-99.

- Taylor, M.J, Rollett, A.J., Tompkins, D. and Chambers, B.J. (2010). Digestate quality and fertiliser value. 15th European Biosolids and Organic Resources Conference. www.european-biosolids.com
- Water UK, (2010). *Recycling of Biosolids to Agricultural Land*. Issue number 3, January 2010. Water UK, 1 Queen Anne's Gate, London.
- Williams, J., Munro, D., Sagoo, L. and Nicholson, F. (2016). Review of guidance on organic manure nutrient supply in the fertiliser manual. AHDB Research Review No. 3110149017 – in press.
- WRAP, (2009). Composting and Biological Treatment Survey / final report: Market survey of the UK organics recycling industry - 2007/08.
- WRAP, (2016). Digestate and compost use in agriculture. Good practice guidance for farmers, growers and advisors. www.wrap.org.uk/content/digestate-and-compost-good-practice-guidance

8. RELATED PROCEEDINGS OF THE SOCIETY.

- 8, (1950), Role of Fertilisers in Increasing Output from Grassland, *R A Hamilton.*
- 51, (1958), Fertilisers and Grassland, *William Davies, T E Williams.*
- 64, (1960), Ten Years Experience with Heavy Applications of Nitrogen on Grassland in the Netherlands, *H van der Molen.*
- 88, (1965), Effect of Fertilisers on the Nutritive Value and Production Potential of Forages, *W F Raymond, C R W Spedding.*
- 142, (1974), Quantity and Timing of Fertiliser N for Grass and Grass/Clover Swards, *J S Brockman.*
- 142, (1974), Use of Nitrogen Fertilisers on Grassland for Milk Production, *F J Gordon.*
- 142, (1974), Variation in Response of Grass to Fertiliser N in Relation to the Environment, *J Morrison, M V Jackson, T E Williams.*
- 142, (1974), Role of Nitrogen Fertiliser in the Production of Beef from Grass, *Prof. W Holmes.*
- 197, (1981), Milk Production - The Role of Fertilisers, *W Thompson, T Blair.*
- 198, (1981), Meat Production - The Role of Fertilisers, *H K Baker.*
- 199, (1981), Nitrogen and Intensification of Livestock Farming in EEC Countries, *P F J van Burg, W H Prins, D J den Boer, W J Sluiman.*
- 229, (1984), Flow of Nitrogen in Grassland, *John C Ryden.*
- 288, (1989), Fertilisers and Grass Quality, *H Beringer.*
- 289, (1989), Nutritive Value of Grass in Relation to Mineral Deficiencies and Imbalances in the Ruminant, *J Price.*

- 301, (1990), Practical Measures to Reduce Nutrient Loss from Grassland Systems, *Dr ir H Korevaar, D J den Boer.*
- 325, (1992), Nitrogen Immobilisation and Leaching in Pasture Soils, *S P Cuttle, P C Bourne.*
- 326, (1992), Nitrogen Economy of Grazed Grassland, *M K Garrett, C J Watson, C Jordan, R W J Steen, R V Smith.*
- 327, (1992), Nitrate Leaching from Intensively Grazed Swards, *E I Lord.*
- 462, (2001), Nitrogen Cycling in Grassland Systems, *C J Watson.*
- 466, (2001), Fertiliser Usage and the Mineral Requirements of Grazing Livestock, *R G Hemingway, J J Parkins.*
- 485, (2001), Management for Biodiversity in Grassland Farming Systems, *J H McAdam, J A Kerr, G E J Fisher, J R B Tallwin.*
- 486, (2001), Inputs of Nutrients and Lime for the Maintenance of Fertility of Grassland Soils, *A E Johnston, P R Poulton, C J Dawson, M J Crawley.*
- 501, (2002), Sulphur Fertilisers, Forage Quality and Animal Production, *R Till.*
- 517, (2003), Effect of Nitrate Legislation on Fertiliser Nitrogen Management for Grassland, *J Humphreys, K O'Connell, C J Watson.*
- 518, (2003), Strategies to Meet Requirements of the EU-Nitrate Directive on Intensive Dairy Farms, *H F M Aarts.*
- 549, (2004), Micronutrients for Grass/ Animal Systems, *G E J Fisher.*
- 618, (2007), Potassium, Sodium and Magnesium in Grass and Animal Nutrition: A Question of Balance, *S C Jarvis, G E J Fisher.*
- 618, (2007), Potassium Requirements for Grass Cut for Silage - A Review, *R G Hemingway.*
- 654, (2009), Management of Nitrogen Inputs on Farm Within the EU Regulatory Framework, *H F M ten Berge, W van Dijk.*
- 660, (2009), Nitrogen Fertilisation of Established Grassland for Milk and Meat, *G E J Fisher, E C Jewkes.*
- 684, (2010), Nutrient Planning in Dairy Farming on Temperate Grassland: The Need for an Integrated Approach, *P R Scott.*
- 712, (2012), Practical Advice for Slurry Application Strategies for Grassland Systems, *S T J Lalor, N J Hoekstra, P N C Murphy, K G Richards, G J Lanigan.*
- 775, (2015), Acid Treatment of Animal Slurries: Potential and Limitations, *D Figueiro, S Surgu, I Fraga, E Vasconcelos, J Coutinho.*
- 776, (2015), Continuing Revision of National Fertiliser Recommendations through Co-operative Action, *J Holmes.*



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