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Dietary effects on the composition of pig slurry and on the plant utilization of pig slurry nitrogen

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SUMMARY

The composition of animal manure is influenced by the diet fed. Efforts are made to decrease nitrogen emission from pig production by optimizing diet composition. This normally results in a lower proportion of N excreted in urine relative to faeces, and may also influence the turnover and utilization of manure N after field application. The effects of pig feed composition on the excretion of urinary and faecal N, on the dynamics of manure N in soil and on the potential utilization of manure N in the field was studied. Growing pigs and sows were fed 12 different diets with variable contents of fibre and protein (with or without synthetic amino acids). Slurries consisting of a mixture of faeces and urine were stored according to common agricultural practice in Northern Europe. The plant availability of N in the resultant slurries originating from animals fed known diets was tested in small field plots with barley, under conditions with minimal N losses. Separate plots were fertilized with increasing amounts of mineral N. Nitrogen uptake in barley was determined and the utilization of slurry N was compared with that of mineral fertilizer N. The net release of mineral N and C from the slurries in soil was also measured in a parallel incubation study.

The mineral fertilizer equivalent of pig slurry N was 72–100% and significantly influenced by feed fibre composition, but not significantly influenced by the protein content. There was a significant positive correlation between enzyme-digestible organic matter in the pig diet (measurement used for feed evaluation) and the plant availability of pig slurry N ($R^2 = 0{\cdot}90$). The ammonium content of stored pig slurry could not be used for prediction of the N availability since the net mineralization of pig slurry N was variable, but there was a significant negative correlation between the pig slurry C/N ratio and the plant availability of slurry N ($R^2 = 0{\cdot}86$).

Increased dietary concentration of fermentable structural carbohydrates (e.g. by including sugar beet pulp in the diet) reduces the excretion of N in urine without affecting the availability of slurry total N, whereas an increased concentration of dietary fibre with a low fermentability (straw) results in less urinary N, but also a lower plant availability of slurry N.

INTRODUCTION

Animal manure is an important source of N for crop production. The composition of animal manure is influenced by feed composition, which varies from farm to farm. The turnover and the plant availability of manure N are influenced by manure composition (Gerdemann *et al.* 1999; Kyvsgaard *et al.* 2000). The manure N left in soil 1 year after application is released at a low annual rate and contributes significantly to the long-term accumulation of organic N in soil (Jensen *et al.* 1999; Sørensen & Amato 2002).

Efforts are made to increase the utilization of dietary N in pig production. The protein content of pig diets can be decreased by optimizing the composition and by addition of synthetic amino acids (Lenis & Jongbloed 1999). The main purpose of dietary protein reduction is to decrease the amount of N excreted in manure per unit of meat produced.

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Table 1. *Composition of pig diets* (*g*/*kg*)

	Growing pigs								Dry sows			
Diet no.	1	2	3	4	5	6	7	8	9	10	11	12
Fibre fermentability (FT)	L*	L	L	L	H	H	H	H	L	L	H	H
Fibre level (FL)	N	N	H	H	N	N	H	H	N	H	N	H
Protein level (PL)	H	N	H	N	H	N	H	N	N	N	N	N
Wheat grain	501	613	402	569	333	401	220	200	452	485	–	407
Barley grain	100	120	150	100	251	339	304	395	385	200	812	46
Sunflower cake	50	51·7	50	99·3	–	–	–	–	56·8	23·0	–	–
Canola cake	177	57·7	150	50	–	–	–	–	30	50	–	–
Barley straw	–	31·0	90	90	–	–	–	–	50	226	–	–
Soya bean meal	150	98·5	139	67·1	154	100	195	98·2	5·0	–	36·7	–
Peas	–	–	–	–	116	42·5	–	–	–	–	–	–
Sweet lupin	–	–	–	–	100	66·1	109	101	–	–	4·5	101
Sugar beet pulp, dry	–	–	–	–	20·0	20·0	150	177	–	–	125	428
DL-Methionine 40	–	0·9	–	0·6	1·4	2·0	1·3	2·5	–	–	0·5	1·3
L-Threonine 50	–	1·8	–	1·5	–	3·0	–	2·9	–	–	0·5	1·9
L-Lysine 50	–	7·7	–	7·6	–	7·0	–	6·5	–	–	–	–
Limestone	10·0	3·2	8·7	3·2	9·6	4·3	7·3	0·3	8·6	5·7	5·9	–
Salt	3·7	3·4	3·0	3·0	4·0	4·0	3·0	4·0	3·0	1·0	3·1	2·4
Microminerals and vitamins	2·0	2·0	2·0	2·0	2·0	2·0	2·0	2·0	2·0	2·0	2·0	2·0
Dicalcium phosphate	6·3	8·7	5·4	7·0	8·6	9·1	8·8	10·2	8·1	6·8	10·4	10·6

* N = normal, L = low, H = high.

The decrease in excreted N is mainly in the urine fraction of the manure, thus enabling a reduction of nitrogen emission (Misselbrook *et al.* 1998; Canh *et al.* 1998*a*, 1999). An increased concentration of fermentable (non-starch) carbohydrates in the diet also reduces the proportion of N excreted in urine, and thereby the ammonium content in pig manure and ammonia emission (Canh *et al.* 1998*b*, 1999; Gerdemann *et al.* 1999). A lower proportion of N excreted in urine may have a negative influence on the utilization of pig slurry N in the field, as a higher proportion of the slurry N will be in the organic form.

The amount and composition of fibre in the diets used in pig production are variable. In some systems pigs have access to straw, and this may also influence the composition and turnover of manure N.

To maximize the utilization of manure N, it is important to know more about dietary effects on the dynamics of manure N in soil. Such information may be used in manure and nutrient management models in the future.

Effects of protein content and fibre composition of diets for growing pigs and sows on the composition of manure and on the dynamics of N during slurry storage and slurry decomposition in soil were studied. The potential plant availability of manure N and its relationship to the diet and manure composition were measured.

