CAST® Issue Paper
Number 42
March 2009

Scientific Assessment of the Welfare of Dry Sows Kept in Individual Accommodations

Dry sows resting and eating in individual gestation accommodations. Photo courtesy of Egebjerg International A/S, Denmark.

Abstract

The use of individual gestation accommodations (IGAs) for dry sows in commercial pork production is an issue that has evoked intense public debate. Public perceptions and misconceptions of welfare issues have the potential to dramatically impact swine production if governments, the swine industry, or consumers react to these issues by outlawing housing systems or by boycotting pork. In determining whether or not the welfare of sows is compromised, individuals and lawmakers may act emotively and without factual scientific information. Too few statistically adequate, scientifically controlled trials on industry farms have been conducted; many reports are not useful for critical evaluation, let alone for developing public policy. Recent reviews, however, indicate that the welfare of dry sows *can be* equivalent in IGAs and group pens.

This Issue Paper provides a review of the most pertinent scientific literature on the welfare of dry sows housed in IGAs. The international Task Force critically evaluates the scientific evidence of IGAs for sows, including considerations for behavior, nutrition and feeding, reproduction, health, manure management, worker safety, and system design. The authors indicate that more large-scale, on-farm, multidisciplinary, scientifically robust research and development is needed before rigid regulations—which would increase production costs but not necessarily sow welfare—should be imposed.

This material is based upon work supported by the United States Department of Agriculture under Grant No. 2007-31100-06019 / ISU Project No. 413-40-02 and Grant No. 2008-38902-19327 and by the Agricultural Research Service under Agreement No. 59-0202-7-144. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the view of the U.S. Department of Agriculture, Iowa State University, or the Agricultural Research Service.

CAST Issue Paper 42 Task Force Members

Authors

Stanley E. Curtis (Chair), Animal Sciences, University of Illinois, Urbana–Champaign

Rodney B. Baker, Veterinary Diagnostic and Production Animal Medicine, Iowa State University, Ames

Mark J. Estienne, Virginia Tech Tidewater Agricultural Research and Extension Center, Suffolk

P. Brendan Lynch, Pig Production Development Unit, Moorepark Research Centre, Ireland

John J. McGlone, Animal and Food Sciences, Texas Tech University, Lubbock

Bjarne K. Pedersen, Danish Farm Design A/S, Denmark

Janeen L. Salak-Johnson, Animal Sciences, University of Illinois, Urbana–Champaign

Reviewers

Jerome O. Geiger, PIC-North America, Hendersonville, Tennessee

Donald G. Levis, Animal Sciences, University of Nebraska Northeast Research and Extension Center, Norfolk

CAST Liaison

Nathaniel L. Tablante, Virginia–Maryland Regional College of Veterinary Medicine, University of Maryland, College Park

Introduction

The Issue: Accommodation of the Dry Sow

How the dry sow ought to be accommodated in commercial pork production is an important public issue on a global scale. There are various stakeholders in the issue and its resolution in the United States will bear some marks from each group. The various viewpoints differ as to their pertinence and validity as well as in what they offer the practical and sustainable process of providing pork for human consumption.

What role can science play in the resolution of the issue? Some scientists and veterinarians are of the opinion that the welfare of any animal has to do with how that animal feels (Duncan 1993). An animal's feelings, however, cannot be measured but must be divined (Duncan and Dawkins 1983; Duncan and Fraser 1997; Gregory 2005). Others knowledgeable and experienced in swine husbandry think that a pig performing at a high rate generally can be assumed to be experiencing wellness (Broom 1996; Curtis 1982, 2007b).

With these varied approaches being taken by scientists and others nowadays, the general public understandably has grown confused. Many of the approaches suffer from subjectivity. Knowledge is the soundest basis for rational action. For this CAST Issue Paper, that knowledge should be scientific evidence on behavioral, health, physiological, and productive and reproductive performance aspects of the dry sow as they relate to her overall state of being.

Several meta-analyses and reviews of the scientific literature on the topic of this Issue Paper have been published (AVMA 2005; Barnett et al. 2001; McGlone et al. 2004a). For the most part, those reviews use holistic assessments of state of being. The result of those critical summaries has been that, in general, accommodating sows during the mating and gestation periods in any of a variety of properly designed and properly operated keeping systems is appropriate from humane as well as enterprise points of view. Each acceptable system has advantages and each has disadvantages. But there exists no compelling evidence from scientific evaluations and comparisons of dry-sow keeping systems that, overall, either individual accommodation or group accommodation is more appropriate than the other (AVMA 2005; Curtis 2007a; Gonyou 2007; Levis 2007; McGlone 2007; McGlone et al. 2004a; Salak-Johnson 2007; Stalder et al. 2007a).

The purpose of this Issue Paper is to provide an authoritative review of the available scientific literature as well as expert opinion on the topic of the overall humaneness of an individual gestation accommodation (IGA)[1] for the sow that will be accessible to a nonscientist, nonveterinarian reader.

The Nature of the Sow

Pigs were domesticated as long as 9,000 years ago (McGlone and Pond 2003). The genotypes of pig reared in present-day production systems differ from those of their ancestral forebears, mainly *Sus scrofa* (European wild pig) and *Sus vittatus* (Asiatic banded pig), and from the domestic pig of 50 years ago (Pond and Mersmann 2001; Ruvinsky and Rothschild 1998). The lard content of a typical market pig fell from 35% around 1960 to 16% in 1980 and 10% in 2000. The sensitivity of backfat to genetic selection was illustrated by Hetzer and Miller (cited by Jones

[1] "Individual gestation accommodation" (IGA) is used in this paper to mean a pen that contains a free-moving (untethered) individual sow and that prevents her from turning around. The term IGA is used here instead of "crate" or "stall" to avoid confusion in terminology commonly used in the United States. "Crate" usually means a four-sided individual pen. Sometimes "stall" means the same thing—a four-sided individual pen—but at other times that term means a three-sided individual enclosure in which a sow either might be fixed (e.g., tethered at girth or neck) or to which she might have access (e.g., from a group pen at feeding time).

[1998]), who selected pigs for high or low backfat thickness. After 16 generations of selection, backfat depth was 65, 38, and 22 millimeters (mm) (2.6, 1.5, and 0.9 inches [in]) in the fat-, control-, and lean-line pigs, respectively.

Changes in genetics and husbandry practices have increased sow productivity from approximately 12 pigs per sow per year in the mid-twentieth century to more than 20 pigs on most units, and up to 30 in top-performing herds. The result is a sow with greatly increased nutritional needs for milk production, but functioning with greatly decreased reserves of body fat.

Pigs reach mature size at 2 to 2.5 years of age (Pomar et al. cited by Pond and Mersmann [2001]); when they have free access to feed, however, they continue to accumulate body fat until 4 or 5 years of age. The lifespan of pigs allowed to complete their normal life is more than 15 years (Pond and Mersmann 2001). Nowadays, the performance of most sows has waned and they are replaced after farrowing their fourth litter.

Traits such as fatness, appetite, mature size, and physical characteristics respond quickly to genetic selection. There are more than 300 breeds of pigs worldwide (Jones 1998). The era of intensive production has led to pigs becoming more docile, lethargic animals that are quite dependent on caretakers for food. Temperament is important for ease-of-handling of sows and for their coexistence in close quarters. Very lean strains of Landrace may be less well able to adjust to being commingled with stranger-pigs (Torrey et al. 2001), whereas the much fatter Chinese breeds are famous for their placidity.

Breeds such as the Yorkshire, Landrace, and Duroc have become dominant in the Western hemisphere. Older, fatter breeds continue to be favored for specialty and niche markets, including outdoor production. Today, most commercial pigs are crossbred; hybrid lines are selected separately for either maternal traits (e.g., prolificacy, appetite, docility, milking ability, or foot and leg soundness) or sire-line traits (e.g., carcass quality, feed-conversion efficiency, or growth rate) that are "terminal-crossed" to produce pigs for slaughter.

Wild and feral pigs have a high capacity for dietary flexibility. Historically, pigs in natural habitats have been classic omnivores, eating a varied diet composed mostly of grasses, fruits, mast crops, and roots as well as some invertebrates and small vertebrates (Edwards 2003; Leus and MacDonald 1997; Schley and Roper 2003). In modern commercial practice, swine diets mainly consist of plant material.

In a natural environment, pigs are social creatures. They prefer to cohabit in bands (small herds) of a few related sows and multiple generations of female offspring (Stolba and Wood-Gush 1989). They display close kinship (often even cross-nursing one another's young [Mendl 1995]), and generally maintain stable social groups. Bands observe a strict dominance hierarchy based mainly on age and body size. Boars do not ordinarily associate with sows except during the sows' mating periods.

Aggression in wild, feral, and domestic pigs in natural and seminatural environments is infrequent and rarely injurious outside of mating periods (Stolba and Wood-Gush 1989). When aggression does arise, the incidents are limited primarily to periods of congregation at a food source, disputes over favored lying places, or when stranger-pigs intrude on a territory defended by a sow group. To decrease aggression, pigs will observe an avoidance order (Jensen 1982), and while grazing or foraging will tend to maintain a certain distance between each other (Stolba and Wood-Gush 1989; Turner et al. 2006). For example, as few as 10 animals per square kilometer $(km)^2$ (0.4 mile $[mi]^2$) have been observed at one time (Welander 2000).

In addition to group-defended territories, pigs defend respective individual spaces ("portable territories") and ordinarily use threats and other nonaggressive behaviors to maintain dominance relationships (Mendl 1995). This predilection is aided by some natural habitats, in the form of woodland areas, which allow the animals refuge from being disturbed by invading pigs (Choquenot and Ruscoe 2003).

Social behaviors in sows are instinctive and most have survived the heavy genetic selection pressure that has been applied to various commercially important traits throughout the twentieth century. In contemporary production systems, sow groups are established arbitrarily on the basis of factors other than kinship. This artificial grouping basically upsets the normal social interactions among sows. The aggressive flare-ups observed between sows kept in an artificial group sometimes are quite physically injurious (and psychically stressful); these behaviors probably are due largely to the sows' unfitness for living in close proximity to others of their kind with whom they have no longstanding kinship bond.

Brief History of Sow Accommodations in the United States

For the past few centuries, sows were kept on farms either in or with access to facilities ranging from minimally managed extensive systems to individual penning in a closed house. By the mid-twentieth century, farmers started moving sows indoors to seek relief from variable weather conditions, environmental-protection pressures, predators, and parasitic and enteric diseases. By the late twentieth century, the majority of sows in the Western hemisphere were kept indoors in IGAs.

The swine enterprise traditionally has been known as the "mortgage lifter" because pigs provided steady, year-round cash flow that allowed farmers to make their mortgage payments. When small pig enterprises on diversified farms became recognized as a reliable source of positive cash flow, farmers began to increase herd sizes. The work of managing breeding pigs is physically challenging. The added stress to herdspeople of caring for larger numbers of pigs during inclement weather was a contributing factor causing the move indoors from outdoor production systems (Curtis 2007a).

Once the farms housed the sows indoors, it was a natural progression to develop systems that increased the efficiency of building utilization by asking: What is the minimal space that can accommodate one sow? Thus, triggered first by avoiding mud and temperature extremes, then by improving parasite and disease control and manure management, and later seeking to increase the efficiency of gestation-house use, individual accommodation of dry sows arose. The success of IGA in overcoming multiple production problems in an economical way led to an exponential increase in its use (Curtis 2007a).

Although farrowing crates have been used in one form or another for more than100 years, U.S. farmers experimented with IGA for sows starting in the 1950s. By the 1970s, IGAs for sows were common, and, by 1990, IGAs were by far the most common sow-keeping system in the United States.

Criticism of the IGA from consumers and activists started in the 1960s in the United Kingdom and Northern Europe (Bäckström 1973). The tether was banned in the European Union (EU) beginning in 2006, and the gestation crate will be banned by 2013. Major announcements in 2007 and 2008 stated that some U.S. production companies and some states will stop using gestation crates, in response to public animal-welfare concerns articulated by animal activists. Currently, producers of more than 25% of U.S. pork have committed to phasing out the gestation crate, and the trend continues with legislative or voluntary proscriptions now under way to eliminate use of the gestation crate.

