

**An evaluation of practices to improve sow productive lifetime
and producer profitability**

by

Robert Frank Fitzgerald

A dissertation submitted to the graduate faculty
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

Major: Animal Science

Program of Study Committee:
Kenneth Stalder, Major Professor
Anna Johnson
Locke Karriker
Philip Dixon
Max Rothschild

Iowa State University

Ames, Iowa

2009

Copyright © Robert Frank Fitzgerald, 2009. All rights reserved.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS	iv
ABSTRACT	vi
CHAPTER 1. GENERAL INTRODUCTION	1
<i>Dissertation organization</i>	2
CHAPTER 2. LITERATURE REVIEW	4
<i>Lameness in Sows</i>	4
<i>Methods to Evaluate Lameness in Sows</i>	8
<i>Body Condition Scoring in Sows</i>	13
CHAPTER 3. A REVIEW OF BEHAVIORAL FACTORS THAT AFFECT SOW PRODUCTIVE LIFETIME	15
<i>Abstract</i>	15
<i>Introduction</i>	16
<i>Sow Mortality versus Sow Productive Lifetime</i>	17
<i>Sow Productive Lifetime: Economics or Welfare?</i>	19
<i>Maintenance Behaviors</i>	20
<i>Social and Sexual Behaviors</i>	24
<i>Stereotypical Behaviors</i>	27
<i>Conclusions</i>	30
<i>Literature Cited</i>	31
CHAPTER 4. THE EFFECT OF HOOF ABNORMALITIES ON SOW BEHAVIOR AND PERFORMANCE	37
<i>Abstract</i>	37
<i>Introduction</i>	39
<i>Materials and Methods</i>	40
<i>Results</i>	50
<i>Discussion</i>	58
<i>List of Figures and Tables</i>	64
<i>Literature Cited</i>	77

CHAPTER 5. THE ACCURACY AND REPEATABILITY OF SOW BODY CONDITION SCORING	79
<i>Abstract</i>	79
<i>Introduction</i>	81
<i>Materials and Methods</i>	82
<i>Results and Discussion</i>	86
<i>List of Figures and Tables</i>	95
<i>Literature Cited</i>	101
CHAPTER 6. AN ECONOMIC ANALYSIS OF FEEDING CULL SOWS	103
<i>Abstract</i>	103
<i>Introduction</i>	104
<i>Materials and Methods</i>	105
<i>Results and Discussion</i>	109
<i>Implications</i>	115
<i>List of Figures and Tables</i>	116
<i>Acknowledgements</i>	127
<i>Literature Cited</i>	127
CHAPTER 7. GENERAL SUMMARY	129
CHAPTER 8. REFERENCES CITED	134

ACKNOWLEDGEMENTS

I would first like to thank my major professor, Ken Stalder, for his guidance, financial support, and wisdom. He has provided me every opportunity to succeed and the financial support to take risks with my project. Most of all, I thank him for his friendship, knowledge, and understanding of my Southern culture.

To my committee members Anna Johnson, Locke Karriker, Max Rothschild and Philip Dixon, I extend thanks for your input, time, and dedication to my education. The thought provoking questions and critique gave me a blueprint for which I can continue to pursue knowledge and learn in the future. I also want to thank Gordon Jones for his knowledge and friendship during my graduate education. To Colin Johnson, I appreciate you being a great friend and colleague.

I would also like to thank my office mates and fellow graduate students. A special thanks goes to Marja Nikkilae, Larry Sadler, Mark Knauer, Jeremy Burkett, Ashley Bushman, and many others that served as friends and colleagues. I mostly enjoyed our extensive discussion of cultures and college football and basketball programs.

I would like to thank Iowa State University and the Department of Animal Science for the dedication towards providing students a program where education and all faculty members within the Department of Agriculture for their friendship and a great education.

I wish to thank Iowa Select Farms, and specifically the employees of the two farms of which I conducted the trials. Their great help was instrumental in data collection as well as they were a great group of people to work with. Further, I thank Mike Murphy and Stacy Barrick for their willingness to allow me to conduct this research on their farms. Thank you

Heard Farms for allowing me to visit their farm with students on numerous occasions, and serving as a research farm for many projects.

I would also like to thank my parents, Frank and Susan, for their encouragement and sacrifices. At an early age, they instilled in me the knowledge of how to succeed and have always served as great role model. I only wish that every child has as great of parents that I have. Also, I thank my sisters, Katy, Laura, and Sarah, all of who have provided me numerous laughs and a great friendship.

Most of all, I graciously thank my wife, Kimberly, for her love, support, and encouragement during my education. You have sacrificed so many things of which I owe you greatly. You are my strong hold and my motivator, and I definitely would have not succeeded without your loving support and kindness.

ABSTRACT

Sow productive lifetime continues to challenge U.S. commercial swine herds and worldwide pork operations in general. The increased prevalence of hoof abnormalities (e.g. hoof and dew claw overgrowth, hoof wall cracks, and foot pad abrasions) in cull sow populations observed at harvest lend evidence to the hypothesis that these abnormalities are detrimental to sow performance. The objectives of this thesis were four-fold. The first objective was to summarize sow behaviors associated with increased sow welfare productive lifetime, specifically maintenance (feed and drink), social (aggression, sow-piglet interaction, and expression of sexual behaviors), and stereotypical behaviors. Results from this review suggest that detrimental behaviors were stereotypical behaviors such as bar biting, aggression between sows through lower feed intake, aggression toward caretakers, and piglet savaging and cannibalism.

The second objective of this study was to evaluate the effects of excessive toe growth, presence of cracks in the outer hoof wall, and the difference in length between the medial and lateral toe of the hoof on lactation performance and sow behavior in mid-lactation. This study concluded that sows with overgrown toes stand less than sows with normal hooves, and those findings are consistent with other studies. Sows were observed standing and eating between 3.3 and 9.1% of the observation period, and, of the variables collected, eating was the primary activity performed while standing. Post feeding, each OG lesion score increase was associated with a 40.0 % decrease in time spent standing and eating. This observation held true for total time spent standing and eating during the observation period [Odds Ratio (OR) = 0.45]. Results from this study demonstrate that foot lesions can impair productivity and

behavior of lactating sows. The degree to which foot lesions impair production and behavior is dependent on lesion type and severity.

The third objective of this study was to estimate observer accuracy and repeatability of body condition scoring sows when scorers have different levels of prior experience. Participants body condition scores were positively associated with body condition scores (BCS) derived by backfat measurements. Averaging over all participants, the ultrasonic trait of last rib backfat yielded the greatest correlation (0.58) with BCS using a 9-pt scale, followed by tenth rib backfat (0.51), tenth rib loin eye area (0.47), and last rib loin eye area (0.43). Similar trends were observed for the BCS₅ scale. Therefore, practice assigning independent BCS should lower repeatability variance, but training to calibrate specific participants may only influence total test variance to a relatively small degree.

The final objective of this study was to estimate the amount of feed and associated costs of adding body weight to cull sows, in an evaluation to improve producer profitability. Adding BW to cull sows could be profitable in the presence of \$0.11 / kg feed prices and labor and housing costs of \$0.25 / d per sow.

CHAPTER 1. GENERAL INTRODUCTION

Sow productive lifetime continues to challenge U.S. commercial swine herds and worldwide pork operations in general. The increased prevalence of hoof abnormalities (e.g. hoof and dew claw overgrowth, hoof wall cracks, and foot pad abrasions) in cull sow populations observed at harvest lend evidence to the hypothesis that these abnormalities are detrimental to sow performance. U.S. pork producers have expressed the need for research identifying hoof abnormalities and plausible causal factors as well as measuring the correlated response in performance of sows exhibiting these abnormalities.

Numerous researchers have reported that lameness is a major factor when culling sows from the breeding herd (Knauer et al., 2006; Stienezen, 1996). Engblom et al. (2007) observed that 8.6 % of sows in Swedish commercial herds were culled due to lameness or foot lesions or both. Ritter et al. (1999) reported that 59 % of 1,747 sows studied had either front or rear hoof lesions. Studies have shown that lameness may significantly contribute to less time spent eating (Leonard et al., 1997), and hence, poor lactation performance and lower reproductive rates. However, these studies did not quantify the performance response associated with varying degrees of hoof lesions.

The first objective was to summarize sow behaviors associated with increased sow welfare productive lifetime, specifically maintenance (feed and drink), social (aggression, sow-piglet interaction, and expression of sexual behaviors), and stereotypical behaviors. Sow behaviors in different feeding programs and housing types and the effects of stereotypical behavior on sow health will also be examined.

The second objective of this study was to evaluate the effects of excessive toe growth, presence of cracks in the outer hoof wall, and the difference in length between the medial and lateral toe of the hoof on 1) lactation performance and 2) sow behavior in mid-lactation.

The third objective of this study was to estimate observer accuracy and repeatability of body condition scoring sows when scorers have different levels of prior experience. Students with no, some, and extensive prior experience evaluating body condition in sows and they twice evaluated body condition on 125 sows. Individual biases were calculated as well as other factors that might have influenced their bias when evaluating body condition in sows.

Because annual replacement rates have reached nearly 50 % over the past years (PigCHAMP, 2007), there is an abundant supply of cull sows. Therefore, the final objective of this study was to estimate the amount of feed and associated costs of adding body weight to cull sows, in an evaluation to improve producer profitability. Body weight, backfat, loin eye area, heart and jowl girth, and flank-to-flank measurements were recorded for 29 cull sows approximately every 14 d for a total of 96 d. Feed disappearance and BW gain for each interval was used to calculate performance traits, total revenue, total costs, and net margin.

Dissertation Organization

A general introduction (Chapter 1) describes the need for the research projects in this thesis. After the literature review in Chapter 2, a series of 4 journal articles were drafted to meet the objectives of this thesis. Chapter 3 discusses behaviors that are associated with sow productive lifetime. The effects of sow hoof lesions on behavior and lactation performance are evaluated in Chapter 4. To improve sow welfare productive lifetime, a study evaluating repeatability and accuracy of body condition scoring is discussed in Chapter 5. Finally to

improve producer profitability, Chapter 6 evaluated the profitability of adding body weight to cull sows. Each journal article is formatted to the style of the *Journal of Animal Science*.

CHAPTER 2. LITERATURE REVIEW

This literature review describes lameness in sows, methods to identify lameness using objective and subjective scoring methods, and hoof lesion prevalence in modern sow operations. The second section describes body condition scoring in sows. The literature review is continued in Chapter 3 with a review article discussing behaviors that affect sow productive lifetime.

Lameness in Sows

Lameness in swine, chickens, horses, and cattle has a large negative economic impact to livestock producers (Corr et al., 2003). A recent evaluation of over 3,000 cull sows by Knauer (2006) reported that 85 % of sows evaluated at harvest have at least one lesion impacting at least one foot. This study reported that front and rear cracked hooves were observed in 22.6 % and 21.1 % of the cull sows evaluated, respectively. These observations are concurrent with those reported by Ritter et al., (1999) who found 59 % of 1,747 sows had either front or rear foot lesions. While both trials used different hoof scoring methods, the main argument that hoof lesions are widespread among breeding sows is clear.

Stalder et al. (2004) noted that lameness is a common reason why sows leave the breeding herd. The abnormal locomotion of pigs have been described as having a shorten stride length, stiff movements, and lowered ability to accelerate and change direction (Main et al., 2000). Lameness is defined by Merriam-Webster (2008) as “having a body part and especially a limb so disabled as to impair freedom of movement” or as “impaired movement or deviation from normal gait” (Wells, 1984). Locomotor disorders can be associated with

neurological disorders, lesions of the hoof or limb, or a mechanical-structural problem, trauma, or metabolic and infectious disease (Smith, 1988; Wells, 1984).

Boyle (1996) observed hooves and dew claws on 3,645 sows on 25 commercial farms. The prevalence of sows that had mildly and severely overgrown rear hooves ranged from 0 to 26 % and 0 to 6.6 %, respectively. Boyle (1996) further noted that mild overgrowth is not of great concern, but those hooves have potential to become severely overgrown with age. That study also found that overgrowth was more prevalent in lateral hooves (outer) as compared to medial (inner) hooves. That observation is supported by Kornegay et al. (1990) who observed lateral hooves grow faster than medial hooves after 150 days of age.

Norwegian researchers Gjein and Larssen (1995a) performed an elegant observational study characterizing hoof and claw abnormalities in a total of 36 loose and confinement housing systems and reported the prevalence of hoof lesions in those housing systems. From their reports, sows were found to have significantly more side wall cracks and heel lesions and trended towards more overgrown heels in the loose housing system compared to confinement housing systems. The third least prevalent abnormality, overgrown heels, resulted in 25 % of the sows at necropsy in confinement housing compared to 45 % in loose housing, whereas the most common abnormalities, heel lesions and side wall cracks, were present in 51 to 80 % of the sows post mortem.

In modern swine management systems, gilts and sows are primarily housed on partially or fully slatted concrete floors. Both types of flooring provide little if any cushion for the sows' feet and legs. Concrete is known to have an abrasive surface, that when wet can become slippery underfoot. This can result in reduced traction and an increase in swollen tendons, and leg and hoof abnormalities (MAFF, 1981). Gjein and Larssen (1995b) analyzed

the impact of pen and stall housing on claw lesions. Three different flooring materials were evaluated, plastic and concrete slats and deep litter bedding. Both slatted flooring materials produced similar percentages of claw lesions on rear legs, 68 % for sows on concrete and 69 % for sows housed on plastic slats. Furthermore, partially slatted pen housing systems yielded significantly more ($P < 0.05$) major claw lesions, as described by greater than superficial cracks or lesions in the epidermis compared to their stall-housed sow counterparts, housed either on partially slatted or solid concrete flooring. However, straw bedding in pen housing systems reduced the prevalence of major claw lesions compared to both pen- and stall-housed sows.

Knauer (2006) found that an increase in body condition scores was associated with increased hoof lesions, and explained this observation as sows increased body weight, the pressure applied to the ground increased and damage may result. Therefore, the wide prevalence of claw lesions in sow populations irrespective of housing or flooring systems is alarming and must be evaluated more thoroughly to improve longevity of gilts and sows. Limited work has been conducted on gilts and sows in regards to how hoof and leg health may impact her performance through gestation, lactation and her overall longevity. Stienezen et al. (1996) looked at 24 mixed parity sows (average parity was 4.7) prior to farrowing and then through lactation on behavioral impacts and changes when sows have over grown hooves. The authors reported no behavioral (percentage standing, dog-sitting or lying) differences ($P < 0.05$) in the 6 hours leading up to the first piglet being born. Some differences were seen when observing the sows immediately before, during, and after their morning feed. Phenotypically normal (control) sows spent more ($P = 0.02$) time feeding (14.5 vs. 8.2 min) and more ($P = 0.009$) time standing (11.4 vs. 4.2 min respectively) than

their over grown hoof counterparts. There were also some differences in the number of slips of the rear legs between control (0.11) and overgrown claws (0.51; $P = 0.05$), and in addition control sows also had fewer number of rising attempts (1.33 vs. 2.33; $P = 0.02$) than their control counterparts. Also, sows with overgrown hooves tended to produce smaller litters at birth compared to the control sows (10.5 vs. 12 pigs born alive, respectively); however, skin lesions trended towards improving during lactation for OG sows. Further, in that study, they found a large range in behaviors with very high individual variation. Stienezen et al. suggested that lack of exercise was the major contributory factor to the development of overgrown hooves, which is also supported by Vaughan (1969).

Hoof overgrowth has also been shown to alter normal sow behaviors. A study by Leonard et al. (1997) found that time spent feeding and standing decreased and weight shifts and slipping increased in sows with overgrown rear claws. These results indicate that sows with overgrown rear claws exhibited discomfort and thus decreased the amount of time weight was distributed on the limb. Bonde et al. (2004) visited six sow herds and assessed hoof length and leg disorders and how this impacted lying down behavior. Sows were observed during spontaneous lying down maneuvers within 30 min after a clinical examination. Recordings were conducted on 555 of the 570 sows. The authors noted that 41 % of the sows showed difficulties in lying down in a gestation stall. Parity also seemed to affect slipping behavior. Sows in their 4th and 5th parity were less likely to slip when lying down compared to younger or older sows.

Penny et al. (1963) performed post-mortem examinations on 31 pigs and measured medial and lateral claw length. They observed a lateral to medial ratio of 1.11:1 for length and 1.13:1 ratio for width. They also noticed a difference in shape, as the lateral claw tended

to be rounded and the medial pointed. Further, they observed that most lesions were localized to the lateral claw of the hind feet. They also observed variation in hoof cracks ranging from shallow, discolored indentations to, as described by Penny “a deep fissure, with marked enlargement and deformity of the claw.”

Nutrient Deficiencies

The formation of hoof horn tissue is a complex biochemical process that involves many nutrients. After epidermal cell differentiation and the production of keratin proteins, cells undergo cornification that, ultimately, provides the integrity of the hoof horn (Tomlinson et al., 2004). As early as the 1940s, researchers have noted the importance of specific nutrients on hoof health, specifically a water soluble vitamin called biotin (Hegsted et al., 1942; Hegsted et al., 1940). Cunha et al. (1946) found that pigs fed a ration with 30 % desiccated egg white, a feedstuff found to bind biotin and make unavailable for utilization, induced biotin deficiency resulting in spasticity of the rear legs and cracks in the feet. Similar results reported by Brooks et al. (1977) found that foot lesions were reduced by 28% in sows supplemented with biotin compared to sows that demonstrated a biotin deficiency. Deficiencies in biotin have also been shown to weaken hoof walls, thereby increasing the risk to injury when in contact with hard surfaces (Bane et al., 1980).

Methods to Evaluate Lameness in Sows

Much like body condition scoring, lameness scoring systems have been widely adopted and are designed to categorize the degree of lameness typically expressed during locomotion. Lameness scoring systems have been developed for dairy cows (Manson and Leaver, 1988), beef cows, dogs, sheep (Welsh et al., 1993), horses, broilers (Kestin et al.,

1992), and swine. These scoring systems have been implemented so that producers can quickly and affordably quantify the prevalence of lameness, body condition, or other traits in the herd on any particular day. In a review of lameness scoring systems in dairy cattle, Whay (2002) explained that a scoring system provides a tool for the assessment of lameness on a herd and individual animal level. Assigning a lameness score to all animals throughout the herd provides the manager knowledge regarding those animals that should be treated and the overall herd prevalence of lameness (Whay, 2002). Repeat scoring of a herd can further lend evidence to the effectiveness of lameness treatment or prevention (Main et al., 2000).

Two subjective scoring systems, the numerical rating scale and visual analogue scale, have been applied to characterizing lameness in animals. A common system utilized in lameness characterization utilizes the numerical rating scale with approximately 4 to 6 ordinal categories. Alternatively, visual analogue scales are scored by the observer assigning a lameness score by placing a mark on a 100 mm line between two endpoints of normal and 'could not be more lame'. Visual analogue scales can be modeled as a continuous variable (Quinn et al., 2007). Comparisons between these systems have been performed in dogs and are discussed in the following paragraph.

In a comprehensive review titled "Gait assessment in dairy cattle", Flowers and Weary (2008) reported two ways to validate subjective lameness scoring systems. They suggest validating these systems by assessing gait on animals with and without (1) known hoof or leg lesions or (2) a treatment designed to reduce lesions. For subjective scoring systems to be repeatable and accurate, they suggest to explicitly describe each score by removing vague wording such as 'sound, mild, moderate, and severe'. They further report

that a sufficient level of reliability is achieved after the observers train on approximately 200 to 300 cows.

Lameness scoring in pigs

A study by Quinn et al. (2007) compared the accuracy of a numerical rating and a visual analogue scale to gait measured by a force plate system. Three observers independently assigned 21 dogs lameness scores at 0, 4, and 8 weeks after an operation and results were compared to peak vertical force and vertical impulse forces derived from the gait analysis. Results from this analysis showed that vertical impulse force was significantly related to the visual analogue score for all three observers; whereas it was only significantly related to the numerical rating scale for one observer. Both scoring systems were not related to peak vertical forces and both failed to accurately assess lameness in the middle of the scale. They proposed that the force applied by a particular limb is hard to detect by observers and may not be completely noticeable unless the animals is at either end of the spectrum. However, they suggested that the visual analogue scale may be more sensitive (term used to describe animals that are truly positive divided by the total number of animals classified as positive) as compared to the numerical scale.

Quinn et al. (2007) also reported that a linear relationship between the visual analogue and numerical score was found for only one observer. They reported that magnitudes of lameness scores differed between observers and were often not in agreement, and that the numerical rating scale and visual analogue scale are not interchangeable.

Main et al. (2000) observed gait and posture behavior of grow-finish pigs in the pen and movement to and from the walkway and, from this observation, developed a 6-pt lameness scoring system that incorporated not only gait but also behavioral responses to

other pigs and human presence. In that same study, they evaluated the agreement between two experienced observers when assigning lameness scores to 201 finishing pigs. The experienced observers were found to have a 94 % agreement between assigned scores. A subsequent study of 7 veterinary students not familiar with the scoring system found that 4 students assigned the same proportion of scores as experienced observers using only 19 pigs but yielded a poor agreement statistic that tested specificity and sensitivity. Of the 6 scores, no pigs were scored in the two lameness scores associated with the highest degree of lameness.

Lameness scoring in dairy cows

In a study of 53 dairy farms located in the UK, Whay et al. (2002) surveyed each farmer to quantify the total number of lame cows (cows being treated, mildly lame, etc.) present on the farm on a particular day. On that same day, an independent, trained observer scored each cow using a 4-pt (0 to 3) scoring system while the cows left the milking parlor. The overall prevalence of lameness in the herd [those cows scored as 2 (lame) or 3 (severely lame)] was underestimated on average of 16.4 % by 51 of the 53 farmers when compared to the independent observer. Whay et al. (2002) proposed that the under estimation of the severity of lameness may be attributable to a number of factors such as a lack of caretaker knowledge, insensitivity to the severity of lameness due to constant exposure, or possibly just reluctance by the farmer to admit the true prevalence of lameness on the farm. Further, Whay et al. proposes that lameness severity may be underestimated in dairy cows experiencing bilateral lameness due to the cows not favoring one particular limb. A study by Mill et al. (1994) found similar results with 9 of 15 English dairy farmers underestimating herd lameness levels. Research of farms located in the Midwestern US show a similar trend as the

researchers estimated herd lameness levels at 2.5 times greater than the manager levels (Wells et al., 1993). Regardless of the reason for the discrepancy between the trained lameness examiner and the farmer, the probability that the farmer will treat individual lameness cases or on the herd level is reduced if the farmer has lower perception of the severity of lameness in the herd.

Use of objective lameness detection methods: Force Plate Analysis

An animal will distribute less weight upon the limb that is painful or structurally unsound (Corr et al., 2003). Both Jevens et al. (1996) and Budsberg et al. (1988) found maximum or peak vertical force (PVF) as an excellent gauge of lameness. Ground reaction forces (GRFs) are produced by the interaction between mass and the ground exhibiting equal and opposite forces during animal locomotion (Clayton, 2005) and have been shown to change as lameness progresses. Objectively measuring variation in vertical forces produced by animals will potentially allow scientists to identify lame individuals before clinical signs. Both Jevens et al. (1996) and Budsberg et al. (1988) found maximum or peak vertical force (PVF) as an excellent gauge of lameness. Lameness is also associated with a larger vertical impulse values [force applied over time; (Clayton, 2005; McLaughlin Jr. et al., 1991)] as well as asymmetries of vertical GRFs between the left-right limbs.

Evans et al. (2005) suggested the use of a multivariate analysis with both peak vertical force and falling slope (FS; the rate at which weight is removed from the limb) as variables to most accurately estimate lameness in Labrador dogs. Both lame and normal dogs were found to have large PVF, yet differed in FS. As a normal PVF threshold was reached, lame dogs experiencing pain tended to unload the limb quicker, thus yielding a large negative FS value. These results were found in dogs with unilateral cranial cruciate ligament ruptures.

Evans et al. (2005) further suggests that different results could be found in animals containing bilateral lameness. Moreover, they found GRFs to be superior compared to visual observation when classifying gait abnormalities in dogs.

Body condition scoring in sows

Sows can enter a negative energy balance during lactation when fat and muscle body reserves are mobilized to produce milk production for piglet growth. After weaning, a limited number of days are available during gestation to replenish the sows' depleted energy stores. In modern pork production systems, sow non-productive days is a key indicator of inefficiency, and thus minimized. Dourmad et al. (1996) suggests that the gestation period is the only period where body energy can be replenished in current production systems. Additionally, they report that modern sows require 8,500 kcal DE/d during gestation, about 1.3 times the maintenance requirement, to replenish body reserves. Sows that have not attained mature size have nutrient requirements to support growth and these requirements must be met through rations provided during lactation and gestation. One possible way to improve reproductive performance after lactation is to reduce the amount of body weight lost during lactation. Johnston et al. (2003) reported that sows fed dried porcine soluble at 1.5% in addition to the corn-soybean base diet increased feed intake during lactation. Accurate sow body condition estimates are essential so that pork producers can provide sows with an appropriate amount of feed needed to replenish body reserves prior to the next lactation. Thus, it is important for swine producers to have the skills necessary for accurate and repeatable quantifying of condition scores so that feed rations can be adjusted accordingly.