MATERIALS AND METHODS

Production of experimental slurries

Eight different diets for growing pigs and four diets for dry sows were formulated (Table 1) in accordance with the Danish nutritional recommendations for pigs. The diets for growing pigs were optimized at two contents of protein by reducing the protein content in half of the diets and supplementing with free amino acids. Diets for growing pigs and for sows contained two levels of fibre of each of two fibre types characterized by their fermentability. Diets containing fibre with 'low' fermentability were prepared by choosing ingredients like cereals (*Gramineae*), canola (*Cruciferae*) or sunflower (*Asteraceae*) as opposed to ingredients with high fermentability such as soya bean, peas and lupin (*Leguminosae*) or sugar beet (*Quenopodiaceae*).

Each diet was fed to five pigs placed in metabolism cages and fitted with bladder catheters. After an adaptation period of 5 days, faeces and urine were collected quantitatively for 7 consecutive days. A representative composite sample of urine and faeces was analysed separately for each pig to determine their chemical composition. The amount of urine and faeces voided was determined for each pig as the average of the 7 days collection. The weight of the growing pigs was 40–60 kg and the weight of the sows was about 220 kg.

Slurry storage and decomposition in soil

Experimental slurries were produced by mixing urine and faeces from the five pigs on each diet in the same proportion as excreted. Water was added equivalent to 0·2 of the weight of total excretion to simulate normal additions from spillage of drinking water, washing water and precipitation during outdoor storage in tanks. Three 420 g portions of each slurry were put into 1-litre glass jars and the slurries were inoculated with organisms from a pig slurry pit by applying 0·25 ml of slurry liquid fraction (from slurry centrifugation) to each jar. The samples were then stored under anaerobic conditions at 8 °C for 16 weeks and at 15 °C for another 4 weeks. After the first 10 weeks the jars were opened, the slurry mixed and the jars closed again. Each jar had a small hole with a rubber stopper pierced by an injection needle attached to a syringe. Thus, increased pressure due to gas evolution would move the syringe piston allowing for expansion. No detectable weight losses were observed throughout the storage time.

The three replicated slurry samples were analysed for dry matter (DM by freeze-drying), ammonium N, total N, total C and water-soluble organic C before and after storage.

Slurry incubation in soil

The stored pig slurries originating from different diets were applied to soil to measure the net release of mineral N and CO_2 during decomposition in soil under controlled conditions. Soil was sampled from the plough layer of the arable field where the field experiment was placed (see below). The soil was a loamy sand containing 80 g clay/kg, 125 g silt/kg, 760 g sand/kg, 35 g organic matter/kg, 21 g total C/kg, 2·1 g total N/kg and pH (H_2O) was 6·8. The water-holding capacity was 0·431 g/g dry soil. The soil was air-dried to a water content equivalent to 40 % of the soil's water-holding capacity (WHC) and then sieved (4 mm). The soil was stored at 8 °C for 2 weeks. Forty-gram (dry soil weight basis) soil samples were transferred to 250 ml polyethylene bottles. Each of the 12 pig slurries was applied to the soil at a rate of 200 mg total N/kg soil, and the soil and slurry were mixed. A reference treatment of $(NH_4)_2SO_4$-N (200 mg N/kg soil in 1 ml water) and a 0 N treatment were also included. Extra water was added to each bottle to increase soil moisture to 55 % WHC, which is near the optimal moisture content for microbial transformation of N and C in soil (Sommers *et al*. 1981). Enough replicates were made of each treatment to allow for destructive sampling and measurement of soil mineral N in triplicate after 1 h, 1 week, 4 weeks and 12 weeks. To minimize the loss of soil water, the bottles were covered with Parafilm with holes for aeration. In addition triplicate samples of each treatment were placed in sealed 2-litre jars with a beaker containing 10 ml 1 M NaOH for measurement of CO_2 evolution. The samples were placed in a dark, temperature-controlled room at 8 °C. The water loss was controlled by weight weekly, and extra water added when needed. The beakers containing NaOH for absorption of CO_2 were replaced after 2 days, 1 week, 2 weeks, 4 weeks, 8 weeks and 12 weeks.

Field experiment

The mineral fertilizer equivalent (MFE) of the slurries was measured in small, framed field plots in a spring barley crop. Open-ended PVC cylinders (30 cm diameter, 30 cm in height) were pressed into soil to 25 cm depth in an arable field at Foulumgaard, Research Centre Foulum, Denmark, in spring 2000. The stored slurries were applied to the framed plots by simulated direct injection. The upper 4 cm soil in the plot was removed, and a 4 cm deep ridge (V-shape) was made across the plot and slurry equivalent to 130 kg total N/ha was applied to the ridge. Finally the upper soil layer was returned ensuring that all the slurry was covered by soil (slurry at 4–8 cm soil depth). Separate plots were fertilized with ammonium nitrate equivalent to 0, 60, 100, 120, 140 and 180 kg N/ha. The treatments were organized in three randomized blocks (three replicates of each treatment). All plots were sown with spring barley (*Hordeum vulgare* L., cv. Alexis) in two rows at 12 cm distance (6 cm distance from the middle of the slurry band), and the surrounding soil was also sown with spring barley. Essential plant nutrients, except N, were applied to all plots at a level sufficient for optimal growth. The soil surrounding the plots was fertilized with 100 kg N/ha in an NPK fertilizer. During the cropping season the field including the plots was treated with herbicides and fungicides according to normal practice in Denmark. The barley crop in each plot was harvested 5 cm above soil surface at maturity in August.

The dry matter and total N in grain and straw were measured. The crop N uptake in grain and straw responded linearly to increasing mineral fertilizer N ($r^2 = 0{\cdot}99$, slope: 0·65), and the MFE of slurry N was calculated from the N response curve:

$$\text{MFE} = \text{Equivalent fertilizer N response}/130 \times 100\%.$$

Analytical methods

Total N (protein) in feed and faeces was determined by dry combustion (Hansen 1989). Crude fibre in feed and faeces was measured by the Weende method (Tecator 1978). Soluble and insoluble fibre in feed and faeces were measured according to Asp *et al.*

