Outdoor pig fattening at two Swedish organic farms—Spatial and temporal load of nutrients and potential environmental impact

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Abstract

In Sweden, outdoor organic pig production is gaining interest. However, the excretory behaviour of pigs may create plant nutrient hotspots in outdoor areas, increasing the environmental impact. This study examined fluxes and balances of N, P, K, Cu and Zn at pen level, and determined the effects of the excretory behaviour of fattening pigs on nutrient load, manure distribution and N, P, K, Cu and Zn concentration in soil within pens at two farms with different outdoor systems (mobile and stationary). A pen in the mobile system had about 72 pigs ha⁻¹ and in the stationary system about 91 pigs ha⁻¹. The average pen balance in the mobile system was 270 kg N, 60 kg P, 110 kg K, 0.4 kg Cu and 1.3 kg Zn ha⁻¹ and in the stationary system 205 kg N, 57 kg P, 99 kg K, 0.4 kg Cu and 1.5 kg Zn ha⁻¹. The smaller net accumulation of nutrients in the stationary system was due to about 30% of excrement nutrients being excreted indoors. A substantial proportion of nutrients (43–95%) from one pig group was found to be concentrated in an area of arable land representing 4–24% of the total pen area. In the mobile system the major part of the defecating was deposited on the hut, feeding and drinking sub-areas. The manure mapping also revealed pig behaviour of avoiding defecation in certain zones. In the stationary system, the concentration of exchangeable P and K in soil (0–30 cm depth) in areas preferred for excretion was more than four-fold higher and the concentration of mineral-N (0–90 cm depth) was about eight-fold higher than in other areas of the pen by the end of the fattening period. Preferred areas for excretion within the pen were affected both by the present pig groups and by previous pig groups 4 years back in time. In the mobile system, the concentration of mineral-N in soil was about three-fold higher in preferred excretion areas compared with other areas. Neither of the two outdoor systems succeeded in avoiding excessive point loads of nutrients. The flexibility of the mobile outdoor system has to be further improved so that no harmful point loads of nutrients can occur. In the stationary system, a nutrient management technique for collecting the manure on the preferred excretion areas on arable land needs to be developed.

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1. Introduction

In Sweden, outdoor organic pig production is gaining interest as it has benefits in terms of animal welfare and low costs of buildings and equipment (Deering and Shepherd, 1985; Andresen, 2000). Organic farmers first developed a mobile outdoor system with pens including moveable huts, feeders and drinking equipment for the fattening pig group where the pigs had access to arable land all the year around.

Nowadays it has become more common for organic farmers to keep fattening pigs on arable land only during the grazing season. One reason is the heavy workload for farmers during cold and wet seasons (Lundqvist, 2000). Swedish regulations on organic pig production currently require pigs to have access to grazing areas during the grazing period (KRAV, 2006). In practice, this is commonly a clover/grass ley. In recent years, another outdoor system for organic fattening pig production has become more common. The fattening pigs use a barn where they have access to a box with litter, feed and water indoors. Outside the barn, the pigs have access to an outdoor pen with a concrete pad and
thereafter a clover/grass ley on arable land. In this system the arable land used is commonly in close proximity to the barn. Both these systems and various combinations of them are used by organic farmers today (Olsson et al., 1996; Svensson et al., 2005).

An excessive stocking density (15 sows ha\(^{-1}\) year\(^{-1}\)) on outdoor areas has been shown to result in a large net input of nutrients and an increased risk of nitrogen leaching (Eriksen and Kristensen, 2001). Therefore it is crucial to achieve a balance between the number of animals kept and the area available for spreading manure. The limiting animal density in Sweden is based on an average manure application of 22 kg P ha\(^{-1}\) arable land over a 5-year crop rotation and corresponds to about 31 fattening pigs ha\(^{-1}\) year\(^{-1}\) or 2.2 breeding sows ha\(^{-1}\) year\(^{-1}\). The amounts of both N and P applied per hectare are then moderate and decrease the risk of nutrient leaching (Steineck et al., 2001). Current knowledge of trace element flows in farming systems is limited, but by calculating trace element flows and balances, the risk of metal accumulation in arable soils can be assessed (Bengtsson et al., 2003; ICOBTE, 2006).

The presence of pigs on outdoor land may have negative environmental effects such as soil erosion and nitrogen losses to groundwater and to the atmosphere (Williams et al., 2000; Eriksen et al., 2002; Evans, 2004). Pig rooting behaviour damages the grass sward and increases the potential for nutrient leaching (Edwards et al., 1998). The timing of the pigs’ presence can also influence the risk of a negative environmental impact. Studies have shown that spreading animal manure in autumn can cause large concentrations of inorganic nitrogen in soil, leading to a higher risk of nitrate pollution of groundwater compared with spreading in spring (Juergens-Gschwind, 1989; Smith et al., 1994). Eriksen and Kristensen (2001) showed that in October, the excretion from about 32 sows ha\(^{-1}\) present for 6 months previously had increased the mean concentration of inorganic N in the topsoil from 5.9 to 43.6 mg/kg soil and that of exchangeable K from 83 to 164 mg exchangeable K per kg soil, compared with a reference area without sows.

