476. Marchant, J.N., Broom, D.M. and Corning, S. 2001. The influence of sow behaviour on piglet mortality due to crushing in an open farrowing system. *Anim. Sci.*, 72, 19-28.

Abstract

The objectives of this study were to establish what changes in posture by sows carried a high risk of piglet crushing in a group farrowing system during early lactation and also to determine what factors influenced the risk of crushing during lying down. A total of 24 Large White × Landrace sows were studied during the first 7 days of lactation in a group farrowing system. Cross-fostering was not carried out so as not to influence behaviour. Dead piglets were removed and cause of death ascertained from external observation and post-mortem examination. Sow and piglet behaviour was video-recorded continuously. A total of 268 piglets were born alive, with 67 liveborn piglets subsequently dying during the 7-day experimental period, 50 as a result of crushing. A total of 7425 posture changes were analysed and 11 types of posture change were identified, the most dangerous being lying down from standing and those involving swapping sides, or rolling over, whilst lying.

Dangerous events during lying down were more likely to occur (1) in the first 24 h after farrowing, (2) when the sow lay down in the middle of the pen, (3) when the sow lay down without carrying out much piglet-directed pre-lying behaviour and (4) when the piglets were spread out but near to the sow. The amount of pre-lying behaviour decreased over time and crushing mortality also decreased. The results confirm that the piglets are most vulnerable to crushing during the first 24 h of life, when they are spending much of their time near the udder and have relatively poor mobility. Co-ordination of behaviour between the sow and her litter is important to reduce the risk of crushing. It is also important that the design of open farrowing systems incorporates knowledge about how crushing deaths occur in order to improve piglet welfare.

Keywords: *farrowing, pigs, maternal behaviour, mortality.*

Introduction

Recently there has been an increase in research into the development of alternatives to the farrowing crate. This has mainly been driven by concerns for the welfare of the confined sow. Alternatives that have been studied include single pens (Cronin and Smith, 1992; Blackshaw *et al.*, 1994), communal systems (Baxter, 1991; Weary *et al.*, 1999), family pens (Kerr *et al.*, 1988; Arey and Sancha, 1996), farrowing nests (Kavanagh, 1995) and oval crates (Lou and Hurnik, 1994). There is evidence that the welfare of the sow is improved in systems that allow her greater behavioural freedom, especially around the time of nest-building (Lawrence *et al.*, 1994) and the late lactation period (Cronin *et al.*, 1991; Rudd *et al.*, 1992). However, in general, this improvement has been at the expense of the welfare of her litter. Liveborn piglet mortality recorded in alternative systems is generally higher than that recorded in conventional farrowing crates (Edwards and Fraser, 1997).

Farrowing crates were developed to make routine sow and piglet management easier for the stockperson, to allow a greater number of animals to be kept per unit area and to decrease piglet mortality.

Any alternative farrowing system has to take all these factors into account, including the needs of the stockperson, if it is to be commercially acceptable (English, 1993). Although giving the sow greater freedom of movement, and perhaps a choice of environment, gives her the opportunity to perform more of her maternal behavioural repertoire, this can present problems. With less restriction, the maternal qualities of the sow will have a greater influence on the survival and growth of her litter. If she is a good mother, piglet survival may be improved. However, if she is a poor mother, piglet mortality may be high. Her natural protectiveness may also make the stockperson's task potentially dangerous (Marchant, 1998).

The exact proportions of piglet mortality due to various causes differ between systems. However, crushing by the sow has been identified as the major primary cause of piglet deaths in indoor (Edwards *et al.*, 1986; Svendsen *et al.*, 1986) and outdoor systems (Edwards *et al.*, 1994). There are several different sow posture changes that present crushing danger to the litter (Edwards *et al.*, 1986; Weary *et al.*, 1996a; Wechsler and Hegglin, 1997). However, in order to ameliorate the problem of crushing mortality in alternative farrowing systems, there is a need to identify key features of sow and piglet behaviour that increase or decrease crushing risk.

The primary objective of this experiment, therefore, was to examine crushing events in detail in order to determine when, where and how they happened and to identify which behavioural factors were most likely to prevent, or result in, a crushing or near-crushing event.

Material and methods

Animals and housing

The experimental subjects were 24 Yorkshire X Landrace sows of similar genetic stock (PIC, Abingdon, UK) and ranging from 1st to 7th parity (mean = 3·6). During gestation, all the sows had been housed in the same building, in a large, dynamic group housing system containing about 35 sows at any one time. The system comprised an indoor strawed lying area, a indoor dunging/feeding area and an outdoor dunging area. The gestation housing system constituted part of another experimental trial and the sows were given a restricted diet via an electronic sow feeder (ESF) system.

