Title: Systematic Literature Review and Needs Assessment of Housing Systems for Gestating Sows in Group Pens with Individual Feeding - **NPB #08-276**

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1.0 INTRODUCTION

Over the past 10 years, animal scientists, veterinarians, producers, and animal rights groups have debated the welfare implications of either housing sows in gestation stalls or in groups. Recent examples of this in the United States can be seen in the prolificacy of editorial letters written by animal experts arguing their opinions on the best course of action with regard to gestation sow housing legislation and position statements (Baker, 1996; Forsythe, 2002; Davidson, 2003; Kornheiser, 2004; Hansen and Bowden, 2005; Koltveit et al., 2005), especially as they pertain to the American Veterinary Medicine Association's (AVMA's) task force report on the housing of pregnant sows (AVMA, 2005; Koltveit, 2006) and the sow confinement issue (Rollin, 2001).

In the United States, the general public is expressing their disapproval of gestation stalls by voting to ban them. Legislation to ban sow gestation stalls has occurred in the following states: Florida in 2002, Arizona in 2006, Oregon in 2007, Colorado in 2008, California in 2008 and Maine in 2009. Gestation stalls and tethers have already been banned in the United Kingdom since 1999. The rest of Europe is phasing out gestation stalls by 2013. On the surface, it may appear that this is a step forward towards improving gestating sow welfare; however, without sound science to help producers decide which group housing system will best meet the needs of their sows and themselves, the switch to group housing could initially result in poorer gestating sow welfare.

However, decisions regarding sow housing can be made objectively if based on expert opinion. For example, experts have ordered the following housing systems according to sow welfare from low to high: tethers and stalls (lowest); indoor group housing (middle); group housing with outdoor and substrate access (highest) (Bracke et al., 2002).

In any event, as stalls are phased out, and group housing is phased in, more research is required to understand how to best manage group housing systems. Most of the research conducted on sow housing has involved comparing group housing with stall housing. Some research suggests that it may be more cost efficient to produce pigs from gestating sows in naturally ventilated hoop shelters with deep bedding, individual feeders and approximately 4.8 m^2/pig, than from stall housed sows in confinement facilities (Lammers et al., 2008). However, only comparing group and stall housing will not provide adequate information that one system is better than another regarding sow welfare. Further complicating the fundamental question of how confinement affects pregnant sow welfare is the issue of the number of alternative group sow housing designs and management regimes which are available. Group housing can be a complex system and comes in many forms. There is a lack of research comparing all of the different options. For example, there is a variety of feeding methods to choose from: sows may be fed as a group (either on the floor or in troughs) or individually. Individual feeding methods can include:

- Free access stalls (provides some protection during feeding, but the back of the stall is open)
- Feeding stalls (where sows are manually locked in for feeding)
- Electronic Sow Feeders (ESF; where sows are recognized by their ear transponder and are fully protected during feeding)
- Biofix or trickle-feeding system (sows can eat simultaneously as feed is delivered slowly and in small portions, but there is not much protection or control over individual feed intake)
- Walk-in/lock-in stalls (sows are free to exit the stall at any time by backing up, which pushes the back gate up; they are fully protected while in the stall)
- Fitmix (unprotected ESF; sows are recognized by an ear transponder, and feed is delivered through a nozzle into the pig's mouth)
- In addition to the variety of feeder types available, there are many pen layouts, group sizes, group types, genetics, enrichments, and feeding regimes to choose from.

Overall, a system's welfare status can be judged based on the 'Five Freedoms'. If sows have freedom from: 1) malnutrition, 2) thermal and physical discomfort, 3) injury or disease, 4) suppression of normal behavior, and 5) fear and stress, then their welfare requirements are considered to be met (Webster, 1987). For producers, an ideal group housing system would result in: 1) high biological performance, 2) low labour input, 3) ease of management, 4) acceptable capital cost, and 5) acceptable financial return (Edwards, 1990). While these two sets of requirements initially appear to be at odds with one another, taken holistically, they can be achieved (or partly achieved) through an integrated evaluation of housing systems.

When evaluating the various sow housing methods, researchers use a variety of outcome measures including: behavior (i.e., aggression, responses to behavioral tests, general behavioral time budgets, stereotypies), injuries (i.e., scratches, lesions, vulva bites, lameness), physiology (i.e., cortisol concentration, heart rate, muscle/bone strength) and productivity (i.e., fertility, litter size, litter weight, piglets/sow/year, backfat, body condition, longevity).

The objective of this review paper is not to compare the use of gestation stalls versus group sow housing, but to take an in-depth look at group sow housing systems which utilize individual feeding and to conduct a needs assessment on these types of gestation sow housing systems.

2.0 METHODOLOGY

For this review, a scientific literature search was conducted from December 2008 – January 2009 and resulted in close to 400 research abstracts identified on the topic of group housing of gestating sows involving individual feeding systems. Of these identified abstracts, 225 research articles were pulled and sorted, from February 2009 to April 2009, based on the variables measured in the research (e.g. group type, space allowance, bedding, etc) as well as factors affected (e.g. production performance, overall well-being, and lifetime productivity). The three main databases that were used included AGRICOLA (USDA, indexes 2500 journals since 1970), CAB International (indexes over 9000 journals, books and conference proceedings), and Scopus (indexes over 16,000 peer-reviewed journals, and numerous conference proceedings and books). Additional databases included: MEDLINE (1960 to present), PUBMED (1960 to present), BIOSYS (1960 to present), AGRIS: International Information System for the Agricultural Sciences and Technology (1974 to present), Animal Behavior Abstracts (1982 to present), Biological and Agricultural Index Plus (1983 to present), Biotechnology Research Abstracts (1983 to present), Canadian Federal Government Databases (accessible through the internet; includes 377 databases by government department), Catalog of the U.S. Government Publications (CGP), and the Conference Papers Index (1982 to present).

3.0 RESULTS

3.1 Space Allowance

Most of the research conducted on space allowance in group housing systems has involved a comparison between group housing and gestation stalls. Very little work has been conducted on the effects of providing different space allowances to group housed sows. Therefore, the research provided below is mainly a comparison of group housing systems with individual feeding and gestation stalls.

3.1.1 Behavior

Aggression

Aggression did not differ when two dynamic groups were fed with an ESF and were provided with different spaces of 2.25 and 3.0 m^2 per sow (Remience et al., 2008). More space resulted in less one-way aggression for new sows introduced into the group. A space allowance between 2.4 and 3.6 m^2 per sow promoted more exploratory behavior and less inactivity among small groups of sows fed in individual feeding stalls (Weng et al., 1998). More social interactions and aggressive encounters occurred at lower space allowances. Over several parities, sows in stalls (1.2 m^2/sow) were more aggressive compared with group-housed sows fed with an ESF (2.4 m^2/sow) and group-housed and fed in individual stalls (2.2 m^2/sow) (Broom et al., 1995). Sows in the ESF system were more aggressive when first mixed.

Stereotypies

Sows in stalls spent more time performing stereotypies than group-housed sows (Broom et al., 1995). However, den Hartog et al., (1993) did not find any differences in the frequency of stereotypies among stall-housed (1.3 m^2/sow) and group-housed sows (2.5 m^2/sow).

General Behavior

Indications of reduced fear during a novelty test suggested that young group-housed sows fed with an ESF adjusted better than stall-housed sows (Jensen et al., 1995). Restrictive housing in stalls (1.2 m^2/sow) caused sows to have more difficulty lying down and standing up (Marchant and Broom, 1996a). As body length increased, sows took longer to lie down in stalls. Group-housed sows in an ESF system with 2.4 m^2/sow took longer to lie down in the open compared with when they used a wall to assist them. General behavioral time budgets (standing, lying, sitting, eating and drinking) did not differ between sows housed in groups of four, with 2.4 m^2/sow, and fed from individual feeding stalls and sows housed in gestation stalls (Harris et al., 2006).

3.1.2 Injuries

More injuries occurred at greater space restriction in group housing with individual feeding stalls, when 2.0, 2.4, 3.6, and 4.8 m^2/sow were compared (Weng et al., 1998). Similarly, in a group housing ESF system, more injuries resulted when less space (2.25 versus 3.0 m^2/sow) was provided (Remience et al., 2008). Sows that were housed in groups in hoop shelters on deep litter, with 2.3 m^2/sow, and fed in individual feeding stalls, had more injuries than stall-housed sows with 1.3 m^2/sow during the first week of gestation (Karlen et al., 2007). Injuries were greater for group-housed sows in an ESF system with 1.7 m^2/sow compared with stall-housed sows (1.2 m^2/sow) at initial group formation (Anil et al., 2003; Anil et al., 2005). However, more injuries were found among stalled sows in late gestation, which was likely due to increased space restriction.

Injuries were negatively correlated with bodyweight for sows in groups, but positively correlated with bodyweight for sows in stalls (Anil et al., 2003; Anil et al., 2005; Bhend and Onan, 2003). However, Harris et al., (2006) did not find differences in injuries sustained during the first week, but more injuries were found for grouped sows by week 13 of gestation compared with stalled-sows. Their grouped sows were housed in groups of four and fed from individual feeding stalls with 2.4 m^2/sow.

More vulva injuries were found among group-housed sows with 2.5 m^2/sow in an ESF system than individually housed sows. (den Hartog et al., 1993; Rizvi et al., 1998). Harris et al. (2006) did not find problems with vulva biting, which they attribute to the use of individual feeding stalls. More sows had to be removed from group housing than from stalls (den Hartog et al., 1993; Anil et al., 2005). In both housing types, lameness was the main reason for removals (Anil et al., 2005). However, more sows in gestation stalls became lame and later in gestation were culled than sows in group housing (Karlen et al., 2007). Harris et al. (2006) found that grouped sows had more lameness at the end of gestation than stalled sows. Claw lesions were greater among group-housed sows compared with stall-housed sows (Kroneman et al., 1993a).

3.1.3 Physiology

Physiological indicators did not differ between sows in stalls (1.3 m^2/sow) and sows in small groups (2.3 m^2/sow) with individual feeding stalls (Sorrells et al., 2007) and neither did urinary cortisol concentrations for stalled sows (1.5 m^2/sow) and grouped sows (2.2 m^2/sow) with individual feeding stalls (Pol et al., 2002). Salivary cortisol concentrations were lower among stalled sows with 1.2 m^2/sow compared with group-housed sows with 1.7 m^2/sow (Anil et al., 2005). During the first week of gestation, group-housed sows (2.3 m^2/sow) tended to have higher salivary cortisol concentrations compared with stalled sows (1.3 m^2/sow) (Karlen et al., 2007). Physiological measures did not differ among sows housed in stalls or sows in groups with either an ESF or individual stalls for feeding (Broom et al., 1995).

Heart rate did not differ later in gestation between group and stall-housed sows (Harris et al., 2006). Grouped sows were housed in groups of four, with 2.4 m^2/sow and fed from individual feeding stalls. Physiological measurements, such as adrenocortical function, plasma progesterone, antibody response and inflammatory response, did not differ between sows housed in the Hurnik-Morris group system or gestation stalls (von Borell et al., 1992). The Hurnik-Morris system is an automated cafeteria housing system, designed for six sow groups, providing 2 m^2/sow. There is the same number of electronic sow feeders as there are sows, and bedding can be used over a concrete lying area (Morris et al., 1993). Later in gestation, sows in stalls had higher neutrophils and lower lymphocytes, making a higher neutrophil:lymphocyte ratio (an indicator of increased stress) compared with group-housed sows in hoop shelters on deep bedding with 2.3 m^2/sow (Karlen et al., 2007).

Most likely due to a lack of exercise, muscle weight and bone strength were reduced for stall-housed sows compared with group-housed sows (Marchant and Broom, 1996b).

3.1.4 Productivity

Hurnik-Morris System versus Gestation stalls

There were no differences found in piglet mortality or viability when sows in the Hurnik-Morris system were compared with stalled sows (Morris et al., 1997). Overall productivity was better among sows in the Hurnik-Morris system (ESF and 2.0 m^2/sow) compared with sows in gestation stalls (1.6 m^2/sow) (Morris et al., 1998). Group-housed sows reached higher parities, had more piglets born and weaned in their lifetime than stall-housed sows. The number of piglets weaned per litter and litter weaning weight were similar in both the Hurnik-Morris system and gestation stalls (von Borell et al., 1992). Pre-farrowing and weaning backfat measurements were similar in both systems.

