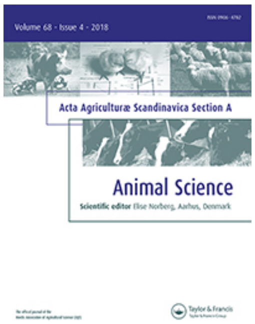

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Inclusion of intensively manipulated silage in total mixed ration to growing pigs – influence on silage consumption, nutrient digestibility and pig behaviour

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ABSTRACT
This study investigated how intensively manipulated grass/clover silage (finer structure than chopped silage) fed in total mixed ration (TMR), influenced feed consumption, total tract apparent digestibility (TTAD) and pig behaviour. Ten Yorkshire x Hampshire (YH) pigs were included in a digestibility experiment and 64 YH pigs in a behaviour experiment. Pigs received TMR with 20% dry matter inclusion of either intensively manipulated (SI) or chopped silage (SC). Behaviour was registered with instantaneous and continuous sampling. SI pigs consumed more silage ($p = 0.001$) and spent more time eating from the through ($p < 0.01$), however no significant difference in TTAD was found ($p > 0.05$). Less social interactions prior to feeding ($p = 0.029$) and less rooting after feeding ($p < 0.05$) were found among SI pigs, indicating SI pigs being more satisfied for a longer time after feeding. We conclude that TMR with intensively manipulated silage benefits feed consumption and increases the opportunities for pigs perform feed-related behaviours.

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KEYWORDS
Ley crops; grass/clover silage; feed consumption; total tract apparent digestibility; social interactions; activity; behaviour enrichment

Introduction

Ley crops, e.g. different species of grass and leguminous plants such as clover, are a potential protein source in diets to pigs as they show favourable protein and amino acid composition (Hermansen et al., 2017). Especially in organic production, leguminous plants play an important role in crop rotations due to its' N-fixing ability. Ley crops are beneficial for soil fertility, increased biodiversity and weed, pest and disease control (Spehn et al., 2002; Aronsson et al., 2007; Nemecek et al., 2008). Simultaneously, the EU regulation for organic production promote the use of sustainable and locally produced feedstuffs and provide a mandatory offer of roughage for organic pigs. Roughage provision, in addition to straw, can further increase the time pigs spend eating and foraging (Olsen et al. 2000) and therefore meets the need of pigs to explore and forage to a greater extent (Høøk Presto et al. 2009).

Forage fibre positively affect the development of the microflora and epithelium in the gut (Fernandez & Danielsen, 2002) and inclusion of e.g. grass- or legume meal can be beneficial to be included as fibre source in the pigs' diets. In order to meet the behavioural needs of pigs however, roughage should rather be manipulative and edible and inclusion of meal or pellets in the diet is a less desirable option. Given the problems such as aggressive encounters with other pigs (Lyons et al., 1995; Beattie et al., 2000) and tail biting (Wallgren et al., 2019) resulting from raising pigs in barren environments, the use of roughage is also relevant for conventional pig production.

To be able to feed ley crops throughout the year, conservation is required and consequently ensiling is common. Pigs' consumption of silage, however, varies according to their age (Wüstholz et al., 2017), the type of ley crops included, nutrient content as well as feeding technique and structure of the silage (Rundgren, 1988; Høøk Presto et al., 2009; Presto Åkerfeldt et al., 2019). The latter has also been found to influence the pigs' behaviour (Presto et al., 2013; Wallenbeck et al., 2014). It was found that when grass/clover silage replaced 20% of the energy in diets to pigs, either fed (intact in a rack) or in a total mixed ration (TMR) (silage was chopped and mixed with the other feed ingredients), the pigs sorted out parts of the silage. Thus, they did not meet their energy requirements which resulted in a slight slower growth. The major challenge of feeding pigs with silage is, in addition to maintaining

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high nutritional quality and high nutrient digestibility, also finding feeding techniques that reduce the amount of feed sorted out, without losing its function as enrichment.

The specific aims of this study were to investigate how silage manipulated in a bioextruder, with a particle length <0.5 cm (i.e. shorter than those about 1–3 cm for chopped silage) and fed as a TMR, influenced the nutrient utilisation and feeding behaviour of the pigs, and if consumption and behaviour was affected by the weight of the pigs. The hypothesis was that a finer structure of the silage would reduce the pigs' ability to sort out different parts of the TMR and that this would lead to increased consumption and higher total tract apparent digestibility (TTAD) of the silage. We further hypothesised that the finer structure of the silage in a TMR still should function as behavioural enrichment for the pigs.

Material and methods

The experiment was performed at the research facility at the Centre of Veterinary Medicine and Animal Science of the Swedish University of Agricultural Sciences, Uppsala, Sweden and at the Swedish Livestock Research Centre, Funbo Lövsta and Uppsala, Sweden, during April–June 2018. The study was approved by the Uppsala Ethics Committee on Animal Research (ethics approval number Dnr C157/2015 and 5.8.18-02003/2018), which is in compliance with EC Directive 86/609/EEC on animal experiments.

