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The fate of nitrogen in outdoor pig production

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Abstract – There may be a conflict between animal welfare and nitrogen pollution in outdoor pig production. In response to concern about nitrogen being lost to the atmosphere and ground water we quantified spatial variation and temporal dynamics of mineral N, ammonia volatilization, denitrification and nitrate leaching from outdoor pig production at three commercial farms in Denmark. From paddocks containing farrowing sows substantial nitrogen losses were observed, particularly around the feeding areas. Gross ammonia emission rates varied between 0.08 and 1.26 kg N·ha⁻¹·d⁻¹ and increased with animal density and N intake. The mean annual loss of ammonia per sow was 4.8 kg N. Denitrification rates averaged 0.52 kg N·ha⁻¹·d⁻¹ in autumn following summer grazing with lactating sows, and 0.10 kg N·ha⁻¹·d⁻¹ in the following spring. Denitrification losses up to 69 to 114 kg N·ha⁻¹ were estimated. Cumulated nitrate leaching during sow grazing and in the following year was 126–276 kg N·ha⁻¹. Of the N input in feed to the paddock 44% could be accounted for in piglets, 13% as ammonia volatilization, 8% as denitrification and 16 to 35% as nitrate leaching. The necessary development towards increasing N-use efficiency in outdoor pig production may include changes in management, such as lowering the stock density and reducing the level of dietary N. Also, a more uniform distribution of nutrients in the field may be achieved by manipulating the excretory behavior of the animals.

nitrogen / outdoor pigs / nitrate leaching / ammonia volatilization / denitrification

Résumé – Le devenir de l'azote dans la production de porcs en plein air. Il peut exister un conflit d'intérêt entre le bien être animal et la pollution par l'azote pour la production de porcs en plein air. En réponse aux préoccupations sur les pertes d'azote dans l'atmosphère et les eaux souterraines, nous avons quantifié la variation spatiale, et la dynamique temporelle de l'azote minéral, de la volatilisation d'ammoniac, de la dénitrification et du lessivage du nitrate dans des élevages de porcs en plein air pour 3 exploitations agricoles au Danemark. Dans les enclos contenant des truies en gestation, des pertes substantielles d'azote ont été observées, particulièrement autour des aires d'alimentation. Les émissions brutes d'ammoniac ont varié entre 0,08 et 1,26 kg N·ha⁻¹·j⁻¹ et ont augmenté avec la densité des animaux et les entrées d'azote. Les vitesses de dénitrification étaient en moyenne de 0,52 kg N·ha⁻¹·j⁻¹ à l'automne suivant un été en présence de truies allaitantes, et 0,10 kg N·ha⁻¹·j⁻¹ au printemps suivant. Le lessivage cumulé du nitrate pendant le séjour des truies et l'année suivante a été de 126–276 kg N·ha⁻¹. Un total de 81 à 100 % de l'azote apporté par les aliments dans l'enclos est assimilé par les porcelets (44 %), volatilisé sous forme d'ammoniac (13 %), dénitrifié (8 %) ou lessivé sous forme de nitrate (16 à 35 %). Le développement nécessaire en vue d'accroître l'efficacité de l'utilisation de l'azote pour la production de porcs en plein air pourrait inclure des changements de gestion de la production, comme par exemple la diminution de la densité des animaux et la réduction du niveau de l'alimentation azotée. Aussi, une meilleure répartition des éléments nutritifs dans l'enclos pourrait être réalisée en gérant le comportement des animaux par rapport à leurs rejets.

azote / porc en plein air / lessivage du nitrate / volatilisation d'ammoniac / dénitrification

1. INTRODUCTION

Outdoor pig production has benefits in terms of animal welfare and low costs of buildings and equipment [2]. However, the high throughput of nutrients means that there is a danger of environmental pollution [22]. This is especially true for nitrogen deposited during grazing which has a low

N-use efficiency [21, 23]. Nitrogen in livestock excreta is a source of atmospheric nitrous oxide and ammonia, and also causes nitrate leaching in the soil. These losses contribute to global warming, acid rain, and the eutrophication of natural environments [13, 15, 20].

Nutrient budgets on the field scale may indicate the potential for N losses but do not reveal how losses occur or the

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distribution between loss pathways. As each has a different impact on the environment, the losses need different control measures and consequently need to be individually determined. Fragmentary information about N losses provides the basis for improved utilization within particular components of the pig production system, but for overall sustainability it is essential to consider all loss pathways concomitantly because changes introduced to remedy one loss process may exacerbate other problems.

