19. Modelling and influencing hygiene conditions in Australian livestock buildings

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Abstract

The main aims of the research presented here were: (1) to model the effects of important housing and management factors on the hygiene level of pig pens; and (2) to evaluate the efficacy of methods aimed at improving pen hygiene. These project aims were achieved by: (1) modelling the hygiene levels measured; and (2) conducting a number of controlled experiments. Hygiene levels were visually assessed in 160 piggery buildings using a standardised 3-step scale system. Engineering and management characteristics of the piggery buildings were recorded at the time of sampling and these building characteristics were used in the subsequent multi-factorial statistical analysis. The mean faecal contamination of pen floors in all study buildings was 36%. According to the model developed, hygiene levels were affected by the size of the farm (as described by the number of sows), seasons, stocking rate per pen (kg weight/m^2) and management of piggery buildings. Summer conditions and continuous flow pig management resulted in reduced hygiene levels in pig pens. Piggery size positively, whereas stocking rate negatively associated with piggery hygiene. The results highlighted potential strategies that can be used to reduce the negative effects of sub-optimal piggery hygiene on pig production, environment, health and welfare of animals as well as piggery staff. The related experiments highlighted the importance of keeping pens dry and potentially using bedding materials to mark resting areas in pens as a means of improving dunging patterns in pig pens.

Keywords: manure, dunging, pigs, hygiene, management, season, cleanliness

19.1 Introduction

Since the introduction of partially slatted floors in piggery buildings, the excretory behaviour of pigs has become a crucial factor in the successful management of pig housing systems (Aarnink *et al.*, 1996; Hacker *et al.*, 1994). The pig's excretory activity can affect the pig's and pen cleanliness (Figure 19.1) with obvious consequences for pig health, worker safety and farm productivity (Whatson, 1978). Incorrect dunging patterns in partly slatted pens may lead to performance problems and almost certainly lead to management and labour problems. Previous studies demonstrated a very strong association between pen hygiene (the percentage of solid floor covered by dung) and air quality (Banhazi *et al.*, 2008b, 2010; Takai *et al.*, 1998). Unfortunately, very little information is available on the factors affecting the excretory behaviour of pigs as in practice many factors could affect the development of dunging patterns in pig pens (Olsen *et al.*, 2001; Randall, 1980). It is generally accepted that several stimuli act together to produce the pigs dunging pattern in pens (Wechsler and Bachmann, 1998).

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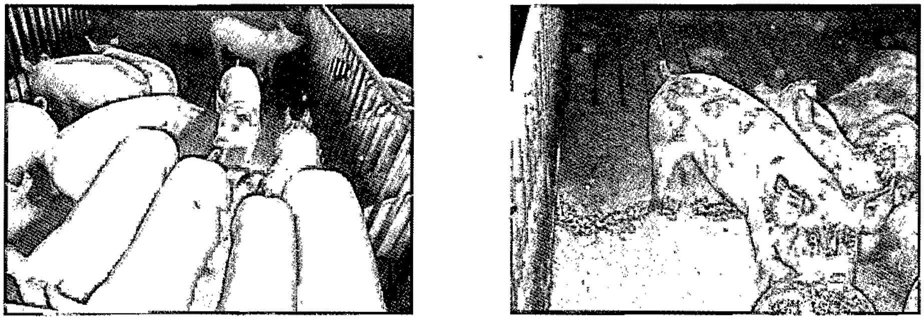

Figure 19.1. Examples of pig pens with good and wrong dunging patterns.

An ideal situation would be for the pigs to eat and sleep and not excrete in the solid area and to drink and excrete in the area which is slatted. The pigs will ideally deposit and then trample on the excreta forcing it to fall through the slats into a channel or pit below, which would then be flushed or scraped depending on the waste management system. The success of this system relies on providing conditions that encourage the pigs to excrete only on the slatted area of the pen.

