Circadian behavioral patterns and body weight affect ammonia emissions in a pig fattening room

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ABSTRACT

The aim of this study was to analyze the effects of the circadian behavioral patterns and body weight of pigs on the ammonia emissions produced in a pig fattening room. The microclimatic conditions, ammonia concentration and carbon dioxide were measured with a special monitoring device. The behavior of pigs (laying areas and urination places) was observed indirectly. The ammonia emissions had a linear relationship with the urination frequency on the solid floor and the body weight (BW) of pigs. In the group with a body weight of 25 kg (BW25), the urination frequency on the solid floor increased by 1% as the ammonia volatilization increased by 0.1 g pig-1 day-1. These levels were doubled in the BW50 group and trebled in the BW75 group. The pigs also had a circadian behavioral pattern. The urination frequencies on the solid floor start to increase in the morning (06–12 h) and with the highest in the afternoon (12–18 h) when the pigs were more active. This resulted in the immediate higher production of ammonia emissions. The pig BW did not affect the laying preferences of the pigs.

Key words: ammonia emissions, behavior, body weight, pig

INTRODUCTION

Pigs prefer different places for laying and dunging (Stolba and Wood-Gush, 1989; Ekkel et al. 2003). To meet the preferences of pigs with respect to the performance of the laying area, the floor type, pen partition, and local climate (temperature, air velocity, and concentration of aerial pollutants) should be taken into consideration. It is well known that pigs prefer to lay on a solid floor (Aarnink et al. 1997). The laying area should have the correct climate conditions so the pig is in its thermal comfort zone. Therefore, it is important to ensure the appropriate air flow over solid floor. This can be achieved by placing a closed partition beside the solid floor (Hacker et al. 1994, Bjerg et al. 2000), which also prevents possible attacks from other pigs (in neighboring pens), and/or by controlling the ventilation rate and temperature (Saha et al. 2011). After the thermal neutral zone is provided, pigs prefer to lay on the warm, solid floor. Baxter (1982) also found a close relationship between the location of the feeder and the laying area, and concluded that pigs tended to lay near the feeder more frequently, while they avoided excreting in that area. This behavior is observed particularly when the feeders are situated in the corners of the laying area (Wiegand et al. 1994).

The preferences of pigs for dunging areas have also been analyzed. Several studies have confirmed that pigs prefer to defecate away from their laying area (Steiger et al. 1979, Stolba and Wood-Gush 1989). In general, pigs excrete on a slatted floor (Aarnink et al. 1997). It has also been suggested that pigs prefer to excrete more frequently in well-illuminated areas (Randall et al. 1983, Taylor et al. 2006). However, after pigs have defined their places for laying and dunging, they usually do not change their behavior (Hacker et al. 1994), unless the conditions are modified. Several studies have confirmed the impact of increased temperatures on the defecation behavior of pigs. At higher ambient temperatures (25ºC for 25 kg pigs and at 21ºC for 80 kg pigs), pigs search for a cooler place to lay (Steiger et al. 1979, Fraser 1985, Huynh et al. 2005, Aarnink et al. 2006). At the same time, pigs increase their rate of urination on the solid floor (Huynh et al. 2005, Aarnink et al. 2006). This behavior is undesirable, mainly because of higher ammonia emissions (Aarnink et al. 1996).

However, very little is known about changes in pig behavior (laying and excreting) after their daily activities are modified during the different fattening stages. This knowledge could help us to understand how ammonia emissions are related to pig behavior on a daily basis. Therefore, the aim of the present study was to analyze the behaviors of pigs (urination and laying) and to determine their relationship to ammonia emissions at different pig body weights (BW; 25 kg, 50 kg, and 75 kg).

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MATERIALS AND METHODS

Animals and feed

This study was performed in accordance with Slovenian legislation related to animal protection (Animal Law 2007). Nine replicate treatments of commercial pigs (Landrace x Large White dams and Landrace x Pietrain sires) were used and each comprised 11 pigs. Three replicates represented one of three testing groups: BW = 25 kg (BW25), BW50, and BW75. All of the groups were provided with pelleted commercial feed, which is normally used in Slovenia (metabolic energy = 12 MJ kg^{-1}; crude protein = 169 g kg^{-1}; lysine = 10 g kg^{-1}). Feed was provided around 7:00 h in the morning and 15:00 h in the afternoon, while drinking water was available ad libitum. No health problems were observed during the study.