In this work we have integrated experimental results from separate parts of a large study into an overall description of N turnover in outdoor pig production. The objective was to quantify simultaneously the different N losses (nitrate leaching, ammonia volatilization and denitrification) and the total N budget of this production system in order to suggest management changes that may steer outdoor pig production towards better N-use efficiency and improved sustainability.

2. MATERIALS AND METHODS

2.1. Field experiment

We examined the spatial variation and temporal dynamics of mineral N (N_{\min}), ammonia volatilization, denitrification and nitrate leaching from outdoor piglet production at three commercial farms in western Denmark, all located on sandy soils and with similar climatic conditions (Tab. I). The core experiment described the distribution of N_{\min} in a 5×5 m grid ($n = 312$) within and outside two adjacent paddocks (Paddocks 1 and 2) on three occasions: in March 1997, shortly before the introduction of 32 sows·ha⁻¹; in October 1997, when the paddocks were abandoned; and in March 1998 [5]. Denitrification rates were determined at all grid points of Paddock 1 in October 1997 and in March 1998 [12]. Ammonia volatilization from these and other paddocks at the same farm was determined using an atmospheric mass balance technique [19]. Additional information about spatial and temporal variability of N loss processes was obtained in separate studies: ammonia volatilization, denitrification losses and nitrate leaching, and associated soil conditions were studied along transects across paddocks. For logistic reasons these process-oriented studies had to be conducted in other paddocks at the same farm or in comparable piglet production systems.

Table I. Time schedule for the experimental activities on three commercial farms.

	1997	1998	1999	2000
Farm 1				
N_{\min} (grid plots)	x	x x		
Amm. volatilization (wind tunnel)			x x x	x x x
— (mass balance)		x	x x x	x x x
Denitrification (grid plots)		x x		
Farm 2				
Denitrification (transect)			x x x x x x	
Farm 3				
Nitrate leaching			xxx	xxxxxxx xxxx

2.2. Analytical methods

2.2.1. Nitrogen balance

The generalized N balance was calculated as N input in feed minus the outputs: N in piglets, ammonia, denitrification and nitrate leaching losses. Ideally, all components of the N balance would be determined simultaneously. As this was not possible, farms with similar soil type, management, feeding of lactating sows and climatic conditions were chosen. It was assumed that the findings were due to the general nature of the processes rather than differences in location or year of measurement.

Nitrogen input in feed was estimated from the feed consumption of lactating sows in the individual paddocks, which was 9.2 kg N per sow per lactation. The calculation of N output in piglets was based on assumptions of ten piglets per farrow, a weaning weight of 15 kg, and 27 g N·kg⁻¹ per piglet [16].

2.2.2. N_{\min} in grid plots

Soil samples were taken in a circle around each point in a radius of 20 cm. At the start of the experiment in March 1997 four bulked soil samples were taken at each point at 0–20 and 20–40 cm depth. Because increased variability was expected, at the following two sampling dates, eight bulked samples were taken at each point and depth. Soil samples were stored at 2 °C until further processing within 48 h. The content of ammonium and nitrate were determined spectrophotometrically on all the bulked samples after extraction with 1M KCl (1:2 w/v).

2.2.3. Ammonia emission

Gross emission rates were measured with an atmospheric mass balance technique [14], which included one mast upwind from the paddocks to measure background concentrations of ammonia, and duplicate masts downwind to measure the enrichment due to ammonia fluxes from the pasture during six 14-day periods. The wind path between upwind and downwind masts always included the feeding area. During each experimental period, the flux was measured for 48, 48, 72, 48, 48 and 72 h. Spatial variations in ammonia volatilization were measured using a wind tunnel [7] made from rectangular steel ducts (300 × 400 mm) covering 0.4 m². The wind speed in the chamber was adjusted to the actual wind speed at 10 cm height. Ammonia emission was measured sequentially along a transect at 2, 4, 6, 12, 18, 24, 30 and 40 m distance from the feeder. Each measurement lasted 10 min and all measurements were carried out within 3 h.

2.2.4. Denitrification

Denitrification rates from intact, uncompacted soil cores (i.d. 44 mm, length ca. 180 mm) were determined using the acetylene blockage method [24] and gas chromatographic analysis of nitrous oxide. Measurements were done in a 5×5 m grid pattern (Paddock 1) on two occasions ($n = 145$), or at 5 m spacing ($n = 10$) along a transect across a similar paddock on 11 occasions covering a period of 336 days

(seasonal study). The spatial distribution of denitrification activity was analyzed with a statistical model, $Y_i = \mu_i + E_i$ where Y_i = denitrification rate at point i , $\mu_i = \exp(\sum \beta_j X_{ij})$ = model output for denitrification at point i , β_j = coefficient for the variable j , X_{ij} = value of variable j at point i , and E_i = random effect; variables included soil moisture, ammonium, nitrate, dissolved organic C (DOC) and the distance to feeders and shelters [12].