Maes et al. (2004) evaluated the relationships between P2 backfat thickness (last rib) and reproduction and lactation performance. They reported a negative association between changes in last rib backfat thickness and piglets weaned per sow. The correlation coefficient between body condition scores and P2 backfat thickness was 0.48, and varied between 3 herds, parity, and the stage of production. The highest correlation was calculated during d 80 of gestation (0.52), compared to at farrowing and weaning. They further suggest that muscling could possibly impact visual scoring of body condition, and the accuracy of evaluating body condition varies with the skill level of the observer.

Young et al. (2001) suggested that body condition scores differ between producers or technicians and, based on results by Thomsen et al. (2008) evaluating lameness scoring, within producers' or technicians' own scores. They reported a positive, but low relationship ($r^2 = 0.19$) of body condition scores assigned by a farm manager and last rib backfat in 1306 sows using A-mode ultrasound. The low relationship in that study could partly be explained by the use of A-mode ultrasound. These devices frequently have difficulty estimating the third backfat layer in fat sows.

Relating to commercial sow production, employees may verbally express their ability to evaluate body condition to their employer, but in reality this discrepancy may yield larger variations in sow body condition in the herd. In a similar study that evaluated the effect of training on intra- and interobserver agreement during lameness evaluation scoring (using a 5-point scale), Thomsen and coworkers (2008) found that while training slightly decreased intraobserver agreement, training slightly improved interobserver agreement.

CHAPTER 3. A REVIEW OF BEHAVIORAL FACTORS THAT AFFECT SOW PRODUCTIVE LIFETIME

A paper to be submitted to the *Applied Animal Behavior Science* journal.

R. F. Fitzgerald,* A. K. Johnson,^{*1} M. V. Boggess,[†] L. A. Karriker[‡], and K. J. Stalder*

*Department of Animal Science, Iowa State University, Ames, Iowa, 50011, USA

[†]National Pork Board, Clive, Iowa, 50325, USA

[‡]Veterinary Diagnostic and Production Animal Medicine, Iowa State University, Ames, Iowa, 50011, USA

ABSTRACT

Poor sow productive lifetime (SPL) continues to challenge U.S. commercial swine herds. Two distinct categories can be identified that result in a sow being culled from the herd. The first is sow economical productive lifetime (SEPL) decisions; the second is sow welfare productive lifetime (SWPL) decisions. Although this paper will focus on SWPL, an example is provided which compares the difference between SEPL and SWPL. A sow that is healthy and has good welfare but who cannot provide an economical return on investment

¹ Correspondence: 2356G Kildee Hall, Ames, IA, 50011-3150, johnsona@iastate.edu, phone: (515) 294-2098, fax: (515) 294-4471.

through pigs per sow per year will be culled by a producer using an SEPL decision. In regards to SWPL, few studies have comprehensively addressed producer decisions for culling over multiple parities and across different gestation systems. Limited research using different genetic lines has focused on SWPL factors that may result in culling, for example detrimental behaviors, overall sow health, feet and leg problems, injury levels and locomotion disorders. To complicate the categories further, some SWPL factors may result in the final culling decision to be classified under SEPL. An example could be extensive postural adjustments or abnormal lying-down behavior in the farrowing phase that results in unacceptable preweaning mortality. The sow may be healthy with great structural soundness, but her poor prolificacy after two successive parities will decrease her overall return on investment and she may be culled through SEPL decisions. Some research has focused on SWPL factors which may result in culling, for example detrimental behaviors (i.e. enhanced aggression or cannibalistic behavior), overall sow health, feet and leg problems, injury levels and locomotion disorders. This review will discuss behavior effects on sow productive lifetime, specifically maintenance (feed and drink), social (aggression, sow-piglet interaction, and expression of sexual behaviors), and stereotypical behaviors.

Keywords: Behavior, Industry, Sow Productive Lifetime, Sow, Welfare

INTRODUCTION

Poor sow productive lifetime (SPL) has become a critical area of concern across the entire U.S. pork production chain. The average length of time a sow stays within a herd has been decreasing over the past decade, with annual culling rates approaching 50 % of the sows in the herd (PigCHAMP, 2007). Such relatively high removal rates not only have

implications on the sows' welfare but it may also detrimentally impact employee morale and create a significant economical problem for pork producers (Stalder et al., 2004).

To compound this challenge, negative publicity associated with sow mortality and productive lifetime rates have and will continue to create potential public relation concern for the U.S. swine industry. Campaigns by animal rights activists (COK, 2005; PETA, 2005) and humane groups (AWI, 2005; HFAC, 2005; HSUS, 2005) along with an increasing push for on farm third party audits by customer associations (FMI, 2005; NCCR, 2005) may create further awareness of this issue throughout the pork production chain, from farm to fork.

A review of factors that affect sow longevity was performed by Stalder et al. (2004). They focused exhaustively on nutritive, genetic, reproductive, and overall production effects and briefly on behavioral effects that improve SPL. Therefore, this review will focus on two areas: 1) the differences between sow mortality and productive lifetime, and 2) the definitions for categories of sow economical productive lifetime (SEPL) and sow welfare productive lifetime (SWPL) focusing specifically on behaviors that may affect her productive lifetime within the breeding herd.

Sow Mortality versus Sow Productive lifetime

Sow mortality

It is important to determine a clear distinction between sow mortality and sow productive lifetime. Sow mortality results in the sow being removed from the herd because of death. Numerous authors have focused on mortality rates pertaining to the sow herd. Studies prior to 2000 have mortality estimates ranging from 3.3 to 6.4 % (Abiven et al., 1998; Dagorn, 1996; Christensen et al., 1995; Chagnon et al., 1991; Madec, 1984). A study of 105

Japanese herds found sow mortality at 3.9 % (Sasaki and Koketsu, 2008). In the U.S., available statistics indicate that 6.6 % of gilts and sows die within the herd on an annual basis (NAHMS, 2000). The most recent estimate of breeding-age female mortality in the U.S. was 4.7 % for 6 mo. (NAHMS, 2008), extrapolating to 9.4 % annually. In a case-control study of 102 swine herds located in western France, Abiven et al. (1998) identified risk factors associated with high levels of annual sow mortality rate (HM), using sow days as a denominator. A higher risk of mortality was observed for multiplying herds (75% of sows at risk of dying) as compared to commercial farrow-to-finish herds (43.8%). Herds of HM status trended ($P < 0.10$) towards a higher association with urinary tract infections, metritis, or lameness prevalence.

Sow Productive Lifetime

Sow productive lifetime refers to the ability of the sow to remain productive in the breeding herd for a period of time before being removed, culled, euthanized, or dies. Culling can be classified into two categories, voluntary or involuntary culling. Voluntary culling is a term describing the situation where the owner or manager of a swine operation has the opportunity to make a conscious choice to retain or cull a breeding herd female. Such decisions may be based on a lack of productivity over multiple parities or perhaps through the result of the sow displaying an undesirable behavior i.e. aggression towards the caretaker. Involuntary culling occurs when a producer does not make or have a choice to cull a sow if the operation is to maintain production at a pre-determined level, as would be the case when a sow fails to cycle, conceive, or becomes severely lame. In the USDA National Animal Health Monitoring Systems report (2006), reasons for sow removal from the herd include age (41.9 %), reproductive failure (21.3 %), lameness (16.0 %), performance (12.0 %) in terms of

small litter size, high pre-weaning mortality, and low birth weight, and other reasons (8.8 %) such as upgrading genetics, poor body condition, or liquidation of the herd. In the NAHMS 2006 report, the ranking of the largest single reasons sows are removed from the herd changed from age to reproductive failure (36.9 %), followed by performance (23.7 %), lameness (11.2 %), old age (11.1 %), and injury (4.9 %). Other reasons increased slightly to 12.2 %.

Sow productive lifetime is a multi-factorial umbrella that encompasses many risk factors that ultimately determine how long sows remain in the breeding herd. Several areas which contribute to a sow having a long and productive lifetime have been identified by the swine industry. These areas include gilt development, swine nutrition and health, genetics, caretaker skills, facilitates, and many others. Under each of these broad umbrella terms, multiple sub-categories can be identified. Taking swine nutrition as an example, sub-categories that may directly or indirectly affect productive lifetime are water quantity and flow rates, feeding systems (e.g. electronic sow feeders, group trickle feeding, and trough or floor feeding), feeding regime and timing, nutrient quality and composition (e.g. feedstuffs, particle size, and fineness of grind), form of diet (liquid, meal or pellet), and prevalence of toxins or molds or both.

Sow Productive Lifetime: Economics or Welfare?

The umbrella terms presented earlier in this paper can be associated to either Sow Economical Productive Lifetime (SEPL) decisions or Sow Welfare Productive Lifetime (SWPL) decisions. An example of what defines the difference between SEPL and SWPL could be a sow that is classified as being disease free and is consuming her daily feed ration

(indicators of good welfare), but who cannot provide an economical return on investment through pigs per sow per year (PPSPY) will often be culled by a producer using an SEPL decision. Another example could be a sow that undertakes extensive postural adjustments in the farrowing phase that results in unacceptable pre-weaning mortality due to crushing will again be culled for SEPL reasons even though the root of the problem is related more to SWPL.

In regards to SWPL, few studies have comprehensively examined producers' decisions for culling over multiple parities and across different production systems. Some research has focused on SWPL factors which may result in culling, for example detrimental behaviors (i.e. enhanced aggression or cannibalistic behavior), overall sow health, feet and leg problems, injury levels and locomotion disorders. Stalder et al. (2004) performed an in-depth review of issues pertaining to all the aforementioned except for behavior and caretaker skills. This review will discuss behavior effects on sow productive lifetime, specifically maintenance (feeding and housing effects), social (aggression, sow-piglet interaction, and expression of sexual behaviors), and stereotypical behaviors.

Maintenance Behaviors

Feeding programs

During the transition from natural to intensive husbandry environments, producers have assumed the responsibility of providing a nutritious diet to the sow on a daily basis. In doing so, sows have drastically reduced the total amount of their daily activity spent foraging or seeking food sources (see de Jonge et al., 2008, for a brief review). Abiven et al. (1998) reported that increasing the number of meals per day from 1 to 3 resulted in a decrease in

odds ratio of high mortality (>5 %) from 2.29 to 0.06. Similarly, feeding programs where lactating sows are limited to < 8 kg and reach that level within 15 d of lactation were related to lower odds of high mortality ($P < 0.10$) as compared to *ad libitum* feeding programs. They explained this by rationing sows daily feed allotment may reduce the number of mortalities due to torsion of organs. Wet meal diets resulted in lower odds ratios for high mortality (Abiven et al., 1998) and less sow aggression (Andersen et al., 1999) compared to dry feed.

Housing effects on behavior

A primary premise made by an individual producer for “acceptable” behavior(s) may be highly dependent on the type of housing system that a producer utilizes. For example, a sow that may be aggressive at the time of parturition towards a caretaker could be retained within a system that is more confined (farrowing stalls), but this behavior may become more problematic or even intolerable and dangerous to caretakers and other animals in a loose housed farrowing system resulting in a different outcome.

Gestation and farrowing stalls limit sow behaviors, postures and overall locomotion (Davies et al., 1996; Rountree et al., 1997) compared to other housing systems. Anil et al. (2001) compared gestation sow injuries in proportion to stall size; the authors noted that stall size can predict the activity level of sows. The authors also suggested that sows require more time to stand up and rise a fewer number of times as sow length increases in proportion to sow stall size. In addition, floor surface has been shown to influence lying-down behavior, interruptions, and slipping (Bonde et al., 2004; Boyle et al., 2000). All these subtle changes in gilt and sow behavior place stress on the sow’s feet and limbs which may result in less time spent eating (Leonard et al., 1997) and hypothetically poorer lactation performance and

lower reproductive rates after lactation. This in turn may reduce the length of time that sows stay productive in the breeding herd.

Some research has determined how hoof and leg health may impact sow behavior throughout gestation, lactation, and her overall longevity. Fernandez de Sevilla et al. (2008) performed survival analysis for Duroc, Landrace, and Large White sows having good or bad leg conformation, and they found that overall leg conformation influenced sow longevity. Moreover, for the purposes of this review, Fernandez de Sevilla et al. proposed five ways leg conformation was related to the five freedoms for animal welfare (Farm Animal Welfare Council, 1992), and thus related to sow productive lifetime. “Effect of significant LC [leg conformation] defects on sow longevity impair sow welfare through the 5 freedoms by 1) limiting sow access to food and water, 2) originating physical discomfort at standing or moving (probably related with pain), 3) directly involving pain and injuries..., 4) probably originating stress due to pain and discomfort, and 5) modifying the expression of normal behavior due to limitations in movement, respectively” (Fernandez de Sevilla, 2008).

Boyle (1997) evaluated hoof length for 133 sows in a research herd and 3512 sows in commercial herds. Of the sows evaluated on the commercial farms, Boyle reported that greater than 1 % and less than 0.5 % of the sows had severe overgrown lateral and medial claws, respectively. Larger percentages were recorded for mildly overgrown lateral (> 10 %) and medial (7 %) claws. Boyle also reported that the greatest prevalence of overgrown hind claws of sows in the research herd occurred in parities 4 to 6.

Numerous studies have reported the relationship between hoof overgrowth and locomotion problems (Boyle, 1997; Hulten et al., 1995, Vaughan, 1969). Stienezen et al. (1996) evaluated behavioral impacts and changes when sows have over grown claws for 24

mixed parity sows (average parity was 4.7) prior to farrowing and then through lactation. The authors reported no behavioral (percentage standing, dog-sitting or lying) differences ($P < 0.05$) in the 6 hours leading up to the first piglet being born. Some differences were seen when observing the sows immediately before, during, and after they were provided feed in the morning of each day. Phenotypically normal (control) sows spent more ($P = 0.02$) time feeding (14.5 vs. 8.2 min) and more ($P = 0.01$) time standing (11.4 vs. 4.2 min respectively) than their over grown claw counterparts. There were also some differences in the number of slips of the rear legs between control (0.11) and overgrown claws (0.51; $P = 0.05$), and in addition control sows also had fewer number of rising attempts (1.33 vs. 2.33; $P = 0.02$) than their control counterparts. Claw or hoof overgrowth has also been shown to alter normal sow behaviors. A study by Leonard et al. (1997) found that time spent feeding and time spent standing decreased and weight shifts and slipping increased in sows with overgrown rear claws. These results indicate that sows with overgrown rear claws exhibited discomfort and thus decreased the amount of time weight was distributed on the limb. Bonde et al. (2004) visited six sow herds and assessed hoof length and leg disorders and how this impacted lying down behavior. Sows were observed during spontaneous lying down maneuvers within 30 min after a clinical examination. Recordings were conducted on 555 of the 570 sows. The authors noted that 41 % of the sows showed difficulties in lying down in a gestation stall. Parity also seemed to affect slipping behavior. Sows in their 4th and 5th parity were less likely to slip when lying down compared to younger or older sows.

Social and Sexual Behaviors

Sow aggression

Gilt and sow interaction with co-specifics, facilities, and caretakers may affect her overall productive lifetime within the herd. Aggression among group-housed sows can be frequently observed during feeding in pen housing systems (except for electronic sow feeding or free access systems) and may lead to reduced sow productive lifetime (Olsson and Svendsen, 1997). Arey (1999) observed that stability of sow groups (establishment of hierarchy) required 7 d, but may be prolonged if sows had to compete for food. Increasing sow partition length between free access feeding stations (in pen housed sows) during feeding has been shown to reduce aggressive behaviors (bites towards head/shoulder and body, bite towards vulva, and pushing) and sow displacements during feeding (Andersen et al., 1999). Evaluating sows fed in troughs with body, shoulder, and no partitions, sows fed in partitions that extend the length of their body yield the least number of aggressive behaviors (Andersen et al., 1999; Barnett, 1997; Baxter, 1986). Aggression during feeding and subsequent displacement of the lower-ranking individual may lead to reduced feed intake (Andersen et al., 1999) and early removal from the herd. Arey (1999) observed aggressive behaviors between sows during floor feeding tests on days 28, 56, and 84 post-weaning. Arey (1999) found that aggressive behaviors were greatest on day 28 and then reduced in occurrence on d 56 and 84.

Behaviors during farrowing

Good maternal ability in gilts and sows can be characterized by high piglet growth rate (though sow's milk supply), small litter weight variation within the litter, little or no piglet mortality (Wülbers-Mindermann et al. 2002), and short duration of parturition (85 to

180 min producing an average litter size of 10.6 piglets per litter; Jensen, 1986). During farrowing, the newborn piglet can face potential savaging and cannibalism by the sow (van der Steen et al., 1988). Although the original function of such behavior is defense of the piglets, it can be a practical problem when the behavior is directed either at the caretaker or at the piglets themselves (Harris and Gonyou, 1996; Fraser and Broom, 1997; Harris and Gonyou, 1998). Cronin et al. (1996) and Jarvis et al. (1999) suggested that this behavior occurs more frequently when gilts are housed in restrictive environments; however this behavior has been observed in outdoor production systems also (*Per. Comm. John McGlone*). The caretaker should take a proactive role either to restrain the sow until all piglets are born and have nursed, or to remove piglets that are being targeted by her aggression via cross-fostering. Once the piglets have been delivered safely, the caretaker needs to focus on keeping those piglets healthy and alive.

Maternal behaviors identified as positive are a reduction in the number of postural adjustments during the first few days of the piglets life, (Weary et al., 1996; Marchant et al., 2000; Marchant et al., 2001), pawing and rooting behaviors in loose-housed system (Marchant et al., 1996; Johnson et al., 2007) to aid the sow in locating piglets buried within the straw before lying, and a quick and consistent response to piglet distress calls (piglet squealing; Weary et al. 1996). Crushed piglets not only represent one of the most important factors limiting sow productivity and hence sow productive lifetime, but also presents researchers and producers a challenge in providing any attempt to improve piglet welfare (Arey, 1993). Blackshaw et al. (1994) observed sows and their litters during 0 to 30 d of lactation in pen and stall housed sows. They found that sows in farrowing stalls expressed a fewer number of active behaviors (stretching, kicking, shaking, or rolling) compared to sows

that farrowed in a pen system when lying down. However, piglet mortality rates increased among sows that farrowed in a pen system (32 %) when compared to sows in farrowing stalls (14 %). Johnson et al. (2007) recorded sow behavior and piglet mortality during the first 72 hr post-farrowing in outdoor huts. They found that piglet mortality, in sows that experienced some level of piglet mortality during the observation period, was observed when sows shift from lying sternal to lying lateral as compared to a change from standing to lying posture. They also observed that sows that killed piglets spent less time pawing in the straw before lying down compared to sows with no piglet mortality in the first 3 d of lactation. For a detailed discussion of sow behaviors that are associated with piglet crushing, see Damm et al. (2005).

Sow responsiveness has been studied by several authors. Friend et al. (1989) attempted to modify sow responsiveness by using a microphone-based, electronic system that automatically administered electric shocks to the sow when a piglet was being crushed. The authors of that study concluded that the system was fairly limited in its design as the piglet had to be approximately 25 cm from the microphone and had to be emitting a loud squeal for the sow to show any response. Although the use of this system saved 5 piglets from being crushed, the authors noted that producers would have to ethically contemplate whether the use of this system offset the additional stress placed on the sow from inappropriate shocks. Hutson et al. (1991) and Hutson (1993) showed sows paid little attention to visual and tactile stimuli of a model piglet but were particularly responsive to auditory cries. Furthermore, if the piglet model was placed under the head of the sow, she was more responsive in rising than if the model was under the back legs. Cronin and Cropley (1991) reported that 83 % of sows stood up upon hearing a piglet vocalizing.

Therefore, poor mothering ability as demonstrated by sow cannibalistic intentions, sow unresponsiveness to piglet distress calls, or an increase in postural adjustment behaviors during the first few days of a litters' life may have implications on a decision being made by the producer to cull that sow at a younger parity.

Estrus expression behaviors of sows and gilts

As stated previously, reproductive failure, either perceived or actual, is one of the largest reported reasons sows are removed from the breeding herd (Lucia et al., 2000). Pedersen (2007) reviewed the influence of social interaction between sows and between sows and their handlers on the expression of sow sexual behavior and motivation. Fear from specific dominant individuals or fear of humans was reported as reducing sexual motivation during mating, even during standing estrus. Multiple factors such as genetic predisposition and lack of or adverse experience with handlers were discussed. A reduction in estrus expression as a result of handler interaction may result in premature removal of sows from the breeding herd.

Stereotypical behaviors

Oral-nasal-facial (ONF) behaviors may include stereotypies but may also include functional behaviors such as feeding, drinking, and rooting, each implying different underlying motivations. The most widely used definition of stereotypies is that they are 'unvarying, repetitive behavior patterns that have no obvious goal or function' (Mason, 1993), and were first recognized in zoo or laboratory animals (Arellano et al., 1992). Such behaviors are generally first noticed because they appear 'abnormal'; although the goal may seem unobvious, such behavior may have some function for the individual animal (Lawrence

and Rushen, 1993) such as a way to cope with stress or frustration (Dantzer, 1986). A number of behaviors have been classified as stereotypies, depending on how well they fit the definition. The most common stereotypies reported in sows include bar biting, chain chewing, sham or vacuum chewing ('chewing' the air), and stone chewing (Dailey and McGlone, 1997; Arellano, 1992; Dantzer, 1986; see Lawrence and Claudia Terlouw, 1993 for a comprehensive review of stereotypic behaviors in pigs). Arellano et al. (1992) found an increase in expression of stereotypies in sows housed in stalls as compared to sows housed in pens. The most prevalent stereotypy observed in stall-housed sows was vacuum chewing (69%; Arellano et al. 1992).

Repetitive chewing or biting behaviors by a sow may cause abnormal wear on her teeth and gums or loss of teeth when biting on bars or feeders. Similarly, abscesses may form as a result of broken, sharp, or jagged incisors (Johnson et al., 2003) or biting protruding or sharp objects and ultimately cause pain while chewing. This in turn may negatively impact how well she is able to eat and maintain body condition and pregnancy, produce milk, and wean piglets. Ultimately, detrimental behaviors that increase teeth wear may influence a producer's decision to cull her at a younger parity.

Multiple papers have been written describing stereotypy functions, their cause and their possible solutions (Dantzer, 1986; Arellano et al., 1992; Spoolder et al., 1995; Mason and Latham, 2004), but few have addressed the link between stereotypes, sow productive lifetime, and dental health within the swine herd. Curtis et al. (2003) hypothesized that based on current thinking among scientists evaluating dental disorders or problems, "local effects" (teeth damage on surrounding structures) and perhaps more importantly "distant effects" (damage in other organs other due to factors in the diseased mouth, then mediated by

circulatory, immune, or nervous system) may be inversely related to sow welfare, productive lifetime, and productivity.

Two major studies have been conducted to determine the prevalence of severe dental wear in cull sows at slaughter plants. Johnson et al. (2003) collected heads of sows at multiple packing plants in the U.S. and Canada and developed an oral lesion scoring system that evaluated incisor and molar wear and incisor loss. Both incisors and molars were categorically scored from 0 to 4, which corresponded to equal increases in severity, and scores of 3 and 4 were considered “significant” lesions. Results from that study indicate that 85 % of culled sows at the plants had “significant” lesions, and mature sows had significantly more molar and incisor wear than immature sows. An examination of 82 mature sows found that 63% of the sows had molar wear, 62 % had incisor wear, and 34 % had lost an incisor. In some sows, tooth wear had proceeded to the gumline and the mandibular alveolar bone had been replaced by a connective-tissue pad. Other dental lesions observed included gingivitis (55 %) and abscessation (4 %). An analysis of 3,158 cull sows at two Midwestern harvest facilities revealed 47.0 % and 42.5 % of the sows had moderate and severe tooth wear, respectively (Knauer et al., 2007).