Group Housing versus Gestation Stalls

A higher farrowing rate was found among stalled sows compared with group housed sows in hoop shelters on deep bedding with 2.3 m^2/sow (Karlen et al., 2007). However, Bates et al. (2003) found a higher farrowing rate among group-housed sows compared with stall-housed sows. The group housed sows were fed from an ESF and had between 1.5-2.9 m^2/sow, depending on the production schedule. Stalled sows weaned fewer piglets, but their piglets weighed more compared with piglets produced by group-housed sows (Karlen et al., 2007).

However, Bates et al. (2003) found that group-housed sows produced and weaned heavier litters compared with stall-housed sows.

Sows in stalls had lower bodyweights compared with group-housed sows fed with an ESF (Broom et al., 1995). However, Harris et al. (2006) did not find differences in body weight between group-housed and stall-housed sows throughout gestation. Grouped sows had 2.4 m^2/sow, were housed in groups of four without bedding, and were fed from individual feeding stalls.

Reproductive measures did not differ among sows housed in stalls, sows in small groups or sows in large groups with an ESF (Broom et al., 1995). Similarly, Harris et al. (2006) did not find any differences in reproductive performance between stall and group-housed sows. However, den Hartog et al. (1993) found that stall-housed sows had more piglets per sow per year and more weaned per sow per year compared with group-housed sows. Bates et al. (2003) concluded that group-housed sows with an ESF had similar or improved performance compared with sows housed in stalls. Group-housed sows in hoop shelters on deep bedding had higher return rates to estrus after mating compared with stalled sows (Karlen et al., 2007).

Group Housing with different space allowances

Weight, backfat, number of piglets born alive or dead, number of weanlings, and weight of litters at birth did not differ between two dynamic groups that had two different space allowances of 2.25 and 3.0 m^2 per sow and fed from an ESF (Remience et al., 2008).

Lammers et al. (2008) suggest that it might cost less to produce pigs from gestating sows in naturally ventilated hoop shelters with deep bedding, individual feeders and approximately 4.8 m^2/pig, than from stall housed sows in confinement facilities.

3.1.4. Summary

Less space appears to result in more social interactions and aggression. Less space resulted in more injuries in systems with both ESF and individual feeding stalls. Physiological measures did not differ in groups with an ESF and groups with individual feeding stalls. Different space allowances in group housing with an ESF did not affect productivity.

3.1.5. Research Needs Assessment

- Comparisons of different space allowances within group housing (with less emphasis on comparing group housing with stall housing)

- More specifically, comparisons of different space allowance in group housing with individual feeding system

3.2 Group Size

3.2.1 Behavior

Sows in large groups with the ESF fought more upon initial mixing, but had fewer total agonistic interactions during the first gestation compared with sows in small groups fed in individual stalls (Broom et al., 1995). Sows in both small and large groups performed similarly by the fourth parity. Sows in small groups tended to perform more stereotypies than sows in large groups during the first parity. Sub-groups have been observed to form during resting periods among new sows entering established large groups (Moore et al., 1993).

3.2.2 Injuries

The risk of vulva biting increased as group size increased (Rizvi et al., 1998). Not only are large group sizes typical in ESF systems, but sows cannot eat simultaneously, which appears to further exacerbate vulva biting. Stimulating the formation of subgroups by providing two simultaneous meals of roughage in the lying area has been found to reduce vulva biting in the ESF system (van Putten and van de Burgwal, 1990). Sows in small groups (8 sows per group) had fewer injuries and better health than sows in larger groups (30 sows per group), regardless of being fed from an ESF or individual stalls (Svendsen et al., 1992). Young sows in small group sizes without feeding stalls (a place to escape) had more injuries than older sows (Kongsted et al., 2007). Injuries were found to be related to parity and body weight in a large dynamic ESF system (Hodgkiss et al., 1998). Smaller sows from younger parities sustained the most injuries.

3.2.3 Productivity

Reproductive measures did not differ among sows housed in stalls, sows in small groups or sows in large groups with an ESF (Broom et al., 1995).

3.2.4. Summary

More aggression resulted in large groups with an ESF compared with small groups with individual feeding stalls. Vulva biting is a problem in ESF systems, which usually have large group sizes. Sows cannot eat simultaneously and this appears to cause frustration and vulva biting results. More injuries result in large groups, regardless of the type of individual feeding system (ESF or feeding stalls). In both small and large groups with an ESF, the smaller and younger sows had more injuries. Increasing group size in an ESF system has different implications than in a system with individual feeders. An increase in group size in a system with individual feeding stalls would require providing more feeding stalls to accommodate more sows. However, in an ESF system, an increase in group size would not only have implications for the social dynamics within the group, but would also put more pressure on the use of the ESF. With more animals expected to use a single feed station, competition would increase.

3.2.5. Research Needs Assessment

- Further comparisons of different group sizes with various individual feeding systems (most research has focussed on ESF)
- More information on effect of group size on physiological measures is required (no studies were found on this topic)
- More information on effect of group size on productivity is needed (only one study discussed the effect of group size on reproductive measures).

3.3 Group Type / Group Composition

Group type is important to consider when determining the best option for group housing. The most common group types are static and dynamic. Sows in static groups remain together in the same group for the entire gestation period. Static groups are relatively small. The composition of dynamic groups change throughout the gestation period and are relatively large. With the correct management criteria, dynamic and static groups were both found to be effective (Strawford et al., 2008).

3.3.1 Behavior

The degree of familiarity did not have an impact on how well the group worked in an ESF system (Strawford et al., 2008). Olsson and Svendsen (1997) found that familiar gilts fought less than unfamiliar gilts. Stage of gestation and parity affect aggression (Strawford et al., 2008). Less aggression resulted when sows were mixed post-implantation. More aggression occurred among older sows, with younger sows sustaining more scratches.

Both static and dynamic groups resulted in more aggression during the first week after mixing compared with the remaining weeks in gestation (Durrell et al., 2002). Sows in large dynamic groups had more aggressive encounters compared with those in small static groups. Social interactions (such as fleeing and attacks) continued throughout gestation, but fighting was greater during the first week in the dynamic groups (Durrell et al., 2002). Sows in small static groups were less active compared with sows in the large dynamic groups.

Low ranking sows were displaced more from the drinkers and were prevented from lying in preferred areas of the pen (O'Connell et al., 2003). Low ranking sows in dynamic groups were the last to gain entry to the ESF and were displaced more from entry into the ESF. Stress and injuries in group housing are predominantly related to aggression at mixing, but in systems with an ESF, regardless of group type and social rank, struggle for entry into the feeder can also cause aggression and stress (Anil et al., 2006). More aggression occurred the longer sows had to wait for entry into the ESF. In a static group, high-ranking sows were found to eat earlier and longer at an ESF, compared with low-ranking sows (Chapinal et al., 2008). When subgroups were added to a group system at different times, the most recent subgroups added ate from the ESF later in the day than sows added earlier (Bressers et al., 1993). Feed order within each subgroup was not found to be stable over time. In the dynamic system, sows are removed and added to the group throughout gestation. A study by O'Connell et al., (2004) reported that the welfare of newly-introduced sows in dynamic groups may compromised when 10% replacement rated are used. However, there appears to be no additional welfare benefit associated with increasing replacement rates about 20%.

3.3.2 Injuries

Injuries to the front part of the body from fighting were greater in dynamic groups compared with static groups (Leeb et al., 2001). Sows in large dynamic groups had more injuries compared with those in small static groups (Durrell et al., 2002). Within a dynamic group of sows, new sows added to the group sustained more injuries than sows already established in the group (Bhend and Onan, 2003). Low ranking sows were found to have more injuries in both static and dynamic groups (O'Connell et al., 2003). For the first week after mixing, low ranking sows had more injuries than higher ranking sows in both the static and dynamic groups.

3.3.3 Physiology

Sows housed in dynamic or static ESF systems had similar salivary cortisol concentrations (Anil et al., 2006; Strawford et al., 2008). Social status within static or dynamic groups did not affect salivary cortisol concentration (O'Connell et al., 2003; Kranendonk et al., 2007). Sows in a large group that were characterized as low success (were able to displace some sows, but were often displaced themselves), had higher basal levels of salivary cortisol levels compared with high success (could displace at least as many as displaced them) and no success (never displaced any other sows) (Mendl et al., 1992).

3.3.4 Productivity

The farrowing performance and longevity of sows in dynamic and static groups in an ESF system did not differ (Anil et al., 2006). Sows from a static ESF system had larger and heavier litters compared with sows in a dynamic ESF system (Simmins, 1993). For the first week after mixing, low ranking sows had lower bodyweights than higher ranking sows in both the static and dynamic groups (O'Connell et al., 2003). High success pigs (could displace at least as many as displaced them) gained more weight compared with low success (could displace but were more often displaced) and no success (could not displace) sows (Mendl et al., 1992). The smallest piglets were produced by low success sows. Litter size and litter weight did not differ among sows of different ranks in a dynamic ESF system (Nowachowicz et al., 1999). Gestation length, litter size, or percentage of live born piglets did not differ between high and low ranking sows (Kranendonk et al., 2007). It has been suggested that group housing could lead to increased fear and stress and therefore negatively affect reproductive performance (Kongsted, 2004).

3.3.5. Summary

The first week post-mixing resulted in more aggression compared with remaining weeks in both static and dynamic groups. Overall, more aggression resulted in dynamic groups than static groups. Sows in small static groups were less active than sows in large dynamic groups. Sows in dynamic groups had more injuries than sows in static groups. New sows added to dynamic groups received many injuries. Sows in static and dynamic groups had similar salivary cortisol concentrations. There is discrepancy in the productivity results comparing sows in static and dynamic groups; some studies have found differences, others have not. Low-ranking sows are at a disadvantage in both static and dynamic groups; especially in an ESF system. They received more aggression and injuries; however, salivary cortisol did not differ among sows of different social status in either static or dynamic groups. Low-ranking sows had poorer productivity compared with high-ranking sows.

3.3.6. Research Needs Assessment

- How to recognize and manage low-ranking sows in a group system; especially the ESF system where there is more competition for feeder access and no place to escape aggressive attacks
- How to reduce competition and aggression for the ESF; which is the single feed resource for many sows
- Improved methods for easing the introduction of new sows to an already established dynamic group
- Understanding if low ranking sows perform better in group housing with individual feeders since they have a place to escape
- Differences in productivity for sows in static and dynamic groups

3.4 Flooring, bedding and environmental enrichment

Environmental enrichment and bedding is one of the best-researched aspects of group gestation sow housing in the current scientific literature. Bedding is an important environmental factor in group sow housing as it functions to absorb urine and feces, and is used to improve the sow's environment and enhance sow welfare (Lay et al., 2000). Some studies concentrate on outdoor housing as these types of systems have expanded rapidly throughout Europe, South Africa and the United States and include a wide range of herd sizes (Honeyman et al., 2001). As of 2005 in the United States, 5% of gestating sows were kept outdoors with an additional 15% of US gestating sows housed in buildings with outdoor access (reviewed by Honeyman, 2005). Comparing extensively bedded indoor and outdoor pig production systems in the United States, Honeyman (2005) also found Hoop-housed pigs with individual feeding stalls exhibited less aberrant behaviors, handled easier than confinement pigs, and provided an acceptable environment for gestating sows (Honeyman et al, 2005).

Other studies have focused on indoor systems that range from simple, low-cost, tent-like structures such as Hoop barns (Brumm et al., 1997) to highly technical systems. In the common Hoop system, a dirt floor is covered with deep bedding material and large bales of straw are often used as bedding and enrichment material in these systems (Honeyman et al., 1999), with concrete flooring for high-traffic feed and water areas which incorporate individual feeding stalls to ensure each sow receives her daily feed allotment (Brumm et al., 1999).

The EU Directive of 2001/93/EC states that all pigs must have permanent access to a sufficient quantity of material to allow proper investigation and manipulation activities. Based on a written questionnaire sent to 29 global pig welfare experts of 14 different nations to assess the welfare of pregnant sows based on housing conditions, the five highest ranked systems were all systems with outdoor access and the provision of some kind of substrate such as straw (Bracke et al., 2002). The highest weighted factors included social contact, health and hygiene status, water availability, space per pen, foraging and bulk, food aggression, rooting substrate, social stability and movement comfort. While tethering and individual housing in stalls were identified as low welfare systems, indoor group-housing systems and an individual-housing system with additional space and substrate were identified as mid-welfare systems. Based on a subsequent e-mail questionnaire to elicit further expert opinion, 8 senior pig scientists assessed 33 enrichment criteria (Bracke et al., 2007). The highest weighted assessment criteria included exploration, animal-material interactions (AMI), tail and ear biting, and rooting. However, the authors could not exclude a "European Bias" to the results nor carry over effects due to the ordering of the assessment criteria in the questionnaire.

