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Nr. A19 1991

N-transformation in Soil, Amended with Digested Pig Slurry

Miljøministeriet Miljøstyrelsen

Danish Research Programme on Nitrogen, Phosphorus and Organic Matter (NPO)

The aim of the NPO Research Programme is to gather knowledge on the decomposition of Nitrogen (N), Phosporus (P) and organic matter (O) in the soil, and on their impact on lakes, watercourses, inlets, groundwater and the sea.

This report is one of a total of about 50 reports to be issued in connection with the implementation of the NPO Research Programme. The National Agency of Environmental Protection (NAEP) is responsible for the programme, under which about 70 NPO projects have been launched, carried out at 25-30 institutions.

In the 1970's and the beginning of the 1980's there was a growing awareness of the threats to life in watercourses etc. presented by discharges of nutrients – and of the risk of nitrate contamination of groundwater. In 1984 a report was prepared, synthesising existing knowledge in this field. The report, known by the name of NPO Report, was published by the NAEP.

To follow up this report the Dansih Parliament took the first steps in 1985 to reduce pollution with nutrients – laying down requirements for storage and application of farm yard manure in the agricultural sector.

For the purpose of improving our knowledge on the impact of nutrients in nature, the Danish Parliament also reserved 50 million DKK for the research programme, running from 1985 to the end of 1990.

The significance of the NPO Research Programme was further underlined with the Danish Parliament's adoption of the Action Plan on the Aquatic Environment in 1987. The results of the NPO Research Programme will play a vital role in the evaluation of the effects of the Action Plan.

To safeguard the technical and economic interests relating to the research activities a steering group was set up, having the overall responsibility for the implementation of the NPO Research Programme. Furthermore, three coordination groups were formed, each of them responsible for one of the three fields: soil and air, groundwater, and surface water.

The reports are published in the series »NPo-forskning fra Miljøstyrelsen« (NPO Research in the NAEP), divided into three sections:

A: reports on soil and air
B: reports on groundwater
C: reports on watercourses, lakes and marine waters.

The NAEP has been secretariat for the research programme. The reports published in this series are edited by the Agency with the assistance of the coordination groups.

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Plant and Soil Science

Miljøministeriet
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SUMMARY

Anaerobically digested pig slurry

Nitrogen (N) mineralization and significance of denitrification in soils amended with anaerobically digested pig slurry and untreated (raw) pig slurry were studied in laboratory experiments.

Soils amended with both types of pig slurry, at a rate of 120 mg NH_4^+-N kg^{-1} soil, equivalent to 50 T slurry per hectare, were incubated aerobically (59 days), at moisture near field capacity, at 10° and 20°C.

Potentially available N

Significantly more mineral-N (mainly nitrate) was produced in soils amended with digested pig slurry (133-140 mg N kg^{-1} soil). These increases may partly have been related to higher ammonium content and lower available carbon content in the soils amended with digested slurry.
Denitrification did not cause a significant loss of N during incubation.

1. INTRODUCTION

Anaerobic digested slurry

During anaerobic production of biogas from pig slurry a large fraction of the organic material in the slurry is decomposed (Table 1). The digested slurry is more resistant to decomposition, as the BOD_5 (Biological Oxygen Demand) decreases to 80-90% of its original value. This is caused by the degradation of easily available carbon compounds during digestion, with only the lignin fraction left intact (Asmus et al.,1988).

Table 1. Composition of pig slurry a) before and b) after anaerobic digestion and c) changing during the process (%).

