The use of digested slurry within agriculture

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Improved utilisation of animal manure has a central role in the efforts to decrease the environmental effects of farming. More efficient utilisation of the nutrients will reduce the mineral fertilizer applied and the influence on the surrounding environment.

In addition, as agriculture develops towards more intensive livestock breeding and larger units there is increased pressure on the farmland. New agricultural and environmental legislation is being developed to reduce this impact.

In many European countries legislation has been passed aimed at reducing the impact of the manure on the surroundings. This legislation typically requires farmers to invest in storage facilities, application equipment etc. In other EU countries such legislation is in preparation, and will require the farmers to undertake these investments in the near future, for example, to fulfill the E.C. nitrate directive.

One way to utilise the manure better is to make the nutrients readily available for the crops. Digestion of manure or other organic biomass in an anaerobic digester transforms part of the organic bound nutrients to a mineral form. This is significant for nitrogen, where the organic nitrogen is released as ammonium, which is readily available for the crops. It reduces the need for applying additional mineral nitrogen fertilizers and it can decrease the ammonia volatilization and nitrate leaching, mitigating environmental impact.

Centralised anaerobic digestion plants (Centralised AD) often increase the possibilities for a more systematic disposal of the manure compared to isolated on-farm plants. Application over a larger area is important for the utilisation of all nutrients in the manure. Transporting the slurry long distances is well known, e.g. in Holland, but it is costly, and a CAD plant could pay a part or all of this cost.

Many plant breeders have a more positive attitude towards receiving digested than traditional undigested manure. Weed seeds are killed during the treatment, and as a result of the transformation of the nitrogen from organic to mineral form allows calculation of the effect of the nutrients, allowing almost the same yield to be harvested as if the same amount of mineral nitrogen fertilizer was applied.

Many farmers and other people agree that the odour on manure spreading is not so intense from digested manure compared to untreated manure. The smell disappeared more rapidly after spreading of digested manure for reasons explained later in this chapter. For many farmers this aspect is one of the most important reasons to build a AD plant, in particular to maintain good relations with their neighbours or if the farm is situated close to a village.
1. Changing the manure

During the digestion of the manure at the AD plant about half of the carbon is released as methane and carbon dioxide (usually referred to as "biogas"). The dry matter content decreases and the digested slurry has a higher viscosity than cattle slurry in particular.

At the same time part of the organic nitrogen, e.g. in proteins, is released as ammonium. Ammonium is directly available for the crops when it is applied to the fields. The rest of the organic nitrogen must be mineralised by soil bacteria before it is available for the crops, which is the reason why organic fertilizers have a lower efficiency compared to mineral fertilizers.

Treating the manure in the digestors increases the pH of the manure half a unit. In pig slurry pH is normally between 7,0-7,4 and in cattle slurry it is between 6,8-7,2. Measurements show pH in digested slurry lies in between 7,4-8,0. The increased pH is unfortunate, because it increases the risk of nitrogen loss from evaporation of ammonia both in the storage period and during application.

Table 1 below shows Danish measurements of dry matter content, pH and nutrient content in pig, cattle and digested slurry. The digested slurry has an increased pH compared to both pig and cattle slurry. The dry matter content as well as total-nitrogen, ammonium, phosphorus and potassium is in between the raw types of slurry, but more like pig than cattle slurry. The measurements shown in table 1 are below the norms due to dilution with water in the stables, storage etc.

The nutrient content of digested slurry depends on which type of slurry is digested, and what the AD plant has received of wastes for co-digestion.

Table 1. Average content of dry matter, pH and nutrients in pig, cattle and digested slurry, measurements of digested slurry from Danish CAD plants.