The farrowing system was unfamiliar to all sows, which had previously farrowed in farrowing crates and comprised of five individual strawed pens, a communal passageway and an outdoor dunging area (see Figure 1). Each pen had a triangular, thermostatically controlled creep in one corner. Three pens had a tubular-metal farrowing rail running around 20 cm out from the wall and 20 cm above the floor whilst the other two pens had sloping sides with a gap at the bottom which enabled piglets an escape area. A trough, a piglet drinker and a sow drinker were situated at the near end of each pen. From the pen, the sow had access to the communal passageway and the outdoor dunging area, while the piglets were contained within the pen by a barrier, up to the age of about 7 to 10 days, i.e. over the entire experimental period. An ESF was situated at one end of the communal passageway and a commercial lactation diet was available *ad libitum*. Water was available from the sow drinkers inside each pen, whenever the sows were shut in and *ad libitum* from sow drinkers situated in the outdoor dunging area.

Experimental procedure

Six batches of four experimental sows, were selected on the basis of expected farrowing date and entered the system at about 7 days prior to farrowing. Additionally, five of the six batches also included a single sow that was not assigned to this study. On entry to the farrowing system, the sows' weight was recorded, P2 backfat measurements were taken and new ESF transponders were fitted. From 7 days prior to predicted farrowing date, the sows were randomly assigned to a farrowing pen and shut in overnight to prevent them from farrowing elsewhere in the system. On the morning following parturition, the sow was released and litter size and composition were recorded. Individual piglet birth weights were also recorded.

As the aim of the experiment was to further our understanding of the way in which sow behaviour affects crushing mortality of her litter, it was considered important not to carry out management procedures that might themselves have influenced her behaviour. Therefore, an ethical decision was taken to not carry out cross-fostering of piglets between experimental sows and to avoid human intervention in any crushing events that occurred during the short, feeding and cleaning out time-period each day that the animal management team were present in the farrowing room.

On a daily basis, any dead piglets were removed, weighed and cause of death established from post-mortem evidence, collected using methods described by Randall and Penny (1967), Wells (1978) and Carr and Walton (1995), together with video-tape evidence. Each piglet was examined for signs of post-parturient locomotion and external trauma, including bruising and lacerations. Body cavities were opened and internal organs were examined.

