NUTRIENT VALUE OF DIGESTATE FROM FARM-BASED BIOGAS PLANTS

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1 INTRODUCTION

Among the commonly claimed benefits of anaerobic digestion are a reduced risk of odour nuisance, a reduction in viable pathogenic organisms and improvements in effluent nutrient (digestate) quality. During anaerobic digestion, organic compounds are broken down, firstly via acetogenic bacteria to methane precursors, largely volatile fatty acids (VFAs) and then to methane and other products via methanogenic bacteria. Under anaerobic conditions, organic forms of nitrogen (N) are converted into ammonium-N (NH_4-N), i.e. readily available nitrogen (RAN). The RAN content of cattle slurry is typically 50% and pig slurry *c.* 60% of total-N (Chambers and Nicholson, 2004). It might be anticipated that a measurable increase in the proportion of readily available N would occur in these materials, as a result of the digestion process. Changes in slurry P availability may also occur as a result of the release of P from organic forms during digestion, leading to an increase in the water-soluble P fraction. This may increase the vulnerability of slurry P to losses by surface run-off or via by-pass flow through field drainage systems, unless application practices are carefully managed and controlled.

The main objectives of this study were:

- a critical review of existing research on the environmental benefits and the nutrient value of farm slurry digestate from anaerobic biogas systems;
- to undertake comparative chemical analysis of slurry feedstock and the resulting digestate output from farm-scale digesters on commercial farms in Scotland.

2 MATERIALS AND METHODS

2.1 Technical review of existing research data

In order to identify suitable information sources, some preliminary networking and initial scoping of known reference material was undertaken, to identify further key reference data. This included a search of known research organisations in Europe and USA, for example, FAO RAMIRAN network conference proceedings and research database (www.ramiran.net). Follow-up requests for papers and reports were made, initially largely via existing relevant contacts, e.g. RAMIRAN network, N European network of specialists (Danish Agricultural Advisory Centre). Relevant analytical data and technical information were also collected from recent projects in the UK.

2.2 Monitoring, sampling and analysis of effluent from farm-based digesters

As part of a strategy to improve the quality of Scottish bathing waters, the Scottish Executive funded research on new approaches to reduce the impact on bathing waters of diffuse agricultural pollution. One of these approaches involved the installation of anaerobic digestion (biogas) plants on farms in the Sandyhills and Saltcoats catchments, in SW Scotland (Anon, 2006). The project provided, also, a good opportunity for study of digester effluent nutrient characteristics in well designed farm digester installations. Careful site selection of two representative farm-scale digesters included consideration of the range and type of livestock, livestock feeding system, match of digester with livestock slurry production and calculated retention times; also potential for representative sampling.

The proposed work was of limited duration and comprised sampling of the two farm sites on two occasions per week over a four-week period. The proposed sampling methodology was designed to facilitate the comparative analysis of feedstock slurry and digestate. To accommodate the "system inertia" arising from digester retention time, the sampling spanned four full weeks of digester operation; giving operational coverage over a *c.* 30

day period, well in excess of the likely operating retention time. Analyses included: dry matter (DM), organic matter, pH, total N, NH_4-N, NO_3-N, total P, bio-available P (water soluble), total K, total S, total Mg, total Na.

3 RESULTS AND DISCUSSION

3.1 Review of existing research data

There is an extensive literature describing the microbial processes involved in the anaerobic degradation of organic substances to the most reduced form of methane (CH_4) (Hobson *et al.,* 1974; Møller, 2001). The energy released in the process is mostly recovered in the methane. The degradation of organic substances is complex, involving (i) slow enzymatic hydrolysis and the formation of sugars, amino acids and fatty acids; (ii) fast acetogenesis of volatile fatty acids (VFAs) and (iii) methane (and CO_2) formation. A number of groups of bacteria are involved in the various stages. Details of the processes are well described in the literature and an appreciation of the biochemistry will assist in understanding the nutrient transformations and the nutrient content of the final digestate product.

Comparative analytical data including digested and undigested livestock slurries were compiled from sources in the UK, Europe and USA, covering the period from 1979 to 2007. Full data are available (Smith *et al.* 2007), though summary data only, are presented in Table 1; results were reported only from studies thought to provide reliable comparisons of digester input and output analyses.