There is some debate as to whether the pigs' preference for a dunging site is related to its microenvironment or it is the least desirable area in which to lie. The aim of dunging pattern management should be to make the designated resting place (concreted area in partly slatted pens) as attractive as possible for the pigs to rest. The slatted areas, on the other hand, should be made unattractive as resting-places (Turner and Lockhart, 1987).

It is believed the effects of thermal environment are very important (Randall *et al.*, 1983) in influencing dunging patterns. It is generally accepted (Baxter, 1982; Olsen *et al.*, 2001) that in piggeries situated in northern hemisphere countries, pigs like to lie in a warmer area and excrete in a cooler place. This could become a problem when pigs are housed in areas above their thermo-neutral temperature range, as often happens in Australia. During a hot period, the pigs are likely to lie in the cool area which is generally the dunging area.

An experiment by Baxter (1982) demonstrated that excretory behaviour of pigs could be influenced by the location of the drinkers and thus floor wetness. It was found that pigs kept in smaller pens, tended to excrete near the drinkers (wet area) and avoided excreting on the resting area. It was suggested that this behaviour might relate to the microclimate created by the water (evaporative cooling) and the wetness itself, which may simulate excretory behaviour and indicate the position of the regular dunging area.

Crowding and disturbance by other pigs will result in fouling of the solid pen surface (Bate *et al.*, 1988; Hacker *et al.*, 1994). Bate *et al.* (1988) suggested that pigs seek isolation for excretory behaviour and that as the animals mature, this isolation becomes more difficult to achieve, and thus pigs tend to develop incorrect dunging patterns near market weight. This compares well with the findings of Hacker *et al.* (1994) who found that increases in pig age and pig weight tend to also increase pen fouling. It has been shown that pigs generally demonstrate a clear preference for defecating in areas that are separate from the lying areas (Simonsen, 1990; Whatson, 1985). However, under intensive housing conditions, all pigs housed in the same pen might not be able to use the same 'toilet area'. Thus under commercial conditions, total separation of lying and dunging area may not consistently achieved.

A study found that piglets prefer to dung close to a wall (Petherick, 1982). This is suggested to be related to a need for security as the piglet feels that it may be disturbed while defecating in exposed areas. This study appears to agree with conclusions drawn by other experiments, emphasising the effects of commotion on excretory behaviour (Bate *et al.*, 1988).

In summary, temperature, commotion and management are clearly cited in the literature as critical factors influencing the development of dunging patterns in commercial piggeries. However, it is not known what factors will influence dunging pattern in Australia under commercial conditions. Therefore, a study was designed with two aims in mind. First to identify the statistically significant factors affecting pen soiling in Australian piggery buildings and then to assess practical management interventions aimed at influencing dunging patters under commercial farm conditions and thus improving pen and building hygiene.

19.2 Materials and methods

19.2.1 Study component 1: field survey and statistical modelling

Details of the design of the study, techniques used for environmental data collection and analysis have been given previously (Banhazi *et al.*, 2008a,b). A total of 160 piggery buildings were included in a study, and housing and management information relevant to individual buildings were documented in detail. Environmental information, including temperature and humidity readings were recorded in all buildings using Tinytalk temperature and humidity data loggers (Tinytalk-2, Hasting Dataloggers, Australia) over a 60 h period.

The dunging pattern in the study buildings were assessed at the time of data collection by classifying the pen cleanliness into three distinct classes, as were done in previous studies (Aarnink *et al.*, 1996, 1997). Pen hygiene was deemed to be 'good' if less than 10% of pen floor was contaminated by faecal material (average area covered by dung = 5%). If between 10 and 50% of the pen floor was contaminated with faecal material, then the hygiene level was deemed to be 'fair' (average area covered by dung = 25%). More than 50% floor contamination resulted in the pen classified as having 'bad' pen hygiene (average area covered by dung = 75%). The data collected was forwarded to South Australia for storage and analysis. To facilitate meaningful data analysis, the classification grades were later turned into percentages, as described above. The dependent variable of interest for this study was the extent of floor contamination (%) with manure. The data was analysed using the forward selection procedure in General Linear Model (GLM PROC) (SAS, 1989). The results presented here are based on the least squares means (± confidence intervals) of fixed effects. As the hygiene standards of pig pens are influenced by many factors, the model was developed at the 90% confidence level to ensure that all important effects likely to influence dunging patterns will be identified.