Table 2. *Chemical composition of diets*

	Growing pigs								Dry sows			
Diet no.	1	2	3	4	5	6	7	8	9	10	11	12
Fibre fermentability (FT)	L*	L	L	L	H	H	H	H	L	L	H	H
Fibre level (FL)	N	N	H	H	N	N	H	H	N	H	N	H
Protein level (PL)	H	N	H	N	H	N	H	N	N	N	N	N
Crude protein (g/kg DM)	231	176	198	186	233	200	232	196	146	139	130	151
Crude fat (g/kg DM)	61	33	57	42	34	34	36	36	29	28	33	31
Crude fibre (g/kg DM)	63	57	93	91	60	50	79	83	61	111	64	112
Lignin (g/kg DM)	27	14	34	29	12	15	12	12	19	26	15	20
Soluble fibre (g/kg DM)	38	39	45	36	46	41	71	71	35	29	65	96
Insoluble fibre (g/kg DM)	169	168	234	226	167	154	215	222	173	274	199	299
$EDOM_{corr}$ (g/kg DM)†	832	817	760	752	844	852	830	837	847	737	870	875
NFE (g/kg DM)	591	691	600	634	617	668	594	629	723	682	728	652
Fermentability‡	0·09	0·07	0·10	0·08	0·09	0·08	0·16	0·17	0·07	0·08	0·13	0·26

* N = normal, L = low, H = high.
† Analyses for growing pigs were corrected by: $EDOM_{corr} = EDOM_{analysis} \times 1{\cdot}106 - 140$ according to Boisen & Fernández (1997).
‡ Diet fermentability estimated as the relative ileo-faecal digestibility difference of dry matter (DDMF − DDMI/DDMF).

(1983). Lignin in feed and faeces was measured according to Goering & Van Soest (1970).

Enzyme digestible organic matter (EDOM) in the feed was measured according to Boisen & Fernández (1997) and digestible dry matter at ileal and faecal level (DDMI and DDMF respectively) were analysed as described by Danfær & Fernández (1999). Diet fermentability was estimated as the relative ileo-faecal digestibility difference of dry matter (DDMF − DDMI/DDMF). Nitrogen-free extractable compounds (NFE) in feed and faeces were calculated as 1000 − ash − crude protein − crude fat − crude fibre (g/kg DM).

Total N in slurry was determined using a Kjeldahl method (Tecator Kjeltec Auto 1030). Inorganic N in slurry and soil was extracted by 2 M KCl (3:100 for slurry (w:w) and 1:4 for soil), followed by centrifugation and filtration. Ammonium and nitrite + nitrate N in extracts were measured by flow colorimetry (Autoanalyzer II). Water-soluble organic C in slurry was extracted by water (1 g slurry in 100 ml water for 15 min), followed by centrifugation and filtration (0·22 μm filter). The extract was analysed for organic C on a carbon analyser (Dohrmann DC180). Total C in slurry was measured on a total C analyser (Leco) after freeze-drying and grounding the slurry.

Dietary and excreta data were analysed separately for growing pigs and for sows. Analyses of variance including effects of fibre type, fibre content, protein content and the second and third order interactions were carried out using the SAS procedure GLM (SAS 1989). Regression analyses were made using the REG CORR procedure (SAS 1989).

RESULTS

Diet composition

The analysed composition of diets (Table 2) was in accordance with that expected from the formulation, with the exception of diet 3 where the protein content was about 12% lower than expected. Fibre content, judged by the content of crude fibre, was in keeping with the planned two contents, 60 and 90 g/kg DM for growing pigs and 60 and 110 g/kg DM for sows for normal and high contents, respectively. Insoluble fibre content reflected the aimed normal and high content but was not different between fibre types. Fibre type was, however, reflected somewhat in the content of soluble fibre, which was higher in the diets with a high fibre content and with a high fermentability. There was no difference in soluble fibre content between diets with a low fermentability. A very similar pattern was found for the calculated fermentability of diets. The digestibility of organic matter and gross energy were calculated from the recorded excreta amount and the analyses of feed and excreta. The *in vivo* determined digestibility of organic matter and of gross energy were highly correlated to the corresponding *in vitro* analysis (EDOM, $r = 0{\cdot}97$ and 0·96, respectively).

Amount and composition of faeces and slurry

The amount of faeces voided by growing pigs and sows was dependent on dietary fibre type and content in combination. The lowest amount was found in pigs fed diets containing highly fermentable fibre. Faeces

Table 3. *Amount and composition of faeces* (n = 5), *urine* (n = 5) *and slurry* (*faeces + urine + water*, n = 3) *from growing pigs and sows fed different diets*

	Growing pigs									Dry sows				
Diet no.	1	2	3	4	5	6	7	8		9	10	11	12	
Fibre fermentability (FT)	L*	L	L	L	H	H	H	H		L	L	H	H	
Fibre level (FL)	N	N	H	H	N	N	H	H		N	H	N	H	
Protein level (PL)	H	N	H	N	H	N	H	N	S.E.	N	N	N	N	S.E.
Faeces														
g/kg dry matter intake[3,8]†	640	690	1000	1140	500	520	770	780	50	537	1210	456	467	39
Water (g/kg)[1,2,8]	696	715	741	774	672	684	727	727	13	674	774	631	659	15
Total N (g/kg DM)[3,4,8]	37	30	33	26	36	34	40	39	1·1	23	21	28	32	1·1
Crude fibre (g/kg DM)[1,2,6]	212	241	279	293	197	182	202	202	6·7	245	335	189	156	4·6
Insoluble fibre (g/kg DM)[1,2,6]	454	537	556	601	434	435	406	419	11·7	567	671	472	362	4·8
Lignin (g/kg DM)[3,4,5]	121	67	113	101	48	57	52	56	1·8	83	104	69	80	4·9
NFE (g/kg DM)[1,2,6]	309	357	326	364	312	332	290	300	7·2	366	368	333	274	6·2
pH[3,8]	6·24	6·11	6·45	6·59	5·99	6·09	5·78	5·57	0·13	7·35	8·12	6·96	6·90	0·13
Urine														
g/kg dry matter intake	3850	2550	1950	2090	3230	4660	2950	3170	423	5000	2150	2430	3970	817
Total N (g/kg)[5,8]	4·5	4·0	6·1	6·2	5·7	3·0	6·9	3·9	1·6	7·1	9·2	8·2	7·5	1·7
Slurry before storage														
DM (freeze-dry) (g/kg)	39	45	80	80	44	34	67	50	0·6	35	80	65	48	0·9
Slurry after storage														
DM (Freeze-dry) (g/kg)	34	36	64	61	39	22	40	38	0·5	29	74	42	36	0·7
Total N (g/kg)	4·17	3·55	5·19	4·64	4·95	2·91	5·21	3·81	0·049	5·37	5·38	5·86	5·77	0·032
NH_4-N (g/kg)	2·91	2·64	3·78	3·19	4·06	2·00	3·59	2·41	0·12	4·68	4·32	5·07	4·73	0·064
Total C (g/kg)	14·6	16·0	28·9	28·2	17·5	9·6	17·9	16·9	0·24	11·5	32·5	16·7	14·3	0·30
Soluble C (g/kg)	0·83	2·57	4·49	1·79	2·48	0·56	2·58	1·80	0·105	1·14	2·29	1·92	1·36	0·027
C/N ratio	3·50	4·49	5·36	5·99	3·52	3·33	3·40	4·38	0·082	2·13	5·89	2·71	2·48	0·059
pH	7·8	7·6	7·5	7·5	7·9	7·9	7·8	7·6	0·10	8·4	8·1	8·1	7·9	0·15