<table>
<thead>
<tr>
<th>Slurry Type</th>
<th>pH</th>
<th>Dry Matter percent</th>
<th>Total-N Kg / ton</th>
<th>Amm-N Kg / ton</th>
<th>P Kg / ton</th>
<th>K Kg / ton</th>
<th>Total-N/ amm-N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pig slurry, n=51</td>
<td>7,2</td>
<td>3,8</td>
<td>4,8</td>
<td>3,6</td>
<td>1,1</td>
<td>2,5</td>
<td>0,7</td>
</tr>
<tr>
<td>Cattle slurry, n=25</td>
<td>7,1</td>
<td>7,0</td>
<td>4,3</td>
<td>2,6</td>
<td>0,8</td>
<td>3,4</td>
<td>0,6</td>
</tr>
<tr>
<td>Digested slurry, n=23</td>
<td>7,6</td>
<td>4,9</td>
<td>4,6</td>
<td>3,3</td>
<td>1,0</td>
<td>2,8</td>
<td>0,7</td>
</tr>
</tbody>
</table>

2. Nitrogen loss under storage and application

In handling the animal manure it is impossible to avoid losses of nitrogen. The sources with greatest effect on the losses are

- evaporation of ammonia during storage
- evaporation of ammonia during application
- denitrification
- leaching of nitrate from the soil
- immobilisation of the nitrogen in the soil

The increased proportion of ammonia in the total nitrogen content and increased pH after digestion mean the risks of loss during handling of the digested slurry will be larger for some of the factors mentioned above. Other factors will decrease the losses. It is important to understand these factors in order to minimise the losses by appropriate handling. It is important to avoid losses of nitrogen to
maximise fertilisation and minimise the environmental impact resulting from the application of organic fertiliser.

### 2.1 Evaporation of ammonia

The relationship between ammonium (NH$_4^+$) and ammonia (NH$_3$) is determined by a chemical equation regulated by the hydrogen ion (H$^+$). The concentration of the hydrogen ions can also be expressed by pH, an increased concentration of hydrogen ions results in a decreased pH.

$$\text{NH}_3 + \text{H}^+ \leftrightarrow \text{NH}_4^+$$

At a low pH ammonia is pressed towards the ammonium form, which can not evaporate. Table 2 below shows the ammonia concentration at different pH.

**Table 2. Percent of ammonia of the total ammonia/ammonium content related to (Stevens et al 1989).**

<table>
<thead>
<tr>
<th>pH</th>
<th>0.04</th>
<th>0.4</th>
<th>4</th>
<th>40</th>
</tr>
</thead>
</table>

From the table it can be seen, that an increase in the pH in the digested slurry of one unit, the concentration of ammonia increasing by with a factor ten. The risk for evaporation increases dramatically.

### 2.2 Losses from storage

During storage of the manure in storage tanks there is a risk of loss of nitrogen due to evaporation of ammonia. Lack of cover or a floating layer increases the risk. For this reason legislation in most countries says, if there is no natural there must be an artificial floating layer or even a cover/roof over the storage tank (e.g. in Holland).

Cattle slurry forms almost always a natural floating layer, pig slurry forms often a floating layer, but digested slurry very seldom forms a floating layer itself. This is due to the process, where the organic parts is digested, and the increased viscosity of the digested slurry. Together with an increased pH, the risk of ammonia evaporation is very high from digested slurry.

Many measurements have been made to compare the emission of ammonia from a free and a covered surface of storage tanks. The measurements show that the evaporation from storage tanks containing digested slurry is greater than from storage tanks containing pig or cattle slurry.

Danish measurements show losses of 18 g NH$_3$ daily from digested slurry without a floating layer, compared with 12 g NH$_3$ from pig or cattle slurry (Sommer et al 1993). This and other measurements show a loss of 6-9 percent of the total nitrogen during the storage period.

On the other hand the loss from evaporation is very easy to reduce. Making a simple floating layer by straw or other types of floating layer reduces the evaporation by 96 percent.
Table 3. Ammonia evaporation from covered or uncovered storage tanks with untreated and digested slurry.