19.2.2 Study component 2: controlled experiment

A limited number of follow-up and controlled experiments were conducted at the University of Adelaide, Roseworthy Research Piggery to evaluate the effects a number of practical management procedures on dunging pattern as listed in Table 19.1.

The management intervention applied and the facilities used are described in details below. Standard one-way ANOVA was used to evaluate the statistically significant changes between treatments and the control pens (StatSoft, 2001).

Experiment 1

The main aim of experiment was to assess the effects of wet pen floors on established dunging patterns in pig pen. Four pens were selected with perfect dunging patterns in partially slatted, naturally ventilated grower/finisher room housing with approximately 90 pigs at a stocking rate of 0.65 m^2/pig. Two pens out of the four were randomly selected and the pen floors were thoroughly wetted using 8 l of water daily. The other two pens in the same rooms, stocked at the same rate, were used as control pens and the floors of these pens were kept dry. Dunging patterns were monitored for 25 days as described previously (Banhazi *et al.*, 2002). The amount of dung cover on the concreted areas were assessed daily and classified into three available categories (poor, fair and good).

Experiment 2

The main aim of this experiment was to assess the effects of using oil impregnated saw dust to influence the establishment of dunging patterns in newly stocked weaner pens. Four pens were selected in freshly cleaned partially-slatted, mechanically ventilated weaner room housing with approximately 15 pigs per pen at a stocking density of 0.34 m^2/pig. Two of the four study pens were randomly allocated to the treatment, which was the application of sawdust on the concreted area.

Table 19.1. Description of controlled experiments aimed at assessing hygiene control methods.

Experiment	Aims	Comments
Wetting pen floors	to assess the effects of wet pen floors on established dunging patterns	attempts were made to artificially induce poor dunging patterns in pens with established good dunging pattern, by wetting the pen floors daily
Using oily saw-dust	to evaluate the effects of using bedding material impregnated with oil on dunging patterns	it was envisaged that the oil impregnated bedding material would improve dunging patterns without producing dust and would also deliver welfare benefits
Creating commotions	to study the effects of commotion on dunging patters	commotion was created in specific areas of the pen, by attaching play-chains strategically at specific locations

Table 19.2. Level of floor contamination (%) across all study buildings.

Parameter	Mean	SD	Range	No. of buildings
Contamination of pen floor by faecal material (%)	36	27	70	112

Table 19.3. Significance of effects associated with hygiene level in the model developed at the 90% confidence levels.

	Probability of the individual effects
Number of sows (farm size)	0.002
Management	0.006
Stocking rate per pen (kg weight/m^2)	0.059
Season	0.086

Significantly higher percentage of floor contamination was observed in summer (46%) in piggery buildings than in winter (36%) (Figure 19.3). In piggery buildings, winter temperatures are lower than in summer, thus pigs tend to use the concreted areas appropriately for resting and the slatted areas for defecating. However, in summer when temperatures are high, pigs are forced to rest on the slatted area in order to keep themselves cool, thus making the slatted area unavailable for defecating. Studies by (Aarnink *et al.*, 2000, 2001) have also shown that the fouling of the solid pen area increases with increases in the ambient temperature. A clear 'Inflection Temperature', the temperature at which pen fouling increases, was found for a range of pig weights. This temperature ranged from 25 °C for 25 kg pigs to 20 °C for 100 kg pigs. Therefore, the main aim of managing dunging patterns in summer should be to discourage pigs to rest on the slatted areas. For example,