* N = normal, L = low, H = high.

† Significant ($P < 0·05$) effect within growing pigs: [1]FT, [2]FL, [3]FT × FL, [4]FL × PL, [5]FT × FL × PL. Significant ($P < 0·05$) effect within dry sows: [6]FT, [7]FL, [8]FT × FL.

Table 4. *Nitrogen excretion from growing pigs and sows fed different diets* (n = 5)

	Growing pigs									Dry sows				
Diet no.	1	2	3	4	5	6	7	8		9	10	11	12	
Fibre fermentability (FT)	L*	L	L	L	H	H	H	H		L	L	H	H	
Fibre level (FL)	N	N	H	H	N	N	H	H		N	H	N	H	
Protein level (PL)	H	N	H	N	H	N	H	N	S.E.	N	N	N	N	S.E.
Faeces N (related to N intake)[4,5]†	0·19	0·21	0·26	0·23	0·16	0·17	0·22	0·26	0·011	0·17	0·25	0·22	0·21	0·013
Urine N (relate to N intake)[2,3,5]	0·44	0·35	0·36	0·38	0·46	0·43	0·37	0·32	0·024	1·07	0·74	0·70	0·78	0·060
Total N (related to N intake)[5]	0·63	0·57	0·63	0·61	0·62	0·61	0·59	0·58	0·024	1·24	1·00	0·93	0·99	0·059
Urine N (related to excreted N)[1,5]	0·69	0·62	0·58	0·62	0·75	0·72	0·62	0·55	0·021	0·86	0·74	0·75	0·79	0·018

* N = normal, L = low, H = high.
† Significant ($P < 0·05$) effect within growing pigs: [1]FT, [2]PL, [3]FT × FL, [4]FT × FL × PL. Significant ($P < 0·05$) effect within dry sows: [5]FT × FL.

volume in diets with a high content of less fermentable fibre was nearly twice that of the diets with a normal content. In contrast, there was only little difference between fibre contents within diets with highly fermentable fibre.

The water content of faeces from growing pigs and sows was highest from diets containing less fermentable fibre. Faecal water content increased with increased fibre content, irrespective of fibre type.

Faecal nitrogen from growing pigs and sows was influenced by fibre type and fibre content interactions. Nitrogen in faeces from slaughter pigs was further affected by the interaction of fibre type and protein content. The highest N concentration was found in faeces from diets containing high contents of highly fermentable fibre. Faeces from diets with high contents of fibre with low fermentability contained less N than diets with normal fibre contents. Similarly, within diets with less fermentable fibre, faecal N increased with increased dietary protein content, whereas protein content in diets with highly fermentable fibre did not influence faecal N.

Faecal pH was lowest in diets with a high content of highly fermentable fibre (Table 3). The highest pH was found in faeces from diets with high contents of low fermentable fibre.

Before storage and after the addition of extra water, the dry matter content of the pig slurries was 34–80 g/kg (freeze-dried, Table 3). The dry matter content was highest for diets with a high fibre content, as expected. After storage the dry matter content was reduced to 22–74 g/kg.

There was no detectable loss of weight and total N during storage (data not shown). After storage, 0·63–0·87 of slurry N was in the form of ammonium-N and ammonium-N was equal to or higher than the proportion of urinary N in the slurry (Table 3). The proportion of carbon lost during storage was 0·11–0·38 as calculated from total C in slurry before and after storage. After storage 0·06–0·16 of the total C was in the form of water-soluble organic C.

pH was 7·5–7·9 in slurry from growing pigs and tended to be lowest for the diets with the highest fibre content (Table 3). The average pH in slurry from sows was 8·1 and significantly higher ($P < 0·001$) than in the slurry from growing pigs.

Nitrogen excretion

Nitrogen excretion in faeces varied from 0·16 to 0·26 of N intake (Table 4). Faeces N excretion was significantly higher for the diets with a high fibre content. However, this relationship was not straightforward, as the excretion of N was jointly influenced by fibre type, fibre content and protein content. Faecal excretion of N within diets with fibre of low fermentability was highest in diets containing high contents of fibre and protein, whereas within diets with fibre of high fermentability, the highest excretion was found in diets containing a high fibre content but a normal content of protein. The excretion of urine N from growing pigs varied from 0·32 to 0·46 of N intake and 0·55 to 0·74 of total excreted N was urine N. Urine N was lowest for diets with a high fibre content, specially accentuated in diets with fibre of high fermentability. The apparent utilization of dietary N in growing pigs defined as (feed N − faeces N − urine N)/feed N was 0·37–0·44. The proportion of urine N in slurry from growing pigs could be predicted from the chemical analysis of the diet, with the highest correlation found between urine N and DDMI ($R^2 = 0·72$, data not shown).

The urine N excretion from dry sows amounted to 0·75–1·07 of N intake, and was higher than that from growing pigs. The sows were fed at maintenance level and for three of the diets, the N excretion was in balance with the N intake, whereas for diet no. 9 N excretion exceeded the intake.