A homogeneous distribution of manure is expected to be a key factor in optimising plant nutrient availability, since variable nutrient deposition increases the potential for losses and makes accurate fertiliser recommendations impossible (Eriksen and Kristensen, 2001). Even with moderate animal densities, the excretoire behaviour of pigs may create plant nutrient hotspots in outdoor areas (Zihlmann et al., 1997; Andresen, 2000). Watson et al. (1998) found a four-fold difference in soil inorganic N between areas preferred for excretion and other areas. Previous studies have shown that the highest load of nutrients can be expected close to the feeding area and the hut, and that at a distance about 30 m away amounts of nutrients in the soil can be comparable with amounts in soil unaffected by pigs (Eriksen, 2001; Eriksen and Kristensen, 2001). The spatial load of nutrients is influenced by pig excretoire behaviour, which in turn can be affected by the outdoor system. Andresen (2000) found that the pigs distributed faeces and urine more evenly with daily allocation of new pasture, while Watson et al. (2003) found that the pattern of excretion could be influenced by the location of the hut and the pen design. This indicates a potential to improve the distribution of manure by considering pig excretoire behaviour when modifying outdoor systems.

The overall objective of this study was to estimate the environmental impact and suggest improvements for nutrient management in two outdoor systems for fattening pigs. Specific objectives were to: (1) quantify fluxes and balances of N, P, K, Cu and Zn at pen level; (2) map the pattern of excreted manure and estimate the nutrient and trace element loads within the pen; and (3) determine the soil content of total N, mineral N, P, K, Cu and Zn within the pen in areas where the pigs preferred to defecate and urinate and in other areas.

2. Materials and methods

2.1. Experimental sites

Two outdoor pig production systems were studied: one mobile and one stationary. The mobile system was located on a commercial pig farm with a production rate of about 700 fattening pigs per year and 150 ha of arable land (4.7 fattening pigs ha\(^{-1}\)). A farm-gate balance was established for the year 2003 according to National Board of Agriculture data (SJV, 2003). The net accumulation at farm-gate level was 66 kg N, <1 kg P and 65 kg K ha\(^{-1}\).

The stationary system was located on a commercial pig farm with a production rate of about 800 fattening pigs per year and 80 ha of arable land (10 fattening pigs ha\(^{-1}\)). The net accumulation at farm-gate level was 58 kg N, 21 kg P and 35 kg K ha\(^{-1}\) (SJV, 2003). Both farms had been organic for 4 years at the time of the study. Between 40 and 50% of the fattening pigs at both farms were produced in barns during wintertime. The mean annual temperature was 5.5 °C and the mean total precipitation was 489 mm per year for the mobile system (Alexandersson and Eggertsson Karlström, 2001) and the soil was tentatively classified as an Eutric Cambisol (FAO, 1998) (Table 1). The corresponding data for the stationary system were mean temperature 6.2 °C, mean total precipitation 524 mm per year (Alexandersson and Eggertsson Karlström, 2001) and the soil was tentatively classified as a Dystric Arenosol (FAO, 1998) (Table 1).

In the mobile system, about 4.0 ha year\(^{-1}\) of clover/grass leys were used for 300 fattening pigs during the grazing period. The rotation interval for pigs on arable land was 4 years. The farm had its own sows and bred its own piglets. The sows and 2-week-old piglets were moved to a pen with clover/grass ley surrounded by electrical fences. After weaning the sows were removed and the
pigs used the pen during the fattening period. The pen was rectangular and included about 40 pigs which had access to grazing, wallowing, huts for shelter, feeding and drinking places where all the facilities were kept stationary within the pen. Each pen was used by one pig group per year.

In the stationary system, about 4.6 ha year\(^{-1}\) of clover/grass leys close to the barn were used for about 400 fattening pigs during the grazing period. The rotation interval for pigs on arable land was 2 years. A small part of the arable land close to the barn was used for pigs every year. The farm bought in piglets. In a barn, each pig group had a box including a long feeding trough, drinking water and a resting place with straw litter. Outside the barn was a concrete pad and beyond the outdoor area arable land with clover/grass ley including a wallowing site. Over time the pen became longer as the farmer used strip-grazing to give the pigs a weekly allocation of about a 10 m long strip of fresh clover/grass ley. The pen was long and narrow and included about 40 pigs. Each pen was used by one pig group during the whole fattening period and another pig group during half the fattening period.

### 2.2. Experimental design

Element flows to and from the pig groups in the mobile and stationary systems were monitored during a 2-year period (2002–2003) taking into account the flows identified at the farms. Pen balances (Eq. (1)) were established as an average for each farm and the pig groups studied and included the elements N, P, K, Cu and Zn. The amounts of feed and the pig weights were based on farm documentation:

$$\text{Pen balance} = \frac{\text{Input of products} - \text{Output of products}}{\text{Sows + Piglets + Sows}}$$

Each year, two pig groups and their pens were documented for the pen balance, behavioural studies, manure mapping and soil sampling in both the mobile and stationary systems. In the first year, the pig groups included represented the period from August to November, while the period from June to September was represented in the second year. At the farm with the mobile system the total

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### Table 1

Analysis of soil in preferred areas for excretion (Pref) and other areas (Other) in pens of the mobile (M) and stationary (S) systems at the end of the fattening period

