THE EFFICIENCY OF BIOGAS DIGESTATE ON GRASSLAND COMPARED TO MINERAL FERTILIZER AND CATTLE SLURRY

Mailiis Tampere, Rein Viiralt
Estonian University of Life Sciences
mailiis.tampere@emu.ee

Abstract
Biogas production from organic wastes is gaining popularity, especially in agriculture, which produces high quantities of organic wastes suitable for anaerobic digestion. Digestate is the valuable by-product of the biogas production that is considered as a valuable fertilizer. The objectives of the experiment conducted from 2012 to 2013 at the Estonian University of Life Sciences were to compare the impact of biogas digestate, undigested (raw) cattle slurry, and inorganic nitrogen fertilizer on grass yield and to assess the fertilizer value of digestate produced from different feedstock. Fertilizers were applied to the grassland rich in low grasses by broadcasting in quantities according to the nitrogen rate of 180 kg ha$^{-1}$ in three split applications. The application rate of organic fertilizers was calculated based on NH$_4$-N content. Grassland yield was determined on four treatments: (i) control (no fertilizer was applied), (ii) mineral N-fertilizer (NH$_4$NO$_3$), (iii) cattle slurry and (iv) cattle slurry digestate. Grass yield was measured three times during the growing period. Our research showed that digestate when applied based on its NH$_4$-N content is effective fertilizer in grassland. It could be used as a substitute for mineral-N fertilizer, but its efficiency is slightly lower when compared to cattle slurry, due to its lower application amount resulting in lower nutrient and organic matter amount applied to the grassland. Co-digestion of cattle slurry with solid manure, hay and silage does not decrease digestate fertilizer value in grassland, because the addition of other substrate increases digestate DM content.

Key words: cattle slurry, digestate, grassland yield.

Introduction
Recycling of organic materials has an essential role for the protection of the environment (Makádi et al., 2012). Therefore, the production of methane-rich biogas has increased considerably in European countries in recent years. As agriculture produces high quantities of organic wastes and residues, which are rich in nutrients, biogas production from it is an efficient way of obtaining energy, but it is also an ecological way for the disposal of agricultural wastes (Ondrejčíková et al., 2009). Anaerobic digestion in livestock production systems is especially appealing as the wastes generated are suitable for digestion and hence can provide an additional source of income and reduce costs (Demirer and Chen, 2005).

The biogas yield depends on the feedstock used for anaerobic digestion, especially on its energy density and biodegradability (Weiland, 2003). In anaerobic digestion process different organic materials could be used alone or they could be co-digested. Cattle manure is an excellent substrate for biogas production in anaerobic digesters, although the gas yield from a single substrate is not high (Yohaness, 2010), because the majority of energy-rich substrates (i.e. carbohydrates and proteins) have been eliminated through the digestive tract of the animal (Weiland, 2003; Lehtomäki et al., 2007). However, mixing cow manure with other kind of waste materials in co-digestion can optimize the production of biogas (Yohaness, 2010). It has been found that co-digestion of slurries with grass silage increases yields of methane (Koch et al., 2009; Wang et al., 2009). This is due to the positive synergy effect of the co-substrates (Lehtomäki et al., 2007; Jagadabhi et al., 2008), which provides the missing nutrients and balances substrate composition (Umetsu et al., 2006).

Undigested residues leaving the biogas reactor, the digestate, is the by-product of methane production, coming from organic wastes (Makádi et al., 2012). It is considered as a valuable fertilizer due to the increased availability of nitrogen and the better short-term fertilization effect (Weiland, 2010). In addition, it reduces the need for applying mineral nitrogen and PK fertilizers, which are becoming increasingly expensive due to their energy-intensive production nature.

Comparison of digestate application with mineral N fertilizers have shown that N from mineral fertilizers is physiologically better exploited (Pospišil et al., 2009) and digestate has lower fertilizer N values (Quakernack et al., 2012), but also that N recoveries of digestate and mineral fertilizers are similar (Gunnarson et al., 2010; Fouda, 2011). When comparing it with undigested slurry some research have showed a slightly lower N removal from anaerobically fermented slurry (Messner and Amberger, 1987), while others have found similar (Möller et al., 2008) or even higher N uptake from digested slurry compared to undigested slurry (Morris and Lathwell, 2004).