Johnson et al. (2003) also reported a difference in the prevalence of incisor lesions among sows housed in stalls indoors (2 herds) when compared to sows housed in an outdoor pasture system (1 herd). Incisor wear was only prevalent for sows housed indoors (35 and 85 %) as compared to sows housed outdoors (0 %). Further, 40 and 5 % of the sows housed indoors and 12 % of sows housed outdoors had incisor loss. Speculation on such dental wear differences between indoor and outdoor housed sows could be due to indoor housed sows were limited to chewing on “man-made” objects (i.e. metal bars, feeding troughs and or water

drinkers) while sows housed in outdoor systems may have access to a wider variety of objects i.e. grass, dirt, roots or insects that may have been less abrasive on their teeth and gums. However, it should be noted that the first molar in gilts erupts between 5 to 7 months of age whereas the third molar erupts at 18 to 24 mo. of age. The more repaid wear of the first molar may be related to time in service and not exclusively to bar biting or stereotypical behaviors as has been previously suggested (*Per. Comm. Wayne Johnson*)

CONCLUSIONS

There has been little welfare research conducted that has linked sow behaviors with her productive lifetime within a herd. Research is needed to determine the association between sow productive lifetime or other measures of lifetime performance with welfare and other behavioral measures evaluated on sows. Such work across, different housing systems across multiple parities at the same time can help in the creation of a comprehensive data base for both SWPL and SEPL factors. This information can then be utilized by individual pork producers to enhance sow productive lifetime and therefore overall welfare within the U.S. swine industry. Furthermore, research endeavors should strive to be more holistic in its approach and encompass a multi-disciplinary team to examine the entire production system including welfare and economics of the system and its relationship with sow productive lifetime. It should be recognized that these types of studies are time consuming, expensive and often difficult to implement, particularly without involving industry partners.

LITERATURE CITED

- Abiven, N., H. Seegers, F. Beaudeau, A. Laval, and C. Fourichon. 1998. Risk factors for high sow mortality in French swine herds. *Prev. Vet. Med.* 33:109-119.
- Andersen, I. L., K. E. Boe, and A. L. Kristiansen. 1999. The influence of different feeding arrangements and food type on competition at feeding in pregnant sows. *Appl. Anim. Behav. Sci.* 65:91-104.
- Anil, L., S. S. Anil, and J. Deen. 2001. Stall housing for pregnant sows: Size and injury levels. In: Allen D. Leman Swine Conference. p 185-186.
- Arey, D. S. 1993. The welfare of pigs in confined and non-confined farrowing systems. *Pig News. Inf.* 14:81N-84N.
- Arey, D. S. 1999. Time course for the formation and disruption of social organization in group-housed sows. *Appl. Anim. Behav. Sci.* 62:199-207.
- Arellano, P. E., C. Pijoan, L. D. Jacobson, and B. Algers. 1992. Stereotyped behaviour, social interactions and suckling pattern of pigs housed in groups or in single crates. *Appl. Anim. Behav. Sci.* 35:157-166.
- AWI. 2005. Animal Welfare Institute homepage. Available: <http://www.awionline.org>. Accessed March 25, 2009.
- Barnett, J. L. 1997. Modifying the design of group pens with individual feeding places affects the welfare of pigs. *Livest. Env.* 5, Proc. of the 5th Int. Symp., Bloomington, MN. Vol. 2, 613-619.
- Baxter, M.R. 1986. The design of the feeding environment for the pig. PhD. Thesis., Univ. of Aberdeen, Scotland.
- Blackshaw, J. K., A. W. Blackshaw, F. J. Thomas, and F. W. Newman. 1994. Comparison of behaviour patterns of sows and litters in a farrowing crate and a farrowing pen. *Appl. Anim. Behav. Sci.* 39:281-295.

- Bonde, M., T. Rousing, J. H. Badsberg, and J. T. Sorensen. 2004. Associations between lying-down behaviour problems and body condition, limb disorders and skin lesions of lactating sows housed in farrowing crates in commercial sow herds. *Livest. Prod. Sci.* 87:179-187.
- Boyle, L. 1996. Skin lesions, overgrown hooves and culling reasons in individually housed sows. M.S. Thesis. University College, Dublin.
- Boyle, L. A., D. Regan, F. C. Leonard, P. B. Lynch, and P. Brophy. 2000. The effect of mats on the welfare of sows and piglets in the farrowing house. *Anim. Welf.* 9:39-48.
- Chagnon, M., S. D'Allaire, and R. Drolet. 1991. A prospective study of sow mortality in breeding herds. *Can. J. Vet. Res.* 55:180-184.
- Christensen, G., L. Vraa-Andersen, and J. Mousing. 1995. Causes of morality among sows in Danish pig herds. *Vet. Res.* 137:395-399.
- COK. 2005. Compassion over killing homepage. Available: <http://www.cok.net/>. Accessed March 25, 2009.
- Cronin, G. M., and J. A. Cropley. 1991. The effect of piglet stimuli on the posture changing behaviour of recently farrowed sows. *Appl. Anim. Behav. Sci.* 30:167-172.
- Cronin, G. M., G. J. Simpson, and G. J. Hemsworth. 1996. The effects of the gestation and farrowing environments on sow and piglet behaviour and piglet survival and growth in early lactation. *Appl. Anim. Behav. Sci.* 46:175-192.
- Curtis, S. E., M. Ellis, and E. W. Johnson. 2003. University of Illinois. Unpublished data.
- Dailey, J. W., and J. J. McGlone. 1997. 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.
- Dagorn, J. 1996. Importance et performances de l'élevage plein air en France. *Techni-Porc* 19: 7-13.
- Damm, B. I., B. Forkman, and L. J. Pedersen. 2005. Lying down and rolling behaviour in sows in relation to piglet crushing. *Appl. Anim. Behav. Sci.* 90:3-20.

- Dantzer, R. 1986. Behavioral, physiological and functional aspects of stereotyped behavior: A review and re-interpretation. *J. Anim. Sci.* 62:1776-1786.
- de Jonge, F. H., S. L. Tilly, A. M. Baars, and B. M. Spruijt. 2008. On the rewarding nature of appetitive feeding behaviour in pigs (*Sus scrofa*): Do domesticated pigs contrafreeload? *Appl. Anim. Behav. Sci.* 114:359-372.
- Fernandez de Sevilla, X., E. Fabrega, J. Tibau, and J. Casellas. 2008. Effect of leg conformation on survivability of Duroc, Landrace, and Large White sows. *J. Anim. Sci.* 86:2392-2400.
- Farm Animal Welfare Council. 1992. FAWC updates the five freedoms. *Vet. Rec.* 131:357.
- FMI. 2005. Food Marketing Institute homepage. Available: <http://www.fmi.org>. Accessed March 25, 2009.
- Fraser, A. F., and D. M. Broom. 1997. Pig welfare problems. In: *Farm animal behaviour and welfare* pp 358-369. CAB INT, Norton, UK.
- Friend, T., L. O'Connor, D. Knabe, and G. Dellmeier. 1989. Preliminary trials of a sound-activated device to reduce crushing of piglets by sows. *Appl. Anim. Behav. Sci.* 24:23-29.
- HFAC. 2005. Humane Farm Animal Care homepage. Available: <http://www.certifiedhumane.com/>. Accessed March 25, 2009.
- HSUS. 2005. Humane Society of the United States homepage. Available: <http://www.hsus.org/>. Accessed March 25, 2009.
- Harris, M. J., and H. Gonyou. 1996. The birthing room: accommodation and behaviour in periparturient gilts. 31. ISAE, International Congress of the International Society for Applied Ethology. p. 31.
- Harris, M. J., and H. W. Gonyou. 1998. Increasing available space in a farrowing crate does not facilitate postural changes in maternal responsiveness in gilts. *Appl. Anim. Behav. Sci.* 59:285-296.

- Hulten, F., N. Lundeheim, A. M. Dalin, and S. Einarsson. 1995. A field study on group housing of lactating sows with special reference to sow health at weaning. *Acta. Vet. Scand.* 36:201-212.
- Hutson, G. D. 1993. The response of sows to novel visual, olfactory, auditory and tactile stimuli. *Appl. Anim. Behav. Sci.* 35:255-266.
- Hutson, G. D., J. L. Wilkinson, and B. G. Luxford. 1991. The response of lactating sows to tactile, visual and auditory stimuli associated with a model piglet. *Appl. Anim. Behav. Sci.* 32:129-137.
- Jarvis, S., K. A. McLean, S. K. Calvert, L. A. Deans, J. Chirnside, and A. B. Lawrence. 1999. The responsiveness of sows to their piglets in relation to the length of parturition and the involvement of endogenous opioids. *Appl. Anim. Behav. Sci.* 63:195-207.
- Jensen, P., 1986. Observations on the maternal behaviour of free-ranging domestic pigs. *Appl. Anim. Behav. Sci.* 16, 131-142.
- Johnson, A. K., J. L. Morrow, J. W. Dailey, and J. J. McGlone. 2007. Prewaning mortality in loose-housed lactating sows: Behavioral and performance differences between sows who crush or do not crush piglets. *Appl. Anim. Behav. Sci.* 105:59-74.
- Johnson, E. W., S. E. Curtis, and M. Ellis. 2003. Dental lesions in breeding swine. *Proc 2003 Allen D. Leman Swine Conf* 30[Suppl]:32.
- Knauer, M., K. J. Stalder, L. Karriker, T. J. Baas, C. Johnson, T. Serenius, L. Layman, and J. D. McKean. 2007. A descriptive survey of lesions from cull sows harvested at two Midwestern U.S. facilities. *Prev. Vet. Med.* 82:198-212.
- Lawrence, A. B., and E. M. Claudia Terlouw. 1993. A review of behavioral factors involved in the development and continued performance of stereotypic behaviors in pigs. *J. Anim. Sci.* 71:2815-2825.
- Lawrence, A. B., and J. Rushen. 1993. Pages 1-5 in Introduction. In: A. B. Lawrence and J. Rushen, Eds., *Stereotypic Animal Behaviour: Fundamentals and Applications to Welfare*. CAB International, Wallingford, UK.

- Leonard, F. C., I. Stienezen, and P. B. Lynch. 1997. Behaviour of sows with overgrown hooves in the farrowing house. In: Agriculture Research Forum, Dublin.
- Lucia Jr., T., G. D. Dial, and W. E. Marsh. 2000. Lifetime reproductive performance in female pigs having distinct reasons for removal. *Live. Prod. Sci.* 63:213-222.
- Madec, F. 1984. Analyse des causes de mortalité en cours de période d'élevage. *Rec. Med. Vet.* 160:329-335.
- Marchant, J. N., and D. M. Broom. 1996. Effects of dry sow housing on muscle weight and bone strength. *Anim. Sci.* 62:105-113.
- Marchant, J. N., A. R. Rudd, M. T. Mendl, D. M. Broom, M. J. Meredith, S. Corning, and P. H. Simmins. 2000. Timing and causes of piglet mortality in alternative and conventional farrowing systems. *Vet. Rec.* 147:209-214.
- Marchant, J. N., D. M. Broom, and S. Corning. 2001. The influence of sow behaviour on piglet mortality due to crushing in an open farrowing system. *Anim. Sci.* 72:19-28.
- Mason, G. J. 1993. Pages 7-40 in *Forms of stereotypic behaviour*. In: A. B. Lawrence and J. Rushen, (eds.) *Stereotypic Animal Behaviour: Fundamentals and Applications to Welfare*. CAB International, Wallingford, UK.
- Mason, G. J., and N. R. Latham. 2004. Can't stop, won't stop: is a stereotypy a reliable animal welfare indicator? *Anim. Welf.* 13:S57-S69.
- NAHMS. 2000. National Animal Health Monitoring System. Part I. Reference of swine health and management in the United States. Fort Collins, CO, USA.
- NAHMS. 2006. National Animal Health Monitoring System. Part III. Reference of swine health, productivity, and general management in the United States, 2006. Fort Collins, CO, USA.
- NCCR. 2005. National Council of Chain Restaurants homepage. Available: <http://www.nccr.net/>. Accessed March 25, 2009.
- Olsson, A. C., and J. Svendsen. 1997. Effect of competition at feeding on sow health and productivity. Swedish University of Agriculture Sciences, Department of Agriculture Biosystems and Technology, Report 113, p 37.

- PETA. 2005. People for the Ethical Treatment of Animals homepage. Available: <http://www.peta.org/>. Accessed March 25, 2009.
- Pedersen, L. J. 2007. Sexual behaviour in female pigs. *Hormones and Behavior* 52: 64-69.
- PigCHAMP. 2007. Benchmarking 2007 annual summary of US herds. Available: http://www.pigchamp.com/summary_archives.html. Accessed March 25, 2009.
- Sasaki, Y., and Y. Koketsu. 2008. Mortality, death interval, survivals, and herd factors for death in gilts and sows in commercial breeding herds. *J. Anim Sci.* 86: 3159-3165.
- Spoolder, H. A. M., J. A. Burbidge, S. A. Edwards, P. H. Simmins, and A. B. Lawrence. 1995. Provision of straw as a origin substrate reduces the development of excessive chain and bar manipulation in food restricted sows. *Appl. Anim. Behav. Sci.* 43:249-262.
- Stalder, K. J., M. Knauer, T. J. Baas, M. F. Rothschild, and J. W. Mabry. 2004. Sow longevity. *Pig News and Info.* 25:53N-74N.
- van der Steen, H. A. M., L. R. Schaeffer, H. de Jong, and P. N. de Groot. 1988. Aggressive behaviour of sows at parturition. *J. Anim. Sci.* 66:271-279.
- Vaughan, L. C. 1969. Locomotory disturbance in pigs. *Brit. Vet. J.* 125: 345:365.
- Weary, D. M., E. A. Pajor, D. Fraser, and A. M. Honkanen. 1996. Sow body movements that crush piglets: a comparison between two types of farrowing accommodation. *Appl. Anim. Behav. Sci.* 49:149-158.
- Wülbers-Mindermann, M., B. Algers, C. Berg, N. Lundeheim, and J. Sigvardsson. 2002. Primiparous and multiparous maternal ability in sows in relation to indoor and outdoor farrowing systems. *Appl. Anim. Behav. Sci.* 73: 285-297.

CHAPTER 4. THE EFFECT OF HOOF ABNORMALITIES ON SOW BEHAVIOR AND PERFORMANCE¹

A paper to be submitted to the *Journal of Animal Science*.

R. F. Fitzgerald,* K. J. Stalder,*² L. A. Karriker,† L. J. Sadler,* H. T. Hill,‡ J. Kaisand,‡ and

A. K. Johnson*

*Department of Animal Science and †Department of Veterinary Diagnostic and Production

Animal Medicine, Iowa State University, Ames, IA 50011

‡Iowa Select Farms, Iowa Falls, IA 50126

ABSTRACT

The objective of this study was to evaluate the effects of cracks in the outer hoof wall [CK], length differences between the medial and lateral toe of the hoof [TS], and excessive toe growth [OG] on sow lactation performance and behavior in mid-lactation. Sows from each treatment group were assigned a severity score (1 to 3), and control sows were assigned a 0 score. Lactation sow performance from 223 litters was collected over 2 experiments; each experiment was conducted on a different 4200-sow operation using the same protocol and performance data were combined for analyses. Total born, number born alive, stillborn, and

¹This paper of the Iowa Agriculture and Home Economics Experiment Station, Ames, Iowa, Project No. 3801, was supported by Hatch Act and State of Iowa Funds. Additional funding was provided by the National Pork Board, Project No. (07-051).

²Corresponding: 109 Kildee hall, Ames, IA 50011; stalder@iastate.edu, phone: 515-294-4683, fax: 515-294-5698

mummies were recorded for each sow as well as the farrowing date. Sow behavior was scored continuously for 45 min prior to and 1 h post feeding in experiment 1 (150 sows) and for a 24 hr period in experiment 2 (10 sows). The ethogram contained 4 postures (standing, sitting, kneeling, and lying down) and a maximum of 4 behaviors within each posture (eating, drinking, defecating/urinating, or other). Performance and behavior data were analyzed using a multiple linear regression. Sows of each treatment began the experiment with similar litter weights ($P > 0.15$) and number of piglets per litter ($P > 0.15$). A significant, negative partial regression coefficient was observed for piglets weaned per litter for sows in the CK and TS groups. A trend ($P = 0.10$) was observed for the association of sows in the CK group to wean -0.21 fewer piglets per litter than control sows. An increase in OG lesion severity score was associated with lighter adjusted litter wean weights compared to control sows. Sows in the control group spent 18.9 % (19.9 min) of the 105 min observation period standing and 12.7 % (13.3 min) of the total time standing and eating. The amount of time spent standing and eating before feed presentation was negatively associated with time spent eating after feeding ($b = -0.24$, $P < 0.01$); that is, for each percent increase in time spent eating prior to feeding was associated with a 79 % decrease in time spent standing and eating post feeding. Sows with overgrown toes spent 50 % less time kneeling for each incremental increase in OG lesion score. Post feeding, each OG lesion score increase was associated with a 40.0 % decrease in time spent standing and eating. This observation held true for total time spent standing and eating during the observation period [Odds Ratio (OR) = 0.45]. In Experiment 2, sows were observed standing and eating between 3.3 and 9.1 % of the observation period, and, of the variables collected, eating was the primary activity performed while standing. Sows spent a very small percentage of their time kneeling (0.11

%). Results from this study demonstrate that foot lesions can impair productivity and behavior of lactating sows. The degree to which foot lesions impair production and behavior is dependent on lesion type and severity.

Keywords: Behavior, Overgrown Toes, Sow Productive Lifetime.

INTRODUCTION

Increased hoof abnormality prevalence (e.g. toe and dew claw overgrowth, hoof wall cracks, and hoof pad abrasions) in sow populations observed at harvest suggest that these hoof defects may be detrimental to sow performance, and in turn, the sow's productive lifetime. An evaluation of cull sows at harvest by Knauer et al. (2007) reported that 85 % of sows had at least a single lesion impacting one or more hooves. Researchers have reported that lameness is a major factor when culling sows from the breeding herd (Knauer et al., 2007; Stienezen, 1996). Engblom et al. (2007) observed that 8.6 % of sows in Swedish commercial herds were culled due to lameness, hoof lesions or both. However, it should be noted that the presence of hoof lesions do not mean that a sow is lame. Similarly, not all cases of lameness in sows are a result of hoof lesions. Several researchers have studied the associated decrease in time spent standing and eating when sows have overgrown rear toes (Leonard et al., 1997; Stienezen, 1996). However, these studies did not quantify the performance response associated with varying degrees of hoof lesions.

Heavier piglet body weights at weaning reach 105 kg approximately 15 days earlier than piglets of lighter weaning weights (Mahan and Lepine, 1991). Also, increased piglet mortality during lactation, possibly due to being less controlled of her movements when lying down, reduces the number of piglets weaned per sow per lactation as well as pose a welfare

issue. Sows that wean lighter litter weight or a fewer number of piglets directly affect producer profitability. Frequently, producers overlook the performance cost as a result of sow hoof ailments and only measure the direct cost of replacing those sows with replacement gilts after they are culled. Therefore, the objective of this study was to evaluate the effects of excessive toe growth, hoof cracks in the outer hoof wall, and length difference between the medial and lateral toe of the hoof on sow performance and behavior in mid-lactation.

MATERIALS AND METHODS

Animals, Housing, and Husbandry

Farms. The project was approved by the Iowa State University Animal Use and Care Committee (IACUC #6-06-6159-S). These studies were conducted on two, 4200-hd sow operations within the same Midwestern U.S. vertically integrated system. Two experiments were conducted because lactation feed delivery was different in each of the facilities and thus required different behavior observation periods. However, the building structures and management objectives were similar at both farms. The buildings utilized a flush manure system and tunnel ventilation.

Gestation. Sows were housed in gestation stalls (Modern Hog Concepts, Iowa Falls, IA; 58 cm width x 244 cm length x 109 cm height). The stalls had solid concrete floors in the front half and slatted concrete floors in the rear half. At 0700 h each day, gestating sows were provided a commercially available corn-soybean based meal ration formulated to meet or exceed the sows' nutrient requirements (NRC, 1998). The feed ration was provided in a water/feed combination trough with the top of the trough level with the floor (Farm A, 13 cm depth x 31 cm width) and raised above the floor (Farm B, same dimensions). Sows were

provided water 3 times / d in cool months (November to April). During summer months (May to October), water delivery was increased to 4 times / d. A drip cooling system was utilized in gestation when temperature reaches 25.6°C. Sows were housed in gestation stalls after they were confirmed pregnant from approximately d 30 of gestation and were moved into farrowing stalls at 112 d of gestation (range 109 to 113 d). Just prior to being placed into farrowing stalls, sows were washed using soap and water to remove manure and promote biosecurity within the farm. Caretakers observed all sows and piglets twice daily (0700 and 1500 h) during gestation and lactation.

Lactation. Ten farrowing rooms were used for Farm A and 2 farrowing rooms were used on Farm B. Within each farrowing room there were 39 farrowing stalls (3 rows of 13 farrowing stalls in each row; Modern Hog Concepts, Iowa Falls, IA; 51 cm width x 214 cm length x 102 cm height with finger bars extending downwards on each side of the stall). Sows were provided water through nipple water drinkers approximately 84 cm from the floor and 36 cm from the front of the stall. The farrowing stalls had wire mesh flooring. Lactating sows were provided a commercially available corn-soybean based meal ration formulated to meet or exceed their nutrient requirements (NRC, 1998) during this phase of production. Feed was provided in a metal feeder at the front of each farrowing stall. Prostaglandin F2 α (Lutalyse, Pfizer Animal Health, New York, NY) was injected following manufacturer's recommendations on approximately d 115 of gestation if the sow did not show imminent parturition signs. High and low ambient temperatures (°C; 30.8 and 19.7°C, respectively) were monitored for each farrowing room during lactation using the 6-stage ventilation system control (Airstream TC5 controller, Automated Production System, Assumption IL) located

outside of the farrowing room. The temperature sensor was located in the center of each farrowing room, approximately 1.4 m above the floor.

Treatment descriptions. Sows were classified into three treatment groups and one control group by the same trained observer while sows were standing in gestation stalls approximately 1 d before sows were placed in farrowing stalls. The treatment groups were 1) presence of cracks in the outer hoof wall [CK], 2) length differences between the medial and lateral toe of the hoof [TS], and 3) excessive toe growth [OG] (Table 1). Sows that had both toe length differences and hoof cracks [TK] are reported in a separate category for descriptive analysis of lesions only and were not considered a separate treatment group. Hoof abnormalities were categorized into 3 scores based on the severity of the lesion, and those categories are shown in Table 1. Sows in the TK group were not given a severity score based on the combination of lesions, but statistical analyses accounted for the individual scores of both toe length differences and hoof cracks using multiple regression. The number, length, location, and hoof crack severity was recorded for each toe and for all sows in all treatment groups. The length difference between the medial and lateral toe were obtained using a standard ruler (3.5 cm width x 30.5 cm length, measured at 0.32 cm increments) placed on the floor of the gestation stall between both toes and parallel to the long axis of the sow and leg. Sow toes classified as OG were measured using the same ruler, placed parallel to the long axis of the sow and leg, but each toe was measured beginning at the coronary band and extending to the leading edge of the overgrown toe

For each treatment sow, a case-control sow [C] was identified with similar body condition score, parity, and size (subjectively evaluated) as her treatment counterpart. Because of the difficulty finding both ideal treatment and control sows within the same parity

within the same farrowing group, treatment and control sows were paired and considered a match using the following parity structure: 1, 2, 3 to 5, and 6 or greater parities. Within a farrowing room, treatment and control sows were placed in 2 rows of farrowing stalls extending the length of the room. Sows were placed in farrowing stalls in a pre-determined order so that an experimental and control sow were housed next to each other; however, treatments were alternated throughout the allotted spaces in the farrowing room. The case-control sows were alternated in the farrowing stalls to remove microclimate effects in the farrowing rooms on any particular treatment group.

Performance and behavioral parameters for both experiments

Sow and litter lactation performance. Once the experimental and control sow population were identified and categorized, they were placed into farrowing rooms based on their expected farrowing dates. After parturition, the date, total number of piglets born, number of piglets born alive, number of stillborn piglets, and mummified fetuses were recorded for each sow before cross-fostering. All piglets that farrowed on a given day were cross-fostered, within 24 h post farrowing, to other sows regardless of treatment or trial status in an attempt to equalize the number of piglets within a litter (approximately 11 piglets / litter). After the litter was established and within 24 h of farrowing, body weights were obtained for each litter. Additionally, the number and weight of pigs cross-fostered (added to or removed from the litter) were recorded. Piglet mortality was recorded including the day of death and piglet weight using a 23 kg hand-held digital scale (Berkley FS-50, Spirit Lake, IA). Weaning weights were measured using a 90 kg analog scale attached to a wheeled, metal weigh crate (WayPig Litter scale, Raytec Manufacturing, Ephrata, PA) 1 to 2 d prior to

weaning. Piglet age at weaning was targeted to average 19 d (range 18 to 22 d). Lactation length was then calculated as the number of days from the date that the litter was weighed (1 to 2 d post-farrowing) to the day weaning weights were obtained.