<table>
<thead>
<tr>
<th>Soil type a (0–30 cm depth)</th>
<th>Year</th>
<th>Site</th>
<th>Year</th>
<th>Site</th>
<th>pH H₂O</th>
<th>Air-dried soil mg kg⁻¹</th>
<th>P-AL d</th>
<th>K-AL d</th>
<th>P-HC d</th>
<th>K-HC d</th>
<th>Cu-HC e</th>
<th>Zn-HC e</th>
<th>Tot-N f</th>
<th>Tot-C f</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay</td>
<td>1</td>
<td>M Pref</td>
<td>6.4</td>
<td>74</td>
<td>190</td>
<td>–</td>
<td>–</td>
<td>44</td>
<td>131</td>
<td>0.25</td>
<td>–</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clay</td>
<td>M Other</td>
<td>6.7</td>
<td>45</td>
<td>210</td>
<td>–</td>
<td>–</td>
<td>43</td>
<td>106</td>
<td>0.26</td>
<td>–</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clay</td>
<td>2</td>
<td>M Pref</td>
<td>6.9</td>
<td>45</td>
<td>455</td>
<td>565</td>
<td>7180</td>
<td>32</td>
<td>86</td>
<td>0.15</td>
<td>1.50</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clay</td>
<td>M Other</td>
<td>6.8</td>
<td>46</td>
<td>430</td>
<td>595</td>
<td>7250</td>
<td>31</td>
<td>89</td>
<td>0.16</td>
<td>1.64</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sandy loam</td>
<td>1</td>
<td>S Pref</td>
<td>6.3</td>
<td>241</td>
<td>355</td>
<td>–</td>
<td>–</td>
<td>10</td>
<td>33</td>
<td>0.15</td>
<td>–</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sandy loam</td>
<td>S Other</td>
<td>6.1</td>
<td>47</td>
<td>86</td>
<td>–</td>
<td>–</td>
<td>6</td>
<td>19</td>
<td>0.13</td>
<td>–</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sandy loam</td>
<td>2</td>
<td>S Pref</td>
<td>6.6</td>
<td>500</td>
<td>648</td>
<td>1370</td>
<td>1403</td>
<td>9</td>
<td>40</td>
<td>0.16</td>
<td>2.13</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sandy loam</td>
<td>S Other</td>
<td>5.9</td>
<td>103</td>
<td>102</td>
<td>831</td>
<td>606</td>
<td>9</td>
<td>31</td>
<td>0.14</td>
<td>1.88</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a FAO (1998).

b ISO (2005).

c Within each extractable plant nutrient at each site and year, average nutrient concentrations with different subscripts are significantly different (*p < 0.05).

d Egneér et al. (1960); SS 028310 (1993); KLS (1965).

e SS 028183 (1986).

f As % of dry matter content.

### Table 2

Number of pigs, stocking time, total pen area and sub-areas within pens in the study

<table>
<thead>
<tr>
<th>System</th>
<th>Mobile 1 a</th>
<th>2 a</th>
<th>3 a</th>
<th>4 a</th>
<th>Stationary 1 a</th>
<th>2 a</th>
<th>3 a</th>
<th>4 a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of fattening pigs</td>
<td>35</td>
<td>34</td>
<td>29</td>
<td>35</td>
<td>40</td>
<td>43</td>
<td>32</td>
<td>52</td>
</tr>
<tr>
<td>Stocking time in the pen (days)</td>
<td>170</td>
<td>153</td>
<td>163</td>
<td>152</td>
<td>119</td>
<td>119</td>
<td>128</td>
<td>128</td>
</tr>
<tr>
<td>Total pen area (m²)</td>
<td>6288</td>
<td>4540</td>
<td>3808</td>
<td>3899</td>
<td>4875</td>
<td>4683</td>
<td>3333</td>
<td>3013</td>
</tr>
<tr>
<td>Feeding area (m²)</td>
<td>300</td>
<td>456</td>
<td>501</td>
<td>461</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Drinking area (m²)</td>
<td>491</td>
<td>198</td>
<td>428</td>
<td>428</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Hut area (m²)</td>
<td>237</td>
<td>400</td>
<td>230</td>
<td>230</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Grazing (m²)</td>
<td>5261</td>
<td>3486</td>
<td>2648</td>
<td>2781</td>
<td>2573</td>
<td>2370</td>
<td>2095</td>
<td>1870</td>
</tr>
<tr>
<td>Concrete pad (m²)</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>39</td>
<td>39</td>
<td>39</td>
<td>39</td>
</tr>
<tr>
<td>Wallowing (m²)</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>282</td>
<td>191</td>
<td>162</td>
<td>160</td>
</tr>
<tr>
<td>Transfer area (m²)</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>1979</td>
<td>2083</td>
<td>1007</td>
<td>944</td>
</tr>
</tbody>
</table>

a Group and pen number.
precipitation was 50 mm, with zero precipitation in August, and the average temperature was between 2.8 and 19.8 °C in the first year. In the second year the total precipitation was 236 mm and the average temperature was between 3.3 and 19.8 °C during the experimental periods. At the farm with the stationary system the total precipitation during the experimental periods was 111 mm and the temperature was between 3.5 and 19.8 °C in the first year, and 410 mm and 10.3–17.6 °C in the second year. At both sites the first year was dryer and warmer while the second year was wetter and warmer than reference normals for 30 years (Alexandersson and Eggertsson Karlström, 2001). The pig groups studied in the mobile system used arable land where pigs never had been before, while in the stationary system the pig groups studied had access to pens used by fattening pigs 2 years previously. The number of pigs, the duration of stocking periods and the pen area per pig group included in the study are presented in Table 2.

The pens were measured and divided into four sub-areas, corresponding to the activity the pigs performed there (Table 2, Fig. 1). Behavioural studies were conducted for each pig group during 2 days on two different occasions representing different ages of the pigs. Each observation day was 8 h long and chosen to match the pigs’ periods of activity. Among other things, defecation and urination were continuously recorded. Each defecation and urination event was then marked on a map of the pen, where the different sub-areas were outlined. Using the number of defecations and urinations per m² and 10 pigs, it was possible to calculate the proportion of manure and urine load on each sub-area. It was then possible to compare sub-areas independent of their size (Benfalk et al., 2005).