TABLE 1 **Changes in nutrient content of livestock slurries and manures as a result of anaerobic digestion[1] (comparison between input and output, as % except for pH) – summarised data only**

Observations	DM	N-total	NH_4-N	P_2O_5	pH	COD
Mean	-25.6	-0.8	25.7	0.7	0.4	-29.9
Median	-25.15	0	29.4	1.05	0.4	-31.8
No. of Observations	12	16	18	10	11	12

[1] Note analytical and source data from all the research, reported in Smith *et al*., 2007

Data from the research showed a reduction in slurry DM content as a result of anaerobic digestion with, overall, a difference of *c.* 25% between input and output slurry DM (Table 1). This reflects the breakdown of organic matter and loss of carbon from the substrate, with the generation of CH_4 and CO_2. The substantial reduction in COD of *c.* 30% is also as anticipated and, whilst a much larger reduction in BOD of *c.* 70%, was also observed, these data were available from four studies only and are not included in the summary. Increases in effluent NH_4-N content and pH are also anticipated as a result of the degradation of proteins and the production of CO_2. Such changes were recorded in most of the studies and resulted in *c.* 26% increase in NH_4-N and 0.4 unit rise in pH (Table 1). There were small and inconsistent changes in N, P_2O_5 and K_2O content; such changes would not be anticipated since these elements should be conserved during digestion. Any small, apparent, changes would be consistent with typical sampling and analytical error and, when averaged across a range of reliable research data, they tend to disappear. The consistency in total content of N, P_2O_5 and K_2O (confirmation of the anticipated lack of change), gives greater confidence in the reliability of the changes observed in DM, NH_4-N and in pH.

Claims of beneficial impacts of anaerobic digestion on effluent analysis are of no real significance if these are not reflected by positive impact in terms of nutrient recovery and crop yield response. Whilst there have been few well controlled comparisons of the impact of digestion on slurry analysis, there are even fewer data involving crop response. In Denmark, field assessments on the utilisation of slurries following a range of treatments, including anaerobic digestion and separation, have been carried out for a number of years. In fact, it is claimed that the utilisation of N in manure has increased dramatically and the use of mineral fertiliser N has decreased by 50% (Birkmose, Danish Agricultural Advisory Centre, *pers. comm*). Schröder and Uenk (2006) studied the nitrogen fertiliser replacement value (NFRV) of undigested and digested cattle slurry in the Netherlands. Efficiency was determined from replicated field trials running from 2002-05. In the first year the NFRV of digested slurry exceeded that of undigested slurry by 5%. However this initial advantage was completely offset when residual N effects, in years 2, 3 & 4, were taken into account, yielding similar long term NFRV's for both types of slurry.

3.2 Analysis of effluent from farm-based digesters

Slurry input and digester output were sampled via sample ports on the feed and delivery screw pumps, accessible from the control room at both of the farm sites. The reactor tank was sampled first (digestate) after mixing, then the holding tank (feedstock), this procedure avoiding any contamination digestate with raw (untreated) slurry. Mean input and output analysis data, with overall differences, are presented in Table 2. An indication of the variability of some observations can also be seen from the data presented, for the Ryes Farm site, in Figure 1.

TABLE 2 **Input and digester output analyses with overall differences from the two farm sites in Scotland (values are mean of 9 observations)**

Site Observations	DM	pH	Ash %DM	N-total	NH_4-N	P_2O_5	Water sol P %DM	Total K_2O
Ryes Farm								
Input	8.1	7.68	34.8	0.29	0.11	0.11	0.012	0.43
Output	6.2	7.84	40.3	0.29	0.13	0.11	0.012	0.42
Difference %[1]	-21.2	0.16	16.7	-	17.7	-	-	-1.9
P value[2]	**0.005**	0.264	**0.017**	0.608	0.092	0.347	0.299	0.368
Digestate store[3]	10.1	7.44	39.4	0.30	0.11	0.22	0.024	0.3
Corsock Farm								
Input	7.7	7.35	16.3	0.29	0.11	0.10	0.025	0.23
Output	6.8	7.58	19.4	0.30	0.12	0.11	0.017	0.23
Difference %[1]	-11.8	0.22	19.1	4.2	4.5	8.2	-32.0	3.4
P value[2]	**0.002**	**0.008**	**<0.001**	0.107	0.296	0.065	**<0.001**	0.262
Digestate store[3]	4.0	7.51	22.8	0.21	0.10	0.09	0.015	0.22

[1] – Difference between output and input values expressed as % input, except pH which is in units (reduction –ve);
[2] – indication of significance from paired t-test between input and output level;
[3] – Large digestate store at each site sampled, once only, towards end of monitoring period.