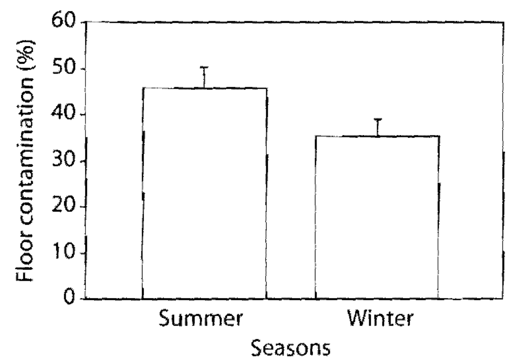

Figure 19.3. Effect of season on hygiene level (%) in Australian piggery buildings (LS means with standard error, P<0.05).

in an effort to reduce the fouling of the solid floor, Aarnink *et al.* (1997) employed slats embedded with a metal stud. This stud prevented the pig from lying on the slatted floor, forcing it to them lie on the solid floor. This significantly reduced the rate of urination and defecation on the solid floor.

Higher level of pen floor contamination was observed in continuous flow (CF) buildings (49%) when compared to building (32%) managed on the all-in/all-out (AIAO) basis (Figure 19.4). It is important to consider the management of the buildings, when assessing dunging patterns, as building management will directly influence both the thermal and social environment of pens. In addition, the beneficial effects of regular cleaning between batches will have a direct impact on pen cleanliness in AIAO buildings.

Sow numbers, which was an indicator of farm size, was positively correlated with hygiene levels in the study buildings (Table 19.4). As expected, on larger farms the floor contamination level tends to increase. It has been hypothesized that, on larger farms, because of work pressures, less time is available for cleaning and general maintenance of the pigs' environment. The increased intervals between cleaning episodes create an ideal environment for reduced building hygiene.

Unexpectedly, stocking rate was negatively correlated with hygiene level in grower, finisher and weaner buildings (Table 19.4). However, further analysis demonstrated that this overall effect was heavily influenced by the close relationship between improved hygiene and increasing stocking rate in weaner buildings (data not shown). In grower/finisher building the relationship was

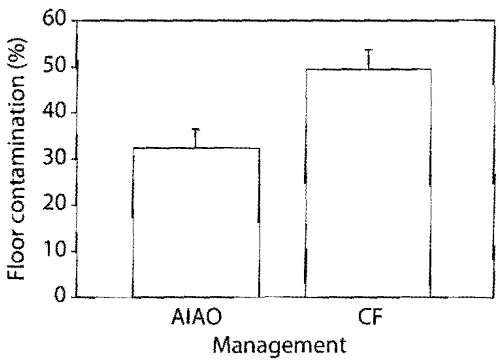

Figure 19.4. Effect of pig management (all-in/all-out, AIAO vs. continuous flow, CF) on floor contamination (%) in Australian piggery buildings (LS means with standard error, P<0.05).

Table 19.4. The effects of covariates on the level of pen floor contamination (%).

Parameter	Covariate	Slope
Pen hygiene	Number of sows (farm size)	Positive
Pen hygiene	Stocking rate (kg pig/m^2)	Negative

positive indicating that increasing stocking rates will result in greater level of floor contamination. The explanation for these results is not easy, but it could be hypothesised that in weaner buildings the higher stocking rates will result in better self-cleaning of the fully slatted floors, which are typically used in weaner buildings. One of the main benefits of using fully slatted pigpens is to be able to separate the pigs from the excreta. The pigs will ideally deposit and then trample on the excreta forcing it to fall through the slats into a channel or pit below. The success of this system relies on providing conditions that encourage the pigs to trample excrete often, so the floor becomes self-cleaning. Obviously, one of the best ways of achieving this is to increase stocking rates in fully-slatted (weaner) buildings. However, in grower/finisher building the increased stocking rate resulted in reduction in pen hygiene, though this effect was not statistically significant.