Evaluating Alternative Sow Accommodations

Behavioral Considerations

The dominance hierarchy in wild or feral bands of females is effectively managed because a female in an extensive setting can readily escape being attacked by moving away from an aggressive, dominant bandmate (Curtis, Edwards, and Gonyou 2001). In an artificial grouping of sows kept indoors, the same basic social interactions take place among sows. When sows in a social group are given progressively less space, the rate of skin-lesion incidence increases (Salak-Johnson et al. 2007), most likely due to increased exposure to the physical components of the pen as well as greater social contact and more stress (Gjein and Larssen 1995a). Sows kept in IGAs typically have fewer skin lesions and social stressors than those kept in groups with the same amount of individual floor space. Consequently, more barn space is required per sow when sows are kept in groups in gestation pens.

Now that the EU and U.S. farms either have decided to house sows in group pens or will be forced to use that practice, and because indoor floor space is expensive, methods are urgently needed to determine the minimum quantity and quality of space for pregnant sows kept in groups. Pork producers started using group housing systems before complete scientific evaluations were at hand by developing and implementing creative group-keeping systems that remain untested at large-scale. These systems include the trickle-feeding system (Hulbert and McGlone 2006), electronic sow feeding systems (Edwards, Armsby, and Large 1988), free-access stalls (den Hartog, Backus, and Vermeer 1993), and others (Johnson et al. 1990; Morris et al. 1993).

The behavior of dry sows can differ among keeping systems. Care must be exercised in the assessing and drawing of conclusions from such observations, however. Often factors other than the category of keeping system per se (e.g., IGA versus group pen) may be partly responsible for such overt differences. Also, different designs within one category of keeping system may lead to different results in scientific studies. Therefore it may not be justified to attribute differences observed in one specific study to the broad categories of keeping systems.

Scientific measurements of behavior used to assess the effect of the accommodation on dry sow state of being range from qualitatively and quantitatively analyzing detailed sequences of sow behavior patterns to quantifying frequencies and time budgets for a sow's engagement in a specific behavior (Altmann 1974; Banks 1982; Dawkins 2003, 2004, 2007; Gonyou 1994).

McGlone and colleagues (2004a) discussed results of research published in the scientific literature in which two or more sow gestation systems were scientifically compared with respect to the principal behaviors that have come to be presumed to indicate a sow's feelings in terms of anxiety, boredom, discomfort, frustration, hunger, pain, and the like—namely, oro-naso-facial (ONF), postural-adjustment and locomotory, and social behavior patterns. Sound stockmanship involves recognition of behavioral signs of anxiety, fear, frustration, pain, and other negative emotions; these emotions are called "affects." The signs of affects—e.g., balking, tail-twirling, nervous panting, escape, and certain vocalizations—are called "affect displays." Stress and distress affect an animal negatively, but to what extent it suffers is not yet known.

Indeed, although some scientists hold that assessing an animal's state of being should be based mostly on its feelings (Duncan 1996, 2001) and although this ultimately may be the ideal approach, it is still not possible to measure animal *feelings* objectively, either in the laboratory or on the farm.

As Duncan (2002) pointed out, the measurements per se of behavior purported to betray an animal's negative feelings can themselves be objective and scientific. Remaining to be unraveled, however, is the *interpretation* of such observations in terms of how much display-associated suffering the animal is experiencing. The pig, in particular, is a species that "does not suffer in silence," making it difficult to gauge just how much the animal actually is suffering.

During its lifetime, every animal will experience many instances of physical and psychic stresses that cause its state of being to be reduced to fairness and illness. Nature equipped animals to cope with most, but not all, of these stresses. Assessment of animal state of being is a matter of drawing lines on a continuum from very well through very ill. Until animal suffering can be quantified on the basis of affect displays, measuring behavior patterns will give only limited information as to the amount of animal suffering present and therefore as to where to draw those lines.

Oro-naso-facial Affect Displays

The pig investigates its environment mainly with its head—its face, mouth, and nose and the associated senses of vision, taste, and smell—so it naturally shows much ONF activity. Some ONF patterns (e.g., sham chewing and bar-biting, especially around feeding time) are presumed to be affect displays, particularly when they are classified as stereotypic. Stereotypies are repetitive, relatively invariable sequences of apparently nonfunctional behaviors that may indicate reduced state of being (Broom and Fraser 2007; Mason 1993). But highly functional behaviors such as eating, drinking, and rooting also are ONF patterns. Therefore, similar ONF behavior patterns may have different motivations, making comparison of sow-keeping systems based on ONF behaviors difficult. To evaluate the adaptation of sows to different types of accommodation, the durations and frequencies of non-eating ONF activities have been measured. Dailey and McGlone (1997a) found no differences in ONF behavior measured during 24 hours in three dry-sow systems: outdoors on bare soil, outdoors on pasture, or indoors in IGA. The three systems differed in space allowance per sow, substrate availability, opportunity to perform social behaviors, and thermal environment. This result suggests that pregnant sows may be highly motivated to show ONF behaviors regardless of the accommodation in which they are residing. Moreover, the nature of the motivation may differ among the three environments.

Vieuille-Thomas, Lepate, and Signoret (1995) observed sows kept in IGA or in groups for the occurrence of stereotypic ONF behaviors. When observed for 1 hour starting at the beginning of morning feeding, sows in IGA showed more stereotypic ONF behavior than sows in groups.

The availability of environmental features such as bars or soil influence ONF behaviors, but the significance of these differences in terms of motivation and welfare remains unclear. Moreover, the propensity to develop stereotypic ONF behaviors is related to age and parity of the sow (von Borell and Hurnik 1991). Indeed, ONF stereotypies seem to be related more to the individual characteristics of sows and less to accommodation systems (Vieuille-Thomas, Lepate, and Signoret 1995). Sows showing stereotypic ONF behaviors were found in both individual and group sow-keeping systems.

In a comparative study, Blackshaw and McVeigh (1984) analyzed sows in group pens or IGAs. Those in groups showed less prefeeding and no postfeeding stereotypic ONF activity. Contrary to this study, Backus and colleagues (1997) found no differences in postfeeding ONF activity among dry sows kept in IGAs (fed twice daily) or in group pens with either free-access stalls or trickle feeding. Results of these two experiments suggest that factors in addition to the type of keeping system influence the incidence of ONF behavior in sows.

Dailey and McGlone (1997a) measured the behavior of gilts kept indoors in IGAs or outdoors in groups. The indoor gilts were less active and sat more (possibly a sign of boredom [Wemelsfelder 1993]). Chewing occurred more in outdoor gilts, but chewing was not associated with rooting. Rooting occurred at similar rates in both environments.

Dailey and McGlone (1997b) also compared the behavior of sows kept individually in three systems: indoor IGAs and outdoor pens (30 meter $[m]^2$ [325 feet $[ft]^2$] per sow) either on soil or on pasture. Sows on each treatment performed total ONF behaviors (stereotypic and nonstereotypic combined) at similar frequencies. Sows in IGAs chewed the structural bars (chewing = jaw movement while contacting any substrate [perhaps functional eating behavior]). Sows on soil chewed rocks and soil and sham-chewed (chewing air). Sows on pasture chewed grass. Sows seem to be highly motivated to express ONF behavior regardless of the environment.

McGlone and colleagues (2004a) concluded from their meta-analysis of a variety of individual study findings that (1) sows in either IGAs or groups show similar ONF behaviors, (2) the causes of ONF activity likely are factors other than the sow-keeping system, and (3) ONF behaviors such as stereotypic bar-biting are not useful as measures for differentiating sow welfare across sow-keeping systems.

Postural and Locomotory Affect Displays

The chief behavioral constraint due to the structure of an IGA is the limitation of sow movement. Standing, lying, and various postures may be affect displays that reflect sow comfort and satisfaction.

A standard IGA ("straight IGA") is designed specifically so a sow cannot turn around. Some critics of IGAs consider this constraint to be a major fault. But to date the scientific evidence does not support that concern. Sows in adjacent IGAs have a strong tendency to affect one another's behavior (i.e., they demonstrate allelomimetic [mimicking] behavior).

In one experiment, respective sows in straight IGAs were located next to sows in IGAs designed to permit turning around (Bergeron, Gonyou, and Eurell 1996). Gilts in the turn-around IGAs stood up more often and had greater rates of ONF behavior toward the IGA structure than those in straight IGAs. Indeed, gilts in straight IGAs did not show more ONF behavior, indicating that ONF behavior (often considered to be an affect display) is not triggered by the lack of opportunity to turn around.

In another experiment, the width of turn-around IGAs was varied: in one model, gilts turned around with relative ease, whereas in a slightly narrower model turning around was possible but required more physical effort (McFarlane, Bøe, and Curtis 1988). Gilts in the narrower turn-around IGAs showed the turning maneuver significantly less than those in the wider ones. This result indicates that, if turning around is a need for sows, it is not a strong behavioral need (see consumer demand theory approach to assessing needs [Dawkins 1983]). Simply making it more difficult to turn around caused the animals to do so less frequently.

Several studies have reported the relationship between IGA dimensions and postural and motor activities of dry sows. In one study, the ability of sows in IGAs to get up and lie down was positively related to sow space allowance (Anil, Anil, and Deen 2002b). In another study, the wider the IGA, the more time sows spent lying in full recumbency (Cariolet et al. 1997). Gilts walked the same distance each day (approximately 129 m [approximately 425 ft]) in IGAs that were either 2.1 or 3.4 m (7 or 11 ft) long (McFarlane, Bøe, and Curtis 1988).

Affect Displays Associated with Social Interaction

Social behavior of pregnant sows is influenced greatly by type of accommodation. In most IGA designs, certain types of communication—auditory, olfactory, visual, and some tactile (snout and feet and legs)—are possible between sows in adjacent accommodations. But neither full body contact nor dominance-subordinance determination is possible in IGA systems.

Blackshaw and McVeigh (1984) compared behavior of pregnant sows in group pens and in IGAs. Grouped sows engaged in more agonistic (aggressive plus submissive) behavior. Within-group agonistic behavior was shown especially at times of initial commingling and feeding (Arey and Edwards 1998).

Morris and colleagues (1993) compared the Hurnik-Morris (HM) sow-keeping system—which permits social eating and resting, individual eating (in individual compartments), physical exercise, and regular exposure to boars—with the IGA system. Gilts spent less time lying in sternal recumbency and performing stereotypies and more time in social activities (e.g., touching) in the HM system than in IGA. Several factors might have been responsible for these differences: space allowance, exercise and socializing opportunities, environmental complexity and richness, and substrate.

With groups of six sows in straw-bedded pens furnished with individual feeding stalls, Weng, Edwards, and English (1998) found that social interaction was affected by floor space (amounts of 2, 2.4, 3.6, or 4. 8 m^2 [approximately 22, 26, 39, or 53 ft^2]). The researchers then related these findings to a physical indicator of welfare, a skin-lesion score. Rooting time increased with space allowance, whereas sitting and standing inactive both decreased, as did total social interaction and aggressive behavior. A minimum space between 2.4 and 3.6 m^2 (26 and 39 ft^2) per sow was necessary to minimize social aggression among the sows.

Nutrition and Feeding Considerations

The nutrition of the breeding sow has been reviewed by Close and Cole (2000) and Lewis and Southern (2001). The response of a breeding sow to feeding is influenced by her body fat reserves. Both underfeeding and overfeeding are detrimental to reproductive performance. There may be residual effects of feeding in an early stage of a reproductive cycle on short-term productivity, including lactation performance. There also are more-long-term effects: underfeeding in one cycle will leave a sow with low fat reserves in the next cycle and, unless corrected, will result in a downward spiral of body condition and reproductive failure.

High feed intake during prepubertal growth is associated with a higher subsequent culling rate (Jorgensen and Sorensen 1998). This relationship is associated with mobility problems that may be influenced by a lack of exercise during pregnancy. Sows obese at farrowing have dystocia (slow or difficult labor or delivery), depressed feed intake, and increased weight loss during lactation (Baidoo 2001; O'Grady, Lynch, and Kearney 1985).

Sows should be "fit but not fat" at farrowing if lactation feed intake is to be stimulated and loss of fat during lactation minimal. Individual gestation accommodation or individual gestation feeding (IGF) of a pregnant sow allows a thin sow to be treated individually without having to overcome competition at the feed trough from older, heavier, stronger—and usually more dominant—rivals in a group. Conversely, with IGA or IGF, an obese sow can be restricted in feed ration to reach the desired body condition by farrowing time.

A high-yielding sow will produce up to 14 liters (3.7 gal) of milk per day at peak lactation (Boyd and Touchette cited by Boyd and Kensinger [1998]). In terms of metabolic body size, the sow's lactation rate is comparable to that of a high-yielding dairy cow.

