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MICROBIOLOGICAL CONTAMINATION OF DIGESTED PRODUCTS FROM
ANAEROBIC CO-DIGESTION OF BOVINE MANURE AND AGRICULTURAL
BY-PRODUCTS

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Running headline: Microbial contamination of digestate

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ABSTRACT

Aims: This study was performed to investigate the microbiological contamination of digestate product (DP) obtained from the anaerobic co-digestion of bovine manure and agricultural by-products.

Methods and results: Microbiological analyses were performed on bovine manure, fresh DP, liquid and solid fractions and stored liquid fraction of DP. A statistically significant reduction of faecal bacterial indicator was found after anaerobic digestion except for Enterococci. After liquid/solid DP separation, bacteria tend to be concentrated in the solid fraction. Storage does not seem to influence the indicator parameters, except for Enterococci. *E. coli* O157:H7 and *Yersinia* were never found in any samples analysed. *Salmonella* was rarely detected in DP samples and its derivates, while *L. monocytogenes* was encountered in many samples.

Conclusions: The results obtained indicate that the hygienic quality of DP is equal or even better than that of the bovine manure and suggest the need to identify specific pathogen indicators related to the hygienic characteristics of digestate products.

Significance and impact of the study: This study highlights that the anaerobic co-digestion of bovine manure and agricultural by-products in a field-scale biogas plant does not increase human health risk respect to the use of animal manure for agricultural fertilization.

Keywords: anaerobic digestion, faecal indicator bacteria, pathogenic bacteria, bovine manure, fertilizer
1. INTRODUCTION

The global energy demand is growing rapidly and about 88% of this demand is met at present by fossil fuels. In this context, it is essential to develop sustainable energy supply systems that aim to cover the energy demand with renewable sources (Amon et al., 2007a). Biogas production from a wide range of energy crops, animal manures and organic wastes is of growing importance as it offers considerable environmental benefits and an additional source of income for farmers. Renewable energy is produced, and after anaerobic digestion the products can be used as a valuable fertilizer for agricultural crops due to the increased availability of nitrogen and superior short-term fertilization effects (Amon et al., 2007b; Weiland, 2010). Reuse of the digested products could present health concerns that must be satisfied before land application becomes an accepted practice. Different studies have shown that livestock faeces can be significantly contaminated with pathogens (Albihn and Vinnerar, 2007). In this context, the microbial quality of manure should not be neglected since many outbreaks of gastroenteritis related to livestock have been reported (Massè et al., 2011). The bacterial pathogens most important with regard to human health include, for example, Salmonella spp., Escherichia coli O157:H7, Campylobacter jejuni and Yersinia enterocolitica. Listeria monocytogenes has also been reported as causative agent of human infections related to livestock (Bagge et al., 2005, Massè et al., 2011).

Some studies attested that sometimes pathogens can survive anaerobic digestion (Sidhu and Toze, 2009) and the growth of the survived bacteria after the application of DP to land has been demonstrated for some bacterial species (Estrada et al., 2004; Johansson et al., 2005). Pathogen inactivation rates are lower in mesophilic than in thermophilic anaerobic digestion plants (Watcharasukarn et al., 2009).
Health concerns related to DP reuse include pathogen transmission to vegetable food, animals and/or agricultural workers and contamination of groundwater or surface water with faecal material deriving from field run-off (Islam et al., 2005; Petersen et al., 2007).

Considering the possibility of reusing DP and its derivates as fertilizers and the related health risk the aim of this study was the evaluation of the microbiological contamination of the products obtained from mesophilic anaerobic co-digestion of bovine manure and agricultural by-products.

2. MATERIALS AND METHODS

2.1 Biogas plant and sampling

The study was performed in an anaerobic digestion plant located in the Piedmont region (Italy). The plant produces energy from renewable sources such as bovine manure and agricultural byproducts. The configuration of the plant and the sampling points are shown in Figure 1. The biogas plant consists of a mixing tank where the input substrates are mixed, two digestion tanks (1 and 2), a liquid-solid DP separator and a storage tank. Samples were collected over one year starting in September 2008 and ending in October 2009. Sampling was performed on input substrates (point A), output material after anaerobic digestion (point B), liquid and solid fractions obtained by DP separation (point C and D) and DP liquid fractions after 120 storing days (point E).