Animals and housing

The study was divided into two experiments; Exp1 on nutrient utilisation and Exp2 on behaviour. Exp1 included 10 Yorkshire * Hampshire (YH) females from two litters with an average body weight (BW) of 28.1 (±1.7) kg at start of the experiment. The pigs were housed in individual pens (1.5 × 1.8 m) on a concrete floor. The divisions between each pen were solid walls and metal bars in front of the pen to allow eye contact between pigs. No bedding was allowed during the experimental period, but the pens had rubber mats in approximately half of the pen area. Each pen had one water nipple and one feed trough and a heat lamp in the corner of the pen. Exp2 included in total 64 female and entire male (vaccinated against boar taint) YH pigs. Entire male pigs were given two injections of Improvac®, containing a modified form of GnRH (Pfizer Ltd; 2 ml per injection) to eliminate boar taint. The 1st injection was given within the first week after moving the pigs to the slaughter pig facilities (approximately 30 kg BW) and a second injection was given 4 weeks thereafter. The pigs originated from two production batches with different BW (32 pigs from each batch) and were housed in two different stables. The BW of the pigs at the start of the experiment was 40.2 (±12.1) kg in batch 1 and 79.3 (±13.6) kg in batch 2. Each batch included 4 groups of pigs in four pens (4 intact litters with 8 pigs per pen). The pens consisted of a concrete floor in the lying and feeding area and a slatted dunging area (one-third of pen area). Total pen area was 10.4 m^2, giving a floor area of 1.3 m^2 per pig. The partitions between pens in the lying area were solid walls and gates with metal bars in the slatted area. The pens had a 3.6 m long feed trough in the front of the pen and one water nipple in the slatted area. All pigs were individually monitored for disease and injuries by the staff every day and all pens were cleaned daily. During the experimental period the pigs did not have access to straw.

Dietary treatments and experimental design

In Exp1, the pigs were moved to the research facility one week prior to start of experiment. They were subjected to a dietary treatment consisting of a cereal-based basal feed, mixed with either intensively manipulated silage (SI, $n = 5$ pigs) or chopped silage (SC, $n = 5$ pigs) in a first experimental period that lasted 11 days, including 7 days of adaptation and 4 days of faecal collection. After the first experimental period, 5 of the pigs were randomly selected to be included in a second experimental period (7 days adaptation and 4 days of faecal collection), receiving a control diet containing only the basal feed (C, $n = 5$ pigs). This period was included to obtain TTAD of the C diet, in order to be used for difference calculations to estimate the digestibility of the silage. Twice a day during the experimental periods prior to feeding (in the morning and in the afternoon), feed residuals and representative samples of faeces were collected and stored in a freezer (−20°C) until analysis. After this collection, all pens were cleaned and thereafter the pigs were fed.

In Exp2 the pigs were subjected to the same dietary treatments as in Exp1, thus 32 pigs (two pens/batch and stable) were fed a cereal-based commercial feed mixed with intensively manipulated silage (SI). Correspondingly, 32 pigs (two pens/batch and stable) were fed the cereal-based commercial feed, mixed with chopped silage (SC), which was considered as the control diet. The pigs were manually fed three times per day. About 90 min after feeding, a visual estimation of the amount of feed residues was made (i.e. if the TMR was totally finished, if there was a smaller or a greater part of the TMR or silage residues left in the feed through or at the floor). However, the residues were not collected. Approximately two hours after the feeding occasion, remaining feed residues were removed from the feed troughs and pen floor preparing for the up-coming feeding occasion. The experimental period lasted six days, including four days of adaptation to the dietary treatment and two days of behaviour observations.

In both Exp1 and Exp2, the SI and SC diets were fed as TMR where the basal and commercial cereal-based feed (crushed pellets) was mixed with the silage prior to feeding. In Exp1 the basal feed in the treatment diets and the control diet, contained an indigestible marker, TiO_2 (Table 1), whereas in Exp2, the commercial feed was a traditional feed for growing pigs (Slaktfor, Lantmännen). The same silage was used for SI and SC in both Exp1 and Exp2, which constituted of a grass/clover ley, 1st cut (harvested in June) and chopped at the field the previous year, and stored in a silo at the Swedish Livestock Research Centre, Funbo Lövsta. Prior to the start of the study, the silo was opened and the silage was taken. Half of the silage was then weighed and portioned into rations per pig (Exp1) or pen (Exp2) and feeding occasion, and stored in plastic bags in a freezer (−20̊C), while half of the silage was packed and transported to be run through a bio-extruder (Lehmann-UMT GmbH, D-08543 Pöhl, Germany) for the intensive treatment. This includes a disruption of the organic material by a double-screw technique, and the organic material is mechanically crushed and atomised, accompanied by breakdown of the cell structure and hence a more efficient decrystallisation of the fibre fraction. Some heating arises by the internal friction that occurs in the process, and a pressure change will increase the accessible surface for microorganisms. After receiving the intensively manipulated silage, this was also weighed and portioned into rations, per pig (Exp1) or pen (Exp2) and feeding occasion, according to the same procedure as the chopped silage.

In Exp1 the total feed allowance was 4% of the average BW at start of the experiment and in Exp2 the total feed allowance was according to the Swedish nutrient recommendations for growing/finishing pigs, based on the average pen BW (Andersson et al. 1997). In both Exp1 and Exp2, the basal and commercial cereal-based feed accounted for 80% of the feed allowance, thus silage inclusion was 20% on dry matter (DM) basis. One day prior to feeding, silage rations were taken out of the freezer for defrosting and in direct connection prior to the feeding occasion, silage rations and cereal-based rations were mixed for each pig (Exp1) or pen (Exp2) in a bucket or in a concrete mixer and then manually fed. Daily feed rations in Exp1, corresponded to 0.68 kg silage mixed with 1 kg basal feed (for pigs in SI and SC treatments) and 1.3 kg basal feed (for pigs in C treatment). In Exp2, the daily feed rations per pig corresponded to 1.2 and 1.5 kg silage for pigs with 40 and 80 kg BW, respectively. This was mixed with 1.5 and 2.3 kg commercial cereal-based feed for 40 and 80 kg pigs, respectively. Chemical composition and energy value of the basal feed, commercial feed, SI silage and SC silage is presented in Table 2.