The proportion of excreted manure and urine on each sub-area was used to calculate the proportion of the total amounts of N, P, K, Cu and Zn in manure and urine from one pig group that loaded the sub-area. The mass balance calculation for each sub-area was a quantitative estimation of the heterogeneity in the nutrient load within an average pen for each system. After each of the two observation occasions, the whole pen was walked systematically and the degree of visible cover of manure in each sub-area was documented on a map using a scale from 0 to 5, with 0 = 0% cover, 1 = 1–25% manure cover, 2 = 26–50% cover, 3 = 51–75% cover, 4 = 76–99% cover and 5 = ground completely covered with manure, i.e. 100%. The map was a spatial estimation of the distribution of manure within the pen.

2.3. Sampling

2.3.1. Feed, pigs and manure

For each pig group included in the pen balance, one 1–2 L sample of each feedstuff included in the diet was analysed for N, P, K, Cu and Zn.

In the stationary system, the amounts of nutrients excreted indoors were estimated by weighing and sampling the indoor litter bedding from two pig groups when the pigs were slaughtered (Rodhe and Jonsson, 1999) and analysing it for N, P, K, Cu and Zn.

2.3.2. Soil

In each pen, soil was sampled at 0–30, 30–60 and 60–90 cm depth just before the pig group entered the pen and after the pig group was removed for slaughter. The areas used for soil sampling were chosen to represent the effect of pig defecation and urination behaviour on the soil content of N, P, K, Cu and Zn. In each pen, we chose one area where we expected that the pigs would prefer to defecate and urinate, based on the assumption that these behaviours would take place near their resting place. If pig manure occurred on the spot at which soil cores were taken, it was first removed from the soil surface. In the mobile system, the sampling area was about 400 m² and was situated between the hut and the feeding area for each pig group (Fig. 1). In the stationary system, the corresponding area was about 44 m² and was situated in the wallowing area for each pig group (Fig. 1). The wallowing area was located in the part of the pen used for pigs each year. In each pen, an area where the pigs...
preferred not to defecate and urinate was also chosen within the grazing area in both systems (Fig. 1). In the mobile system this area was again about 400 m². However, in the stationary system it was unclear how the strip-grazing would affect defecation and urination behaviour and therefore two areas were chosen, one within the transfer area (about 44 m²) and one within the grazing area (about 200 m²).

2.4. Chemical analyses

2.4.1. Feed, pigs and manure

Sub-samples of 1 g feed were digested by automatic wet digestion (Tecator Digestion System) using solvents described by Frank (1976, 1983). The preparation of the liquid phase and the dry residue was as described by Frank and Petersson (1983). Simultaneous analysis of Cu, K, P and Zn was performed using an inductively coupled plasma-atomic emission spectrometer, ICP-AES (JY 50P, JY Horiba, division Jobin Yvon, Longjumeau, France). Nitrogen was determined by an automated Kjeldahl procedure (Tecator AB, Höganaäs, Sweden).

Data on the content of N, P, K, Cu and Zn in pigs of different ages were taken from Fernández (1998) and Mahan and Newton (1995).

Samples of 2 L thawed litter bed with manure were dried at 105 °C for 12 h and homogenised. The contents of Cu, K, P and Zn in 1 g of the dried sample were extracted and analysed by a method described in SS-ES ISO (1998). The contents of dry matter and N were determined after thawing and homogenisation. Nitrogen was determined by an automated Kjeldahl procedure (Tecator AB, Höganaäs, Sweden).

2.4.2. Soil

Twenty-four soil cores were taken in the topsoil (Lindén, 1977) and 12 soil cores were taken in the sub-soil (Lindén, 1979) in each sampling area. The soil cores were divided into three layers: 0–30, 30–60 and 60–90 cm depths. The samples from each sampling area were mixed in layers to form composite samples, which were deep-frozen (−20 °C) until analyses were made (Aronsson and Torstensson, 1998). A part of the composite samples from the topsoil was air-dried at a temperature of 18 °C before analysis.

The frozen bulk samples of soil representing 0–30, 30–60 and 60–90 cm depth were homogenised by grinding and extracted with 2 M KCl (after Bremner and Keeney, 1966). Thereafter ammonia nitrogen (NH₄-N) and nitrate nitrogen (NO₃-N) were determined colorimetrically with an auto-analyser (TRAACS 800, method nos. ST9002-NH₄D and ST9002-NO₃D). The values were recalculated to kg N per hectare by taking into account the actual soil water content and with the assumption that the weight:volume ratio in the topsoil was 1.25 kg per dm³ and in the sub-soil 1.5 kg per dm³. The air-dried bulk samples of soil for 0–30 cm depth were analysed for exchangeable soil P and K, which estimates the amounts of plant-available P and K (Egnér et al., 1960; KLS, 1965; SS, 1993). Non-exchangeable soil P, K, Cu and Zn were also analysed and amounts of plant nutrient reserves estimated (Egnér et al., 1960). Total N and total C were determined as % of the soil dry matter content.

2.5. Statistical analysis of mineral nitrogen in soil

The amounts of mineral N (NH₄-N and NO₃-N) in soil were statistically analysed within each system and year, with two replicates representing two pig groups and their pens. For the statistical analysis with a split-plot design, a mixed procedure was used (SAS Institute Inc., 1994). The areas which were preferred and not preferred for defecation and urination were treatments analysed as main plots, while soil depths were treatments analysed as subplots. The samplings of mineral N in soil at the start and end of the pigs’ presence were treatments analysed as repeated measurements.

