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## Feeding silage to fattening pigs – effects on nitrogen utilization and ammonia losses from fresh manure

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### ABSTRACT

This study evaluated the effect of feeding silage to pigs on nitrogen (N) utilization and ammonia (NH<sub>3</sub>) volatilization. In total, 128 Yorkshire × Hampshire (30–110 kg) pigs were fed commercial feed (Control) or commercial feed mixed with dried, milled silage in pelleted form (Pellet-S), fresh, chopped silage (Silage-Ch) or intensively treated silage (Silage-Pr). Silage replaced 20% of the crude protein (g/kg). Diet affected daily N excretion, which was higher for pigs fed Silage-Ch and Silage-Pr than for pigs in the Pellet-S and Control treatments. Ammonium nitrogen (NH<sub>4</sub>-N) content in the manure and NH<sub>3</sub> volatilization from fresh manure were higher for Control pigs than for pigs in the other treatments. Overall, these results show that pre-treatment of silage influences N utilization and excretion. Furthermore, the results indicate that feeding silage to pigs can reduce NH<sub>3</sub> volatilization from fresh manure.

### ARTICLE HISTORY

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### KEYWORDS

Finishing pig; silage; TMR; nitrogen; ammonia volatilization

### Introduction

To increase the sustainability of pig production, nutrient use efficiency and nutrient recycling must be optimized. Improving nitrogen (N) use efficiency is particularly important if N losses to air, groundwater and surface water are to be avoided (Monteiro et al., 2017). Two major factors affecting N losses are excess supply of protein in the diet of pigs and poor manure management (Rotz, 2004; Oenema et al., 2007; Philippe et al., 2011). In Europe, ammonia (NH<sub>3</sub>) losses from livestock production are one of main contributors to eutrophication and acidification of land and water (Philippe et al., 2011; Le Dinh et al., 2022). To reduce excretion of N by pigs, optimized feeding strategies that prevent over-feeding of protein are commonly used. At the same time, feed rations need to provide an optimal ratio of amino acids and meet the pig's nutritional requirements. There is increasing interest in use of alternative feed-stuffs in pig diets to reduce the environmental impact from feed production and reduce competition for human-edible resources (van Zanten et al., 2014). Protein derived from grass forage has been studied recently, with promising results regarding protein quality and usability in the diet of monogastric animals (Damborg et al., 2020; Stødkilde et al., 2019; Ravindran et al., 2021).

Organic farms, whether dairy, pig or arable, typically have a significantly higher proportion of clover/grass ley crops than conventional farms, in order to obtain N inputs through biological fixation (IFOAM, 2021). Organic farms aim for a high degree of self-sufficiency and use of locally produced feed sources. A key challenge for organic pig producers is to find suitable feed sources that can meet existing demands, including the nutrient requirements of pigs, without oversupplying protein (Zollitsch, 2007). In conventional farming, ley crops are generally used for grazing or as roughage for ruminants, but in organic farming they are often used as roughage for non-ruminant livestock to comply with organic feeding regulations (EC, 2008). Recent studies have evaluated the use of processed grass as a source of protein for fattening pigs (Damborg et al., 2020; Stødkilde et al., 2019; Santamaría-Fernández & Lübeck, 2020; Ravindran et al., 2021). Those studies found that grass and forage legume fractions have a favourable protein and amino acid composition and can have high feed value for monogastric animals. However, feeding fresh silage is a more interesting approach, as it reduces the need for processing and provision of fresh silage can improve pig welfare through enabling foraging behaviour (Presto et al., 2013; Wallenbeck et al., 2014). It

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could also have advantages for the environment by lowering  $\text{NH}_3$  losses from fresh pig manure, which could reduce acidification and eutrophication of surface waters. When pigs are fed a high-fibre diet, there is increased microbial activity in the hindgut. The microbes use N for fermentation, so more N is incorporated into microbial biomass and then excreted in the faeces, causing a shift in excretory pattern from urinary N excretion to faecal N excretion (Bindelle et al., 2008; Jha & Berrocoso, 2016). Since N in faeces is less rapidly degraded to  $\text{NH}_3$  than urea-N in urine, this shift in excretion pattern results in reduced  $\text{NH}_3$  volatilization (Zervas & Zijlstra, 2002; Bindelle et al., 2008; Galassi et al., 2010; Jarret et al., 2012). Moreover, microbial fermentation in the hindgut increases production of volatile fatty acids, thereby lowering the pH in the manure, which further reduces  $\text{NH}_3$  volatilization from the manure (Zervas & Zijlstra, 2002; Aarnink & Verstegen, 2007; Galassi et al., 2010). Including ley biomass in pig diets could have the advantages of supplying protein without competing with human-edible resources, improving farm profits and increasing the degree of feed self-sufficiency while reducing the need for imported protein. However, there are some challenges regarding the use of silage in pig diets, e.g. there is a need for more effective solutions for incorporating silage into pig diets and minimizing the amount of silage residues. Previous studies on feeding fresh silage in a total mixed ration (TMR) have found that pigs tend to sort out palatable parts of the ration, which results in feed residues and reduced energy intake and daily weight gain (Wallenbeck et al., 2014; Presto Åkerfeldt et al., 2019). However, if the TMR includes silage with shorter stem length, consumption increases (Presto Åkerfeldt, Holmström, Wallenbeck, & Ivarsson, 2018; Friman et al., 2021) and the pigs maintain sufficient growth performance (Friman et al., 2021).

There is still a knowledge gap regarding how feeding fresh silage in a TMR affects N utilization and  $\text{NH}_3$  volatilization from manure, and how particle size and feeding strategy influence these parameters. Therefore, this study examined the effects of introducing grass-clover silage into the diet of fattening pigs (30–110 kg live weight) on N use efficiency in the pigs. Specific objectives were to determine N utilization and excretion in pigs fed diets containing the same silage source, but with different pre-treatments, and to quantify the potential of silage-based diets in reducing N losses. The starting hypotheses were that addition of grass-clover silage to the feed ration reduces N utilization by pigs and increases N excretion; and that feeding silage-based diets with higher fibre content decreases  $\text{NH}_3$  losses from fresh manure.