Table 1. Ingredient composition of the basal feed in Exp1 (% of ingredients).

Ingredient	Amount, %
Barley	51.993
Wheat	25.000
Wheat bran	10.000
Wheat middlings	8.000
Soy bean protein concentrate	2.000
Limestone	1.701
Sodiumchloride (NaCl)	0.346
Titaniumdioxide (TiO_2)	0.250
Premix finishing pigs	0.150
Lysine	0.436
Threonine	0.078
Methionine	0.046

Chemical analysis

Feed samples of the basal feed and silages were milled through a 1-mm sieve and then analysed for dry matter (DM) content by drying at 103°C for 16 h. Ash content was analysed by combustion at 550°C for 3 h (Jennische & Larsson, 1990). Nitrogen content was determined by the Kjeldahl method (Nordic Committee on Food Analysis, 1976) and crude protein (CP) was calculated as N × 6.25. Correction of the CP content for losses of nitrogen at freeze-drying was performed according to the Nordic Feed Evaluation System (Åkerlind et al., 2011). Neutral detergent fibre (NDF) was determined with ND solution (100%), amylase and sulphite (Chai & Udén 1998). Contents of acid detergent fibre (ADF) (index no. 973.18), were determined according to

Table 2. Chemical composition and energy contents of commercial feed, basal feed, chopped and intensively manipulated silage (SI) and chopped silage (SC).

	Commercial feed[a] (Exp2)	Basal feed (Exp1)	SI	SC
Dry matter (DM, g kg^{-1})	880	905	332	325
Net energy (NE), MJ kg^{-1} DM	10.6	–	–	–
Gross energy (GE), MJ kg^{-1} DM	–	18.1	19.6	19.6
Crude protein (CP), g kg^{-1} DM	150	126	187	190
Crude fat, g kg^{-1} DM	38	27	–	–
Ash, g kg^{-1} DM	52.3	51	98	95
Neutral detergent fibre (NDF), g kg^{-1} DM	–	155	459	462
Acid detergent fibre (ADF), g kg^{-1} DM	–	60	249	252
TiO_2, g kg^{-1} DM	–	2.4	–	–

[a]Nutrient content according to product declaration (Piggfor, Delta, Lantmännen Lantbruk, Malmö, Sweden).

AOAC (1990). Amino acids (AA) were determined by HPLC (SS-EN ISO 13, 903:2005). Gross energy (GE) content was measured with an Isoperibol bomb calorimeter (Parr 6300, Parr Instrument Company, Moline, IL, USA).

Estimations and calculations of nutrient utilisation

For estimation of the nutrient utilisation in Exp1 feed consumption and TTAD of organic matter (OM), energy, CP and NDF was calculated. Feed residuals were collected during the experimental period after each feeding and were pooled and weighed for each pig. The residuals were then analysed for DM by drying at 103°C for 16 h. TTAD of the treatment diets was calculated using the indicator technique (Sauer et al., 2000) according to the equation:

$$TTAD_T = 100 - (I_T * DC_F)/(DC_T * I_F)$$

where $TTAD_T$ is the total tract apparent digestibility value of the dietary component in the treatment diet (%), I_T is the indicator concentration in the treatment diet (g kg^{-1}), DC_F is the dietary component concentration in faeces (g kg^{-1}), DC_T is the dietary component concentration in the treatment diet (g kg^{-1}) and I_F is the indicator concentration in faeces (g kg^{-1}).

TTAD of the silage was calculated by difference according to Bureau et al. (1999):

$$TTAD_{Sil} = AD_T + [(AD_T - AD_C) * (propDC_C)/(propDC_{Sil})]$$

where $TTAD_{Sil}$ is the apparent digestibility value of the dietary component in the silage (%), AD_T is the apparent digestibility value of the dietary component in the treatment diet (g kg^{-1}), AD_C is the apparent digestibility value of the dietary component in the control diet (g kg^{-1}), $propDC_C$ is the proportion of the dietary component in the control diet and $propDC_{Sil}$ is the proportion of the dietary component in the silage.

Behaviour observations

Manual direct behaviour observations were performed during the last two days of the experimental period in Exp2. Data were collected by instantaneous (scan) and continuous sampling. Relevant behaviours were chosen and tested prior to the start of the study and the behaviour observations were performed according to an ethogram (Table 3).

The pigs were observed in the morning, prior to and after feeding, in the middle of the day, apart from feeding, and in the afternoon prior to and after feeding. Observations started with a scan sampling of all pigs in the pens, in each pen respectively. This was then followed by 1 min continuous observation of the eight pigs in the first pen. Thereafter, scan sampling was performed of all pigs in each pen respectively again, followed by 1 min continuous sampling of the second pen, and so it continued throughout the four pens. This procedure was called a 'session' and it took about 8 min. In the morning and afternoon, the behaviour observations were performed both prior to feeding with 1 session (8 min), and after feeding with 1 session repeated 4 times (32 min). The observations after feeding started directly when all pigs had received their feed in the troughs. In the middle of the day, apart from feeding, the observations were performed with 1 session repeated 4 times (32 min). A timeline over an observation day and the session is shown in Figures 1 and 2.

During the scan sampling all occurring behaviours for each pig in that exact moment of scanning of the pen

Table 3. Ethogram used for the instantaneous and continuous observations.