3. Results

3.1. Pen balance

The average amounts (kg) of N, P, K, Cu and Zn into and out of one pig group for a fattening period were larger for the stationary system than for the mobile system (Table 3). The reason was the average greater number of pigs in each group of about 91 pigs ha⁻¹, compared with about 71 pigs ha⁻¹ in the mobile system. However, the

Table 3

<table>
<thead>
<tr>
<th>System</th>
<th>Mobile</th>
<th>Stationary</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>P</td>
</tr>
<tr>
<td>Inputs (kg)</td>
<td>226</td>
<td>48</td>
</tr>
<tr>
<td>(±S.D.)</td>
<td>35</td>
<td>7</td>
</tr>
<tr>
<td>Outputs (kg)</td>
<td>101</td>
<td>20</td>
</tr>
<tr>
<td>(±S.D.)</td>
<td>9</td>
<td>1</td>
</tr>
<tr>
<td>Average pen balance (kg a)</td>
<td>125</td>
<td>28</td>
</tr>
<tr>
<td>Balance (kg pig group⁻¹ ha⁻¹)</td>
<td>270</td>
<td>60</td>
</tr>
</tbody>
</table>

a Average element amounts defecated and urinated indoors in the litter bed in the stationary system were excluded.

b The average pen area was 4634 m² for the mobile farm and 4634 m² for the stationary farm.
pen balance showed a larger average net accumulation outdoors in the mobile system (270 kg N, 60 kg P and 100 kg K ha\(^{-1}\)) compared with the stationary system (205 kg N, 57 kg P and 99 kg K ha\(^{-1}\)). One reason was that the pigs defecated and urinated in the litter bed indoors in the stationary system. The amount (% by weight) of nutrients excreted indoors in the stationary system was around 19% of the total amount excreted for one pig group and around 41% of the total for another pig group. The estimated average amount of nutrients excreted indoors for a pig group was thus assumed to be around 30% of the total amount excreted.

### 3.2. Distribution of nutrients within the pen

In the mobile system about 95% of the total average amounts of nutrients excreted were deposited on the hut, feeding and drinking sub-areas, which represented about 24% of the pen area (Table 4). The nutrient load on these sub-areas represented a N, P and K application of 620–1790, 130–400 and 260–730 kg ha\(^{-1}\), respectively. On the other hand, about 5% of the total average amounts of nutrients excreted were deposited outdoors in the mobile system (270 kg N, 60 kg P and 100 kg K ha\(^{-1}\)) compared with the stationary system (205 kg N, 57 kg P and 99 kg K ha\(^{-1}\)). One reason was that the pigs defecated and urinated in the litter bed indoors in the stationary system. The amount (% by weight) of nutrients excreted indoors in the stationary system was around 19% of the total amount excreted for one pig group and around 41% of the total for another pig group. The estimated average amount of nutrients excreted indoors for a pig group was thus assumed to be around 30% of the total amount excreted.

### Table 4

The proportional nutrient load in different sub-areas within an average pen (n = 4) in the mobile (M) and the stationary (S) systems

<table>
<thead>
<tr>
<th>System and sub-areas</th>
<th>Defecations and urinations(^{a})</th>
<th>g m(^{-2})</th>
<th>mg m(^{-2})</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Numbers</td>
<td>Proportions (%)</td>
<td>N</td>
</tr>
<tr>
<td>M Hut</td>
<td>0.99</td>
<td>39</td>
<td>179</td>
</tr>
<tr>
<td>M Feeding</td>
<td>0.96</td>
<td>37</td>
<td>107</td>
</tr>
<tr>
<td>M Drinking</td>
<td>0.48</td>
<td>19</td>
<td>62</td>
</tr>
<tr>
<td>M Grazing</td>
<td>0.13</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>S Concrete pad</td>
<td>2.05</td>
<td>43</td>
<td>1051</td>
</tr>
<tr>
<td>S Wallowing</td>
<td>2.03</td>
<td>43</td>
<td>206</td>
</tr>
<tr>
<td>S Grazing</td>
<td>0.35</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>S Transfer area</td>
<td>0.34</td>
<td>6</td>
<td>4</td>
</tr>
</tbody>
</table>

\(^{a}\) The relative proportion per sub-area was based on the average number of defecations and urinations in each sub-area per 10 pigs and 10 m\(^2\) in relation to the total average number of defecations and urinations during two observation periods.

\(^{b}\) The proportions of nutrients in each sub-area were based on the average pen balance, Table 3.
on the grazing area, which represented about 76% of the pen area. The nutrient load on the grazing area represented a N, P and K application of 20, 10 and 10 kg ha\(^{-1}\), respectively, while the load of Cu and Zn represented an application of 0.03 and 0.09 kg ha\(^{-1}\), respectively. In the stationary system about 43% of total average amounts of nutrients excreted on arable land were deposited on the wallowing area, which represented about 4% of the pen area (Table 4). The element load on the wallowing area represented a N, P and K application of 2060, 600 and 1010 kg ha\(^{-1}\), respectively, while the load of Cu and Zn represented an application of 4.3 and 15 kg ha\(^{-1}\), respectively. About 14% of total average amounts of nutrients excreted outdoors were deposited on the transfer and grazing areas, which represented about 94% of the pen area. The nutrient load on these areas represented a N, P and K application of 30–40, 10 and 10 kg ha\(^{-1}\), respectively, while the load of Cu and Zn represented an application of 0.07 and 0.25 kg ha\(^{-1}\), respectively.

3.3. Spatial distribution of manure within the pen

The pattern of manure distribution in pens is presented for the second observation occasion (Figs. 2 and 3) except for the second year in the stationary system, where the wallowing areas in the two pens were so muddy that there were no visible differences between manure and soil. Therefore the manure map of the wallowing area from the first observation occasion is presented.