The objectives of this study were to compare the impact of biogas digestate, undigested (raw) cattle slurry, and inorganic nitrogen fertilizer on low grasses grassland yield and to assess the fertilizer value of digestate produced from different feedstock.
Materials and Methods

The experiment was conducted at the Erika Experimental Station, Estonian University of Life Sciences (58°23′32″ N, 26°41′31″ E; elevation 60 m) in 2012 and 2013 on the soil type classified as a Stagnic Luvisol (World Reference Base for Soil Resources). Sward, which was established in 2008, consisted of smooth meadow grass (Poa pratensis), red fescue (Festuca rubra L.), perennial ryegrass (Lolium perenne) and white clover (Trifolium repens). In 2012, white clover had been lost from the sward due to the poor wintering conditions. In 2013 the same happened to perennial ryegrass, which is a short-term grass species in Estonian conditions. Treatments were in four replicates in randomized complete block design: (i) control (no fertilizer was applied), (ii) mineral N-fertilizer (NH$_4$NO$_3$), (iii) cattle slurry and (iv) cattle slurry digestate. NH$_4$NO$_3$ and organic fertilizers were applied in quantities according to the nitrogen rate of 180 kg ha$^{-1}$ in three split applications (60 kg N ha$^{-1}$). The application rate of organic fertilizers was calculated based on NH$_4$-N content. Fertilizers were applied by broadcasting three times in the growing period in 3.05., 12.06. and 3.08. in 2012 and in 3.05., 11.06. and 30.07. in 2013. Cattle slurry was applied in quantities of 67 t ha$^{-1}$ (23+22+22 t ha$^{-1}$) and 76 t ha$^{-1}$ (25+29+22 t ha$^{-1}$) in 2012 and 2013 accordingly and digestate 57 t ha$^{-1}$ (19+19+19 t ha$^{-1}$) and 72 t ha$^{-1}$ (19+29+24 t ha$^{-1}$) in 2012 and in 2013 accordingly.

Grass yield and dry matter (DM) were determined by using the methodology described by Mannetje (2000). Grass yield was determined from experimental plots of 8.8 m$^{-2}$ (2.2 × 4 m) three times (5.06.12., 23.07.12., 23.09.12., 4.06.13., 23.07.13., 23.09.13.) in the growing period with experimental plot harvester Haldrup equipped with an electronic weighing device. The DM content (%) of biomass from the subsamples (100 g) was determined by drying the sample in forced-drought oven for six hours at 105 °C and calculated using the following formula:

$$\text{DM} = \left(\frac{M_d}{M_f}\right) \times 100$$

where $M_d$ is the weight of dry material (g), and $M_f$ is the weight of fresh material (g).

The meteorological conditions during the experimental period were monitored with a Metos Compact (Pessl Instruments) electronic weather station. The growing period of 2012 was cooler than that in 2013. The temperatures in 2013 exceeded long term average temperatures. Still the grass growing conditions were more favourable in 2012, when the sum of precipitation during the growth period was similar to the long-term average. Better moisture conditions in 2012 probably increased also the efficacy of used fertilizes. In 2013, the precipitation was considerably lower than in 2012 and long-term average, inhibiting also the plant growth. The average air temperatures during the study period and long-term observations are shown in Table 1.

Table 1

<table>
<thead>
<tr>
<th>Month</th>
<th>Decade</th>
<th>Average temperature, °C</th>
<th>Total precipitation, mm</th>
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</thead>
<tbody>
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<td>April</td>
<td>I</td>
<td>0.0</td>
<td>-1.7</td>
</tr>
<tr>
<td></td>
<td>II</td>
<td>5.1</td>
<td>6.0</td>
</tr>
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<td></td>
<td>III</td>
<td>9.9</td>
<td>6.1</td>
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<tr>
<td>May</td>
<td>I</td>
<td>10.4</td>
<td>12.3</td>
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<tr>
<td></td>
<td>II</td>
<td>12.3</td>
<td>16.4</td>
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<td></td>
<td>III</td>
<td>12.2</td>
<td>15.6</td>
</tr>
<tr>
<td>June</td>
<td>I</td>
<td>11.5</td>
<td>19.5</td>
</tr>
<tr>
<td></td>
<td>II</td>
<td>15.2</td>
<td>15.2</td>
</tr>
<tr>
<td></td>
<td>III</td>
<td>14.1</td>
<td>19.9</td>
</tr>
<tr>
<td>July</td>
<td>I</td>
<td>19.3</td>
<td>18.3</td>
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<tr>
<td></td>
<td>II</td>
<td>15.3</td>
<td>17.3</td>
</tr>
<tr>
<td></td>
<td>III</td>
<td>19.6</td>
<td>17.9</td>
</tr>
<tr>
<td>August</td>
<td>I</td>
<td>16.6</td>
<td>19.8</td>
</tr>
<tr>
<td></td>
<td>II</td>
<td>15.2</td>
<td>16.3</td>
</tr>
<tr>
<td></td>
<td>III</td>
<td>14.1</td>
<td>14.7</td>
</tr>
<tr>
<td>September</td>
<td>I</td>
<td>12.3</td>
<td>13.0</td>
</tr>
<tr>
<td></td>
<td>II</td>
<td>13.7</td>
<td>13.5</td>
</tr>
<tr>
<td></td>
<td>III</td>
<td>10.6</td>
<td>6.6</td>
</tr>
</tbody>
</table>