Milk production by the sow is determined mainly by the rate of extraction of milk by the litter and is, to some extent, independent of feed intake. A sow will continue to produce milk for her piglets even though depleting her own bodily reserves of fat and protein. Unless those depots are replenished during the next dry period, future productivity and performance will be affected adversely.

"Thin-sow syndrome" in recently weaned sows was a serious problem in the commercial industry in the past, leading to high infertility, mortality, and culling rates. Thin sows have a high maintenance energy requirement because of poor tissue insulation, and they need a high metabolizable energy intake to be able to deposit as much fat as needed for fitness.

Although sows are almost always culled before reaching the end of their natural lifespan and mature weight, improved husbandry of breeding sows associated with increasing annual productivity has resulted in greater sow body weights. Data from an Irish research herd showed that prefarrowing sow weight went from 208 kilograms (kg) (458 pounds [lb]) in 1975 to 263 kg (579 lb) in 1999 (Lynch 2000) for similar distributions of parities (the number of times a sow has borne offspring). In the United Kingdom, from 1983 to 1993, the body weight of first-parity sows at weaning went from 153 to 185 kg (337 to 407 lb) while backfat thickness at weaning went from 25 to 15 mm (1.0 to 0.6 in), and that of parity-3 sows went from 190 to 242 kg (419 to 533 lb) and backfat from 22 to 17 mm (0.9 to 0.7 in). Danish studies indicate that sow body weight and length have increased by 20% and 10%, respectively, from 1986 to 2003 (Moustsen, Poulsen, and Nielsen 2004). These increases in body weight (and consequently body dimensions) necessitate reassessment of the dimensions of IGAs (McGlone et al. 2004b) and feeders (Taylor 1990; Taylor et al. 1988) if sows are to live in comfort and without injury, as confirmed by Anil and colleagues (2002a, 2002b). Increases in size also affect a sow's dietary energy requirement for maintenance.

Feeding in Individual versus Group Gestation Accommodations

Difficulty in regulating individual-sow feed intake is a major disadvantage of keeping sows in groups. Socially dominant sows tend to eat excessively at the expense of submissive sows.

Where sows are not provided an individual feed allocation (as in back-gated feeding stalls or electronic sow feeders [ESF]), uneven feed intake invariably results in increased inter-individual variation in body-weight gain during gestation. Techniques to minimize such variation have included trickle-feeding (Hulbert and McGlone 2006), part- or full-length partitions forming stalls at the feed trough (Walker and Beattie 1994), and use of feed slurry (Bøe, Anderson, and Kristiansen 1999). Distribution of wet feed to sows in groups can be problematic, with dominant sows quickly learning to position themselves repeatedly in the most advantageous positions relative to slurry flow (Olsson 1997).

A breeding sow will consume approximately 1.2 tons of feed per year. The kind of accommodation partly determines a sow's daily and annual ration requirements and intakes. Individually fed sows spent 14% of their time in stereotypic behavior (repetitive movements with no apparent function, taken as a sign that a sow is attempting to cope with some external or internal stimulus or lack thereof [Wemelsfelder 1993]) compared with 4% for group-fed sows (Broom, Mendl, and Zanella 1995). Cronin and colleagues (1986) estimated that "unnecessary" behavior in sows showing a high frequency and duration of stereotypes accounted for 23% of a sow's daily energy expenditure compared with 7% for tethered sows showing few stereotypes and 4% in group-kept sows. Appleby and Lawrence (1987) reported more activity and more repetitive behavior when tethered pregnant gilts were fed a daily ration of less than 2 kg (less than 4.4 lb). In cool or cold environments, individually kept sows, either in IGAs or on tether (both being unable to huddle to conserve body heat) also have a higher feed requirement because of greater heat loss to the surroundings (Estienne, Harper, and Knight 2006; Verstegen and Curtis 1988).

Boyle and colleagues (2002) found indications that some sows kept in pens during pregnancy find a farrowing crate quite aversive, which might affect their feeding behavior and at least partly negate any beneficial effect of loose keeping systems on muscular fitness (Marchant and Broom 1996). In within-herd comparisons of IGA and group-pen systems, lack of control of feed intake and high aggression rate were problems in the latter (Nielsen 2003). This finding, which confirmed expectations based on knowledge of the basic nature of the sow (Einarsson et al. 2008; Mburu et al. 1998; Mwanza et al. 2000a, b; Razdan et al. 2004; Tsuma et al. 1996a, b), may have occurred partly because the caretakers experienced difficulty in simultaneously operating two sow-keeping systems having different tasks.

Increasing feeding frequency for sows and gilts in groups from 2 to 6 times daily—in an attempt to decrease fighting when feed was delivered on the floor—slightly decreased skin and vulvar injuries but overall affected neither performance nor the apparent welfare of the animals (Schneider et al. 2007).

Fiber in the Diet

A pregnant commercial sow typically is restricted-fed at a rate of only approximately one-third of what her voluntary intake would be if she had ad libitum access to feed. This practice is based on scientific evidence that the sow's health, productivity, and longevity are enhanced when her access to feed is restricted (Close and Cole 2000; Lewis and Southern 2001; Whittemore 2006).

Ad libitum feeding of pregnant sows might be expected to decrease aggression by reducing competition for feed. But pig populations may tend to regress to greater fat deposition (Jones 1998). And, even on high-fiber, low-energy-density diets, sows fed ad libitum tend to overconsume energy and become morbidly obese (Brouns, Edwards, and English 1995; Kirkden and Pajor 2006; Zoiopoulos, English, and Topps 1983).

European Union legislation (EC 2001a, b) requires that "to satisfy their hunger and given the need to chew, all dry pregnant sows and gilts must be given a sufficient quantity of bulky or high-fiber food as well as the high energy food." In addition, "sows and gilts must have permanent access to manipulable material." An accompanying document lists suitable manipulable materials as "straw, hay, wood, sawdust, mushroom compost, peat and mixtures of such which do not compromise the health of the animals." The regulations do not define "sufficient" or explain how a high-fiber feed should be offered.

From results of behavior studies, it was concluded that feeding a bulky diet can increase sow state of being more effectively than the presence of a manipulable material (wood chips) on the floor (de Leeuw and Ekkel 2004). Bulkiness, water-binding capacity, and low palatability were given as reasons for decreased intake of high-fiber feeds (de Leeuw 2005).

Stewart (2008) examined the provision of access to chopped barley straw from a rack to sows in small (4-sow) static groups on unbedded, part-slatted concrete floors. Sows were fed a cereal-soy diet or a high-fiber diet (15% soy hulls, 9% crude fiber). Although either treatment alone decreased stereotypic behavior, straw and a bulky diet had additive effects in decreasing sham-chewing and bar-biting. Approximately 0.3 kg of straw/day (0.7 lb/day) was used. Meunier-Salaun and colleagues (2001) concluded that the effect of type of dietary fiber on the behavior and physiology of the sow needed more research, including investigation of the mechanisms (e.g., gastrointestinal tract distension or postprandial [after a meal] concentrations of circulating metabolites) by which these diets affect satiety.

Strategies to improve sow satiety can have other consequences. Use of high-fiber diets will require a greater volume of feed storage, result in an increased amount of manure due to the lower digestibility, and therefore possibly lead to poorer hygiene (especially regarding mastitis or metritis). Feeding dilute wet slurry increases manure volume and heat loss (and hence increases feed requirement).

Group Pens with Electronic Sow Feeders

Competition for feed in group-feeding systems results in aggression, injury, and submissive behavior in sows. With ESF, rationing of feed to sows according to their individual needs is possible, but aggression also is common with ESF while sows stand in line waiting to enter the feeding station. In group pens with ESF, sows are kept either in groups of 40 to 70 with one feeder or in larger groups with more than one feeder. Each sow is fitted with an electronic ear tag. Once a sow enters the feeding station, her tag is recognized by the system's computer and the daily feed allowance is dispensed in a number of feedings. Feed is added to the trough according to a feeding curve in set amounts (e.g., 100 grams) at set intervals (e.g., every 30 to 60 seconds) until either the sow exits or her daily allocation has been dispensed.

Rate of eating varies with sow age, and the set interval between feed drops must match the eating rate of the slower eaters if accumulation of feed is to be avoided. That interval in turn determines the feeding time required per sow per day and the number of sows each ESF can serve. Eating takes only 15 minutes per sow per day (a range of 12 to 29 minutes), but nevertheless the capacity of a single ESF is only 40 to 70 sows because, once a sow has occupied and used the station, she may loiter there, especially if she is lowly dominant and can use the station as a haven (Edwards 1985). Newer models are outfitted with steel bars above floor level that prevent the sow from lying down. Vulva biting is one of the most serious results of aggressive interactions that are associated with group systems that do not allow simultaneous feeding (AVMA 2005). Problematic equipment and pen design are some of the causes of a high incidence of vulva biting (Levis 2007; Olsson et al. 1992). The design of ESF differs mainly in the position of entrance/exit gates and trough configuration. Sows tend to queue at the entrance to a station.

Most sows prefer to eat the daily ration in one visit to an ESF. More frequent feeding increases the number of sow visits, thereby increasing feeder occupancy and leading to greater social disturbance (Edwards 1985; Edwards and Riley 1986; Jensen et al. 1995, 2000).

Some sows (5% by one estimate) may fail to adapt or be too aggressive and as a result must be handled separately or culled (Chiappini and Barbari 1989). Pedersen (1994) reported from experience with ESF in partly slotted-floor pens that up to one-fourth of the sows had to be culled for failure to eat or leg problems. He concluded that high culling rates might be expected during the 1- to 1⅓-year transition from IGA to group pens with ESF. Where bedding was used, injury and performance problems were fewer, but straw usage was high at approximately 1000 kg (2200 lb) per sow per year (i.e., around 2.8 kg [6.2 lb] per sow per day.) Much lower straw usage was reported by Barbari and colleagues (1993): more than 1 kg (more than 2.2 lb) per sow per day in winter, 0.65 kg (1.4 lb) in summer.

Group Pens with Floor Feeding

Feeding sows on the floor, a practice suitable only for solid-floored houses, has been characterized as being simple, inexpensive, and requiring little maintenance. But, importantly, this method does not provide for individual feed rationing. Differences in eating speed mean that, with restricted-ration regimens, dominant sows invariably will overeat. Extreme variation among sows in feed intake is common, with low-ranking sows eating as little as 65% of the group average intake, resulting in variable body condition at farrowing (Brouns, McMenamy, and Edwards 1992). Competition at feeding time always is intense (Lambert et al. 1985), resulting in physical and psychic stress and injury. Distribution of feed to decrease bossing can be done by dumping or spinner (Langhamer 1991). It is essential to keep sows in cohorts based on a range of expected farrowing dates of no more than 2 weeks.

High-fiber diets decrease mineral retention, and this could be important for sows fed a high-fiber diet with intentionally marginal phosphorus (P) content (for environmental protection reasons). A study by Girard and colleagues (1995) showed that increasing the fiber concentration in sow diets often incrementally decreased the serum concentration of some nutrients (e.g., vitamin B12, calcium, P, copper, and zinc).

Reproduction Considerations

Researchers investigating potential consequences on reproduction of continuously keeping sows in IGAs have focused largely on the effects of accommodation type on three key measures of performance: farrowing rate (sows giving birth as a percentage of sows mated), litter size, and nonproductive days (when sows are neither pregnant nor lactating).

Based on a comprehensive meta-analysis of results of more than 10 studies published in the scientific literature, McGlone and colleagues (2004a) concluded that, in general, sows kept in IGAs have greater or equal reproductive performance compared with sows kept in group systems. For example, in an Australian study conducted during summertime, the farrowing rate was greater for moderately fed sows kept in IGAs (82.5%) than for those kept in groups of 22 or 23 (69.0%) (Love et al. 1995). There was no effect of accommodation type on litter size.

When pregnant sows kept either in IGAs or in groups of 70 were compared with sows individually tethered, the number of pigs born alive was greater for IGA (10.32) than for tethering (10.07), with grouping being an intermediate number (10.11) (Backus et al. 1991). Sows kept in crates or free-access stalls had fewer nonproductive days and 0.7- to 1.1-days shorter weaning-to-estrus interval than those in groups (Backus et al. 1997). There are good reasons to ask whether different kinds of sow accommodation result in differences in a sow's productive lifetime, but answers depend on further scientific investigation (Stalder et al. 2007b).

Swine have relatively high embryonic and fetal mortality, with most deaths (20% to 30%) occurring during the first 30 days of gestation (Pope and First 1985). Embryos are extremely fragile during early gestation, and various social (e.g., fighting among sows), nutritional (e.g., overfeeding, particularly gilts), and environmental (e.g., heat) conditions can cause embryonic death.