<table>
<thead>
<tr>
<th></th>
<th>Ammonia evaporation, g / m² without floating layer</th>
<th>Artificial surface cover</th>
<th>Reduction by surface cover</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untreated slurry</td>
<td>400</td>
<td>16</td>
<td>96 percent</td>
</tr>
<tr>
<td>Digested slurry</td>
<td>600</td>
<td>24</td>
<td>96 percent</td>
</tr>
</tbody>
</table>

Economic calculations of the costs of covering the storage tanks with straw or another cheap cover have shown the farmer has no overall expenditure. The cost for the cover comes back through increased available nitrogen in the slurry and thereby savings in the mineral fertilizer purchase. Covering the storage tank by a plastic dew, where the rain can be run off costs a lot more. But if the farmer can use the extra available space (20 percent) this is also neutral. Dutch legislation tells the farmers to put the latter type of cover on the storage tanks like a tent, which has a high cost but also enables the farmer to build a smaller storage tank.

2.3 Losses under field application

Many factors influence ammonia loss during application on the fields. The size of the losses determine the fertilizing effect of the digested slurry. The factors which influence this include the nature of the slurry (dry matter and pH), weather conditions, soil conditions and crop type and the techniques used for applying the manure.

Measurements have shown, that high pH increases the ammonia evaporation where it is applied. By reducing the pH by 1/2 unit the evaporation will be 10 percent-units less. As digested slurry has a pH up to one unit higher than untreated slurry, the chances of nitrogen lose when spreading the slurry is increased as shown in figure 1.

![Figure 1. Evaporation of ammonia after application depending on pH in the slurry (Sommer and Christensen 1990).](image)

The dry matter content has an effect on the evaporation of ammonia during application. High dry matter content increases evaporation. A high content of dry matter hinder the slurry infiltration into the soil. Digested slurry has the advantage here, as it has a lower dry matter content and a high
viscosity. This is also one reason why the smell from digested slurry disappears only a short time after application.

The time between application and incorporation into the soil of the slurry is very important for the evaporation of ammonia. Measurements show that incorporating a few hours after application almost prevents evaporation, but if the slurry is left for 24 hours on a bare soil surface 20-30 percent of the total nitrogen can be lost.

4.2 Denitrification

Denitrification is a natural process, where bacteria reduce nitrate (NO\textsubscript{3}) to free nitrogen (N\textsubscript{2}) or nitrogen oxides (NO\textsubscript{X}). Free nitrogen does no harm to the environment as 80 percent of the air is nitrogen, but the nitrogen oxides are very strong greenhouse gases.

Denitrification happens under conditions where nitrogen is present under anaerobic conditions, due to bacteria metabolism. Anaerobic conditions result in small zones in the soil where oxygen has been depleted by microbial degradation of organic material applied to the soil (such as happens when raw slurry is applied to the soil).

Application of digested slurry decreases the potential for denitrification and loss of nitrogen compared to untreated pig or cattle manure, because a large part of the organic material already is digested, and material applied to the soil is less readily available for bacteria to metabolize.

Measurements to compare cattle and digested slurry have been made in Danish field trials. Over a 16 day period the measurements show loss from denitrification of 20 kg of nitrogen per ha after cattle slurry and 5 kg of nitrogen after digested slurry. The largest denitrification rate was from 1-4 days after application.

Pig slurry generally has a lower dry matter content than cattle slurry. Pig slurry infiltrates the soil faster than cattle slurry, resulting in increased air fluctuation in the soil from the metabolism of the organic matter and decreased denitrification risk. Further measurements have shown increased rates of denitrification from pig slurry compared to cattle slurry.

The different measurements of denitrification show very different rates depending on soil conditions, water content etc. But digestion of the slurry at the biogas plant reduces the denitrification by 3-4 times in general. This decreases the loss of nitrogen, which should be available for the crop and it also reduces the emission of green house gases.