Reference		Dry matter	Total N	NH_4^+-N	BOD_5	Liquid fraction Tot.C	Liquid fraction Tot.N	Cellulose	Hemicellulose	Lignin
		kg m^{-3}								
Asmus et al. 1988	a)	85	4.3	2.1	13.3			11	70.5	5
	b)	53	4.3	3.1	2.8			7	0.3	5
	c)	-38%	0	+48%	-79%			-36%	-99%	0
Larsen 1986	a)	81	7.3	4.7						
	b)	64	7.3	5.7						
	c)	-21%	0	+21%						
Koriath et al. 1985	a)	32	2.6	1.3	15.2					
	b)	27	2.6	2.1	1.2					
	c)	-16%	0	+62%	-92%					
This study	a)	41	6.6	5.3		5.6	4.8			
	b)	32	6.6	5.5		4.3	4.5			
	c)	-22%	0	+4%		-23%	-6%			

Anaerobic digestion leads to a decrease in organic C and N compounds and to an increase in the content of NH_4^+-N (Table 1).
When used as a N source, slurry often results in large N losses. Parts of the N is lost through volatilization, denitrification and leaching (Lind et al., 1990; Thompson, 1989; Ørtenblad et al., 1990).
Estimation of mineralization of nitrogen (production of NH_4^+-N + NO_3^--N) or nitrification (production of NO_3^--N) are valuable for assessing the nutrient status of slurry and for predicting the amount of nitrogen likely to be made available for crop growth by mineralization.

Available N

Available N may be predicted by determination of inorganic N produced in soil during incubation under aerobic conditions, for various times (Debosz et al., 1987).

The purpose of the this work was to compare the effect of anaerobically digested pig slurry and raw pig slurry on nitrogen availability and the denitrification losses in agricultural soils, during aerobic incubation.

2. MATERIALS AND METHODS

Soils and slurry.

The three soils selected (see Table 2), were sampled from 0-20 cm, dried to 9% (W/W) water, sieved (<2 mm), and stored at 2°C in polyethylene containers, until the beginning of the incubation.

Type of slurry

Pig slurry was obtained from the experimental digester of Karl Kamp Inc. in Nr. Åby. Some informations on composition of the slurry are given in Table 1.

Table 2. Characteristics of soils used for incubation experiments. Partly after Heidmann (1989 a and b).

Parameter		Askov	Ødum	Foulum
Soil type[1]		Sandy loam	Sandy loam	Coarse sandy loam
Initial mineral-N content ($mg\ N\ kg^{-1}$)	NH_4^+-N	1.5	0.5	0.8
	NO_3^--N	18.6	10.6	25.4
pH ($CaCl_2$)		6.6	6.7	6.2
Total N ($g\ kg^{-1}$)		1.2	1.6	1.6
Organic C ($g\ kg^{-1}$)		13	18	19
Bulk density ($g\ cm^{-3}$)		1.6	1.4	1.5
Sand (63-2000 μ) %		62	74	80
Clay (<2 μ) %		11	9	8
Water content (%)		16[2]	21[3]	18[3]

1- According to Soil Survey Staff after Nielsen and Møberg (1984 and 1985).

2- equivalent to 85% of field capacity.

3- equivalent to 100% of field capacity.

Experiment.

Incubation

Laboratory experiment was carried out for 59 days and included two types of pig slurry (anaerobically digested and undigested-raw slurry), and two incubation temperatures (10 and 20°C). Soils were treated with 120 mg NH_4^+-N kg^{-1} in slurry, equivalent to 50 T slurry per hectar. Untreated controls were also included. Sufficient water was added to bring the soils almost to field capacity (Table 2). The fine soil was mixed thoroughly, subdivided into portions of about 50 g and each portion was placed in a plastic tube, 6 cm high, 2,5 cm wide. Samples were compacted gently to a bulk density very close to in situ conditions. To reduce water losses during incubation the tubes were placed in glass jars. The amount of water lost from the soil samples during incubation was measured gravimetrically at 7-d intervals and was replaced, if it was > 1 ml.

Acetylene inhibition

At day 0, 2, 4, 7, 17, 31 and 59, six tubes from each treatment were transferred to six glass jars, fitted with two serum stoppers, for gas sampling. Half of these jars received 6% acetylene (n=3), the others none (n=3). The jars without acetylene were used for CO_2 determination. The jars with acetylene were used for measurement of N_2O production (denitrification) (Lind et al., 1990).

Mineral N

Measurement of N-mineralization.
At various intervals (see above) 3 samples from each treatment were extracted with 2N KCl (1:2). The extracts were analysed for nitrate and ammonium. N-mineralization rates were calculated as the average daily rate from day zero to the measurement day.