In some production systems, sows are kept in IGAs throughout pregnancy. There is growing interest, however, in defining shorter periods of gestation during which the use of IGA is most beneficial and useful. In terms of reproductive performance, individual keeping should be of most benefit during early gestation—sometimes in a separate "control unit" (see System Design Considerations section)—and there is scientific evidence to support this concept. A particularly stress-sensitive stage in pig reproduction is the implantation phase, when hormonal perturbation can increase embryo mortality and hence decrease conception rate, litter size, or both (Scientific Veterinary Committee 1997). Therefore, EU welfare legislation permits sows to be kept in IGAs for the entire implantation period until 4 weeks after mating. Pregnancy rate at day 30 postmating was 15% higher for gilts kept in IGAs than for those kept in groups of 3, although embryo number was unaffected by keeping system (Estienne, Harper, and Knight 2006). Similarly, pregnancy rate at day 28 postmating was greater, and spontaneous abortion between days 17 to 26 was less, for sows kept in IGAs compared with those kept in groups of 20 in pens deep-bedded with straw and furnished with individual feeding stalls (Munsterhjelm et al. 2008).

In contrast to these findings, Schmidt and colleagues (1985) reported a 12% higher farrowing rate for sows kept in groups of 4 or 5 (78%) than for those kept in IGAs for the first 30 to 35 days after mating (66%). And van Wettere and colleagues (2008) reported no difference in pregnancy rate or embryo survival to day 26 for gilts kept in IGAs or in groups of 6. In that study, groups were composed of gilts that either had been together originally before mating or were commingled with unfamiliar gilts either at day 3 or 4 or at day 8 or 9 postmating.

In summary, most scientific evidence indicates that reproductive performance of dry sows kept in IGAs is at least as good as, and in some instances exceeds, that of sows kept in groups. This finding suggests that the state of being of dry sows in IGAs is at least comparable to that of those in group pens. In terms of reproductive performance, the most beneficial period for using IGA via a control unit is the first month postmating. Equivocal results among studies sometimes occur and may be due to differences in factors other than the keeping system per se (IGA versus group pen). These differences include the quality of husbandry, floor type, quality and quantity of space, group size, time postmating at which sows are commingled, presence or absence of bedding, nature of bedding (if used), feeding system used, and sow genetics.

Clinical Examination and Health Considerations

Infectious diseases continuously threaten to overtake the health of a group of sows, and thereby their well-being. The risks associated with emerging infectious diseases and the impact of zoonoses on swine and humans alike indicate the clear value of indoor facilities for dry sows. There is virtually no biosecurity in outdoor swine-production systems. Where humans, their livestock and poultry, and feral and wild birds and mammals cohabit in a milieu of great microbial exchange, there is a high likelihood of debilitating zoonotic infectious disease in all species.

Great strides in disease control and elimination have been made in modern indoor operations. Biosecurity methods have lagged somewhat the trend to confinement, but modern practices have proved to be effective. Production systems of all sizes have realized the health and welfare advantages of indoor accommodations for swine. All-in, all-out confinement management strategies plus judicious use of pharmaceuticals have eliminated most internal and external parasites that plagued U.S. swine production as recently as 1980. A number of serious infectious diseases—including *Actinobacillus* pleuropneumonia, pseudorabies, brucellosis, dysentery, degenerative atrophic rhinitis, and a host of others—have been either eradicated or clinically eliminated by the facilitation of modern housing design and operation and numerous husbandry and veterinary practices.

Those enterprises that faithfully observe functional biosecurity programs are guardians of the public health. But ribonucleic acid (RNA) viruses that rely on rapid mutation and genomic re-assortment to avoid host immunogenic-change mechanisms for survival (e.g., porcine reproductive and respiratory syndrome [PRRS] virus and influenza virus) seem to thrive by parasitizing large populations of location-connected pigs. In a modern production enterprise, the RNA viruses are the only exception to the generalized health improvements wrought by confinement housing.

Health Status Determination

The health status of any animal population has numerous determinants (Curtis and Bäckström 1992; Muirhead 1976; Webster 1970). Generally, the health status of a herd and the pigs within it is determined by the array of infectious agents present in that population, the nature of the agent-swine host interaction (e.g., carrier state, persistence), challenge levels, population immune status ("herd immunity"), specific type of immunity involved, and a number of other factors. Once a population achieves stable health, it is typically the introduction of a new infectious agent that alters the health and state of being of the animals.

The health of an individual sow in a stable-health population is largely the result of nutritional status, injury status, genetic susceptibility (resistance/tolerance), interaction with the micro- and macroenvironment, and stress level. Confinement housing of dry sows—whether in IGA or group pens—is subject to the same risk factors as those for new disease introduction. Accommodation type does not influence pathogen exclusion (isolation of host), but may affect biomanagement and bio-containment (quarantine of host), which are the other two components of a biosecurity program.

Other than the injuries and wounds mentioned, the association of health-related differences between IGA systems and group-pen gestation systems has not been addressed thoroughly in scientific studies. The IGA does minimize inter-individual contact, which decreases the rate of spread of pathogenic microbes that are transmitted by contact or closeness.

Any effects that may exist regarding the type of gestation accommodation on the clinical manifestations of specific infectious diseases in sows have not been documented scientifically. Field experience supports this assumption. To repeat, in group keeping systems, differences in feeding methods (ESF), floor space (less than 2.3 m^2 [25 ft^2] per sow), and parity (P-1) have been documented to increase musculo-skeletal injuries, skin abrasions and lacerations, and vulvar bite wounds (Durrell 2000; Salak-Johnson et al. 2007; Svendsen, Olsson, and Svendsen 1992). Also, production records indicate a greater rate of mortality in outdoor production than in indoor at all stages of production (Miao, Glatz, and Ru 2004). Mortality rates for sows in IGAs compared scientifically with rates in group systems have not been reported.

Accounting for variation in contributory factors and making risk assessments among farms and among systems even on the same farm are challenging tasks (Bracke, Metz, and Spruijt 2001). Historic clinical experiences and expert impressions often must suffice. A relatively scant literature exists on studies addressing overall health-status differences between different kinds of indoor dry-sow accommodation.

More health-status comparisons are available comparing indoor and outdoor operations. Mortality levels for indoor-housed U.S. and Canadian breeding herds for the 2-year period beginning January 2006 (PigCHAMP Benchmarking 2008) indicate that annual sow mortality rate averages less than 10% and preweaning mortality of piglets less than 12%. Both rates are considerably lower than those generally reported for most outdoor systems, although well-designed and well-managed outdoor systems can result in productivity comparable to that indoors (Johnson, Morrow-Tesch, and McGlone 2001; McGlone 2007).

The 20 largest pork producers in the United States now account for more than 50% of the productive sows and approximately 60% of the pigs produced. Although these numbers are only a rough measure of health, it is apparent that even the largest U.S. farms and corporations have greater productivity and lower mortality than most outdoor and small-farm enterprises, indicating a high state of being in the sows (Curtis 2007b).

In addition to results of scientific inquiries, most expert assessments and voluminous production data indicate that IGAs provide the better opportunity for routine health care and greatest productivity. Sow mortality and culling records began to be published circa 1970, but became widely available only around 1990. This same period saw major changes in genotypes to satisfy consumer demand for leaner pork and greater performance rates, making any attempt at comparison between modern and earlier production systems difficult and therefore of little value. Studies indicate differences between dry-sow accommodations with respect to the various maladies already discussed. No comparisons have been reported for differences among keeping systems in terms of disease-agent activity and pathogenicity.

Information on individual-sow health differences has been based on attempts to measure stress-related compounds, including acute phase proteins and glucocorticoids. But only a few studies evaluating differences in immune, cytokine, chemokine, and other inflammatory immune modulators between accommodations have been reported.

Sow Welfare Assessments

The recent legislation-driven return to "loose housing" of dry sows in penned groups in some parts of Europe has been fraught with new sow-welfare problems arising from deficiencies in the modern keeping systems. Many of these problems are related to the sow-health facet of her state of being. Expert assessments have been made of sow welfare in several current systems. Three of these are the following.

From an American perspective, McGlone (2006) compared sow welfare in a Swedish deep-bedded, sow-pool system and the typical U.S. crated-sow system. His considered expert opinion was that dry sows kept in the Swedish system experienced a poor state of being, whereas dry sows kept in gestation crates experienced superior overall welfare. Likewise, results of using an objective scoring system led Curtis and Johnson (2005) to conclude that, in general, the needs and well-being of sows were better supported in IGAs than in group-pen systems.

From a European perspective, Damm (2008) judged that keeping dry sows in group pens currently provides a framework in which keeping systems resulting in a high state of being in the sows can eventually be developed. This author went on to say that achieving sow well-being in "loose housing" (penned groups) will require inputs from several stakeholder groups, including animal behavior and husbandry researchers, veterinarians, industry personnel, and technical advisors.

One important factor is that the caretaker can easily observe and have access to the individual sows residing in an IGA. It is widely recognized that treatment, vaccination, and care practices that directly impact a sow's health are much more manageable in IGAs.

Moreover, in groups of more than 30 sows, it can be difficult to evaluate the condition of every individual in the group. This is especially so for a sick sow, which often spends most of her time lying in a part of the pen distant from the alleyway. Also, an early sign that a sow is ill often is a decrease in feed intake, which is much more readily detected when the sow is kept in an IGA. It is more difficult to quickly observe that sows are no longer consuming feed at a normal rate with floor-feeding in loose housing than with IGA or individual-stall feeding in loose-housing systems. This difficulty can compromise the health of downstream production if newly weaned pigs are moved off-site before the presence of a new pathogenic agent in the herd is recognized.

Given the importance of a sow's body condition at farrowing time for reproductive performance and the sow's tenure in the breeding herd, the ability to adjust a sow's daily feed ration relatively easily to preclude excessive fatness or thinness is a major advantage of the IGA approach.

Sows' Injuries and Social Stress

The amount of fighting between sows and consequent serious injury (e.g., bitten ears, tails, and vulvas as well as head and shoulder abrasions and lacerations) and social stress incurred are substantially greater in sows kept in group pens rather than in IGAs. In sows in groups of 12, Edwards and colleagues (1993) recorded more damage to vulvas in floor-fed sows than in ad libitum-fed sows. Weber and colleagues (1993) reported more aggression and sow injuries with ESF installations than with other group sow-keeping systems (groups of 4, 8, or 9 with individual feeding places). Injuries were less frequent where sows had adequate bedding, more frequent in small groups and where floor-space allowance was less than 2.5 m^2 (less than 27 ft^2) per sow. More recent casual observations with newer ESF designs confirm these findings.

There are additional consequences of fighting among pregnant sows as shown by lingering effects on not only the dam, but on the fetuses as well. Tuchscherer and colleagues (2002) reported that daily stress of as little as 5 min duration during late gestation decreased sow-to-piglet transfer of colostral antibodies, decreased cell-mediated immune functions, and increased mortality in suckling piglets. This alteration in immune biology also seemed to increase those piglets' susceptibility to infectious agents later in life.

There are, however, body injuries and lesions that occur more frequently in IGAs. Overgrown hooves, which may come partly from inadequate walking on sufficiently abrasive floor surfaces, and other foot-and-leg lesions can result not only in impaired mobility (lameness) when sows are walked between units (Boyle et al. 2002) but also in less time spent eating (Boyle 1996) and decreased reproductive performance (Deen, Anil, and Anil 2008). Lameness is especially common in sows residing in IGA-based sow units (Bäckström 1973; Tillon and Madec 1984), and sows culled for foot-and-leg problems comprise a large fraction of all culled sows (Deen, Anil, and Anil 2008; Gjein and Larssen 1995a, b). But lameness also occurs in group-keeping systems (Gjein and Larssen 1995c, d). Moreover, in IGA systems with well-designed and well-maintained floors, claw lesions tend to be rare. Foot-and-leg injuries seem to be related more to the nature of the floor than to IGA per se. Moreover, claw lesions are not the only cause of lameness and leg weakness. Arthritis and structural maladies also may be involved. Sows kept in IGAs had leg bones with only two-thirds the breaking strength of those of sows penned in groups (Marchant and Broom 1996).

An IGA system also was associated with decreased leg-muscle weight in pregnant sows, and that circumstance can increase the frequency of broken bones and other injuries (Marchant and Broom 1996). Although speculative, muscle weakness may increase the chance of a sow slipping, resulting in physical injury. Grondalen (1974) found that swine that exercised more (e.g., group-penned sows) were less likely to fall after slipping than others did (e.g., IGA-kept sows).