Straw

The most popular bedding material for group housed gestation sows reported in the scientific literature is straw (Arey, 1993). As a whole, consumer perception is that animals raised with straw have better welfare (reviewed by Tuyttens, 2005) and experts on pig welfare assign considerable importance to the availability of straw substrates in their welfare assessment of housing systems (Spoolder et al., 2003). However, the use of straw is not without its disadvantages due to cost, increased labour, hygiene concerns (this has been noted in particular with organic systems) and incompatibility with manure and drainage systems (Tuyttens, 2005). Some studies have investigated whether there are suitable alternatives to straw with similar welfare benefits to group housed sows, with varying results due to difficulty in comparing substrate attributes. As Tuyttens (2005) notes, evaluating the welfare relevance of straw from the scientific literature is far from easy for several reasons: (1) the composition, structure, quality and quantity of straw can be quite varied; (2) there is no real consensus among scientists about the definition of animal welfare or on the way it can be assessed; (3) most studies do not specifically investigate the welfare impact of straw, but discuss this item as one of many aspects of animal housing or animal management; (4) the importance of straw may vary with age of the animal and their housing conditions and management.

3.4.1 Behavior

Stolba and Wood-Gush (1984) found that through the use of behavioral observations, the behavioral needs of sows can be determined, and the environment adapted or designed and enriched appropriately. In that context, numerous studies have shown that the enrichment of a barren housing environment with straw, peat, extra space, etc. has a favourable effect on pig behavior. The primary difficulty is environmental complexity which can present animals with many conflicting choices (Newberry and Estevez, 1997). More dynamic approaches to environmental enrichment recognize the trade-offs between these choices, with the optimal outcome maximizing animal welfare. It is often difficult to determine what is “natural” for animals kept under a range of different housing conditions (Newberry, 1995). A common failing is the tendency to over-simplify behavior measuring responses to “specific features” of an environment in isolation from other features of the animal’s usual environment (e.g. other animals; Newberry and Estevez, 1997). Behavior is plastic; this makes it difficult to make definitive decisions about the values of specific environmental features, as there may be a range of answers to the question of environmental requirements for animals. Animals will go through normal patterns of use and non-use of enrichment depending on time of day and group dynamics. Thus, the value of enrichment should not be judged based on use, but on the overall outcome of its provision on the animal’s welfare. Some undesirable oral behaviors include acts of aggression, tail biting, vulva biting, and stereotypies which have been confirmed by numerous studies (Fraser, 1975; Burbidge et al., 1994), including those involving the use of individual feeding stalls (Spoolder et al., 1995). In general, environmental enrichment tends to reduce the incidence of undesirable behaviors. For example, when sows are maintained on solid flooring with a straw bedded lying area 1.7 m² per sow and fed using ESF stalls, more agonistic interactions have been observed between sows in lying areas, and in the vicinity of the feeders compared with dunging areas (Hodgkiss et al., 1998).

Straw

Straw functions as an important stimulus and outlet for exploration, foraging, rooting and chewing behaviors, particularly if feed restricted. Kelly et al. (2000) concluded that even a small quantity of straw will suffice to keep pigs busy for most of their time and provided welfare benefits. Fraser et al. (1991), Arey (1993), and Day et al. (2002) also reported a tendency for straw directed behavior to increase with the quantity of straw provided. For example, pigs in deep bedded hoops have fewer aberrant behaviors, more play behavior, lower plasma cortisol in response to handling, and fewer injuries than pigs reared in confinement (Lay et al, 2000) likely due to this increase in straw-directed behavior. The behavior repertoire of grow-finish pigs (30-80 kg) has been found to be more varied if pigs are kept on straw bedding compared with barren slatted floors (Guy et al., 2002a), and bedding may be a more important factor than space in pen design (Beattie et al., 1996). In an operant conditioning study, Pedersen et al. (in press) found that pigs were willing to work to obtain access to 1 kg of straw on a daily basis (with access obtaining 100 g of straw at a time). Thus, despite, having to do a considerable amount of work to obtain access to the straw reward, the pigs were highly motivated to do so.

Fraser (1985) noted that straw also has many additional, distinct advantages for sow welfare as it satisfies comfort requirements by providing texture, good drainage properties and thermal insulation. As pigs spend an estimated 80% of their time lying (Marx and Mertz, 1989; Ekkel et al, 2003), adequate lying comfort is important for their welfare. As a substrate, straw tends to ease the effects of stress resulting from concrete floors (Warnier and Zayan, 1985), particularly while lying.

Synthetic Mats

The use of synthetic rubber mats in an ESF system has also been investigated as an alternative flooring material to provide sow comfort and overcome some of the disadvantages of the use of straw (Tuyttens et al., 2008b). In this study, lying mats did not affect activity levels (proportion of time spent standing, sitting and lying), nor was lying bout duration, time spent lying per lying posture (sternal, half recumbent, recumbent) or the getting-up duration. Sows using the lying mats were observed changing position more often, adopting the recumbent lying position a majority of lying time. However, the health consequences, long-term durability, and the relative preference for mats versus straw have not been tested to any great extent. Additionally, these synthetic mats provide fewer possibilities for sows to control their thermal microclimate when compared with loose bedding substrates. Tuyttens (2005) noted that synthetic mats may need to be combined with other enrichment in order to accommodate the recreational and nutritional functions that straw provides. Other floor substrates such as peat and mushroom compost may better resemble natural lying surfaces, may be more attractive to sows than straw, and cause fewer problems with sow housing systems.

Aggression

In addition to nesting, exploratory and foraging behaviors, group housed sows have a normal pattern of social behavior, which includes some level of aggressive or agonistic behavior. Some countries, such as the Netherlands, have experienced reservations regarding the group housing of sows due to the incidence of fighting that may be observed. In some situations, these fights can lead to animals being severely wounded. It has been hypothesized in the scientific literature that this may be due to a defective process of learning proper social behavior, however, it is also possible that the learning process is quite normal, but that the aberrations are caused by an imperfect husbandry system, (e.g., an inadequate feeding station; Tuyttens, 2005).

The effect of straw on aggression is not always clear. Andersen et al (1999) reported that the provision of straw may not be the most important element in reducing aggression within stable groups of loose housed sows. According to Arey and Franklin (1995), the provision of straw in group housing systems did not lead to a reduction of fighting in newly mixed groups either. The relation between straw and undesirable behavior is further complicated by the level of feed restriction. However, these studies and many others do not allow these effects to be attributed to straw as its influence cannot be separated from other resources provided such as extra space. (e.g., Buré, 1981; Ruitercamp, 1986) or another type of housing (e.g. van Putten and Dammers, 1976; Arellano et al., 1992).

Some of the alternatives to straw enrichment reviewed by Studnitz et al. (2007) included peat moss, spent mushroom compost, compost, bark chips, whole tree chips, branches, roughage (barley-peas-wholecrop), alfalfa hay, beets, pieces of wood, tires, rags, open rope ends, rubber toys, chains, and beams (Beattie et al., 1996; 2001; Bure et al., 1983; Horrell and A'Ness, 1995; Haskell et al., 1996a, 1996b; Long, 2002; Olsen, 2001; Olsen et al., 2000; Olsen et al., 2002; Madsen, 2001; Arey and Maw, 1995; Petersen et al., 1995; Petersen, 1997; Schaefer et al., 1990; Pearce and Paterson, 1993; Pearce et al., 1989; Hill et al., 1998; Feddes and Fraser, 1994). In general, the above studies demonstrated a positive effect of providing materials on reducing the incidence of pen mate directed behaviors, including aggression and biting, when compared with a barren environment alternative. Only one study found that hard to manipulate items (e.g. metal and used tethers) were effective in reducing aggression (Blackshaw et al., 1997), however animals quickly lost interest in these materials over a period of three weeks, likely due to a lack of novelty. Several studies have demonstrated that providing rooting substrate reduces aggression levels (Schaefer et al., 1990; Beattie et al., 1996; Olsen et al., 2002; Guy et al., 2002b). Beattie et al. (2001) found that pigs provided with racks full of mushroom compost exhibited less nosing, biting and chewing of pen mates, while Durrell et al. (1997) found that tail biting was higher in stall-fed, group housed sows without mushroom compost. These results suggest that pigs will re-direct rooting and biting behaviors towards the pen in the absence of any rooting substrate. Adding substrate reduces this re-direction of behavior and improves welfare by minimizing injury through tail biting. Studnitz et al., (2007) speculated that this reduction in aggression may not be the direct result of the enrichment materials themselves, but as a secondary effect of the enrichment re-directing attention away from pen mates, thereby reducing aggressive interactions as well. In one study, the provision of alfalfa from a feed rack actually increased agonistic competition amongst animals (Madsen, 2001). However, as the purpose and the circumstances vary considerably between various substrate materials, it is very difficult to compare the effects on pig behavior and welfare. Exploratory behavior was used as the primary assessment criteria in this case, because it is considered essential for the survival of the domestic pig's ancestor, the wild boar.

Bedding preferences

Sow preference for bedding material should also be considered. When provided with a choice between various floor substrates, Beattie et al. (1998) reported that pigs spent most of their time on peat, mushroom compost and sawdust, and on sand, whereas bark and straw scored only slightly better than concrete. The authors concluded that pigs may be attracted to substrates with a similar texture to earth/dirt. The preference for particular floor characteristics or bedding materials may also depend on the thermal conditions inside the sow house (Morrison et al., 1987). On hot summer days, deep bedded houses may therefore lead to problems if sows have no means to cool down. The preferred floor temperature may also vary according to sow age (Geers et al., 1990) or reproductive stage (Philips et al., 2000). Studnitz et al (2007) conducted a review of the current scientific literature to determine which materials are best suited as rooting substrates for pigs. Exploration motivation was the primary behavioral need used to assess the various rooting materials. Based on the pig ethogram and literature on pig use and preferences for various materials, the authors concluded that a rooting substrate must stimulate the exploratory behavior of pigs for an extended length of time in order for it to be considered suitable for rooting. The more complex, changeable, destructible, and manipulable a substrate in addition to containing sparsely distributed edible parts, the better the substrate for stimulating exploratory behavior. A trough filled with quality earth, for example, can reduce the frequency of passive lying down, aggressive behavior, and ear and tail biting (Wood-Gush and Beilharz, 1983; Appleby and Wood-Gush, 1988). Work by Sneddon and Beattie (1995) and Durrell et al. (1997; individual feeding stalls) also found that good quality enrichment can be inexpensive, while also reducing aggressive behaviors, injuries, and floor sniffing.

Numerous studies have specifically assessed the effectiveness of straw in reducing aberrant oral behaviors directed towards pen mates (Bure et al., 1983; Fraser et al., 1991; Petersen et al., 1995; Arey and Franklin, 1995). Kelly et al. (2000) found that deep bedding in addition to Straw-Flow™ resulted in a lower incidence of behavior redirected toward pen mates and pen fixtures compared with pigs housed in barren environments. Jensen et al. (2000) studied four commercial Danish sow herds, which differed with respect to the provision of a layer of unchopped straw used as bedding material in conjunction with ESF. The activity and aggression in the feeding area as well as the duration per sow of the period with high feeder occupation were lowest in herds where a layer of straw bedding was provided. Changing feeding start from day time to night time was accompanied by a reduced feeder occupation in the period following start of the feeding cycle. Number of regroupings and space allowance had no apparent effect on average frequency of aggression, but space allowance may have improved social function by weakening the association between activity and aggression. However, due to the small number of herds in the study, the results should be considered descriptive, rather than conclusive.