On both farms, an attempt was made to select sows with similar farrowing dates. However, in cases where sows farrowed extremely early or later than the average of the entire room or where farrowing room space was needed due to large number born alive, the entire litter was removed from the sow and replaced with a younger litter. This event occurred for 14 out of a total of 223 sows involved in the trial. Additionally, the 14 events occurred entirely in Experiment 1. An equal number of piglets were removed and then replaced for all 14 litters. In such cases, both litters were weighed and data were incorporated into the calculated variable of total weight produced during lactation. This event was minimized in this trial; however, due to trial sows encompassing greater than 60 % of the total space in a particular room, this event inevitably occurred. Further, 15 sows (12 sows in Experiment 1 and 3 sows in Experiment 2) were weaned prior to their case-control sow due to piglet morbidity or mortality or both. These sows were removed from analysis because they were removed before their case-control sow and they had below average weaning weights. Total weight produced per sow during lactation was calculated using the following formula:

Adjusted weight produced in lactation = litter wean weight + piglet mortality weight + weight of pigs removed – weight of pigs added – weight of cross-fostered litter at birth.

Sow Behavior. Behavior was filmed using one 12 V closed circuit color television camera (Model WV-CP484, Panasonic Matsushita Co. Ltd, Kadoma, Japan) per parity matched treatment-control group and information was recorded onto a digital video recorder

(RECO-204, Darim Vision, Pleasanton, CA) at 10 frames / s. Sows within the same room were recorded on the same day when the lactation length averaged 10 d. Prior to independently scoring sow behavior, two trained observers practiced scoring the same video using the Observer software (The Observer, Ver. 5.0.25 Noldus Information Technology, Wageningen, The Netherlands). Behavior times scored by each observer were compared and agreement (all behaviors and postures were correctly identified and times were ± 30 sec of each observer) was achieved before any video was scored. Behavioral scoring was performed without the observers' knowledge of the treatment group to reduce bias.

The behavioral ethogram contained 4 postures (standing, sitting, kneeling, and lying down) and a maximum of 4 behaviors within each posture. Behaviors and postures were modified from the Encyclopedia of Farm Animal Behavior (2009). Standing was sub categorized into 4 behaviors: eating, drinking, defecating / urinating, and just standing. Sitting was sub categorized into 3 behaviors: eating, drinking, and just sitting. Eating was defined as the sow appearing to actively consume food by placing their head inside the feed trough, or alternatively, the observers were able to visually identify sows that appeared to be chewing food. Drinking was defined as the sow placing her mouth or nose on the nipple water which gave the appearance that the sow was ingesting water. Defecating and urinating were scored when a sow was observed in a crouching position, remaining stationary, and excreting feces or urine from the body. Lying down was categorized as lying sternal or as lying lateral on their left or right side. Lateral recumbency was defined as full lateral contact of the body with the legs fully extended. A lying down event was defined as the sow transitioning from a standing to kneeling then to a lying down position. Sows could remain in a kneeling posture for any length of time before lying down. The number of completed lying

down events (sows that went from standing to kneeling to lying in one sequence) and the total number of lying down events attempted (the number of completed lying down events + the number of lying down events where sows transitioned from a standing to a kneeling posture and then back to a standing posture) were recorded per observation.

Experiment 1. Performance and 105-min sow behavior observation. Experiment 1 was conducted on Farm A using a total of 188 sows (Supermom, Newsham Genetics, Des Moines, IA) sows. The distribution of sows by treatment is shown in Table 2. Farrowing rooms were equipped with individual feed drop boxes (Automated Production Systems, Assumption, IL) connected to a delivery system that automatically placed the food in the sows' feeders and subsequently refilled the containers 4 times•d⁻¹ every 6 h at 0245, 0845, 1445, and 2045 h. Mid-experiment, Farm A initiated a change in the time that feed was dropped from the feed boxes and the new feed times were 0215, 0815, 1415, and 2015 h. Farm employees adjusted the quantity of feed allotted to each sow at the same time each day during lactation. Described by the farm standard operating procedure (*personal communication, Iowa Select Farms*), sows were provided 1.8 kg of feed on the days just prior to farrowing. The day after farrowing, feed provided to lactating sows was increased 0.9 kg•d⁻¹ until each sow reached their maximum daily intake as measured by a function of disappearance and determined by the caretaker.

Feed intake data was collected for 139 sows and lactation performance was collected on 188 sows. Behavior was recorded on d 10 of lactation (± 3 d) at 0845 h for 64 sows and on d 10 and 11 of lactation at 0815 h for 86 sows. Thus, behavior data were collected for 150 sows at least once during lactation for a total of 236 observations. The days of lactation were chosen because sows were at mid-lactation and anticipated to be at or near maximum feed

intake. Each sow observation was recorded for 45 min prior to feed delivery and 1 h after feed was available (a total of 105 min / observation) and this provided 24,780 minutes or 413 h. Two investigators entered the farrowing room immediately after feed was dropped and made each sow stand by placing a hand on the sow's back. The investigators verified that each sow was standing before leaving the room, and sows were not disturbed by caretakers until the behavioral recording ended.

Experiment 2. Performance and 24-h behavior observation. A total of 35 sows (Line 23 and 29, Pig Improvement Company, Hendersonville, TN) sows were categorized into treatment and control sows on Farm B and performance data were collected (distribution of sows by treatment in Table 2). Genetic line of each sow was not available on an individual basis at this farm. Data collection procedures were similar to Experiment 1 except for the following: after d 4 of lactation, sows were provided *ad libitum* access to feed. Thus, sow feed intake data was not available for this experiment. Behavior data were collected as previously described, for 10 sows (5 control, 3 OG, and 2 TS sows). Since there was not a defined time point for feeding the sows, behavioral observation occurred continuously for 24 h beginning at 0900 h on d 10 (± 3 d) of lactation and ending at the same time on d 11. The total amount of time collected was 2,400 min or 240 h.

Data analysis. Sows were blocked within room and farm. Between 2 and 8 sows were included in a block, depending on the similarity of parity and location within the farrowing room. Sows from different rooms were not included in the same block. Thus, sow block accounted for differences between farms as well as differences between rooms within a farm.

Sow performance variables collected during lactation (piglet mortality, adjusted litter BW at weaning, feed intake, number of piglets born alive, number of stillborn piglets, and

mummified fetuses) were combined from both experiments. Lesions as well as the severity of each lesion (0 to 3) were included in a multiple linear regression model using the MIXED procedure (SAS Institute, Inc., Cary, NC).

The number of piglets in the litter after cross-fostering was tested for significance as a linear covariate for litter BW after cross-fostering, piglet mortality, the number of piglets weaned, and litter BW at weaning. Lactation length, the number of piglets weaned, and litter BW after cross-fostering were used as linear covariates for litter BW at weaning. Piglet mortality data was analyzed using generalized linear mixed models (GLIMMIX, SAS) fitting a Poisson distribution to the data. Treatment means for piglet mortality were back-transformed into the original unit of measure using the ILINK function. For all covariate effects, the covariate mean was used when estimating treatment effect means at each lesion severity score.

Behavior data were evaluated by experiment and were transformed using the logit function. The total time budget for some treatment groups do not sum to 100 % because a logit transformation was used before analyses. This transformation is non-linear; in that, the back-transformed means do not linearly equal the original values. The sow served as the experimental unit. In Experiment 1, lesions and their severity were evaluated using multiple regression of each behavior, similar to the analysis conducted for performance data. Block was included in the model as a fixed effect. Sow within block was used as a random effect to account for correlations between the day of observation (10 and 11 d of lactation) for sows that had repeated measurements. An environmental impediment during several lying down events was observed for one sow in Experiment 1. This caused her to stand nearly the entire time after feeding and was not a result of her lesion score. Therefore, this sow was removed

from behavior analyses and resulted in 149 unique sows with a total of 235 observations. The percent of time spent standing before feeding was used as a linear covariate for the percent time spent standing after feed delivery. Odds ratios were calculated and presented in the text as one unit increases represents either a percent increase or decrease in time spent in the specific behavior or posture.

For performance and behavior data, multiple linear regressions were estimated for each treatment group severity score (0 to 3). Thus, sows designated as control were included in the models as a severity score zero. The partial regression coefficients derived from the models estimate the associated increase or decrease in performance or behavior trait when the severity score is increased by one unit. For all variables listed in tables and figures, the control group is the starting value for associations with each severity score increase. No significance tests were calculated to compare regression coefficients between treatment groups.

In Experiment 2, behavior data were collected for 10 sows. Each of the treatment sows (2 TS and 3 OG sows, listed as abnormal in Table 4) had lesion scores greater or equal to 2. Behavior video for CK sows was discarded because video was lost for 2 h during feeding on the morning of d 11 of lactation. Therefore, behaviors were compared for the 5 treatment sows versus the 5 control sows. Thus, the binary variable, with or without lesions, was used as a fixed effect in the model. No random variables were used in Experiment 2 because the sows were housed within the same area of 1 room (within a 4 stall radius) and were all of parity 1 sows. Sitting and feeding was removed from behavioral analysis because only 2 sows were observed to sit and eat before or after feeding in Experiment 1 and no sows were observed in this position from Experiment 2.

RESULTS

General lesion description. Sows from several different parities were evaluated in this study because hoof abnormalities are not limited to a particular parity. The parity distribution of sows at both farms by treatment is shown in Table 2. Sows included in this project on Farms A and B had an average parity of 4.1 and 1.7, respectively. Prior to initiating this experiment, Farm B was primarily used as a gilt development unit, and thus a younger average parity was observed for sows on that farm. The greatest number of hoof abnormalities was found in parity 3 to 5 sows, followed by sows in parity 6 to 8, parity 2, and finally parity 1.

Of the 223 sows from both experiments, 79 sows were considered the control population and the remaining 144 sows were found to have hoof lesions which varied in their degree of severity. Sows were also given a score that was positively correlated with the severity of the lesion. Averaging only those sows with at least one hoof lesion, Farm A and B averaged severity scores of 1.5 and 2.0, respectively. Only 11.8 % of sows with a hoof lesion were assigned the most severe score of 3, whereas 47.2 and 41.0 % of the 144 sows were assigned scores of 1 and 2, respectively. Sows denoted as a score of 0 were control sows.

Only 6 of 61 sows classified in the TS group and 1 of the 22 OG sows had toe length differences greater than 1.3 cm in the front hooves, and only 4 of the 6 six sows had only toe length differences in the front hooves. Only 6 sows had cracks in the front hooves. No sows were classified in the OG group because of overgrown front toes.

Sow and piglet performance during lactation for Experiments 1 and 2

Number of piglets born alive. Piglet weights from 223 litters were collected over the 2 experiments and were combined for analyses. Data were combined because the same protocol was used for both experiments and blocking of the treatment and control sows allowed comparisons within blocks, which accounted for farm and room level effects. The number of piglets born alive was not linearly associated with severity lesion score for any treatment group ($P > 0.15$); that is, all lesion scores over all treatment groups averaged the same number of piglets born alive as control sows.

Number of piglets and litter weight after cross-fostering. Piglets were cross-fostered to other sows within the same room for sows that farrowed on the same day and were equalized to 11 piglets / sow. Treatment severity score partial regression coefficients for both litter weight and litter size at cross-fostering were not significantly different than zero ($P > 0.15$, Table 3). Therefore, there was strong evidence that sows within each treatment group began the experiment with equal litter sizes and litter weights.

Pre-weaning mortality. Increased piglet mortality during lactation was associated ($P = 0.02$) with an increase in CK and TS severity score (Table 3). Although the slope was positive, there was no evidence to suggest that piglet mortality increase with OG severity score. Piglet mortality increased with the number of piglets in the litter after cross-fostering ($P = 0.02$). A significant, negative partial regression coefficient was found for piglets weaned per litter for sows in the CK and TS groups; that is, as lesion severity increased, the number of piglets weaned per litter decreased. All severity scores for each treatment group averaged fewer piglets weaned per litter than control sows.

Piglets weaned per litter. A trend ($P = 0.10$) was observed for the association of sows in the CK group to wean -0.21 fewer piglets per litter than control sows. Also, a significant association ($P = 0.02$) was observed for fewer piglets weaned per litter for sows in the TS group. Results for piglets weaned per litter by treatment group were similar to those for piglet mortality. The partial regression coefficients for piglets weaned per litter for all treatment groups were within 0.05 units for those calculated for piglet mortality, albeit the coefficients for piglets weaned per litter were negatively associated with an increase in severity score. This observation is logical as piglet mortality increases and no additions to the litter after cross-fostering, piglets weaned per litter must decrease.

Adjusted litter weaning weight. An increase in lesion severity score was associated with lighter adjusted litter wean weights for all treatment groups; however, only the slope for sows in the OG group was significantly ($P = 0.03$) different from zero. An associative trend ($P = 0.07$) was observed for sows in the CK group to wean lighter litters as lesion score increased. Litter BW at cross-fostering, lactation length, and piglets weaned were all positively associated ($P = 0.01$) with litter wean weight (Table 3).

Feed disappearance during lactation for sows. A large negative association ($b = -10.8$ kg per increase in lesion score; b = partial regression coefficient) was found between OG lesion scores and feed disappearance during lactation; however, the slope was not significantly different from zero ($P = 0.13$) and no feed data were recorded for sows in the OG 2 and 3 severity scores. Interestingly, feed disappearance increased for sows in the CK and TS groups. A positive linear relationship ($P < 0.01$) was found between lactation length and the total feed disappearance during lactation.

Adjusted litter weaning weight per kg feed intake. Lesion scores of sows in the CK group were negatively associated with litter weaning weight per kilogram of feed intake. A negative associative trend was observed for sows in the TS group and litter weaning weight per kilogram of feed intake.

Experiment 1. 105-min sow behavioral observation

Overall time budget for sows. A time budget for 3 postures (standing, sitting, and lying down) by treatment group is shown in Figure 1. Sows in the control group spent 18.9 % (19.9 min) of the 105 min observation period standing (Figure 1), 1.3 % (1.4 min) sitting, 0.3 % (0.3 min) kneeling, and 76.1 % (79.9 min) of the time lying lateral or sternal. Each score increase in CK lesions was associated with a 1.2 odds ratio for standing ($P = 0.02$). However, each increase in OG lesion score was associated sows spending 54 % less time standing ($P = 0.01$). No significant associations were observed for the total amount of time spent sitting for any treatment groups compared to control sows. As a result of the time budget adding to near 100% and significant associations were observed for standing times, the opposite associations were observed for times spent lying; that is, as CK sows spent more time standing, those same sows inherently spent less time lying down. Odds ratios for times spent lying down were 0.8, 1.0, and 1.3 for each score increase in CK, TS, and OG lesions, respectively. Each posture will be discussed further on the basis of before and after feeding.

Standing Postures. Control sows spent 12.7 % (13.3 min) of the total time standing and eating. Before feeding, control sows spent 1.2 % of time standing and eating (Figure 2). However after feed delivery, sows increased time spent standing and eating to 10.7 %. Sows were provided feed 4 times / d, and some sows did not consume the entire amount of the

provided ration immediately after feed delivery. Therefore, the amount of time spent standing and eating before feed presentation was negatively associated with time spent eating after feeding ($b = -0.24$, $P < 0.01$); that is, for each percent increase in time spent eating prior to feeding was associated with a 79 % decrease in time spent standing and eating post feeding. Standing and eating estimates for each lesion score were estimated using the average of time spent standing and eating prior to feeding (2.3 % of the 105 min observation period).

Before feed delivery, there was no evidence ($P > 0.15$) that sows of different treatment severity levels were associated with different amounts of time spent standing and eating compared to control sows. Post feeding, each OG lesion score increase was associated with a 40.0 % decrease in time spent standing and eating. This observation held true for total time spent standing and eating during the observation period [Odds Ratio (OR) = 0.45]. A positive odds ratio (1.19, $P = 0.06$) was observed for total time spent standing and eating for sows in the CK group. A negative association was observed between total time spent standing during the 105 min observation and increasing OG lesion score. Each increase in lesion score was associated with a 54 % decrease ($P = 0.01$) in time spent standing as compared to control sows. However, an odds ratio of 1.2 ($P = 0.02$) was observed for each lesion score increase on total time spent standing for CK sows. This result is unexpected, in that one may hypothesize that sows with severely cracked hooves, thus assuming some level of pain, would be less controlled when lying down. One plausible explanation for this result is that some hoof cracks may visually appear more severe or appear to cause more pain than what truly occurs. Some hoof cracks may only be superficial and not penetrate to more sensitive areas of the toe or foot. Because only the methods to determine true crack severity

include radiographs or sacrificing the animal, the costs to do this were prohibitive in the current study.

Kneeling and Sitting Posture. There were no significant associations observed for time spent kneeling before feeding for any treatment group compared to control sows. Sows with OG toes spent 53 % less time kneeling after feeding ($P = 0.01$) and 50 % less time ($P < 0.01$) kneeling over the entire observation period for each incremental increase in lesion score (Figure 3). Sows with CK and TS lesions had odds ratios near 1.0 (1.01 and 1.04 before feeding and 1.09 and 1.01 after feeding, respectively) for time spent kneeling and partial regression coefficients were not significantly different than zero ($P > 0.15$).

Control sows spent 0.7 and 1.2 % of the sitting time before feeding performing drinking and other behaviors, respectively. After feeding, control sows spent 0.8 and 0.7 % of sitting time after feeding performing drinking and other behaviors, respectively. Compared to control sows, each lesion severity score increase for all treatment groups was not linearly associated with the time spent sitting before and after feeding as well as the total time spent sitting ($P > 0.15$).

Lying Down Posture. Sows categorized in the CK group spent less ($P = 0.01$) time for the total observation period lying down compared to their control counterparts (Figure 4). As the severity of OG lesion increases, total time spent lying down increases (OR = 1.69, $P = 0.02$). In contrast, CK lesion scores were negatively associated with time spent lying down before ($P = 0.06$) and after ($P < 0.01$) feeding. Because time spent sitting was not linearly associated with lesion scores of any treatment group and kneeling only accounted for a relatively small percentage of the sows' time budget, generally the time spent standing was balanced by the time spent lying down. For example, CK sows spent the greatest portion of

time standing and the least percentage of time lying down. The percentage of time lying down was not linearly associated with TS severity scores before or after feeding ($P > 0.15$).

Repeated Lying Down Events. Sows that show abnormal lying down (described by Bonde et al. (2004) as interruptions in the sequence by stopping the lying down behavior and resuming from an earlier stage such as standing, or described as slipping or uncontrolled movement) may increase piglet mortality through uncontrolled sudden movements. Sows averaged 1.9 completed lying down events during the 105 min observation. Including all attempted a lying down event an average of 2.3 times per observation period. Four sows (2 OG and 2 C sows) were removed from the treatment analysis of lying down events because those sows did not perform the defined lying down behavior. These sows lowered from a standing to a sitting position using their rear legs instead of the front legs instead of lowering to a kneeling posture on their front knees. In most cases, this was observed when sows were standing and drinking, lost traction with their rear hooves, and experienced severe slips and lowered to a sitting posture. The only OG sow (of 13 total sows classified as OG in experiment 1) that did not complete the lying down event on the first attempt required 13 times to successfully complete one lying down event. This sow had the appearance that she wanted to lie down, and failing to do so, caused her to have larger than normal standing time as well as time spent kneeling. Thus, this observation was removed from subsequent behavior analyses. The number of completed and attempted lying down events for sows by treatment group is listed in Figure 5. After removing those observations, sows in the C, CK, TS, OG, and TK groups completed 89.3, 80.9, 93.1, 100.0, and 77.4 % of the 525 attempted lying down events. With the OG sow removed, the number of attempts required when lying

down above those that were defined as completed ranged from 0 to 6 per observation for all sows.

Experiment 2. 24-h behavior observation

General time budget. Averaging over the 10 sows, the greatest portion of time was spent in lateral recumbency (88.7 ± 3.26 %, mean \pm SD), splitting the time nearly equally between the left (40.0 ± 14.5 %) and right (35.9 ± 17.8 %) side. However, left to right side ratios ranged from 0.3 to 6.6 (time spent lying laterally on the left side divided by the times spent on the right side), suggesting that some sows had a preference for lying lateral on their right or left side for no apparent reason. The closest ratio to equal time on both sides was 1.3. Sows averaged 12.9 ± 5.0 % of the 24-h period lying sternal. Sows spent a very small percentage of their time kneeling (0.1 %). Sows averaged 35 % of the time in a sitting posture drinking from the nipple waters. For the remainder of time spent in a sitting posture (65 %), sows were observed to watch other activity in the room, perform biting, and interacted with her piglets. Sows in this experiment were observed standing between 5.6 and 10.9 % of the observation period, and of the variables recorded, eating was the primary activity performed while standing (range 3.3 to 9.1 %). Only 2 additional attempts to complete a lying down event (for 101 completed events) were observed. Sows averaged 10.1 lying down events during the observation period.

Treatment comparisons. There was no evidence to suggest that sows in treatment groups were associated with less time standing, kneeling, or lying down compared to control sows (Table 4). However, sows with hoof lesions were observed to spend 1.5 % more time ($P < 0.01$) sitting than control sows.

DISCUSSION

General lesion description. In this study, the rear hooves were the major location of all hoof cracks, toe size differences, and overgrown toes, and these results are supported by those previously reported studies (Gjein and Larssen, 1995; Stienezen, 1996). The minimum differences in toe length for sows to be categorized as TS 1, 2, and 3 were 1.3, 1.9, and 2.5 cm, respectively, and this difference occurred between the toes of the rear hooves. Penny et al. (1963) performed post-mortem examinations at a slaughter house on 31 mixed breed and gender pigs that had a lesion in the lateral foot and measured medial and lateral toe length. They observed a lateral to medial ratio of 1.11:1 for length and 1.13:1 ratio for width. They also reported a difference in shape, as the lateral toe tended to be more rounded and the medial pointed. Further, they observed that most lesions were localized to the lateral toe of the rear hooves.

The average lesion scores on Farm A and B were 1.5 and 2, respectively, and 11.8% of the lesions evaluated were in the most severe score. There were very few extreme lesions evaluated and this likely made it difficult to greater differences in performance or behavior. Boyle (1996) evaluated toe length for 133 mixed parity sows in a research herd and 3512 sows in commercial herds. Of the sows evaluated on commercial farms, Boyle reported that greater than 1 % and less than 0.5 % of the sows had severe overgrown lateral and medial toes, respectively. Larger percentages were recorded for mildly overgrown lateral (> 10 %) and medial (7 %) toes from that same study. Further, Boyle also reported that the greatest prevalence of sows' overgrown toes on the rear hooves occurred in parities 4 to 6 in the research herd where the investigation took place.

Most of the hoof cracks in the present study were localized to the rear hooves; however, crack length, severity, and type varied. One plausible reason for the greater prevalence in the rear hooves is that some of the sows were observed to place either the lateral or medial toe of the rear hooves between the concrete slat flooring. If sows placed a large amount of weight or had to move suddenly, this could result in an abnormal amount of weight on a part of the outer hoof wall that might not be accustomed to bearing that weight. Also, another hypothesized reason is the difference in microenvironment between the front and rear feet. The rear feet are in a microenvironment where percent moisture may be greater as well as the presence of manure. The longest recorded hoof crack was 5.1 cm long. Most of the sows assigned to the most severe hoof crack score had obvious separations (where a fingernail or larger could be placed in the crack) in the outer hoof wall. In these cases, cracks could allow bacteria and other pathogens to infect the hoof, potentially affecting other body organ systems and moreover impacting sow performance (e.g. lower milk production during lactation, lower feed intake, etc.). Similarly, Penny et al. (1963) observed hoof crack variation ranging from shallow, discolored indentations to, as described by Penny et al. “a deep fissure, with marked enlargement and deformity of the claw.” In the present study, 7 of the 38 sows having cracked toes were classified in the most severe category. Further, length of hoof crack might not be the most accurate method to determine hoof crack severity, and future studies might consider more objective assessments that might be more correlated to pain or discomfort to assign sows to severity scores. In this study, inaccuracies in determining true hoof crack severity may explain the unexpected results for some behavior traits.

Performance. Partial regression coefficients for number born alive were not significantly different than zero for all treatment groups compared to the control. Similar observations were made for litter size and weight at cross-fostering for all treatment groups, suggesting that sows of all scores started the experiment with approximately the same litter size and weight.

During lactation, CK and TS sows were associated with increased piglet mortality compared to control sows, and subsequently, were associated with weaning fewer piglets per litter. As lesion scores increase for OG sows, sows were associated with spending less time kneeling when lying down. This observation coupled with no additional attempts needed when lying down suggests that these sows have the least controlled movements when lying down. Bonde et al. (2004) reported that sows with overgrown rear toes were 11.5 times more likely to show abnormal lying down behavior than sows with normal hooves. Thus, unexpectedly, lesion scores for sows in the OG group were not associated with an increase in piglet mortality.