Housing

The study was conducted in the Pig Research Center at the Faculty of Agriculture and Life Sciences (University of Maribor, Slovenia), where a naturally ventilated system was used. Fresh air entered the room through a diffuse ceiling and there was one exhaust unit with a mechanical ventilator. In the present study, the same pens were used for all test groups (Fig. 1). Each pen had a solid floor (75%) and a slatted floor (25% slatted; Fig. 1). The feeder was positioned in the laying area (solid floor) while the drinking bowl was placed on the opposite side at 34 cm above the slatted floor. The pen partition was closed on both sides of the pen. The slurry pit was 2.0 m deep and was cleaned 2 weeks before the start of the research. The floor pens were cleaned once each day (in the morning).

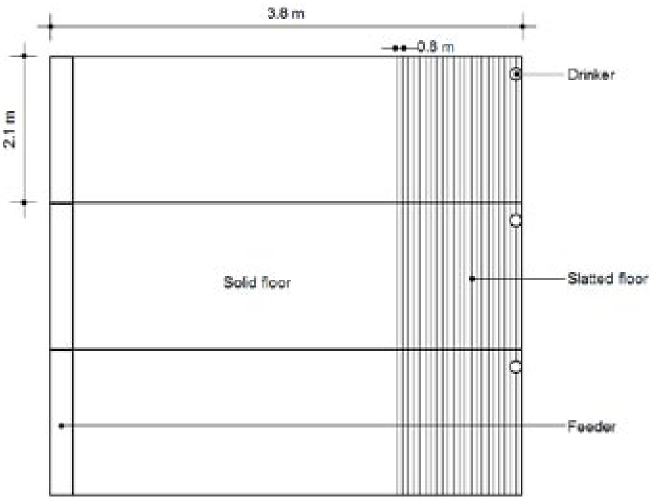

Figure 1: Layout of the pens used for each group

Measurements and calculations

Production parameters

All pigs were weighed individually at the beginning and at the end the experiment. The amount of feed per day was regularly checked. The feed intake was recorded per replicate and it was later divided by the number of pigs to calculate the daily intake per pig.

Behavioral parameters

The pigs were recorded with video cameras (The Imaging Source GigE color camera, 1024 × 768 pixels, Germany). Inox video cameras were placed on the wall. Recordings were made using one camera per indoor pen area. The behavior of the pigs was videotaped continuously. The videos were saved directly onto a Thecus N5200b server (USA) and analyzed subsequently using the GeoVision program (USA). A low level of human activity was preferred during recording (for control). The following were recorded from the videos.

1. Continuous analysis of pig urination. The analysis distinguished urination on the solid floor and on the slatted floor.
2. Scan sampling was performed every 1 h to determine the laying positions pigs, i.e., solid or slatted floor. Pigs laying on the border between the solid and slatted floors were assigned to the floor type where most of their body mass resided.

Microclimatic parameters

An Echo monitoring system (Echo d.o.o., Slovenia) was used to measure microclimatic parameters. The following parameters were measured.

- Indoor/outdoor temperature, air velocity, and relative humidity
- Ammonia concentrations and carbon dioxide

Indoor/outdoor temperature, air velocity, and relative humidity

The temperature was measured with resistance thermometers (Pt 100), which had a range of –40°C to +60°C and an accuracy of 1°C. The relative humidity was determined using a semiconductor sensor with an accuracy of ± 1% and the air velocity was measured using a thermal thin-layered detector. All of the data (temperature, relative humidity, and air velocity) were recorded four times each day and were stored automatically on an internal hard drive.

Ammonia concentration and carbon dioxide

The ammonia concentration was measured indoors using an electrochemical galvanic cell, where each group was tested separately. The sensor measurement accuracy was 1 ppm and the measurement range was 0–100 ppm. The ammonia concentration was not measured in the incoming air. In general, the incoming ammonia concentration was <5% of the ammonia concentration in the exhaust air (Aarnink et al. 1995). Therefore, the measured ammonia concentration could differ by up to 5% from the actual concentration.