2.2.5. Nitrate leaching

Nitrate leaching was determined in four individual sow paddocks using a total of 72 ceramic suction cups installed at 1 m depth [4]. In each paddock, four groups of suction cups were installed. These were placed 10, 16, 22 and 28 m from the feeding end of the paddocks. Nitrate concentrations were determined in soil water leaching from the root zone about every 2 weeks. When no drainage occurred, sampling was omitted. The water balance was calculated using the Evacrop model [11] for which inputs were daily meteorological measurements (precipitation, temperature and evaporation), the crop type, time of sowing and soil physical parameters. Nitrate leaching in each period was estimated using the trapezoidal rule [9], assuming that nitrate concentrations in the extracted soil water represented average flux concentrations.

Nitrate leaching caused by sows and piglets was estimated from the difference between leaching within the paddocks and the 'background' leaching outside the paddocks.

3. RESULTS AND DISCUSSION

3.1 N_{\min} in grid plots

In April 1997, before sows were introduced into Paddock 1 and 2, soil N_{\min} at 0–40 cm depth averaged 16 kg $N \cdot ha^{-1}$. After 6 months with lactating sows in the paddocks, this level had increased to 179 kg $N \cdot ha^{-1}$ (Fig. 1a), during which time the feed N input exceeded the output in piglets by 490 kg $N \cdot ha^{-1}$. Thus, more than 300 kg $N \cdot ha^{-1}$ was retained in the soil in organic forms or lost to the environment during the summer grazing period. The high levels close to feeding sites were probably caused by the lactating sows receiving large quantities of feed which reduced their forage behavior and led to increased excreta deposition here.

By the following spring only 16% of the N_{\min} observed in October 1997, or 29 kg $N \cdot ha^{-1}$, was recovered (Fig. 1b). Environmental losses probably accounted for most of the net decrease of 150 kg $N_{\min} \cdot ha^{-1}$ during the winter period.

3.2 Ammonia emission

Gross ammonia emission rates varied between 0.08 and 1.26 kg $N \cdot ha^{-1} \cdot d^{-1}$ (Fig. 2) and increased with animal density (gray bars in Fig. 2), as well as with N intake as a result of decreasing N-use efficiency [19]. Ammonia emissions depended primarily on feed input [19] and were further

enhanced by increasing wind speed, air temperature and solar irradiation, which influence either the transport of ammonia across the soil-air interface [18] or the emission potential in the soil phase [8]. High temperatures preceding a measurement period caused ammonium depletion in the soil and thus reduced the ammonia emission actually measured. Therefore, annual rates of ammonia emission were estimated using time-series theory [1], calculating the step response effect of