19.3.2 Study component 2: controlled experiment

Experiment 1

In the control pens the correct dunging patterns did not change throughout the experimental period. However, incorrect dunging pattern was observed in the experimental pens soon after the wetting commenced and the level of soiling deteriorated rapidly in these pens (Figure 19.5). The difference in floor contamination level was statistically significant between the experimental (35%) and control pens (5%). The experiment demonstrated that liquid coverage on the pen floor would trigger incorrect dunging. To induce incorrect dunging in pens with established correct dunging patterns requires considerable wetting. However, it was hypothesised that for example spraying oil/water mixture on pen floors, if incorrectly managed could have a longer wetting effect than water alone which can easily evaporate in warm weather (Banhazi, 2005). After spraying pen floors (delivering very large droplets of oil/water mixture) in one dose per day, pens floors could appear to be wet for an extended period which can potentially trigger incorrect dunging patterns. Therefore care has to be taken when spraying or cleaning pen floors to avoid extensive, daily wetting of pen floors in pigpens in order to avoid the deterioration of pen hygiene (Figure 19.5).

The results also demonstrated the need to dry the rooms after cleaning and before re-stocking to avoid the emergence of incorrect dunging patterns in freshly stocked pens. Although, dunging patterns are believed to be influenced by many factors, wet pen flooring is clearly a risk factor.

Experiment 2

During the first run of the second experiment no significant difference between the treatment and control pens were found (Figure 19.6). Although, the treatment pens remained relatively clean (8%), the control pens also remained dung-free (11%). That experiment highlighted the difficulties involved in studying dunging patterns. It is generally accepted that many, sometimes 'unidentified' factors, influence dunging patterns. Farm experience also proved that sometimes adjoining pens could have different dunging patterns and resultant hygiene levels. The reasons behind the difference are often difficult to explain. Therefore, even under experimental conditions, the results are sometimes difficult to control and predict.

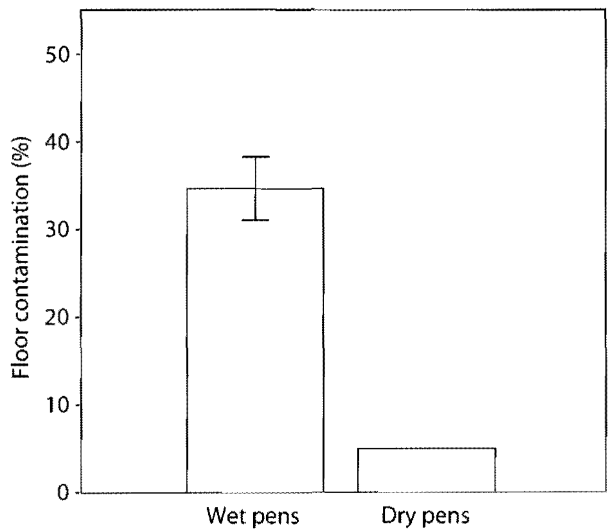

Figure 19.5. Floor contamination level (%) observed in the wet and dry pens during experiment 1. (LS means ± standard error, P<0.001).

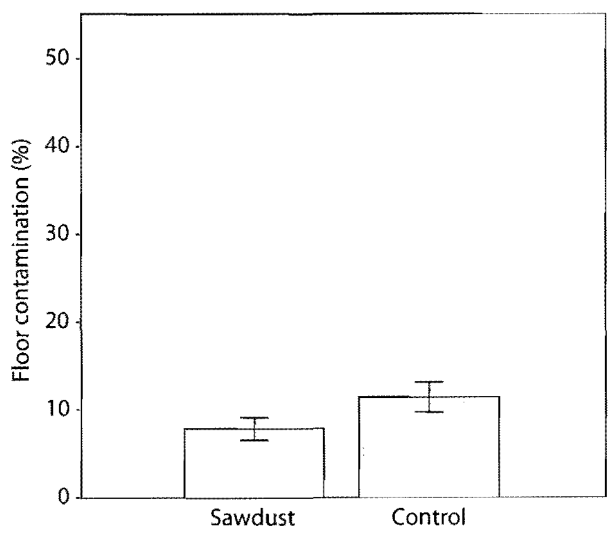

Figure 19.6. Floor contamination level (%) observed in the pens with and without sawdust during experiment 2a. (LS means ± standard error, P=0.12).