CO_2 evolution

Measurement of C-mineralization.
Gas samples from the jars without acetylen (n=3) were analysed for CO_2, at each sampling

time, using a gaschromatograph. Carbon mineralization rates were calculated as the average daily rate for each measuring period.

Denitrification measurement

N_2O measurements

Denitrification losses were measured by the acetylene inhibition method. Gas samples were taken from the headspace atmosphere of each jar, using a syringe. Each measuring period varied between 1 and 3 days depending on the rate of N_2O evolution and each jar was sampled three times, in order to determine the linear N_2O evolution rate. Denitrifiction was calculated from the increase in N_2O concentration, the total gas volume, the water content in the soil, bulk density and Bunsen's coefficient for the solubility of N_2O in water (Tiedje, 1982).

Analysis.

Chemical analysis for nitrate, ammonium and carbon

Nitrate and ammonium were determined spectrophotometrically, after extraction with 2 M KCl (1:2), with an Technicon Autoanalyser (Henriksen and Selmer-Olsen, 1970) or by flow injection (Giné et al. 1980). C determination in pig slurry was performed on the liquid fraction of the slurry, which was separeted by centrifugation. Total soluble C was determined using a Dohrmann DC 180 Carbon Analyzer, which used a low temperature, persulphate-UV oxidation procedure. The water content was determined gravimetrically by drying the soil at 105°C for 24 hours.

Statistical analysis

The statistical analysis was performed using the Statistical Analysis System (1989).

Mean nitrate- and ammonium-concentrations were calculated for each combination of day, temperature and slurry type.

Statistical analysis

Due to the log normal distribution exhibited by the denitrification measurements mean log denitrification rates were calculated and were subsequently used in the statistical test. Means were tested for significant differences with the GLM program of the SAS system.
The mean denitrification rates were calculated from the mean log denitrification rates using the exponential function.

3. RESULTS

3.1. N and C mineralization

Experiment was performed on three agricultural soils, which did not differ substantially in texture and contents of organic N and C; two sandy loam and one coarse sandy loam soil. It could been shown, that the N-transformation in soil was more influenced by the kind of pig slurry used than by the soil type.

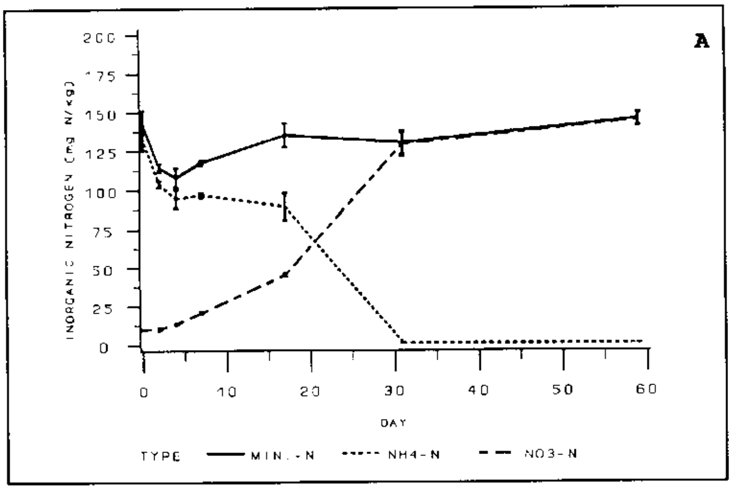
The evolution of the total inorganic N, NH_4^+-N and NO_3^--N during incubation of sandy loam soil (Ødum) after amendments with the two types of pig slurry, at 10° and 20°C was shown in Fig. 1 and 2, respectively.

Untreated pig slurry

Addition of raw pig slurry (120 mg NH_4^+-N kg^{-1} soil) to sandy loam soil (Ødum) resulted in an immediate consumption of NH_4^+-N and at the same time a long decline in total inorganic N in the soil, at both temperatures (Fig. 1A and 2A). There was a greater immobilization of NH_4^+-N and a faster production of NO_3^--N (nitrification) at higher temperatures (20°C), at the beginning of incubation. But efter 30 days of incubation the amount of NO_3^--N produced was at the same level at both temperatures, and only a small amount of NH_4^+-N was detected in soils (Fig. 1A and 2A).