## Material and methods

The effects of feeding silage on N excretion and  $\text{NH}_3$  volatilization in fresh pig manure have been reported in an earlier study using the same animals, diets, and experimental pen design (Friman et al., 2021). The present study focused on a small timeframe in which the pigs were moved pen-wise to a manure collection pen, where faeces and urine were collected continuously on pen level. The study was performed at the Swedish University of Agricultural Sciences research station at Funbo Lövsta, Uppsala (latitude 60°N). The work was approved by the Uppsala Ethics Committee on Animal Research (ethics approval number Dnr 5.8.18-14309/2019), which complies with EC Directive 86/609/EEC on animal studies.

### Experimental design

#### Animals and housing

The study included 128 fattening pigs (Swedish Yorkshire × Hampshire) from two production batches in a system with two weeks between batches. The pigs were housed in 16 pens (8 pens per batch), with eight pigs per pen. Each pen included four gilts and four male pigs from different litters, and thus no siblings were included in the same pen. The male pigs were immunocastrated with Improvac™, with a first injection at 77 days of age and a second at 105 days. Each pen had a concrete floor in the feeding and lying area and a slatted floor in the dunging area at the back of the pen (one-third of pen area). Two water nipples were provided in the slatted area and a 4.5 m feeding trough along the front of the pen. Total pen area was 11 m<sup>2</sup>, giving a floor area of 1.4 m<sup>2</sup> per pig. The pigs were provided with litter comprising approximately 1 kg of wood shavings daily.

#### Dietary treatments

Four different dietary treatments were compared. Pigs in the eight pens per batch received either a control diet (Control) or one of three experimental diets (Pellet-S, Silage-Ch, Silage-Pr), i.e. there were four pens per diet. All three experimental diets included silage, replacing 20% of dietary crude protein content (g/kg), fed as pellets (Pellet-S) or in a total mixed ration (TMR) as chopped (Silage-Ch) or intensively processed silage (Silage-Pr).

The silage used in the experimental diets originated from a first-year ley consisting of red clover (*Trifolium pratense*) (10%), white clover (*Trifolium repens*) (5%), timothy (*Phleum pratense*) (50%), meadow fescue (*Festuca pratensis*) (20%) and perennial ryegrass (*Lolium perenne*) (15%). The silage was from the second harvest (in mid-July) and the crop was cut in the field

with a forage harvester and chopped to 4–15 mm particle size. A silage additive (ProMyr NT570, Perstorp Holding AB, Malmö, Sweden) was added during harvesting, at a rate of 5 L per 100 kg fresh matter. After harvest, the crop was dried in the field for 24 h and then ensiled in a silage bun, with plastic wrap covering the ground. The same silage was used in the Pellet-S, Silage-Ch and Silage-Pr diets, but with different pre-treatments.

To produce the Pellet-S diet, the silage was sent to a dry feed producer (Genevads Grönfodertork, Laholm, Sweden). The pelleting process started with heat-drying of the silage in a three-way drum dryer at 100°C for 3–4 min. The silage was then milled to 8 mm and made into 8-mm pellets, which were cooled in a band cooler for 30 min. These pure silage pellets were used as an ingredient to produce a complete feed containing silage. The silage used in the Silage-Ch diet was included as intact, chopped silage (cut to approximately 4–15 mm), while the silage in the Silage-Pr diet was intensively processed with a bio-extruder (model MSZ-B15e, LEHMANN Maschinenbau GmbH, Rüdersdorf, Germany) to particle size 1–3 mm before inclusion in the diet. The bioextruder was equipped with rotating double-screws and set at 50% rotation speed, and the out-flow passage was fully opened. The double-screws, in combination with high pressure, reduced the silage particle size and ruptured cell walls.

During the study period, the pigs weighed 59.1 kg ( $\pm$  6.8 kg) and received on average 23.0 MJ NE ( $\pm$  1.9 MJ NE) per day, which amounted to approximately 2.3 kg ( $\pm$  0.4 kg) feed per pig and pen daily. The feed ration followed the Swedish nutrient recommendations for fattening pigs, which are based on average pen live weight (LW). These state that pigs should be fed *ad libitum* from 30 to 65 kg weight, with an energy allowance of 14.5, 18.3, 22.1 and 25.9 MJ NE at 30, 40, 50 and 60 kg weight, respectively, and thereafter fed a restricted diet with a maximum feed ration of 25.9 MJ NE (Andersson et al., 1997). Pigs that received the Control diet and Pellet-S diet were fed by an automatic (computerized) feeding system. For the Silage-Ch and Silage-Pr diets, the silage was mixed with the basal feed in a mixer (Syntesi 140, Epox Maskin AB) before every feeding and the mixed feed was fed manually. The basal feed was optimized to meet the nutritional requirements of fattening pigs when mixed with silage in a 60:40 ratio.

Chemical composition and energy value of the control diet, Pellet-S diet, basal feed used in the Silage-Ch and Silage-Pr diets, and Silage-Ch and Silage-Pr diets as-fed are presented in Table 1. More detailed descriptions of the animals, feed production, preparation of feed

rations and feeding regime from start of the study to slaughter of the pigs can be found in Friman et al. (2021).

## Data collection

### Collection and analyzes of fresh manure

The term ‘manure’ is used in this paper to refer to a mixture of faeces and urine. To evaluate the effect of the dietary treatments on N excretion and NH<sub>3</sub> volatilization from fresh manure, fresh manure was collected at pen level. At an average age of 95 days (95  $\pm$  1 d) and average LW of 59.1 kg ( $\pm$  6.8 kg), the pigs were moved pen-wise to one of two modified pens, positioned adjacent to each other, that allowed collection of both urine and faeces from two groups of pigs simultaneously (Figure 1). The pens had a concrete floor (with gravelled surface to avoid slipping) with 10° slope towards the manure culvert. A bucket was placed in the manure culvert to enable continuous collection of urine and avoid losing any manure during collection (Figure 1).