In the mobile system, the spatial distribution of manure in the pens studied showed a similar pattern (Fig. 2). The pigs did not defecate close to the hut, while the soil surface was completely covered with manure about 1–15 m from the hut. The shape of the sub-area completely covered with manure differed between pens, but extended towards the feeding area in all pens. In one pen in 2002, the farmer had built a wall of straw bales for shade next to the hut. Close to the straw bales the pigs did not defecate, while 1 m away towards the feeding area the sub-area was completely covered with manure. In all pens the pigs did not defecate close to the feeding troughs, the drinking water and the wallow. The main part of the grazing areas was covered with manure to 1–25% and in general the degree of cover increased closer to the hut in all pens. In one pen in the second year, there was a zone completely covered with manure in the feeding area along the electric fences.

In the stationary system too, the spatial distribution of manure showed a similar pattern in all pens studied (Fig. 3). The concrete pad just outside the barn was completely covered with manure in all pens. The wallowing area had zones which were completely covered with manure except in

![Fig. 3. The manure map for each experimental pen in the stationary system. The numbers within each pen corresponded to the degree of manure cover on the ground: 0 = 0% cover, 1 = 1–25% cover, 2 = 26–50% cover, 3 = 51–75% cover, 4 = 76–99% cover and 5 = 100% cover.](image-url)
one pen in year two. Close to the wallow the pigs did not defecate in one pen in year one, while the wallowing area had 1–25% manure cover in the other pens. On the transfer areas there were larger zones with a 1–50% cover of manure, compared with the wallowing area. On the other hand, zones with 76–99% cover and 100% cover also occurred. The main part of the grazing area had zones with no visible manure up to zones with a 26–50% cover of manure. One pen in year two had a zone with 76–99% cover and another zone with 100% cover.

3.4. Nutrient amounts in the topsoil

In both years of the study, the pens in the stationary system had on average significantly larger amounts of plant-available P in areas preferred for defecation and urination (241 and 500 mg kg\(^{-1}\) air-dried soil) compared with other areas (47 and 103 mg kg\(^{-1}\) air-dried soil) (Table 1). In the second year, there were on average significantly larger amounts of plant-available K (648 mg kg\(^{-1}\) air-dried soil) and of non-exchangeable P, K and Zn (1370, 1403 and 40 mg kg\(^{-1}\) air-dried soil) in the area preferred for defecation and urination compared with other areas (102 mg plant-available K, and 831 mg non-exchangeable P, 606 mg non-exchangeable K and 31 mg non-exchangeable Zn kg\(^{-1}\) air-dried soil). In the pens in the mobile system, there were no such clear differences in soil nutrient amounts between areas where the pigs preferred to defecate and urinate and other areas.

3.5. Mineral N in soil

In both years after a few months of pig presence, the mobile system had higher extractable mineral-N concentration in soil (0–90 cm depth) in preferred excretion areas (corresponding to 230 kg ha\(^{-1}\)) compared with other areas (corresponding to 72 kg ha\(^{-1}\)) (Fig. 4). Just before the pigs entered the pen, there was no difference in mineral-N concentration in soil between the sub-areas and the soil layers. In the first year in the stationary system, there was a higher extractable mineral-N concentration in soil (0–90 cm depth) in areas preferred for excretion (corresponding to 350 kg ha\(^{-1}\)) compared with other areas (corresponding to 16–41 kg ha\(^{-1}\)), both before the pig groups studied entered the pen and just after they left (Fig. 4). In the second year, the presence of the pig group studied had contributed to a significantly higher mineral-N concentration in soil (0–90 cm depth) in areas preferred for excretion (corresponding to 350 kg ha\(^{-1}\)) compared with other areas (100–140 kg ha\(^{-1}\)). In preferred excretion areas, the mineral-N concentration in soil was higher in the stationary system than in the mobile system. In the stationary system, the concentration of mineral-N in each of the soil layers was significantly higher in preferred excretion areas than in other areas. There was no significant difference in soil mineral-N concentration between the transfer and grazing areas before and after the pigs.

4. Discussion

4.1. Pen balance

It should be noted that in the pen balance for the mobile system, the net accumulation of nutrients may not only
depend on nutrients in faeces and urine but also on possible feed losses, as the pigs were fed outdoors. Considerable feed losses during feeding outdoors have been observed (Andresen, 2000). In the mobile system, the average net P accumulation for one pig group corresponded to 60 kg P ha\(^{-1}\), while for stationary system it was 57 kg P ha\(^{-1}\). This indicated a pig density on arable land producing over twice the recommended level of 22 kg P ha\(^{-1}\) year\(^{-1}\). An excessive animal density also leads to a N and K surplus, which can result in N and K losses (Eriksen, 2001; Öborn et al., 2003). However, spread over the rotation times used at the two farms, the pigs would create an actual net input of Cu and Zn to arable land. A grain and straw harvest of barley in the plain districts of Svealand in central Sweden removes about 0.03 kg Cu and 0.18 kg Zn ha\(^{-1}\), while for stationary system it was 57 kg P ha\(^{-1}\). This indicated a pig density on arable land producing over twice the recommended level of 22 kg P ha\(^{-1}\) year\(^{-1}\). An excessive animal density also leads to a N and K surplus, which can result in N and K losses (Eriksen, 2001; Öborn et al., 2003). However, spread over the rotation times used at the two farms, the pigs would create an actual net input of Cu and Zn to arable land. A grain and straw harvest of barley in the plain districts of Svealand in central Sweden removes about 0.03 kg Cu and 0.18 kg Zn ha\(^{-1}\), respectively, at pen level. There is generally no direct link between the impact of trace elements, their balance and long-term soil quality, but the trace element balance makes it possible to evaluate the direction of change in a system (Bengtsson, 2005). In this study, the pen balance showed that the pigs contributed to a net input of Cu and Zn to arable land. A grain and straw harvest of barley in the plain districts of Svealand in central Sweden removes about 0.03 kg Cu and 0.18 kg Zn ha\(^{-1}\) year\(^{-1}\) (Andersson, 1992). Thus harvesting barley for 3 years at the farm with the mobile system and for 1 year at the farm with the stationary system would not be enough to balance the net input of Cu and Zn from the pigs.