However, the second run of the second experiment did demonstrate a statistically significant difference between treated (8%) and untreated (40%) pens (Figure 19.7). Overall, sawdust applications can be recommended as a viable management method to influence dunging patterns.

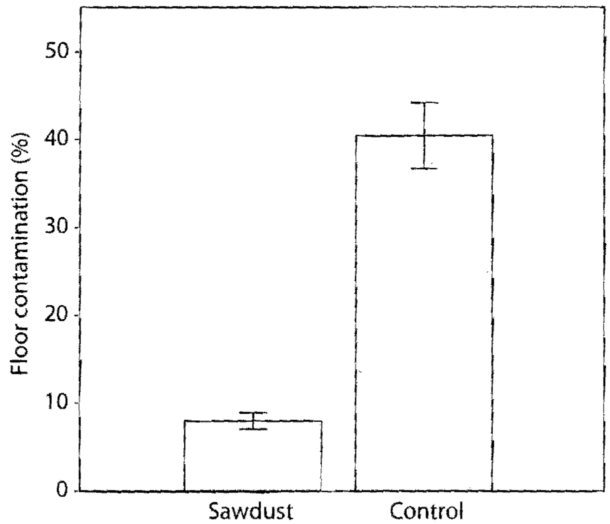

Figure 19.7. Floor contamination level (%) observed in the pens with and without sawdust during experiment 2b. (LS means ± standard error, P*<0.001).*

However, sawdust application might be recommended as a 'preventative technique' rather than a problem solving method, as it is highly unlikely to be able to correct existing dunging problems. The application of oily sawdust is preferred rather than dry sawdust to reduce the opportunity of airborne dust generation from the dry bedding material.

Experiment 3

The third experiment did not prove the positive use of play chains (Figure 19.8), as the contamination level of the solid concreted area significantly increased (45%) when the play chains were placed above the slatted area. Floor contamination level (6%) in pens without chains (control) and in pens were the chains were placed over the solid area remained similar (8%). However, it underpinned claims, that chains can be used to 'clean-up' areas where dunging is undesirable (P. Pattison, personal communication). During this experiment the slatted dunging area was 'cleaned-up' by forcing the pigs to relocate their 'toilet' area to the concreted part of the pen. This effect was clearly undesirable, but proved that fact that too much activity in the designated dunging area will discourage pigs to use the slatted 'toilet' area appropriately, as indicated in previous publications (Bate *et al.*, 1988; Petherick, 1982).

One of the limitations of the study was the size and shape of pens used in the study. It has been stated previously by Dutch researchers (P.F.M.M. Roelofs, personal communication) that chains will only work in pens that are correctly designed. It was suggested, that pens should be long and narrow and designed in a way to ensure that there are three clearly identifiable areas exist in the pen, such as dunging, resting and activity/feeding areas. The selection of the dunging and resting

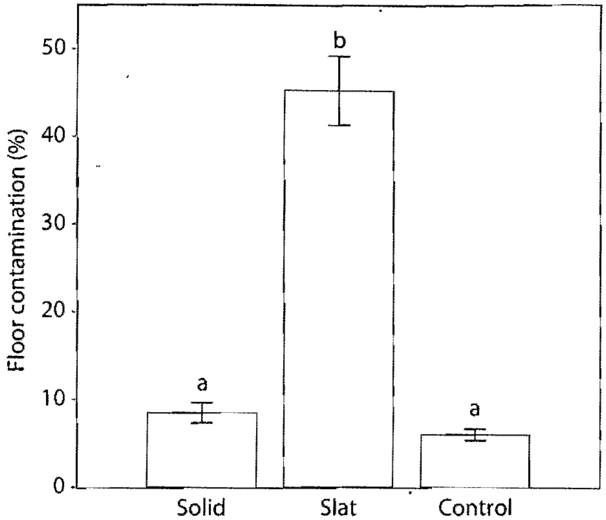

Figure 19.8. Floor contamination level (%) observed as the result of three different treatments during experiment 3. (Different letter above the graph indicates significant difference) (LS means ± standard error, P<0.001).

areas is usually interrelated, as pigs are believed to avoid urinating and defecating in places where they eat or rest.