Fresh manure was collected from pigs from two different original pens and dietary treatments per day, i.e. sampling fresh manure from all eight pens in each batch took four days (Figure 2). Batch 1 was sampled first and batch 2 two weeks later (Figure 2).

Pigs were fed in their home pen at 07:00 h and moved to the modified manure collection pens 45 min after feeding. In the collection pens, they did not receive any feed, but had free access to water. Once every hour, the pigs were moved to a waiting area positioned next to the collection pens and all manure on the pen floor was manually scraped and transferred to a plastic container with a tight-fitting lid to prevent gaseous losses. Any faeces and urine that accumulated in the bucket in the manure culvert were also added to the plastic container.

When a total of 5 L of manure had been obtained from the hourly collections, the pigs were moved back to their home pen. The plastic container was stored in a cool room (+4°C) to minimize NH<sub>3</sub> losses. The time taken to collect a 5-L manure sample per pen was recorded and later used to calculate the average collection time for all pens in each treatment. Average collection time per treatment was used in turn to calculate total daily manure production (24 h). After each sampling had been completed and the pigs had been moved back to their home pen, the collection pen was thoroughly cleaned with water and left to dry until the next day, when a new round of manure collection started. The 5-L manure samples from each pen were pooled into a 10-L sample per dietary treatment in each batch and these two 10-L samples were merged further into a pooled 20-L manure sample

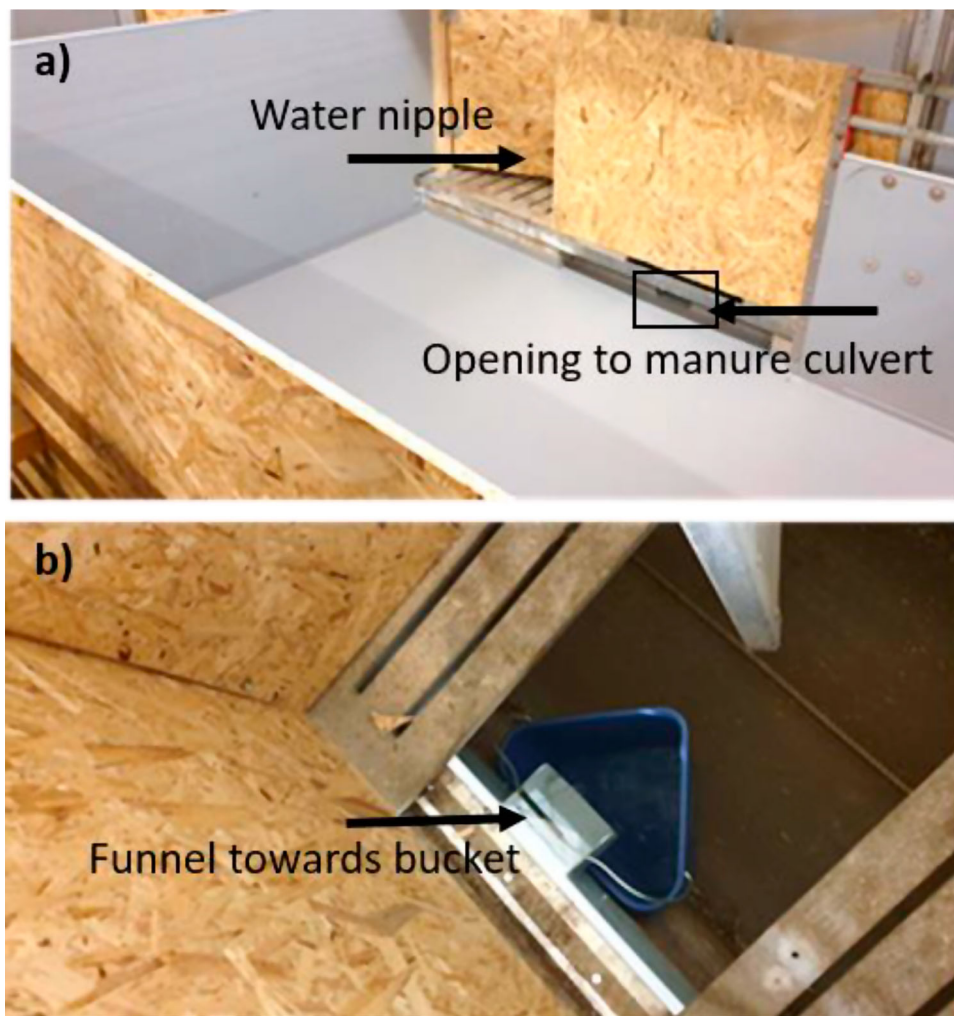
**Table 1.** Chemical composition ( $\text{g kg}^{-1}$  dry matter (DM)), energy content ( $\text{MJ kg}^{-1}$  DM) and amino acid content (% feed) in the Control diet, Pellet-S diet, basal feed for the total mixed ration (TMR), chopped (Silage-Ch) and intensively treated (Silage-Pr) silage and TMR as fed (Silage-Ch and Silage-Pr) (source: Friman et al., 2021).