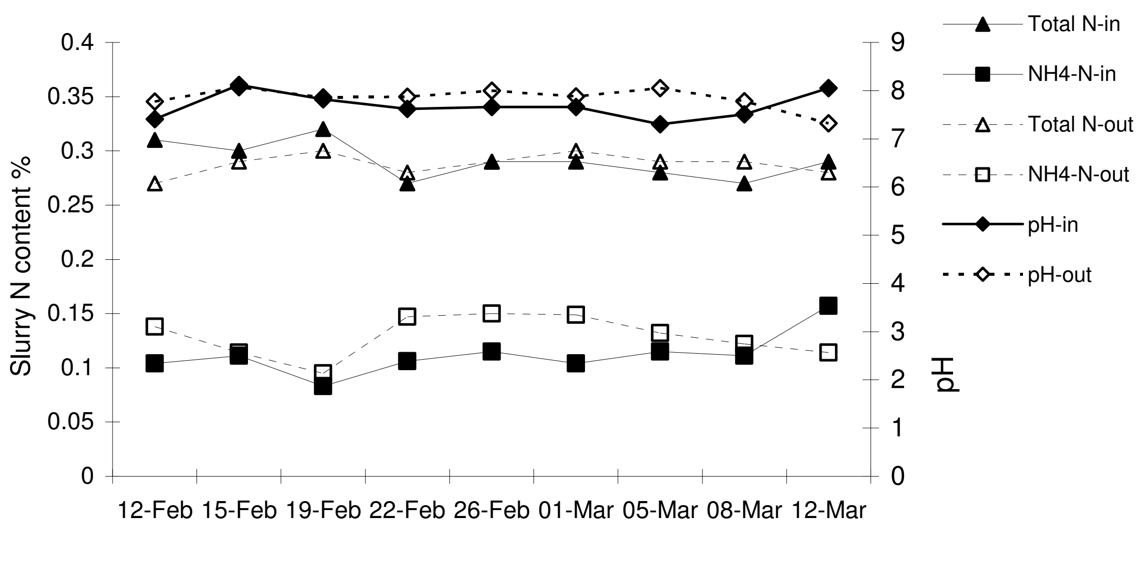

FIGURE 1 **Monitoring changes in pH, total and NH4-N in digester input and output, at Ryes Farm**

In general the results followed the pattern of those identified within the technical review, with a substantial and highly significant reduction ($P<0.01$) in slurry DM content of 21% at Ryes and 12% at Corsock. Similarly, the highly significant increase in ash content at both sites reflects the breakdown of organic matter and removal of carbon as CH_4 and CO_2 against the background of minerals retention confirmed, for example, by the consistent levels or small and non-significant changes in total N, total phosphate and total potash. Although an 18% increase in NH_4-N in the digestate was recorded at Ryes Farm, which is in line with the levels of performance reported in the literature, this increase failed to reach statistical significance (Table 2). A rather small increase in

NH_4-N (4.5%) was observed at Corsock, also non-significant. The variability in the NH_4-N data can be seen with time in Figure 1 and is reflected by a relatively high coefficient of variation (cv %) for both slurry input and digestate (not shown here).

Small increases in pH also occurred at both sites but again were inconsistent and failed to reach statistical significance. The greatest variability was associated with the more ephemeral parameters like NH_4-N and DM content, which are subject to rapid change, particularly in dilute slurries as a result of solids settlement and, in the case of NH_4-N, ionic buffering within the slurry; also, as a result of microbial activity within the digestion process, retention time and C:N ratio of the substrate mix. Water soluble P content was very low in the slurry at both sites (1.5 – 4.2% of total P), with no difference between input and digestate at Ryes. The apparent decrease in water soluble P in the digestate at Corsock must be treated with caution, however, since the laboratory detection limit for this particular determination was only slightly below the reported levels and differences between observations at this level be considered unreliable.

The analysis of the slurry on the single occasion from the large storage tank was closely similar, in both cases, to the overall mean of the digestate analyses, except for a reduced DM content at Corsock, this latter case reflecting the likely dilution by rainfall within the store at that site, and the normal in-store settlement of solids.

4 CONCLUSIONS

As a result of the digestion process a number of changes in slurry analysis can be expected, which were confirmed by the literature and the monitoring results. These include a substantial reduction (up to 25%) in solids content and a consequential increase in ash content, due to the conservation of minerals and reduced slurry carbon (and organic matter content). Increases in slurry pH (up to 0.5 pH units) and NH_4-N content (up to 25%) may also occur, though these changes are less consistent than the reduction in solids content and organic matter content, and may be transient or dependent on digester operating conditions and the analysis of the feedstock slurries.

Increased slurry NH_4-N content, even with reduced NH_3 emissions, does not guarantee improved utilisation of slurry N and increased savings in fertiliser N. The limited research data on agronomic assessments has generated mixed results with small, short term, or inconsistent benefits. There is evidence, from the literature and from other recent research, to suggest that an increased availability factor for the phosphate (P) content of AD slurries might be appropriate, although the monitoring data failed to show any increase in the water soluble P content of the digestate.

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