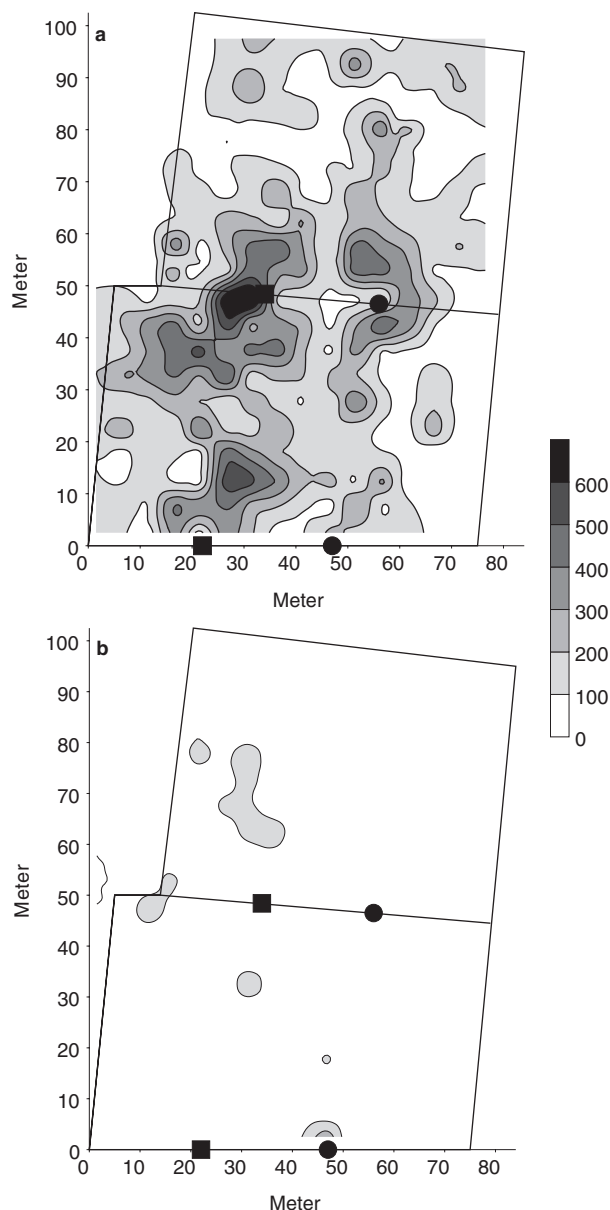


Figure 1. Distribution of mineral N ($kg \cdot ha^{-1}$) at 0–40 cm depth in two paddocks grazed from April to October 1997 by 32 sows ha^{-1} . (a) Soon after the sows were removed (October 1997); (b) the following spring (March 1998). Position of feeders: April–July 1997 (●) and August–October 1997 (■). The contour diagrams were created by linear interpolation between the 5×5 m grid-based empirical measurements.

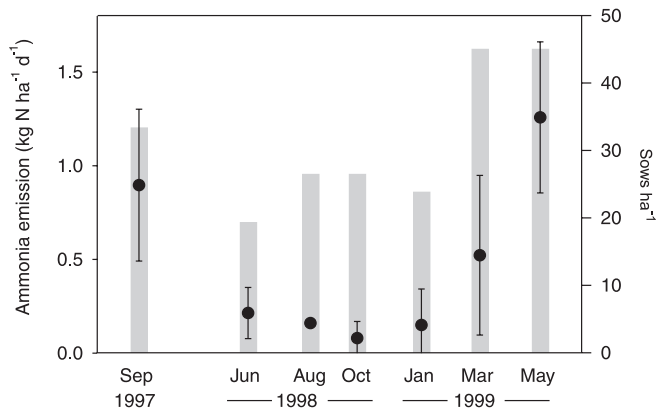


Figure 2. Ammonia emission from paddocks grazed by sows with piglets. The emission rates represent the mean \pm SE of 12 measurements obtained during a period of 14 days. The losses were measured using a micrometeorological mass balance technique. Grey bars indicate the number of sows per hectare during measurements.

each variable. The full model was significant at $P < 0.001$ (d.f. = 10, $R^2 = 0.81$) [19]. The mean annual loss of ammonia per sow, including piglets, was 4.8 kg N (i.e. similar to the loss from indoor piglet production [6]). Changing from housing systems to outdoor paddocks therefore does not contribute to reduced ammonia losses from livestock production, currently the most significant source of atmospheric ammonia in Europe [3].

3.3 Denitrification

Denitrification rates inside Paddock 1 averaged 0.52 kg N·ha⁻¹·d⁻¹ in October 1997 and 0.10 kg N·ha⁻¹·d⁻¹ in March 1998 [12]. Figure 3 shows the temporal dynamics of

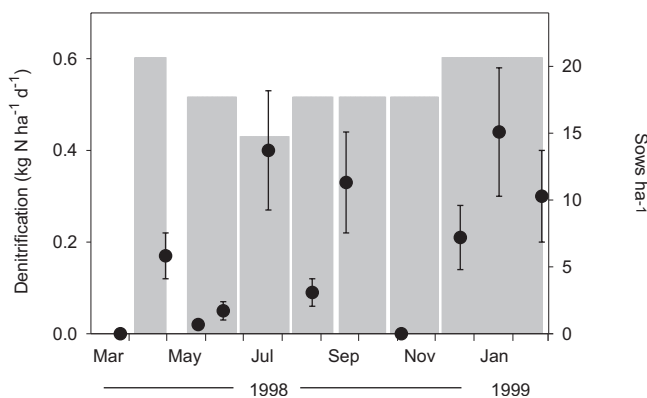


Figure 3. Denitrification rates (circles) were determined for intact soil cores taken at 5 m spacing ($n = 10$) along a transect across a paddock with 12 farrowing-sows ha⁻¹·yr⁻¹. The results shown are mean \pm SE for the ten cores on 11 sampling days between March 1998 and February 1999. Grey bars in the plot indicate when and how many sows were in the paddock.

denitrification activity in the seasonal study and further indicates when and how many sows were in the paddock. The average daily loss for the 336-day period studied was 0.19 kg N·ha⁻¹, corresponding to 12.0 g N·sow⁻¹·d⁻¹.