	Control diet	Pellet-S diet	Basal feed <sup>b</sup>	Chopped silage, Silage-Ch	Intensively treated silage, Silage-Pr	Silage-Ch as-fed	Silage-Pr as-fed
Dry matter, %	88	89	88	34	35	66	67
Gross energy	18.3	18.9	19.5	16.7	17.2	18.4	18.6
Net energy <sup>c</sup>	11.0	11.0	11.8	8.1	8.9	10.3	10.6
Crude protein	191	202	205	183	178	196	194
Crude fat	36	51	69	–	–	41	41
Ash	51	59	42	95	97	63	64
Neutral detergent fibre	126	157	117	384	361	224	215
Lysine	0.945	0.890	1.02	0.727	0.690	0.903	0.888
Methionine	0.270	0.247	0.282	0.288	0.269	0.284	0.277
Threonine	0.629	0.713	0.765	0.720	0.684	0.747	0.733
Valine	0.742	0.846	0.857	0.880	0.895	0.866	0.872

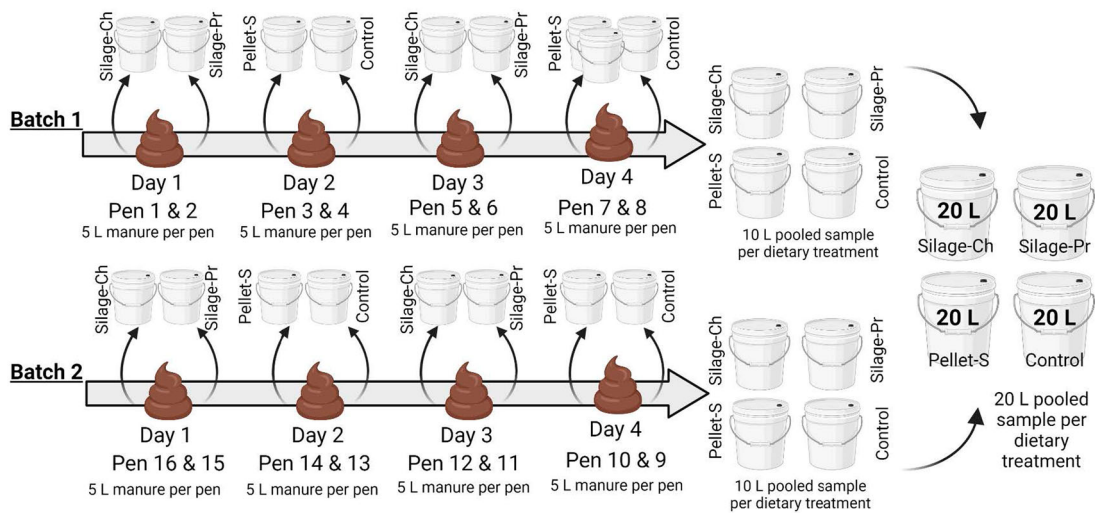
<sup>a</sup>Pellet-S: complete pelleted feed including silage pellets; Silage-Ch: commercial feed mixed with chopped silage fed as total mixed ration (TMR); Silage-Pr: commercial feed mixed with intensively processed silage fed as TMR.

<sup>b</sup>Basal feed optimized for mixing with silage in TMR.

<sup>c</sup>Estimated according to Lindberg and Andersson (1998), where energy digestibility ( $\text{dE}\%$ ) =  $94.8 + (-0.93 \times \text{NDF}\%)$  and digestible energy ( $\text{DE}$ ) =  $\text{dE} \times \text{GE}$ ,  $\text{ME} = 0.95 \times \text{DE}$  and  $\text{NE} = 0.75 \times \text{ME}$ .



**Figure 1.** The picture shows the layout of the manure collection pen and the (a) location of the water nipple and the opening towards the manure culvert and (b) the bucket placed in the manure culvert. The wooden walls prevent water from splashing into the bucket in the manure culvert.



**Figure 2.** A schematic overview of the sampling method. Each day pigs from two pens were moved to two different manure collection pens. In total, 5-L of manure was collected per pen. The 5-L manure samples from each pen were pooled into a 10-L sample per dietary treatment in each batch and these two 10-L samples were merged further into a pooled 20-L manure sample representing one dietary treatment from both batch 1 and 2.

representing one dietary treatment from both batch 1 and 2 (Figure 1).

#### Chemical analysis of fresh manure

From the 20-L pooled manure sample from each dietary treatment, two sub-samples (each approximately 0.5 L) were extracted, frozen and sent to Eurofins (Eurofins Agro Testing Sweden AB, Kristianstad, Sweden) for chemical analysis according to internationally approved standard methods (EC, 2009). The samples were analyzed for dry matter (DM) content (%), tot-N content (g/kg), ammonium nitrogen ( $\text{NH}_4\text{-N}$ ) content (g/kg) and pH. For determination of DM, the manure samples were dried at 103°C for 20 h (EC, 2009). Total-N and  $\text{NH}_4\text{-N}$  content was determined by the Kjeldahl + de-war-das method (EC 152/2009 mod) (EC, 2009). pH was measured directly in the sample.

#### Calculation of nitrogen content in fresh manure

To account for different numbers of pigs ( $n = 30\text{--}32$ ) in each dietary treatment, the calculations in this study were first performed on pen level. The values were then divided by the actual number of pigs in each dietary treatment, to obtain a mean value for each pig.

Expected content of N in fresh manure was calculated using Swedish standard values (Swedish Board of Agriculture, 2018), based on daily feed intake (ADFI) (kg) and average daily weight gain (ADWG) (g/d). Calculated N content was then compared with the N content determined by Eurofins analysis, to see how well the values matched. The N content in fresh manure (g/d) was

calculated based on N intake (g/d) via feed provided during the day of manure collection (for each specific pen, calculated as kg feed multiplied by N (g/kg) content in the diet (calculated as crude protein (g/kg) divided by 6.25)), and the amount of N (g) retained in ADWG (g/d). Individual weighing of the pigs was performed two weeks before and two weeks after manure was collected (i.e. with 28 days between weighings) and ADWG was calculated as:

$$\begin{aligned} & (\text{Pig LW after manure collection} \\ & - \text{Pig LW before manure collection}) / 28 \end{aligned} \quad (1)$$

The content of N in manure (g) was calculated as:

$$\text{N in fed feed (g)} - (\text{ADWG (g)} \times 0.026) \quad (2)$$

where 0.026 is a constant which assumes that 2.6% of weight gain retains N (Poulsen & Kristensen, 1998; Poulsen et al., 2006; Swedish Board of Agriculture, 2018).