Use of enrichment devices and "toys"

In terms of enrichment, pigs also appear to have a preference for "toys" which they can easily bite and chew. Recently van de Weerd et al. (2003) tested 74 different enrichment objects for pigs. Overall, destructible and ingestible objects that stimulate forage and explorative behavior best kept the pigs' interest. Long straw in a box was the fourth most popular object after five days of exposure. Young et al. (1994) developed the "Edinburgh foodball", which better allowed sows to express foraging behavior. When rooted, the device delivers small food rewards randomly, in space, time and quantity. Food restricted gilts were found to interact with this device over long periods of time, and preferentially directed their routine activities at the foodball instead of straw. Furthermore, sows provided with a foodball showed a similar forging and activity time budget to that observed in free range pigs, which is often regarded as an indicator of good welfare. Whenever allocating enrichment material, two important considerations should be made 1) that proper exploration and manipulation is possible (is this enrichment biologically relevant?), and 2) that fighting for access to the substrate is minimal.

Outdoor group housing systems

In a comparison of indoor versus outdoor reared sows utilizing individual feeding stalls, Dailey and McGlone (1997) found that pregnant gilts kept outdoors were more active and spent more time chewing objects, and spent less time sitting and lying compared with indoor gilts. The outdoor environment appeared to reduce the incidence of oral-nasal behaviors compared with the indoor production system.

3.4.2 Injuries

The scientific literature demonstrates that oral behaviors in pigs housed in a barren environment without manipulable substrates are often directed toward pen settings or pen mates, which cause injury (Ruitercamp, 1987; McKinnon et al., 1989). When sows were assessed for injuries, such as vulva biting, in subsequent weeks the results demonstrated that sows kept in a commercial dynamic group with bedding can coexist without sustaining serious levels of injury. However, the quality of the sow's housing space is very important.

Lameness

Lameness in sows is a common injury issue, as group housing of sows makes high demands on the locomotory systems of sows, resulting in lameness, predominantly due to foot problems. The occurrence of lameness and foot lesions is influenced by the housing conditions and management on the farm. Morris et al (1998) culled fewer sows in their group housing system than in their gestation stall housing system. Their group housing system provided small amounts of bedding. Similarly Karlen et al (2007) reported a considerably higher level of culling for lameness in their gestation stall system than among their sows housed in groups on deep bedding. In contrast, Anil (2006) reported a higher culling rate for lameness in their group housed sows than among stalled sows. In this case, the group housed sows were on slatted floors, and they attributed lameness to injuries during post-grouping aggression. Taken together, these studies suggest that floor type and bedding may significantly affect degree of lameness in group housing, but studies that compare bedded and non-bedded management within the same system are required.

3.4.3 Physiology

In a study of loose housed sows in small groups with individual feeding stalls, Spoolder et al. (1996) investigated the interactive effects of straw provision and food level during pregnancy on performance and stress response as measured through ACTH challenge (measure of chronic physical stress). Significantly more "no straw" sows failed to start the second parity compared with sows provided with straw. The cortisol results from the study suggest differences between treatments to be of acute, rather than a chronic nature (re: ACTH challenge results). These results may help to explain earlier findings in which sows housed on straw during pregnancy produced more milk and heavier piglets in sows without straw (Høljgaard-Olsen and Nielsen, 1966).

Thermal microclimate

It is known that bedding improves the physical comfortable floor and - unless temperatures are high - straw enables pigs to somewhat control their microclimate thereby increasing thermal comfort (reviewed by Tuyttens, 2005). Results from a 1988-1989 survey investigating the use of non-insulated buildings with deep straw bedding for dry sow group housing were used to determine the best housing layout and management/husbandry practices that could be adapted to current systems and improve animal welfare and the working environment

(Svendsen et al., 1992). As part of the survey, 100 farmers were interviewed by telephone, with 36 follow-up site visits. Three main types of housing systems were visited: 1) deep straw bedding with individual feeding stalls, 2) a system using ESF, and 3) individual feedings stalls, a dung alley, and a bedded lying area. Overall, cold winter temperatures did not appear to present problems to the sows, however some experienced frostbite, and the cold temps caused dung to freeze, making removal more difficult. Operations varied in the incidences of injuries, thin sows, and “anxious” sows, despite the identical housing design. This indicates that management and husbandry have an impact on the occurrence of these problems. Thus, non-insulated group sow housing utilizing deep straw bedding (in various) designs can function well, but require good management and husbandry standards.

3.4.4 Productivity

In 2005, Honeyman reported that group housed sows in a bedded hoop barn may have slightly better reproductive performance than crated sows (i.e., fewer days in the breed-to-wean interval and more pigs born alive per litter). Sows group-housed on deep litter with individual walk-in/lock-in feeding stalls, and natural ventilation, gave birth to more live pigs per litter than sows gestated in stalls (Lammers et al., 2007). However, pre-weaning mortality was not different for the 2 housing treatments. In contrast, sows housed in stalls returned to estrus sooner than sows housed in groups. These results indicate that gestating sows can be housed as groups in deep-bedded hoop barns equipped with individual feeding stalls and will perform comparably to gestating sows housed in confinement systems with individual gestation stalls. In a comparison of large groups housed in deep litter (also housed in hoop structures with individual feeding stalls) to conventional gestation stalls, sows housed in hoops had more scratches, a higher return rate to estrus after mating, and tended to have higher salivary cortisol in the first week of gestation (Karlen et al., 2007). In contrast, stalled sows showed a higher incidence of lameness at 9 and 15 weeks of gestation, lower reproductive failure, and higher farrowing rate. While stalled sows tended to wean fewer pigs compared with group housed sows, the piglets of stalled sows weighed more at weaning. These results suggest that sows housed in large groups in deep litter faced greater welfare challenges in the early stages of gestation based on the findings of increased scratches, a higher rate of return to estrus and a trend for higher cortisol concentrations early in gestation, all possibly due to aggression experienced in the group housed system. Gestation stall housing increased the incidence of pregnancy uptake by 28d, whereas group sow housing with bedding, despite individual feeding stalls, increased the incidence of early disruption of pregnancy, perhaps due to social stress associated with group sow housing systems (Munsterhjelm et al., 2008). The type of housing system did not have an effect on the total exploratory or total passive behaviors observed. Stalled sows explored floors and fixtures (not bedding) more and performed more passive sitting than the group-housed sows; behavioral signs indicative of decreased welfare, but no corresponding reproductive effects.

Outdoor group sow housing systems

An Eastern-European study on the reproductive lifetime performance of sows kept indoors and outdoors (non-insulated huts with deep straw bedding) indicated that outdoor production systems may be associated with lower reproductive performance when climatic and environmental conditions are not favourable (Akos and Bilkei, 2004). Litter performance was not influenced by straw treatment. The study authors concluded that the provision of straw may buffer the adverse effects of a low food level on weight and back fat gain in group-housed pregnant sows, despite no effect on reproductive performance.

Hoop structures with deep bedding

Group housing sows in deep bedding hoop structures, with individual feeding, may produce pigs at a lower cost than individual gestation stalls in confinement facilities if the bedded group housing system is managed optimally (Lammers et al., 2008). Specifically, construction and operating costs were compared for 1) gestation stalls and 2) group sow housing with and feeding stalls and deep straw bedding in a naturally ventilated hoop barn. Hoop barn gestation facilities can be constructed for 70% of the cost of gestation stall facilities. Fuel and electricity costs are higher in mechanically ventilated gestation buildings, although bedding costs are higher in the hoop barns. Assuming equal prolificacy (based on earlier studies), feed cost per weaned pig is 7% more for sows gestated in hoop barns, but total cost per pig weaned is 3% less for pigs produced by sows gestated in group in hoop barns compared with pigs from a gestation stall system. When an increase of 0.7 pigs/litter for the hoop system was included in the cost analysis, the result stated that was hoop barn weaned pig cost was 10% less than the cost of a weaned pig from a gestation stall system.

3.4.5. Summary

Overall, while straw is often regarded as the bedding standard in deep-bedded group sow housing systems, it is worth pursuing better economic alternatives that allow for rooting behavior, control of the thermal environment, reduce lameness, is easy to remove, and which does not cause problems for manure management systems. Overall, providing straw bedding as a source of enrichment has many positive effects on sow behavior, however these same properties may not be unique to straw alone. Overall, sows provided with bedding tend to incur fewer injuries and exhibit less pen mate directed aberrant behaviors (e.g. ear and tail biting). However, both aggression and foot health problems can still persist in any deep bedded group sow housing systems. Overall, providing sows with straw decreased acute stress cortisol, buffered the effects of low feed level on weight and back fat gain, and decreased the incidence of frostbite. However, the specific impact of bedding on overall performance (e.g. milk production and growth) depends on the quality of the conducted research and what was measured. Furthermore, the effect of bedding alternatives on sow physiology have not been studied to any real extent. Overall, thoroughly bedded sow housing systems have been shown to decrease reproductive failure, increase pregnancy uptake, and increase farrowing rate. However, the majority of studies conducted with regard to the effect of bedding on sow productivity have used straw bedding, while alternative bedding materials are assumed to have a similar effect.

3.4.6 Research Needs Assessment

- Larger group sizes – most sow housing studies have group sizes of 4-6 sows each
- Direct comparison of group housing systems that incorporate individual feeding systems
- Bedding and enrichment in sows over-studied with regard to behavior and injuries, but less information on physiological effects (e.g. reliable stress measures)
- Value-added potential of used bedding substrate utilized in group sow housing systems
- Effect of flooring and bedding on lameness and leg injury

3.5 Feeding Regime

For the sake of this review, feeding regime includes data available on diet formulations (e.g. effect of increased fiber in the diet), number of feedings per day, feeding schedule, feeding order, etc. As such, the discussion on feeding regime is quite varied and takes many issues into consideration. It is also important to note, that regardless of whether gestating sows are housed in stalls or in groups or whether they are group or individually fed, all gestating sows are feed restricted as a means of reducing reproductive problems.

3.5.1 Behavior

While the conventional restricted feeding practices during gestation help to maximize economic performance (Meunier- Salaün et al., 2001), hunger and frustration as a result of unfulfilled feeding motivation have been linked to the occurrence of stereotypic activity, increased aggression, and feeding competition in group housing systems, all of which are indicative of decreased welfare in the sow. Adding fiber to the gestating sow diet to increase bulk has been demonstrated to result in doubled eating times, a 20% reduction in feeding rate, a 30% reduction in operant response in feed motivation tests, and a 7-50% reduction in stereotypic behavior (Meunier-Salaün et al., 2001). However, in this study, there was inadequate information on the effects of dietary fiber on physiological stress and health. There is also evidence that group-housed sows with ESF in non-bedded or barren systems exhibit increased aggression between pen mates, possibly as a result of hunger. Spoolder et al. (1997) investigated the effects of food level on performance, aggression, and skin damage in combination with a deep-straw system. Low-fed sows were more active and showed more straw manipulation than high fed sows. However, no difference in aggression or skin damage was found between treatments. Thus, the authors concluded that in a deep-straw system, aggression is not influenced by feeding level. Feed restriction, not physical restraint, has been found to be a major factor in increased activity levels and higher incidences of drinking and chain manipulation in sows fed with individual stalls (Terlouw et al., 1991). Furthermore, these activities do not seem to replace post-feeding nosing and rooting of substrates. Zonderland et al. (2004) found that the overall performance of stereotypies in stall-fed sows is a useful indicator of satiety, in addition to inactivity, self-directed behavior and substrate-directed behavior.