2.2 Microbiological analyses

2.2.1 Faecal indicator parameters
Each sample (50 g) was homogenized in sterilized 0.9% NaCl solution using a Stomacher Laboratory-Blender 400 (PBI International, Milan, Italy). Serial dilutions were prepared and inoculated in triplicate on specific agar media to enumerate bacterial indicators: mesophilic counts on Tryptic Soy Agar (TSA, Applichem) at 37°C for 24 h; *Escherichia coli* on Tryptone bile X-glucoronide medium (TBX, Biolife) at 44°C for 24 h; Enterobacteriaceae on Violet Red Bile Glucose Agar (VRBG, Oxoid) at 37°C for 24 h; faecal enterococci on Kanamycin Aesculin Azide Agar Base (KAA, Biolife) at 37°C for 24-48 h. Bacterial counts were expressed as log CFU g\(^{-1}\) of wet matter.

The influence of the anaerobic digestion process and of DP storage on survival of the microbial indicator parameters was evaluated using analysis of variance (ANOVA, SYSTAT, version 8.0).

The presence of *Clostridium perfringens* was determined on Tryptose Sulphite Cycloserine Agar (TSC, Biolife) after anaerobic incubation at 42°C for 24 h and was confirmed with the reverse CAMP test. A qualitative analysis was performed for helminth eggs detection based on sample purification by flotation and microscope examination.

### 2.2.2 Pathogens

*Salmonella* analysis (25 g sample): after pre-enrichment in Buffered Peptone Water (BPW, Oxoid) (24 h at 37°C), an aliquot (100 µL) was inoculated into Rappaport-Vassiliadis broth (RV, 10mL, Biolife) (18-24 h at 42°C) and another aliquot (1000 µL) was inoculated into Selenite Broth base (SB, 9 mL, Biolife) (24 h at 37°C). Both RV and SB broths were streaked on Bismuth Sulphite Agar (BSA, Biolife) and Xylose Lysine Desoxycholate Agar (XLD, Biolife) and incubated at 37°C for 24 h. Colonies
with typical *Salmonella* morphology were confirmed with the agglutination test (Biolife) and biochemical tests using the Biolog Microbial Identification System (BIOLOG, Inc.).

(Listeria monocytophages) analysis (25 g sample): after pre-enrichment in Fraser Broth (Biolife) and enrichment Fraser Base Broth (Oxoid) (24 h at 30°C). Aliquots of pre-enrichment and enrichment broths were streaked on Listeria Palcam Agar Base (Biolife) (37°C for 24 h) and ALOA Agar (Biolife) (30°C for 48 h). Colonies with typical *Listeria* morphology were confirmed as *Listeria monocytogenes* by Real-Time PCR (iQ-Check *Listeria monocytogenes* Kit, BioRad).

*E. coli* O157:H7 analysis (25 g sample): after enrichment in Tryptic Soy Broth (Biolife) supplemented with novobiocin (42°C for 24 h), samples were subcultured onto MacConkey Sorbitol Agar (CT-SMAC, Biolife) plates by streaking (24 h at 37°C). Suspected colonies were confirmed by multiplex PCR as reported by Bonetta et al. (2010).

*Yersinia* spp. analysis (1-10g samples): after inoculation in both Yersinia PSB Broth (Biolife) (25°C for 5 d) and Yersinia ITC Broth Base (Biolife) (25°C for 48 h), samples were cultured onto CIN Agar (Biolife) (30°C for 48 h). Suspected colonies were confirmed with biochemical tests of the Biolog Microbial Identification System (BIOLOG, Inc.). The results of pathogen contamination were expressed as presence/absence.

### 3. RESULTS

#### 3.1 Faecal indicator parameters
The results of the bacterial indicator counts in the bovine manure, DP and its derivates are reported in Table 1. Comparison of the bacterial indicator levels of the input substrate (bovine manure) and DP revealed a statistically significant decrease of all the parameter counts after anaerobic digestion (E. coli \( p < 0.05 \), mesophilic count \( p < 0.001 \)) and Enterobacteriaceae \( p \leq 0.001 \) with the exception of Enterococci.

The liquid/solid separation of fresh DP led to higher bacterial content in the solid fraction with respect to the liquid one (Table 1), with the exception of Enterococci, which were equally distributed between the two fractions.

Storage of the DP liquid fraction for 120 days did not reduce the mesophilic counts, did not influence E. coli or Enterobacteriaceae counts (which were already very low in the DP liquid fraction), but it resulted in a significant reduction of the Enterococci counts \( (p < 0.05) \).