2.5 Leaching

Through leaching nitrate is washed down from the growing layer of the soil. It ends up in ground water or is washed into rivers and lakes. Normally leaching is increased as a result of the application of increased amounts of manure or mineral fertilizers. The rate of leaching is greater after application of animal manure than mineral fertilizer, because part of the organic nitrogen content in the manure is released as ammonium after harvest, transformed to nitrogen and then leached when the autumn rains come. Grain crops are expected to use only half of the organic nitrogen released, grassland is expected to utilize three quarters of the mineralisation.
Another reason for increased leaching from areas with manure application compared to mineral manure is an under estimation of the effect of the nitrogen in the manure. Under estimation of the effect of the nitrogen results in excess spreading of mineral fertilizer, and the surplus nitrogen will be leached. It is therefore necessary to be able to predict the effect of the animal manure spread on the fields.

As mentioned above part of the organic nitrogen is metabolised to ammonium when animal manure is digested anaerobically. This reduces the loss of nitrogen from leaching. In table 4 the loss of nitrogen mainly due to leaching is calculated for three different kinds of manure. It is estimated, that 60 percent of the mineralised nitrogen is taken up by the crop.

<table>
<thead>
<tr>
<th>Table 4. Estimated losses of nitrogen after application of cattle, pig and digested slurry.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Content of organic nitrogen</strong></td>
</tr>
<tr>
<td>Cattle slurry</td>
</tr>
<tr>
<td>Pig slurry</td>
</tr>
<tr>
<td>Digested slurry</td>
</tr>
</tbody>
</table>

How much of the mineralised nitrogen will be utilised depends on the type of crop. Cattle farms normally have crops with long growing seasons (e.g. grass, maize etc.). Consequently, in general the mineralised nitrogen will be utilized best on cattle farms. In table 4 the same efficiency, 60 percent, is used for all three types of slurry.

2.6 Immobilisation

After application of animal manure in the field immobilisation can also happen, i.e. binding of the ammonium and nitrate to soil biomass. This happens when the soil bacteria need nitrogen for the metabolism of carbon rich organic matter. The immobilised nitrogen is released again later. Both animal manure and the soil organic matter can cause the immobilisation.

In the soil there is competition between the crop and the soil bacteria for the nitrogen, where the bacteria are the stronger. The immobilised nitrogen only becomes available to the crop after mineralisation later in the growing season.

Digestion of animal manure will reduce the potential for immobilisation because the organic matter already is digested at the biogas plant. There is a decreased need for oxygen in the soil, and at the same time a decreased risk for loss of nitrogen from the soil by denitrification.

3. Field trials with digested slurry

The supply of nitrogen has a direct influence on the yield in the growing season, while the supply of phosphorus and potassium can be seen over some years, because loss of phosphorus and potassium is limited.

It is difficult to predict the effect of the nitrogen in digested slurry, as well as in animal manure in general, because both the evaporation of ammonia and the effect of the organic nitrogen has large
variations between different applications. With a large part of the nitrogen in the ammonium form, and a minor content of easily digestable organic matter one can expect a relatively fast fertilizing effect of digested slurry.

Spring sown crops utilise the digested slurry best, because the volatilation of ammonia can be avoided by incorporating the slurry immediately after application. On application on a green area, a minor or a major part of the ammonia can evaporate, depending on the crop and weather conditions. A crop with a long growing season is utilizing the nitrogen most efficiency, as a larger part of the mineralized nitrogen is taken up by the plants.

Field trials with different crop types and techniques for application are shown below. The effect of the nitrogen is calculated in the trials and expressed as nitrogen efficiency. Nitrogen efficiency express how many kg of mineral fertilizer nitrogen which can replace 100 kg of total nitrogen in digested slurry.

3.1 Field trials with spring sown crops
The most efficient utilization of the digestate is application in spring before the crop is sown. It allows rapid incorporation of the slurry into the soil, so the risk of ammonia evaporation can be reduced.