Diet composition

Diet composition, including the use of higher energy ingredients and feedstuffs that provide more bulk (e.g. fiber) will impact hunger motivation, thereby also influencing sow behavior. The effects of diet composition (low vs.. high fiber; using sugar beet pulp) and feeding level (restricted vs. *ad libitum*) during gestation was investigated for effects on behavior patterns in group housed gilts fed in stalls (Brouns et al., 1994). Behaviors observed included general activity, time spent feeding, lying, standing, rooting, licking, sham chewing, bar biting, and generalized oral behaviors. Gilts fed a high fiber diet took longer to consume their daily feed, were less active, and engaged in less oral behavior. The incidence of aberrant oral behaviors was minimized when the fibrous diet was offered *ad libitum*. Thus, providing individually stall-fed sows with a sugar beet pulp diet promoted satiety and reduced stereotypies. van der Peet-Schering et al. (2003) studied the effect of stall-feeding sows a starch diet or a diet with a high level of fermentable non-starch polysaccharide (fNSP) during gestation over the first two parities on the development of stereotypic behavior. High fNSP-fed sows reduced the frequency of total non-feeding oral activities in gestating sows. fNSP-rich diets (sugarbeet pulp; SBP) was shown to reduce stereotypic behavior (de Leeuw et al. 2004; 2005). In practice, feed allowance of non-lactating sows is restricted in order to prevent excessive fatness and reduced reproductive performance. However, hunger is linked to increased activity levels, which correlates with higher incidences of stereotypies. The current study found that self-directed behaviors (most pronounced immediately following feeding) and oral behaviors decreased and inactivity increased with increasing fNSP level in the diet. However, substrate-directed behavior was not affected by fNSP level in the diet. Ru and Bao (2004) investigated ESF-feeding dry sows *ad libitum* with high fiber diets. Current research indicates that feeding high fiber diets to dry sows enables sows to be fed *ad libitum*, but the effect of dietary fiber on feed intake and nutrient utilisation is dependent on the quality of fiber sources. Most research has focused on sugar beet pulp, straw, lucerne meal and by-products, but there is a need to identify and evaluate some widely available and cheap fiber materials and feed grains for developing the best strategy to control nutrient intake of dry sows while feeding *ad libitum.*

Straw racks for supplemental fiber

In addition to supplying fiber directly into the diet formulation, some research has also been done investigating the use of straw racks to provide supplemental fiber into the sow diet. In group housing studies in which sows were fed using free access stalls, Spoolder et al. (1995; 1996) evaluated activity levels in high and low-fed sows with and without access to straw. As added enrichment, chain loops were attached to the front of each feed stall, and behavior was recorded over two parities. Observed activity levels were highest just after feeding, with the low-fed sows more active than the high-fed sows. Most of the activity during this time period was directed toward substrates. In the low-fed "no straw" sows, most behavior was directed towards the chains and bars, resulting in levels three to four times higher than in the other groups. Low-fed straw sows directed their foraging behavior mainly towards the straw. The authors concluded that in feed-restricted pregnant sows, abnormally high levels of chain and bar manipulation can be prevented by providing straw which acts as a foraging substrate. In large, dynamic groups of ESF sows, the effect of providing access to straw in racks on welfare has also been investigated (Stewart et al., 2008). The results found 6% of sows visited each rack during the morning hours (08:00 to 12:00). On average, more sows spent time at the post- rather than pre-feeding rack provided during a 24 hour period. Overall, sows in the straw treatment spent significantly less time exploring the floor and engaged in general exploratory behavior, possibly as a result of providing an outlet for exploratory and/or foraging behavior. However, injury scores did not differ between treatments. While average sham chewing levels did not differ between treatments, sows exhibited most sham chewing post-feeding. Because straw did not affect the incidence of sham chewing, the authors concluded that the welfare benefits associated with straw racks is limited.

Feeding schedule

In addition to hunger level, the feeding schedule can also impact sow behavior, namely through the feeding order. Sows in ESF systems adapt to their daily feeding schedule and routine by establishing a relatively stable hierarchy in the order of eating which is determined by social rank, duration of stay in the system, experience with the feeding station gained in earlier pregnancies and the number of litters (Lembeck et al., 1996). The sows adapt their daily routine around this schedule of feeding, and changing feeding start from day time to night time is often accompanied by reduced ESF feeder occupation in the period following start of the feeding cycle (Jensen et al., 2000). Feeding order tends to be relatively stable, quickly established and maintained in studied Fitmix systems (Chapinal et al., 2008). These findings highly correlate with dominance rank. High-ranking sows will feed earlier and make as many – but longer- visits as low-ranking sows, thus occupying the feeder more time every day. Optimizing the feeder efficiency may take several weeks, even in stable groups of sows.

In another study, aggression was found to be a problem as a result of increased activity levels associated with the straw racks, but decreased activity around the ESF feeding station (Kroneman et al., 1993). Sows exhibited a preference for taking straw from a rack compared with straw from the floor in the lying area. Straw increased the number of aggressive interactions among sows, and led pigs away from the waiting area and the feeding station.

Feed intake

Increases in feed intake during pregnancy can reduce grazing behavior during daytime as well as increase the rectal temperature of stall-fed sows (Santos Ricade and Lean, 2002). The interactions observed in the study suggested that extremely high ambient temperatures had more effect on grazing behavior and body temperature than energy intake in pregnant sows kept outdoors when under hot, tropical conditions.

3.5.2 Injuries

In the Netherlands, the first experience with group sow housing utilizing individual ESF feeding stations was not satisfactory, with vulva biting and hoof lesions as predominant health problems in the system (Kroneman et al., 1993). When feeding stations were designed with separate entrances and exits (walk through feeding stations, instead of back exit stations), the vulva biting decreased in incidence, but did not disappear completely. As such, vulva biting was largely the result of aggression, mainly induced by queuing while waiting to enter the feeding station. This may have been influenced by the fact that, by nature, pigs eat in social groups rather than individually. Frustration due to restricted feeding (and lack of satiation) also was found to result in vulva biting. Rizvi et al. (1998) conducted a postal survey with 410 pig farms in England to investigate risk factors for vulva biting and found group housing, electronic sow feeders (ESF), feeding once a day, providing *ad libitum* access to water, and the number of sows per drinker are all correlated with vulva biting, tail biting, and an increased percentage of cull sows. These findings support recent work by Zurbrigg and Blackwell (2006) who observed once daily feeding using an ESF in a dynamic system could lead to a higher incidence of vulva lesions compared to other automatic feeding methods and manual feeding.

Diet formulation

When individually stall-fed a low-energy conventional diet formulation, animals exhibited a slightly higher incidence of skin lesions than those on a high fiber diet, with those on a higher level of conventional diet being intermediate (Martin and Edwards, 1994). In this case, since the animals were outdoors, sows had the ability to spread out while performing foraging behaviors and the aggression seen in a confined space would have been less likely to occur. The authors concluded that, when feed distribution is adequate, outdoor feeding of sows imposes relatively little disadvantage on low ranking animals. In fact, aggression levels were low when compared with group feeding indoors. Thus, provision of bulk in the diet can prolong the feeding time, thereby reducing feeding motivation, with potential beneficial effects on sow welfare

Feed intake

In 2007, Kongsted et al, monitored indicators of feed intake, fear of humans, and social behavior in group housed sows in 14 herds, which utilized both ESF and individual feeding stalls. First parity sows had significantly more skin lesions than older sows in herds with no escape possibilities (e.g. small group sizes with no feeding stalls). Back fat and back fat gain increased with increasing parity to a larger extent in herds with group feeding than in herds with individual feeding.

Increased dietary fiber

The inclusion of increased dietary fiber had a beneficial effect on the incidence of sow injuries reported in the literature. Sows in loose herds with ESF that were not fed additional roughage had 1.7 times greater risk of body lesions than sows in herds that used additional roughage feeding (Gjein and Larssen, 1995). In fact, the relative risk of vulva biting was 2.6 times higher in loose herds with no roughage feeding as compared with loose herds with appetite feeding of roughage. Sows in the loose herds with an ESF feeding station with a mechanical hind gate had 1.8 times greater risk of vulva lesions than sows in loose herds that used a feeding station with an electronic gate.

3.5.3 Physiology

Pigs in hoops will ingest some straw bedding, which may affect behavior and/or growth (Huenke and Honeyman 2001). As such, the provision of straw may buffer the adverse effects of a low food level on weight and back fat gain in stall-fed group-housed pregnant sows, even while it has no effect on reproductive performance (Spoolder et al., 1996). Additionally, sows fed more are known to gain more weight and back fat over the course of two pregnancies than lower fed sows (Spoolder et al., 1996). Interestingly, this study also found the higher fed sows with no straw had the highest levels of basal cortisol, which is indicative of a stress response.

3.5.4 Productivity

Petherick and Blackshaw (1989) investigated the effects of three feeding regimes (ration, *ad libitum*, and ration + straw) on sow reproductive performance (in groups of 4 sows over three consecutive gestations) using partial barriers on all feed stalls. Sows fed *ad libitum* ate approximately three times the amount of food that was allocated to them on ration + straw. However, feeding regime was not found to affect any reproductive performance measures (numbers of piglets live born, stillborn, weaned, birth or weaning weights). The authors found it probable that no adverse effects of the feeding regimes were found due to the short time (13 days) of each treatment and because multiparous animals were used in the study. These results suggested that the welfare of ration-fed sows, whose appetite is not satiated, may be improved by the provision of fibrous feedstuffs.

Diet composition

van der Peet-Schering et al. (2004) conducted a study investigating the effects of restricted vs. *ad libitum* feeding a diet which included a high level of fermentable non-starch polysaccharides (NSP) to group housed gestating sows (feeding stall system). They found that a*d libitum* fed sows ate 1.3kg/d more during gestation than restrictively fed sows. However, gestation feeding regime did not affect the number of total piglets born, live-born and stillborn piglets, piglet birth weight, weaning-to-estrus interval, or the percentage of sows that returned to estrus after the first insemination. The maximum voluntary feed intake was reached in parities 3, 4, or 5, remaining stable in subsequent parities. The mean daily feed intake of *ad libitum* fed sows also increased from 2-6 weeks of gestation and then decreased until week 15 of gestation. On average, *ad libitum* sows spent 90 min/d eating. The authors concluded that it is possible to feed gestating sows a diet with a high level of fNSP *ad libitum* without negative effects on reproductive performance.

Energy intake

In a review to determine whether variation in energy intake in group housed sows influences variation in litter size and pregnancy rate, Kongsted (2005) found that both pregnancy rate and litter size may be influenced by very low energy intake in the first 4 weeks of pregnancy. Based on the studies reviewed, low ranking sows may consume considerably less than high ranking sows (e.g. 50-80% of feed) in group-housed systems, which suggested that the variation in feed intake in a group of restricted fed pregnant female pigs may be large enough to influence pregnancy rate and litter size. However, most of the studies included in the review were based on individual-stall housed sows or group-fed (e.g. trough) group-housed sows, not sows individually fed in a group housing system.

3.5.5. Summary

Overall, restricted feeding in group housed sows leads to increased hunger and frustration, which leads to increased stereotypic and aggressive behavior. However, adding quality fiber to the sow diet increases satiety and doubles eating time thereby effectively reducing the incidence of oral and stereotypic behaviors. Overall, restricted feeding regimes lead to increased skin and hoof lesions, and vulva biting, which also impact the number of cull sows. Some of these problems can be reduced through increased dietary fiber, however overall aggression may not differ significantly between feed restricted sows and those given a higher fiber diet. Overall, feed restricted sows show higher basal cortisol levels and rectal temperatures, while bulking diets with added high quality fiber may actually buffer the impact on weight and back fat gain. Overall, restrictive feeding in group housed sows leads to smaller litter sizes and a decrease in pregnancy rate, which may be further impacted by a sow’s status in a group hierarchy. However, not all studies investigating the effect of feeding regime and bulk diets form a consensus on additional measures of sow productivity (e.g. number of stillborn or weaned as well as birth and weaning weights of piglets).

3.5.6 Research Needs Assessment

- Effect of fiber, diet formulation, feed level and feed intake on physiological stress measures (e.g. after introduction into a large dynamic group)

3.6 Feed/Water Resource Allocation

Feed and water resource allocation includes those studies which have focused on how group housed sows were fed (e.g. feeder type, feeder design, where sows were fed within the pen, etc). This review aims to include refereed articles which used group housing in conjunction with individual feeders, fully pulling out the effects of individual feeder types, without a direct comparison, is very difficult. As such, a major research gap identified from this review includes the need to perform research directly comparing many aspects of sow welfare (i.e. behavior, injuries, stress response and reproductive performance) in group housed sows which utilize different individual feeding systems.