Digested pig slurry

Addition of anaerobically digested pig slurry (120 mg NH_4^+-N kg^{-1} soil) to sandy loam soil (Ødum) and incubation at 10° and 20°C caused a shorter decline in inorganic N in soil, compared to the raw pig slurry treatment.



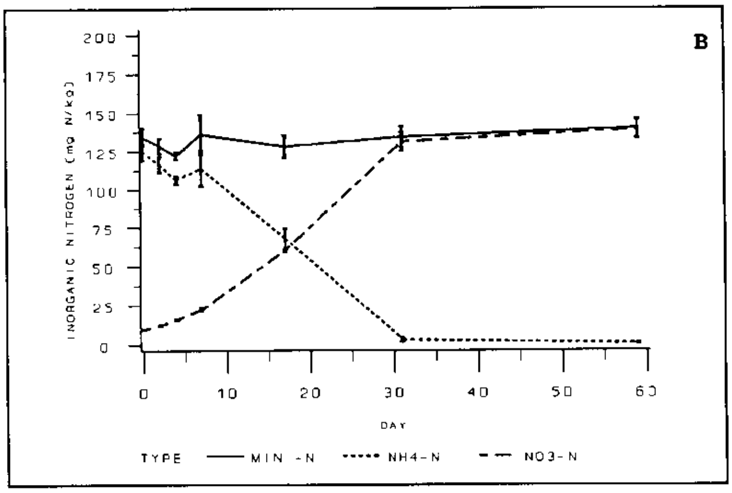


Fig. 1. Evolution of total inorganic N, NH_4^+-N and NO_3^--N as influenced by A) raw pig slurry B) digested pig slurry amendment (120 mg NH_4^+-N kg^{-1} soil) to Ødum soil incubated at 10°C. Bars show standard deviation.

The decline was especially big at 20°C, where immobilization of NH_4^+-N was greatest. Short immobilization of NH_4^+-N, after addition of digested pig slurry to soils, was followed, at both temperatures, by continuous increase in nitrification rate, which led to accumulation of high amounts of NO_3^--N at the end of the incubation period (Fig. 1B and 2B).