Carbon dioxide was measured using two-dimensional infrared (IR) spectrum detectors. Sensors were used to determine the concentration of carbon dioxide indoors, where an absorption frequency of 4.265 μm was used. The measurement range for carbon dioxide was 0–2000 ppm, with a measurement accuracy of 1 ppm.

All of the sensors were calibrated manually each week. During calibration, the ammonia sensor was set to 0 ppm and the carbon dioxide sensor, was set to 385 ppm.

Data analysis

The ammonia emissions were calculated from the ammonia concentrations recorded during the research. The total heat production rate of the fattening pigs was calculated first, according to the equation provided by CIGR (2002):

$$\phi_{tot} = 5.09\,m^{0.75} + [1 \times (0.47 + 0.003\,m)]\,[n \times 5.09\,m^{0.75} \quad 5.09\,m^{0.75}] \qquad \text{(Eq. 1)}$$

where:
Φ_{tot} - Total animal heat dissipation in animal houses, W
m - Body mass of the pigs, kg
n - Daily feed energy relative to φ_m
Φ_m - Pig maintenance (5.09 $m^{0.75}$), W

The carbon dioxide production was calculated based on the total heat production data, according to the following CIGR method (2002):

$$c = \frac{0.185 \times \phi_{tot}}{1000} \times 24 \qquad \text{(Eq. 2)}$$

where:
c - CO_2 production, $m^3\ day^{-1}$
Φ_{tot} - Total animal heat dissipation in the animal houses, W

The ventilation rate was calculated using equation 3 (carbon dioxide balance), according to De Sousa and Pedersen (2004):

$$V = \left(\frac{c}{CO_2\ in - CO_2\ out \times 10^{-6}} \right) \qquad \text{(Eq. 3)}$$

where:
c - CO_2 production, $m^3\ day^{-1}$
CO_2 in - CO_2 concentration measured indoors, ppm
CO_2 out - CO_2 concentration measured outdoors (385 ppm), ppm

The ammonia emissions were calculated using equation 4, according to CIGR (2002) and De Souza and Pedersen (2004), as follows:

$$AE = V \times AC \times [(17/22.4) \times (273.13/(273.13 + t)] \qquad \text{(Eq. 4)}$$

where:
AE - Ammonia emission, g day^{-1}
V - Ventilation rate, $m^3\ day^{-1}$
AC - Ammonia concentration, ppm
t = Temperature, ^0C

The ammonia emissions and behaviors of the pigs (laying and urination) were calculated on a daily basis, as well as separately in the morning (06–12 h), afternoon (12–18 h), night (18–24 h), and early in the morning (00–06 h) to determine the circadian variation.

All of the data were analyzed using IMB SPSS 20. The production parameters (BW, mean daily gain, and mean feed intake) were calculated using the descriptive statistics and expressed as the mean ± SE for each separate test group (BW25, BW50, and BW75). The circadian behavioral patterns in the urination frequency and laying area preferences were compared for groups BW25, BW50, and BW75 using the Chi-square test. The data were expressed as the mean ± SD. The statistical differences are shown in the Figures as *** ($P < 0.001$).

RESULTS AND DISCUSSION

Production parameters

The pigs in the BW25, BW50, and BW75 groups had mean BWs of 22.0 kg (SE = 0.66), 48.8 kg (SE = 0.29), and 76.2 (SE = 0.78) kg; mean daily gains of 656 g d^{-1} (SE = 8.9), 742 g d^{-1} (SE = 1.6), and 638 g d^{-1} (SE = 1.7); and mean feed intakes of 1.48, 2.28, and 2.30, kg d^{-1}, respectively.

Behavioral parameters

Behavioral patterns

Figure 2 shows the differences in the urination frequencies on the solid floor for the different test groups (BW25, BW50, and BW75). Pigs in the BW25, BW50, and BW75 groups had daily urination frequencies of 3.2, 2.7, and 3.9 times per pig, respectively, and there were no significant differences in the urination frequencies (Fig. 2) between replicates within the testing groups ($P = 0.690$). The urination frequencies were affected significantly by the BW during the overall fattening period (between BW25, BW50, and BW75) ($P = 0.000$). A comparison of BW25 and BW50 (BW increase of 55%) showed that the urination frequency on solid floor increased by 10% (48 ± 5% vs. 58 ± 5%). As the BW increased further by 35% (group BW50 vs. group BW75), the urination frequency on the solid floor increased by an additional 16% (74 ± 5%). Previous studies did not document an increased urination frequency on solid floors. As the BWs of the pigs increased, they urinated more often on the solid floor because there was insufficient space per pig (Aarnink et al. 1996, Spoolder et al. 2000, Savary et al. 2009). It has also been observed that pigs change their laying behavior. With increasing body weight, pigs lay more often on slatted floors (Aarnink et al. 1996, Savary et al. 2009). However, this was not the case in the present study.