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Chemical composition of cattle slurry and digestate was determined in Estonian University of Life Sciences at the Laboratory of Plant Biochemistry. The pH of cattle slurry and digestate was determined in 1 N KCl, dry matter (DM) by oven drying for 2 hours at 135 °C. Total Nitrogen (N<sub>tot</sub>) content was determined by the Kjeldahl method (Tecator ASN 3313). Ammonium nitrogen (NH<sub>4</sub>-N) in samples was extracted with 2 M KCl using the flow injection analysis (Tecator ASN 65-32/84) and nitrate nitrogen (NO<sub>3</sub>-N) with 2 M KCl using the flow injection analysis (Tecator ASN 65-31/84). The plant material was converted to Kjeldahl digest. Total phosphorous (P) was analyzed by stannous chloride method (Fiastar 5000 AN 5242, ISO/FDIS 15681), calcium (Ca) with o-cresolphthalein complexone (Fiastar 5000 AN 5260), and magnesium (Mg) by titan yellow method (Fiastar 5000 ASTN90/92). For potassium (K) determination flame photometry was used (AOAC 1990).

The organic matter (OM) content was determined by loss on ignition at 360 °C.

The composition of the cattle slurry did not differ significantly between experimental years (Table 2), but there was a difference in digestate. The feedstock of the digestate in the first year was only slurry from dairy cattle (the average age of animals five to seven years) housed indoors the whole year round. In the second year, dairy cattle slurry was co-digested with solid dairy manure, hay from natural grasslands and silage residues. Therefore, the DM (dry matter) content of the digestate was higher in 2013 when compared to 2012, and it was comparable to DM content in raw cattle slurry.

Significant differences among treatments were determined using one-way analysis of variance (ANOVA). The comparison of treatment means was done using the least significant difference (LSD) test. All calculations were performed using the statistical package Statistica 12 (StatSoft.Inc). The probability level was set at 0.05.

### Results and Discussion

Our results showed that in two-year average fertilization with organic fertilizers increased the grassland yield significantly (p<0.05) when compared to control (Table 3). It was probably due to the organic