The increased incidence of decubitus ulcers (pressure sores) in sows has been attributed to the relative physical inactivity associated with residing in an IGA. Broom, Mendl, and Zanella (1995) found that 16% of sows residing in IGAs developed ulcers on the shoulders and legs. Zurbrigg (2006) studied the occurrence of shoulder ulcers in sows kept in individual crates in a farrowing unit; the study identified several risk factors. These factors include low body condition score (BCS) (sows with a BCS less than 3 at weaning were nearly 4 times more likely to have shoulder sores); low flank-to-flank measurement (97 to 104 centimeters [cm] was associated with nearly 3 times the likelihood of ulcers); breed (Yorkshire less likely); parity (P-5 or greater more likely); and floor type (tri-bar metal more likely than slotted cast-iron). Wetness on concrete slotted floors also is recognized as a risk factor.

Early reports indicated that sows in IGAs tend to be predisposed to urinary-tract infections, apparently related to low physical activity and water intake (Bäckström 1973; Tillon and Madec 1984). In a more recent study, however, insufficient water intake was not associated with increased risk of cystitis (Martineau and Almond 2008).

Solid floors and the presence of wet bedding increase the likelihood of challenge from multicellular and microbic pathogens (e.g., ascarids or enteric bacteria) and the likelihood that those pathogens will survive. For example, group systems with bedding have a high infection rate with *Salmonella*, which has food-safety implications for humans.

Manure Management Considerations

For good air quality, hygiene, and safety, a sow should be separated from her excreta insofar as possible. Conventional breeding and gestation barns where sows are kept in IGAs typically have floors slotted so as to allow manure to fall into a pit below. The pit may contain water, and the manure is emptied into a lagoon or tank outside for storage or treatment. Collected manure may be flushed to a lagoon by a surge of water from a special tank. Manure also may be collected in an anaerobic deep pit under the floor or in an outdoor above-ground storage unit, or it may be scraped mechanically from the pits and moved outdoors as semisolid material. At appropriate times, collected and stored manure may be applied as a soil amendment to cropland.

Regardless of the type of manure management system used, manual manure handling within the barn is typically minimal. For IGA, the sows' stamping plus some hoeing by the caretaker forces manure through the floor slots. With well-designed and well-operated manure management systems and properly ventilated barns, air in the sows' microenvironment will be relatively free of noxious gases and other pollutants.

Some group pens for dry sows are located over partly or totally slotted floors, and manure management is similar to that for IGA with slotted floors, although often more time-consuming and less safe for the caretaker working in the midst of sows on often-slippery floors. Other group keeping systems, such as those that use bedding, do require more labor. Once the manure pack begins to build up, fresh straw must be added routinely at the wet spots that usually develop. Wet spots can be the source of salmonellosis. When properly managed and not allowed to become too wet, manure packs emit little manure gas. Periodically, the manure pack is completely removed, applied as a solid to the land as a soil amendment, and then replaced with bedding material.

More than 800 kg (1,800 lb) of bedding material per sow per year is required for deep-bedded systems. Barns using bedding do increase substantially the amount of manure to be handled. Regardless of the type of accommodation (IGA or group pen, slotted floor or bedded), even a 125-kg (275-lb) sow produces approximately 4 kg (approximately 9 lb) of manure (feces plus urine) daily that must be removed. Inadequate handling of manure build-up can result in an unhealthy, unsafe environment for sows and caretakers alike. With proper oversight and follow-through, many different systems can provide for a good environment in which to house sows and to work.

Ergonomic and Worker Safety Considerations

The primary purposes of IGAs are to control individual feed intake; prevent the sow from turning around and defecating and urinating in the feeding area; decrease bossing and fighting; contain manure; provide for easy control of the sow while protecting the caretaker during examination, insemination, or treatment; and optimize the efficiency of barn-space use (Barnett et al. 2001). The IGA allows the sow to stand up, lie down, and sit while permitting the caretaker access from both front and rear in order to carry out chores and treatment.

Common design features of an IGA include steel partitions fastened to the floor and stabilized by steel bars at the top (the bars also prevent the animal from jumping up and turning around). Partition designs include vertical bars, horizontal bars, or metal mesh, which allow animals visual contact and perhaps some tactile contact but prevent aggression. The height of the partition is in the range of 90 to 110 cm (35 to 43 in), (i.e., high enough to prevent the sow from accessing the adjacent IGA, turning around, or rubbing the back on crossbars). The bottom rail of the partition prevents the sow from sliding under the partition and intruding bodily into an adjacent IGA but allows some space for the sow's legs while lying.

A lockable rear gate in a crate-type IGA allows the caretaker to let the sow enter the crate but prevents her from leaving it. Steel bars or metal mesh (often in the form of a gate) at the front prevent the sow from leaving its place in that direction unless the gate is opened.

Feed can be provided on the floor, in a trough, or in a wide groove recessed in the floor at the front of the IGA. The trough runs the length of the row of IGAs and may be either communal or have partitions for individual places. Feed may be provided in dry or wet form. Water may be supplied either by individual watering devices or in a trough that is manually or automatically supplied. Flooring typically is partly or fully slotted concrete.

The IGAs' functional requirements mean that the design of the IGA is important for sow well-being as well as sow performance. A good IGA design should allow the sow sufficient space to eat and drink, lie down, sit, rest, get up, and stand comfortably. Moreover, the IGA should be designed to prevent injuries and aggression and allow excreta to leave or be removed from the facility easily.

Ergonomically, a good IGA should facilitate those manual chores that are normally carried out during the period from weaning until the sow is moved to the farrowing facility, including stimulation of the sow at mating time, artificial insemination, pregnancy checking, clinical examination and sampling, and medical treatment, all without risk of injury to the caretaker.

Commercially available IGAs are designed to meet the spatial needs of the average-sized female. Because gilts and sows in a typical herd vary considerably in size according to their age, body condition, and reproductive stage (McGlone et al. 2004b), the space needs of each female in a herd often will not be fulfilled by an average-sized IGA. A young, relatively small gilt requires a relatively narrow stall to prevent her from turning around, whereas an older, larger multi-parity sow will need more space for changing body position (Anil, Anil, and Deen 2002b; Baxter and Schwaller 1983).

Dimensions of commercial IGAs vary from 45 to 70 cm (18 to 28 in) in width, and length varies from 160 to 250 cm (63 to 98 in) including the trough (EFSA 2007; Gregory and Devine 1999). To gain a better understanding of how commercially available products meet the gilts' and sows' spatial requirements, body dimensions of sows should be compared with the size of the IGAs available on the market. The sow's static need for space has been determined in American (Curtis et al. 1989; McGlone et al. 2004b) and Danish crossbred sows (Moustsen, Poulsen, and Neilsen 2004). Results indicate that the 95th percentile of sows in all studies had similar dimensions for various body measures at introduction to the farrowing house.

Sows also need space for shifting body position from lying to standing and vice versa, and from side to side while lying, and these needs should be considered in the design of IGAs (Petherick 1983). Baxter and Schwaller (1983) determined the sow's need for dynamic space in lying down and getting up by measuring their virtual space envelopes when moving to extremes and calculating the deviations of these from their body dimensions. On the basis of the need for space by sows for lying down and getting up, Baxter and Schwaller (1983) developed a formula to estimate how much space is required for accommodating 95% of the sows in their study. They concluded that an IGA should measure at least 234 cm (92 in) × 81 cm (32 in). Curtis and colleagues (1989) used the same formula to estimate the need for dynamic space in sows of various sizes and concluded that a 300-kg (660-lb) sow, corresponding to the 95th percentile for body weight, requires an IGA that is 220 cm (86 in) long and 86 cm (34 in) wide to get up and lie down without touching IGA partitions or ends.

Petersen and Moustsen (2005) developed guidelines for dimensions of IGA based on their measures of Danish crossbred sows. They recommended that the width of an IGA should be 60 or 70 cm (24 or 28 in) to accommodate small and large sows, respectively, while stall length excluding the feeding trough should be 210 cm (83 in) regardless of sow size. In addition, they assumed that the space above the trough might be used by the sow for changing body posture (i.e., to accommodate the dynamic space requirement). Earlier Danish guidelines advocated a sow-zone dimension of 60 cm × 190 cm (24 in × 75 in) (Petersen and Moustsen 2005). The new recommendation for two sizes of IGAs accommodates sow body-size variation to a greater extent than previous schemes did.

The feeding place is another important part of an IGA. Ideally, it should accommodate the sow's eating behavior and consequent need for eating space. Taylor (1990) studied sows' eating movements and developed virtual space-envelope dimensions that would accommodate a sow's eating manner. He concluded that feed wastage and head injuries are decreased when the sow's needed head space while ingesting feed is not intruded on by feeder structure.

In a preference study of preferred eating height, Baxter (1991) concluded that swine prefer eating from a position at or slightly above floor level. In some commercial settings, however, the sow's feeding surface is located below floor level as a groove in the floor that forces the sow to kneel while eating. Sometimes, it is located several centimeters (a few inches) above the floor. In both cases, the limited space of an IGA together with the location of the trough below or above ground level might seriously hamper a sow's ability to ingest feed and water in an unimpeded, nonfrustrating way.

Good hygiene is fundamental for maintaining healthy sows; therefore, it is important that the manure be removed effectively from the rear of an IGA (see Manure Management Considerations section). Usually, a partly slotted concrete floor is used for this purpose, the slotted portion being located at the rear of the sow. Again, the sow's static body dimensions and dynamic space envelopes should serve as guidelines for designing the floor (Petherick 1983). Slot width should not exceed claw width and slots should run parallel with the IGA's main axis to decrease risk of injuries when a sow stands up (Baxter 1984).

Judging from comparisons of static body dimensions, dynamic space requirements, and data from scientific studies, not all commercially available IGAs meet the sow's need for space. Measures of body dimensions and space needs of gilts and sows should be compared with commercially available IGA designs and used for evaluating and improving existing designs for the benefit of sow state of being and performance. Moreover, evaluation of husbandry procedures associated with IGAs might be used for pinpointing design features that affect worker safety, e.g., topside cross-bars that might interfere with examination, insemination, sampling, and vaccination procedures.

System Design Considerations

The classical breed-to-weanling facility is based on separate *mating*, *control, gestation*, and *farrowing-lactation* units. In the mating unit, there is space for sows and gilts for one week. After mating, gilts and sows are moved to the control unit, where they stay for 4 weeks to support early embryonic development and implantation. (In group-pen keeping systems, this 4-week period in IGA is very important to support pregnancy by minimizing the stress of fighting that always occurs on the commingling of sows and often results in embryonic mortality and return to estrus [Einarsson, Madej, and Tsuma 1996].) Subsequently, animals that are confirmed pregnant are moved to the gestation unit, where they stay for 11 weeks before being moved to the farrowing-lactation unit.

The mating and control units are two of the most important parts of a sow farm. They must facilitate attainment of a high pregnancy rate, large number of piglets born, uniform and appropriate sow body condition, long sow productive life, and low return-to-estrus rate. In other words, the design of the mating and control units must complement the operation at the hands of the caretakers in obtaining high reproductive performance. The gestation unit is basically a parking place where sows should be kept as comfortable as possible to support the pregnancy. Thus, overall sow-facility design and operation should result in a sow's having a lifetime production of a large number of robust piglets.

Among design considerations, it must be decided first whether the mating and control units will be separate or combined. There are both advantages and disadvantages of having separate units. With a separate mating unit, it is easy for the staff to focus their work on mating procedures, which take place only in a limited part of the entire facility. Moreover, it is easy to include an "eros center," meant to let the boars prepare the sows sexually by locating several boar pens adjacent to places where open females reside until inseminated.

A separate mating unit is disadvantageous, however, in that sows must be moved an extra time compared with a combined mating and control unit wherein the sow stays in the same individual accommodation from weaning until being moved to the gestation unit (i.e., unless she returns to estrus). With larger sow herds and increasing labor cost, the tendency has been to design a combined mating and control unit to avoid the extra relocation of sows as well as logistical complications.

Recent studies have shown that stimulation of a sow actually may be improved if she is not continuously exposed to a boar (Knox et al. 2004). Thus, the boars are sometimes now being kept in a separate boar unit or in the gestation unit. They are introduced to the gilts and sows only the first couple of days after weaning and again on the day of insemination.