Each lesion score increase for sows in the OG group was significantly associated with 2.1 kg less adjusted litter body weight at weaning. For the 22 OG sows in this study, this would equal 71.3 kg less piglet weight at weaning. Multiplying the partial regression coefficients for each treatment group times the number of sows within each severity score (an average of TS and CK coefficients was used for TK sows), 144 treatment sows weaned a total of 215 kg less piglet body weight compared to control sows. Commercial sow operations frequently record the number of piglets weaned per litter, piglet mortality during lactation, and other easily obtained measurements for sows during lactation and use that data for culling criteria. However, most farms do not weigh individual litters at weaning due to

the expense associated with obtaining that data. Thus, the adjusted litter weaning weight might have the most unnoticed consequence of hoof lesions in many commercial swine production systems.

Sow Behaviors and Postures in Experiment 1. Sows classified in the OG group spent less time standing and eating as lesion severity increased when compared to control sows. This observation is concurrent with findings previously reported. Stienezen (1996) compared the behavior from stall-housed sows with overgrown rear toes (13 sows, 6.8 cm average length of rear toes) to a control population (11 sows, 4.8 cm average length of rear toes) during farrowing and lactation. Steinezen also reported that sows with overgrown rear toes spent less time feeding (8.2 vs. 14.5 min, respectively) and standing (4.2 vs. 11.4 min, respectively), slipped more with the rear hooves while standing (0.9 vs. 0.2 times / min), and needed more rising attempts (2.3 vs. 1.3) when raising from the lying down to the standing position when compared to control sows. In that study, sows with overgrown toes tended to produce smaller litters at birth compared to the control sows (10.5 vs. 12 piglets born alive, respectively). Further, in that study, a large range of behaviors was observed and that a great amount of individual variation existed. They suggested that lack of exercise was the major contributory factor to the development of overgrown toes, which is also supported by Vaughan (1969). However, the authors of the present study suggest that overgrown toes are often accompanied with overgrown dew claws. Dew claws do not typically touch the ground in an animal that is structurally correct (NHF, 2004). Hence, the lack of exercise contribution to overgrown toes or dew claws or both is not likely the cause for this condition. A study by Leonard et al. (1997) found that sows' feeding and standing time decreased and weight shifts and slipping increased among sows with overgrown rear toes. These findings indicate that

sows with overgrown rear toes exhibited signs of discomfort and, thus, decreased the amount of time weight was distributed on the limb with the affected hoof or toe.

Sows categorized in the CK and TS groups averaged more time standing and eating when compared to control sows. One plausible explanation for this is there were an insufficient number of sows receiving the most severe lesion score, and the performance of these sows was diluted by sows with less severe hoof cracks or toe size differences in order to accurately estimate the effects. For TS sows, toe lengths have not yet reached the lengths required to be classified as OG. Therefore, with time and further growth of the toes, some of the sows might be classified as OG and thus the associated loss in performance may occur.

Sow Behaviors and Postures in Experiment 2. Sows spent between 3.3 and 9.1 % (mean = 5.7 %) of the 24-h day with her head in the feeding trough. In this group of 10 sows, eating occurred only while standing as opposed to eating that can take place when a sow is in the sitting position. Eating was the primary activity recorded while standing, ranging from 55 to 91 % of the time spent standing. Producers should identify sows standing for an excessive amount of time after feeding (2 standard deviations above the mean equals 29.4 min post feeding) and confirm that there are no environmental impediments such as inappropriately placed bars or sharp objects that prohibit sows from lying down. Sows appeared to have a preference for the side when lying laterally, after successfully lying down; however, averages of time spent lying laterally on each side over the 10 sows appeared relatively equal between both the right and left side.

In conclusion, this study indicates that litter weaning weight adjusted for on-test weight and number of piglets at crossfostering was negatively associated with lesion score increases in OG ($P = 0.03$), CK ($P = 0.07$), and TS ($P = 0.39$) sows. There was no evidence

that sows with hoof lesions produced fewer number born alive. Sows with overgrown toes were associated with standing less time after feeding, and this result is consistent with previously reported findings. Increased piglet mortality during lactation was associated with an increase in CK and TS severity score, and thus, sows from those treatment groups weaned fewer piglets per litter.

LIST OF TABLES AND FIGURES

Table 1. Hoof lesion classification methods used in the evaluation of behavior and performance for commercial sows at a Midwestern U.S. swine integrator.

Control Sows [C]	
0	Absence of hoof cracks, less than 6.4 cm in length, and less than 1.3 cm difference between the outer and inner toe
Cracked hooves [CK]¹	
1	Presence of crack in hoof less than 1.3 cm in length
2	Crack in hoof of 1.4 to 2.5 cm in length
3	Crack in hoof greater than 2.6 cm or multiple cracks
Lateral and medial toe size differences [TS]²	
1	Toe length difference between 1.3 and 1.9 cm
2	Toe length difference between 2.0 and 2.5 cm
3	Toe length difference greater than 2.6 cm
Overgrown toe [OG]³	
1	One toe of a hoof must be within 6.4 and 8.3 cm in length
2	One toe of a hoof must be within 8.4 to 10.2 cm in length
3	One toe of a hoof must be greater than 10.3 cm in length
¹ The number, length, location, and severity of hoof cracks were recorded for each toe and for all sows in all treatment groups.	
² The length difference between the medial and lateral toe were obtained by using a standard ruler (measured at 0.32 cm increments) placed on the floor of the gestation stall between both toes and parallel to the long axis of the sow and leg.	
³ Toes were measured beginning at the coronary band and extending to the leading edge of the overgrown toe.	

Table 2. Distribution of sows categorized as having normal hooves [C] or as having hoof cracks [CK], differences in toe length [TS], overgrown toes [OG], or both hoof cracks and toe length differences [TK] by parity, lesion severity score, farm and experiment, conducted at a Midwestern U.S. swine integrator.

	N	Parity ¹				Lesion Severity Score ²				Farm ³		Behavior Data			
		1	2	3-5	6-8	0	1	2	3	A	B	Experiment 1		Experiment 2	
												N ⁴	Obs ⁵	N	Obs
Totals		26	36	122	39	79	68	59	17	188	35	150	236	10	10
Treatment Group															
C	79	11	11	42	15	79	-	-	-	68	11	53	86	5	5
CK	38	5	8	20	5	-	11	20	7	32	6	28	43	-	-
TS	61	5	10	37	9	-	36	20	5	51	10	38	58	2	2
OG	22	5	5	8	4	-	13	7	2	15	7	13	18	3	3
TK	23	0	2	15	6	-	8	12	3	22	1	18	31	-	-
Treatment Score															
0	79	11	11	42	15	-	-	-	-	11	15	53	86	5	5
1	68	5	11	46	6	-	-	-	-	21	15	48	75	-	-
2	59	7	11	26	15	-	-	-	-	117	5	42	65	3	3
3	17	3	3	8	3	-	-	-	-	39	0	7	10	2	2

¹Because of the difficulty finding both ideal treatment and control sows within the same parity within the same farrowing group, treatment and control sows were paired and considered a match using the following parity structure: 1, 2, 3 to 5, and 6 or greater parities

²Sows were also given a score that was positively correlated with the severity of the lesion. Sows classified as score 1 served as the control group; whereas sows of score 2, 3, or 4 were found to have some severity of hoof lesion.

³This study was conducted over two experiments. Experiment 1 was conducted on Farm A (Supermom sows, Newsham Genetics, Des Moines, IA) where feed intake data were recorded. Experiment 2 was conducted on Farm B (Line 23 and 29 sows, Pig Improvement Company, Hendersonville, TN) where no feed intake data were available.

⁴The number of unique sows for which behavior was measured.

⁵ Behavior was recorded on d 10 of lactation (\pm 3 d) at 0845 h for 64 sows and on d 10 and 11 of lactation at 0815 h for 86 sows. Thus, a total of 236 observations over 2 d of data collection.

Table 3. Lactation performance¹ of 223 sows categorized as having normal hooves [C] or as having hoof cracks [CK], differences in toe length [TS], or overgrown toes [OG], conducted at a Midwestern U.S. swine integrator.

Item	Number of Piglets Born Alive ² , N			Number of piglets after cross- fostering ³ , N			Litter BW after cross-fostering, kg		
	Estimate	SE	<i>P</i>	Estimate	SE	<i>P</i>	Estimate	SE	<i>P</i>
Treatment Group									
Control [C]	10.90	0.34		10.88	0.13		17.24	0.27	
Cracked Hooves, <i>b</i> ⁴	0.05	0.30	0.86	0.04	0.11	0.72	-0.14	0.24	0.57
CK 1	10.95	0.34		10.92	0.13		17.10	0.27	
CK 2	11.00	0.54		10.96	0.21		16.97	0.43	
CK 3	11.05	0.81		11.01	0.31		16.83	0.64	
Toe Length Differences, <i>b</i>	-0.10	0.33	0.76	-0.06	0.13	0.66	-0.32	0.27	0.23
TS 1	10.79	0.33		10.83	0.13		16.92	0.26	
TS 2	10.69	0.56		10.77	0.22		16.60	0.45	
TS 3	10.59	0.87		10.71	0.34		16.28	0.69	
Overgrown Toes, <i>b</i>	0.03	0.58	0.96	-0.02	0.22	0.93	0.32	0.46	0.48
OG 1	10.92	0.56		10.86	0.22		17.56	0.44	
OG 2	10.95	1.09		10.84	0.42		17.88	0.86	
OG 3	10.98	1.65		10.82	0.63		18.20	1.30	
Block Effect, ⁵ <i>P</i>			0.24			0.57			0.15
Covariance Effects									
Number of piglets in litter after cross- fostering	-	-	-	-	-	-	1.18	0.17	<0.001

¹Lactation and litter performance data were combined over two experiments. Sow genetics used in Experiment 1 and 2 were from Newsham Genetics (Supermom; Des Moines, IA) and Pig Improvement Company (Line 23 and 29; Hendersonville, TN).

²Farrowing data was missing from the farm database for 1 sow.

³Piglets were cross-fostered within 24-h between sows that farrowed on the same day. Litter size was targeted at 11 piglets/sow.

⁴*b* = beta for partial regression coefficient of treatment group.

⁵Between 2 to 8 sows were blocked in remove effects due to parity, room, farm, and genetics. Treatment and control sows were paired and considered a match using the following parity structure: 1, 2, 3 to 5, and 6 or greater parities.

Table 3. (Continued)

Item	Piglet Mortality during Lactation ⁶ , N			Piglets weaned per litter, N			Adjusted Litter Wean BW ⁷ , kg		
	Estimate	SE	<i>P</i>	Estimate	SE	<i>P</i>	Estimate	SE	<i>P</i>
Treatment Group									
Control [C]	0.02	1.60		9.15	0.15		44.61	0.63	
Cracked Hooves, <i>b</i> ⁴	0.25	0.11	0.02	-0.21	0.12	0.10	-0.93	0.51	0.07
CK 1	0.02	-		8.95	0.15		43.68	0.61	
CK 2	0.03	-		8.74	0.23		42.74	0.94	
CK 3	0.03	-		8.53	0.34		41.81	1.39	
Toe Length Differences, <i>b</i>	0.30	0.12	0.02	-0.35	0.14	0.02	-0.52	0.59	0.39
TS 1	0.02	-		8.80	0.14		44.09	0.57	
TS 2	0.03	-		8.45	0.24		43.58	0.98	
TS 3	0.04	-		8.11	0.36		43.06	1.52	
Overgrown Toes, <i>b</i>	0.16	0.19	0.40	-0.13	0.24	0.60	-2.16	0.98	0.03
OG 1	0.02	-		9.02	0.24		42.46	0.97	
OG 2	0.02	-		8.90	0.45		40.30	1.85	
OG 3	0.03	-		8.77	0.68		38.14	2.80	
Block Effect, ⁵ <i>P</i>			0.88			< 0.01			< 0.01
Covariance Effects									
Number of piglets in litter after cross-fostering	1.25	1.09	0.02	0.05	0.09	0.61	-	-	-
Litter BW at cross-fostering, kg	-	-	-	-	-	-	0.45	0.16	0.01
Lactation Length, d	-	-	-	-0.03	0.10	0.74	1.78	0.40	< 0.0001
Piglets weaned per litter, N	-	-	-	-	-	-	4.05	0.35	< 0.0001

⁴*b* = beta for partial regression coefficient of treatment group.

⁵Between 2 to 8 sows were blocked in remove effects due to parity, room, farm, and genetics. Treatment and control sows were paired and considered a match using the following parity structure: 1, 2, 3 to 5, and 6 or greater parities.

⁶Piglet mortality during lactation were analyzed using a Poisson distribution. The beta estimates and their standard errors are listed on the log scale. Least Square Means were back-transformed using the ILINK function of SAS.

⁷Adjusted weight produced in lactation = litter wean weight + piglet mortality weight + weight of pigs removed – weight of pigs added – weight of cross-fostered litter at birth.

Table 3. (Continued)

Item	Sow feed Disappearance during Lactation ⁸ , kg			Adjusted Litter Wean BW per kilogram feed intake, kg/kg		
	Estimate	SE	<i>P</i>	Estimate	SE	<i>P</i>
Treatment Group						
Control [C]	125.84	2.23		0.41	0.01	
Cracked Hooves, <i>b</i> ⁴	1.98	1.96	0.32	-0.02	0.01	0.02
CK 1	127.82	2.37		0.39	0.01	
CK 2	129.80	3.74		0.37	0.02	
CK 3	131.79	5.48		0.35	0.02	
Toe Length Differences, <i>b</i>	3.04	2.46	0.22	-0.02	0.01	0.07
TS 1	128.88	2.44		0.39	0.01	
TS 2	131.92	4.37		0.37	0.02	
TS 3	134.96	6.66		0.36	0.03	
Overgrown Toes, <i>b</i>	-10.79	6.99	0.13	0.004	0.03	0.90
OG 1	115.04	6.62		0.41	0.03	
OG 2	-	-		-	-	
OG 3	-	-		-	-	
Block Effect, ⁵ <i>P</i>			<0.01			0.04
Covariance Effects						
Litter BW at cross-fostering, kg	-	-	-	0.01	0.00	0.03
Lactation Length, d	5.03	1.52	< 0.01	-0.01	0.01	0.16
Piglets weaned per litter, N	-	-	-	0.03	0.01	< 0.001

⁴*b* = beta for partial regression coefficient of treatment group.

⁵Between 2 to 8 sows were blocked in remove effects due to parity, room, farm, and genetics. Treatment and control sows were paired and considered a match using the following parity structure: 1, 2, 3 to 5, and 6 or greater parities.

⁸Feed intake data were recorded for 135 sows. No data were available for sows in the OG 2 and 3 severity scores.

Table 4. Standing, sitting, kneeling, and lying down posture¹ least squares means (\pm SE) over a 24-h time period for 10 sows classified as having hoof lesions (abnormal) or normal hooves in an evaluation of the effects of toe abnormalities on lactating sow performance from a Midwestern U.S. swine integrator.

Item	Standing									
	Eating		Drinking		Defecate / Urinate		Other ²		Total time standing	
	Total	SE	Total	SE	Total	SE	Total	SE	Mean	SE
Treatment Groups ³ , <i>P</i>	0.47		0.82		0.45		0.47		0.95	
Abnormal ⁴	6.3%	0.5	0.1%	0.6	0.2%	0.6	1.3%	0.6	7.9%	0.5
Control	5.6%	0.5	0.1%	0.6	0.2%	0.6	1.6%	0.5	8.0%	0.5
Block Effect, <i>P</i>	0.17		0.33		0.46		0.10		0.24	

¹Sows in Experiment 2 were observed for a continuous 24-h period beginning at 9 AM on d 10 of lactation and ending at the same time on d 11. Sow genetics used in this experiment were Pig Improvement Company (Line 23 and 29; Hendersonville, TN).

²Other behaviors include all behaviors not specifically recorded. Most frequently, sows were just sitting or standing and watching other activity in the room, bar biting, or interacting with her piglets.

³Differences between treatment groups for all behaviors were $P > 0.05$.

⁴Sows classified in the abnormal category had overgrown toes (N = 3) or toe length differences (N = 2).

Table 4. (Continued)

Item	Sitting					
	Drinking		Other		Total	
	Total	SE	Total	SE	Mean	SE
Treatment Groups, <i>P</i>	<i>0.18</i>		<i>0.01</i>		<i>< 0.01</i>	
Abnormal	1.4%	0.6	2.4%	0.5	3.9%	0.5
Control	0.6%	0.6	1.5%	0.5	2.4%	0.5
Block Effect, <i>P</i>	<i>0.11</i>		<i>0.02</i>		<i>< 0.01</i>	

Table 4. (Continued)

Item	Kneeling		Lying Down							
			Sternal		Lateral, Left		Lateral, Right		Total	
	Total	SE	Total	SE	Total	SE	Total	SE	Mean	SE
Treatment Groups, <i>P</i>	<i>0.69</i>		<i>0.45</i>		<i>0.39</i>		<i>0.44</i>		<i>0.15</i>	
Abnormal	0.1%	0.6	13.9%	0.6	44.9%	0.6	27.2%	0.6	87.7%	0.5
Control	0.1%	0.6	11.1%	0.5	35.2%	0.6	37.6%	0.6	89.4%	0.5
Block Effect, <i>P</i>	<i>0.27</i>		<i>0.36</i>		<i>0.40</i>		<i>0.37</i>		<i>0.02</i>	

Figure 1. Time budget of sows for 45 min prior to and 1 h post feeding by treatment and lesion severity in an evaluation of the effects of toe abnormalities on lactating sow¹ performance from a Midwestern U.S. swine integrator.

¹Sows (Newsham Supermom, Des Moines, IA) were categorized as having overgrown toes [OG], differences in toe length [TS], hoof cracks [CK], both hoof cracks and toe size differences, or normal hooves [C] and assigned a severity score of 0 to 3. No behavior data were collected for the OG 3 group because of the low prevalence of this severity on Farm A.

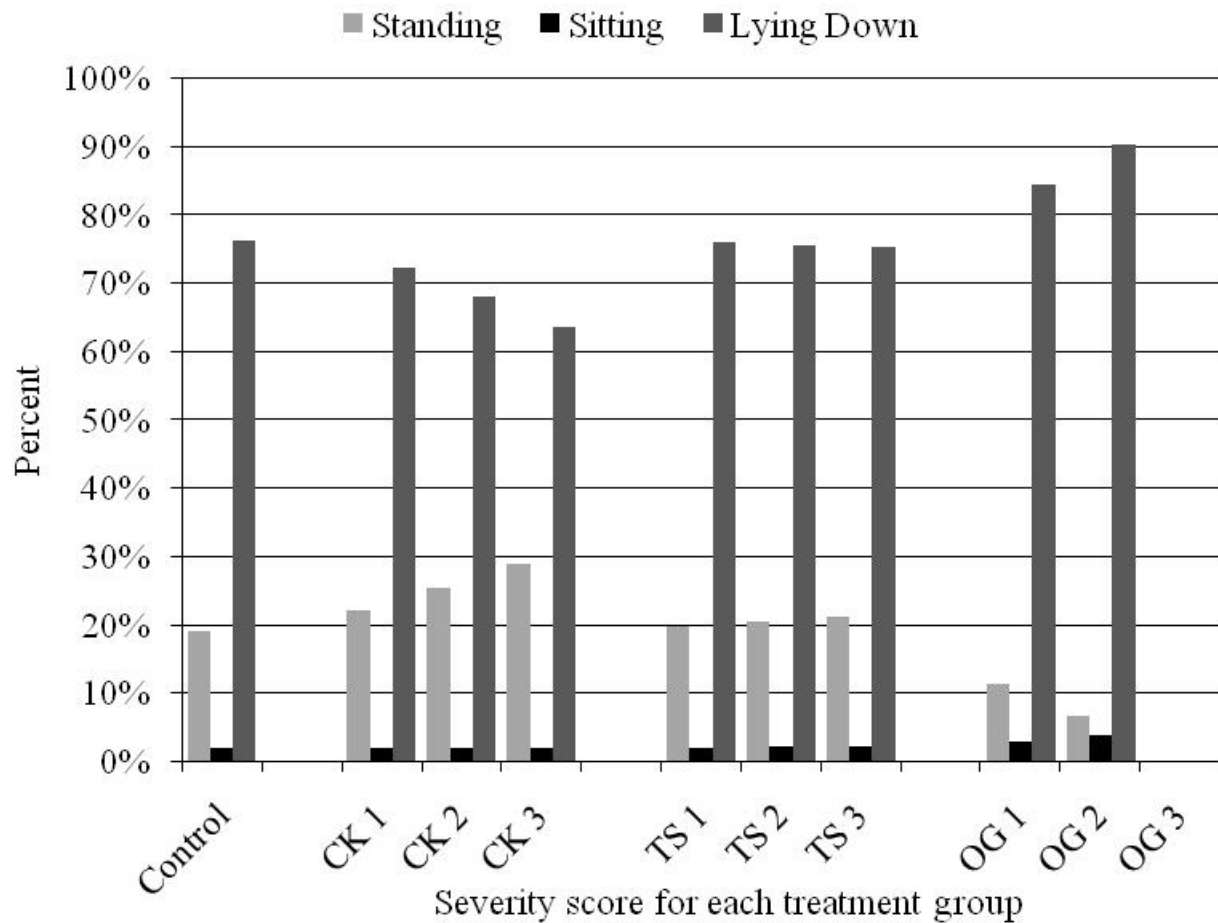


Figure 2. Percent of time spent standing and eating before and after feeding during a 105 min observation period by treatment and lesion severity in an evaluation of the effects of toe abnormalities on lactating sow¹ performance from a Midwestern U.S. swine integrator.

¹Sows (Newsham Supermom, Des Moines, IA) were categorized as having overgrown toes [OG], differences in toe length [TS], hoof cracks [CK], both hoof cracks and toe size differences, or normal hooves [C] and assigned a severity score of 0 to 3. No behavior data were collected for the OG 3 group because of the low prevalence of this severity on Farm A.

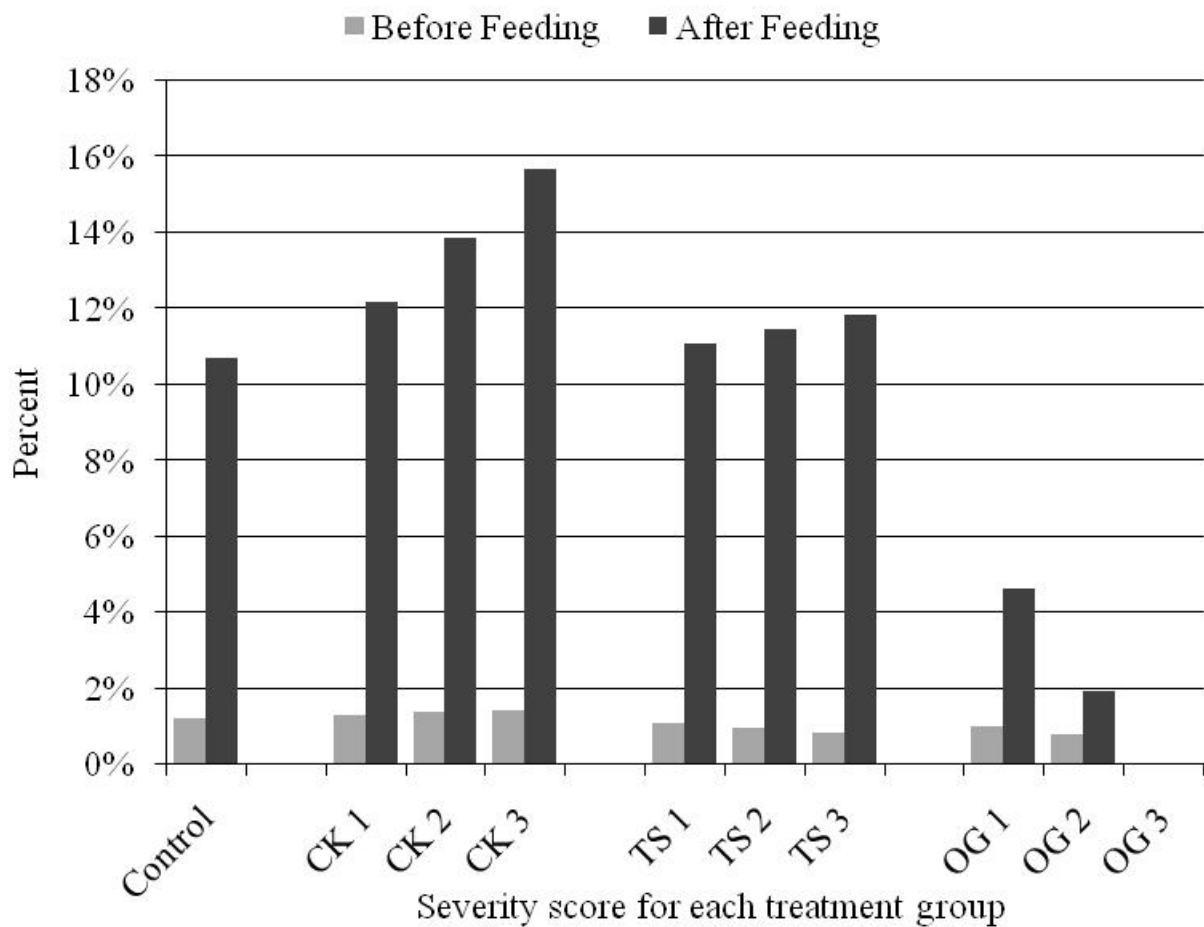


Figure 3. Percent of time spent kneeling after feeding and total time spent kneeling during a 105 min observation period¹ by treatment groups and severity lesion in an evaluation of the effects of toe abnormalities on lactating sow² performance from a Midwestern U.S. swine integrator.