The time taken to collect 5 L of manure for each pen was averaged for each dietary treatment. The value obtained was used to calculate total daily manure production (kg/pig/24-h period) as:

$$\begin{aligned} & (20\text{L}) / \text{Number of pigs in the treatment} \\ & \times (24\text{h}) / \text{Collection time for 5 L manure} \end{aligned} \quad (3)$$

where 20 is total volume of collected manure per dietary treatment and it was assumed that 1 L of manure had a volume weight of 1:1 (i.e. 1 L weighed 1 kg).

Finally, based on the analyzed chemical composition in the manure samples, N excretion per day (g) was calculated per treatment and divided by number of pigs in

each dietary treatment:

$$\frac{(\text{Measured content of N (g/kg)} \times 20) \times (24\text{h})}{\text{Collection time for 5 L manure)/} \quad (4)$$

Number of pigs in the treatment

### NH<sub>3</sub> measurements

To assess NH<sub>3</sub> volatilization from fresh manure in the different dietary treatments, a laboratory-scale experiment was performed on the pooled manure sample from each dietary treatment. For this, the pooled samples were mixed well and 1-L subsamples were extracted and placed in plastic trays (50 cm × 50 cm) set out in a randomized design in a well-ventilated cool room, with a controlled temperature of +10°C, in the RISE laboratory in Uppsala. This procedure was repeated four times (Blocks 1–4) (i.e. in total 16 trays, four per dietary treatment). The temperature in the manure was measured at the start and room temperature was measured during the experiment, using a temperature logger (TinyTag TV-4050, Gemini, Great Britain). The NH<sub>3</sub> concentration in air above the manure surface in each tray was measured using passive diffusion samplers (type PDS 20 × 10 mm) fitted in ventilated chambers (cuvettes) according to Svensson (1993) and Larsson et al. (1999). The appropriate exposure time was determined using a Kitagawa APS-1 gas meter with 105SD NH<sub>3</sub> test tube (0–20 ppm). The exact exposure time for each tray of fresh manure was documented (around 15 min). The passive diffusion samplers were then removed from the trays, placed in capsules with tight-fitting lids and sent to the laboratory for extraction and analysis of absorbed NH<sub>3</sub>. Amount of volatilized NH<sub>3</sub> was

calculated as described by Svensson (1993) and Larsson et al. (1999).

### Statistical analyzes

Four pigs had to be excluded from the experimental treatments (one each from Silage-Ch and Silage-Pr, two from Pellet-S) due to illness not caused by the dietary treatments and were not included in the statistical analysis. A further one pig was excluded from the Control treatment. Descriptive statistics were calculated in SAS, version 9.4 (SAS, 2021), using Proc MEANS. The effect of dietary treatment on weight gain was analyzed using Proc MIXED, with pig as experimental unit. The model included dietary treatment (Control, Pellet-S, Silage-Ch and Silage-Pr), batch (1 and 2) and gender (male and female) as fixed effects, and pen nested within batch (pen 1–16, 8 pens/batch, i.e. including the effect of the unique pig group) and birth litter nested within batch as random effects. Initial weight was included as a continuous covariate when analyzing daily weight gain and was found to be significant. For feed energy, protein and neutral detergent fibre (NDF) intake and nitrogen conversion ratio (NCR) (g N per kg growth), the model included dietary treatment (Control, Pellet-S, Silage-Ch and Silage-Pr) and batch (1 and 2) as fixed effects, with pen as the experimental unit. No statistical analysis was performed on the manure samples or on NH<sub>3</sub> volatilization, due to few replicates and lack of variation. Differences in the chemical composition of manure, N excretion and NH<sub>3</sub> volatilization are thus only presented as numerical differences between treatments.

**Table 2.** Effect of treatment on feed intake, nitrogen (N) intake, neutral detergent fibre intake (NDF), weight gain and N conversion ratio (g N g N kg<sup>-1</sup> gained) in pigs fed the four diets (Control, Pellet-S, Silage-Ch and Silage-Pr)<sup>a</sup> on the day on which fresh manure was collected. The values relating to feed are mean per pig in each treatment, based on the feed provision per pen. Live weight values from weighing before and after manure collection, and daily weight gain during manure collection, are based on individual weights. All values are least square means, with pooled standard error (SEM). Inv = no. of pigs per treatment.

	Control (Inv = 32)	Pellet-S (Inv = 30)	Silage-Ch (Inv = 31)	Silage-Pr (Inv = 31)	SEM	P*
Feed intake (kg d <sup>-1</sup> )	2.4 <sup>a</sup>	2.6 <sup>a</sup>	3.2 <sup>b</sup>	3.2 <sup>b</sup>	0.1	0.001
Energy intake (MJ NE d <sup>-1</sup> )	23.5 <sup>ab</sup>	25.1 <sup>b</sup>	21.6 <sup>a</sup>	21.9 <sup>a</sup>	0.7	0.010
Nitrogen intake (g N d <sup>-1</sup> )	65.1	73.5	66.1	66.8	2.1	0.060
Neutral detergent fibre intake (g NDF d <sup>-1</sup> )	268.4 <sup>a</sup>	358.4 <sup>b</sup>	469 <sup>c</sup>	463.6 <sup>c</sup>	12.0	0.001
Nitrogen conversion ratio (g N kg <sup>-1</sup> growth)	59.1	65.9	65.0	61.6	2.3	0.198
Live weight before manure collection (kg)	44.9 <sup>ab</sup>	45.6 <sup>b</sup>	42.9 <sup>c</sup>	44.2 <sup>ac</sup>	0.4	0.001
Live weight after manure collection (kg)	76.1 <sup>a</sup>	76.5 <sup>a</sup>	71.9 <sup>b</sup>	74.6 <sup>ab</sup>	1.2	0.010
Daily weight gain during manure collection (g d <sup>-1</sup> )	1100 <sup>a</sup>	1116 <sup>a</sup>	1018 <sup>b</sup>	1086 <sup>a</sup>	14.0	0.002

<sup>a</sup>Pellet-S: complete pelleted feed including silage pellets; Silage-Ch: commercial feed mixed with chopped silage fed as total mixed ration (TMR); Silage-Pr: commercial feed mixed with intensively processed silage fed as TMR.