Regardless of whether the units are separate or combined, the design requires some preliminary idea of the number of sows per batch and the expected farrowing rate. The females that should be mated are composed of newly weaned sows, females that have returned to estrus, and replacement gilts. The number of female places can be estimated as shown in Table 1.

The design should allow for variation in farrowing rate. For example, designing a system for a farrowing rate of 90% is too optimistic. Most units should be designed for a farrowing rate of 85%, but in conditions with less possibility for environmental control or known health problems it might be wiser to design the mating and control unit for a farrowing rate of 80%.

Also, it is necessary to account for extra places for sows that are moved between units as a consequence of the reproductive cycle (i.e., moving of animals from farrowing unit to mating unit, from mating to gestation, and from gestation to farrowing-lactation). Because the farrowing-lactation unit must be cleaned and disinfected before receiving new sows, a

Table 1. Effect of farrowing rate on number of places in a combined mating and control unit for a sow herd with 1,000 sows, 44 sows per batch (including 22% gilts)

	Farrowing rate (%)		
	80	85	90
Gilts mated per week	12	11	11
Sows mated per week	43	41	38
Total mated per week	55	52	49
Buffer spaces per week (10%)	5	5	5
Total spaces per week	60	57	54
Total spaces – 5 weeks	300	285	270

"parking space" must be found for newly weaned sows until the farrowing unit is ready to accept late-term sows and thereby free upstream space.

The combined mating and control unit also must have space for replacement gilts. Gilts should be moved into the unit from the quarantine or gilt-pool unit at 23 to 25 weeks of age and grouped in pens according to age. If gilts are penned in small groups of 6 to 8, it is relatively easy to observe and record the date of first estrus and subsequently to move gilts to individual accommodations (together with the sows) when they are ready to be inseminated at the second or third estrus.

Future Directions

It is difficult to predict the future design and operation of pregnant sow accommodations. Until the past decade, cost of production was the primary driving force behind development of pork-production systems. Today, societal views are directly impacting commercial pork production systems in the EU and parts of the United States. Two science-based views may be expressed in the current situation. Many scientific evaluations have concluded that the state of being of the pregnant sow is equivalent whether sows are kept in IGAs or in group pens (AVMA 2005; Barnett et al. 2001; McGlone et al. 2004a). But, based on that conclusion, divergent strategies have emerged and are espoused by different sectors of the pluralistic society in the United States.

First, one might decide that, because sow welfare is equivalent in either IGAs or group pens, and because capital and operating costs are less with IGA systems, then IGAs should be scientifically refined to improve sow welfare in systems where sows are kept in IGAs.

Alternatively, because sow welfare is equivalent in either IGAs or group pens, and because certain consumer/activist views favor group pens, then group keeping systems should be scientifically refined to improve sow welfare in systems where sows are kept in groups.

One could logically adopt either view. Until that choice is settled on and accepted by a large majority of people in the United States, the nature of accommodations for pregnant sows will remain a public issue. As that choice is being made, however, it must be borne in mind that although the choice will range from relatively trivial to virtually nonexistent with respect to its overall effect on the pregnant sow's state of being, it will be of substantial consequence with respect to sow and piglet health, the cost of pork production, and the availability and price of pork products. In any case, the choice should be made with sound science being given due consideration. Moreover, once that decision has been reached, further scientific research and development should be applied to the dry-sow accommodation system that has been adopted.

Literature Cited

Altmann, J. 1974. Observational study of behavior: Sampling Methods. *Behaviour* 49(3):227–267.

American Veterinary Medical Association (AVMA). 2005. A comprehensive review of housing for pregnant sows. *J Am Vet Med Assoc* 222:1580–1590.

Anil, L., S. S. Anil, and J. Deen. 2002a.

Evaluation of the relationship between injuries and size of gestation stalls relative to size of sows. *J Am Vet Med Assoc* 221:834–836.

Anil, L., S. S. Anil, and J. Deen. 2002b. Relationship between postural behaviour and gestation stall dimensions in relation to sow size. *Appl Anim Behav Sci* 77:173–181.

Appleby, M. C. and A. B. Lawrence. 1987. Food restriction as a cause of stereotypic behaviour in tethered gilts. *Anim Prod* 43:103–110.

Arey, D. S. and S. A. Edwards. 1998. Factors influencing aggression between sows after mixing and the consequences for welfare and production. *Livest Prod Sci* 56:61–70.

Bäckström, L. 1973. Environment and animal health in piglet production. A field study of incidences and correlations. *Acta Vet Scand* (Suppl 41):200–240.

Backus, G. B. C., S. Bokma, T. A. Gommers, R. de Koning, P. F. M. M. Roelofs, and H. M. Vermeer. 1991. Farm systems with cubicles, tethered sows and group housing. *Res Inst Pig Husbandry* Report P1.61. Rosmalen, The Netherlands.

Backus, G. B. C., H. M. Vermeer, P. F. M. M. Roelofs, P. C. Vesseur, J. H. A. N. Adams, G. P. Binnendijk, J. J. J. Smeets, C. M. C. van der Peet-Schwering, and F. J. van der Wilt. 1997. Comparison of four housing systems for non-lactating sows. *Res Inst Pig Husbandry* Report P5.1 p. 4. Rosmalen, The Netherlands.

Baidoo, S. K. 2001. Sow nutrition for productivity and longevity: Any new ideas? *Proc Allen D. Leman Conf*, University of Minnesota. Pp.223–226.

Banks, E. M. 1982. Behavioral research to answer questions about animal welfare. *J Anim Sci* 54:434–446.

Barbari, M., U. Chiappini, and P. Rossi. 1993. Survey on the behaviour of pregnant sows housed in collective pen with straw bedding. Pp. 453–460. In E. Collins and C. Boon (eds.). *Livestock Environment IV: Fourth International Symposium*. University of Warwick, Coventry, England, July 6–9.

Barnett, J. L., P. H. Hemsworth, G. M. Cronin, E. C. Jongman, and G. D. Hutson. 2001. A review of the welfare of issues for sows and piglet in relation to housing. *Aust J Agri Res* 52:1–28.

Baxter, M. R. 1984. *Intensive Pig Production: Environmental Management and Design*. Granada Publishing, London.

Baxter, M. R. 1991. The design of the feeding environment for pigs. In E. S. Batterham (ed.). *Manipulating Pig Production III*. Proc. 3rd Biennial Conf Australasian Pig Sci Assoc (APSA), Nov. 24–27, Albury, New South Wales.

Baxter, M. R. and C. E. Schwaller. 1983. Space requirements for sows in confinement. Pp. 181–199. In S. H. Baxter, M. R. Baxter, and J. A. C. MacCormack (eds.). *Farm Animal Housing and Welfare*. Martinus Nijhoff, Boston.

Bergeron, R., H. W. Gonyou, and T. E. Eurell. 1996. Behavioral and physiological responses of Meishan, Yorkshire and crossbred gilts to conventional and turn-around gestation stalls. *Can J Anim Sci* 76:289–297.

Blackshaw, J. K. and J. F. McVeigh. 1984. Stereotype behaviour in sows and gilts housed in stalls, tethers and groups. Pp. 163–174. In M. W. Fox and L. D. Mickley (eds.). *Advances in Animal Welfare Science*. Martinus Nijhoff Publishers, Dordrecht, The Netherlands.

Bøe, K. E., I. L. Anderson, and A. L. Kristiansen. 1999. Feeding stall design and food type for group housed dry sows—Effect on aggression and access to food. *Proc 33rd Int Cong Int Soc Appl Ethol*, Lillehammer, Norway. P. 63.

Boyd, R. D. and R. S. Kensinger. 1998. Metabolic precursors for milk synthesis. Pp. 71–95. In M. W. A. Verstegen, P. J. Moughan, and J. W. Schrama (eds.). *The Lactating Sow*. Wageningen Press, Wageningen, The Netherlands.

Boyle, L. 1996. Skin lesions, overgrown hooves and culling reasons in individually housed sows. M.Agr.Sc. Thesis. University College, Dublin, Ireland.

Boyle, L. A., F. C. Leonard, P. B. Lynch, and P. Brophy. 2002. Effect of gestation housing on behaviour and skin lesions of sows in farrowing crates. *Appl Anim Behav Sci* 76:119–134.

Bracke, M. B. M., J. H. M. Metz, and B. M. Spruijt. 2001. Development of a decision support system to assess farm animal welfare. *Acta Agric Scand A, Anim Sci* 51(Suppl 30):17–20.

Broom, D. M. 1996. Animal welfare defined in terms of attempts to cope with the environment. *Acta Agric Scand A, Anim Sci* (Suppl 27):22–28.

Broom, D. M. and A. F. Fraser. 2007. *Domestic Animal Behaviour and Welfare*. 4th ed. CABI Publishing, Cambridge, Massachusetts. 438 pp.

Broom, D. M., M. T. Mendl, and A. J. Zanella. 1995. A comparison of the welfare of sows in different housing conditions. *Anim Sci* 61:369–385.

Brouns, F., F. McMenamy, and S. A. Edwards. 1992. Dominance hierarchies in sows and the consequence for liveweight gain in competitive and noncompetitive feeding systems. *Proc British Soc Anim Prod Winter Meeting*, Paper 145.

Brouns, F., S. A. Edwards, and P. R. English. 1995. Influence of fibrous feed ingredients on voluntary intake of dry sows. *Livestock Prod Sci* 54:301–313.

Cariolet, R., C. Vieuille, P. Morvan, F. Madec, M.-C. Meunier-Salaun, J. C. Vaudelet, V. Courboulay, and J. P. Signoret. 1997. Evaluation du bien-être chez la truie gestante bloqueé: relation entre le bien-être et la productivité numerique. (Welfare assessment in the pregnant sow kept in stalls and relationship with productivity). *J Rech Porcine Fr* 29:149–160.

Chiappini, U. and M. Barbari. 1989. Design of houses for pregnant sows using computerised feeding systems. In V. A. Dodd and P. M. Grace (eds.). *Proc 11th Int Cong Ag Eng (CIGR)*, Dublin, Ireland.

Choquenot, D. and W. A. Ruscoe. 2003. Landscape complementation and food limitation of large herbivores: Habitat-related constraints on the foraging efficiency of wild pigs. *J Anim Ecol* 72:14–26.

Close, W. and D. J. A. Cole. 2000. *Nutrition of Sows and Boars*. Nottingham University Press, Nottingham, United Kingdom. 377 pp.

Cronin, G. M., J. M. F. M. van Tartwijk, W. van der Hel, and M. W. A. Verstegen. 1986. The influence of degree of adaption to tether-housing by sows in relation to behaviour and energy metabolism. *Anim Prod* 42:257–268.

Curtis, S. E. 1982. Measurement of stress in animals. Pp. 1–10. In W. R. Woods (ed.). *Proc Symp Management Food-Producing Animals*, Purdue University, West Lafayette, Indiana.

Curtis, S. E. 2007a. Whys and wherefores in the evolution of sow keeping systems. *Proc Sow Housing Forum*, National Pork Board, Des Moines, Iowa.

Curtis, S. E. 2007b. Commentary: Performance indicates animal state of being: A Cinderella axiom? *Prof Anim Sci* 23:573–583.

Curtis, S. E. and L. Bäckström.1992. Housing and environmental influences on production. Pp. 884–900. In A. D. Leman, B. E. Straw, W. L. Mengeling, S. D. Allaire and D. J. Taylor (eds.).