Table 5. *Linear correlations between the mineral fertilizer equivalent of slurry N (MFE), the net release of mineral N from slurry after 12 weeks incubation in soil (in relation to slurry N), the net mineralization of slurry C after 12 weeks incubation in soil (in relation to slurry C) and chemical composition of the eight diets fed to growing pigs*

	1	2	3	4	5	6	7	8
1. MFE (% of total N)	1	0·81*	0·34	0·53	−0·70	−0·73*	0·98***	−0·38
2. Mineral N in soil, 12 w (mineral N/total slurry N)		1	−0·18	0·46	−0·80*	−0·41	0·78*	−0·66
3. Slurry C mineralization, 12 w (CO_2-C/total slurry C)			1	0·20	0·45	−0·40	0·15	0·77*
4. Crude protein (g/kg DM)				1	−0·15	−0·17	0·46	−0·05
5. Crude fibre (g/kg DM)					1	0·54	−0·77*	0·89**
6. Lignin (g/kg DM)						1	−0·80*	0·15
7. EDOM (g/kg DM)							1	−0·44
8. Fibre (sol. + insol.) (g/kg DM)								1

Significant correlations are indicated by * $P<0·05$, ** $P<0·01$, *** $P<0·001$.

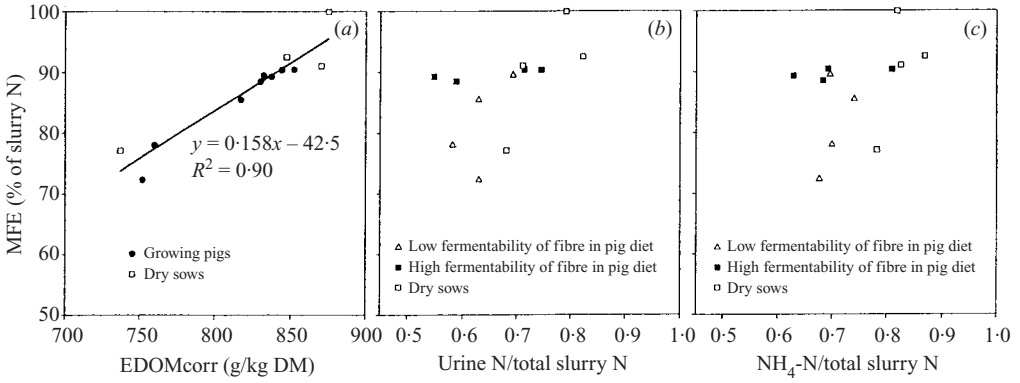

Fig. 1. Mineral fertilizer equivalent (MFE) of pig slurry N applied to spring barley in relation to (*a*) enzyme digestible organic matter in feed corrected for growing pigs according to Boisen & Fernández (1997) (EDOMcorr), (*b*) urine N in slurry and (*c*) ammonium-N in stored slurry.

Fertilizer value of slurry N

The mineral fertilizer equivalent (MFE) of stored slurry N was measured in small plots under conditions of minimal ammonia volatilization (simulated direct injection). The digestion and utilization of nitrogen differs in growing pigs and sows. Different relations between diet and slurry composition can therefore be expected, and only slurry from growing pigs was included in the analysis of relationships between diet composition and the MFE of slurry (Table 5). There was a highly significant correlation ($r=0·98$, $P<0·001$) between EDOM in the diet and MFE (Fig. 1*a*).

MFE was also related to the measured composition of slurry from growing pigs and sows (Table 6). There was an insignificant relationship between MFE and the ammonium content of slurry (Fig. 1*c*), but a highly significant, positive correlation between the N concentration in slurry dry matter and MFE (Table 6) and a negative correlation between C/N ratio in slurry and MFE (Fig. 2).

The MFE of slurry N correlated significantly with the net release of mineral N from slurry after 12 weeks of incubation in soil in the laboratory (Table 6). However, the MFE was generally higher than the net release of slurry N after incubation (Fig. 2).

Urine N consists mainly of urea and other easily decomposable N compounds and the proportion of urine N in slurry was expected to be important for the MFE of the slurry. However, MFE was not well predicted from the proportion of urine N in slurry alone (Fig. 1*b*), but when it was combined with the measured composition of faeces in a two-factor model, a good prediction of MFE was obtained (Table 7). When the faeces content of crude fibre or insoluble fibre was used, 92% of the variation in MFE could be explained. Both these factors were negatively related to MFE. Inclusion of the concentration of NFE or N concentration in faeces DM in

Table 6. *Linear correlations between the mineral fertilizer equivalent of slurry N (MFE), the net release of mineral N from slurry after 12 weeks incubation in soil (in relation to slurry N), the net mineralization of slurry C after 12 weeks incubation in soil (in relation to slurry C) and chemical composition of the 12 slurries from growing pigs and sows*

	1	2	3	4	5	6	7	8
1. MFE (% of total N)	1	0·86***	0·54*	0·67*	0·40	0·85***	−0·93***	0·13
2. Mineral N in soil, 12 w (mineral N/total slurry N)		1	0·20	0·83***	0·60*	0·83***	−0·85***	−0·16
3. Slurry C mineralization, 12 w (CO_2-C/total slurry C)			1	0·02	0·14	0·46	−0·47	0·29
4. Urine N/total N				1	0·85***	0·73**	−0·65*	−0·13
5. NH_4-N/total N					1	0·61*	−0·51	0·12
6. Total N in DM						1	−0·97***	0·12
7. C/N ratio							1	−0·02
8. Soluble organic C/total C								1

Significant correlations are indicated by * $P<0·05$, ** $P<0·01$, *** $P<0·001$.

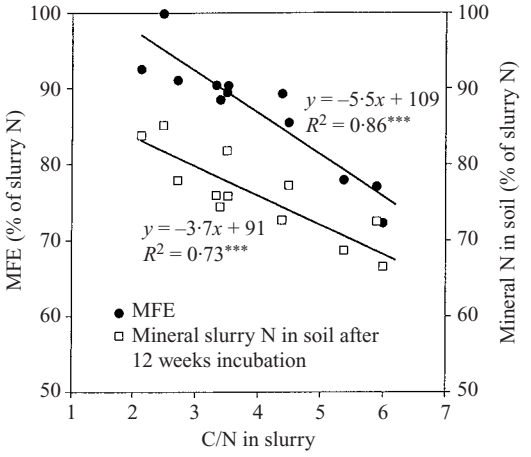

Fig. 2. Relationship between C/N ratio in slurry and mineral fertilizer equivalent (MFE) of pig slurry N applied to spring barley and net release of slurry mineral N after 12 weeks incubation in soil at 8 °C.

the two-component model also improved the prediction of MFE. Slurry from growing pigs and sows was included in this analysis.