Behaviour	Definition
Laying	Laying down on the stomach or side.
Sitting	Front legs and the back part in contact with the floor.
Standing	Standing at all four feet or walking.
Eating	Snout in contact with feed trough, eating from feed through or moving around feed.
Rooting	Snout in contact with floor, eating from the floor or moving around feed residues without eating.
Drinking	Snout in contact with water nipple.
Social interactions	Snout in contact with other pig, bites other pig somewhere on body, pushes away other pig, climbing on other pig or persistent fighting with other pig.
Manipulating the surroundings	Snout in contact with fittings or surroundings, e.g. walls, fence, chains or grid.

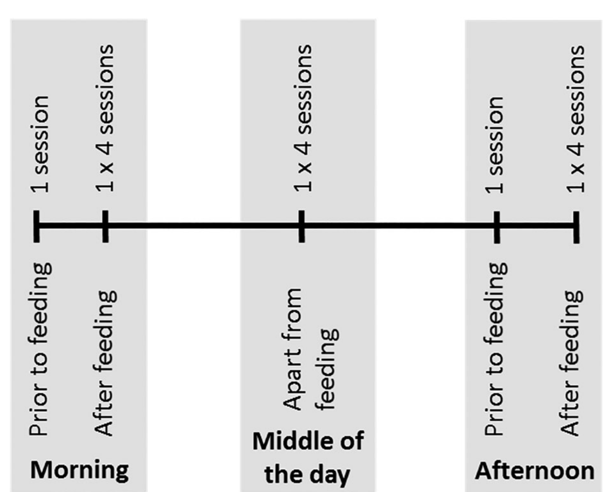

Figure 1. Timeline over the daily observations, in the morning, middle of the day and afternoon.

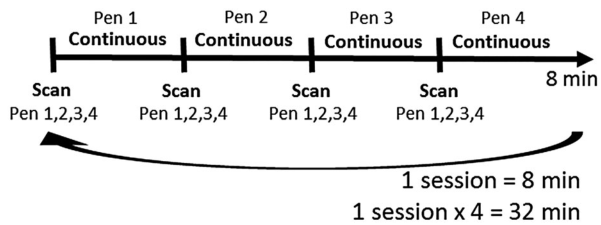

Figure 2. Timeline over a session and the procedure of data collection by instantaneous (scan) and continuous sampling.

were noted. During the continuous sampling all behaviours that occurred during the 1 min observation were recorded.

Statistical analysis

In Exp1 the statistical analysis was performed in SAS, Proc Mixed I (Version 9.4, 2016). The models for digestibility of organic matter (OM), energy, CP and NDF included treatment as fixed effect (SI, SC) and pig as a random effect. For growth, start weight was included in the model as a covariate. The analysis included pig as the statistical unit. At overall significant effect of treatment, differences between treatments were tested using least square means (t-tests). Results are presented as least square means with standard error (SEM).

In Exp2 the statistical analysis was performed using Minitab 18 (Minitab, 2018). From the continuous sampling, the variables analysed were 'eating', 'rooting', 'drinking', 'social interactions' and 'manipulate surroundings'. From the scan sampling, the variables analysed were 'active' (merging the variables 'eating', 'rooting', 'drinking', 'social interactions' and 'manipulate surroundings') and 'non-active' (merging the variables 'laying', 'sitting' and 'standing'). Data were examined for normal distribution and were found to be approximately normally distributed. Behaviour differences between treatments (SI and SC) and pig BW (40 and 80 kg) were analysed separately for the different observation occasions; previous to feeding, after feeding and separate from feeding.

Differences in the variables 'eating', 'rooting', 'drinking', 'social interactions, 'manipulate surroundings' and 'active' were analysed with general linear models. The model included the effects of day (1 and 2), treatment (SI and SC), pig BW (40 and 80) and time of day (AM and PM). Interactions between effects were examined and were included in the final model if significant ($p < 0.05$). The observation occasion 'separate from feeding' occurred only in the middle of the day, thus, the effect 'time of day' and interactions with 'time of day' was not included. The statistical units for the continuous and scan sampling was the number of times that a behaviour occurred per session (8 min) and percentage of scans (time) per observation session, respectively. Results are presented as fitted mean values with standard error of mean (SEM).

Results

Consumption of silage

In Exp1, the pigs fed with the SI diet consumed a higher proportion of the silage than pigs fed with the SC diet, 19.1% vs. 15.3% of the total DM intake (mean values, $p = 0.001$). Based on the direct visual observations in Exp2, we estimated that pigs in treatment SI finished almost all feed while pigs in treatment SC had more feed residues (still, major part consumed). Heavier pigs (80 kg) in treatment SI finished all the feed while lighter pigs (40 kg) in treatment SC were judged to have the largest amount of feed residues.

Total tract digestibility of nutrients and energy (Exp1)

The pigs in the SI and SC treatment did not differ in total weight gain during the experimental period (4.0 and 3.9 kg, respectively, $p = 0.769$) and no statistical differences were found for TTAD of OM, energy, CP and NDF in diets and silages. When comparing the TTAD for the silages, a large numerical variation in the TTAD of OM, energy and CP was found (Table 4).

Behaviour (Exp2)

Continuous sampling

During the observations prior to feeding in the morning and in the afternoon, the pigs did not have any feed, thus did not perform any eating behaviour. There were no significant differences in rooting behaviour between pigs in treatment SI and SC ($p = 0.217$, Table 5). However, pigs in treatment SC had a higher frequency of social

Table 4. Total tract apparent (TTAD) digestibility (%) of OM[a], energy, CP[b] and NDF[c] in diets and silages. Results presented as least square means with standard error (SEM).