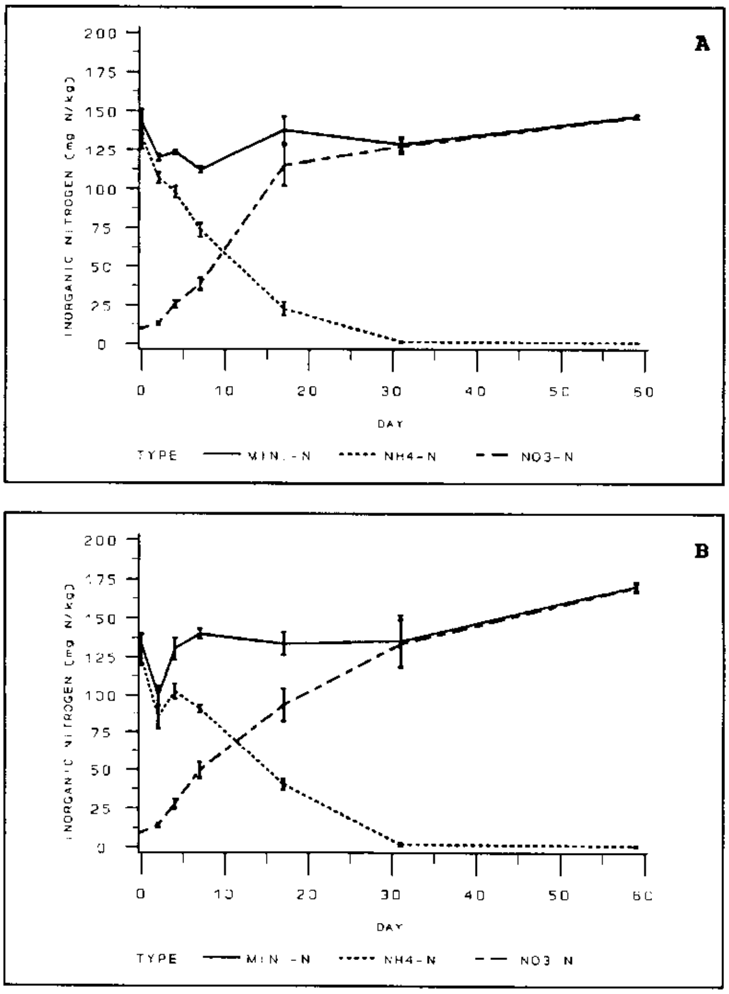


Fig. 2. Evolution of total inorganic N, NH_4^+-N and NO_3^--N as influenced by A) raw pig slurry B) digested pig slurry amendment (120 mg NH_4^+-N kg^{-1} soil) to Ødum soil incubated at 20°C. Bars show standard deviation.

Type of soil	To compare the effect of digested pig slurry with raw pig slurry on nitrogen available in soil, the means from the three soils studied were taken into consideration (Table 3). Substantial amounts of nitrate were produced in all treatments after 59 days of incubation (Table 3). Anaerobically digested pig slurry significantly increased nitrate produced in soil, compared with raw pig slurry. Nitrogen added in raw pig slurry was significantly less nitrified (92-94%) than that added with digested pig slurry (106-116%) (Table 3).

Table 3. Effect of type of pig slurry added (120 mg NH_4^+-N kg^{-1} soil) to soil# on formation of nitrate-N after 59 days of incubation, at 10° and 20°C.

Temperature	Pig slurry type	Increase in NO_3^--N§ during incubation	Nitrification of added NH_4^+-N to NO_3^--N§
		mg N kg^{-1} soil	%
10°C	Raw	107a*	94a
	Digested	130b	106b
20°C	Raw	105a	92a
	Digested	144b	116b

Mean of three soils

§ Increase in NO_3^--N and nitrification of added NH_4^+-N with pig slurry were estimated by subtracting the amount of NO_3^--N produced by soil alone from that produced by soil + added pig slurry.

* Within each temperature series the values in each column are significantly different (95% level of probability), when not followed by the same letter.

C-mineralization

C-mineralization in soil amended with anaerobically digested pig slurry and raw pig slurry was described using the rate of CO_2 evolution.

Three phases of decomposition, as indicated by changes in the rate of CO_2-C evolution (Table 4), were observed and identified as rapid (initial flush), intermediate and slow.

CO_2-C evolution rates were higher in raw pig slurry treated soil compared to digested pig slurry, at rapid and intermediate phases, during incubation at 20°C (Table 4).

Table 4. Mean daily CO_2-C evolution in soil# incubated at 10°C and 20°C as influenced by pig slurry amendment (120 mg NH_4^+-N kg^{-1} soil).

Temperature	Pig slurry type	Incubation days					
		2	4	7	17	31	59
		mg C kg^{-1} soil day^{-1}					
10°C	Raw	22a*	9a	5a	3a	2a	1a
	Digested	22a	9a	5a	3a	2a	1a
20°C	Raw	38a	17a	11a	5a	2a	2a
	Digested	31b	11b	8b	3a	2a	2a

Mean of three soils.

* Within each temperature series the values in each column are significantly different (95% level of probability), when not followed by the same letter.

3.2 Denitrification

Amendment with raw pig slurry

Soil amended with 120 mg NH_4^+-N kg^{-1} soil in raw pig slurry and incubated at 20°C (Table 5) had a maximum denitrification rate at the beginning of the incubation, of 6.9 μg N kg^{-1} h^{-1}, which subsequently decreased to reach a mean rate of 0.01 μg N kg^{-1} h^{-1} during day 28-59.

Table 5. Mean N_2O production rate in soil# amended with 120 mg NH_4^+-N kg^{-1} soil in raw and digested pig slurry, and incubated at 10° or 20°C.