### Table 2

<table>
<thead>
<tr>
<th>Factor</th>
<th>Sampling time</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>26.04.</td>
<td>30.05.</td>
</tr>
<tr>
<td><strong>Cattle slurry</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>6.9</td>
<td>7.4</td>
</tr>
<tr>
<td>DM %</td>
<td>8.7</td>
<td>8.2</td>
</tr>
<tr>
<td>N&lt;sub&gt;tot&lt;/sub&gt; kg t&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>4.7</td>
<td>4.7</td>
</tr>
<tr>
<td>NH&lt;sub&gt;4&lt;/sub&gt;-N kg t&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>2.6</td>
<td>2.8</td>
</tr>
<tr>
<td>NH&lt;sub&gt;4&lt;/sub&gt;-N in N&lt;sub&gt;tot&lt;/sub&gt; %</td>
<td>55.0</td>
<td>55.8</td>
</tr>
<tr>
<td>NO&lt;sub&gt;3&lt;/sub&gt;-N kg t&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>P kg t&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>0.9</td>
<td>0.8</td>
</tr>
<tr>
<td>K kg t&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>2.3</td>
<td>2.2</td>
</tr>
<tr>
<td>Ca kg t&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>1.5</td>
<td>1.2</td>
</tr>
<tr>
<td>Mg kg t&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>0.7</td>
<td>0.7</td>
</tr>
<tr>
<td>OM in DM %</td>
<td>69.0</td>
<td>72.0</td>
</tr>
<tr>
<td><strong>Digestate</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>8.3</td>
<td>8.1</td>
</tr>
<tr>
<td>DM %</td>
<td>3.5</td>
<td>3.8</td>
</tr>
<tr>
<td>N&lt;sub&gt;tot&lt;/sub&gt; kg t&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>4.3</td>
<td>4.4</td>
</tr>
<tr>
<td>NH&lt;sub&gt;4&lt;/sub&gt;-N kg t&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>3.1</td>
<td>3.2</td>
</tr>
<tr>
<td>NH&lt;sub&gt;4&lt;/sub&gt;-N in N&lt;sub&gt;tot&lt;/sub&gt; %</td>
<td>73.0</td>
<td>73.0</td>
</tr>
<tr>
<td>NO&lt;sub&gt;3&lt;/sub&gt;-N kg t&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>P kg t&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>0.8</td>
<td>0.8</td>
</tr>
<tr>
<td>K kg t&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>2.2</td>
<td>2.2</td>
</tr>
<tr>
<td>Ca kg t&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>1.1</td>
<td>0.8</td>
</tr>
<tr>
<td>Mg kg t&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>0.6</td>
<td>0.6</td>
</tr>
<tr>
<td>OM in DM %</td>
<td>56.0</td>
<td>57.0</td>
</tr>
</tbody>
</table>
matter in those fertilizers that contribute to the soil organic matter turnover (Makádi et al., 2012). In two-year average the use of mineral N-fertilizer did not have a significant (p<0.05) impact on the yield, although it was slightly higher when compared to control. We found out that digestate was as good as inorganic fertilizer N sources for improving grass growth when compared to mineral N-fertilizer treatment, the digestate increased (p<0.05) the yield by 1.02 t ha⁻¹ and 0.64 t ha⁻¹ more than digestate in 2012 and 2013 accordingly. When compared to mineral N-fertilizer treatment, the digestate increased (p<0.05) the yield by 1.83 and 0.92 t ha⁻¹ and cattle slurry by 2.85 and 1.56 t ha⁻¹ in 2012 and 2013 accordingly. The amount of cattle slurry applied exceeded the application amount of digestate by 10 and 4 t ha⁻¹ in 2012 and 2013 accordingly, as there was more NH₄-N in the N_{tot} in digestate (3.2 and 2.5 kg t⁻¹) when compared to cattle slurry (2.7 and 2.4 kg t⁻¹). However, the yields between two treatments were significantly different (p<0.05) only in the second year. We hypothesize that this could be due to the carry-over effect from the first year. When compared to digestate the amount of applied cattle slurry was higher. Therefore, the sward fertilized with cattle slurry received more N_{tot} (63.1 kg ha⁻¹) in 2012, which could have increased the second year yield due to the mineralization of the organically bound nitrogen.

The grassland yield depended on the experimental year (p<0.05). When comparing experiment years, average yields in all treatments were higher (p<0.05) in 2012 (9.62 t ha⁻¹) when compared to 2013 (5.93 t ha⁻¹), because the second year meteorological conditions were not as favourable for grass growth when compared to the first year. This

In both experiment years the yields in cattle slurry treatment were higher when compared to digestate treatment, although in the first year the difference was not statistically significant (p<0.05). Cattle slurry increased the yield by 1.02 t ha⁻¹ and 0.64 t ha⁻¹ more than digestate in 2012 and 2013 accordingly. When compared to mineral N-fertilizer treatment, the digestate increased (p<0.05) the yield by 1.83 and 0.92 t ha⁻¹ and cattle slurry by 2.85 and 1.56 t ha⁻¹ in 2012 and 2013 accordingly. The amount of cattle slurry applied exceeded the application amount of digestate by 10 and 4 t ha⁻¹ in 2012 and 2013 accordingly, as there was more NH₄-N in the N_{tot} in digestate (3.2 and 2.5 kg t⁻¹) when compared to cattle slurry (2.7 and 2.4 kg t⁻¹). However, the yields between two treatments were significantly different (p<0.05) only in the second year. We hypothesize that this could be due to the carry-over effect from the first year. When compared to digestate the amount of applied cattle slurry was higher. Therefore, the sward fertilized with cattle slurry received more N_{tot} (63.1 kg ha⁻¹) in 2012, which could have increased the second year yield due to the mineralization of the organically bound nitrogen.