	Diet				Silage[d]			
	SI	SC	SEM	*P*-value	SI	SC	SEM	*P*-value
OM[a]	72.5	73.0	2.10	0.736	31.3	23.6	9.74	0.373
Energy	71.3	71.2	1.75	0.928	35.6	24.0	4.99	0.146
CP[b]	60.2	60.2	3.15	0.985	16.8	8.1	12.96	0.345
NDF[c]	39.0	37.6	3.02	0.755	32.3	31.6	7.50	0.956

Notes: [a]Organic matter. [b]Crude protein. [c]Neutral detergent fibre. [d]The silage TTAD was estimated by difference calculations (Bureau et al., 1999) using the following values (%) for apparent digestibility of the control diet (AD_C): OM = 84.6; energy = 82.3; CP = 79.1 and NDF = 44.1.

Table 5. *P*-values, SEM and number of times behaviours occurred per session (8 min) in the different treatments and pig body weights (BW) prior to feeding $N = 16$, after feeding $N = 64$ and apart from feeding $N = 32$.

	Treatment				BW			
	SI	SC	SEM	*P*-value	40	80	SEM	*P*-value
Prior to feeding								
Eating	–	–	–	–	–	–	–	–
Rooting	9.5	6.0	0.25	0.217	7.0	8.5	0.25	0.592
Drinking	4.5	2.5	0.21	0.410	4.5	2.5	0.21	0.410
Social interactions	8.5	13.0	0.17	0.029	10.0	11.5	0.17	0.449
Manipulating	9.5	8.5	0.27	0.742	8.0	10.0	0.27	0.512
After feeding								
Eating	53.6	35.9	0.32	<0.01	46.4	43.2	0.32	0.486
Rooting	15.6	37.8	0.25	<0.01	27.2	26.4	0.25	0.620
Drinking	5.5	5.0	0.11	0.680	5.6	4.8	0.11	0.536
Social interactions	5.8	5.5	0.11	0.834	6.4	5.6	0.11	0.531
Manipulating	0.6	0.5	0.03	0.734	0.6	0.5	0.03	0.734
Apart from feeding								
Eating	–	–	–	–	–	–	–	–
Rooting	1.8	5.3	0.13	0.016	2.8	4.3	0.13	0.292
Drinking	1.0	6.4	0.06	0.696	0.5	1.3	0.06	0.243
Social interactions	6.5	5.3	0.15	0.466	6.8	5.0	0.15	0.309
Manipulating	3.3	4.0	0.11	0.545	1.3	6.0	0.11	<0.01

interactions prior to the feeding than pigs in treatment SI ($p = 0.029$). Rooting tended to occur more frequent on the second day of observation with 10.5 vs. 5.0 times per session for day 2 and 1 respectively (SEM = 0.23, $p = 0.045$). The BW of the pigs did not have a significant effect on the occurrence of any of the observed behaviours ($p > 0.05$ for all, Table 5).

After feeding, in the morning and afternoon, pigs in treatment SI spent more time eating than pigs in treatment SC ($p < 0.01$) whereas the SC pigs had a higher frequency of rooting compared with the pigs in treatment SI ($p < 0.01$). Social interactions and manipulating the surroundings were unaffected by treatment ($p = 0.834$ and $p = 0.734$, respectively) and BW of the pigs did not affect their behaviour ($p > 0.05$ for all, Table 5).

At observations in the middle of the day, apart from feeding, any feed residues had been removed from the pens. Thus, the pigs did not have any feed and no eating behaviour occurred. Pigs in treatment SC did, however, spend more time on rooting behaviour compared with pigs in treatment SI ($p = 0.016$). Drinking, social interactions and manipulating of pen surroundings were unaffected by treatment. Pig BW did not affect rooting, drinking and social interactions ($p > 0.05$ for all), but 80 kg pigs did manipulate the pen surroundings more frequently than 40 kg pigs ($p < 0.01$, Table 5). There was also a significant difference between the different observation days, where social interactions occurred to a greater extent (9.0 vs. 2.8 times per session for day 1 and 2, respectively, $p = 0.001$).

Scan sampling

In general, the pigs were most active during the observation occasions after feeding, on average 92% compared with 20% and 8% for the occasions prior to and apart from feeding, respectively (Figure 3). It was found that there was an effect of time of day with higher activity level after feeding in the morning than in the afternoon (95.7% vs 88.4%, respectively, $p < 0.01$). Pigs in treatment SI were less active than pigs in treatment SC both at the observations after feeding and apart from feeding ($p = 0.003$ and $p = 0.002$, respectively). Before feeding though, the activity level did not differ between the pigs in treatment SI and SC ($p > 0.05$, Figure 3).

Activity level was only affected by the BW of the pigs before feeding, with more activity among 80 kg pigs than among 40 kg pigs ($p = 0.05$, Figure 4). Effect of observation day on activity level was not consistent. The pigs were more active in the middle of the day, separate from feeding, on the first day of observation (10.3 vs 6.2% for day 1 and day 2 respectively, $p = 0.011$) whereas they were more active after feeding during the second day (90.5 vs 93.6% for day 1 and 2, respectively, $p = 0.012$).