Figure 3 shows an example of the laying preferences of pigs on the solid floor. As the BW increased, the laying pattern of pigs on the solid floor remained relatively constant. In BW25, BW50, and BW75, the pigs had laid on the solid floor for averages of 80%, 80%, and 76% of the time, respectively, but only 6%, 7%, and 7% of the time on the slatted floor. High differences in the preferences for laying areas were observed within the groups. For groups BW25, BW50, and BW75, the

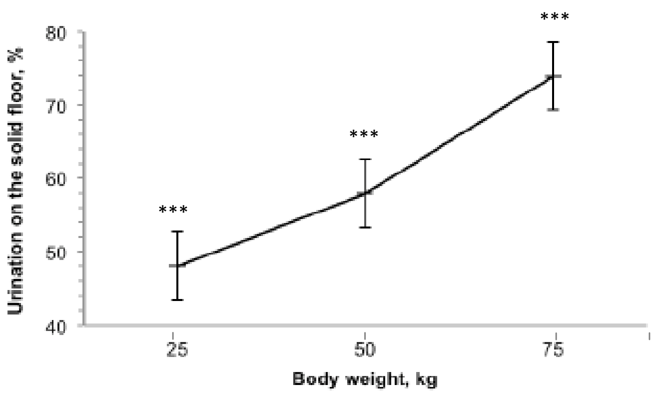

Figure 2: Urination pattern on the slatted floor with increasing pig body weight

SDs were 18%, 17%, and 25% for pigs laying on the solid floor, whereas the SDs were 5%, 5%, and 9% for pigs laying on the slatted floor (Fig. 3).

Circadian behavioral variation

Table 1 shows the frequency of urination and laying by fattening pigs in the different groups (BW25, BW50, and BW75) at different times (00–06 h, 06–12 h, 12–18 h, 18–24 h). In general, pigs urinated at least in the night time (18–24 h) and early in the morning (00–06 h). In the morning (06–12 h), the urination frequency increased (P = 0.000), with a peak in the afternoon (12–18 h) (P = 0.000) in all groups. At the same time as the peak urination frequency on the solid floor (in the afternoon at 12–18 h), the pigs laid less on the solid floor (P = 0.000), regardless of their BW. In a previous study, there was a relationship between laying on the solid floor and excretion behavior. Huynh et al. (2005) and Aarnink et al. (2006) found that pigs excreted more frequently on the solid floor and that they lay less on the solid because of increased laying on the slatted floor. However, this change in behavior was observed when the ambient temperature increased. This was not the case in the present study (conducted at thermal neutral ambient indoor temperatures). We found that the pigs did not change their behavior and they laid on the slatted floor more. In the afternoon, the pigs became more active (or laid less) (P = 0.000). Previous studies have shown that pigs start to urinate when they increase their activities, such as feeding (Groenestein et al., 2003, de Sousa and Pedersen 2004, Guarino et al. 2008). Guarino et al. (2008) observed that most pigs urinated 1 h or 2 h after feeding. Urination may also be related to the lighting regime because it has been reported that pigs prefer to urinate more often when light is provided (Randall et al. 1983, Taylor et al. 2006), which is probably because pigs are more active during the day time (Olsen et al. 2001). In the present study, artificial indoor lighting was provided for 8:00 h, starting at 7:00 h in the morning, and feed was provided at the same time (7:00 h and 15:00 h).