¹Percent of time spent kneeling before feeding was not analyzed because low percentages of time were recorded for this period.

²Sows (Newsham Supermom, Des Moines, IA) were categorized as having overgrown toes [OG], differences in toe length [TS], hoof cracks [CK], both hoof cracks and toe size differences, or normal hooves [C] and assigned a severity score of 0 to 3. No behavior data were collected for the OG 3 group because of the low prevalence of this severity on Farm A.

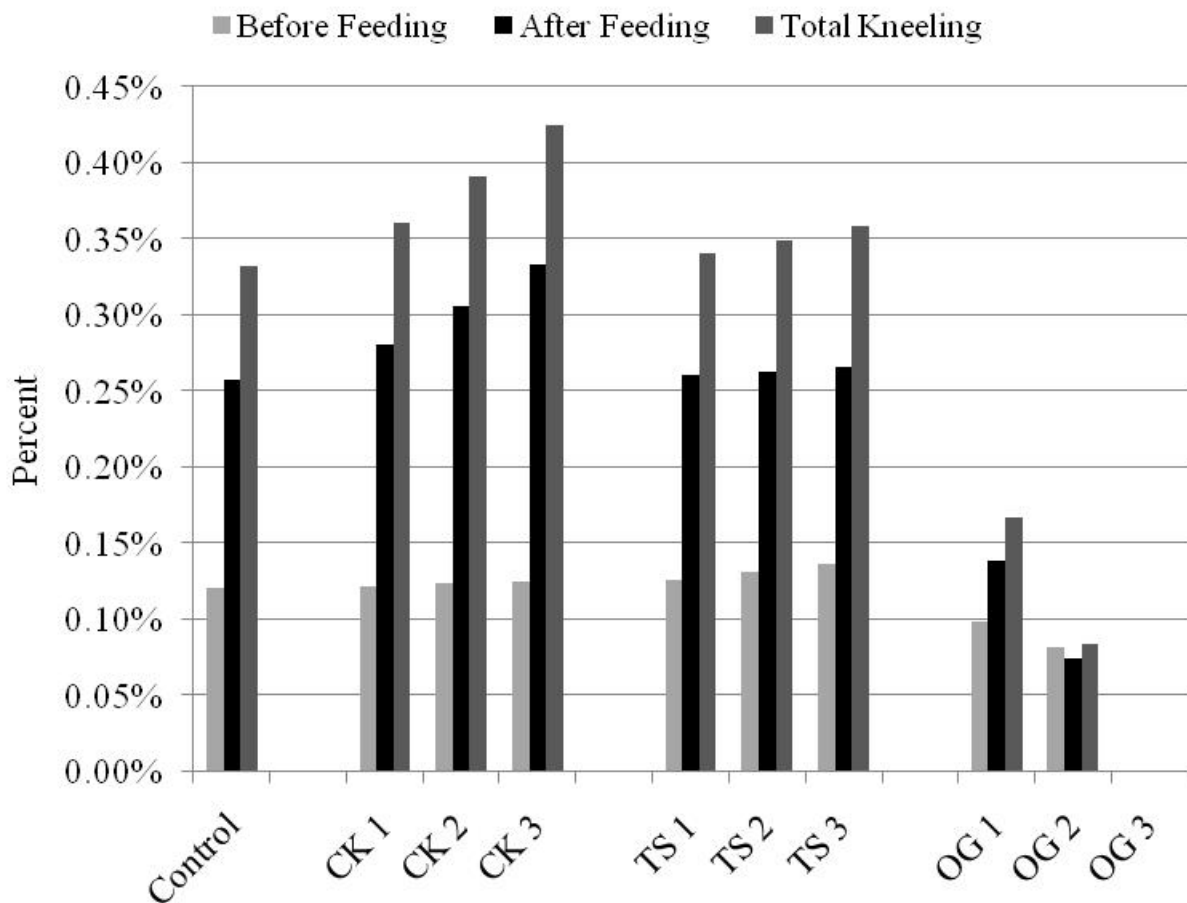


Figure 4. Percent of time spent lying down before and after feeding during a 105 min observation period by treatment groups and severity lesion in an evaluation of the effects of toe abnormalities on lactating sow¹ performance from a Midwestern U.S. swine integrator.

¹Sows (Newsham Supermom, Des Moines, IA) were categorized as having overgrown toes [OG], differences in toe length [TS], hoof cracks [CK], both hoof cracks and toe size differences, or normal hooves [C] and assigned a severity score of 0 to 3. No behavior data were collected for the OG 3 group because of the low prevalence of this severity on Farm A.

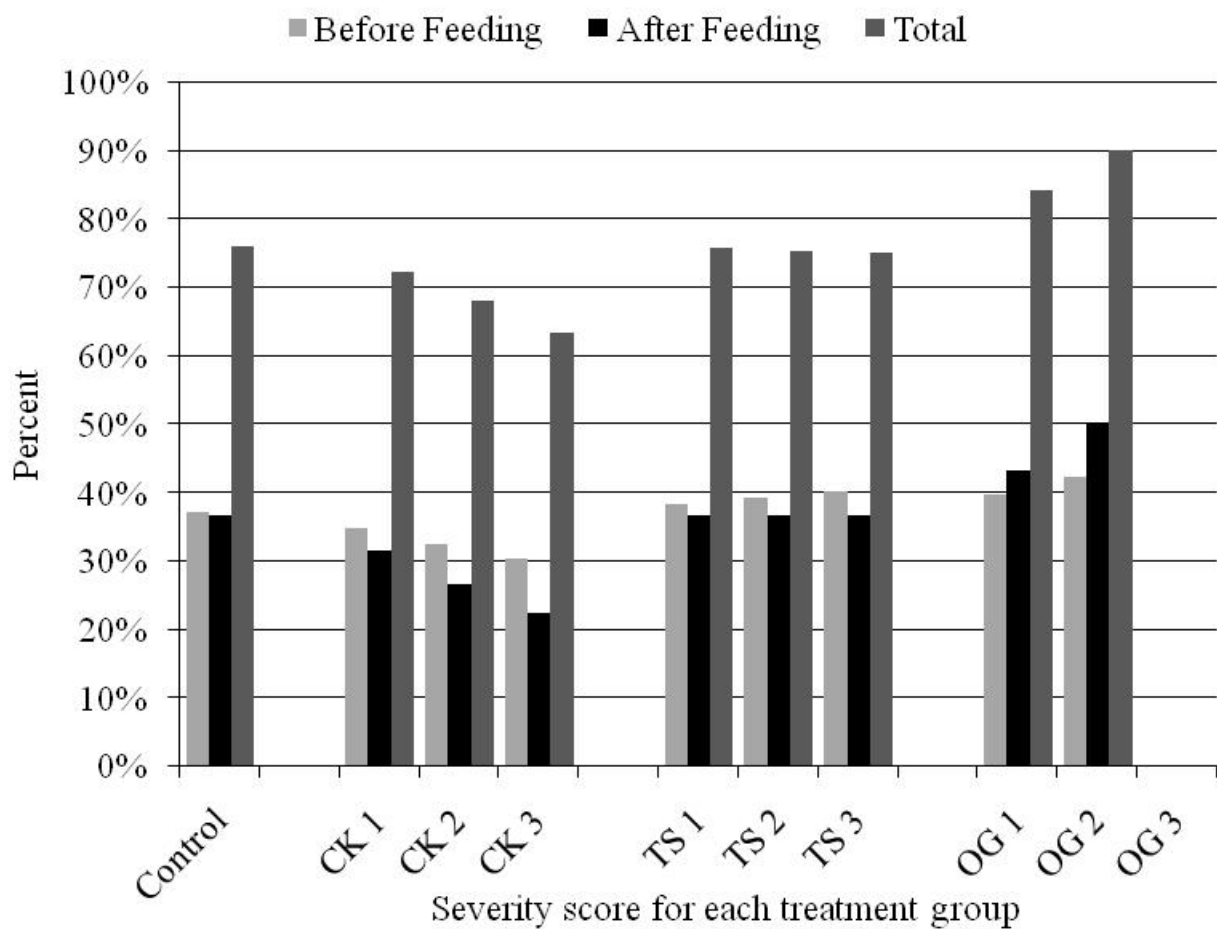
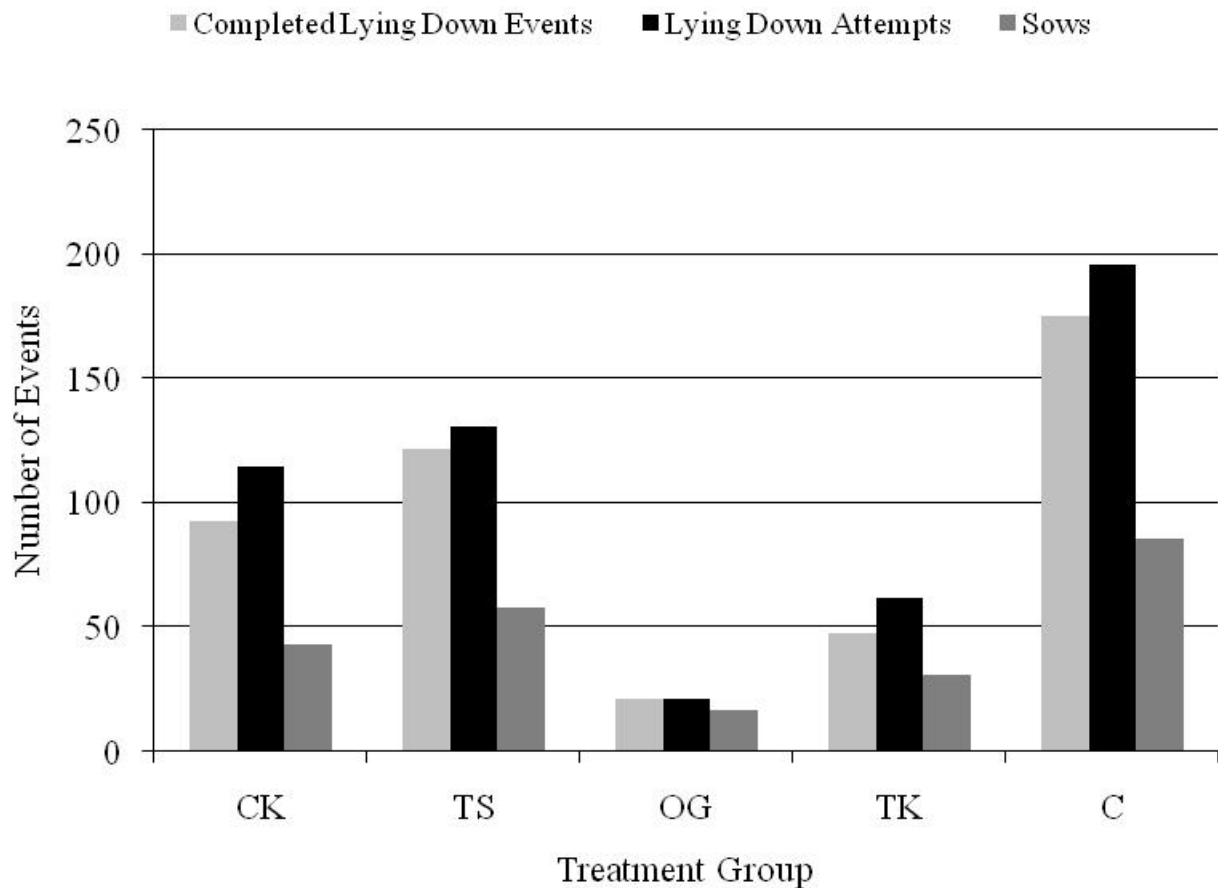


Figure 5. The number of completed and attempted lying down events during a 105 min observation period and the number of sows by treatment group in an evaluation of the effects of toe abnormalities on lactating sow¹ performance from a Midwestern U.S. swine integrator.

¹Sows (Newsham Supermom, Des Moines, IA) were categorized as having overgrown toes [OG], differences in toe length [TS], hoof cracks [CK], both hoof cracks and toe size differences [TK], or normal hooves [C] and assigned a severity score of 0 to 3. No behavior data were collected for the OG 3 group because of the low prevalence of this severity on Farm A.



LITERATURE CITED

- Bonde, M., T. Rousing, J. H. Badsberg, J. T. Sorensen. 2004. Associations between lying-down behaviour problems and body condition, limb disorders and skin lesions of lactating sows housed in farrowing crates in commercial sow herds. *Livest. Prod. Sci.* 87:179-187.
- Boyle, L. 1996. Skin lesions, overgrown hooves and culling reasons in individually housed sows. M.S. Thesis. University College, Dublin.
- Engblom, L., N. Lundeheim, A. M. Dalin, and K. Andersson. 2007. Sow removal in Swedish commercial herds. *Livest. Sci.* 106:76-86.
- Encyclopedia of farm animal behavior. USDA-ARS Livestock Research Unit.
http://www.depts.ttu.edu/liru_afs/EFAB/. Accessed March 24, 2009.
- Gjein, H., and R. B. Larssen. 1995. 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.* 36:433-442.
- Knauer, M., K. J. Stalder, L. A. Karriker, T. J. Baas, C. Johnson, T. Serenius, L. Layman, and J. D. McKean. 2007. A descriptive survey of lesions from cull sows harvested at two Midwestern U.S. facilities. *Prev. Vet. Med.* 82:198-212.
- Leonard, F. C., I. Stienezen, and P. B. Lynch. 1997. Behaviour of sows with overgrown hooves in the farrowing house. Agricultural Research Forum, Faculty of Agriculture, U.C.D Belfield, Dublin.
- Mahan, D. C., and A. J. Lepine. 1991. Effect of pig weaning weight and associated nursery feeding programs on subsequent performance to 105 kilograms body weight. *J. Anim. Sci.* 69:1370-1378.
- NHF. 2004. Selecting for feet and leg soundness in replacement gilts. Removable poster in National Hog Farmer Magazine. Penton Media, Inc., Overland Park, KS.
- NRC. 1998. Nutrient Requirements of Swine: 10th ed. National Academy of Science, Washington, D.C.

- Penny, R. H., A. D. Osborne, and A. I. Wright. 1963. The causes and incidences of lameness in store and adult pigs. *Vet. Rec.* 75:1225-1237.
- Stienezen, I. 1996. Welfare of confined sows with overgrown hooves in the farrowing house, M.S. Thesis. Moorepark Dairy Production Research Institute, Fermoy, Ireland.
- Vaughan, L. C. 1969. Locomotory disturbance in pigs. *Brit. Vet. J.* 125:345:365.

CHAPTER 5. THE ACCURACY AND REPEATABILITY OF SOW BODY CONDITION SCORING⁴

A paper submitted to the *Professional Animal Scientist* journal.

R. F. Fitzgerald,* K. J. Stalder,*⁵ P. M. Dixon,† A. K. Johnson,* L. Karriker,‡ and G. F.

Jones§

*Department of Animal Science, †Statistics, and ‡Veterinary Diagnostic and Production

Animal Medicine Department, Iowa State University, Ames, Iowa 50011

§Department of Agriculture, Western Kentucky University, Bowling Green, Kentucky,

42101

ABSTRACT

The objective of this study was to estimate observer accuracy and repeatability of body condition scoring sows when scorers have different levels of prior experience. Three groups of participants (n = 15) for this study were identified as having no (NE, n = 7), some (SE, n = 4), and extensive (EE, n = 4) prior experience evaluating conformation or body condition in livestock species. Two persons having extensive prior experience with body condition scoring served as instructors (TR) during the training sessions. Twenty-five of a total 150 sows were utilized in the participant training session, and the remaining sows (n =

⁴This paper of the Iowa Agriculture and Home Economics Experiment Station, Ames, Iowa, Project No. 3801, was supported by Hatch Act and State of Iowa Funds.

⁵ Department of Animal Science, Iowa State University, 109 Kildee Hall, Ames, Iowa 50011, USA, phone: 515-294-4683, fax: 515-294-5698, stalder@iastate.edu

125) were utilized during the independent scoring process. Sows utilized in the scoring process were objectively categorized into a 5- and 9-point body condition score (BCS₅ and BCS₉, respectively) using last rib backfat estimates. Participant BCS₅ and BCS₉ deviation evaluations from BCS_{backfat}, revealed a tendency for participants to overestimate BCS in some sows and underestimate BCS in others. Repeatability, a measure of variance attributed to individual participants between rounds of scoring, was the largest contributor (70.6 %; lower values are more desirable) to the total test variability. One plausible way to reduce repeatability error would be to average multiple, independent scores by the same participant on the same sow. Reproducibility, a measure of variance attributed to BCS assigned by multiple participants, only accounted for 29.4 % of the total test variation, suggesting that participants were adequate in their estimation of BCS in sows. Because participant variance only accounted for 16.3 % of the total test variance, much more opportunity exists to reduce repeatability variance as compared to variance associated with consistently over- or under-estimating BCS. Averaging over all participants, the ultrasonic trait of last rib backfat yielded the greatest correlation (0.58) with BCS₉, followed by tenth rib backfat (0.51), tenth rib loin eye area (0.47), and last rib loin eye area (0.43). Similar trends were observed for the BCS₅ scale. Therefore, practice assigning independent BCS should lower repeatability variance, but training to calibrate specific participants may only influence total test variance to a relatively small degree.

Keywords: Body condition score, Repeatability, Reproducibility, Sows.

INTRODUCTION

Sows can enter a negative energy balance during lactation when fat and muscle body reserves are mobilized to support produce milk for piglet growth. After weaning, a limited number of days are available during gestation to replenish the sows' depleted energy stores. In modern pork production systems, sow non-productive days is a key indicator of inefficiency, and thus minimized. Because non-productive days are minimized, Dourmad et al. (1996) suggests that the gestation period is the only period where body energy can be replenished in current production systems. Additionally, they report that modern sows require 8,500 kcal DE/d during gestation, about 1.3 times the maintenance requirement, to replenish body reserves.

Sows that have not attained mature size have nutrient requirements to support growth and these requirements must be met through rations provided during lactation and gestation. One possible way to improve reproductive performance after lactation is to reduce the amount of body weight lost during lactation. Thus, it is important for swine producers to have the skills necessary for accurate and repeatable quantifying of condition scores so that feed rations can be adjusted accordingly. For a more detailed review of the application of body condition scoring systems, see Burkholder (2000).

Young et al. (2001) suggested that body condition scores differ between producers or technicians and, based on results by Thomsen et al. (2008) evaluating lameness scoring, within producers' or technicians' own scores. Relating to commercial sow production, employees may verbally express their ability to evaluate body condition to their employer, but in reality this discrepancy may yield larger variations in sow body condition in the herd.

Thus, the objective of this study was to estimate the accuracy and repeatability of participants with different experience levels when scoring body condition.

MATERIALS AND METHODS

The protocol and use of these animals was reviewed and approved by the Iowa State University Animal Use and Care Committee (# 4-08-6548-S) and Institutional Review Board for human subjects (# 08-218).

Animal Description

Crossbred sows (Yorkshire x Landrace, $n = 150$) of parity 1 to 6 were housed in standard gestation stalls (0.75 m x 2.15 m). Using a cloth tape measure, heart girth and flank-to-flank measurements were obtained following procedures described by Iwasawa et al. (2004). Sow BW were calculated using the lactation sow BW equation listed in Sulabo et al. (2007) and ranged from 163 to 299 kg. Backfat and loin eye area were ultrasonically (Aloka 500, Corometrics Medical Systems, Wallingford, CT) estimated at the tenth and last rib by a National Swine Improvement Federation certified real-time ultrasound technician (Bates and Christian, 1994).

Twenty-five of the 150 sows were utilized in participant training, and the remaining sows ($n = 125$) were utilized during the scoring process. Sows utilized in the scoring process were objectively categorized into a 5- and 9-point body condition score (BCS_5 and BCS_9 , respectively) using last rib backfat estimates. Backfat guidelines for BCS_5 (1, 2, 3, 4, and 5) are described in Hill et al. (1998). The BCS_9 scale was modified from the BCS_5 scale by adding half measures to the integers (i.e. 1, 1.5, 2, 2.5, ..., 5). Backfat guidelines and sow

distributions for BCS₅ and BCS₉ are listed in Table 1. Sows of the same BCS may or may not have been housed next to another sow of the same BCS. Variables denoted with a subscript 5 or 9 refer to that variable being calculated using the BCS₅ or BCS₉ scale, respectively.

Participant Description

Three study participant groups were recruited from student populations enrolled in the Animal Science curriculum at Western Kentucky University. Of the 15 total students recruited (male = 9, female = 6), a total of 7, 4, and 4 participants were identified as having no (NE), some (SE), and extensive (EE) prior experience evaluating conformation or body condition in livestock species (i.e. pigs, beef cattle, dairy cattle, etc.), respectively. Ideal NE participants included students that had limited visual and physical contact with livestock and had no previous knowledge of body condition scoring methodology in any livestock species. Participants identified for the SE group had previous experience with BCS in beef cattle (Burmeister, 2006), and EE participants included students that had participated on a university-sponsored livestock evaluation team and had detailed knowledge of livestock anatomy and body condition scoring. Student knowledge of BCS was not objectively assessed prior to trial initiation. Investigators identified the students based on the students' participation on livestock evaluation teams or their ability to verbally communicate body condition scoring methodology. Two persons having extensive prior experience with body condition scoring and evaluating swine conformation served as trainers (TR) during the training sessions and as a comparative reference for this study.

Participant Training Description

Students completed two, 1-hr training sessions which included one classroom and one on-farm, live animal instructional session. During the 1 hr classroom training, students were

provided a diagram of a sow that illustrated anatomical locations where body condition is typically evaluated and pictures of sows representing each BCS (Fitzgerald et al., 2008). Students were instructed to observe sow body condition on the shoulder blade (scapula), spine, hip bones, and tail head. The trainer also discussed methods to objectively determine backfat (A-mode ultrasound, Lean-Meater, Renco Corp, Minneapolis, MN; and B-mode ultrasound, Aloka 500 ultrasound machine), heart girth, and flank-to-flank measurements. Both trainers having previous experience assessing body condition in sows were responsible for the classroom training session.

Students participated in an on-farm training session utilizing 25 sows prior to scoring a separate group of 125 trial sows on the same day. Because all participants could not attend on the same day, two consecutive days were available for participants to attend one day of the on-farm training and scoring sessions. Participant 16 (Trainer 1) conducted the on-farm training session on d 1, and Participant 17 (Trainer 2) conducted the on-farm training session on d 2. On d 1, both trainers evaluated BCS on the 25 practice sows and verbal agreement was established before training any participants. During the on-farm training session for students, the trainer reinforced information presented in the classroom using live sows of different BCS. With the guidance of the trainer, the students practiced determining BCS by verbally assigning individual scores to 25 practice sows using the BCS₉ scale.

Participant Scoring Description

Students and trainers scored sows using the BCS₉ scale from the front of the gestation stalls. Thus, participants were able to view the head, back, and both sides of the sows while the sows were in a standing position. This vantage point was established to mimic situations where a producer simultaneously scores sows and adjusts feed drops to provide more, less, or

the same amount of the gestation ration. Participants were instructed to assign BCS to the 125 sows independently of other participants. Once the first round was completed for each participant, they were asked to reevaluate the same sows in a different order so that participants could not maintain identity and their associated scores. Sows were also scored by two trainers on the same day they conducted the on-farm training session.

Statistical Analysis

In this study, scores derived from B-mode ultrasonic last rib backfat estimates served as the ‘official’ BCS (BCS_{backfat}) for each sow. From participants original BCS_9 , a BCS_5 was derived by taking the integer of the score. For example, sows assigned a BCS_9 of 4.5 would equal a BCS 4 on the 5-point scale.