3.4 Nitrate leaching

In a study with single-sow paddocks, nitrate leaching averaged 126–276 kg N·ha⁻¹ in four paddocks during the grazing period and the following year [4]. Most of this nitrate was derived from organic N that was mineralized after the paddocks had been abandoned. In contrast to low nitrate leaching in the year of grazing (25–30 kg N·ha⁻¹), losses were considerable in the following autumn and winter. Throughout the measuring period of 18 months, nitrate leaching inside paddocks was on average 320 kg N·ha⁻¹ with the major part near the feeding area. Ten meters from the feeding area, leaching losses were 500 kg N·ha⁻¹ and, at 16 m distance from the feeding area, about 200 kg N·ha⁻¹ was leached and outside paddocks about 100 kg N·ha⁻¹. The combination of sandy soil with high winter rainfall leads to a large proportion of the N surplus being lost by nitrate leaching near the feeding area.

3.5 Spatial variation

In agreement with observations in single-sow paddocks, the distribution and fate of N within Paddocks 1 and 2 were characterized by dramatic spatial variations as a result of the inhomogeneous deposition of excreta by the animals. Nitrogen concentrations at 0–40 cm depth were again highest close to the feeding sites, while at 30–40 m distance there were patches with N levels similar to the reference area outside the paddocks (Fig. 1a). Ammonia emission rates ranged from 0 to 28 kg NH₃-N·ha⁻¹ per day and the highest losses were recorded near the feeding area and in the vicinity of the shelters. Presumably urine patches were the main source of emissions [12]. Similarly, denitrification rates were higher around the feeding sites [12]. A statistical model indicated that distance from the feeder and concentrations of nitrate and dissolved organic C (DOC) were the main factors influencing the distribution of denitrification activity. The seasonal study suggested that DOC interacted with soil water content, i.e. there was a positive effect of DOC on denitrification activity at soil water contents below 25% (approx. field capacity).

3.6 Nitrogen balance

Production data and process studies were combined to establish a tentative mass balance for the piglet production system represented by Paddock 1 (Tab. II). The feed input was 880 kg N·ha⁻¹, while the output in piglets corresponded to 390 kg N·ha⁻¹, or 44% of the feed input. The model developed for ammonia emission and the seasonal study of denitrification indicated losses of 114 and 69 kg N·ha⁻¹, respectively, or 13 and 8% of the feed input in Paddock 1. Nitrous oxide emissions to the atmosphere, which in grazing systems with cattle or sheep have constituted 0.2–10% of the

Table II. Tentative nitrogen mass balance for the piglet production system.

	kg N·ha ⁻¹	Output (% of feed input)
Input Feed	880	
Output Piglets	390	44
Ammonia volatilization	114	13
Denitrification	69	8
Nitrate leaching	141–308	16–35
Total	714–881	81–100

N deposited [10], could not be quantified with the measurement approach used in this study. Ammonia volatilization rapidly ceases following infiltration of urine [17] and thus should be largely restricted to the grazing period. Denitrification may also have occurred episodically during the winter. However, nitrate leaching was probably the main sink for inorganic N. The leaching potentials recorded in the study with single-sow paddocks corresponded to 16–35% of the feed input, and the delayed mineralization of N that we observed implies that the loss of N from Paddock 1 may have been considerably higher than suggested by the measured net loss of 150 kg N_{min}·ha⁻¹. This interpretation is supported by the fact that N distribution within the paddock was only weakly reflected in the N uptake of a succeeding potato crop [5]. The estimates given above for piglet production, ammonia emission, denitrification and leaching potential together may account for 81–100% of the feed input of N in Paddock 1.

4. CONCLUSION

Outdoor pig production carries a high risk of nutrient loss, because excreta are deposited under a wide range of climatic conditions and are less uniformly distributed than when they are spread mechanically. Our study provides experimental evidence for the fact that a substantial amount of surplus N in these systems is lost to the environment. The low N-use efficiency and adverse effects on the environment conflict with the sustainability of outdoor pig production as it is currently practiced. The necessary development towards increasing N-use efficiency in outdoor pig production may include changes in management, such as lowering the stock density and reducing the level of dietary N. Also, a more uniform distribution of nutrients in the field may be achieved by manipulating the excretory behavior of the animals, for example by regularly shifting the positions of the shelters and feeders.

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