The anaerobic digestion process does not seem to reduce the percentage of positive sample for C. perfringens: 78% of fresh DP was contaminated by C. perfringens; liquid/solid separation of fresh DP and storage of the DP liquid fraction did not reduce C. perfringens positive samples percentage. Helminth eggs were never found in bovine manure, DP samples and its derivates.

**3.2 Pathogens**

The frequency with which bacterial pathogens were detected in all the samples is reported in Table 2. Neither E. coli O157:H7 nor Yersinia spp. were ever found in bovine manure or in DP.

Salmonella spp. and L. monocytogenes were rarely detected in samples of bovine manure (20%). DP resulted occasionally contaminated by Salmonella (8%), while the
The presence of *L. monocytogenes* was encountered in 25% of DP samples. Liquid and solid fractions of DP were rarely contaminated by *Salmonella*, but always presented *L. monocytogenes* contamination. In the stored liquid fraction of DP *Salmonella* was never detected and *L. monocytogenes* was found only in one sample (33%). All *Salmonella* strains isolated were identified as *Salmonella choleraesuis*.

4. DISCUSSION

4.1 Faecal indicator parameters

In general, bacterial indicator counts in bovine manure and DP samples monitored in this study are in agreement with those reported in other studies (Soupir et al., 2006; Watcharasukarn et al., 2009). Respect to the other indicator parameters analyzed, Enterococci showed similar counts before and after anaerobic co-digestion. This finding could be due to the great variability of Enterococci counts, with values ranging between < 2 (detection limit) and 5.3 Log$_{10}$ CFUg$^{-1}$, both in bovine manure and in fresh DP samples. Otherwise it could depend on an effective variability of the microbial reduction efficiency by the digestion process. This trend also may reflect the unsuitability of Enterococci, that is considered by the European regulation on animal by-products, a reference parameter for monitoring the digestion process efficiency towards the reduction of microbial contamination.

Considering the purpose of reusing DP as fertilizer in agriculture it is important to highlight that the microbiological quality of the DP analysed in this study always complied with the microbial parameter thresholds of the Italian law for fertilizers (*E. coli* < 1000 CFU/g) (D.M. 29819/2009). However, the greater part (58%) of the fresh
DP samples exceeded the standard for Enterococcaceae reported in the European regulation on animal by-products (Commission Regulation EC n. 208/2006).

Considering the results obtained after liquid/solid separation, the presence of a greater bacterial content in the solid fraction has been reported also in other studies (Vanotti et al., 2005; Higgins et al., 2007), and this finding has been attributed to the following hypotheses: i) sample matrix effects; ii) recontamination of samples; iii) re-growth of viable but not culturable microorganisms (VBNC) stressed after anaerobic digestion.

Although there is some controversy in the literature regarding the VBNC state, most of the evidence seems to support this phenomenon (Arana et al., 2007; Higgins et al., 2007).

The DP liquid fraction after 120 days’ storage complied with the standards of the EC regulation for agricultural DP reuse for Enterococcaceae.

The presence of *C. perfringens* contamination in the DP and its derivates observed in this study was also reported in earlier studies. Bagge et collaborators (Bagge et al., 2005) observed that if there are any pathogenic spore-forming-bacteria in the incoming manure they persist in the digested residues. Therefore *C. perfringens* could pose a hygienic problem when DP and its derivates are spread on land.

### 4.2 Pathogens

Considering the results obtained in this study, the mesophilic anaerobic digestion causes a reduction in the *Salmonella* content as reported in many works (Horan et al., 2004; Sidhu and Toze, 2009), but the absence of *Salmonella* in 25 g of DP should be demonstrated in representative samples of the digestion residues before using DP as fertilizer (D.M. 29819/2009; Commission Regulation EC n. 208/2006). However, the
anaerobic digestion process seems to have less ability to reduce *Listeria monocytogenes* contamination. This finding is in contrast with the results obtained by Horan et al. (2004) in a study performed in a lab-scale digester. Probably, as recently noted by other authors, microorganism dynamics during anaerobic digestion process are likely different between lab-scale and field-scale digesters (Wagner et al., 2008).