According to Taylor and Kuyatt (1994), repeatability is a statistic that evaluates the “closeness of the agreement between the results of successive measurements on the same measurand carried out under the same conditions of measurement.” Reproducibility is a statistic that evaluates the “closeness of the agreement between the results of measurement of the same measurand carried out under changed conditions of measurement” (Taylor and Kuyatt, 1994); in this study, the changed condition refers to the participant. Thus, variance associated between scoring rounds within the same participant is repeatability whereas the variance associated with different participants assigning the same score to a sow is reproducibility. Variance components that are large in magnitude are undesirable.

Reproducibility and repeatability variance components were computed using participant BCS_5 and BCS_9 deviations and their absolute values from BCS_{backfat} as the dependent variable in Analysis of Variance methodology (MIXED, SAS Institute, Inc., Cary, NC). Experience level of participants was used as the fixed effect, and sow, participant

within experience level, and the interaction of sow by participant within experience level were used as random terms in the model. Best Linear Unbiased Predictions (BLUPs) estimates for each participant and experience level were derived from the model, and their absolute values were further evaluated for heterogeneity of variance using the Levene's test for unequal variance. Likelihood-based methods to evaluate heterogeneity of variance were not used because attempts to fit models with heterogeneous variances did not converge after 12 hours of computing.

Participant BCS₉ values were averaged over both rounds of scoring and evaluated using two multiple linear regression models to determine if 1) only body condition or 2) body condition plus other conformation factors such as tenth and last rib loin eye area or flank girth were associated with participant assigned BCS values. R-square statistics were computed for each model to determine if the full model accounted for greater variation than the backfat only model.

Pearson correlation coefficients were calculated between BCS₅ and BCS₉ assigned by participants and ultrasonic measures and between participants' first and second round of scoring using the CORR procedure of SAS.

RESULTS AND DISCUSSION

A total of 4, 4 and 7 participants were categorized into the EE (participants 1 through 4), SE (participants 5 through 8), and NE (participants 9 through 15) groups. Participants 16 and 17 served as trainers and conducted the training sessions on d 1 and 2, respectively.

Results from this study are presented on both BCS scales. The reason for using the BCS₉ scale in addition to the more traditional BCS₅ scale was to reduce the probability of

participants guessing the correct BCS as well as the BCS₉ scale could assume a normal distribution. Of the 125 sows, 60.0% of the sows were categorized as a BCS₅ 3 compared to 28.8% using the BCS₉ scale (Table 1). However, the remaining 31.2% of the 60.0% were categorized as a 3.5 on the BCS₉ scale. Minimum and average scores on the BCS₅ were 1.0 and 2.90 and on the BCS₉ was 1.5 and 3.17, respectively. Only 3 sows were categorized as BCS 5 on both scales. In this study, sow BCS were approximately normally distributed for both scales, which is representative of commercial sow operations where producers train employees to BCS sows. However, the authors suggest that, for this study, non-normally distributed BCS may have been more advantageous as to reduce the probability that the participants assigned the correct BCS by chance alone.

Simple means for backfat, muscle, and body conformation are shown in Table 2. Tenth and last rib backfat averaged 25.9 and 18.7 mm, respectively, for all sows in the study. Tenth rib backfat increased an average of 8.6 mm for each score increase in BCS₅ and 4.5 mm for each half score increase in BCS₉. Positive linear trends for tenth ($P < 0.05$ for BCS₅ and BCS₉) and last rib ($P = 0.13$ and $P = 0.03$ for BCS₅ and BCS₉, respectively) loin eye area with BCS were not as evident as those in backfat, which may be attributed to the fact that sows were categorized into BCS based on backfat. However, flank-to-flank measurements and heart girths increased in length as BCS increased, yielding moderate Pearson correlation coefficients of 0.52 and 0.36 for BCS₅ ($P < 0.001$ different than zero) and 0.58 and 0.44 for BCS₉ ($P < 0.001$ different than zero), respectively. Heart girth was found to be moderately correlated (0.69) with flank-to-flank measurements.

Deviations from the $BCS_{backfat}$

Mean deviations, in this study named participant bias, between BCS_9 assigned by participants of different experience groups and $BCS_{backfat}$ for 2 rounds of scoring are shown in Figure 1. Mean deviations from the official over both rounds and all experience levels for BCS_5 and BCS_9 were 0.01 (average $BCS = 2.91$) and -0.03 (average $BCS = 3.14$), respectively. There was no evidence ($P = 0.41$ for BCS_9 and $P = 0.43$ for BCS_5) to suggest that deviations from participants of different experience levels were different from zero (Table 3). However, the EE, NE, and TR group consistently underestimated $BCS_{backfat}$ whereas the SE group overestimated $BCS_{backfat}$ during both rounds of scoring. When implementing subjective BCS methods in swine production, it is important for scorers to be cognizant of their average bias so that scorers could increase or decrease their assigned BCS and feed could be adjusted more accurately.

Variance Components

Before pooling participants from both days of scoring into one dataset, F tests were computed to test for day of scoring variance component equality. There was evidence (F value = 2.09, $P < 0.05$) of unequal variances between days of scoring for the participant by sow component, which is the variance associated with inconsistent BCS scoring by participants on an individual sow. However, there was no evidence to suggest that participant variance (variance attributed to consistent biases among participants; F value = 0.72, $P > 0.05$) or repeatability (residual variance; F value = 1.05, $P > 0.05$) were unequal between both scoring days, which suggests that both trainers performed equally when teaching multiple participants to assign BCS_9 . Therefore, analyses were conducted using the entire pooled dataset.

Variance components derived from analyses evaluating deviations in participant assigned BCS₅ and BCS₉ are shown in Table 3. From the computed Levene's tests, there was no evidence for unequal variances between participants of different experience levels for participant within group variance ($P = 0.78$), sow by participant variance ($P = 0.60$), and repeatability ($P = 0.47$). Clearly, repeatability was the largest contributor to the total test variability (total variation = reproducibility + repeatability), accounting for 70.6 % of the total variation. One plausible way to reduce repeatability error would be to average multiple, independent scores by the same participant on the same sow for approximately 15 to 20 sows. If a pork producer attempts to average multiple scores, it is important to obtain each score independently of the other, as the first score could bias the second score. Another plausible way to reduce repeatability error would be for participants to practice assigning BCS to sows, as trainers (those participants that had the greatest amount of practice) had the numerically lowest repeatability variance of all experience levels.

Reproducibility only accounted for 29.4 % of the total test variation, suggests that participants were adequate in their estimation of BCS in sows. Calibrating participant BCS (correcting for consistently over- or under-estimating BCS over all sows) would only reduce participant variance. Because participant variance only accounted for 16.3 % of the total test variance, much more opportunity exists to reduce repeatability variance as compared to variance associated with consistently over- or under-estimating BCS. However, because some participants averaged under estimating BCS₉ as large as 0.49 scores, this aspect of training should not be overlooked.

Because of the importance of identifying outlier sows (less than 2.5 and greater than 4.0 BCS₉ sows), analysis of variance using only sows only in those categories was

performed. Results for repeatability and reproducibility variances calculated from that analysis were similar (within 5%, data not shown) to variances obtained when using all sows. Thus, participants were similar in their estimation of the ends of the distribution as well as the entire distribution of sows.

In this study, reproducibility and repeatability intraclass correlations [calculated using the equations listed in Evans (1978) and used by Vizcarra and Wiettemann (1996) and Nicholson and Sayers (1987)] for all participants were 0.59 and 0.71 for the BCS₉ and 0.58 and 0.68 for the BCS₅ scale, respectively. Vizcarra and Wiettemann (1996) evaluated the reproducibility and repeatability of participant BCS₉ in cattle for 3 groups of participants with different levels of experience. They reported a significant difference in both reproducibility and repeatability between experience levels; that is, a group of 4 participants that had at least 2 yr of BCS₉ experience had the greatest reproducibility and repeatability values (0.65 and 0.83, respectively). However, in that study, participants were allowed to palpate the cows if they preferred. They concluded that trained participants could evaluate BCS₉ to within 1 unit (0.5 scores in this study). In this study, reproducibility and repeatability intraclass correlations were smaller in those previously reported by Nicholson and Sayers (1987) where they evaluated participant assigned BCS using a 6- and 9-pt scale on *Bos Indicus* cattle. They reported reproducibility and repeatability statistics for 4 participants on the BCS₉ scale was 0.84 and 0.88 (range 0.84 to 0.88), respectively. However, in that study, cows ranged in BCS₉ from 1 to 6 as compared to sows were assigned to 8 of the BCS₉ categories.

Regression of BCS₉

Upon further evaluation of participant BCS₅ and BCS₉ deviations from BCS_{backfat}, a tendency was observed for most participants to overestimate BCS in some sows and underestimate BCS in others. From this observation, a hypothesis was formed to determine whether participants considered factors other than body condition when estimating BCS in sows. To evaluate this hypothesis, regression analyses of participant deviations were performed using 1) a full model that included tenth and last rib backfat and loin eye area, and flank-to-flank measurements as the regression terms and 2) a reduced model with only tenth and last rib backfat variables. The full model accounted for a larger portion of variance in BCS₉ [$R^2 = 0.50$; Error Sums of Squares (ESS) = 789.15] compared to the reduced model ($R^2 = 0.36$; ESS = 792.34). Of the two regression terms in the reduced model, tenth rib backfat was not linearly associated with BCS₉; however, when included in the full model, a slightly positive ($b = 0.008$ score / mm increase in tenth rib backfat; $P < 0.01$) association with BCS₉ was observed. A positive, linear association was observed for last rib backfat and BCS₉ in the full ($b = 0.05$, $P < 0.001$) and reduced ($b = 0.07$, $P < 0.001$) models. Regression terms tenth ($b = 0.02$) and last ($b = 0.008$) rib loin eye area were positively associated ($P < 0.01$ for each regression term) with BCS₉ in the full model. Flank-to-flank measurement was not linearly associated ($P = 0.82$) with BCS₉. There was strong evidence that participants may have included other factors such as muscle composition to assist them in their evaluation and estimation of sow body condition. Although both tenth and last rib loin eye area were highly correlated (0.79), a low Pearson correlation coefficient of 0.22 was observed between last rib loin eye area and backfat, which may lend more evidence to the observation that participants truly evaluated muscle in addition to body condition.

Correlations

Pearson correlation coefficients for BCS₅ and BCS₉ with ultrasonic measures are shown in Table 4. Correlations between participant assigned BCS₉ and ultrasonic measures were consistently greater than those calculated using the BCS₅ scale, but were within one standard deviation. Averaging over all participants, the ultrasonic trait of last rib backfat yielded the greatest correlation (0.58) with BCS₉, followed by tenth rib backfat (0.51), tenth rib loin eye area (0.47), and last rib loin eye area (0.43). Similar trends were observed for the BCS₅ scale. Young and coworkers (2001) found a positive, but low relationship ($r^2 = 0.19$) of BCS₅ assigned by a farm manager and last rib backfat in 1306 sows using A-mode ultrasound. In this study, last rib backfat estimates were estimated using B-mode ultrasound.

Both tenth and last rib loin eye area were positively correlated with BCS₅ and BCS₉ for all participants. Larger loin eye area may have influenced participants to assign larger BCS to sows as compared to if BCS were assigned based on body condition alone. However, this result should not be considered negative, as both body condition and muscle are mobilized to support piglet growth through milk production.

Maes et al. (2004) evaluated the relationships between P2 backfat thickness (last rib) and reproduction and lactation performance. They reported a negative association between changes in last rib backfat thickness and piglets weaned per sow. The correlation coefficient between body condition scores and P2 backfat thickness was 0.48, and varied between 3 herds, parity, and the stage of production. The highest correlation was calculated during d 80 of gestation (0.52), compared to at farrowing and weaning. They further suggest that muscling could possibly impact visual scoring of body condition, and the accuracy of evaluating body condition varies with the skill level of the observer.

Pearson correlation coefficients were calculated between participants' first and second round of scoring and values are listed in Table 4. Correlations between rounds of scoring within participants averaged 0.69 for BCS₉, ranging from 0.43 to 0.82. A high correlation (0.73) was calculated for BCS₉ between the two participants in the TR group over both rounds of scoring.

Feeder Adjustments

Accurate sow body condition estimates enable producers to adjust feed rations to replenish or maintain body reserves. To hypothetically evaluate whether participants would have performed some corrective feed adjustment for sows outside BCS₉ 3.0 and 3.5 scores, sows assigned BCS_{backfat} less than 3.0 and greater than 3.5 were counted separately as well as the number of sows assigned to those categories by the participants. Participants averaged performing some level of corrective feed ration adjustments for 51.6 %, ranging from 21.7 to 88.3 %, of the 60 possible opportunities (30 sows of BCS₉ less than 3.0 x 2 rounds of scoring) to identify a sow of less than BCS₉ 3.0 (Table 5). Similarly, of the possible 40 opportunities to identify a BCS₉ 4.0 or greater, participants correctly adjusted 48.8 %, ranging from 25.0 to 70.0%. Six participants had both scores within a 10% range (average = 5.0 %; e.g. participant 2 found 60.0% of sows with BCS₉ less than 3.0 and 62.5% of sows with BCS₉ 4.0 or greater); whereas, the remaining participants averaged a 31.7 % difference between correctly adjusting feeders for thin and fat sows.

Whereas it is important to identify all sows that need some level of ration adjustment, BCS₉ 2.5 and 4.0 was only 0.5 scores different than sows that were assumed to not need ration adjustment. Thus, the same procedure that evaluated sows less than 3.0 and greater than 3.5 was performed for sows less than 2.5 and greater than 4.0 in an effort to identify

participants that correctly identified sows that need a larger amount of ration adjustment. Participants averaged performing some level of feed ration adjustment for only 32.0 % of the 30 opportunities to identify a sow of BCS₉ 2.0 or less. The participants were poorer at identifying sows assigned 4.5 or greater (average = 18.7 % of the 22 scoring opportunities). Therefore, producers might be providing excess feed to sows that are heavily conditioned. The poor ability of some participants to identify a large portion of the outlier sows lends further evidence to the large repeatability errors observed for participants in this study. Body condition scoring is an ongoing process when gestation feed quantity is properly and regularly adjusted. Producers and barn workers should evaluate sows' body condition on a regular basis (for example bi-weekly or monthly) in order to ensure that sows enter the farrowing barn at or near the ideal body condition.

In conclusion, participants in this study tended to assign BCS on their own scale and had individual specific biases towards over- or underestimating BCS in sows. There was no evidence in this study for unequal variances between participants of different experience levels for variance associated with reproducibility and repeatability on both BCS scales. Repeatability was the largest contributor to the total test variability, accounting for 70.6 % of the total variation, and reproducibility accounted for the balance of variation (29.4 %). Therefore, practice assigning independent BCS should lower repeatability, but training to calibrate specific participants would only have small influences in total test variation of participant assigned BCS deviations from BCS derived from backfat.

LIST OF TABLES AND FIGURES

Table 1. Last rib backfat guidelines utilized to categorize sows into a 5- and 9-point body condition score and the subsequent distribution by BCS.

BCS ¹	Backfat, mm				Number of sows ²	
	BCS ₅		BCS ₉		BCS ₅	BCS ₉
	Minimum	Maximum	Minimum	Maximum	N	N
1.0	0	10	0	7.5	6	0
1.5	-	-	7.5	10		6
2.0	10	15	10	12.5	24	9
2.5	-	-	12.5	15		15
3.0	15	23	15	19	75	36
3.5	-	-	19	23		39
4.0	23	30	23	26.5	17	9
4.5	-	-	26.5	30		8
5.0	30	-	30	-	3	3

¹BCS = Body condition score; BCS were scored using a 5 [BCS₅; 1, 2, ..., 5] or 9 [BCS₉; 1, 1.5, 2, ..., 5] point BCS scale.

²Sows were assigned BCS using last rib backfat estimates.

Table 2. Mean tenth and last rib backfat and loin eye area, heart girth, and flank-to-flank measurements for 125 sows categorized into body condition scores¹ (BCS) using last rib backfat estimates in a study of estimating visual body condition scores.

BCS ¹	10 th rib backfat, mm		Last rib backfat, mm		10 th rib loin eye area, mm		Last rib loin eye area, mm		Heart girth, mm		Flank-to-flank measurement, mm	
	BCS ₅	BCS ₉	BCS ₅	BCS ₉	BCS ₅	BCS ₉	BCS ₅	BCS ₉	BCS ₅	BCS ₉	BCS ₅	BCS ₉
1.0	12.7	-	9.1	-	44.6	-	48.3	-	50.7	-	38.2	-
1.5	-	12.7	-	9.1	-	44.6	-	48.3	-	50.7	-	38.2
2.0	18.7	16.0	13.1	11.4	51.4	53.9	52.5	54.9	54.1	51.6	39.6	38.9
2.5	-	20.4	-	14.0	-	50.1	-	51.3	-	55.4	-	40.1
3.0	26.5	24.4	18.9	17.0	53.1	50.4	51.8	48.3	55.6	53.9	41.5	40.5
3.5	-	28.4	-	20.7	-	55.5	-	55.0	-	57.1	-	42.3
4.0	34.9	33.6	26.4	24.7	53.7	54.8	54.9	56.3	56.6	57.3	43.7	43.6
4.5	-	36.4	-	28.3	-	52.5	-	53.4	-	55.8	-	43.9
5.0	43.9	43.9	33.2	33.1	53.7	53.7	54.7	54.7	60.0	60.0	44.0	44.0

¹BCS = Body condition score; BCS were scored using a 5 [BCS₅; 1, 2, ..., 5] or 9 [BCS₉; 1, 1.5, 2, ..., 5] point BCS scale. Sows were assigned BCS using last rib backfat estimates.

Table 3. Variance components and intraclass correlations calculated from the evaluation of deviations from body condition scores (BCS) derived from backfat for participants categorized as trainers (TR; n = 2) or as students having extensive (EE; n = 4), some (SE; n = 4), or no (NE; n = 7) prior BCS experience on two scales¹

Experience Level	Least Squares mean deviation ²	Sow ³	Participant within Group ⁴	Sow by Participant within Group ⁵	Error Variance	Reproducibility Variance ⁶ , %	Repeatability Variance ⁷ , %	Reproducibility intraclass correlation ⁸	Repeatability intraclass correlation ⁹
BCS ₉									
All Participants	-	0.269	0.030	0.024	0.131	0.29	0.71	0.59	0.71
EE	-0.09	0.277	0.022	0.038	0.132	0.31	0.69	0.59	0.72
SE	0.10	0.276	0.011	0.011	0.144	0.13	0.87	0.62	0.67
NE	-0.07	0.279	0.041	0.012	0.135	0.28	0.72	0.60	0.71
TR	-0.04	0.243	0.048	0.029	0.085	0.48	0.52	0.60	0.79
<i>P</i>	<i>0.41</i>	-	<i>0.78</i>	<i>0.60</i>	<i>0.47</i>				
BCS ₅									
All Participants	-	0.331	0.030	0.027	0.184	0.24	0.76	0.58	0.68
EE	-0.05	0.342	0.017	0.043	0.185	0.25	0.75	0.58	0.69
SE	0.14	0.324	0.008	0.016	0.196	0.11	0.89	0.60	0.64
NE	-0.03	0.335	0.044	0.016	0.188	0.24	0.76	0.57	0.68
TR	0.02	0.308	0.050	0.054	0.140	0.43	0.57	0.56	0.75
<i>P</i>	<i>0.43</i>	-	<i>0.44</i>	<i>0.84</i>	<i>0.61</i>				

¹Sows were assigned an official 5- (1, 2, ..., 5) and 9-point (1, 1.5, 2, ..., 5) BCS using last rib backfat estimates. Deviations were calculated as BCS assigned by participants minus BCS_{backfat}.

²Deviations were calculated as BCS assigned by participants minus BCS_{backfat}.

³Estimated variance in deviations from BCS_{backfat} between sows

⁴Variance attributed to different consistent biases among participants (i.e. average participant over- or under- estimation of BCS_{backfat})

⁵Variance associated with inconsistent scoring of BCS by participant idiosyncratic evaluation of a particular sow

⁶Reproducibility = (variance of participant + variance of sow by participant within experience level) / total variance. Total variance = variances of participant within group + sow by participant within group + error.

⁷Repeatability of BCS by the same participant on the same sow. Repeatability = error variance / total variance

⁸Reproducibility intraclass correlation = sow variance / entire variance. Entire variance = variance of sow + participant + sow by participant + error (Evans, 1978).

⁹Repeatability intraclass correlation = (sow variance + participant variance + sow by participant variance) / entire variance (Evans, 1978).

Table 4. Mean Pearson correlation coefficients and their standard deviations for tenth and last rib backfat and loin eye area estimates¹ and rounds of scoring with participant assigned body condition score (BCS) using a 5- and 9- point scale² by participant experience level.

Experience Level ³	BCS ₅				BCS ₉					
	10 th rib backfat	Last rib backfat	10 th rib loin eye area	Last rib loin eye area	BCS ₅	10 th rib backfat	Last rib backfat	10 th rib loin eye area	Last rib loin eye area	Rounds of scoring
Mean										
EE	0.50	0.56	0.45	0.42	0.94	0.52	0.58	0.47	0.45	0.74
SE	0.48	0.55	0.44	0.42	0.93	0.51	0.59	0.49	0.45	0.72
NE	0.44	0.50	0.42	0.38	0.92	0.48	0.54	0.45	0.40	0.62
TR	0.54	0.60	0.46	0.45	0.93	0.58	0.65	0.49	0.48	0.81
Standard Deviation of Mean										
EE	0.08	0.07	0.04	0.03	0.01	0.06	0.06	0.04	0.01	0.05
SE	0.03	0.03	0.04	0.06	0.03	0.03	0.02	0.02	0.04	0.05
NE	0.07	0.07	0.05	0.06	0.02	0.07	0.06	0.07	0.07	0.14
TR	0.11	0.06	0.01	0.02	0.01	0.08	0.04	0.02	0.03	0.02

¹Ultrasonic measures were estimated using a B-mode ultrasound device.

²Sows were assigned an official 5- (1, 2, ..., 5) and 9-point (1, 1.5, 2, ..., 5) BCS using last rib backfat estimates. Deviations were calculated as BCS assigned by participants minus BCS_{backfat}.

³Participants were categorized as trainers (TR; n = 2) or having extensive (EE; n = 4), some (SE; n = 4), or no (NE; n = 7) prior experience assigning BCS in sows.

Table 5. Percentage of sows¹ that participants correctly performed² some amount of corrective adjustment to the sows' ration in a study assigning proper body condition scores in gestating sows.

Day of Training	Experience Level	Participant	N of BCS ₉ 2 or less sows	Correctly assigned 2.0 or less sows, %	N of BCS ₉ 2.5 or less sows	Correctly assigned 2.5 or less sows, %	N of BCS ₉ 4 or greater sows	Correctly assigned 4 or greater sows, %	N of BCS ₉ 4.5 or greater sows	Correctly assigned 4.5 or greater sows, %
1	EE	1	13	43.3%	33	55.0%	17	42.5%	4	18.2%
1	EE	2	7	23.3%	36	60.0%	25	62.5%	8	36.4%
1	EE	3	11	36.7%	44	73.3%	15	37.5%	2	9.1%
2	EE	4	8	26.7%	36	60.0%	20	50.0%	3	13.6%
1	SE	5	6	20.0%	19	31.7%	28	70.0%	8	36.4%
1	SE	6	9	30.0%	29	48.3%	21	52.5%	7	31.8%
1	SE	7	15	50.0%	36	60.0%	27	67.5%	9	40.9%
1	SE	8	4	13.3%	15	25.0%	25	62.5%	6	27.3%
1	NE	9	6	20.0%	27	45.0%	19	47.5%	4	18.2%
1	NE	10	15	50.0%	42	70.0%	14	35.0%	0	0.0%
1	NE	11	4	13.3%	13	21.7%	26	65.0%	1	4.5%
2	NE	12	18	60.0%	53	88.3%	10	25.0%	1	4.5%
2	NE	13	12	40.0%	32	53.3%	19	47.5%	0	0.0%
2	NE	14	11	36.7%	33	55.0%	13	32.5%	3	13.6%
2	NE	15	4	13.3%	18	30.0%	15	37.5%	3	13.6%
1	TR	16	9	30.0%	27	45.0%	27	67.5%	6	27.3%
2	TR	17	11	36.7%	33	55.0%	11	27.5%	5	22.7%

¹N of sows assigned BCS over two rounds of scoring (i.e. a total of 250 scoring opportunities). The number of sows with BCS 2.0 or less (n = 30), 2.5 or less (n = 60), 4 or greater (n = 40), or 4.5 or greater (n = 22).