3.6.1 Behavior

Supplemental straw

Krause et al. (1997) studied the provision of supplemental straw placed in "feeding racks" by comparing four treatments: 1) ESF for sequential feeding of sows with straw rack (ESF with straw), or not (ESF without straw), and electronically-controlled simultaneous feeding in boxes and with straw available (FB with straw) or no straw in the feeding rack (FB without straw). The animals were most active in FB with straw and least active in ESF without straw, therefore, the interaction between feeding system and availability of straw was significant. Animals visited the FB treatments more than the ESF treatments. Synchronization of eating straw was higher in the FB system while the engagement with the concentrate feeder was higher in the ESF system. More hind quarter injuries were recorded in ESF sows, whereas the availability of straw appeared to have no effect. The authors concluded that the sequential feeding of group housed ESF-fed animals contributed toward the development of serious behavioral problems (e.g. agonistic interactions resulting in injury) among the animals. Stewart et al. (2008) recently investigated the effect of providing access to straw in "peak racks" on the welfare of sows in large dynamic groups of 35 sows each also using an ESF system. In this case, sows were either given access to two racks containing chopped barley straw or a control diet with no straw racks. Six percent of sows were observed at each rack during the morning hours (08:00 to 12:00). On average, more sows spent time at the post- rather than pre-feeding rack provided during a 24 hour period. Overall, sows in the straw treatment spent significantly less time exploring the floor and engaged in general exploratory behavior, possibly as a result of providing an outlet for exploratory and/or foraging behavior. While average sham chewing levels did not differ between treatments, sows exhibited most sham chewing post-feeding. As straw did not affect the incidence of sham chewing, the authors concluded that the welfare benefits associated with straw racks is limited. When ESF-fed sows were provided with grass silage racks as opposed to straw racks. O'Connell (2007) found that on average 78.5% of the sows observed using the grass silage racks were newly-introduced animals in a large dynamic group. Newly introduced animals in the silage treatment also spent more time lying in kennel areas, less time lying in slatted areas, and less time performing exploratory behavior within kennel than sows on a control treatment. Furthermore, sham chewing behavior was reduced through the provision of grass silage racks.

Feeder type

Throughout the review of the scientific literature, it was possible to conduct a small number of direct comparisons of individual feeder types. For example, Broom et al. (1995) studied two group sow housing systems with individual feeding (one with feeding stalls, the other with ESF) which were compared with gestation stalls. When the two group sow housing systems were compared, sows with ESF showed more fighting, especially immediately after mixing, but fewer total agonistic interactions than sows in groups of five during the first pregnancy. Oral stereotypies were slightly higher in small groups, perhaps due to the smaller pen space, than in larger groups, but much lower than in stalls. By the fourth pregnancy there were few differences between sows in small and large groups and all sows seemed to have adapted well to the conditions. Overall, sows provided with partial stalls were found to exhibit fewer aggressive interactions around feeding (Barnett et al., 1996). These findings support the physiological data from previous results from the same research group that found pregnant sows provided with partial feeding stalls have lower average daytime cortisol concentrations once social relationships in the group have stabilized (Barnett et al., 1992). However, this type of effect can take anywhere from 10 days to 4 weeks. On the basis of the cortisol data, both studies suggest a welfare benefit to the provision of partial feeding stalls. Activity levels were also highest just after feeding in free access stalls with front-mounted chain loops. Most of the activity during this time period was directed toward any substrates provided in the pen (Spoolder et al., 1995).

Hulbert and McGlone (2006) specifically evaluated the effects of pen versus crated housing systems and drop versus trickle (Biofix) fed systems on behavioral responses during 2 consecutive gestation periods. Sows housed in groups of 5 spent more time standing during the early morning hours of 04:00 to 08:00 than crated sows. Housing system was found to have a complex effect on sow behavioral sequences, however penned sows had more sequences associated with stress than crated sows. Oral-nasal-facial (ONF) behaviors included chewing, rooting, and rubbing, in addition to activity levels. The authors concluded that sows are able to adapt within each environment through behavioral mechanisms without the need to invoke major physiological adjustments (since none of the housing environments evaluated were associated with significant physiological stress responses).

Feeder use patterns

Chapinal et al. (2008) observed feeder use patterns in group-housed pregnant sows fed using just the Fitmix system and found maximum feeder activity occurred in the hours following the start of each feeding cycle. During this experiment, there was a relatively stable, quickly established, and maintained feeding order, which correlated with dominance rank. High ranking sows fed earlier and made the same number, but longer, visits as low-ranking sows. Thus, higher ranking sows occupied the feeder for longer periods of time every day. As such, in medium-size (e.g. groups of 20 sows each), stable groups of sows, Fitmix seems to be an efficient feeding system. In ESF systems with a forward exit from the feed station, the results have shown increased station visits daily, but non-feeding visits tend to be of shorter duration so that total occupation time is similar (Edwards et al., 1988). Sows learn to circumvent the computer-controlled mechanism locking the rear gates and may show aggression towards animals in the station. As such, a forward exit station with positive closing of the rear gate is desirable, but some problems with station design remain to be solved.

3.6.2 Injuries

Lameness

Overall, ESF fed sows show a higher incidence of lameness compared to other group housed systems (Zurbrigg and Blackwell, 2006). However, the results may have been biased as they include a farm which had mechanical problems with the electronic sow feeder. Thus, the increased lameness observed in the ESF sows may have been due to an unconnected malfunction rather than the system itself. Often, dirtiness in pigs can be an indicator of lameness and injury in sows, since lame sows tend to spend more time lying. The same survey found that pigs in the ESF dynamic system were dirtier than other group sow systems surveyed. In their evaluation of pen vs.. crated housing systems,

Hulbert and McGlone (2006), using stall-feeding, found that lesion scores did not differ among treatments. However, earlier studies have found that electronic sow feeders are also correlated with greater vulva biting, tail biting, and an increased percentage of cull sows (Rizvi et al., 1998).

Lesions

Leeb et al. (2001) studied the effect of feeding area design, including ESF, on farm, in 55 herds of pregnant group-housed sows. Group size, design of the feeding area and area per sow all had a significant influence on the extent of lesions. In housing systems with deep bedding, the incidence of callosities, which are positively correlated with decubital lesions, was significantly lowered. The authors concluded that skin lesion patterns in sows can be used as a welfare indicator and that adequately designed feeding areas, good management and the maintenance of groups with established social structures can minimize fighting. Smooth lying surfaces and the opportunity for sows to move around within the group system also reduced the incidence of callosites.

Aggression

Provision of spent mushroom compost suspended in racks of stall fed sows has been shown to reduce aggression and injuries, however this was provided as an environmental enrichment versus part of a feeding regime (Durrell et al., 1997). Krause et al. (1997) found more hind quarter injuries were observed in ESF sows provided either with or without straw racks. The authors concluded that the sequential feeding of group housed ESF-fed animals contributed toward the development of serious behavioral problems (e.g. agonistic interactions resulting in injury) among the animals. However, a more recent study found that injury scores did not differ between treatments when sows in large dynamic groups with ESF stations were provided with pre- and post-feeding straw racks (Stewart et al., 2008).

3.6.3 Physiology

Disease

Overall disease occurrence was found to be low when sows are housed in groups compared with individual feeding stalls (Kroneman et al., 1993). In drop-fed feeding stalls, sows were found to have greater phagocytosis compared with trickle fed sows (Hulbert and McGlone, 2006). When urinary cortisol was measured in conjunction with an Adreno-cortico-trophic Hormone (ACTH) challenge test to determine the affect of housing on stress levels, including when individual feeding stalls are utilized (Pol et al., 2002), urinary cortisol levels were higher in sows exhibiting a low level of stereotypies in comparison with sows exhibiting the most stereotypies. As such, urinary cortisol has been able to provide additional information on the assessment of chronic stress and improve the evaluation of animal welfare when used in conjunction with other welfare indicators.

It has been suggested that deviations in feeding order may indicate disease, estrus, reproductive and/or other problems. Bressers et al. (1993) studied the pattern of ESF feeding station use by sows in a dynamic group housing situation. However, feeding order was not sufficiently stable to allow the stockman to detect health or other problems.

3.6.4 Productivity

Relatively little research has been conducted on the impact of individual feeding systems within group housing on sow productivity. Spoolder et al. (1996) studied sows in loose housed groups of 6 sows with individual free access feeding stalls and found that significantly more "no-straw" sows failed to start the second parity than sows provided with straw. In a study using drop-fed vs.. trickle fed individual feeding stalls, Hulbert and McGlone (2006) found that productivity measures did not differ among feeder treatments.

3.6.5. Summary

Feed station design is a very important determinant of behavior in group sow housing systems with individual feeding. Generally, most studies have focused on aggression and injuries associated with ESF systems (e.g. lameness, vulva biting, tail biting, and agonistic interactions resulting in injuries). However, stress cortisol and immune function data is sparse, but is valuable information for assessing different feeding systems, particularly in light of noted behavior and injury problems correlated with different feeding station designs. Overall, more research is needed with regard to the effect of individual feeding systems on sow productivity measures.

3.6.6 Research Needs Assessment

- Direct comparisons between group sow housing systems using individual feeders (not gestation stalls or group feeding to individual feeders) on health/disease, injury, behavior, lameness, and productivity
- Further studies on the impact of feed order through ESF on herd disease susceptibility
- Feeding area design on injury, physiology and productivity

3.7 Air Quality

Air quality has been studied in conjunction with group sow housing, but not with particular reference to individual feeding, and does not enjoy the breadth of research teams that other aspects of group sow housing (e.g. environmental enrichment) have received. Most air quality work in group sow housing was conducted with regard to the environment, not for its impact on the sows or stockworkers themselves.

Ammonia emissions

Groenestein et al. (2001) compared the ammonia emissions of sows kept in individual feeding stalls, versus group housing with either ESF or free access stalls (groups of 62-64 sows each). The results showed that diurnal ammonia emissions are biphasic in both individual and free access stalls, relating to feeding times. In an ESF system, ammonia emissions were monophasic, coinciding with an afternoon feeding period with an additional small peak in the morning after the lights were turned on. The authors also found that under thermoneutral conditions, giving sows a larger area of free space (e.g. group housing) did not imply an increase in ammonia emissions. In a later study involving EFS feeding stations, Groenestein et al. (2006) assessed the contribution of straw bedding, concrete floors, slats and slurry in the pits to ammonia emission in a straw-bedded group housing system for sows. To do this, the ammonia volatilisation response of urine on each potential emitting surface was studied under laboratory conditions. The lowest maximum volatilisation rates were obtained from straw bedding, irrespective of slurry content, and from the slurry in the pit under the waiting area in the pen. The highest volatilisation rate was obtained from the concrete floor in the walking alley. The volatilisation rate peaked fastest with heavily soiled straw, slurry in the pit under the waiting and drinking area, concrete floor, and slurry from the reference system, and latest from unsoiled straw. The results demonstrate that in straw bedded group sow housing systems, the largest source of ammonia emission is in the urine puddle on the concrete floor in the walking alley, and the smallest is from urination on the straw. Furthermore, only when the slurry content is very high in the straw bedding does the rate at which ammonia is produced from urea increase. The implication from the findings is that straw bedding in a group-housing system for sows decreases the ammonia emission per m^2 after urination. This study did not investigate the affects of straw bedding on other gaseous emissions. Through further modelling, Groenestein et al. (2007) developed a tool for designing straw-bedded sow group-housing systems with low ammonia emissions for use with ESF feeding. Measures used to reduce the amount of urination on solid floors and increasing urination on areas of the pen with straw bedding was encouraged when designing group sow housing systems. In addition to this, Griffing et al. (2007) conducted a review of gaseous ammonia in pig production through an analysis and comparison of 26 experimental studies of ammonia emissions from pig buildings that utilize some form of pit/slurry system.

3.7.1 Behavior

Ammonia emissions

Pigs show a strong preference for fresh air, and are even willing to leave a preferred chamber area to avoid ammonia when placed in a two-sided preference chamber designed at the Silsoe Institute in the UK (Smith et al., 1996). These results suggest that pigs find the smell of ammonia aversive in the pig barn.

Bos et al. (2003) have suggested a number of different recommendations for designing an ESF straw-based group sow housing system with special attention on reducing environmental pollution and gas emissions based on recursive control. Using knowledge of natural animal behavior and how individuals interact with their environment without complicated technical or human intervention or surveillance a “walk around house” for pregnant sows with ESF feeding stations and straw bedding was adapted from Groenestein (2000). This design solved gas emission problems by encouraging sows to circulate freely within the group sow housing system in a specific direction through the pen. More importantly, the pen design and space allocation was based on the sow's daily time budget. For example, the lying area utilizes 80% of the pen area, since the sow spends 80% of her time lying. The lying area is made of solid flooring and is covered by deep straw bedding. Feeding and drinking areas are located away from the lying area, which is physically separated. Sows instinctively do not foul their lying area, therefore, most urination and fouling occurs in the 'waiting' area prior to the feeding and drinking areas of the pen, which are equipped with slatted flooring. The slurry pit under this slatted area is further divided up into compartments preventing manure from spreading to areas under the floor where it was not deposited, and reducing the surface area of the slurry. The deep bedding area further allows for sows to consume straw bedding as roughage, if they choose to do so. Supplying pigs with peat on a large tray may also help to reduce abnormal behavior, but without blocking slurry evacuation channels (Buré et al. 1983).