Discussion

Increased proportion of ley in the crop rotation will increase soil fertility and biodiversity and make a more efficient land use, turning land with poorer conditions into high quality feed resources. The main part of pig production is located in areas of flat country, where a large proportion of the arable land is based on cereal production, which increase the risk of field N and P losses, compared to crop rotations with ley production (Aronsson et al., 2007). Rotation with perennial grasses was found to double the biomass yield and biomass N

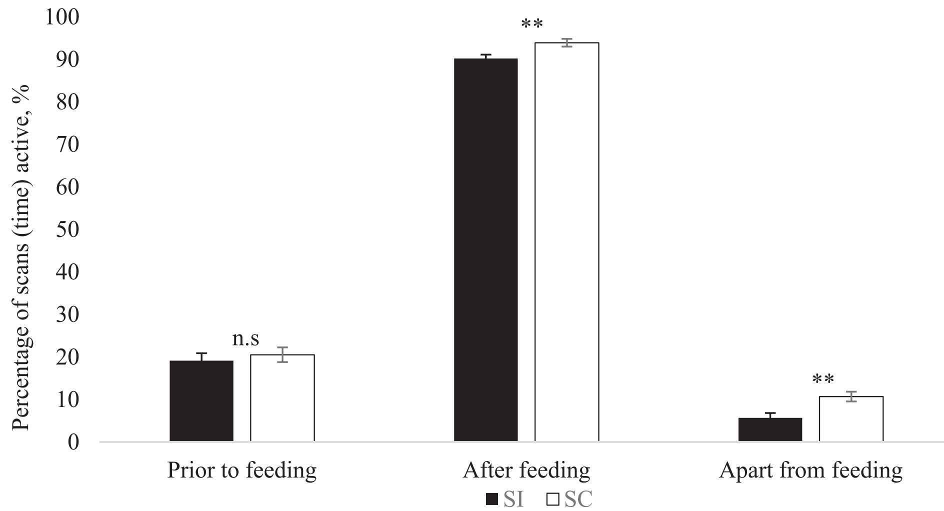

Figure 3. Percentage of scans (time) active in pigs in the different treatments (SI and SC). $N = 64$ prior to feeding, $N = 256$ after feeding and $N = 128$ apart from feeding.

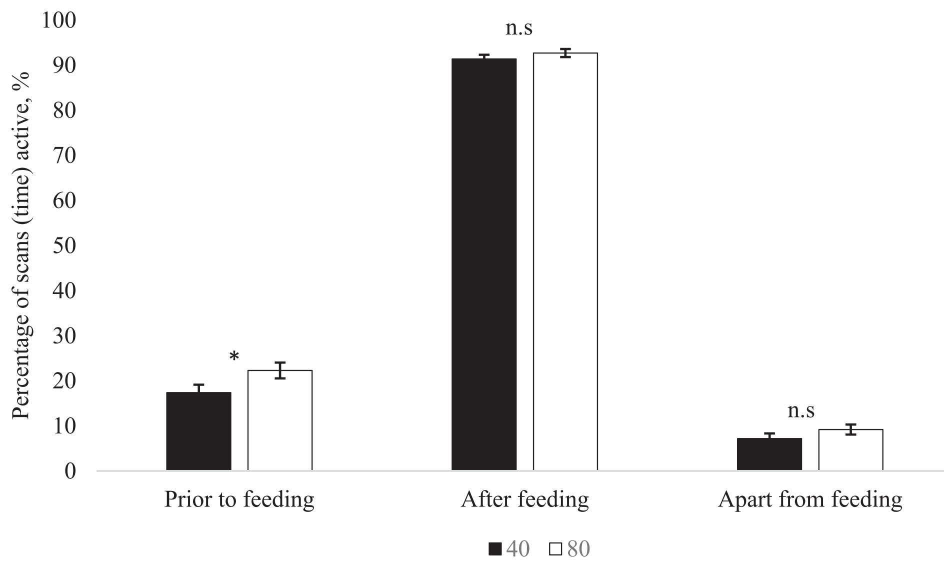

Figure 4. Percentage of scans (time) active in pigs with different BW (40 and 80 kg). $N = 64$ prior to feeding, $N = 256$ after feeding, and $N = 128$ apart from feeding.

and reduce nitrate leaching by 70–80% compared to the traditional systems with annual crops (Pugesgaard et al., 2015; Manevski et al., 2017, 2018). Long term monitoring on the agricultural plains in southern Sweden have also shown lower soil carbon contents, compared to arable soils in forest districts with large areas of ley production (Eriksson et al., 2010). This makes silage an interesting option as it can enable use of a locally produced (all-year round) feed resource in an efficient and sustainable way. In many countries organic pigs get access to ley crop silage on a daily basis, as a substrate for environmental enrichment and nutrient supply, however, it is seldom or never formulated in the feed rations as nutrient source, and the inclusion in pig diets needs to be applicable.

In order to include silage as a substantial part of the feed ration (thus replace parts of the cereal-based feed) without production losses, the silage needs to be fully consumed by the pigs. Previous research demonstrate that inclusion of 20% grass clover meal (energy basis) in a pellet, was fully consumed by the pigs and didn't affect growth or carcass quality negatively (Wallenbeck et al., 2014). However, when the silage was included in the same proportion (20% energy basis) but fed either chopped (in TMR) or intact (in racks), the pigs sorted out parts of the silage (approximately 5–10% of the amount fed) with a slightly slower growth rate (4–12% lower) as a consequence. In accordance, the silage consumption in finishing pigs fed grass or grass/clover silage was found to range between 6% and 19% of DM intake (Bellof et al., 1998; Carlson et al., 1999; Bikker et al., 2014). This corresponds well to the results found in the present study with consumption levels of 19.1% and 15.3% of the total daily DM intake for SI and SC, respectively. The results found by Wüstholz et al. (2017) on the other hand, indicate higher consumption levels (~ 20% in the starter phase,~ 40% in the grower phase and up to 50% in the finishing phase) of the total daily DM intake, when fed alfalfa silage (*ad libitum* in feed troughs) and restricted concentrate feeding. The results from Wüstholz supports our findings that heavier pigs (80 kg) in treatment SI finished all the feed while lighter pigs (40 kg) in treatment SC were judged to have the largest amount of feed residues. In our study, silage that was intensive manipulated for shorter particle length and finer structure (SI) also were proven to increase the silage consumption to be almost fully completed compared with the chopped silage. This is in contrast to the study by Wüstholz et al. (2017), who found higher consumption levels in total, but no difference between chopped and extruded (finer structure) alfalfa silage among pigs from 30 to 90 kg BW. At even higher BW (90–105 kg), pigs in that study, in fact, consumed a slightly lower amount of the extruded silage compared to the chopped one.