Diseases of Swine, 7th ed. Iowa State University Press, Ames.
Curtis, S. E. and E. W. Johnson. 2005. Assessing sow state of being objectively: Genetic implications. *Proc 30th Joint Genetics Symp*, National Swine Improvement Federation and Canadian Centre for Swine Improvement, Ottawa, Ontario.
Curtis, S. E., S. A. Edwards, and H. W. Gonyou. 2001. Ethology and psychology. Pp. 41–78. In W. G. Pond and H. J. Mersmann (eds.). *Biology of the Domestic Pig*. Cornell University Press, Ithaca, New York.
Curtis, S. E., R. J. Hurst, H. W. Gonyou, A. H. Jensen, and A. J. Muehling. 1989. The physical space requirement of the sow. *J Anim Sci* 67:1242–1248.
Dailey, J. W. and J. J. McGlone. 1997a. Oral/nasal/facial and other behaviors of sows kept individually outdoors on pasture, soil or indoors in gestation crates. *Appl Anim Behav Sci* 52:25–43.
Dailey, J. W. and J. J. McGlone. 1997b. Pregnant gilt behavior in outdoor and indoor intensive pork production systems. *Appl Anim Behav Sci* 52:45–52.
Damm, B. I. 2008. Loose hosing of sows—Is this good welfare? *Acta Vet Scand* 50(Suppl 1):S9.
Dawkins, M. S. 1983. Battery hens name their price: Consumer demand theory and the measurement of 'ethological needs.' *Animal Behaviour* 31:1195–1205.
Dawkins, M. S. 2003. Behaviour as a tool in the assessment of animal welfare. *Zoology* 106:383–387.
Dawkins, M. S. 2004. Using behaviour to assess animal welfare. *Animal Welfare* 13 (Suppl):S3–57.
Dawkins, M. S. 2007. *Observing Animal Behavior: Design and Analysis of Quantitative Data*. Oxford University Press, New York. 168 pp.
Deen, J., L. Anil, and S. S. Anil. 2008. Lameness tops welfare concerns. http://enews.penton.com/enews/nationalhogfarmer/north_american_preview_0/2008_october_17 (1 February 2009)
de Leeuw, J. A. 2005. Stimulation of behavioural and nutritional satiety in sows. Ph.D. Thesis, Wageningen University, The Netherlands
de Leeuw, J. A. and E. D. Ekkel. 2004. Effects of feeding level and the presence of a foraging substrate on the behaviour and stress physiological response of individually housed gilts. *Appl Anim Behav Sci* 86:15–25.
den Hartog, L. A., G. B. C. Backus, and H. M. Vermeer. 1993. Evaluation of housing systems for sows. *J Anim Sci* 71:1339–1344.
Duncan, I. J. H. 1993. Welfare is to do with what animals feel. *J Ag Environ Ethics* 6 (Suppl 2):8–14.
Duncan, I. J. H. 1996. Animal welfare defined in terms of feelings. *Acta Agric Scand A, Anim Sci* (Suppl 27):29–35.
Duncan, I. J. H. 2001. Can we understand and use feelings of animals as a concept of animal welfare? *Food Chain 2001, Proc. European Union Conf*, Uppsala, Sweden. Pp. 131–134.
Duncan, I. J. H. 2002. Poultry welfare: Science or subjectivity? *Brit Poult Sci* 43:643–652.
Duncan, I. J. H. and M. S. Dawkins. 1983. The problem of assessing well-being and suffering in farm animals. Pp. 13–24. In D. Smidt (ed.). *Indicators Relevant to Farm Animal Welfare*. Martinus Nijhoff, The Hague, The Netherlands.
Duncan, I. J. H. and D. Fraser. 1997. Understanding animal welfare. In M.C. Appleby and B. O. Hughes (eds.). *Animal Welfare*. CAB International, Wallingford, United Kingdom.
Durrell, J. L. 2000. Sow behaviour, skin lesions and productivity in small static versus large dynamic groups. Ph.D. Thesis, Queens University, Belfast, Ireland.
Edwards, S. A. 1985. Group housing systems for dry sows. *Farm Build Prog* 80:19–22.
Edwards, S. A. 2003. Intake of nutrients from pasture by pigs. *Proc Nutr Soc* 62:257–265.
Edwards, S. A. and J. E. Riley. 1986. The application of the electronic identification and computerised feed dispensing system in dry sow housing. *Pig News Infor* 7:295–298.
Edwards, S. A., A. W. Armsby, and J. W. Large. 1988. Effects of feed station design on the behaviour of group housed sows using an electronic individual feeding system. *Livestock Prod Sci* 19:511–522.
Edwards, S. A., F. Brouns, and A. H. Stewart. 1993. Influence of feeding system on the welfare and production of group housed sows. Pp. 166–172. In E. Collins and C. Boon (eds.). *Livestock Environment IV: Proc 4th Int Symp*, ASAE, St. Joseph, Michigan.
Einarsson, S., A. Madej, and V. Tsuma. 1996. The influence of stress on early pregnancy in the pig. *Anim Reprod Sci* 42:165–172.
Einarsson, S., Y. Brandt, N. Lundheim, and A. Madej. 2008. Stress and its influence on reproduction in pigs: A review. *Acta Vet Scand* 50:48–55.
Estienne, M. J., A. F. Harper, and J. W. Knight. 2006. Reproductive traits in gilts housed individually or in groups during the first thirty days of gestation. *J Swine Health Prod* 14(5):241–246.
European Communities (EC). 2001a. Council Directive 2001/88/EC of 23 October 2001 amending Directive 1991/630 EEC laying down minimum standards for the protection of pigs. *Official J European Communities* 1.12.2001. L. 316:1–4.
European Communities (EC). 2001b. Council Directive 2001/93/EC of 9 November 2001 amending Directive 1991/630 EEC laying down minimum standards for the protection of pigs. *Official J European Communities* 1.12.2001 L316:36–38.
European Food Safety Authority (EFSA). 2007. Scientific report on animal health and welfare aspects of different housing and husbandry systems for adult breeding boars, pregnant, farrowing sows and unweaned piglets. *EFSA J* 572:2–107.
Girard, C. L., S. Robert, J. J. Matte, C. Farmer, and G. P. Martineau. 1995. Influence of high fibre diets given to gestating sows on serum concentrations of micronutrients. *Livestock Prod Sci* 43:15–26.
Gjein, H. and R. B. Larssen. 1995a. Housing of pregnant sows in loose and confined systems—a field study. 1. Vulva and body lesions, culling reasons and production results. *Acta Vet Scand* 36:185–200.
Gjein, H. and R. B. Larssen. 1995b. Housing of pregnant sows in loose and confined systems—a field study. 2. Claw lesions: morphology, prevalence, location and relation to age. *Acta Vet Scand* 36(4):433–442.
Gjein, H. and R. B. Larssen. 1995c. Housing of pregnant sows in loose and confined systems—a field study. 3. The impact of housing factors on claw lesions. *Acta Vet Scand* 36(4):443–450.
Gjein, H. and R. B. Larssen. 1995d. The effect of claw lesions and claw infections on lameness in loose housing of pregnant sows. *Acta Vet Scand* 36(4):451–459.
Gonyou, H. W. 1994. Why the study of animal behavior is associated with the animal welfare issue. *J Anim Sci* 72:2171–2177.

Gonyou, H. W. 2007. Indoor group housing. *Proc Sow Housing Forum*, National Pork Board, Des Moines, Iowa.

Gregory, N. G. 2005. *Physiology and Behaviour of Animal Suffering*. Blackwell Science, Oxford, United Kingdom.

Gregory, N. G. and C. D. Devine. 1999. Survey of sow accommodation systems used in New Zealand. *New Zealand J Ag Res* 42:187–194.

Grondalen, T. 1974. Leg weakness in pigs. *Acta Vet Scand* 15:555–573.

Hulbert, L. E. and J. J. McGlone. 2006. Evaluation of drop versus trickle-feeding systems for crated or group-penned gestating sows. *J Anim Sci* 84:1004–1014.

Jensen, P. 1982. An analysis of agonistic interaction patterns in group-housed dry sows aggression regulation through an "avoidance order." *Appl Anim Ethol* 9:47–61.

Jensen, K. H., B. K. Pedersen, L. J. Pedersen, and E. Jørgensen. 1995. Well-being in pregnant sows: Confinement versus group housing with electronic sow feeding. *Acta Ag Scand A, Anim Sci* 45:266–275.

Jensen, K. H., L. S. Sorensen, D. Bertelsen, A. R. Pedersen, E. Jorgensen, N. P. Nielsen, and K. S. Vestergaard. 2000. Management factors affecting activity and aggression in dynamic group housing systems with electronic sow feeding: A field trial. *Anim Sci* 71:535–545.

Johnson, A. K., J. L. Morrow-Tesch, and J. J.McGlone. 2001. Behavior and performance of lactating sows and piglets reared indoors or outdoors. *J Anim Sci* 79:2571–2579.

Johnson, R. W., S. E. Curtis, R. K. Balsbaugh, and I. A. Taylor. 1990. Sow behavior in a hinged free-pivoting sided gestation system. *J Anim Sci* 68 (Suppl 1):263–264.

Jones, G. F. 1998. Genetic aspects of domestication, common breeds and their origin. Pp. 17–50. In M. F. Rothschild and A. Ruvinsky (eds.). *The Genetics of the Pig*. CAB International, Wallingford, United Kingdom.

Jorgensen, B. and M. T. Sorensen. 1998. Different rearing intensities of gilts—II. Effect on subsequent leg weakness and longevity. *Livestock Prod Sci* 54:167–171.

Kirkden, R. D. and E. A. Pajor. 2006. Motivation for group housing in gestating sows. *Anim Welfare* 15:119–130.

Knox, R. V., S. M. Breen, K. L. Willenburg, S. Roth, G. M. Miller, K. M. Ruggiero, and S. L. Rodriguez-Zas. 2004. Effect of housing system and boar exposure on estrus expression in weaned sows. *J Anim Sci* 82:3088–3093.

Lambert, R. J., M. Ellis, and P. Rowlinson. 1985. The effects of feeding frequency on levels of aggression and 24-hour behaviour patterns of large groups of loose housed dry sows. *Anim Prod* 40:546 (abst).

Langhamer, B. 1991. Dump feeding of sows—an alternative way of managing a loose housing system. *NAC Pig Unit Newsletter* No. 40, p. 4–8.

Leus, K. and A. A. MacDonald. 1997. From babirusa (*Babyruosa babyrussa*) to domestic pig: The nutrition of swine. *Proc Nutr Soc* 56:1001–1012.

Levis, D. G. 2007. Gestation sow housing options. *Proc Sow Housing Forum*, National Pork Board, Des Moines, Iowa.

Lewis, A. J. and L. L. Southern (eds.). 2001. *Swine Nutrition*. 2nd ed. CRC Press, Boca Raton, Florida.

Love, R. J., C. Klupiec, E. J. Thornton, and G. Evans. 1995. An interaction between feeding rate and season affects fertility of sows. *Anim Reprod Sci* 39:275–284.

Lynch, P. B. 2000. Factors Affecting Voluntary Feed Intake of the Lactating Sow during the Lactating Period. Ph.D. Thesis, University College, Dublin, Ireland. 281 pp.

Marchant, J. N. and D. M. Broom. 1996. Effects of dry sow housing conditions on muscle weight and bone strength. *Anim Sci* 62:105–113.

Martineau, G. P. and G. Almond. 2008. Urinary tract infections in female pigs. CAB Reviews: Perspectives in Agriculture, Veterinary Science. *Nutr Natural Resources*, 3, 048:1–9.

Mason, G. J. 1993. Forms of stereotypic behavior. Pp. 11–18. In A. B. Lawrence and J. R. Rushen (eds.). *Stereotypic Animal Behaviour: Fundamentals and Applications to Welfare*. CAB International, Oxon, United Kingdom.

Mburu, J. N., S. Einarsson, H. Kindahl, A. Madej, and H. Rodriguez-Martinez. 1998. Effects of post-ovulatory food deprivation on oviductal sperm concentration, embryo development and hormonal profiles in the pig. *Anim Reprod Sci* 52:221–234.

McFarlane, J. M., K. E. Bøe, and S. E. Curtis. 1988. Turning and walking by gilts in modified gestation crates. *J Anim Sci* 66:326–333.

McGlone, J. J. 2006. Comparison of sow welfare in the Swedish deep-bedded system with the US crated-sow system. *J Amer Vet Med Assoc* 229:1377–1380.

McGlone, J. J. 2007. Hoop/outdoor group housing. *Proc Sow Housing Forum*, National Pork Board, Des Moines, Iowa.

McGlone, J. J. and W. G. Pond. 2003. *Pig Production*. Thomson Delmar Learning, Clifton Park, New York. 395 pp.

McGlone, J. J., E. H. von Borell, J. Dean, A. K. Johnson, D. G. Levis, M. Meunier-Salaun, J. Morrow, D. Reeves, J. L. Salak-Johnson, and P. L. Sundberg. 2004a. Review: Compilation of the scientific literature comparing housing systems for gestating sows and gilts using measures of physiology, behavior, performance, and health. *Prof Anim Sci* 20:105–117.

McGlone, J. J., B. Vines, A. C. Rudine, and P. DuBois. 2004b. The physical size of gestating sows. *J Anim Sci* 82:2421–2427.

Mendl, M. 1995. The social behaviour of non-lactating sows and its implications for managing sow aggression. *Pig Vet J* 34:9–20.

Meunier-Salaun, M. C., S. A. Edwards, and S. Robert. 2001. Effect of dietary fibre on the behaviour and health of the restricted fed sow. *Anim Feed Sci Technol* 90:53–69.