Groenestein et al. (2003) studied the effect of feeding schedule on ammonia emission from individual and group housing systems for sows. In stall, ESF and feeding stall systems, the diurnal patterns of the indoor temperature, animal activity and ammonia emission changed considerably with the feeding schedule. It was concluded that changing the feeding schedule alters the diurnal pattern of the ammonia emission, but if the animals are fed sequentially, the ammonia emission falls by 10% if the feeding starts in the afternoon instead of the morning.

3.7.2 Injuries

Ammonia emissions

While investigating six commercially available, and six experimental floors for pig pens for shock absorption, friction coefficients, and heat conduction, Pedersen and Ravn (2008) found that concrete slatted floors were ideal to reduce the risk of slipping, but not with respect to ammonia. Despite being slippery, plastic and cast iron slatted floors were found to be better for the environment in respect to air quality, and were also warmer for the pigs to lie on. Ammonia levels were higher from slatted floors of made of concrete than from slatted floors made of plastic or cast iron. Ammonia emission was measured in a wind tunnel with ammonia water wetted floors.

3.7.3 Summary

Ammonia emissions can change considerably with the feeding schedule. Overall, the challenge is to design flooring that reduces slipping and lameness while also improving the environment with respect to air quality.

3.7.4 Research Needs Assessment

- Air quality has been studied in the group sow housing system, but not specifically with individual feeding

- Lack of literature on the effect of air quality on the physiology and productivity of group housed sows

3.8 Genetics

3.8.1 Behavior

Stereotypies were observed for one hour post feeding, in two stall fed genotypes (Large White and Large White x Landrace; Vieuille-Thomas and Signoret, 1995). However, the genotypes were confounded by housing treatment comparisons. A reduction in stereotypies was observed when the Large White/Landrace was housed in groups, however it is not known whether the same reduction would have been observed in the Large White only genotype. Despite group housed sows exhibiting the lowest incidence of stereotypies, it still consisted of 66% of sows performing them. In a subsequent study, Marchant and Broom (1996) studied the amount of time taken to lie down and stand up in different ESF group sow housing systems in relation to both physical and genetic parameters. Compared with stalled sows, group housed sows took longer to lie down in an open area versus against a wall, perhaps this is because pigs are thigmotactic and stalled sows have to lie against the pen wall. There was no genetic difference found in the total time taken for sows to stand up or lie down, however body length was significant. In stall-fed sows, Dailey and McGlone (1997) found few significant genotype and genotype by environment interactions found in a study using pregnant gilts of PIC Camborough-15, PIC Camborough-Blue and York x Landrace based on overall behaviors observed, which indicated that these particular genotypes generally express similar behavior.

Aggression

In a study designed to estimate the genetic variation in aggressive behavior of sows at mixing into group housing, and in maternal ability for the same sows, Lovendahl et al., (2005) calculated heritabilities for performed aggression traits and found them to be intermediate ($h^{2} =$ 0.17 and 0.24), but lower for received aggression ($h^{2} =$ 0.06 and 0.04). Heritability of maternal behavior was also low ($h^{2} =$ 0.08). The authors conceded that while the standard errors for the estimates of genetic correlation were large, they indicate that less aggressive sows are stronger responding mothers ($r_g = -0.3$). The authors concluded that performed aggression in sows is a heritable trait, and selection against aggression is possible without offsetting maternal behavior.

3.8.2 Injuries

Studies on the genetic correlation of injuries to group housed sows (e.g. lameness or lesions) which are individually fed, were found to be lacking in the scientific literature.

3.8.3 Physiology

Leanness

Based on their review of the impact of group size on damaging behaviors, aggression, fear and stress in animals such as pigs, Rodenburg and Koene (2007) have suggested that genetic selection against damaging behavior seems promising. For example, Breuer et al. (2003) found breed differences in tail biting behavior among grow/finish pigs, which was also found to be negatively correlated with leanness (Breuer et al., 2005).

3.8.4. Summary

Genetics may anecdotally play a role in stereotypy development and general activity in group housed sows, however without sufficient studies to specifically investigate the effect of genetics, no firm conclusion can be reached. With only one study investigating the effect of genetics on sow injuries as a result of aggressive traits at time of mixing, further research is required. However, preliminary data suggests that it may be possible to select against aggression in sows without reducing maternal behavior. However, further research is needed to reach a firm conclusion.

3.8.5 Research Needs Assessment

- Further research on how sows of various genotypes and breeds fare behaviorally or physiologically (including injury and productivity measures) in small and large group sow housing systems with individual feeding.
- Most studies involving the effect of genetics or breed on group sow behavior are loosely studied or anecdotal.

4.0 Concluding Summary

In group-housed gestating sows managed through individual feeding systems such as electronic sow feeders (ESF) or individual feeding stalls, some key highlights can be made from a comprehensive review of the current scientific literature.

Space allowance

Specifically, reduced space allowances result in more injuries in systems with both ESF and individual feeding stalls, as reduced space also results in more social interactions and aggression. Furthermore, physiological and productivity measures did not differ in sow groups differing in stocking density, regardless of feeding system used.

Group Size

Increasing group size in an ESF system has different implications than in a system with individual feeders. An increase in group size in a system with individual feeding stalls would require providing more feeding stalls to accommodate more sows. However, in ESF systems, an increase in group size would not only have implications for the social dynamics within the group, but would also put more pressure on the use of the ESF station(s). With more animals expected to use a single feeding station, competition would naturally increase.

Group type

With regard to group type, dynamic groups often experience more aggression and injuries than static sow groups. Furthermore, the newest sows added to a dynamic group tend to receive the most injuries. Overall, the first week post-mixing results in more aggression compared with the remaining weeks in both static and dynamic groups. Sows in small static groups were less active than sows in large dynamic groups. However, sows in static and dynamic groups were found to have similar salivary cortisol concentration (used as an indication of stress in farm animals). A discrepancy was found in productivity results which compared sows in static and dynamic groups; some studies have found differences while other studies have not. Low ranking sows were also found to be at a disadvantage in both static and dynamic groups, especially in an ESF system, as these sows received more aggression and injuries, while also exhibiting poorer productivity compared with high-ranking sows. However, salivary cortisol levels did not differ among sows of different social status in either static or dynamic groups.

Bedding and enrichment

Providing straw bedding as a source of enrichment has many positive effects on sow behavior, however these same properties may not be unique to straw alone. As such, more alternatives to straw bedding need to be investigated further. As a whole, sows provided with good bedding material tend to incur fewer injuries and exhibit less pen mate directed aberrant behaviors (e.g. ear and tail biting). However, both aggression and foot health problems can still persist in deep-bedded group housing systems, regardless of feeder type used. The specific impact of bedding on overall performance (e.g. milk production and growth) depends on the quality of the conducted research and what was measured. The effect of bedding alternatives on sow physiology have not been studied to any real extent. However, thoroughly bedded sow housing systems have been shown to decrease reproductive failure, increase pregnancy uptake, and increase farrowing rate. Interactions between feeder type and enrichment materials have not been specifically studied with regard to group housing of gestating sows.

Feeding regime

Restricted feeding in gestating sows is common practice as a means of decreasing farrowing difficulties. However, restricted feeding in group housed sows leads to increased hunger and frustration, which stimulates an increase in stereotypic and aggressive behavior. Adding quality fiber to the sow diet increases satiety and doubles eating time, thereby effectively reducing the incidence of aberrant behaviors. The current scientific literature provides many viable ideas of ways to include additional fiber in the sow diet in conjunction with ESF or individual feeding stall systems.

In addition to behavioral concerns, restricted feeding regimes can also lead to increased skin and hoof lesions, vulva biting, and tail biting, which also impact the number of cull sows. Some of these problems can also be reduced through an increase in dietary fiber. However, overall aggression may not differ significantly between feed restricted sows and those given a high fiber diet. The literature suggests that feed restricted sows, regardless of feeding system, show higher basal cortisol levels and rectal temperatures, bulking diets with added high quality fiber may buffer the impact.

Feed and water resource allocation

Feed station design is a very important determinant of behavior in group sow housing systems with individual feeding. The majority of studies have focused on aggression and injuries associated with ESF systems (e.g. lameness, vulva biting, tail biting, and agonistic interactions resulting in injuries). Overall, stress cortisol and immune function data in the scientific literature is sparse, but valuable information for assessing different feeding systems, particularly in light of noted behavior and injury problems correlated with varying feeding station designs. More research is needed with regard to the effect of individual feeding systems on sow productivity measures.

Air quality

Air quality in group sow housing has not been studied with specific attention to feeder type or design. Overall, ammonia emissions are the primary air quality concern with regard to group sow housing, and were found to change considerably with the feeding schedule. In particular, flooring designs which also reduce slipping and lameness in group housed sows also tend to improve the environment with respect to air quality. No research has been conducted on the effects of group sow housing air quality parameters on sow physiology or productivity.

Genetics

Genetics may anecdotally play a role in stereotypy development and general activity in group sow housing, however without sufficient studies to specifically investigate the effect of genetics, no firm conclusion can be drawn. Preliminary data suggest that it may be possible to select against aggression in sows without reducing maternal behavior, however feeding system was not a factor in the study design.

5.0 Summary of Overall Needs Assessment

Overall, extensive literature exists on the influence of environmental enrichment, stocking density, and group size on the behavior of sows in group housing. However, substantial research gaps have been identified with regard to genetics, air quality (i.e. specific impacts on the sows themselves), physiology and productivity. Further research areas on group housing with individual feeding systems should include:

- Comparisons of different space allowances within group housing (with less emphasis on comparing group housing with stall housing). More specifically, comparisons of different space allowance in group housing with individual feeding systems
- Comparison of different group sizes with various individual feeding systems (most research to date has focussed on ESF)
- Comparison of the effect of group size on physiological measures is needed (no research currently available)
- Comparison of the effect of group size on productivity is needed (only one study on reproduction was found)
- How to recognize and manage low-ranking sows in a group system; especially the ESF system where there is more competition for feeder access
- How to reduce competition and aggression for the ESF; which is the single feed resource for many sows
- Improved methods for easing the introduction of new sows to an already established dynamic group
- Understanding if low ranking sows perform better in group housing with individual feeders since they have a place to escape
- Differences in productivity for sows in static and dynamic groups
- Effects of pen shape/design/size in group housing systems with individual feeding on behavior, injuries, physiology and productivity

- Little research on how sows of various genotypes and breeds fare behaviorally or physiologically (including injury and productivity measures) in small and large group sow housing systems with individual feeding
- Most studies involving the effect of genetics or breed on group sow behavior is loosely studied or anecdotal
- Air quality has been studied in the group sow housing system, but not specifically with individual feeding
- Lack of literature on the effect of air quality on the physiology and productivity of group housed sows
- Larger group sizes – most sow housing studies have group sizes of 4-6 sows each
- Direct comparison of group housing systems that incorporate individual feeding systems

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Table 1. Summary of research literature categorized by topic and feeder type studied.