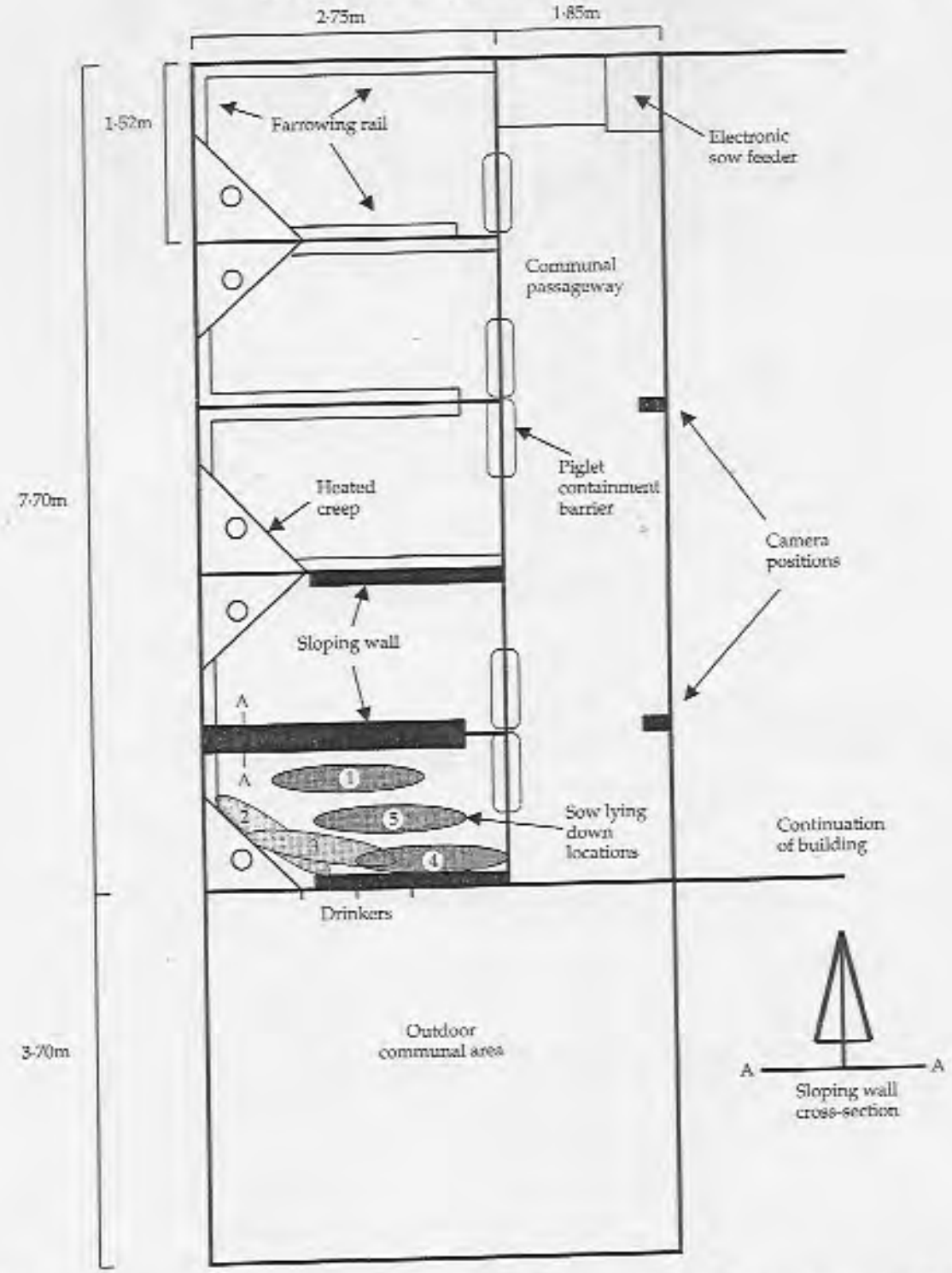

Figure 1 Floor plan of community farrowing system showing individual farrowing pens, communal passageway and outdoor area. A cross-section of the sloping wall (A-A) shows the piglet escape area. The five possible sow areas where the sow can lie down are shown: (1) long wall, (2) creep, (3) creep/creep wall, (4) creep wall, (5) open.

The degree of lung inflation was determined and the quantity of gastro-intestinal tract contents was recorded.

At 7 days after farrowing, the sows were again weighed and P2 backfat measurements were taken. Individual piglet weights were recorded and average daily live weight gain calculated. The sows and their litters were then moved to other farrowing accommodation for the remainder of the lactation period. Having only a 7-day post-farrowing observational period allowed quicker turn-over of animals yet still covered the period when the majority of piglet deaths occurred in this system.

Sow behaviour in the two sloping-wall pens and two farrowing rail pens was recorded continuously throughout the 14-day experimental period, *via* two cameras (Panasonic WV-CD110AE) attached to time-lapse video-recorders (Panasonic AG6720A) set to record in 24-h mode, i.e. three frames per s. Each camera was mounted above the communal passage and directed to cover two pens (see Figure 1). After parturition, the behavioural data were analysed to determine the following.

(1) The amount and type of posture changes during each 24-h period.

(2) The number of posture changes resulting in piglet deaths due to crushing.

(3) The number of posture changes resulting in a near crushing, with the piglet being knocked out of the way by the sow's movement or trapped but subsequently escaping. The piglet could either release itself or be released by the actions of the sow in response to the tactile stimulus or a combination of tactile and auditory stimuli presented by a trapped piglet.

(4) The position of the sow within the pen when she lay down. Sows could lie down in five different locations within the pen (see Figure 1).

(5) The type and number of behaviours performed before lying down-i.e. the number of separate actions of rooting (root) and pawing (paw) the ground, purposefully moving the head to look at the piglets (look) and nudging the piglets (contact) in the period immediately before the sow moved into a kneeling position at the start of the act of lying down. The time frame for the pre-lying phase was variable between and within sows and the start of this was determined by working backwards from the start of the act of lying down until the sow was engaged in non-preparatory behaviour.

(6) Total time taken to lie down. This was the duration from when one front foot was lifted and the knee placed onto the floor up to when the hindquarters dropped so that the upper thigh of one leg landed on the floor. For a detailed description of lying down see Baxter and Schwaller (1983).

(7) The position of the piglets in the pen when the sow lay down – i.e. whether or not the piglets were within 0·5 m of the sow when she lay down and whether the piglets were clustered together or scattered. Clustered was defined as all piglets contained within an imaginary circle of 0·75 m diameter.

Statistical analysis

As there were no differences between pen designs in productivity or behaviour, all data were pooled. The data were analysed to calculate the proportion of all posture changes that were dangerous posture changes, i.e. posture changes that resulted in crushing or near-crushing. As there were no relationships between parity and total number or proportion of dangerous posture changes, these proportions were then compared using Friedman ANOVA. Treatment factors represented type of posture change (d.f. = 10), day after farrowing (d.f. = 6), lying down location (d.f. = 3), amount of pre-lying behaviour (d.f. = 4) and piglet position (d.f. = 1), all blocked by sow. The mean amounts of total pre-lying behaviour, rooting, looking, pawing and making contact were also compared using Friedman ANOVA, using day after farrowing as the treatment factor, blocked by sow. All statistical analyses were performed using statistical software MINITAB (1998).

Results

Overall, 268 piglets were born alive and 32 piglets born dead from the 24 experimental litters. Sixty-seven liveborn piglets subsequently died over the 7 days after farrowing giving a mean liveborn mortality of 25·0%. Liveborn mortality in individual litters ranged between 0% and 53·8%. Post-mortem examination revealed that a total of 50 liveborn piglets died as a result of traumatic injury, 14 died from starvation/hypothermia and three died from unknown causes. Of the 50 traumatic injury deaths, six were the result of being trodden on by the sow, unassociated with any change in posture. All sow posture changes over the 7 days after farrowing were analysed in detail (total = 7425, mean per sow = 309·4, range between 136 and 444) and the remaining 44 deaths were associated with eight of the 11 types of posture change identified. Unsurprisingly, the posture changes which carried the greatest risk were those from standing to lying, sitting to lying and all four types of posture changes

Table 1 *The total number of each of the 11 types of posture change, the number of crushing events and the number of dangerous events recorded from 24 sows over 7 days post farrowing in an open farrowing system*