Temperature	Pig slurry type	Incubation days					
		1	2	4	14	28	59
		μg N kg^{-1} soil h^{-1}					
10°C	Raw	1.37a*	0.04a	0.07a	0.06a	0.01a	0.01a
	Digested	0.21b	0.02a	0.03a	0.03a	0.02a	0.01a
20°C	Raw	6.87a*	2.12a	0.5a	0.11a	0.01a	0.01a
	Digested	0.1b	0.2b	0.1a	0.01b	0.01a	0.02a

Means of three soils.
* With each temperature the values in each column are significantly different (95% level of probability), when not followed by the same letter.

Digested pig slurry

When soil was incubated with the same amount of digested pig slurry and at the same temperature (Table 5), the maximum in activity was seen after 2 days of incubation, but at a lower level (0.2 μg N kg^{-1} h^{-1}). At 10°C the peak of denitrification activity was seen at the first day of incubation, 1.4 and 0.2 μg N kg^{-1} h^{-1}, for raw and digested pig slurry, respectively.

Temperature effect

The denitrification rate at both temperatures fell to a mean rate 0.01 μg N kg^{-1} h^{-1} and between day 28 and 59 there was neither a difference in denitrification activity between soil amended with raw or digested slurry nor a difference in activity at the two temperatures.

Total denitrification loss

During the incubation time only small denitrification losses could be measured. At 20°C the total loss during 59 days of incubation was estimated to 0.4 and 0.04 mg N kg^{-1} in soil amended with raw and digested pig slurry, respectively. The estimated loss in soil incubated 59 days at 10°C with raw and digested pig slurry was 0.09 and 0.03 mg N kg^{-1}, respectively.

4. DISCUSSION AND CONCLUSION

Anaerobic digestion of pig slurry

Anaerobic digestion of pig slurry removed 23% of the carbon in the liquid fraction and a part of the organic nitrogen was mineralized to ammonium. These transformations may influence the fertilizing value of pig slurry in the soil.

In the case studied the anaerobic digestion was obviously of poor efficiency in increasing NH_4^+-N amount in pig slurry used (4%) in contrast to findings of Larsen (1986), Asmus et al. (1988) and Koriath et al. (1985), who found increases of NH_4^+-N in the range from 27% to 60%.

Mineralization

Laboratory study showed, that soils amended with raw pig slurry immobilized more nitrogen, whereas in soils amended with digested pig slurry net mineralization prevailed. The pattern of immobilization and mineralization observed here was similar to that reported by Chaussod et al. (1986) and Ørtenblad et al. (1990).

Chaussod et al. (1986) found, that raw pig slurry immobilized nitrogen and depressed crop yields in pot experiments, whereas application of digested pig slurry did not result in such net immobilization and depressive effect.

Fertilizing effect

Anaerobic digestion improves fertilizing value of pig slurry, but in the field experiments fertilizing effect of digested slurry was only slightly better than that of undigested slurry (Larsen, 1986 and Vetter et al., 1987).

Gaseous losses

Following application of pig slurry in soil gaseous nitrogen losses can occur. The major process involved is ammonia (NH_3) volatilization and possibly denitrification.

The amount of ammonia volatilization from pig slurry applied to soil depends on the chemical characteristics of the slurry (pH, NH_4^+-N and dry matter), as well as application method, and physical and chemical characteristics of soil.

Ammonia volatilization

Experiments have shown, that high pH, NH_4^+-N and dry matter content in slurry leads to large volatilization losses (Nelson, 1982; Sommer and Christensen, 1989). In a field experiment, where ammonia volatilization from raw and digested pig slurry applied to soil has been compared, no difference in volatilization was found (Sommer and Christensen, 1990), probably reflecting, that anaerobic digestion did not change the content of ammonium. At the same time slurry incorporation method was more important for volatilization losses than slurry processing (Sommer and Christensen, 1990; Vetter et al., 1987).

In the present experiment a part of ammonia applied with slurry may have volatilized during the incubation, but this loss was probably very small, as the slurry was immediately incorporated into the soil.
Compared to the losses due to volatilization, denitrification losses are generally much lower.