Measurements have shown that large losses of ammonia can happen, even if the slurry stays on the soil surface only a short time before it is incorporated into the soil. Therefore an application technique with direct injection is preferred. But the technique needs heavy machinery with only a limited working area compared to other application techniques. Therefore it is not widely used, except in Holland where the legislation requires the farmers to use the technique on certain types of crops, e.g. grassland.

In Danish field trials the different techniques have been compared in spring barley. Here direct injection and broadspread with immediate incorporation, both before sowing, have been compared to broadspread and application with draghose, when the crop is 20 cm.

Table 5. Yield of spring barley with different techniques of application compared to mineral nitrogen fertilizer (calcium ammonium nitrate, CAN). Danish field trials.

<table>
<thead>
<tr>
<th>Application before sowing</th>
<th>Application on 20 cm crop</th>
</tr>
</thead>
<tbody>
<tr>
<td>direct injection</td>
<td>broadspread and harrowing</td>
</tr>
<tr>
<td>Yield compared to mineral fertilizer, Hkg/ha</td>
<td>+2.5</td>
</tr>
<tr>
<td>Nitrogen efficiency</td>
<td>75</td>
</tr>
</tbody>
</table>

The trials can be seen in figure 2. Application when the plants are 20 cm using draghose has increased the yield 2-3 Hkg compared to broadspreading. Spring barley is a relatively open crop, so application on a growing crop the leaves will not protect against evaporation of ammonia, as happens with winter seeds.
Over three years field trials have been undertaken with digested slurry from a Danish on-farm plant, where cattle slurry has been directly compared with digested slurry. As in the trials before the largest effect have been observed after spring application before the crop is sown. On average the nitrogen efficiency has been 64 for the digested slurry and 50 for the untreated cattle slurry. The different in the nitrogen efficiency is equal to the increased part of nitrogen on ammonium form after digesting the cattle slurry.

Swedish field trials in oats show similar results. Plots with CAN gave a yield on 58.1 Hkg per ha, when the same amount of nitrogen in digested slurry before sowing gave a yield on 57.5 Hkg/ha. Application of the slurry to the growing crop using a draghose decreased the yield to 42.3 Hkg per ha. The nitrogen efficiency in the trials was very low (only 38 and 22).

Fodder beets and maize are crop where an optimal utilization of digested slurry can be reached. They are sown at spring time and have a long growing season. Fodder beets takes up the nitrogen until harvest. This is shown in 12 Danish field trials where yield was better in slurry fertilized plots compared to fertilized with mineral fertilizer. The amount of nitrogen applied was the same in ammonium nitrogen, and the increased yield was explained by the utilization of organic nitrogen in the slurry, mineralised during the growing season.

Some results have been reported for maize. Plots with digested slurry incorporated into the soil before sowing or directly injected to 30 cm maize plants gave an increased yield compared to plots with mineral fertilizer. Application with draghose when the maize was 30 cm decreased the yield 20 Area units per ha, where an area unit is the amount of maise with the same energy content as 100 kg of barley.
Figure 3. Digested slurry compared to mineral fertilizer, CAN, in maize. One area unit is the amount of maize with the same energy content as 100 kg of barley.

In conclusion the field trials with digested slurry applied to spring sown crops showed that a good and safe fertilizing effect can be achieved from digested slurry if it is incorporated into the soil immediately after application. The risk for evaporation of ammonia is high due to increased pH. Table 6 shows an estimation of the evaporation and the nitrogen efficiency for the digested slurry.

Table 6. Estimated loss of nitrogen by evaporation of ammonia, in percent of total nitrogen in digested slurry, and the nitrogen efficiency depending on time on soil surface.