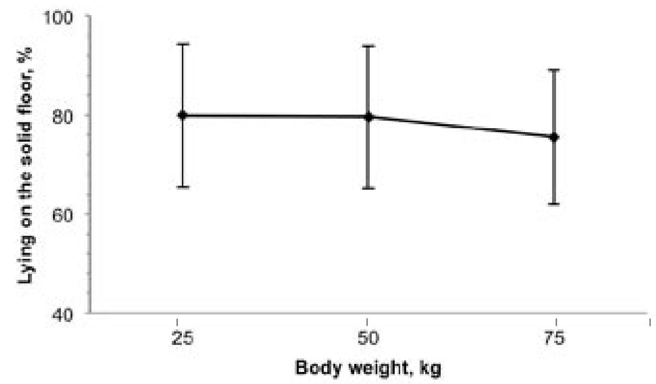

Figure 3: Laying pattern on the solid floor with increasing pig BW

However, it is not known why the pigs change their laying behavior and/or excreting behavior in the afternoon (12–18 h). It is possible that the pigs are more active during feeding time and with a higher light intensity. Thus, they start to urinate more often on the solid floor (near the feeder).

After comparing the different groups (BW25, BW50, and BW75), we found that the BW75 pigs urinated significantly less often (P = 0.000) in the afternoon (12–18 h) and more (P = 0.000) in the night time (18–24 h) compared with early in the morning (00–06 h) (P = 0.000) relative to BW25 and BW50 pigs. We hypothesized that pigs had to change their urinating patterns as their BW increased, which normally leads to space limitations. Weary el al. (2008) found that pigs with a lower status in the social hierarchy avoid contacts at the feeder and drinker. Therefore, it is possible that pigs with a low status are more active and urinate more often during the night time because they avoid contacts at the feeder and the drinking bowl. It is also possible explanation that the pigs with a higher BW (BW75) were more thirsty and hungry in the night time.

Ammonia emissions

Figure 4 shows the relationship between the urination frequency (%) on the solid floor and the ammonia emissions (g pig^{-1} day^{-1}). The regression, line Y = 0.671X – 22.795 (R^2 = 94%), shows that the ammonia emission increased linearly with increasing urination on the solid floor. The regression analysis detected a clear effect of the frequency of urinating on the solid floor on the ammonia emissions (P = 0.000). This relationship between the urination frequency and ammonia emissions has been reported in previous studies. Urine puddles on the solid floor are important sources of ammonia emissions, which are produced due to urea degradation by the enzyme urease (Groenestein et al. 2007; Ivanova-Peneva et al. 2008). Therefore, ammonia volatilization from the urine pools is related to the proportion of the solid floor in the pen. Hoeksma et al. (1992) observed that ammonia volatilization was about 30% of the total ammonia emission in pens with 62% slatted floor. Aarnink et al. (1996) also analyzed ammonia volatilization in pens with 25% and 50% slatted floors. With a 50% slatted floor, the ammonia emissions from the solid floor contributed 23% of the total emissions, and 40% of the emissions when a 25% slatted floor where used. These data shows that as the proportion of slatted floor is reduced, the ammonia emissions increase from urine pools on the solid floor, while there is a simultaneous decrease in the proportion of ammonia volatilization produced from the slurry pit. In the present study, we also calculated the impact on the am-

Table 1: Frequency (mean ± SD) of urination and laying patterns of pigs in the different bodyweight groups (BW; 25 kg, 50 kg, and 75 kg) and at different times (00–06 h, 06–12 h, 12–18 h, and 18–24 h)

Variable	BW, kg	Time, h			
		06–12	12–18	18–24	00–06
Total urination, % of total urination frequency	25	27 (1)	39 (2)	19 (1)	16 (2)
	50	21 (2)	49 (3)	14 (1)	14 (4)
	75	20 (1)	29 (2)	26 (1)	25 (1)
Urination on slatted floor, % of total urination frequency	25	9 (2)	23 (2)	11 (2)	6 (1)
	50	7 (3)	21 (3)	4 (2)	9 (3)
	75	8 (1)	8 (1)	7 (4)	2 (1)
Urination on solid floor, % of total urination frequency	25	18 (1)	18 (2)	7 (3)	9 (2)
	50	12 (3)	23 (5)	6 (2)	7 (2)
	75	32 (4)	25 (1)	16 (3)	25 (1)
Total pigs laying, % of total pigs laying	25	93 (1)	64 (2)	88 (1)	95 (1)
	50	90 (2)	60 (3)	89 (2)	91 (1)
	75	88 (2)	45 (3)	94 (1)	88 (1)
Pigs laying on solid floor, % of total pigs laying	25	88 (5)	58 (4)	80 (5)	92 (4)
	50	87 (4)	53 (3)	80 (6)	80 (4)
	75	88 (5)	35 (3)	75 (5)	88 (5)