Posture change	Total no. of posture changes	Resulting in crushing death		Resulting in near crushing	
		No.	%	No.	%
Standing to lying	1165	22†	1·9	66	5·7
Lying to standing	776	0	0	0	0
Lying to sitting	881	0	0	0	0
Sitting to standing	389	1	0·3	0	0
Sitting to lying	492	4	0·8	8	1·6
Lying sternally to lying laterally — same side	1801	4	0·2	5	0·3
Lying laterally to lying sternally — same side	1455	0	0	0	0
Lying sternally to lying laterally — swap side	112	2	1·8	2	1·8
Lying sternally to lying sternally — swap side	163	3	1·8	4	2·5
Lying laterally to lying laterally — swap side	15	1	6·7	3	20·0
Lying laterally to lying sternally — swap side	176	5	2·8	5	2·8
Total	7425	42	0·6	93	1·3

† Two lying events each resulted in the deaths of two piglets simultaneously.

which involved swapping sides whilst lying, i.e. rolling over ($\chi^2 = 70{\cdot}0$, $P < 0{\cdot}001$; see Table 1). However, whereas it had been hypothesized that standing to lying would account for the large majority of deaths due to crushing, in reality this posture change only accounted for half the crushing deaths. Rolling accounted for a higher than expected proportion of crushing deaths.

Nearly half of the crushing deaths occurred within the first 24 h, with a steady decline thereafter. This coincided with the peak in the number of posture changes per hour (see Figure 2). All posture changes involving lying down from standing were further analysed, as this type of posture change was responsible for the greatest numbers of near-crushings and crushing deaths. Out of a total of 1165 lying down events analysed, only 88 lying down events could be classified as dangerous — 22 events resulted in 24 piglet crushing deaths and 66 others

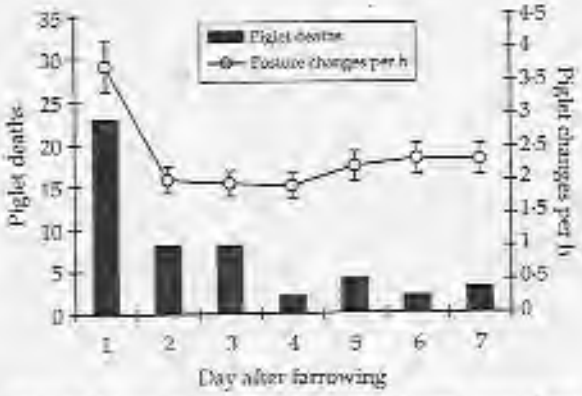

Figure 2 Mean ± s.e. number of posture changes carried out per h within the home pen over each day of the 7-day post-farrowing period.

Table 2 *Total number of lying down events, number of dangerous lying down events and number of lying down events resulting in piglet deaths per day, recorded from 24 sows over 7 days post farrowing in an open farrowing system*

Day after farrowing	Total lying down events	Dangerous lying down events	Percent which were dangerous	No. of lying down events resulting in death
Day 1	237	31	13·1	13†
Day 2	161	10	6·2	3
Day 3	148	7	4·7	1
Day 4	140	10	7·1	2
Day 5	165	13	7·9	2
Day 6	165	11	6·7	1
Day 7	149	6	4·0	0

† Two lying down events each resulted in the deaths of two piglets simultaneously.

Table 3 *Total number of lying down events, number of dangerous lying down events and number of lying down events resulting in piglet deaths in relation to location of the sow when lying down, recorded from 24 sows over 7 days post farrowing in an open farrowing system*

Lying place	Total lying down events	Dangerous lying down events	Percent which were dangerous	No. of lying down events resulting in death
Long wall	742	36	4·9	3
Creep	125	6	4·8	1
Creep/creep wall	57	1	1·8	0
Creep wall	128	4	3·1	1
Open	113	41	36·3	17†

† Two lying down events each resulted in the deaths of two piglets simultaneously.

were near crushings. The number of dangerous lying events per sow ranged between 0 and 9 (mean = 3·7). Dangerous lying events were most likely to occur during day 1 — the 24-h period from the start of parturition ($\chi r^2 = 13·9$, $P < 0·05$; see Table 2).

Of the five possible lying down locations, lying down in the open was most dangerous ($\chi r^2 = 36·4$, $P < 0·001$; see Table 3). Although a total of 47 dangerous lying events occurred elsewhere in the pen, only five deaths were recorded, which indicates that the piglet protection measures incorporated into the pen design did appear to function reasonably well and at least minimized the severity of most dangerous lying events.