<table>
<thead>
<tr>
<th>Weather conditions*</th>
<th>Direct injection</th>
<th>Hours before incorporation into the soil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaporation percent</td>
<td>Optimal</td>
<td>0 5 6 8 11 20 25 25 20 12 6</td>
</tr>
<tr>
<td>Nitrogen efficiency</td>
<td>Optimal</td>
<td>80 75 75 75 75 70</td>
</tr>
</tbody>
</table>

*Optimal: temperature <15 °C, no wind, high humidity, light soil. Bad: temperature >15 °C, windy, low humidity, hard soil surface

3.2 Field trials overwintering crops

Digested slurry should only be applied in spring to overwintering crops, except grassland and rape seed which can utilize nitrogen in autumn and need fertilizer at that time.

An application in early spring on wet soil can cause structure hazzards on the soil. Pressure from the slurry tanker and traktor will result in hard soil layers, which is difficult for the plant roots to penetrate.

If the slurry is applied later in the spring wheels may damage the crop. Trials have been made to measure this problem and the yield reduction from the wheels damage to the crop. The results are shown in table 7. The trailer used for pesticide application costs 2.5 hkg/ha. The yield reduction from further using the trailer for slurry application is limited especially in the early stages of the crop development.
Table 7. Damage from driving with slurry tanker in winterwheat.

<table>
<thead>
<tr>
<th></th>
<th>Yield loss from driving with slurry tanker, Hkg /ha</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Crop 15 cm</td>
</tr>
<tr>
<td>Trailer only</td>
<td>-2.5</td>
</tr>
<tr>
<td>Trailer, 10 ton tanker</td>
<td>-2.8</td>
</tr>
<tr>
<td>Trailer, 20 ton tanker</td>
<td>-3.1</td>
</tr>
<tr>
<td>No trailer, 20 ton tanker</td>
<td>-1.0</td>
</tr>
</tbody>
</table>

3.2.1. Winterwheat

When applying slurry on fields where there is a growing crop the slurry must be spread on the soil surface, which increases the risk for ammonia volatilation. Winter cereals should only have fertilizer in springtime.

Figure 4 shows field trials in winterwheat with application of the slurry in early spring time when the crop is small (15 cm), but the soil can be wet causing soil structure hazards. Later application on 30 cm high plants, where the crop covers the soil reduces ammonia volatilation, but the weather has become warmer.

![Figure 4](image.png)

**Figure 4.** Yield and nitrogen efficiency of digested slurry with different application techniques in winter wheat. The yield and nitrogen efficiency is compared to mineral fertilizer (cacia ammonium nitrate, CAN).

The yield was almost the same for the early application for the three different techniques and only slightly reduced compared to mineral fertilizer. On later application the crop covers the surface reducing the ammonia volatilation, but at the same time the soil surface has become hard hindering infiltration of the slurry into the soil.
Table 8. Field trials in winter wheat with different techniques of slurry application compared to mineral nitrogen fertilizer (calcium ammonium nitrate, CAN). Danish field trials.

<table>
<thead>
<tr>
<th></th>
<th>Early application, crop 15 cm</th>
<th>Late application, crop 30 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Injection broadspread draghose</td>
<td>broadspread draghose</td>
</tr>
<tr>
<td>Yield compared to mineral fertilizer, Hkg /ha</td>
<td>- 2.4 - 3.3 - 2.3</td>
<td>- 4.2 - 1.5</td>
</tr>
<tr>
<td>Nitrogen efficiency, percent</td>
<td>70 53 61</td>
<td>51 64</td>
</tr>
</tbody>
</table>

3.3.2 Grassland

On grassland it is difficult to achieve a useful effect from the digested slurry, unless the slurry is injected directly into the soil, as it has to be done in Holland. When the slurry is applied in early spring the grass is short and the soil wet, so the slurry has difficulties infiltrating the soil. When the slurry is applied after cutting the grass is short, the soil is hard and normally it is warm weather.

![Figure 5. Effect of digested slurry compared to mineral fertilizer, CAN, on grassland. One area unit is the amount of grass with the same energy content as 100 kg of barley.](image)

Figure 5 shows Danish field trials with application of digested slurry in early spring and after the first cut in the end of May. Both the yield and nitrogen efficiency of the slurry is best after direct injection. Direct injection limits the work area and needs more power and energy from the tractor.