<sup>b</sup>Basal feed optimized for mixing with silage in TMR.

\*Different superscript letters within rows indicate pairwise differences at  $P < 0.05$ .

## Results

### Daily feed intake and daily weight gain

The feed provided was fully consumed in all four treatments and no residuals were collected. Pigs in the Silage-Ch and Silage-Pr treatments had higher daily feed intake ( $P < 0.001$ ) than pigs in the Pellet-S and Control treatments, but N intake did not differ significantly between the dietary treatments. NDF intake was significantly higher in pigs in the Silage-Ch and Silage-Pr treatments than pigs in the Pellet-S and Control treatment ( $P < 0.001$ ), and pigs in the Pellet-S treatment had higher NDF intake than those in the Control treatment ( $P = 0.001$ ) (Table 2).

Comparison of ADWG in pigs based on their LW before and after manure collection revealed that dietary treatment had a significant effect ( $P = 0.002$ ). Live weight gain was significantly lower in pigs in the Silage-Ch treatment compared with those in all other treatments ( $P = 0.002$ ). Before manure collection, pigs in the Silage-Ch treatment had significantly lower LW than pigs in the Pellet-S ( $P < 0.001$ ) and Control treatments ( $P = 0.01$ ), while pigs in the Silage-Pr treatment had lower LW than those in the Pellet-S treatment ( $P = 0.05$ ). At the weighing after manure collection, pigs in the Silage-Ch treatment had significantly lower LW than those in the Pellet-S ( $P = 0.01$ ) and Control treatments ( $P = 0.02$ ). There were no significant differences in NCR between pigs in the four dietary treatments (Table 2).

### Manure production and nitrogen in fresh manure

The dietary treatments had a numerical effect on the chemical composition of fresh manure. Fresh manure from pigs in the Silage-Ch and Silage-Pr treatments had numerically higher tot-N content (g/kg DM)

**Table 3.** Content of dry matter (DM %), total nitrogen (tot-N) (g/kg fresh manure and % DM), ammonium-nitrogen (NH<sub>4</sub>-N) (g/kg fresh manure and % DM) and pH in fresh manure (faeces + urine) from pigs fed the four dietary treatments (Control, Pellet-S, Silage-Ch and Silage-Pr)<sup>a</sup>.

	Control	Pellet-S	Silage-Ch	Silage-Pr
DM (%)	18	17	14	16
Tot-N (g/kg)	8.8	8.0	7.4	7.6
Tot-N (% DM)	48.9	47.1	52.9	47.5
NH <sub>4</sub> -N (g/kg)	3.6	2.7	2.7	2.2
NH <sub>4</sub> -N (% DM)	20.0	15.9	19.3	13.8
pH	6.97	6.39	6.89	6.62

<sup>a</sup>Pellet-S: complete pelleted feed including silage pellets; Silage-Ch: commercial feed mixed with chopped silage fed as total mixed ration (TMR); Silage-Pr: commercial feed mixed with intensively processed silage fed as TMR.

<sup>b</sup>Basal feed optimized for mixing with silage in TMR.

than fresh manure from the Control treatment (Table 3).

The NH<sub>4</sub>-N content (g/kg) was numerically lower in fresh manure from pigs in the Silage-Pr treatment than in manure from pigs in the other treatments. The content of NH<sub>4</sub>-N in manure did not differ between pigs in the Pellet-S and Silage-Ch treatments. Pigs in the Control treatment had numerically higher NH<sub>4</sub>-N content in manure than pigs in the treatments that contained silage.

Dietary treatment influenced the DM content of manure, which was highest in the Control and Pellet-S treatment and lowest in the Silage-Ch treatment. Manure pH was not affected by dietary treatment (Table 3).

The time taken to collect 5-L of manure was on average 3 h for the Silage-Ch and Silage-Pr treatments and 4 h for the Pellet-S and Control treatments. Total manure production was numerically higher for pigs in the Silage-Ch and Silage-Pr treatments than for pigs in the Pellet-S and Control treatments. Daily N excretion (g N/d) was numerically higher for pigs in the Silage-Ch and Silage-Pr treatments than those in the Pellet-S and Control treatments. Pigs in the Pellet-S treatment excreted less N than pigs in the Control treatment (Table 4).

### Ammonia volatilization from manure

The amount of NH<sub>3</sub> volatilized from manure was numerically higher (17.9 g NH<sub>3</sub>-N L<sup>-1</sup>) for pigs in the Control treatment than for pigs in the treatments containing silage (Figure 3). Manure from pigs in the Silage-Pr treatment showed lower NH<sub>3</sub> volatilization (5.2 g NH<sub>3</sub>-N L<sup>-1</sup>) than manure from pigs in the other treatments. However, NH<sub>3</sub>-N volatilization from manure did not differ between pigs in the Pellet-S (11.3 g NH<sub>3</sub>-N L<sup>-1</sup>) and Silage-Ch (10.9 g NH<sub>3</sub>-N L<sup>-1</sup>) treatments. There was a direct relationship between NH<sub>4</sub>-N content (g/kg) in fresh manure and NH<sub>3</sub> volatilization, where higher NH<sub>4</sub>-N content resulted in higher NH<sub>3</sub> volatilization (Figure 3). The procedure used for extracting subsamples from the pooled manure sample (20 L) for each dietary treatment gave representative samples for NH<sub>3</sub> volatilization analysis, as confirmed by the two subsamples having similar nutrient content.

## Discussion

Previous studies have used mathematical models to calculate expected N excretion based on N content in feed, feed intake and the amount of N contained in daily weight gain (Poulsen & Kristensen, 1998; Vu et al.,



**Table 4.** Time taken to collect 5-L of fresh manure, daily manure production, nitrogen (N) retained in average daily weight gain (ADWG), calculated N excretion based on standard values, and measured daily N excretion based on chemical analysis in fresh manure (faeces + urine) from pigs in the four dietary treatments (Control, Pellet-S, Silage-Ch and Silage-Pr)<sup>a</sup>. N in ADWG values are based on individual pig weights. Daily manure production and measured daily N excretion values are based on the pooled manure sample from each dietary treatment, taking into account the time required for manure collection (5-L) and number of individual pigs (Inv) in each treatment, presented as means for each pig per treatment. All values except N in ADWG are per kg fresh manure.