There was no significant effect of time taken to lie down on the incidence of dangerous lying events ($\chi r^2 = 8·7$, $P > 0·05$). However, there was an effect of the amount of piglet-directed behaviour carried out in the period before lying down, with dangerous lying events more likely to occur if very little pre-lying behaviour was carried out ($\chi r^2 = 26·6$, $P < 0·001$; see Table 4). Pre-lying behaviour itself was maximal on the day of farrowing. Total pre-lying behaviour declined significantly over the course of the experimental period ($\chi r^2 = 17·9$, $P < 0·01$; see Figure 3). In terms of types of pre-lying behaviour,

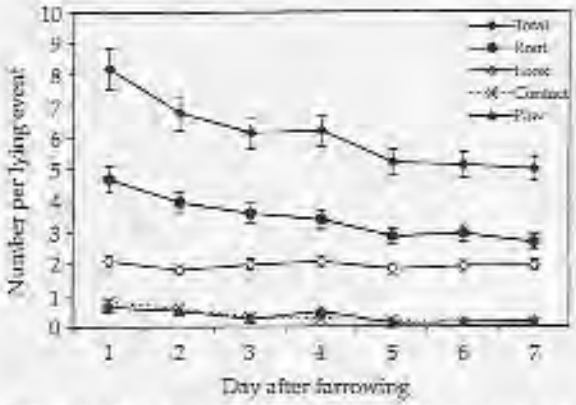

Figure 3 Mean ± s.e. number of pre-lying behaviours per lying down event carried out over each day of the 7-day post-farrowing period.

significant declines were seen in rooting the straw ($\chi r^2 = 26·4$, $P < 0·001$) and making contact with piglets ($\chi r^2 = 30·9$, $P < 0·001$). Pawing the ground prior to lying down also tended to decrease over time ($\chi r^2 = 11·1$, $P < 0·1$).

In terms of the position of the piglets, nearness to the sow during lying down events was significantly

Table 4 *Total number of lying down events, number of dangerous lying down events and number of lying down events resulting in piglet deaths in relation to number of piglet-directed behaviours carried out prior to lying down, recorded from 24 sows over 7 days post farrowing in an open farrowing system*

No. of behaviours	Total lying down events	Dangerous lying down events	Percent which were dangerous	No. of lying down events resulting in death
0-2	164	36	22·0	10†
3-5	392	29	7·4	9†
6-8	223	15	4·6	3
9-11	158	6	3·8	0
12+	126	2	1·6	0

† One lying down event in each category resulted in the deaths of two piglets simultaneously.

more dangerous when the piglets were spread out rather than clustered together ($\chi^2 = 19{\cdot}0$, $P < 0{\cdot}001$). There were 83 dangerous lying down events recorded out of a total of 250 lying down events when piglets were spread out and near the sow. This is compared with only three out of 262, when piglets were clustered together and near the sow.

Discussion

Piglet mortality in this farrowing system was high at an average of 25% over just 7 days of lactation, although this is probably compounded by the fact that cross-fostering, a recognized method to reduce pre-weaning mortality (English *et al.*, 1977), was not carried out. As expected, the majority of this mortality occurred over the first 3 days after farrowing with nearly half in the first 24 h. This corresponds with mortality distribution recorded in other studies (e.g. Glastonbury, 1976; Dyck and Swierstra, 1987; Holyoake *et al.*, 1995). Crushing by the sow accounted for 71·6% of liveborn piglet deaths. This is a greater proportion than that found in farrowing crates (English *et al.*, 1977; Edwards *et al.*, 1986; Svendsen *et al.*, 1986) but similar to that found outdoors (Edwards *et al.*, 1994). However, it must be remembered that this study only examined the first 7 days of lactation and the majority of mortality after this would probably be due to causes other than crushing (Dyck and Swierstra, 1987).

Our results show that several different sow behaviours can result in crushing deaths in this open farrowing system. Half of the crushing deaths occurred when the sow lay down from standing and a further one-quarter occurred when the sow rolled over. There is some similarity with the study of Olsson and Svendsen (1989) who also recorded half of the crushing deaths in an open pen to be due to transitions between standing and lying. There are, however, also contrasts with other studies. Olsson and Svendsen (1989) found only 7% of crushings occurred when the sow rolled over. Weary *et al.* (1996a) reported that only one-quarter of crushing deaths occurred when the sow lay down from standing and two-thirds occurred when the sow rolled over. These disparities are most likely due to different thermal environments affecting the amount of time piglets spend in proximity to the sow and different sow genotypes with different body conformations and hence, different abilities to control body movements.

The overall incidence of crushing and proportion due to different body movements is greatly influenced by the extent to which the farrowing system will allow certain posture changes to be carried out. Edwards *et al.* (1986) reported that 13 of 15 observed crushing deaths in farrowing crates occurred when the sow lay down; eight when lying down from a sitting position and five when lying down from a standing position. Unsurprisingly, there were no piglet deaths caused by the sow rolling over as this body movement is essentially prevented by the close confinement experienced in a farrowing crate. Crates are also designed to prevent crushing deaths when the sow lies down from standing, and in the study by Edwards *et al.* (1986), they appeared to keep crushing deaths during this type of posture change at a relatively low level. However, sows' movements during lying down and standing up are restricted in confined housing systems (Marchant and Broom, 1996) and consequently, they may change postures between sitting and lying more readily than between standing and lying. The relatively high number of crushing deaths during sow transitions between sitting and lying in the study of Edwards *et al.* (1986) would appear to support this theory. It is also known that sows housed in farrowing crates do spend less time standing and more time sitting than sows housed in open farrowing pens (Cronin *et al.*, 1996).