In Germany the ammonia volatilisation has been measured on grassland. With broadspreading the volatilisation was increased approximately 50 percent applied on 20 cm grass compared to 5 cm grass, because the slurry sticks to the grass leaves. Direct injection gave to lowest volatilisation application on 20 cm grass, only half of the volatilisation compared to broadspread. But in practice application does not happen on such a long grasscover.

3.2.3 Acidification

The effect of the nitrogen in the digested slurry is closely related to the volatilisation of ammonia, which again is connected to the pH, as mentioned before. Adding an acid to the slurry decreases the
pH. Decrease in pH displaces the equilibrium between ammonia and ammonium, so there is less nitrogen in ammonia form and the risk for volatilisation is decreased.

To decrease pH sulphur acid can be used. It is the cheapest acid and at the same time the crops demand for sulphur can be met. Digested slurry has a sulphur content on approximately 0.4 kg per ton, and only a small part of it is available for the crop. Normally sulphur is applied with mineral fertilizers. Concentrated sulphur acid contains 0.6 kg sulphur per liter.

On Danish CAD plants it has been investigated, how the sulphur acid will change pH in the digested slurry. Measurements from eight CAD-plants have shown identical result, it takes 2 liters of concentrated slurry to decrease pH one unit, from pH 8 to pH 7, but to decrease pH further one unit, it takes additional 6 liters of acid.

Crops needs 10-30 kg of sulphur per ha, the low end to cereals and the high end to rape seeds or grassland. Application of 30 ton per ha of digested slurry, the sulphur demand can be meet by adding 0.6 kg per ton or one liter of sulphur acid. Addition of more will result in the sulphur being leached.

Digested slurry can be used as a complete fertilizer, which means it supplies the crop with all nutrients needed, by adding sulphur and nitrogen. As an N-source nitrogen urea can be used, it is an easily diluted and a very cheap nitrogen source.

Field trials have been made in Denmark on winterwheat to compare digested slurry with additional sulphur acid, and adding urea or CAN. Adding acid increased the yield, but the differences in the four trials was very limited, which is explained by the application at very optimal conditions with no ammonia losses. The nitrogen efficiency is also very high (between 80 and 90).

Trials have also been undertaken on grassland. Adding sulphuric acid to the digested slurry has increased the yield. The application was done in sunshine. Application of an extra 25 N in urea increased the yield and in particular when applied together with the acid to minimise the ammonia volatilisation.

Figure 6 Yield in grass trials after addition of sulphur and urea to digested slurry.
The trials demonstrate that it is safe to apply the digested slurry to a over wintering or growing crop. It is possible to reach a high efficiency if the crop covers the soil surface, applying by draghose underneath the leaf surface. Application to an open crop like beets or maize should be done by some form of direct injection. Application on grassland is the same. The digested slurry can also be improved by adding nutrients like nitrogen, which must be applied to the crops anyway, or sulphur, e.g. through sulphuric acid which also improves the nitrogen effect of the slurry. Making a complete fertilizer the farmer can save money and work time, but application must be done carefully.

4. Practical example.

The field trials have shown that by best practice it is possible to reach a very good efficiency of fertilisation with digested slurry. The high efficiency is built on the whole chain of handling, storage and application in the field, to eliminate the risk of volatilation of ammonia, and thereby loosing the nitrogen from the digested slurry.

To show how the digested slurry can be utilised, and what it means for the economy on the farm, an example from a farm which is a member of a Danish centralised AD plant is referred to. This should be related to the chapter analysing the economics of AD plants and digestion of manure and organic wastes. The analyses of the economics of AD-plants only takes the plant costs into account, where as the farmers also have some other benefits. In this respect aspect there are differences between on-farm plants and CAD plants.