4.2. Estimated nutrient amounts within the pen

Several studies have found pig defecation and urination behaviour to result in an uneven distribution of faeces and urine (Zühlmann et al., 1997; Andresen, 2000; Eriksen and Kristensen, 2001). In this study, the main proportion of nutrients (43–95%) was distributed on an area representing 4–24% of the total pen area, showing that the nutrient load could be extremely concentrated to a sub-area representing about 199 m\(^2\) for the wallowing area in the stationary system and about 1090 m\(^2\) for the hut, feeding and drinking area in the mobile system. Watson et al. (2003) reported similar results, with free-roaming pigs concentrating over 90% of the nutrients in faeces and urine to about 10% of the pen area. In this study, the P point load per hectare of arable land from one pig group represented an application of 760 kg P ha\(^{-1}\) in the mobile system and 600 kg P ha\(^{-1}\) in the stationary system (Table 4), which were far above the recommended balanced rate of 22 kg P ha\(^{-1}\) (Steinack et al., 2001). Watson et al. (2003) concluded that in a 15-month period with 35 sows ha\(^{-1}\), levels of P in soil were double the original background concentration and sufficient to saturate the soil profile in preferred excretion areas, showing that a point load of nutrients represents a significant environmental risk. At the farm in the present study with the stationary system, the pigs excreted a substantial proportion of the nutrients (43%) on the concrete pad. This manure was removed and spread in the crop rotation. The total net input to the pen for one pig group then decreased from 27 kg P (Table 3) to 15 kg P (Table 4). The contribution from the pigs using the arable land every second year thus resulted in a net P accumulation of 16 kg ha\(^{-1}\) year\(^{-1}\), so the farm with the stationary system then also had a balanced animal density on pen level. In both systems, the grazing areas were not preferred by pigs for defecation and urination, resulting in nutrient loads per hectare of half the maximal balanced rate (Table 4). The nutrient load from one pig group was then acceptable from an environmental and crop production perspective on the major part of the pen, the grazing area, in both systems. In the stationary system, the nutrient load was similar on the transfer and grazing areas, indicating that the pigs had similar defecation and urination behaviours on these sub-areas.

4.3. Spatial distribution of manure in the pen

The manure mapping revealed pig behaviour of avoiding defecation in resting areas, i.e. just outside the hut in the mobile system (Fig. 2). Other zones with no visible manure further away from the hut (Fig. 2) and the barn in the stationary system (Fig. 3) also occurred in the pens. These may represent other preferred pig resting places, e.g. close to the wallow and the feeding troughs. On the other hand, the preferred defecation area was located near the resting place (1–15 m away) in both the mobile and stationary systems. These results agree with findings by Stolba and Wood-Gush (1981), who found that pigs preferred to defecate and urinate in a zone between 5 and 15 m from the nestling site. The zones that were completely covered with manure in the pens were in general smaller in the stationary system than in the mobile system. This may have been an effect of the pen design. The small and narrow pens in the stationary system gave the pigs only one route to walk between the barn, the wallowing area and the grazing area. In the mobile system, the pigs could choose different ways between the hut and the feeding, wallowing and grazing areas, leading to a larger zone covered with manure. The stationary system used strip-grazing, which gave the pigs access to new grazing areas every second week. Andresen (2000) found that fattening pigs allocated new grazing areas each day used them intensively for foraging, defecation and urination, leading to about 45% of all defecation and urination events in the pen occurring in these areas. However, in the present study the effect of strip-grazing was not so clear, perhaps because the pigs got a new strip to graze less frequently and also because they had to move at least 200 m to reach the grazing area.

4.4. Nutrients in the topsoil

In the stationary system, the concentration of exchangeable P and K in soil (0–30 cm depth) was more than 4-fold...
higher and the concentration of non-exchangeable P and K was more than 1.5-fold higher in preferred areas compared with other areas (Table 1). The nutrient concentration in soil in the area preferred for excretion was influenced by the pig groups studied and by previous pig groups 4 years back in time using this sub-area of the pen each year. Eriksen and Kristensen (2001) also found that the concentration of extractable P and exchangeable K in soil (0–20 cm depth) in areas preferred for excretion increased more than 1.4- and 3.4-fold within 6 months. They also found a significantly higher concentration of extractable P and exchangeable K in soil close to the hut and feeding areas than at a distance 30–40 m further away.

In the mobile system, the variability in excretal returns did not give any clear difference in P and K concentrations in soil between preferred excretion areas and other areas (Table 1). One reason was probably that the excretal returns only represented one pig group (72 fattening pigs ha$^{-1}$) present for about 5.3 months. The other reason could be that the type of clay soil on this farm naturally contained large amounts of plant-available K and non-exchangeable K (Salomon, 1999).