Turnover of N and C in soil in relation to diet and slurry composition

All the pig slurries caused net immobilization of N equivalent to 5–20 % of slurry ammonium-N within the first week (Fig. 3). The initial N immobilization was lowest for slurry no. 1. For some unknown reason the ammonium content of slurry no. 1 was lower than slurry no. 2, even though slurry no. 1 contained a higher proportion of urine N. After the first week there was a net release of mineral N in the soils amended with slurry from growing pigs, whereas mineral N remained nearly constant in soil with slurry from sows (except diet no. 12).

The net release of mineral N and C in slurry from growing pigs after 12 weeks in soil was also related to diet composition by linear regression analysis. There was a significant negative relationship between the net release of mineral N and crude fibre in the diet (Table 5) and a significant positive correlation between EDOM in the diet and the net release of mineral N after 12 weeks.

The net release of slurry N from growing pigs and sows after 12 weeks in soil could also be well predicted from the concentration of N in dry matter (Table 7) or the C/N ratio measured in the slurry (Fig. 2).

The net mineralization of slurry C in soil varied significantly and 25–46 % of the slurry C was released as CO_2 after 12 weeks (Fig. 4). However, the net mineralization of slurry C was significantly correlated with only soluble + insoluble fibre in the diet (Table 5), and neither was there a high correlation between the net mineralization of slurry C and the measured composition of the slurry (Table 6).

DISCUSSION

Diet and slurry composition

The 12 test diets were formulated to satisfy the nutritional requirements of the pigs in accordance with present official recommendations in Denmark. A further requisite was that the diets should resemble diets used in practice as much as possible. Both requisites were achieved. But in doing so, the differences between dietary treatments were not as experimentally stringent as could be wished. Fermentability differences were achieved by choice of fibre source and not by a specific chemical analysis and in addition, some of the ingredients were included in

Table 7. *Prediction of mineral fertilizer equivalent of pig slurry N (MFE, % of total N) from the proportion of urine N in the slurry (urine N/total N) and the faeces composition of 12 different slurries. Best fitting linear models with a significant effect of faeces composition are shown*

Faeces parameter	Model	R^2	P
Crude fibre (g/kg DM)	MFE = 89·0 + 33·4 urine N − 0·108x	0·92	<0·0001
Insoluble fibre (g/kg DM)	MFE = 85·0 + 45·5 urine N − 0·0577x	0·92	<0·0001
NFE (g/kg DM)	MFE = 98·0 + 54·5 urine N − 0·145x	0·80	<0·0007
N in DM (g/kg DM)	MFE = 14·0 + 71·8 urine N + 0·793x	0·80	<0·0008
0 (Urine alone)	MFE = 49·9 + 55 urine N	0·45	<0·018

all diets, although at different contents (wheat, barley and soya bean meal). That is probably the main reason why most of the responses found were the product of the interaction of two or three dietary factors. Thus, it can be difficult to get a clear interpretation of the differences found between dietary treatments. However, as these results are most probably a real (although wider) reflection of practical conditions, then the quantitative diet/slurry relations presented can be a useful guide.

The current study also shows the current lack of chemical analyses that are capable of qualitative characterization of diets. Fibre type characterization was not completely achieved by any of the analyses performed. The best description was given by soluble fibre analysis and the *in vitro* analysis ('fermentability', Table 2).

Utilization of pig slurry N in relation to diet and slurry composition

The mineral fertilizer equivalent (MFE) of slurry N from growing pigs could be well predicted from the enzyme digestible organic matter (EDOM) of the feed. EDOM is a measure used for evaluation of the feed nutritional value, and Boisen & Fernández (1997) showed that EDOM, after making a correction, gives an estimate of the *in vivo* digestibility of energy in the diet. When this correction was used on the diets for growing pigs (it was not applied on sows who have a more efficient digestion), a high correlation was found between EDOM and MFE for both growing pigs and sows (Fig. 1*a*). EDOM is used as a routine analysis of feedstuffs in Denmark and is normally available to the farmer.

The proportion of urine N and ammonium-N in pig slurry was reduced by increasing the concentration of fermentable fibres (fermentable non-starch carbohydrates) in the diet as found in other studies (Kreuzer *et al.* 1998; Canh *et al.* 1998*b*, 1999; Gerdemann *et al.* 1999). In accordance with Gerdemann *et al.* (1999), the proportion of urine N and ammonium-N in pig slurry was reduced without affecting the MFE of the slurry (Fig. 1*b*).

Previous studies have shown decreased excretion of urinary N with decreased protein content, but with a sufficient content of essential amino acids in the diet (Canh *et al.* 1998*a*; Misselbrook *et al.* 1998). However, in the present study there was no unambiguous effect of protein content on urinary N when comparing the paired treatments with high and normal protein content (Table 3). This could be due to other differences in diet composition between the paired treatments influencing the proportion of urinary N.

The utilization of N in pig diets has improved during recent years, due to the more efficient use of protein by the incorporation of synthetic amino acids in the diets. It has been discussed whether this would result in a lower utilization of manure N, as a lower proportion of N is excreted in urine and more in faeces. Our results show that for diets with a high proportion of highly fermentable fibre, the protein content and proportion of urine N has a negligible influence on the potential utilization of slurry N, whereas for diets with a high proportion of straw (less fermentable fibre), the utilization of slurry N is lower.

The potential utilization of slurry N was not well predicted from the proportion of ammonium-N in slurry (Fig. 1*b*), indicating that the mineralization of slurry organic N varied with slurry composition. However, the MFE of slurry N could be predicted from the C/N ratio (Fig. 2). The DM/N ratio is easier to measure than the C/N ratio, and there was also a significant correlation between the DM/N ratio and MFE. N and C losses during storage influence the C/N ratio in slurry. In the present study there were no detectable N losses during storage, whereas under practical conditions ammonia losses are inevitable and influenced by the manure ammonium concentration (Canh *et al.* 1998*a*; Paul *et al.* 1998) and the slurry physical conditions (temperature, dry matter content, etc.). All the slurries were stored under similar conditions, and applied to the same soil using one application method. Further studies are required to measure whether the clear relation between the slurry C/N ratio and the N availability is also valid under more variable storage, soil and application conditions.