The sow rolling over is accepted as a dangerous manoeuver in open farrowing systems (Weary *et al.*, 1996a; Wechsler and Hegglin, 1997) and has even been used to derive a score of the quality of maternal care (Wechsler and Hegglin, 1997). However, the degree of danger posed is very much dependent on the position of the piglets when the behaviour is carried out. Newborn piglets and sows have very different heat requirements of perhaps 28 to 30°C and 14 to 18°C respectively (English *et al.*, 1977). Most farrowing systems incorporate a separate creep area for the piglets, which can be maintained at a higher temperature than that of the farrowing room as a whole. If the heated creep area is working as intended, piglets should be spending the majority of their time in this area, except during suckling. If, however, the temperature differential between the house and creep is not maintained, piglets may use the sow as the source of supplementary heat and spend much of their time huddled close to her. Piglets with low weight gain have also been shown to spend significantly more time next to the sow's udder (Weary *et al.*, 1996b). Whatever the reason, piglets that are huddling next to the sow are obviously at very great risk if she then rolls over on top of them. The risk of deaths from this behaviour may potentially be reduced by effective cross-fostering to reduce within-litter variation in birth weight and weight gain and by ensuring that the creep area is attractive in terms of thermal and tactile properties (Lay *et al.*, 1999).

Lying down from standing accounted for half of crushing deaths during this study. A large number of the dangerous lying down events occurred during the first 24-h period from the birth of the first piglet onwards. Sows carried out a mean of 9·87 lying down events (s.e. = 1·07, range = 1 to 22) during this 24-h period. In a semi-natural environment, the sow is usually passive during parturition and rarely carries out posture changes. It has been proposed that this passivity may be due to the fact that the sow gives birth to a large number of precocial young and that to engage in piglet-directed behaviour as each piglet is born, may place them at unnecessary risk of crushing (Jensen, 1988). In indoor farrowing systems, however, sows are often observed changing posture frequently during the first 24 h after farrowing (Weary *et al.*, 1996a; Harris and Gonyou, 1998; Herskin *et al.*, 1998) and even during parturition itself (Jarvis *et al.*, 1999). This could be due to behavioural restriction and/or the physical discomfort caused by the flooring substrate (Herskin *et al.*, 1998; Weary *et al.*, 1998). The latter is supported by a study that shows a reduction in posture-changing during and after parturition following intra-muscular injection of analgesia (Hausmann *et al.*, 1999).

In terms of where the sow lay down in the pen, the greatest risk of crushing occurred if she lay down without support in the middle of the pen. Sows housed in open systems will frequently use a solid surface to lean against when lying down (Marchant and Broom, 1996). Sows that do not use a surface as an aid when lying down will often lose muscular control when lowering their hindquarters to the floor. These difficulties are particularly apparent in sows with long body lengths and low proportions of locomotor muscles to body weight (Marchant and Broom, 1996). Weihsler and Hegglin (1997) have reported that where control is lost, i.e. when the sow lets her hindquarters fall to one side, 48·6% of such events are dangerous. In this study, 36·3% of lying down events that occurred in the middle of the pen were dangerous and 15·0% resulted in piglet deaths. This inability to control unsupported lying down may be a primary factor in the high incidence of crushing deaths recorded in open farrowing systems.

Not only is the behaviour of the sow during lying down important, so is the behaviour she carries out before she lies down (Signoret *et al.*, 1975; Blackshaw and Hagelso, 1990). Ideally, if piglets are in the area in which the sow is going to lie down, she will root through the area, nudging the piglets out of the way, paw the straw and look around to see where the piglets are. Once she has ensured the area is clear of piglets, she will lie down quickly into the space. This study has re-emphasized the importance of piglet-directed pre-lying behaviour. Although the time taken to lie down did not influence the risk of crushing, the amount of piglet-directed behaviour did. Dangerous lying down events were much more frequent when the sow performed no or very little such behaviour. The amount of pre-lying behaviour carried out declined over lactation, being maximal on the day of parturition, when the piglets are at their most vulnerable in terms of mobility and when risk of crushing is greatest. Rooting and making contact with piglets were the behaviours that decreased significantly over this period. This perhaps demonstrates a greater co-ordination between her behaviour and that of her litter (Schmid and Hirt, 1993).

This effect is perhaps also illustrated in the data concerning the piglet behaviour as the sow lay down. Clearly piglets can only be crushed if they are near the sow when she lies down. However, the results demonstrate that nearness itself is not necessarily a risk factor if piglet behaviour is co-ordinated and they are clustered together. If they are clustered together, the risk of crushing is low. If they are spread out, it is presumably very difficult for the sow to determine each piglet's location and the risk of crushing is very greatly increased. Pen designs which promote the co-ordination of sow-piglet behaviour are likely to reduce the likelihood of piglet crushing (Schmid, 1991). One element that can potentially decrease co-ordination is that of piglet hunger. In systems where the sow can leave the litter, suckling events can become sow-controlled early in lactation. If the sow returns to the pen when piglets are hungry, their behaviour may be less well co-ordinated and they will be spread out when the sow attempts to lie down.