In our study facilities the pens were rather wide and relatively short. Therefore, it was hypothesised that in these types of pens, the activity created over the solid area also disturbed the resting area, forcing some of the pigs to seek isolation in the slatted areas (Figure 19.8). Therefore, reduced amount of slatted areas was available for the pigs to use for dunging, in turn forcing some of them to dung on the concreted areas. Casual behaviour observation of pigs during the trial appeared to support this theory.

Producers need to avoid disturbing both resting and dunging area. It appears that for both resting and dunging area should be 'quiet' places and play chains (if used) need to be located in areas, where the resulting extra movement will not negatively influence the dynamic of the pen and therefore dunging patterns within the pens.

The study also demonstrated that 'negative' interventions influencing dunging behaviour are probably more reliable than 'positive' interventions. Positive interventions aimed at rectifying incorrect dunging patterns might not always yield the expected results. Therefore, it is probably easier to identify management interventions that have to be avoided, rather than management procedures that could be recommended with confidence to create more hygienic pen conditions.

19.4 Conclusions

Our results demonstrated that the correct management of air temperature and stocking rate (SR) are the most practically beneficial ways of improving pen hygiene in piggery buildings. Temperature decrease will have a beneficial effect on pen hygiene in partially slatted pens, but there is a lower limit below which temperature cannot be reduced, as it would interfere with thermal comfort. In the same way, SR cannot be decreased drastically, due to potential negative economic impact. Farm size again cannot be manipulated, as the general trend toward larger farm size is driven mainly by economic considerations. In the same way, seasonal effects have to be accepted, but producers must be aware of the increased risks of reduced pen hygiene associated with summer periods.

All these and potentially other factors must be taken into consideration, as practical experience demonstrated that dunging patterns are influenced by the combination of many factors under commercial conditions. Only through careful management and design of pigpens will correct dunging patterns be achieved. Care must be taken when designing and importantly managing the buildings and pens to create a pen environment that is suitable for the development of correct dunging patterns.

The controlled experiments demonstrated that wet pen floors are clearly a risk factor for the development of incorrect dunging patterns, but saw dust might be used to positively influence dunging behaviour. Play-chains might also be used effectively to influence dunging behaviour, however the use of this technique can only be recommended in pens with a suitable design.

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References

Aarnink, A.J.A., Schrama, J.W., Verheijen, R.J.E. and Stefanowska, J., 2000. Effect of ambient temperature on pen fouling by pigs. 10th International Congress on Animal Hygiene, Maastricht, the Netherlands, pp. 933-937.

Aarnink, A.J.A., Schrama, J.W., Verhijen, R.J.E. and Stefanowska, J., 2001. Pen fouling in pig houses affected by temperature. Livestock Environment VI, May 21-23, Louisville, Kentucky. The Society for engineering in agricultural, food, and biological systems, pp. 180-186.

Aarnink, A.J.A., Swierstra, D., van den Berg, A.J. and Speelman, L., 1997. Effect of type of slatted floor and degree of fouling of solid floor on ammonia emission rates from fattening piggeries. Journal of Agricultural Engineering Research 66: 93-102.

Aarnink, A.J.A., Van den Berg, A.J., Keen, A., Hoeksma, P. and Verstegen, M.W.A., 1996. Effect of slatted floor area on ammonia emission and on the excretory and lying behaviour of growing pigs. Journal of Agricultural Engineering Research 64: 299-310.

Banhazi, T., 2005. Oil spraying systems for piggeries to control dust. In: Fahy, T. (ed.) Proceedings of AAPV Conference, AVA, Gold Coast, QLD, Australia, pp. 76-80.