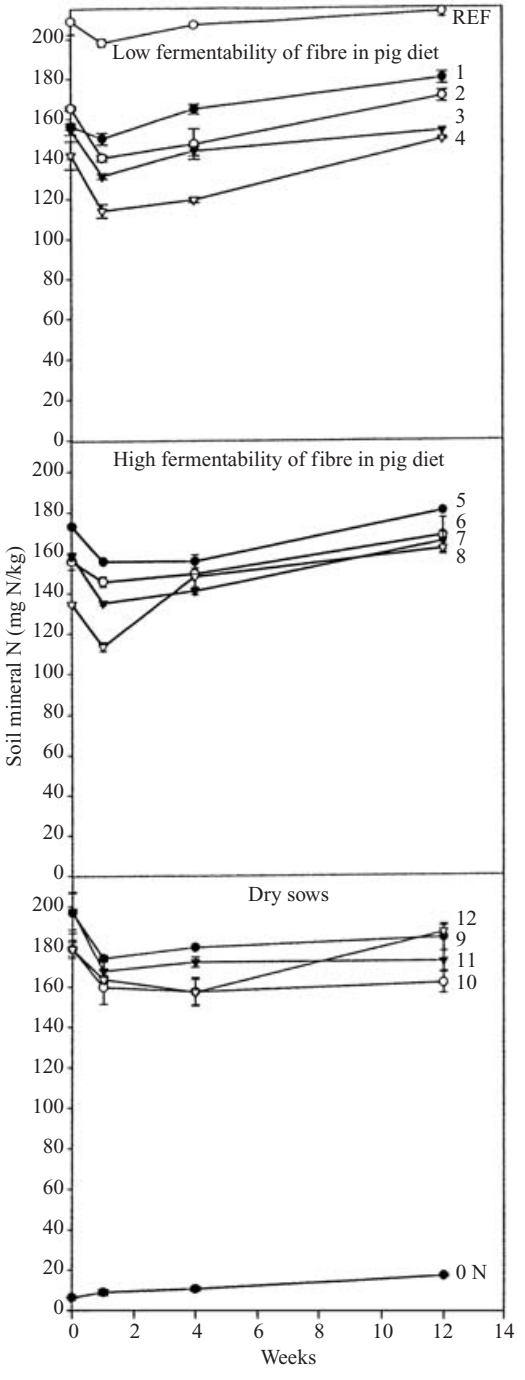

Fig. 3. Soil inorganic N during 12 weeks after application of pig slurries from pigs fed different diets (200 mg total N/kg). The numbers refer to diet numbers in Table 1. A reference treatment with 0 N (0 N) or 200 mg N/kg in ammonium sulphate (REF) was also included. Bars indicate S.E. ($n = 3$).

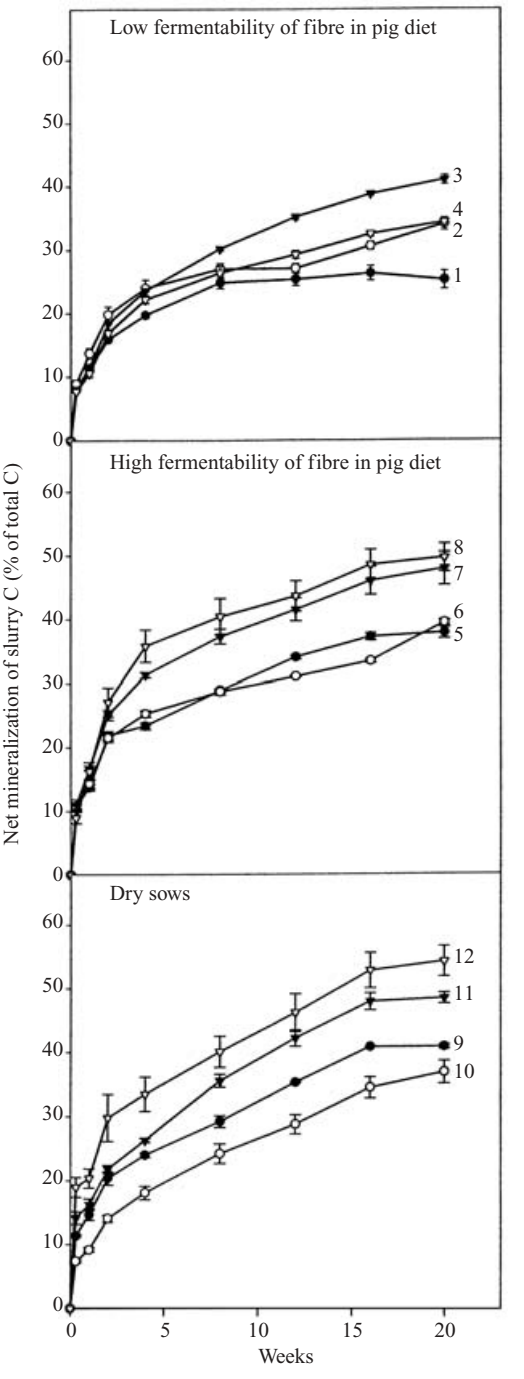

Fig. 4. Net mineralization of pig slurry C in soil during 20 weeks of incubation, calculated as CO_2 evolution from soil applied with slurry minus CO_2 evolution from soil without slurry. The numbers refer to diet numbers in Table 1. Bars indicate S.E. ($n = 3$).