monia emissions of the urination frequency on the solid floor by different pig groups (BW25, BW50, and BW75). When the urination frequency on the solid floor increased by 1%, the ammonia volatilization increased by 0.1 (SD = 0.01) g pig^{-1} day^{-1} in BW25, by 0.2 (SD = 0.02) g pig^{-1} day^{-1} in BW50, and by 0.3 (SD = 0.02) g pig^{-1} day^{-1} in BW75. Our results show that the ammonia emissions (due to the urination frequency on the solid floor) were also affected by the pig BW.

Figure 5 shows the relationship between BW (BW25, BW50, and BW75) and ammonia emissions (g pig^{-1} day^{-1}). The linear regression line (Y = 1.6x + 4.4 (R^2 = 90%)) shows that the ammonia emissions increased from approximately 9.5 g pig^{-1} for the BW25 pigs to approximately 25.3 g pig^{-1} for the BW75 pigs. The regression analysis showed that the ammonia emissions increased significantly with pig BW (P = 0.000).

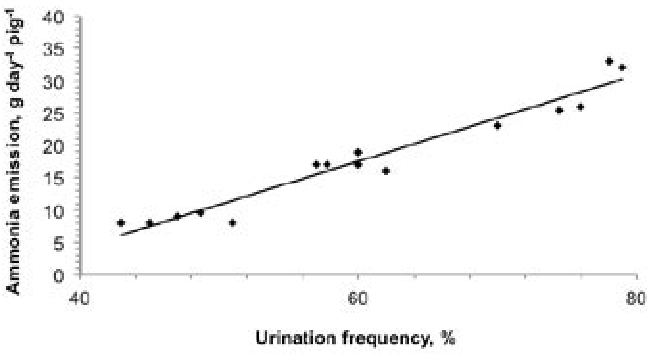

Figure 4: Relationship between the urination frequency (%) and ammonia emissions (g pig^{-1})

Circadian variation in ammonia emissions

Figure 6 shows the relationships between the ammonia emissions (g pig^{-1}) and urination frequency (%) for different pig BW groups, and at different times (in the morning (06–12 h), in the afternoon (12–18 h), in the night (18–24 h), and early in the morning (00–06 h)). The peak ammonia emissions coincided with the peak urination frequency on the solid floor. The linear regressions showed that 86%, 65%,

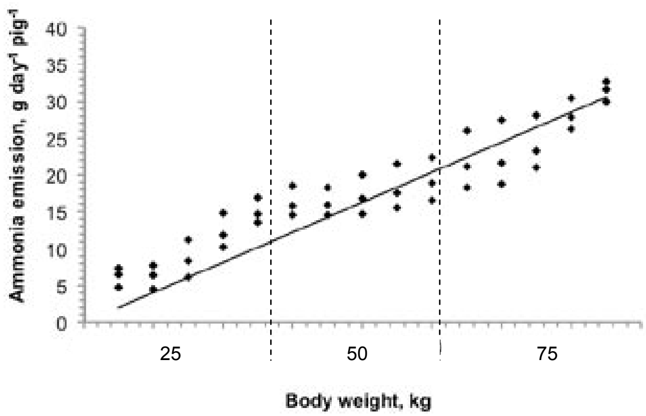

Figure 5: Relationship between pig body weight (BW25, BW50, and BW75) and ammonia emissions (g day^{-1} pig^{-1})

and 77% of the variation in ammonia emissions by groups BW25, BW50, and BW75, respectively, could be explained by the urination frequency. The data shows that there was no time gap between the moment of urination on the solid floor and the increase in the ammonia emissions. These findings agree with Elzing and Swierstra (1993) who found that the hydrolysis of urea in urine to ammoniacal N occurs immediately when urine splashes on the floor.