	Feeder Type	
	ESF	Individual Feeding Stalls (includes full and partial stalls)
Space Allowance	von Borell et al., 1992 den Hartog et al., 1993 Morris et al., 1993 Broom et al., 1995 Jensen et al., 1995 Morris et al., 1997 Rizvi et al., 1998 Morris et al., 1998 Anil et al., 2003 Bates et al. 2003 Anil et al., 2005 Remience et al., 2008	Broom et al., 1995 Weng et al., 1998 Pol et al., 2002 Harris et al., 2006 Karlen et al., 2007 Sorrells et al., 2007 Lammers et al.,2008
Group Size	van Putten and van de Burgwal, 1990 Svendsen et al., 1992 Broom et al., 1995 Rizvi et al., 1998 Hodgkiss et al., 1998	Svendsen et al., 1992 Kongsted et al., 2007
Group Type/Group Composition	Bressers et al., 1993 Simmins, 1993 Olsson and Svendsen, 1997 Nowachowicz et al., 1999 Durrell et al., 2002 O'Connell et al., 2003 O'Connell et al., 2004 Anil et al., 2006 Chapinal et al., 2008 Strawford et al., 2008	
Flooring, Bedding, & Enrichment	Kroneman et al., 1993 Hodgkiss et al., 1998 Leeb et al., 2001 Jensen et al., 2000	Svendsen et al., 1992 Spoolder et al., 1995 Spoolder et al., 1996 Dailey and McGlone, 1997 Durrell et al., 1997 Andersen and Bøe, 1999 Leeb et al., 2001 Lammers et al., 2007 Karlen et al., 2007 Lammers et al., 2008 Munsterhjelm et al., 2008
Feeding Regime	Kroneman et al., 1993 Gjein and Larssen, 1995 Lembeck et al., 1996 Spoolder et al. 1997 Rizvi et al., 1998 Jensen et al., 2000 Ru and Bao, 2004 Kongsted, 2006 Zurbrigg and Blackwell, 2006 Chapinal et al., 2008 Stewart et al., 2008	Petherick and Blackshaw , 1989 Terlouw et al., 1991 Brouns et al., 1994 Martin and Edwards, 1994 Spoolder et al. 1995; 1996 Santos Ricade and Lean, 2002 van der Peet-Schering et al. , 2003 Van der Peet-Schering et al., 2004 Zonderland et al., 2004 Kongsted, 2006
Feed/Water Resource Allocation	Edwards et al., 1988 Bressers et al. 1993 Rizvi et al., 1998 Broom et al. 1995 Krause et al. 1997 Leeb et al. 2001 Zurbrigg and Blackwell, 2006 O'Connell 2007 Chapinal et al, 2008 Stewart et al. 2008	Barnett et al., 1992 Kroneman et al., 1993 Broom et al. 1995 Spoolder et al., 1995 Barnett et al., 1996 Spoolder et al. 1996 Durrell et al., 1997 Leeb et al. 2001 Pol et al., 2002 Hulbert and McGlone 2006
Air Quality	Groenestein 2000 Groenestein et al. 2001 Bos et al. 2003	Groenestein et al. 2001 Groenestein et al. 2003

	Groenestein et al. 2006 Groenestein et al. 2007	
Genetics	Marchant and Broom 1996	Vieuille-Thomas and Signoret, 1995 Dailey and McGlone, 1997

Table 2. Summary of research literature categorized by topic and results measures (eg. behaviour, injury, physiology, and productivity data).

	Measures			
	Behaviour	Injuries	Physiology	Productivity
Space Allowance	den Hartog et al., 1993 Broom et al., 1995 Jensen et al., 1995 Marchant and Broom, 1996a Weng et al., 1998 Harris et al., 2006 Remience et al., 2008	den Hartog et al., 1993 Kroneman et al., 1993 Rizvi et al., 1998 Weng et al., 1998 Anil et al., 2003 Bhend and Onan, 2003 Anil et al., 2005 Harris et al., 2006 Karlen et al., 2007 Remience et al., 2008	von Borell et al., 1992 Morris et al., 1993 Broom et al., 1995 Marchant and Broom, 1996b Pol et al., 2002 Anil et al., 2005 Harris et al., 2006 Karlen et al., 2007 Sorrells et al., 2007	von Borell et al., 1992 den Hartog et al., 1993 Broom et al., 1995 Morris et al., 1997 Morris et al., 1998 Bates et al., 2003 Harris et al., 2006 Karlen et al., 2007 Lammers et al., 2008 Remience et al., 2008
Group Size	Moore et al., 1993 Broom et al., 1995	van Putten and van de Burgwal, 1990 Svendsen et al., 1992 Hodgkiss et al., 1998 Rizvi et al., 1998 Kongsted et al., 2007	No publications	Broom et al., 1995
Group Type/Group Composition	Bressers et al., 1993 Olsson and Svendsen, 1997 Durrell et al., 2002 O'Connell et al., 2003 O'Connell et al., 2004 Anil et al., 2006 Chapinal et al., 2008 Strawford et al., 2008	Leeb et al., 2001 Durrell et al., 2002 Bhend and Onan, 2003 O'Connell et al., 2003	Mendl et al., 1992 O'Connell et al., 2003 Anil et al., 2006 Kranendonk et al., 2007 Strawford et al., 2008	Mendl et al., 1992 Simmins, 1993 Nowachowicz et al., 1999 O'Connell et al., 2003 Kongsted, 2004 Anil et al., 2006 Kranendonk et al., 2007
Flooring, Bedding, & Enrichment	Honeyman, 2005 Tuyttens et al., 2008		Spoolder et al., 1996	Lammers et al., 2007 Lammers et al., 2008
Feeding Regime	Spoolder et al., 1995; 1996	Kroneman et al., 1993 Gjein and Larssen, 1995 Rizvi et al. 1998 Zurbrigg and Blackwell 2006 Kongsted et al., 2007		Petherick and Blackshaw, 1989 Van der Peet-Schering et al., 2004
Feed/Water Resource Allocation	Edwards et al., 1988 Broom et al., 1995 Spoolder et al., 1995 Barnett et al., 1996 Krause et al.,1997 Chapinal et al., 2008 Stewart et al., 2008	Krause et al., 1997 Rizvi et al., 1998 Zurbrigg and Blackwell, 2006	Barnett et al., 1992 Kroneman et al., 1993 Pol et al., 2002	Spoolder et al., 1996 Hulbert and McGlone, 2006
Air Quality	Groenestein, 2000 Groenestein et al.., 2003			
Genetics				

Producer Factsheet

Space Allowance

- Less space appears to result in more social interactions and aggression.
- Less space resulted in more injuries in systems with both ESF and individual feeding stalls.
- Physiological measures did not differ between groups with an ESF and groups with individual feeding stalls.
- Space allowances in group housing with an ESF did not affect productivity.

Group Size

- More aggression resulted in large groups with an ESF compared with small groups with individual feeding stalls.
- Vulva biting is a problem in ESF systems, which usually have large group sizes. Sows cannot eat simultaneously and this appears to cause frustration and vulva biting results.
- More injuries result in large groups, regardless of the type of individual feeding system (ESF or feeding stalls).
- In both small and large groups with an ESF, the smaller and younger sows had more injuries.
- Increasing group size in an ESF system has different implications than in a system with individual feeders. An increase in group size in a system with individual feeding stalls would require providing more feeding stalls to accommodate more sows. However, in an ESF system, an increase in group size would not only have implications for the social dynamics within the group, but would also put more pressure on the use of the ESF. With more animals expected to use a single feed station, competition would increase.

Group Type / Group Composition

- The first week post-mixing resulted in more aggression compared with remaining weeks in both static and dynamic groups.
- Overall, more aggression resulted in dynamic groups than static groups.
- Sows in small static groups were less active than sows in large dynamic groups.
- Sows in dynamic groups had more injuries than sows in static groups.
- New sows added to dynamic groups received many injuries.
- Sows in static and dynamic groups had similar salivary cortisol concentrations.

- There's discrepancy in the productivity results comparing sows in static and dynamic groups; some studies have found differences, others have not.
- Low-ranking sows are at a disadvantage in both static and dynamic groups; especially in an ESF system. They received more aggression and injuries; however, salivary cortisol did not differ among sows of different social status in either static or dynamic groups. Low-ranking sows had poorer productivity compared with high-ranking sows.

Flooring, bedding and environmental enrichment

- Providing straw bedding as a source of enrichment has many positive effects on sow behavior, however these same properties may not be unique to straw alone.
- Sows provided with bedding tend to incur fewer injuries and exhibit less penmate-directed aberrant behaviors (eg. ear and tail biting). However, both aggression and foot health problems can still persist in any deep-bedded group sow housing system.
- Providing sows with straw decreased acute stress cortisol, buffered the effects of low feed level on weight and back fat gain, and decreased the incidence of frostbite. However, the specific impact of bedding on overall performance (eg. milk production and growth) depends on the quality of the conducted research and what was measured. The effect of bedding alternatives on sow physiology have not been studied to any real extent.
- Thoroughly bedded sow housing systems have been shown to decrease reproductive failure, increase pregnancy uptake, and increase farrowing rate. However, the majority of studies conducted with regard to the effect of bedding on sow productivity have used straw bedding, while alternative bedding materials are assumed to have a similar effect.

Feeding Regime

- Restricted feeding in group housed sows leads to increased hunger and frustration, which leads to increased stereotypic and aggressive behavior. However, adding quality fiber to the sow diet increases satiety and doubles eating time thereby effectively reducing the incidence of oral and stereotypic behaviors.
- Restricted feeding regimes lead to increased skin and hoof lesions, vulva biting, and tail biting, which also impact the number of cull sows. Some of these problems can be reduced through increased dietary fiber, however overall aggression may not differ significantly between feed restricted sows and those given a higher fiber diet.
- Feed restricted sows show higher basal cortisol levels and rectal temperatures, while bulking diets with added high quality fiber may actually buffer the impact on weight and back fat gain.

- Restrictive feeding in group housed sows leads to smaller litter sizes and a decrease in pregnancy rate, which may be further impacted by a sow's status in a group hierarchy. However, not all studies investigating the effect of feeding regime and bulk diets form a consensus on additional measures of sow productivity (eg. number of stillborn or weaned as well as birth and weaning weights of piglets).

Feed/Water Resource Allocation

- Feed station design is a very important determinant of behavior in group sow housing systems with individual feeding.
- The majority of studies have focused on aggression and injuries associated with ESF systems (e.g. lameness, vulva biting, tail biting, and agonistic interactions resulting in injuries).
- Stress cortisol and immune function data is sparse, but is valuable information for assessing different feeding systems, particularly in light of noted behavior and injury problems correlated with different feeding station designs.
- More research is needed with regard to the effect of individual feeding systems on sow productivity measures.

Air Quality

- Ammonia emissions can change considerably with the feeding schedule
- The challenge is to design flooring that reduces slipping and lameness while also improving the environment with respect to air quality.
- No research conducted on effects on physiology or productivity.

Genetics

- Genetics may anecdotally play a role in stereotypy development and general activity in group housed sows, however without sufficient studies to specifically investigate the effect of genetics, no firm conclusion can be reached.
- With only one study investigating the effect of genetics on sow injuries as a result of aggressive traits at time of mixing, further research is required. However, preliminary data suggests that it may be possible to select against aggression in sows without reducing maternal behavior.
- No research conducted on effects on productivity

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Research Needs Assessment Factsheet

Space Allowance

- Comparisons of different space allowances within group housing (with less emphasis on comparing group housing with stall housing)
- More specifically, comparisons of different space allowance in group housing with individual feeding systems

Group Size

- Further comparisons of different group sizes with various individual feeding systems (most research has focused on ESF)
- More information on effect of group size on physiological measures is required (no studies were found on this topic)
- More information on effect of group size on productivity is needed (only one study discussed the effect of group size on reproductive measures).

Group Type / Group Composition

- How to recognize and manage low-ranking sows in a group system; especially the ESF system where there is more competition for feeder access and no place to escape aggressive attacks.
- How to reduce competition and aggression for the ESF; which is the single feed resource for many sows.
- Improved methods for easing the introduction of new sows to an already established dynamic group.
- Understanding if low ranking sows perform better in group housing with individual feeders since they have a place to escape.
- Differences in productivity for sows in static and dynamic groups.

Flooring, bedding and environmental enrichment

- Larger group sizes – most sow housing studies have group sizes of 4-6 sows each.
- Direct comparison of group housing systems that incorporate individual feeding systems
- Bedding and enrichment in sows over-studied with regard to behavior and injuries, but less information on physiological effects (eg. reliable stress measures)

- Value-added potential of used bedding substrate utilized in group sow housing systems.
- Effect of flooring on lameness and leg injury.

Feeding Regime

- Effect of fiber, diet formulation, feed level and feed intake on physiological stress measures (eg. after introduction into a large dynamic group)

Feed/Water Resource Allocation

- Direct comparisons between group sow housing systems using individual feeders (not gestation stalls or group feeding to individual feeders) on health/disease, injury, behavior, lameness, and productivity
- Further studies on the impact of feed order through ESF on herd disease susceptibility.
- Feeding area design on injury, physiology and productivity

Air Quality

- Air quality has been studied in the group sow housing system, but now specifically with individual feeding
- Lack of literature on the effect of air quality on the physiology and productivity of group housed sows

Genetics

- Further research on how sows of various genotypes and breeds fare behaviorally or physiologically (including injury and productivity measures) in small and large group sow housing systems with individual feeding.
- Most studies involving the effect of genetics or breed on group sow behavior is loosely studied or anecdotal.

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