In 1990 a demonstration farm was started. The aim of the project was to show how to reach an optimal fertilizing value from the treated slurry on farm scale, and to be an example for other members of centralised AD-plants. The farmer is a milk producer with approximately 115 livestock units and 84 ha arable land (sandy soil). From 1991 all the slurry has been delivered to the biogas plant and digested slurry is recieved in return.

Up to 1990 the farm had a storage capacity for 6 months’ slurry production. In 1990 a new storage tank was built increasing the capacity to 12 months’ production. The slurry is only spread with draghose-technique, which makes sure of an even distribution across the single field. Spreading on black soil the slurry is incorporated immediately after spreading avoiding loss by volatilisation of ammonia. A continuous registration of all input and output to and from the stables and the fields makes it possible to calculate the nutrition balances.

Changing the time of application and using new application techniques has optimized the fertilizing value of the anaerobically treated slurry. From the manure a larger part of the nitrogen requirements is covered. Table 9 shows the requirement of nitrogen and the application of mineral fertilizer and manure. The requirement is decreased from 211 kg N per ha in 1990 to 162 kg N per ha in 1993 because of a change in crop to more clover and other nitrogen fixing crops.

<table>
<thead>
<tr>
<th>Purchase of mineral nitrogen</th>
<th>Value of manure</th>
<th>Nitrogen efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Euro</td>
<td>Euro / livestock unit</td>
<td></td>
</tr>
<tr>
<td>Kg N per Ha</td>
<td>52</td>
<td>27</td>
</tr>
</tbody>
</table>

1990 9,680 163
The purchase of nitrogen in mineral fertilizer has decreased from 163 to 58 kg per ha. In calculating the lower requirements it has decreased by 56 kg N per ha or 34 percent. The N-efficiency has increased from 27 in 1990 to 58 in 1993. The N-efficiency shows, how much nitrogen in mineral fertilizer is needed to replace 100 kg of total-nitrogen in the anaerobically treated slurry.

<table>
<thead>
<tr>
<th>Year</th>
<th>N (kg/ha)</th>
<th>P (kg/ha)</th>
<th>K (kg/ha)</th>
<th>N-Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1991</td>
<td>8,360</td>
<td>130</td>
<td>62</td>
<td>35</td>
</tr>
<tr>
<td>1992</td>
<td>5,950</td>
<td>93</td>
<td>67</td>
<td>45</td>
</tr>
<tr>
<td>1993</td>
<td>3530</td>
<td>58</td>
<td>73</td>
<td>58</td>
</tr>
</tbody>
</table>
Figure 7 shows the application of mineral fertilizer and manure, and the N-efficiency in the years 1990 to 1993. The manure part is shown as how much of the nitrogen is needed for the fertilizer plan and how much is surplus. The surplus nitrogen applied is potentially leachable nitrogen, nitrogen built up in soil reserve and losses by ammonia volatilation or denitrification. One can never reach a N-efficiency 100 per cent in organic fertilizers, the maximum of digested slurry is approximately 75 per cent.

The nitrogen supplied from the manure calculated in the fertilizer plans has increased from 48 kg per ha in 1990 to 103 kg per ha in 1993. At the same time the surplus nitrogen application from manure has decreased from 131 to 75 kg per ha.

The total nitrogen balance is shown in figure 8. The total input in 1993 is 73 per cent of the 1990 level. Harvest is at the same level during the period. The larger N-fixation is due to the change to more clover-grass and other N-fixing crops.

Figure 8. Nitrogen balance for dairy farm being a member of a CAD-plant.
Through better utilisation of the slurry and a change in crop the costs for the mineral fertilizer have decreased from 9,680 euro to 3,530 euro during the four year period, as it is shown in table 9. With improved utilisation of the nutrition content the value of the manure is increased by 40 per cent. Retrenchment on the fertilizer bill covers the costs for building the storage tank, which the farmer had to build anyway according to the legislation.
5. References


4. Köttner (199-) Ökologische düngerwirtschaft mit biogasgülle. Paper from Fachverband Biogas e.V.