	Control (Inv = 32)	Pellet-S (Inv = 30)	Silage-Ch (Inv = 31)	Silage-Pr (Inv = 31)
Time taken to collect 5 L manure (h)	4	4	3	3
Measured daily manure production (kg/d) <sup>1</sup>	3.8	4.0	5.2	5.2
N in ADWG (g) <sup>2</sup>	28.6	29.0	26.5	28.3
Calculated N excretion (g/d) <sup>3</sup>	36.5	44.2	39.5	38.4
Measured N excretion (g/d) <sup>4</sup>	33.0	32.0	38.0	39.0

<sup>a</sup>Pellet-S: complete pelleted feed including silage pellets; Silage-Ch: commercial feed mixed with chopped silage fed as total mixed ration (TMR); Silage-Pr: commercial feed mixed with intensively processed silage fed as TMR.

<sup>b</sup>Basal feed optimized for mixing with silage in TMR.

<sup>1</sup>Calculated as: (20-L manure/Number of pigs in the treatment) × (24/collection time for 5-L manure) where 1-L of manure have a volume weight of 1:1, e.g. 1 L weighs 1 kg.

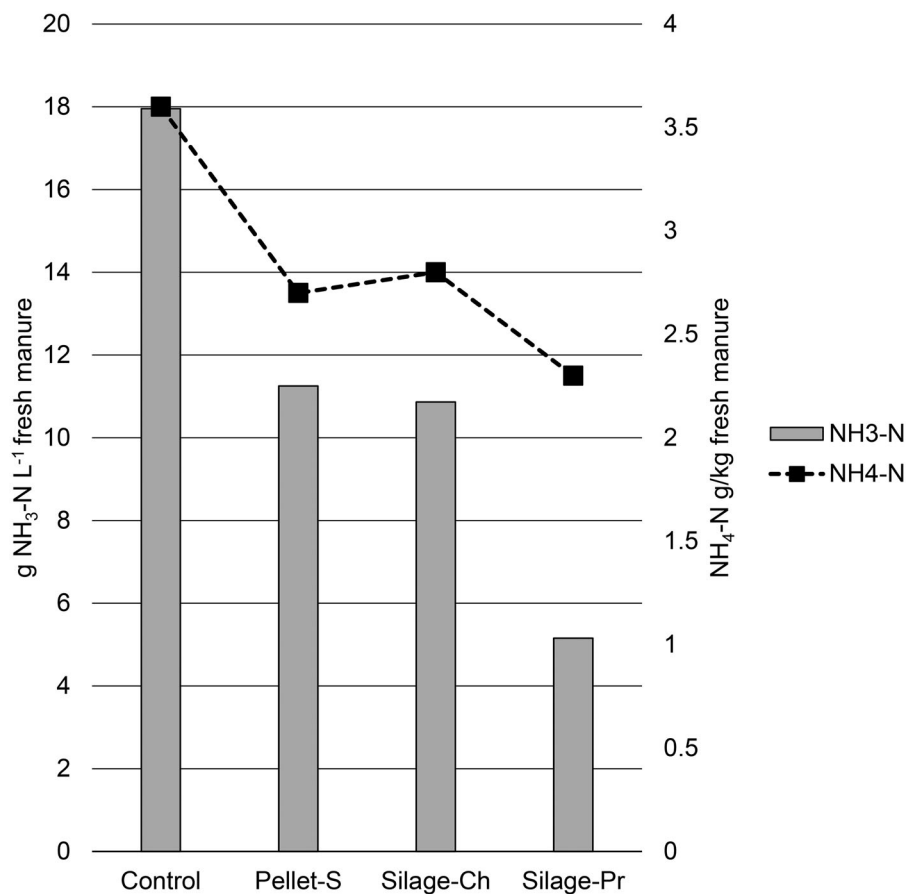
<sup>2</sup>Calculated as: average daily weight gain × 2.6%.

<sup>3</sup>Calculated as: nitrogen intake – nitrogen in average daily weight gain.

<sup>4</sup>Calculated as: (Measured content of N (g/kg) × 20) × (24 (h)/Collection time for 5-L manure)/Number of pigs in the treatment.

2009; Poulsen et al., 2006). It has been shown that N excretion can be calculated with high accuracy using this standardization of N intake minus N retention in

growth. The volume produced and composition of the faeces are primarily dependent on the chemical composition of the feed, while the volume of urine produced is



**Figure 3.** Effect of diet, Control, Pellet-S, Silage-Ch and Silage-Pr, on (bars) ammonia (NH<sub>3</sub>) volatilization (g NH<sub>3</sub>-N L<sup>-1</sup>) from 1-L of fresh manure (faeces + urine) to the air above and (dotted line) content of NH<sub>4</sub>-N (g NH<sub>4</sub>-N kg<sup>-1</sup>) in fresh manure. Pellet-S: complete pelleted feed including silage pellets; Silage-Ch: commercial feed mixed with chopped silage fed as total mixed ration (TMR); Silage-Pr: commercial feed mixed with intensively processed silage fed as TMR.

dependent on how much water the pig drinks (Poulsen & Kristensen, 1998). Since N excretion differs between individual pigs due to biological variation, but also other factors (Friman et al., 2021), the present study used pooled manure samples to reduce the influence of this biological variation on the overall dietary treatment effects.