Banhazi, T., Murphy, T., Hillyard, K. and Kloppers, M., 2002. The effects of a wet floor on dunging patterns. In: Revell, D.K. and Taplin, D. (eds.) Animal production in Australia, ASAP, QLD, Australia, p. 372.

Banhazi, T.M., Rutley, D.L. and Pitchford, W.S., 2010. Validation and fine-tuning of a predictive model for air quality in livestock buildings. Biosystems Engineering 105: 395-401.

Banhazi, T.M., Seedorf, J., Rutley, D.L. and Pitchford, W.S., 2008a. Identification of risk factors for sub-optimal housing conditions in Australian piggeries – Part I: study justification and design. Journal of Agricultural Safety and Health 14: 5-20.

Banhazi, T.M., Seedorf, J., Rutley, D.L. and Pitchford, W.S., 2008b. Identification of risk factors for sub-optimal housing conditions in Australian piggeries – Part II: airborne pollutants. Journal of Agricultural Safety and Health 14: 21-39.

Bate, L.A., Hacker, R.R. and Phillips, P.A., 1988. Effect of growth on porcine defecation patterns. Canadian Agricultural Engineering 30: 191-192.

Baxter, M.R., 1982. Environmental determinants of excretory and lying areas in domestic pigs. Applied Animal Ethology 9: 195.

Hacker, R.R., Ogilvie, J.R., Morrison, W.D. and Kains, F., 1994. Factors affecting excretory behavior of pigs. Journal Of Animal Science 72: 1455-1460.

Olsen, A.W., Dybkjaer, L. and Simonsen, H.B., 2001. Behaviour of growing pigs kept in pens with outdoor runs: II. Temperature regulatory behaviour, comfort behaviour and dunging preferences. Livestock Production Science 69: 265-278.

Petherick, J.C., 1982. A note on the space use for excretory behaviour of suckling piglets. Applied Animal Ethology 9: 367-371.

Randall, J.M., 1980. Selection of piggery ventilation systems and penning layouts based on the cooling effects of air speed and temperature. Journal of Agricultural Engineering Research 25: 169-187.

Randall, J.M., Armsby, A.W. and Sharp, J.R., 1983. Cooling gradients across pens in a finishing piggery. II. effects on excretory behaviour. Journal of Agricultural Engineering Research 28: 247-259.

SAS, 1989. SAS/STAT® User's Guide, Version 6, Fourth Edition, Volume 2, SAS Institute, Cary, NC, USA.

Simonsen, H.B., 1990. Behaviour and distribution of fattening pigs in the multi-activity pen. Applied Animal Behaviour Science 27: 311-324.

StatSoft, I., 2001. STATISTICA. StatSoft, Inc., Tulsa, OK, USA.

Takai, H., Pedersen, S., Johnsen, J.O., Metz, J.H.M., Groot Koerkamp, P.W.G., Uenk, G.H., Phillips, V.R., Holden, M.R., Sneath, R.W., Short, J.L., White, R.P., Hartung, J., Seedorf, J., Schroder, M., Linkert, K.H. and Wathes, C.M., 1998. Concentrations and emissions of airborne dust in livestock buildings in Northern Europe. Journal of Agricultural Engineering Research 70: 59-77.

Turner, J.D. and Lockhart, R., 1987. Observation on pig lying and dunging behaviour in finishing pens incorporating a raised slatted dunging area. Occasional Publications No. 11 – British Society of Animal Production: 142.

Wechsler, B. and Bachmann, I., 1998. A sequential analysis of eliminative behaviour in domestic pigs. Applied Animal Behaviour Science 56: 29-36.

Whatson, T.S., 1978. The development of dunging preference in piglets. Applied Animal Ethology 4: 293.

Whatson, T.S., 1985. Development of eliminative behaviour in piglets. Applied Animal Behavior Science 14: 365-377.