Although the current study did not evaluate the effect of silage inclusion on carcass quality, one could expect that without any silage refusals thus a high consumption level, the nutrient requirements could be met and the pigs should be able to express their potential for growth and lean deposition (Wallenbeck et al., 2014; Wüstholz et al., 2017). An effect of silage inclusion that has been seen is lower dressing percentage, possible due to greater gut fil (Bikker et al., 2014; Wallenbeck et al., 2014). Moreover, proportion of lean meat in the carcass increased with increased proportion of ley crops in the diet (Danielsen et al., 2000; Świątkiewicz & Hanczakowska, 2008; Bikker et al., 2014; Wallenbeck et al., 2014), probably as a result of a lower energy intake and lower capacity for fat deposition.

Forages are expected to reduce nutrient and energy digestibility. Due to a lower utilisation of energy from volatile fatty acids absorbed in the hindgut than from nutrients absorbed in the ileum, inclusion of dietary fibre content would have a negative effect on the metabolisable and net energy utilisation. The present study could not confirm any significant difference in the TTAD of nutrients and energy between the SI silage and the SC silage, neither for the diets nor for the silages. Compared with similar inclusion levels, the TTAD of OM, energy and CP for the diets in this study corresponds well with the figures presented by Andersson and Lindberg (1997a) on TTAD of barley based diets with inclusion of red clover or perennial ryegrass meal. We found lower TTAD of OM, energy and CP than those presented for diets with lucerne or white clover meal inclusion (Andersson & Lindberg, 1997b), clover-grass silage inclusion (Carlson et al., 1999) and chicory forage or grass meal inclusion (Ivarsson et al., 2012), but just slightly lower NDF digestibility compared with the figures by Andersson and Lindberg (1997a,b). There were large numerical differences, although not statistically significant, between the OM, energy and CP digestibility values for the intensively manipulated (SI) and chopped (SC) silage per se, with higher TTAD values for the SI silage. The digestibility values of OM, energy, CP and NDF for the chopped silage (SC) found in the present study are generally lower than previously reported digestibility values of different forages. For the intensively manipulated silage (SI), the digestibility values of OM (31.3%) and CP (16.8%) are slightly lower than those found for lucerne, white- and red clover, clover-grass silage and chicory. However they are comparable (or even higher) with the values for grass meal [30.6% (OM) and 4.9% (CP)] and perennial ryegrass [22.0% (OM) and 8.0% (CP)] (Andersson & Lindberg, 1997a,b; Carlson et al., 1999; Ivarsson et al., 2012). The TTAD of energy and NDF in our study was in accordance with the results reported by Andersson and Lindberg (1997a,b) as well as TTAD of energy for grass meal, presented by Ivarsson et al. (2012). The relatively large variation in digestibility values between studies, as well as within studies, can likely be explained by the methodology applied to assess ingredient specific values. We calculated digestibility values for the silage by difference and included 20% on a dry matter (DM) basis, as this would be applicable (in practical pig farming). Nevertheless, we assessed that this would be a physiologically reasonable dietary level of fibre in the diet. However, digestibility values obtained through difference calculations gets very vulnerable, even to small errors in the dataset, when low inclusion levels are applied. This has also been acknowledged earlier in studies estimating the digestibility of feed ingredients by difference calculation (Høøk Presto et al. 2011; Ivarsson et al., 2012). Although inclusion level of SI and SC silage was the same, SC pigs consumed a lower amount of the silage, which might have had a negative effect on the estimation of energy and nutrient digestibility. Moreover, the pigs used in this study were relatively young and weighted on average 28.1 kg at the start of the experiment. It is well known that the ability to digest fibre increases with age and using older pigs had therefore likely given higher NDF digestibility values. The relatively low (for SC silage in particular) and inconsistent CP digestibility values in the present study might have been due to a higher proportion of digesta shifted to hindgut digestion on the silage diets compared to the control diet. This results in more microbial matter and nitrogen being excreted in the faeces, when high levels of forage is included in the diet (Andersson & Lindberg, 1997a,b; Lindberg & Andersson, 1998). The relatively low energy digestibility of the silages will influence the corresponding estimates on the content of net energy of the silages to be low.