In summary, crushing by the sow may account for up to three-quarters of early piglet mortality in open farrowing systems. There are many types of posture change during which crushing may occur and it is important that the design of the system tries to restrict or ameliorate the consequences of the most dangerous types of movement. Co-ordination of sow and piglet behaviour is a key factor in reducing crushing risk and high quality maternal behaviour is an important consideration if an open farrowing system is to be successful.

Acknowledgements

The authors would like to thank Roger Stiles and the other Terrington stockmen for their care of the pigs, and also Steve Malkin, Carl Widdowes and Amanda Burfoot for their help in data collection. This joint project by ADAS Terrington and the University of Cambridge was supported by the UK Ministry of Agriculture, Fisheries and Food.

References

Arey, D. S. and Sancha, E. S. 1996. Behaviour and productivity of sows and piglets in a family system and in farrowing crates. *Applied Animal Behaviour Science* **50:** 135-145.

Baxter, M. R. 1991. The 'freedom' farrowing system. *Farm Building Progress* **104:** 9-15.

Baxter, M. R. and Schwaller, C. E. 1983. Space requirements for sows in confinement. In *Farm animal housing and welfare* (ed. S. H. Baxter, M. R. Baxter and J. A. C. MacCormack). *Current topics in veterinary medicine and animal science, vol. 24*, pp. 181-194. Martinus Nijhoff, The Hague.

Blackshaw, J. K., Blackshaw, A. W., Thomas, F. J. and Newman, F. W. 1994. Comparison of behaviour patterns of sows and litters in a farrowing crate and a farrowing pen. *Applied Animal Behaviour Science* **39:** 281-295.

Blackshaw, J. K. and Hagelso, A. M. 1990. Getting up and lying down behaviours of loose-housed sows and social contacts between sows and piglets during day 1 and day 8 after parturition. *Applied Animal Behaviour Science* **25:** 61-70.

Carr, J. and Walton, J. R. 1995. Recognising the stillborn piglet. *PIGS-Misset* **March 1995:** 30-31.

Cronin, G. M., Barnett, J. L., Hodge, F. M., Smith, J. A. and McCallum, T. H. 1991. The welfare of pigs in two farrowing/lactation environments: cortisol responses of sows. *Applied Animal Behaviour Science* **32:** 117-127.

Cronin, G. M., Simpson, G. J. and Hemsworth, P. H. 1996. The effects of the gestation and farrowing environments on sow and piglet behaviour and piglet survival and growth in early lactation. *Applied Animal Behaviour Science* **46:** 175-192.

Cronin, G. M. and Smith, J. A. 1992. Effects of accommodation type and straw bedding around parturition and during lactation on the behaviour of primiparous sows and survival and growth of piglets to weaning. *Applied Animal Behaviour Science* **33:** 191-208.

Dyck, G. W. and Swierstra, E. E. 1987. Causes of piglet death from birth to weaning. *Canadian Journal of Animal Science* **67:** 453-547.

Edwards, S. A. and Fraser, D. 1997. Housing systems for farrowing and lactation. *The Pig Journal* **39:** 77-89.

Edwards, S. A., Malkin, S. J. and Spechter, H. H. 1986. An analysis of piglet mortality with behavioural observations. *Animal Production* **42:** 470 (abstr.).

Edwards, S. A., Smith, W. J., Fordyce, C. and MacMenemy, F. 1994. An analysis of the causes of piglet mortality in a breeding herd kept outdoors. *Veterinary Record* **135:** 324-327.

English, P. R. 1993. A review of farrowing facilities in relation to the needs of the sow and her piglets and the aspirations of the caring stockperson. *Pig Veterinary Journal* **31:** 124-143.

English, P. R., Smith, W. J. and MacLean, A. 1977. *The sow: improving her efficiency*. Farming Press, Ipswich.

Glastonbury, J. R. W. 1976. A survey of preweaning mortality in the pig. *Australian Veterinary Journal* **52:** 272-276.

Harris, M. J. and Gonyou, H. W. 1998. Increasing available space in a farrowing crate does not facilitate postural changes or maternal responses in gilts. *Applied Animal Behaviour Science* **59:** 285-296.

Haussmann, M. F., Lay, D. C., Buchanan, H. S. and Hopper, J. G. 1999. Butorphanol tartrate acts to decrease sow activity which could lead to reduced pig crushing. *Journal of Animal Science* **77:** 2054-2059.

Herskin, M. S., Jensen, K. H. and Thodberg, K. 1998. Influence of environmental stimuli on maternal behaviour related to bonding, reactivity and crushing of piglets in domestic sows. *Applied Animal Behaviour Science* **58:** 241-254.

Holyoake, P. K., Dial, G. D., Trigg, T. and King, V. L. 1995. Reducing pig mortality through supervision during the perinatal period. *Journal of Animal Science* **73:** 3543-3551.

Jarvis, S., McLean, K. A., Calvert, S. K., Deans, L. A., Chirnside, J. and Lawrence, A. B. 1999. The responsiveness of sows to their piglets in relation to the length of parturition and the involvement of endogenous opioids. *Applied Animal Behaviour Science* **63:** 195-207.