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### Table 3

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Cut</th>
<th>Total</th>
<th>DM increase in yield, t ha⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
<td>II</td>
<td>III</td>
</tr>
<tr>
<td><strong>DM t ha⁻¹ mean of 2012-2013</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>2.73A</td>
<td>1.65A</td>
<td>1.72A</td>
</tr>
<tr>
<td>NH₄NO₃</td>
<td>3.02A</td>
<td>1.90A</td>
<td>2.21A</td>
</tr>
<tr>
<td>Cattle slurry digestate</td>
<td>3.37A</td>
<td>2.36A</td>
<td>2.78A</td>
</tr>
<tr>
<td>Cattle slurry</td>
<td>3.99A</td>
<td>2.57A</td>
<td>2.79A</td>
</tr>
<tr>
<td><strong>DM t ha⁻¹ 2012</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>4.47A</td>
<td>1.13A</td>
<td>1.91A</td>
</tr>
<tr>
<td>NH₄NO₃</td>
<td>4.59A</td>
<td>1.60A</td>
<td>2.56A</td>
</tr>
<tr>
<td>Cattle slurry digestate</td>
<td>4.93A</td>
<td>2.28C</td>
<td>3.38C</td>
</tr>
<tr>
<td>Cattle slurry</td>
<td>5.83C</td>
<td>2.31C</td>
<td>3.46C</td>
</tr>
<tr>
<td><strong>DM t ha⁻¹ 2013</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>1.00A</td>
<td>2.17A</td>
<td>1.53A</td>
</tr>
<tr>
<td>NH₄NO₃</td>
<td>1.46C</td>
<td>2.20C</td>
<td>1.86B</td>
</tr>
<tr>
<td>Cattle slurry digestate</td>
<td>1.81C</td>
<td>2.43A</td>
<td>2.20C</td>
</tr>
<tr>
<td>Cattle slurry</td>
<td>2.15C</td>
<td>2.83A</td>
<td>2.10C</td>
</tr>
</tbody>
</table>

*Within the same column, values with different letters are significantly different (p<0.05).*
is also demonstrated by higher yield increases in the first year when compared to the second year (Table 3). Although the average temperatures in 2012 were lower when compared to 2013, in 2012, there was more precipitation than in 2013 (Table 1). From the first decade of April until the third decade of September the precipitation was 377 mm and 270 mm in 2012 and in 2013 accordingly. In addition, considerably lower first cut yields in 2013 were probably due to the longer snow cover and lower amount of precipitation in the spring, which strongly slowed the grass growth at the beginning of the vegetative period. Another reason why the yields in 2013 were lower than in 2012 could be that in the second year the sward consisted predominantly of smooth meadow grass and red fescue, as perennial ryegrass had disappeared from the sward. The average yield of fertilized swards was 10.32 t ha⁻¹ and 6.25 t ha⁻¹ in 2012 and 2013 accordingly.

It should be taken into account when assessing the yields in both years that in 2012 the digestate was the result of only cattle slurry anaerobic digestion, but in the year 2013 the cattle slurry was co-digested with solid manure, hay and silage. The composition of the digestate used in the second year was similar to raw cattle slurry, because the addition of solid manure, hay and silage to the digester increased the DM content of the digestate (Table 2). Digestion of co-substrates is common practice in the biogas plants, because the digestion of cattle slurry as the only substrate is not economical (Weiland et al., 2003) due to lower biogas yield and also due to limited availability of animal wastes. Comparison between the yield increases in digestate treatments when compared to cattle slurry between the years showed that the yield in digestate treatment was 75.12% and 73.11% from the yield increase in cattle slurry treatment in 2012 and 2013 accordingly. This result leads to the conclusion that co-digested cattle slurry is as effective in grassland as the digestate from only cattle slurry anaerobic digestion.

Conclusions

In conclusion it can be said that the digestate is an effective grassland fertilizer, and it could be used as a substitute for mineral fertilizers. When applied based on their NH₄-N content, the digestate efficiency is little lower when compared to cattle slurry. Swards fertilized with digestate get less other plant nutrients due to the lower application rate of the digestate, which reduces its efficiency when compared to cattle slurry. Co-digestion of cattle slurry with manure, silage and hay does not decrease the digestate fertilizer value when used in the grassland.

Aknowledgement

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References