Denitrification losses

In our study only a minor part of nitrogen added in the slurry was denitrified during the incubation period, equivalent to 0.03-0.3% of added NH_4^+-N.
The reason for the low denitrification losses was probably the low soil water content, which is known to be very important (Tiedje, 1989). At a soil moisture lower than field capacity N losses, by reduction of NO_3^-, could hardly be important. In an earlier study Lind et al. (1990) found that the denitrification rate at 125% FC was 100 times the rate for 100% FC.

Nitrate influence

Another factor, that could have retarded denitrification, was the nitrate concentration in the soil (Thompson, 1989).
The small denitrification activity in this study could not be caused by exhaustion of nitrate, as the concentration was steadily increasing during the course of incubation.
These results suggest, that the low production of N_2O was due to factors other than low NO_3-content, possibly the scarcity of anaerobic sites or available C.

The difference in N-mineralization and denitrification in soil amended with raw or digested pig slurry can be explained by the differences in chemical composition, between the two types of slurry used. Only the most resistant fractions of the organic material could be found after anaerobic digestion. This means, that during digestion the amount of easily available carbon in the digested slurry is lowered. This is also substantiated by the large decrease in BOD_5 after digestion (Asmus at al., 1988).

Available carbon

In our study less CO_2 was produced from soil amended with digested pig slurry. The lower content of mineralizable carbon (available C) in soil amended with anaerobically digested slurry was closely related to lower carbon content in the liquid fraction, after digestion of the slurry.

Easily available carbon in soil and pig slurry had an important effect on such processes as mineralization - immobilization and denitrification in soil (deCatanzaro and Beauchamp, 1985); Reinertsen et al., 1989; Stanford et al., 1975).

Temperature

In the soils examined a clear relationship was seen between increasing temperature and increasing mineralization and denitrification rates, as also noted by others (Keeney et al., 1979; Lind et al., 1990 and Vinther, 1990). The average temperature coefficient during incubation showed for nitrification a weak temperature response $Q_{10} = 1.3$, for C mineralization more commonly observed value $Q_{10} = 2$, while denitrification responded more vigorously, but only at the beginning of incubation, $Q_{10} = 4$.

Conclusion

The biological method, based on aerobic incubation, at a constant water potential (100% FC) and temperature indicated, that potentially more available N (mostly nitrate) was mineralized from anaerobically digested pig slurry than from raw slurry. Three soils studied showed similar pattern of mineralization, which was influenced by the type of pig slurry used, especially its organic composition, and the incubation temperature. Denitrification losses were low during the first few days of incubation and negligible in the last period of incubation.

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Data Sheet

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Title:
N-transformation in Soil, Amended with Digested Pig Slurry

Subtitle:

Author(s):
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Performing organization(s):
Danish Research Service for Plant and Soil Science,
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Abstract:
Laboratory experiments were conducted to study the effect of anaerobic digestion of pig slurry on nitrogen (N) transformation in three agricultural soils.
Anaerobic digested pig slurry caused a larger N-mineralization than raw slurry due to increased ammonium-N content. At the same time smaller amounts of N were lost by denitrification induced by the lower content of easily available carbon in the digested slurry.

Terms:
pig slurry; decomposition; biodegradation; analytical methods; nitrogen CAS 7727-37-9

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Undertitel:

Forfatter(e):
Debosz, Kasia; Maag, Michael

Udførende institution(er):
Statens Planteavlsforsøg

Resumè:
En laboratorieundersøgelse af tre landbrugsjorder tilsat almindelig og afgasset svinegylle viste, at både mineralisering og denitrifikation var stærkt afhængig af gylletype. Afgasning af gylle bevirkede større mineralisering p.g.a. større ammoniumindhold i den afgassede gylle. Samtidig gav afgasning mindre tab af N ved denitrifikation p.g.a. lavere indhold af let tilgængeligt kulstof i afgasset gylle. Mineralisering og denitrifikation var størst i perioden lige efter tilsætning af gylle og faldt derefter.