The absence of *Salmonella* in 25 g of material is considered the standard for its use as fertilizer as a guarantee of bacterial pathogen absence. However, the results obtained in this study indicate that *Listeria monocytogenes* can be present without *Salmonella* contamination; this situation suggests the need to reconsider the usefulness of *Salmonella* as the sole indicator of bacterial pathogen presence. Moreover a long storage time seems to have the greatest effect on pathogen reduction, as verified in other studies (Cote et al., 2006). Considering that *Salmonella* is the parameter used to control fertilizer safety, only the stored DP liquid fraction should be used as fertilizer for land application, but considering that this fraction was contaminated (33%) by *Listeria monocytogenes* consumer health risks cannot be excluded.

5. CONCLUSIONS

In conclusion, the results obtained in this study indicate that the hygienic quality of DP is equal or even better than that of the input material (bovine manure). An analogous conclusion has been reached by EFSA in an evaluation of the biological risk of the mesophilic process of biogas and compost treatment of animal by-products (EFSA, 2007). Therefore, in comparison with the use of animal manure for agricultural fertilization, the use of digestate produced by bovine manure and agricultural biomass
co-digestion may not result in new routes of pathogens and disease transmission between animals and humans via environmental matrices.

However, this conclusion should take into account that this study was performed in an anaerobic digestion plant where the sources and quality of the input substrates were constant, and the ratio among the input substrates was steadily maintained. Thus, under these conditions, the anaerobic co-digestion of bovine manure and agricultural by-products does not seem to increase human health risk. Moreover, the results obtained in this survey suggest the need to reconsider the usefulness of Salmonella as a bacterial pathogen indicator and to identify specific pathogen indicators related to the hygienic characteristics of the digestion plant input materials.

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and VIII to Regulation (EC) No 1774/2002 of the European Parliament and of the
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29818).


Table 1. Mean, minimum and maximum values (expressed as log_{10} CFU g^{-1}) of bacterial indicator parameters in input and output materials of a biogas digestion plant

<table>
<thead>
<tr>
<th></th>
<th>Mesophilic count</th>
<th>E. coli</th>
<th>Enterobacteriaceae</th>
<th>Enterococci</th>
</tr>
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<tr>
<td></td>
<td>mean</td>
<td>min</td>
<td>max</td>
<td>mean</td>
</tr>
<tr>
<td>Bovine manure</td>
<td>8.0</td>
<td>6.4</td>
<td>8.5</td>
<td>5.0</td>
</tr>
<tr>
<td>Fresh DP</td>
<td>6.4</td>
<td>5.3</td>
<td>6.8</td>
<td>1.9</td>
</tr>
<tr>
<td>Solid</td>
<td>8.0</td>
<td>6.2</td>
<td>8.4</td>
<td>4.4</td>
</tr>
<tr>
<td>Liquid fraction</td>
<td>6.3</td>
<td>5.7</td>
<td>6.6</td>
<td>&lt;2</td>
</tr>
<tr>
<td>Stored liquid fraction</td>
<td>6.4</td>
<td>6.1</td>
<td>6.5</td>
<td>&lt;2</td>
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Table 2. Frequency (%) of bacterial pathogens in the different types of samples analysed.

<table>
<thead>
<tr>
<th>Pathogens</th>
<th>Bovine manure</th>
<th>Digestates</th>
<th>Solid fraction</th>
<th>Liquid fraction</th>
<th>Stored liquid fraction</th>
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</thead>
<tbody>
<tr>
<td><em>Salmonella</em></td>
<td>20 (1/5)</td>
<td>8 (1/12)</td>
<td>25 (1/4)</td>
<td>33 (1/3)</td>
<td>0 (0/3)</td>
</tr>
<tr>
<td><em>L. monocytogenes</em></td>
<td>20 (1/5)</td>
<td>25 (3/12)</td>
<td>100 (4/4)</td>
<td>100 (3/3)</td>
<td>33 (1/3)</td>
</tr>
<tr>
<td><em>E.coli O157:H7</em></td>
<td>0 (0/5)</td>
<td>0 (0/12)</td>
<td>0 (0/4)</td>
<td>0 (0/3)</td>
<td>0 (0/3)</td>
</tr>
<tr>
<td><em>Yersinia spp.</em></td>
<td>0 (0/5)</td>
<td>0 (0/12)</td>
<td>0 (0/4)</td>
<td>0 (0/3)</td>
<td>0 (0/3)</td>
</tr>
</tbody>
</table>
Figure 1. Flow diagram of the biogas plant and sampling points.

A - Input substrates: cattle slurry (n=5), agricultural biomass (n=5); B - fresh DP (n=12); C - liquid fraction of DP (n=3); D - solid fraction of DP (n=3); E - 120 days harvested liquid fraction of DP (n=3).