Jensen, P. 1988. *Maternal behaviour of free-ranging pigs. I. Results of a three-year study.* Report 22. Department of Animal Hygiene, Swedish University of Agricultural Sciences, Skara.

Kavanagh, N. T. 1995. A comparison between free-access farrowing nests and farrowing crates on a 500-sow unit. *The Pig Journal* **35:** 10-18.

Kerr, S. G. C., Wood-Gush, D. G. M., Moser, H. D. and Whittemore, C. T. 1988. Enrichment of the production environment and the enhancement of welfare through the use of the Edinburgh family pen system of pig production. *Research and Development in Agriculture* **5:** 171-186.

Lawrence, A. B., Petherick, J. C., McLean, K. A., Deans, L. A., Chirnside, J., Vaughan, A., Clutton, E. and Terlouw, E. M. C. 1994. The effect of environment on behaviour, plasma cortisol and prolactin in parturient sows. *Applied Animal Behaviour Science* **39:** 313-330.

Lay, D. C., Haussmann, M. F., Buchanan, H. S. and Daniels, M. J. 1999. Danger to pigs due to crushing can be reduced by the use of a simulated udder. *Journal of Animal Science* **77:** 2060-2064.

Lou, Z. and Hurnik, F. J. 1994. An ellipsoid farrowing crate: its ergonomical design and effects on pig productivity. *Journal of Animal Science* **72:** 2610-2616.

Marchant, J. N. 1998. Sow aggression towards the stockperson: relationships with approach test parameters and piglet survival. *Proceedings of the 32nd international congress of the International Society for Applied Ethology* (ed. I. Veissier and A. Boissy), p. 109. Institut National de la Recherche Agronomique, France.

Marchant, J. N. and Broom, D. M. 1996. Factors affecting posture-changing in loose-housed and confined gestating sows. *Animal Science* **63:** 477-485.

MINITAB. 1998. *MINITAB reference manual (release 12.2)*. MINITAB Inc. USA.

Olsson, A.-C. and Svendsen, J. 1989. *Grisningsförlopp och moder-avkomma-samspel i olika inhysningssystem.* Sveriges Lantbruksuniversitet, Intsitut för landbrukets byggnadsteknik, Lund, Rapport 65.

Randall, G. C. B. and Penny, R. H. C. 1967. Stillbirths in pigs: the possible role of anoxia. *Veterinary Record* **81**: 360-361.

Rudd, A. R., Mendl, M. T., Simmins, P. H. and Broom, D. M. 1992. Behavioural consequences of allowing the farrowing and lactating sow greater freedom. *Journal of Animal Science* **70**: 168 (abstr.).

Schmid, H. 1991. Natürliche Verhaltenssicherungen der Hausschweine gegen das Erdrücken der Ferkel durch die Muttersau und die Auswirkungen haltungsbedingter Störungen. *Ph.D. thesis, University of Zurich.*

Schmid, H. and Hirt, H. 1993. Species specific behaviour of sows and piglets that prevent crushing. *Proceedings of the international congress on applied ethology* (ed. M. Nichelmann, H. K. Wierenga and S. Braun), pp. 455-458. Kuratorium für Technik und Bauwesen in der Landwirtschaft, Darmstadt, Germany.

Signoret, J. P., Baldwin, B. A., Fraser, D. and Hafez, E. S. E. 1975. The behaviour of swine. In *The behaviour of domestic animals* (ed. E. S. E. Hafez), pp. 295-329. Balliere Tindall, London.

Svendsen, J., Bengtsson, A. C. H. and Svendsen, L. S. 1986. Occurrence and causes of traumatic injuries in neonatal pigs. *Pig News and Information* **7**: 159-179.

Weary, D. M., Pajor, E. A., Bonenfant, M., Ross, S., Fraser, D. and Kramer, D. L. 1999. Alternative housing for sows and litters. 2. Effects of a communal piglet area on pre- and post weaning behaviour and performance. *Applied Animal Behaviour Science* **65**: 123-135.

Weary, D. M., Pajor, E. A., Fraser, D. and Honkanen, A.-M. 1996a. Sow body movements that crush piglets: A comparison between two types of farrowing accommodation. *Applied Animal Behaviour Science* **49**: 149-158.

Weary, D. M., Pajor, E. A., Thompson, B. K. and Fraser, D. 1996b. Risky behaviour by piglets: a trade-off between feeding and risk of mortality by maternal crushing? *Animal Behaviour* **51**: 619-624.

Weary, D. M., Phillips, P. A., Pajor, E. A., Fraser, D. and Thompson, B. K. 1998. Crushing of piglets by sows: effects of litter features, pen features and sow behaviour. *Applied Animal Behaviour Science* **61**: 103-111.

Wechsler, B. and Hegglin, D. 1997. Individual differences in the behaviour of sows at the nest-site and the crushing of piglets. *Applied Animal Behaviour Science* **51**: 39-49.

Wells, G. A. H. 1978. *Post mortem* technique for the pig. *The Pig Journal* **2**: 19-25.

(Received 13 March 2000—Accepted 20 July 2000)