Therefore, it is not surprising that the lowest ammonia emissions were recorded in the night (18–24 h) and early in the morning (24–06 h), because pigs urinated the least (Table 2) at these times in all three groups. The ammonia emissions increased significantly (P = 0.000) in the morning (06–12 h) in all groups (BW25, BW50, and BW75). In BW50 and BW75, the emissions increased by 16% and 18%, respectively, while in BW25, the ammonia emissions increased at twice that rate (36%) and increased by a further 7% in the afternoon (12–18 h). However, the ammonia emissions increased by 10% in BW50 but only by 3% in BW75. Thus, the differences between the highest ammonia emissions (in the afternoon) and the lowest (early in the morning) declined as the pig BWs increased. The difference between the afternoon and early in the morning for BW25 was 36%, while for BW50 it was 25%, and 21% for BW75.

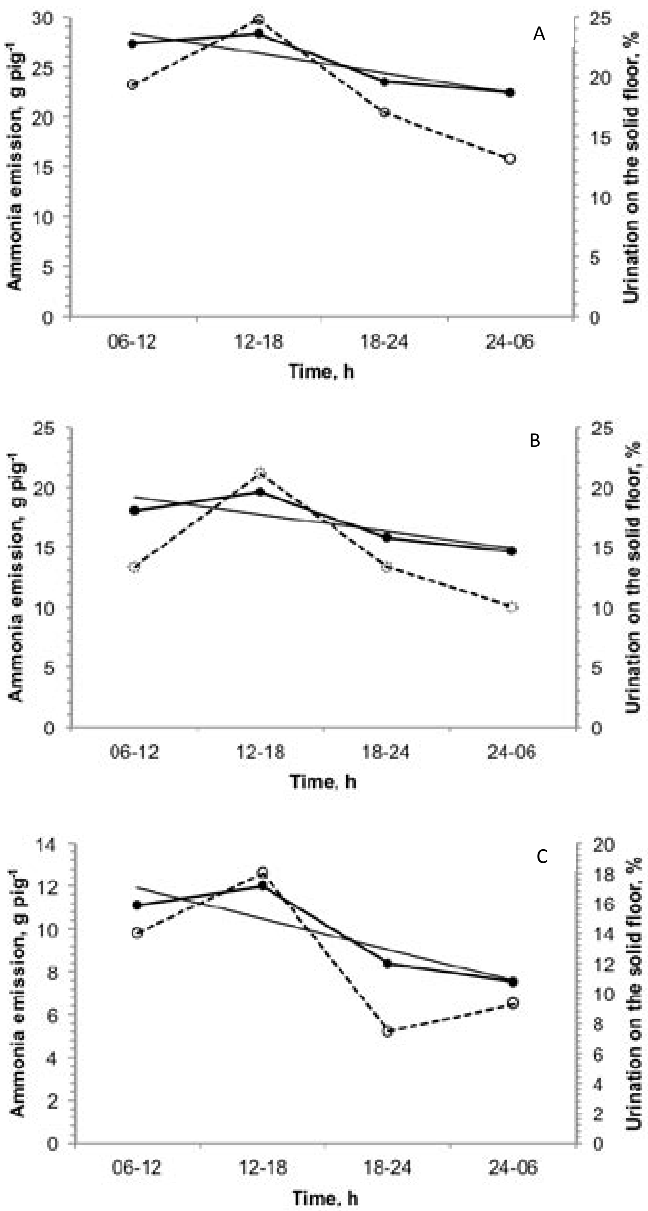

Figure 6: Relationship between ammonia emissions (g pig^{-1}) (—) and the urination frequency (%) (- - -) by different pig BW groups (C) BW25, (B) BW50, and (A) BW75

CONCLUSIONS

This study of the circadian behavioral patterns and changes in the BW of pigs detected a clear effect on the ammonia emissions produced in the pig fattening room. As the pig BW increased from 25 kg to 75 kg, the daily urination frequency on the solid floor increased by 26%, but there were no differences in the laying preferences. After analyzing the circadian variation in the urination frequency, we found that the urination frequency started to increase in the morning (06–12 h), probably due to the lighting regime and feeding time, with the highest peak in the afternoon (12–18 h) in all BW groups (BW25, BW50, and BW75). The ammonia emissions had a linear relationship with the urination frequency on the solid floor which differ among the pig BW groups. Our results show that the ammonia emissions produced in pig fattening room started to increase in the morning and the highest emissions were observed in the afternoon. These results suggest that the standard pen cleaning regime (in the morning) could be adjusted to the fouling of the pens and to production of ammonia emissions. Therefore, we recommend that the floor pens should be cleaned in the afternoon when the ammonia emissions are highest.

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