The values obtained based on the standardized assumption seemed to be accurate for the Control, Silage-Ch and Silage-Pr treatments, as calculated and analyzed manure N content were similar. However, the assumption seemed to be less accurate for the Pellet-S treatment, where N excretion was lower than expected. The reason for these differing results is not clear, but one suggestion is that the pigs in the Pellet-S treatment diverted more N than expected into muscle tissue. In the study by Friman et al. (2021), pigs in the Pellet-S treatment had higher daily weight gain from start of the study until slaughter (30–110 kg) than pigs in the other treatments, which indicates that this suggestion could be valid. However, further studies are needed to provide confirmation.

The N content in fresh manure, expressed as tot-N (g) per kg fresh manure, was lower in the diets with higher fibre content. However, since daily manure production was higher for the pigs in the Silage-Ch and Silage-Pr treatments, total excretion of N (g) per 24-h period was higher for pigs in those treatments than for pigs in the Pellet-S and Control treatments, which were fed less fibre. Increased manure production following higher fibre intake has also been reported in previous studies, and is likely caused by greater water retention in the large intestine (Canh et al., 1998; Galassi et al., 2010; Mpendulo et al., 2018). However, some studies have found that increased fibre intake does not result in higher total N excretion (Zervas & Zijlstra, 2002; Shriver et al., 2003; Bindelle et al., 2008; Galassi et al., 2010). The numerically higher N excretion from pigs fed the higher fibre diets in this study (Silage-Ch and Silage-Pr) is therefore not in agreement with previous findings. It has been found that high fibre intake shifts N excretion from urinary-N to faecal-N (Zervas & Zijlstra, 2002; Shriver et al., 2003; Bindelle et al., 2008; Galassi et al., 2010). In the present study, it was not possible to separate the urine from the faeces in order to investigate this shift between faecal and urinary N excretion, but the values obtained can be compared with total N excretion (urine + faeces) levels reported in previous research. One reason for the contradictory results could be the different fibre source used in this study (i.e. grass-clover silage) compared with previous studies (soybean hulls, sugar beet pulp) (Zervas & Zijlstra, 2002; Shriver et al., 2003;

Bindelle et al., 2008; Galassi et al., 2010). The latter are rich in soluble fibre, which is fermented and digested to a larger extent than insoluble fibre (Galassi et al., 2010), whereas grass-clover silage contains more cellulose and more insoluble fibre. This might have affected N excretion in the present study, since organically bound N is not digested by the pig, thereby increasing N excretion.

The experimental diets were optimized in terms of energy and protein content, but their NDF content differed, which might have had an impact on N excretion. For example, the silage used in the Pellet-S diet was more processed and the NDF content was lower than in the diets with fresh silage. The same source of fibre was used in all three experimental diets, but the pre-treatments of the silage and the difference in NDF content likely influenced the digestibility of the fibre, and hence excretion of N. The differences in N excretion seen for the treatments in this study, and between this and previous studies, indicate that more detailed analysis is needed, especially regarding digestibility and availability of N in the diet when new feed sources are tested, but also regarding the effect of different pre-treatment methods. Further research involving detailed analysis of separate urine and faeces samples could be valuable in understanding the N excretion pattern when using grass-derived feed sources.

The results showed that feeding pigs a diet containing silage has the potential to reduce both  $\text{NH}_4$  content (g/kg fresh manure) and  $\text{NH}_3$  volatilization. Numerous studies have observed a reduction in  $\text{NH}_3$  volatilization from manure when pigs are fed a high-fibre diet, as a result of reduced pH in the manure and reduced N excretion as urea in the urine (Scipioni & Martelli, 2001; Zervas & Zijlstra, 2002; Nahm, 2003; Shriver et al., 2003; Aarnink & Verstegen, 2007; Galassi et al., 2010).

The degree of  $\text{NH}_3$  volatilization at the surface of liquid manure is influenced by factors such as pH, initial total ammonium nitrogen (TAN) concentration, convective mass transfer, temperature etc. (Ni et al., 1999). In the present study, convective mass transfer coefficient and temperature were fixed and dietary treatment had no significant effect on pH in the manure, so the TAN content of fresh manure was the main factor influencing  $\text{NH}_3$  volatilization. Increasing the fibre content by including silage in the diet lowered the TAN (g/kg fresh manure) content in pig manure by around 25–40% compared with the Control treatment. This indicates good potential to reduce  $\text{NH}_3$  losses from manure, since including grass-derived feed sources in the diet of pigs in this study

reduced NH<sub>3</sub> volatilization by 35–70%. However, it should be pointed out that the experimental results presented here only represent a 24-h snapshot at a specific time in the total production period, and exclusively within an indoor housing environment. Further studies are needed to quantify NH<sub>3</sub> volatilization during the whole fattening pig production period, from 30 kg to slaughter.

Incorporating ley crops as a feedstuff for pigs into existing crop rotations can be assumed to require some adjustment time. Organic farms normally already include clover-grass leys in their crop rotation, so it could be easier to introduce silage into pig diets on organic farms.

Based on the results obtained in this study regarding possible reductions in NH<sub>3</sub> volatilization from manure, combined with data on pig performance and beneficial effects of ley in the crop rotation, there is good potential for using silage as a feedstuff for fattening pigs. In addition, ley crops have benefits for ecosystem services provision (Albizua et al., 2015; Manevski et al., 2018; Brady et al., 2019; Martin et al., 2020 etc.), further justifying use of silage in the diet of pigs.

## Conclusions

This study showed the importance of validating standardized N excretion values based on N intake minus N retention in growth when a new feed source for fattening pigs is introduced in practice. This study can conclude that pre-treatment of the silage affected digestibility and utilization of the feed, and hence N excretion. It is therefore important to consider the content and type of fibre supplied when assessing N excretion. Introducing silage into the diet of pigs showed potential to decrease NH<sub>3</sub> volatilization from fresh manure.

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## Disclosure statement

No potential conflict of interest was reported by the author(s).

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## Data availability statement

Raw data were generated at the Swedish University of Agricultural Sciences research station at Funbo Lövsta, Uppsala, and at RISE Research Institutes of Sweden, Uppsala. Derived data supporting the findings of this study are available from the corresponding author JF on request.

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