Emneord:
husdyrgødning; omsætning; mikrobiologisk nedbrydning; analysemetoder; nitrogen CAS 7727-37-9

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Rapport fra koordinationsgruppe A for jord og luft

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NPo-forskning fra Miljøstyrelsen

Rapporter fra koordinationsgruppe A for jord og luft

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Nr. A 4 : Ammoniakafsætning omkring et landbrug med malkekvæg
Nr. A 5 : Ammoniakmonitering
Nr. A 6 : Atmosfærisk nedfald af næringssalte i Danmark
Nr. A 7 : NH_3-fordampning fra handels- og husdyrgødning
Nr. A 8 : Næringsstofudvaskning fra arealer i landbrugsdrift
Nr. A 9 : Kvælstofomsætning og -transport i to dyrkede jorder
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Nr. A18 : Atmosfærisk ammoniak og ammonium i Danmark
Nr. A19 : N-transformation in Soil, Amended with Digested Pig Slurry
Nr. A20 : Simulering af kvælstoftab med SOIL-N-modellen
Nr. A21 : Landbrugets gødnings- og arealanvendelse i 1983 og 1989

Den med * mærkede titel er ikke trykt på udgivelsesdagen for denne rapport, men forventes trykt i løbet af 1991.

Nr. A19 er tidligere annonceret med titlen:
Afgasset gylles indflydelse på N-omsætning i jorden.

N-transformation in Soil, Amended with Digested Pig Slurry

Po-forskning nr. A19 1991

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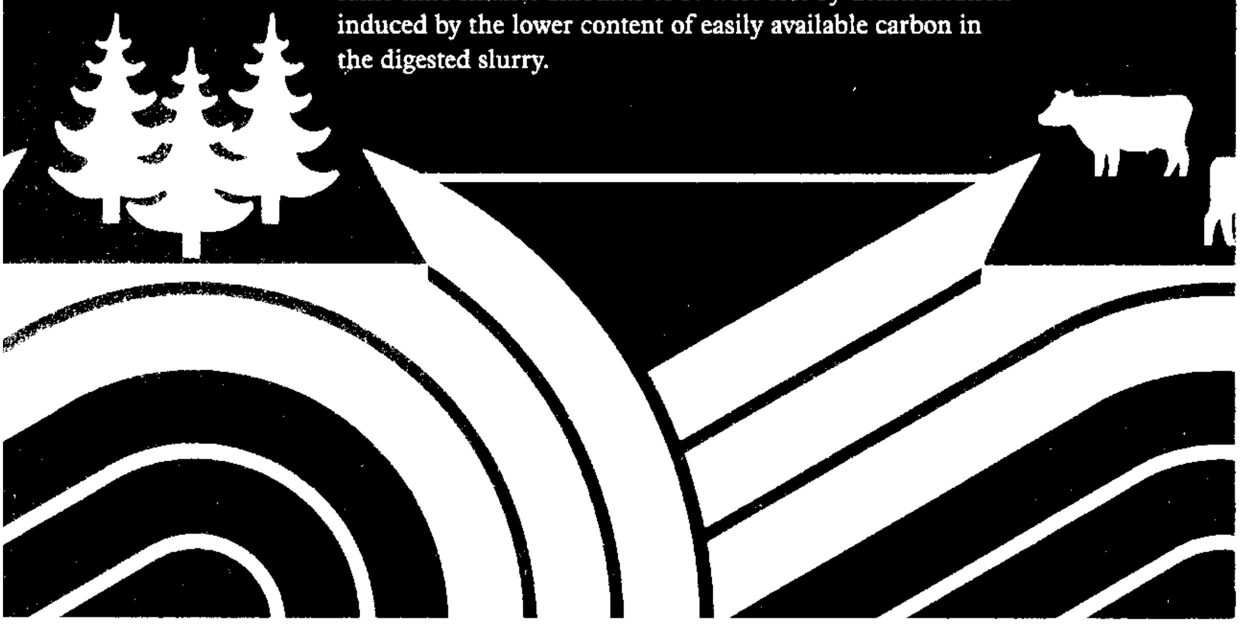

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