Table 8. *Influence of pig diet on the overall utilization of feed N in pigs and the estimated potential utilization of pig slurry N in the first crop. The calculations were based on the experimental data, but corrected assuming N emission from houses and storage equivalent to 25 % of the measured ammonium content of the stored slurry. Diet numbers refer to Table 1*

	Growing pigs								Dry sows			
Diet no.	1	2	3	4	5	6	7	8	9	10	11	12
Diet N retention in pigs (related to feed N)	0·37	0·44	0·38	0·39	0·38	0·40	0·41	0·42	−0·24	0·00	0·02	0·02
N in faeces + urine = slurry (related to feed N)	0·63	0·56	0·62	0·61	0·62	0·60	0·59	0·58	1·24	1·00	0·98	0·98
Gaseous N loss, estimated (related to slurry N)	0·17	0·19	0·18	0·17	0·20	0·17	0·17	0·16	0·22	0·20	0·21	0·20
Gaseous N loss, estimated (related to feed N)	0·110	0·104	0·109	0·103	0·125	0·104	0·101	0·091	–	0·20	0·20	0·20
N in crop (MFE, related to slurry N)	0·90	0·86	0·78	0·72	0·90	0·90	0·89	0·89	0·93	0·77	0·91	1·00
N in crop, corrected for N loss (related to slurry N)*	0·87	0·82	0·73	0·67	0·88	0·88	0·86	0·87	0·90	0·72	0·89	1·00
N in crop, corrected for N loss (related to feed N)*	0·45	0·38	0·38	0·34	0·44	0·44	0·42	0·43	–	0·58	0·69	0·78
Residual N in soil (related to slurry N)*	0·13	0·18	0·27	0·33	0·12	0·12	0·14	0·13	0·10	0·29	0·11	0·00
Residual N in soil (related to feed N)*	0·07	0·08	0·14	0·17	0·06	0·06	0·07	0·06	–	0·23	0·09	0·00
N retention in pigs + N in first crop (related to feed N)*	0·82	0·82	0·76	0·73	0·82	0·84	0·83	0·85	–	0·58	0·71	0·80

* Corrected for gaseous N emission from slurry in animal house and during storage. The lost N was assumed to have the same plant availability as mineral fertilizer N.

Residual manure N in soil

The slurries were applied by simulated direct injection and were immediately covered with soil. In a parallel experiment in the same field with ^{15}N-labelled slurry (labelled NH_4-N) and labelled mineral N fertilizer we found low and similar losses of labelled N from the slurry and the mineral fertilizer, indicating that ammonia losses from slurry were negligible (data not shown). This implies that the slurry N not taken up in the crop remained in the soil after barley harvest. If we assume negligible losses of manure N from the soil, then the residual slurry N left in the soil after the barley crop, compared with the mineral fertilizer treatment, was equivalent to <10–28 % of total pig slurry N. Jensen *et al.* (1999) and Sørensen & Amato (2002) showed that the residual manure N present in soil after the first crop is released slowly and most of it remains in the soil for many years under temperate conditions. On livestock farms, animal manure is applied regularly and significant amounts of residual manure N accumulate in the soil. A relatively high proportion of the residual manure N may be lost to the environment by leaching because it is released in periods without plant growth (Thomsen *et al.* 1997). Thus, N leaching losses may be increased when more residual manure N is left in soil. On the other hand, residual organic N (and organic matter) may also have beneficial effects on soil quality, such as improved soil structure and higher microbial activity. A recent investigation indicates that soil organic matter tends to decline in Danish agricultural soils on farms without livestock and also on farms with pig production (Heidmann *et al.* 2001). The present study indicates that the pig diet composition has significant influence on the accumulation of residual organic manure N in soil.

The MFE of slurry N measured in the field was generally higher than the net release of mineral N after 12 weeks in soil in the laboratory (Fig. 2), indicating that the net mineralization of slurry N was higher in the field. The difference was highest for the slurries with the lowest C/N ratio (Fig. 2). The crop N uptake was presumed to take place for about 12 weeks after manure application. In the incubation study, soil temperature was a constant 8 °C whereas in the field the mean soil temperature was higher and fluctuating, which may have resulted in a higher mineralization rate of manure N in the field. A second reason for the difference could be that the slurry was mixed with soil in the laboratory study, while in the field the slurry was concentrated in a band in the soil, which may result in less N immobilization than when the slurry is mixed with soil (Sørensen & Jensen 1995; Sørensen & Amato 2002).

Dietary effects on the overall fate of N at farm level

There were no significant gaseous losses of N from the slurry between the time of excretion from the animal

until application in the field in the present study. Under practical conditions ammonia will be lost in animal houses and from storage tanks. Poulsen *et al.* (2001) estimated average gaseous N losses under Danish conditions to be equivalent to 16% of total N excretion in houses and another 2% to be lost during storage with a straw cover on the slurry surface. In Table 8 the expected effects of ammonia emission on the utilization of manure N derived from different diets are estimated. Ammonia emission from slurry is influenced by a number of factors like ammonium content, pH, dry matter, temperature, etc. Slurry pH was only little influenced by the diet in the present study, and we assumed the N emission to be equivalent to 25% of the measured ammonium content after storage. Based on this assumption the loss of gaseous N would be equivalent to 16–22% of the N excretion (Table 8). The diet with the highest content of fermentable fibre (diet 8) had 10–15% lower estimated N emission compared with the more conventional diets.

It was assumed that ammonia N would have the same plant availability as mineral fertilizer N. Ammonia emission from slurry results in a higher proportion of organic N in the manure and a lower N availability. However, the calculated MFE of slurry total N is only slightly reduced when ammonia emission during storage is accounted for (Table 8).

Under conditions with minimal losses of manure N after field application, as in this study, the diet composition has little influence on the overall utilization of the feed N (N retention in growing pigs plus field crops receiving the manure N), except when the diet has a high content of less fermentable fibre. In that case, more residual manure N is left in soil and more manure N may be lost by leaching in the long term.

CONCLUSIONS

Increased dietary concentration of fermentable structural carbohydrates reduces the excretion of N in urine without affecting the plant availability of slurry total N, whereas increased concentration of dietary fibre with a low fermentability results in less urinary N, but also a lower plant availability of slurry N. No effect of protein content on the availability of slurry N was found. The plant availability of pig slurry N could be predicted from the dietary content of enzyme digestible organic matter (EDOM) and also from the C/N ratio in the stored slurry. The proportion of urinary N in slurry gave a poor prediction of the plant availability of slurry N, but when combined with the fibre content of faeces a good prediction was possible. The overall utilization of feed N (retention in pigs plus potential plant utilization of slurry N) was similar for most of the diets, but it was lower for the diets with a high content of low-fermentable fibre.

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