In the stationary system, there was a tendency for the variability in excretal returns to result in higher concentrations of Zn in soil in preferred excretion areas compared with other areas (Table 1). Net accumulation of Zn is not desirable in a long-term perspective as regards soil fertility (Andersson, 1992). However, the amounts of Cu and Zn in the soil in preferred excretion areas and other areas in the stationary system can be classified as low (Eriksson et al., 1997), indicating no problem with hazardous amounts so far. In the mobile system, there were no clear differences in concentration of Cu and Zn in soil between preferred excretion areas and other areas. The reasons can be the lower animal density and the high background values of Cu and Zn in soil, which are typical for the type of clay found on the farm (Eriksson et al., 1997).

4.5. Mineral N in soil

In the mobile system, the fattening period started on a clover-grass ley where no pigs had been before. However, the presence of the pigs in the pen for some months resulted in approximately three-fold higher mineral-N concentrations in soil (0–90 cm depth) in the areas preferred for excretion compared with other areas (Fig. 4). In the stationary system, the part of the pen that included the preferred excretion area was used in the first year by pigs during the second half of their fattening period before the pig group studied entered. The effect of the previous pigs was apparent as an eight-fold higher concentration of mineral N in soil in preferred excretion areas compared with other areas, before the pig group studied used the pen (Fig. 4). The presence of the pig group studied gave a five- to eight-fold higher mineral-N concentration in preferred excretion areas compared with other areas in autumn. Watson et al. (2003) reported approximately five-fold higher mineral-N concentrations in soil in preferred excretion areas compared with other areas, after some months of sows being present. The highest average mineral-N concentration in soil (0–90 cm depth) found by these authors in the preferred areas was about 645 kg ha$^{-1}$. After 6 months with lactating sows, Eriksen and Kristensen (2001) found approx. 49-fold higher mineral-N concentrations in topsoil (0–20 cm depth) in preferred excretion areas compared with other areas. Eriksen (2001) found that the amounts of mineral-N in soil increased with a higher animal density. The higher mineral-N concentration in preferred areas in the stationary system, compared with the mobile system, can be an effect of 1.5 pig groups having used the same wallowing area each year for defecation and urination.

In both systems before the pig groups studied entered, the average concentration of mineral-N in soil (0–90 cm) in areas not preferred for excretion (average 26 kg mineral-N ha$^{-1}$, Fig. 4) was less than that found in spring under unfertilised ryegrass established after a cereal crop year (55 kg mineral-N ha$^{-1}$) (Stenberg et al., 1999). In both systems after some months of pigs being present, the soil concentration of mineral-N in areas not preferred for excretion was 39–140 kg N ha$^{-1}$ (0–90 cm depth) compared with the 49 kg mineral-N ha$^{-1}$ found by Watson et al. (2003). A high soil mineral-N concentration in autumn without a growing crop can increase the risk of N-leaching. However, a crop such as perennial ryegrass can have a nitrogen uptake of about 50 kg ha$^{-1}$ between August and November (Aronsson, 2000) which could have decreased the risk. Eriksen and Kristensen (2001) found that the mineral-N concentration in soil (0–90 cm depth) in areas not preferred for excretion was comparable with reference values from soil not influenced by pigs, indicating no higher risk of N leaching from these areas. In the present study there were higher mineral N concentrations in topsoil in areas not preferred for excretion in the second year, compared with the first year. The reason can have been the higher precipitation in the second year. More humid conditions during the grazing period can stimulate soil N mineralisation (Aronsson, 2000). The potential risk for N leaching was also larger in the stationary system because of a coarser soil texture.

4.6. Plant nutrient management and environmental impact

The integration of outdoor pigs in the crop rotation has to be planned carefully and among other things contribute to a resource efficient use of plant nutrients in animal manure. In this study, the different organisations of the two outdoor pig systems resulted in more severe point loads of nutrients on arable land in the stationary system than in the mobile system. The flexibility of the mobile system resulted in the pigs having access to a larger area of arable land over a 4-year rotation period and the preferred area for excretion was regularly moved. The stationary system had limited...
possibilities to use more arable land or move the preferred area for excretion. A nutrient management technique for collecting the manure on the preferred excretion area and spreading it on other fields for crop production would minimise the nutrient load on the arable land area.

In the mobile system, the pig groups studied avoided defecating close to the feeders, the wallowing area and the drinking water. The net accumulation of nutrients in soil at the feeding area observed by Eriksen and Kristensen (2001) may then be an effect of feed losses rather than defecation. One aspect of decreasing the risk of negative environmental impact is to develop feeding equipment that minimises feed losses in outdoor pig production, which also was recommended by Quintern and Sundrum (2006).

In this study, the mobile system did not succeed in preventing excessively high nitrogen loads between the hut and the feeding troughs. The flexibility of this outdoor system has to be further improved to where the equipments are so mobile that no harmful point loads of nitrogen occur. The spatial variability in nutrients that occurs in outdoor pig production makes it difficult to plan fertiliser applications in subsequent years. Farms where pigs are produced outdoors may be ideal for precision farming approaches to subsequent fertiliser planning.

5. Conclusions

In order to achieve sustainable use of plant nutrients, a balanced animal density per unit area is a basic requirement. In this study, the animal density was in general balanced on the arable land area used for pigs in the mobile and the stationary systems. In both types of system, the excretory behaviour of pigs created sub-areas with high loads of nutrients and high mineral-N concentrations in soil, corresponding to about 24% of the pen area in the mobile system and to about 4% of pen area in the stationary system. The excretory behaviour of the pigs was affected differently by the two systems studied and thus different solutions would be required to make these systems more environmentally sustainable.

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References