Miao, Z. H., P. C. Glatz, and Y. J. Ru. 2004. Review of production, husbandry and sustainability of free-range pig production systems. *Asian-Australasian J Anim Sci* 17(11):1615–1634.

Morris, J. R., J. F. Hurnik, R. M. Friendship, M. M. Buhrt, and 0. B. Allen. 1993. The behavior of gestating swine housed in the Hurnik-Morris System. *J Anim Sci* 71:3280–3284.

Moustsen, V. A., H. L. Poulsen, M. B. F. Nielsen. 2004. Dimensions of crossbred sows. Report 649. Danish Pig Producers, Copenhagen. 10 pp. (Krydsningssøers dimensioner – Danish).

Muirhead, M. R. 1976. Veterinary problems of intensive pig housing. *Vet Rec* 99:288–292.

Munsterhjelm, C., A. Valros, M. Heinonen, O. Halli, and O. A. T. Peltoniemi. 2008. Housing during early pregnancy affects fertility and behavior of sows. *Reprod Dom Anim* 43:584–591.

Mwanza, A. M., P. Englund, H. Kindahl, N. Lundeheim, and S. Einarsson. 2000a. Effects of post-ovulatory food deprivation on the hormonal profiles, activity of the oviduct and ova transport in

sows. *Anim Reprod Sci* 59:185–199.
Mwanza, A.M., A. Madej, H. Kindahl, N. Lundeheim, and S. Einarsson. 2000b. Postovulatory effect of repeated administration of ACTH on the contractile activity of the oviduct, ova transport and endocrine status of recently ovulated and unrestrained sows. *Theriogenology* 54:1305–1316.
Nielsen, N.-P. 2003. Everything old is new again—Sow housing. *Adv Pork Prod* 14:91–99. University of Alberta, Calgary, Alberta, Canada.
O'Grady, J. F., P. B. Lynch, and P. A. Kearney. 1985. Voluntary feed intake by lactating sows. *Livestock Prod Sci* 12:355–366.
Olsson, A. C. 1997. Liquid feeding for nonlactating group housed sows: Function and feed competition. Pp. 626–631. *Livestock Environment V—Vol 2*. American Society of Agricultural Engineers, St. Joseph, Michigan.
Olsson, A. C., J. Svendsen, M. Andersson, D. Rantzer, and P. Lenskens. 1992. Group housing of sows. 1. Electronic dry sow feeding on Swedish farms. An evaluation of the use of the system in practice. *Swedish J Ag Res* 22:153–162.
Pedersen, B. K. 1994. Dry sow housing after tethering. Pp. 42–49. *Teagasc Pig Conference*. Teagasc, Fermoy, Ireland.
Petersen, L. B. and V. A. Moustsen. 2005. Guidelines for gestation stalls for cross-bred sows. Report 0502, Danish Pig Producers, Copenhagen. 10 pp. (Vejledende anbefalinger til dimensioner på bokse til krydsningssøer i løbe-, kontrol- og drægtighedsafdeling – Danish.)
Petherick, J. C. 1983. A biological basis for the design of space in livestock housing. Pp. 103–120. In S. H. Baxter, M. R. Baxter, and J. A. D. MacCormack (eds.). *Farm Animal Housing and Welfare*. Martinous Nijhoff, Boston, Massachusetts.
PigCHAMP Benchmarking. 2008. Farms.com. http://www.farms.com/ (16 January 2009)
Pond, W. G. and H. J. Mersmann. 2001. General characteristics. Pp. 1–40. In W. G. Pond and H. J. Mersmann (eds.). *Biology of the Domestic Pig*. Cornell University Press, Ithaca, New York.
Pope, W. F. and N. L. First. 1985. Factors affecting the survival of pig embryos. *Theriogenol* 23:91–105.
Razdan, P., P. Tummaruk, H. Kindahl, H. Rodriguez-Martinez, F. Hulten, and S. Einarsson. 2004. Hormonal profiles and embryo survival of sows subjected to induced stress during days 13 and 14 of pregnancy. *Anim Reprod Sci* 81:295–312.
Ruvinsky, A. and M. F. Rothschild. 1998. Systematics and evolution of the pig. Pp. 1–16. In M. F. Rothschild and A. Ruvinsky (eds.). *The Genetics of the Pig*. CAB International, Wallingford, United Kingdom.
Salak-Johnson, J. L. 2007. The reality of sow stalls. *Proc Sow Housing Forum*, National Pork Board, Des Moines, Iowa.
Salak-Johnson, J. L., S. R. Niekamp, S. L. Rodriguez-Zas, M. Ellis, and S. E. Curtis. 2007. Space allowance for dry, pregnant sows in pens: Body condition, skin lesions, and performance. *J Anim Sci* 85:1758–1769.
Schley, L. and T. J. Roper. 2003. Diet of wild boar *Sus scrofa* in Western Europe, with particular reference to consumption of agricultural crops. *Mammal Rev* 33:43–56.
Schmidt, W. E., J. S. Stevenson, and D. L. Davis. 1985. Reproductive traits of sows penned individually or in groups until 35 days after breeding. *J Anim Sci* 60:755–759.
Schneider, J. D., M. D. Tokach, S. S. Dritz, J. L. Nelssen, J. M .DeRouchey, and R. D. Goodband. 2007. Effect of feeding schedule on body condition, aggressiveness and reproductive failure in group housed sows. *J Anim Sci* 85:3462–3469.
Scientific Veterinary Committee. 1997. The welfare of intensively kept pigs. European Commission, Brussels. 190 pp., http://ec.europa.eu/food/fs/sc/oldcomm4/out17_en.pdf (11 February 2009)
Stalder, K. J., A. K. Johnson, L. A. Karriker and J. McKean. 2007a. Gestation sow housing and its implications on health. *Proc Sow Housing Forum*, National Pork Board, Des Moines, Iowa
Stalder, K. J., R. F. Fitzgerald, A. K. Johnson, L. A. Karriker, and D. J. Meisinger. 2007b. A Summary of the 13th Discover Conference on Sow Productive Lifetime, http://www.nsif.com/Conferences/2007/pdf/SowProductiveLifetime.pdf (1 February 2009)
Stewart, C. L. 2008. Effects of dietary fibre and the provision of a foraging substrate on the welfare of sows in different grouping systems. Ph.D. Thesis. Queens University, Belfast, Ireland. 186 pp.
Stolba, A. and D. G. M. Wood-Gush. 1989. The behaviour of pigs in semi-natural environment. *Anim Prod* 48:419–425.
Svendsen, J., A. C. Olsson, and L. Svendsen. 1992. Group housing of sows. 3. The effect on health and reproduction. A literature review. *Swedish J Ag Res* 22:171–180.
Taylor, I. A. 1990. Design of the Sow Feeder: A Systems Approach. Ph. D. Thesis, University of Illinois, Urbana–Champaign.
Taylor, I. A., S. E Curtis, M. R. Bäckström, and J. L. Groppel. 1988. Design of feeders for swine: Kinematics, behavior, and individuality. Pp. 390–398. *Proc 6th Int Cong Anim Hygiene*, Skara, Sweden.
Tillon, J. P. and F. Madec. 1984. Diseases affecting confined sows. Data from epidemiological observations. *Annales de Recherches Veterinaires* 15:195–199.
Torrey, S., E. Pajor, S. Weaver, D. Kuhlers, and T. Stewart. 2001. Effect of genetic selection for loin eye area on belly nosing and plasma cortisol in weanling Landrace pigs. *J Anim Sci* 79 (Supp 1):14 (Abst.).
Tsuma, V.T., S. Einarsson, A. Madej, H. Kindahl, and N. Lundeheim. 1996a. Effect of food deprivation during early pregnancy on endocrine changes in primiparous sows. *Animal Reprod Sci* 41:267–278.
Tsuma, V.T., S. Einarsson, A. Madej, H. Kindahl, N. Lundeheim, and T. Rojkittikhun. 1996b. Endocrine changes during group housing of primiparous sows in early pregnancy. *Acta Vet Scand* 37:481–490.
Tuchscherer, M., E. Kanitz, W. Otten, and A. Tuchscherer. 2002. Effects of prenatal stress on cellular and humoral immune responses in neonatal pigs. *Vet Immunol Immunopathol* 86:195–203.
Turner, S. P., M. J. Farnworth, I. M. S. White, S. Brotherstone, M. Mendl, P. Knap, P. Penny, and A. B. Lawrence. 2006. The accumulation of skin lesions and their use as a predictor of individual aggressiveness in pigs. *Appl Anim Behav Sci* 96:245–259.
van Wettere, W. H. E. J., S. J. Pain, P. G. Stott, and P. E. Hughes. 2008. Mixing gilts in early pregnancy does not affect embryo survival. *Anim Reprod Sci* 104:382–388.
Verstegen, M. W. A. and S. E. Curtis. 1988. Energetics of sows and gilts in gestation crates in the cold. *J Anim Sci* 66:2865–2875.

Vieuille-Thomas, C., G. Lepate, and J. P. Signoret. 1995. Stereotypies in pregnant sows: Indications of influence of the housing system on the patterns expressed by the animals. *Appl Anim Behav Sci* 44:19–27.

von Borell, E. and J. F. Hurnik. 1991. Stereotypic behavior, adrenocortical function, and open field behavior of individually confined gestating sows. *Physiol Behav* 49:709–713.

Walker, N. and V. E. Beattie. 1994. Welfare of sows in loose housed systems. Pp. 21–28. *67th Annual Report*. Agricultural Research Institute, Northern Ireland.

Weber, R., K. Friedli, J. Troxler, and C. Winterling. 1993. The influence of computerised individual feeding system on the behavior of sows. Pp. 495–502. In E. Collins and C. Boon (eds.). *Livestock Environment IV. Proc 4th Int Symp*, ASAE, St. Joseph, Michigan.

Webster, A. J. F. 1970. Environmental and physiological interactions influencing resistance to infectious disease. In R. H. Dunlop and H. W. Moon (eds.). *Resistance to Infectious Disease*. Modern Press, Saskatoon, Saskatchewan, Canada.

Welander, J. 2000. Spatial and temporal dynamics of wild boar (*Sus scrofa*) rooting in a mosaic landscape. *J Zool* 252:263–271.

Wemelsfelder, F. 1993. The concept of animal boredom and its relationship to stereotyped behavior. Pp. 65–95. In A. B. Lawrence and J. R. Rushen (eds.) *Stereotypic Animal Behaviour: Fundamentals and Applications to Welfare*. CAB International, Wallingford, United Kingdom.

Weng, R. C., S. A. Edwards, and P. R. English. 1998. Behaviour, social interactions and lesion scores of group-housed sows in relation to floor space allowance. *Appl Anim Behav Sci* 59:307–316.

Whittemore, C. T. 2006. Optimisation of feed supply to growing pigs and breeding sows. Pp. 472–506. In I. Kyriakis and C. T. Whittemore (eds.). *Whittemore's Science and Practice of Pig Production*. Blackwell Publishing, Oxford, United Kingdom.

Zoiopoulos, P. E., P. R. English, and J. H. Topps. 1983. A note on intake and digestibility of a fibrous diet self-fed to primiparous sows. *Anim Prod* 37:153–156.

Zurbrigg, K. 2006. Sow shoulder lesions: Risk factors and treatment effects on an Ontario farm. *J Anim Sci* 84:2509–2514.

The mission of the Council for Agricultural Science and Technology (CAST) *is to assemble, interpret, and communicate credible science-based information regionally, nationally, and internationally to legislators, regulators, policymakers, the media, the private sector, and the public. CAST is a nonprofit organization composed of 36 scientific societies and many individual, student, company, nonprofit, and associate society members. CAST's Board of Directors is composed of representatives of the scientific societies and individual members, and an Executive Committee. CAST was established in 1972 as a result of a meeting sponsored in 1970 by the National Academy of Sciences, National Research Council.*

ISSN 1070-0021

Additional copies of this issue paper are available from CAST. Linda M. Chimenti, Director of Council Operations. World Wide Web: http://www.cast-science.org.

Citation: Council for Agricultural Science and Technology (CAST). 2009. *Scientific Assessment of the Welfare of Dry Sows Kept in Individual Accommodations.* Issue Paper 42. CAST, Ames, Iowa.

Council for Agricultural Science and Technology
4420 West Lincoln Way
Ames, Iowa 50014-3447, USA
(515) 292-2125, Fax: (515) 292-4512
E-mail: cast@cast-science.org

Nonprofit Organization
U.S. POSTAGE
PAID
Permit No. 18
Ames, Iowa