According to previous research (Roberts et al., 1993; Olsen et al., 2000; Høøk Presto et al., 2009) provision of silage offer pigs to express their natural foraging and exploratory behaviours. Large differences in behaviour between pigs reared in barren respectively enriched environments have been found (Petersen et al., 1995; Beattie et al., 1996, 2000). Presto et al. (2013) showed that pigs fed TMR with chopped silage or intact silage in a rack, spent a larger proportion of their time foraging compared with pigs fed only pelleted feed and straw as enrichment. The present study confirmed that TMR with inclusion of silage that was intensively manipulated for a shorter particle length and finer structure (SI) increased the silage consumption to be almost fully completed. This was also reflected in an increased time that the pigs spent eating from the feed trough. Correspondingly, pigs in the SC treatment with TMR with larger silage particles were rooting on the floor for a longer time. This indicates that they sorted out the silage to a greater extent. Despite this, social interactions between pigs in the pen or manipulating with pen fittings were unaffected by treatment in the present study. This indicates that both SI and SC treatments function as enrichment. It supports previous research showing that provision of silage have a positive influence on social behaviours, i.e. lower proportion of social interactions of pigs compared with pigs fed pelleted feed, both with and without silage inclusion (Presto et al., 2013) and lower frequency of aggressive behaviours among pigs with access to roughage than pigs with a diet without roughage (Høøk Presto et al., 2009). It is also in accordance with the conclusions made by Beattie et al. (2000) that environmental enrichment can improve welfare of pigs by reducing the frequency of aggressive social interactions. Pigs housed in barren environments often lack the opportunity to perform foraging and explorative behaviours, which causes a re-direction of behaviours towards other pigs or pen fittings (Lyons et al., 1995; Beattie et al., 2000).

Interestingly, our results indicate a positive effect of silage inclusion, even during those periods when pigs were not active with foraging behaviour, i.e. prior to the feeding events and in the middle of the day when there was no feed available. Before the feeding events, pigs in the SI treatment showed a lower frequency of social interactions than pigs in the SC treatment. Additionally, in the middle of the day, the SC pigs were spending more time on rooting behaviour compared with the SI pigs. As no feed or silage were available at this time and the fact that SC pigs consumed a lower proportion of the silage, could indicate that the SC pigs were experiencing more hunger. A higher silage consumption level might have led to that pigs in the SI treatment had a greater gut fill and possibly was satisfied for a longer time after the feeding. It has been suggested that longer periods of satiety due to higher dietary fibre content might lower the occurrence of severe aggressive interactions. Comparisons between pigs fed pelleted feed (with or without silage inclusion) showed a higher number of wounds among pigs without the silage inclusion indicating that even when roughage is milled and pelleted, it influences the social environment in a pig group (Presto et al., 2013). Emerging data also demonstrate a communication between the gut, microbiota and the brain, showing that the gut microbiota is involved in neural development and function, both in the enteric nervous system and centrally in the brain. Feed composition, and in particular dietary fibre, influences the microbiota with and an interplay between fibre intake and microbiota gut-brain axis may be a key to both short- and long term effects related to feed intake and explorative behaviours (Foster et al., 2017).

The higher activity level after feeding was expressed as eating and rooting behaviour among the pigs in the SI and SC treatments respectively. This can be regarded as normal, as pigs in commercial indoor production systems are most active adjacent to feeding. Similarly, Høøk Presto et al. (2009) found a higher frequency of pigs eating silage in the afternoon and more exploration among the pigs in the morning. Correspondingly, Olsen et al. (2000) found a higher activity level among the pigs in their study in the afternoon between 12.00 and 16.00, but also in the morning between 07.00 and 09.00. The pigs in the SC treatment in the present study had an even higher activity level after feeding (both in the morning and in the afternoon) and in the middle of the day, separate from feeding, compared with the pigs in the SI treatment. This increased activity could both indicate an increased feed-related behaviour (in terms of rooting/searching for sorted out silage from the pen floor) as well as increased occurrence of social interactions. The variables eating, rooting, drinking, social interactions and manipulate surroundings were merged into the active variable in the present study, which makes it difficult to distinguish between the different behaviours performed. Pigs being active could thus, in fact, be regarded as positive as they expressed more feed-related behaviours, but also negative as it might indicate more aggressive social interactions.

The social interactions of the pigs, in general, did not differ among lighter (40 kg BW) and heavier (80 kg BW) pigs and activity level was only affected by the BW of the pigs before feeding, with a higher activity level among 80 kg pigs than among 40 kg pigs. According to the results found by Presto et al. (2013), the proportion of time spent eating and nosing on other pigs decreased with age (i.e. 30, 50, 70 and 100 kg of live weight), but the proportion of time spent in front of the feed through increased with age, while time spent in the lying area of the pen decreased.

Differences found between the observation days could be related to either the animal condition e.g. health status or influence by the stable environment i.e. temperature. During the experimental period (Exp2), the outside temperature was high, on average +24°C. This might have contributed to higher temperatures in the stables. Quiniou et al. (1998) indicate that exposure to heat have a negative effect on pigs' feed-related behaviour. Higher temperatures have been found to reduce pigs' ingestion time per day with less time spent by the feeding station. Moreover, although the observations were performed accordingly to standard procedures and with the intention to not disturb the pigs, the presence of the observer may have affected the pigs' behaviour to some extent.

Conclusion

In conclusion, this study supports that feeding pigs TMR with intensively manipulated silage benefits silage consumption. Higher TTAD of nutrients could however not be statistically proven and large variation within and between studies, emphasis more research on nutrient digestibility of ley crop silage when included in diets to pigs. TMR with silage inclusion increase pigs' activity level and gives opportunity to both longer eating times and abilities for pigs to root. Silage with a shorter particle length and finer structure did not restrict the pigs in terms of behavioural enrichment. Our results indicate that this feeding strategy has the potential to enable an efficient use of ley crop silage as a nutrient feed source to pigs, with the extension to further improve pig welfare. The practical implications of managing this type of feeding strategy at farm level however, needs to be considered.

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

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