²Assuming participants would not adjust drop feeders of BCS₉ 3 or 3.5 sows

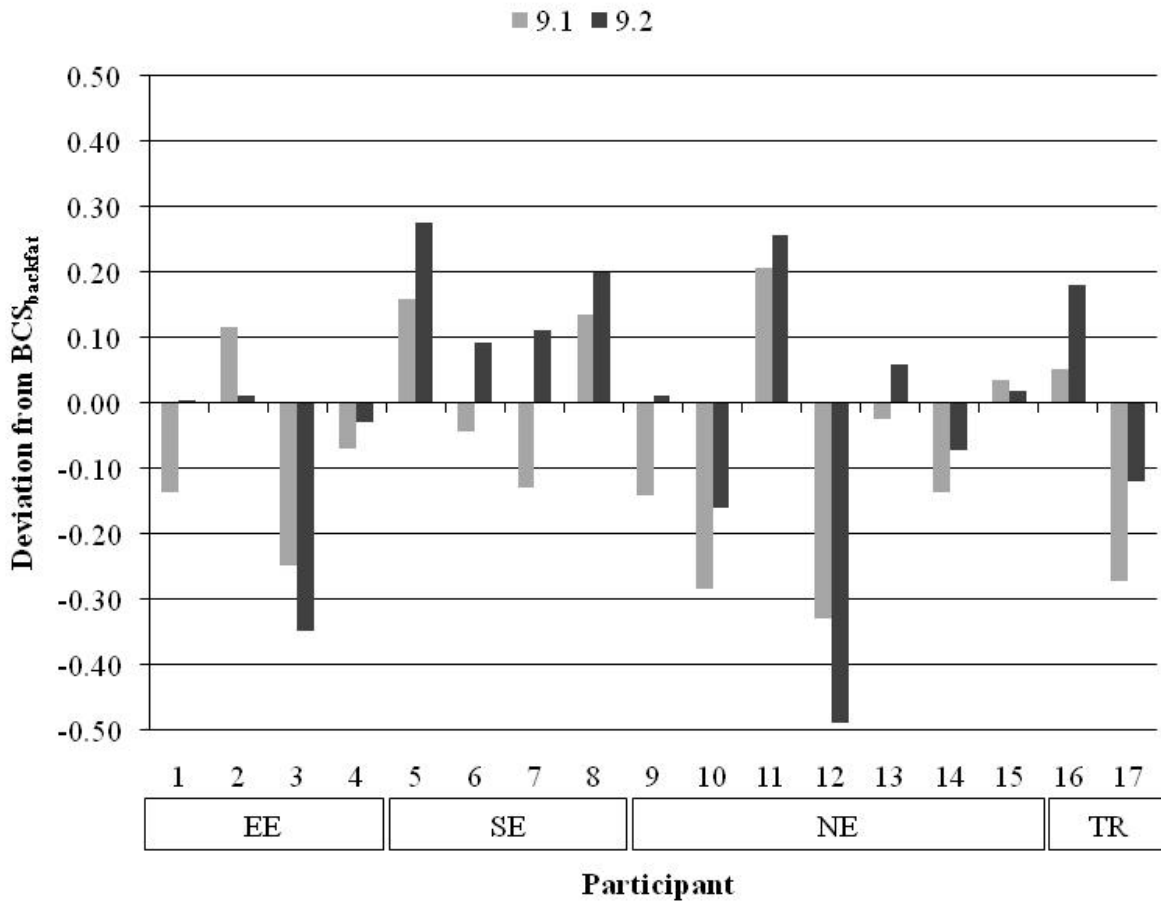
Figure 1. Mean deviations¹ between participant assigned and objectively measured² body condition score (BCS³) in sows by experience level⁴.

¹Participants assigned BCS₉ to 125 sows twice; thus, 9.1 represents mean deviations for individual participants on the first round, and 9.2 represents the second round

²BCS_{backfat} = sows were assigned BCS using last rib backfat estimates from real-time ultrasound measurements.

³BCS₉ = Body condition score; BCS were scored using a 9 [BCS₉; 1, 1.5, 2, ..., 5] point BCS scale.

⁴Participants were categorized as trainers (TR; n = 2) or as students having extensive (EE; n = 4), some (SE; n = 4), or no (NE; n = 7) prior BCS experience.



LITERATURE CITED

- Burkholder, W. J. 2000. Use of body condition scores in clinical assessment of the provision of optimal nutrition. *J. Amer. Vet. Med. Assoc.* 217:650-654.
- Burmeister, P. R. 2006. Effects of training and experience on repeatable and reliable assessment of beef cattle body condition scores. M.S. Thesis. Western Kentucky University, Bowling Green.
- Dourmad, J. Y., M. Etienne, and J. Noblet. 1996. Reconstitution of body reserves in multiparous sows during pregnancy: Effect of energy intake during pregnancy and mobilization during the previous lactation. *J. Anim. Sci.* 74:2211-2219.
- Evans, D. G. 1978. The interpretation and analysis of subjective body condition scores. *Anim. Prod.* 26:119-125.
- Fitzgerald, R. F., K. J. Stalder, L. A. Karriker, C. Johnson, L. Layman, and A. K. Johnson. 2008. Developing and utilizing visual tools to assist pork producers in employee training in the evaluation of sow body condition. *J. Ext.* 46:2T0T7.
- Hill, G., D. W. Rozeboom, N. Trottier, D. C. Mahan, L. Adeoli, T. Cline, D. Forsyth, and T. B. Richert. 1998. Tri-state swine nutrition guide. http://ohioline.osu.edu/b869/b869_44.html. Accessed January 15, 2009.
- Iwasawa, T., M. G. Young, T. P. Keegan, M. D. Tokach, S. S. Dritz, R. D. Goodband, J. M. DeRouchey, and J. L. Nelssen. 2004. Comparison of heart girth or flank-to-flank measurements for predicting sow weight. p. 17 in 2004 Swine Day, Kansas State Univ., Manhattan.
- Maes, D. G. D., G. P. J. Janssens, P. Delputte, A. Lammertyn, and A. de Kruif. 2004. Back fat measurements in sows from three commercial pig herds: relationship with reproductive efficiency and correlation with visual body condition scores. *Livest. Prod. Sci.* 91:57-67.
- Nicholson, M. J., and A. R. Sayers. 1987. Repeatability, reproducibility and sequential use of condition scoring of *Bos Indicus* cattle. *Trop. Anim. Health. Prod.* 19:127-135.
- SAS Institute, Inc. 2003. SAS OnlineDoc 9.1. SAS Institute, Inc., Cary, NC.

- Sulabo, R. C., M. D. Tokach, S. S. Dritz, E. J. Wiedemann, R. D. Goodband, J. M. DeRouchey, and J. L. Nelssen. 2007. Validation of flank-to-flank allometric equations in predicting weight of lactating sows and lactation weight change. p. 54 in Swine Day, Kansas State Univ., Manhattan.
- Taylor, B. N., and C. E. Kuyatt. 1994. Guidelines for evaluating and expressing the uncertainty of NIST measurement results. Appendix D, NIST Technical Note 1297, 1994 ed. National Institute of Standards and Technology, Gaithersburg, MD.
- Thomsen, P. T., L. Munksgaard, and F. A. Togersen. 2008. Evaluation of a lameness scoring system for dairy cows. *J. Dairy Sci.* 91:119-126.
- Vizcarra, J. A., and R. P. Wiettemann. 1996. Reproducibility, repeatability, and degree of expertise required to assess body condition score in beef cattle. *Prof. Anim. Sci.* 12:28-31.
- Young, M. G., M. Tokach, R. D. Goodband, J. L. Nelssen, and S. S. Dritz. 2001. The relationship between body condition score and backfat in gestating sows. p. 5 in Swine day, Kansas State Univ., Manhattan.

CHAPTER 6. AN ECONOMIC ANALYSIS OF FEEDING CULL SOWS^{1,2}

Modified from a paper published in the *Professional Animal Scientist* journal.

Robert F. Fitzgerald,* Kenneth J. Stalder,^{*3} PAS, Colin D. Johnson,* Lori Layman,† and

Locke Karriker†

*Department of Animal Science, Iowa State University, Ames, Iowa 50011

†Veterinary Diagnostic and Production Animal Medicine Department, Iowa State University,
Ames, Iowa 50011

ABSTRACT

The objectives of this study were to estimate the amount of feed and associated costs of adding BW to cull sows. Body weight, backfat, loin eye area, heart and jowl girth, and flank-to-flank measurements were recorded for 29 cull sows approximately every 14 d for a total of 96 d. Feed disappearance and BW gain for each interval was used to calculate performance traits, total revenue, total costs, and net margin. The period of greatest efficiency was from 0 to 14 d, equaling 0.37, 0.41, 0.26, and 0.28 for sows in USDA market

¹ Reprinted with permission of *Prof. Anim. Sci.*, 2008, 24:355-362

² This paper of the Iowa Agriculture and Home Economics Experiment Station, Ames, Iowa, Project No. 3801, was supported by Hatch Act and State of Iowa Funds. Additional funding was provided by the National Pork Board, Project No. (05-081).

³ Correspondence: 109 Kildee Hall, Department of Animal Science, Iowa State University, 109 Kildee Hall, Ames, Iowa 50011, USA, phone: 515-294-4683, fax: 5125-294-5698, stalder@iastate.edu

weight classes 1 through 4, respectively. Feed efficiency decreased throughout the trial, yet at a slower rate. Average daily feed intake (i.e. feed disappearance), BW gain, and revenue increased ($P < 0.001$) throughout the trial at a decreasing rate. Simple means for GF, ADFI, and ADG for all sows were 0.17, 5.22 kg/d, and 0.93 kg/d, respectively. Two scenarios using expensive and inexpensive feed and fixed costs were compared. A maximum net return of \$13.01 per sow was observed at 42 d post trial initiation, using feed costs of \$0.11/kg and \$0.25/d fixed costs. Analyses of cull sow market prices from 1996 through 2005 illustrate that the greatest prices for cull sows occur during May through August and below average prices are typical during November through January. Adding BW to cull sows is only profitable when producers utilize inexpensive feed and existing, depreciated facilities with relatively little labor requirements.

Keywords: Cull sows, BW gain, economics

INTRODUCTION

Sow replacement rates have exceeded 60% in recent years (Olson, 2006) resulting in approximately 3.6 million cull sows produced annually in the U.S. (NASS, 2006). Once the decision to cull a sow from the breeding herd has been made, a pork producer must decide to either immediately market the sow or to increase marketable BW by retaining and feeding her for some period of time. This decision is based on a combination of current cull sow market value and “wet” sow (i.e. sows that still possess mammary tissue typically after weaning) discount, available housing space, feed cost, health of the animal, and other variables. Revenue from marketing cull sows contributes to the profitability of pork operations. Greater salvage values have decreased the optimal parity for removal of cull sows from the

breeding herd (Rodriguez-Zas et al., 2006). Thus, pork operations experiencing low average parity at removal might lower sow replacement costs by increasing sow market weight and, hence, value. Cull sow markets are divided into 4 BW categories (AMS, 2005). Price per kilogram for cull sows typically increases as market BW become heavier (AMS, 2005). Increasing sow BW at marketing can improve price received.

Limited information is available about the efficiency and profitability of adding BW to modern sows that have greater genetic capacity for lean tissue deposition compared to sows of genetic lines from 1980 (Fix et al., 2007). The first objective of this study was to estimate the amount of feed and associated costs required to add BW to cull sows from a modern, lean genetic type. The second objective of this study was to identify market trends in cull sow market prices from 1996 to 2005 to predict future market prices.

MATERIALS AND METHODS

The protocol and use of these animals was reviewed and approved by the Iowa State University Animal Use and Care Committee (IACUC #7-05-5926-S).

Twenty-nine sows were purchased from a Mid-West US integrated pork operation. Sows of thin body condition without obvious illness or injury and possessing a low risk of mortality were requested from the pork operation in order to complete the study. The sows were housed in an existing farrowing and nursery facility which was unoccupied for more than 5 yr. This facility contained 17 standard farrowing stalls (0.75 m x 2.15 m) and 12 nursery pens (1.67 m x 4.15 m), where one sow was housed per stall or pen.

Upon their arrival to the housing facility, sows were visually examined for health problems by a swine veterinarian. Blood samples were collected to determine infectious

disease exposures for each sow. Sows were monitored for signs of disease at each feeding including visual observation for: anorexia, coughing, diarrhea, lacrimation, lameness, and lethargy. Rectal temperature was measured on sows observed to have clinical signs. The veterinarian examined each sow as needed and determined the treatment protocol for each individual clinical case.

Sows were allowed 2 d of rest and acclimation to their new environment before beginning the trial and received a feed allotment of 2 kg/d. Sows were weighed and categorized into 1 of 4 USDA market weight classes (AMS, 2005) based upon BW of 136 to 205 kg (MWC1), 205 to 227 kg (MWC2), 227 to 250 kg (MWC3), and 250 to 341 kg (MWC4). Tenth and last rib backfat, loin eye area, and loin depth were ultrasonically (Aloka 500, Corometrics Medical Systems, Wallingford, CT) estimated by a National Swine Improvement Federation certified real-time ultrasound technician (Bates and Christian, 1994). In the same locations, backfat was also measured using a Lean-Meater (Renco Corporation, Minneapolis, MN). Body condition was objectively evaluated using published guidelines (Hill et al., 1998). Real-time ultrasound estimates of last-rib backfat were used to classify sows into body condition scores [(BCS); 1 (thin) to 5 (fat)] at the initiation of the project and at the end of each of the seven 14 ± 2 d measurement period.

Heart girth and flank-to-flank measurements were made on each sow following procedures described by Iwasawa et al. (2004). Jowl girth measurements were also obtained using methods similar to those used to obtain heart girth measurements. Briefly, jowl girth was measured as the circumference of the sows' neck directly in front of the shoulder. Heart and jowl girth as well as flank-to-flank measurements were obtained using a cloth tape (Prym-Dritz Corp., Spartanburg, SC) while the sows were in a standing, relaxed position in

their respective stall or pen. Body weight, ultrasonic and physical measurements were evaluated approximately every 14 ± 2 d throughout the trial.

Sows were individually fed a 13% CP (as fed) gestation ration (3.4 Mcal/kg; Table 1) twice daily and the amount of feed provided was measured using a manual weighing scale (Nasco, Fort Atkinson, WI) and recorded at each feeding. A sow feeding program was developed to provide the sow with feed a minimum of 23 h/d and to decrease the risk of a sow not consuming her feed allocation for a particular day. This feeding regimen provided an incremental 0.45 kg increase every day as long as there was no feed remaining in the sows' feeder. If the sow did not consume all of the feed provided at any feeding, the amount of feed offered was decreased approximately 1 to 3 kg until the sow returned to eating the entire daily allowance. Unconsumed feed as a result of moisture or loss of appetite was recovered from individual feeders and weighed using a manual scale (Nasco, Fort Atkinson, WI). Feed disappearance was calculated as the feed provided minus the feed recovered.

Sows remained in the experiment until one of two conditions occurred. If the sow reached BCS 5 or, alternatively, the sow failed to gain BW in 2 consecutive 14-d periods (28 d) she was removed from the trial. When the sows were removed from the experiment, they were euthanized and underwent necropsy evaluation to catalog any gross lesions present.

Estimated gross revenue was calculated for each 14 d period and equaled the product of cumulative sow BW gained during the period of the experiment and the average market price for the sow's respective market weight classification. Once individual sows reached a heavier market weight class, similar calculations were made using the average market price for the heavier class.

Feed costs at each 14 d period were calculated by multiplying the total amount of feed consumed from the beginning of the experiment by two different feed costs of \$0.11 and \$0.20/kg . Additionally, two different fixed costs per day { \$0.25 [\$0.10/d cost for rented or debt free, depreciated facilities (Edwards, 2002) + \$0.10/d labor + \$0.05/d utilities] and \$1.00 [\$0.85/d cost for newly constructed sow facility + \$0.10/d labor + \$0.05/d utilities]} were multiplied by the number of days in the experiment and summed with feed costs to estimate total cost. Net return was calculated by subtracting total costs from total revenue. Net return received by adding BW to cull sows were evaluated using the least and most expensive combinations of the 2 feed costs of \$0.11 and \$0.20/kg and 2 fixed costs of \$0.25 and \$1.00/d.

Regression analyses for BW, revenue, and total costs were performed using the Mixed procedure of SAS (SAS Inst. Inc., Cary, NC). Initial market BW class and housing type was included in the model as fixed effects. The interaction of initial market BW class with days on experiment was used to evaluate BW gain curve differences for initial market weight classes throughout the trial. All dependent variables were regressed on the linear and quadratic experimental days variable. Both the intercept and experimental days were used as random terms in the model and sow nested within initial market weight class represented the repeated measurement. Intercepts and slopes of all dependent variables were used to construct net margin graphs and BW gain curves for sows from each initial market weight class.

Cull sow average market price, average BW, and number marketed from March of 1996 to December of 2005 were obtained from USDA market news services (USDA Market News, 1996-2005). Monthly and yearly cull sow value was estimated for MWC1 through

MWC4 using the GLM procedure of SAS (SAS Inst., Inc., Cary, NC). Total sow BW (kg; total sow BW = average BW x number marketed) marketed within each market weight class was used as a linear covariates for cull sow value. Price differentials between sow market weight classes within months and years were calculated by subtracting the lighter weight division from the heavier weight division (ex. Price differential = average price for sow BW of 205 to 227 kg – average price for sow BW of 136 to 205 kg).

The CORR procedure of SAS (SAS Inst., Inc., Cary, NC) was utilized to calculate Pearson correlation coefficients between BW, heart and jowl girth and flank-to-flank measurements. Pearson correlation coefficients were calculated between tenth and last rib backfat estimates using real-time ultrasonics and the Lean-Meater device (Renco Corporation).

RESULTS AND DISCUSSION

At the initiation of the study, 7, 6, 6, and 10 sows were categorized into MWC1 through MWC4, respectively. Three sows were removed from the trial at 14 d due to poor performance as a direct result of lethargy and disease and were removed from any analyses. These sows lost a total of 30.38 kg over the 14-d period (mean = -10.13 kg per sow). Necropsy evaluation of these sows found inner ear infection, metritis stemming from retained piglets, and severe lameness. Of the remaining 26 sows, 2 sows failed to reach the heaviest market weight class before they were removed from the experiment at d 96.

Housing cull sows in stalls or nursery pens was not a significant source of variation for BW gain ($P = 0.62$) or revenue ($P = 0.36$) and was removed from the model. A trend was observed in the least and most expensive total cost scenarios where adding BW to cull sows

housed in stalls increased ($P = 0.1$) total costs by \$0.62 and \$1.14, respectively, over their entire feeding period when compared to pen-housed cull sows. However, because no adjustment factor was used to account for increased housing costs for the pen-housed sows and this difference in total cost was relatively small, housing type was removed from the final model used to evaluate these data.

Pearson correlation coefficients were calculated between heart and jowl girth, flank-to-flank measurement, and BW. The largest coefficient was found between heart girth and BW measurements (0.94). Flank-to-flank and jowl girth measurement correlations with BW were 0.81 and 0.83, respectively. The correlation between heart girth and flank-to-flank measurement was 0.80. This result is consistent with those of Iwasawa and co-workers (2004). In the present study, the favorable correlation with BW along with the ease of measurement suggests that the flank-to-flank measurement as the most ideal variable to predict BW in sows housed in a stall.

Pearson correlation coefficients between Lean-Meater and real-time ultrasound devices were 0.93 at the tenth rib and 0.94 at the last rib. When compared to real-time ultrasound, the Lean-Meater device overestimated last rib backfat thickness (mm) for sows having BCS 1 and 2 and underestimated backfat for sows having BCS 3, 4, and 5 (Table 2) . Similar trends were observed when estimating tenth rib backfat when using the Lean-Meater ultrasound, however differed for BCS 2 sows. The Lean-Meater ultrasound device overestimated backfat thickness (mm) for sows having BCS 1 and underestimated backfat for sows having BCS 2, 3, 4, and 5 when compared to real-time ultrasound devices. Results from this study are similar to those reported by Wiseman and colleagues (2007). In that study, they found that A-mode devices underestimated backfat thickness in pigs with greater than 10

mm. Wiseman and colleagues (2007) further suggest A-mode devices have difficulty detecting the third layer of backfat, and that statement is supported by similar trends in this study.

Initial average cull sow BW were 184.9 kg, 227.1 kg, 244.0 kg, and 269.4 kg for MWC1 through 4, respectively. Sow BW gain curves by initial market weight class are shown in Figure 1. Initial BW was significantly different ($P < 0.001$) among sows from each of the market weight classes. Sow BW increased ($P < 0.001$) by 1.52, 1.65, 1.35, and 1.33 kg/d for MWC 1 through 4, respectively throughout the experiment. The overall quadratic slope was negative ($P < 0.001$) indicating that sows gained BW at a slower rate (-0.0075 kg/d). The interaction of initial market weight class and the number of days sows were on the experiment was not a significant ($P = 0.18$) source of variation. Hence, sows within different initial market weight classes gained BW at the same rates.

Simple means for GF, ADFI, and ADG for all sows over the 96 d trial were 0.17, 5.22 kg/d, and 0.93 kg/d, respectively. Least squares means for sow performance traits are listed in Table 3 by initial MWC. Average daily feed intake (i.e. feed disappearance) increased throughout the trial, yet at a slower rate. The maximum ADFI consumed for an initial MWC was 6.38 kg/d from 42 to 56 d. Sows in different initial MWC increased ADFI at the same rate ($P = 0.31$).

Similar observations can be made in regards to G:F for sows in this study. Cull sows were less efficient in converting feed to BW throughout the experiment, however reached a plateau at approximately 56 d and continued at approximately the same G:F for the remainder of the trial. Similar to BW and ADFI, there was no evidence found in this study to support a difference in GF rates among initial MWC. Yet, sows in MWC 2 tended to be more

efficient than sows of initial MWC 3 or 4 over the entire 96 d experiment. Only numerical differences were observed between MWC 1 and 2.

Average cull sow prices from 1996 to 2005 were calculated for MWC 1 through 4 and the overall mean for each MWC averaged \$0.73, \$0.80, \$0.83, and \$0.87/kg, respectively. Because revenue is related to BW gain, similar trends were observed when evaluating predicted revenue by the number of days sows remained in the experiment (Figure 2). A positive relationship ($P < 0.001$) was observed between revenue and experimental days increasing at \$1.29, \$1.39, \$1.16, and \$1.15/d per sow; yet revenue increased over time at a decreasing ($P < 0.001$) rate (-\$0.0061/d per sow). Additionally, sows from the different market weight classes at the beginning of the trial increased in value at the same rate ($P = 0.32$). At 96 d in the experiment, numerical difference of \$23.86 was observed between MWC2 (\$77.58) and MWC4 (\$53.71).

Two economic evaluations were conducted using each combination of feed and fixed costs for adding BW to cull sows. Net return from marketing culls sows from different initial market weight classes was evaluated using market conditions of \$0.11/kg feed cost and \$0.25 fixed cost in Figure 3 and with \$0.20 feed cost and \$1.00 fixed cost in Figure 4. Adding BW to cull sows was only profitable in scenarios using the lowest feed cost (\$0.11/kg) and the lowest fixed cost (\$0.25/d). Further, adding BW to cull sows that were initially classified into the two lowest market weight classes yielded the greatest profit numerically at approximately 42 d in the experiment. The maximum profit increase above salvage value was observed for MWC1 at \$13.01 per sow. Revenue equaled total cost at approximately 90, 80, 45, and 53 d on trial for MWC1 through 4, respectively, using the lowest feed and fixed costs. However, profit was not achieved for scenarios that used the greatest feed and fixed costs. Results from

this study suggest that adding BW to cull sows was not profitable when feed costs (\$0.20/kg) or fixed costs (\$1.00/d) are high (data not shown) or under both conditions (Figure 4).

The classification of BW into categories along with average monthly and yearly cull sow prices by MWC categories are shown in Figures 5 and 6, respectively. These prices represent plant-delivery including freight and commission (AMS, 1996-2005). Cull sow prices follow a general trend. Above average cull sow prices usually occur during the months of May through August and below average prices more often occur November through January. Both monthly and yearly cull sow prices closely follow and, in some instances, have exceeded market hog prices (Figure 6). Average monthly and yearly price differentials between MWC categories are shown in Figures 7 and 8, respectively. The figures illustrate the advantage, or sometimes disadvantage, of feeding sows to the next market weight class. Often price differentials between categories can yield as much as \$17.00/100 kg depending upon the month and year, and that price difference occurs between MWC1 and MWC2. However, in some cases, cull sow harvest facilities will discount sows that have reached heavier weights (Figure 8). Based on 1996-2005 prices in Figure 8, this discount occurred frequently when market pig prices were low and supply of cull sows was relatively high. This resulted in a reduced demand for cull sows and relatively lower prices. Thus, in order to maximize the cull sow salvage value, producers must carefully examine historical market tendencies and use that data to help predict the most optimal time-point to market cull sows.

A pork producer managing a farrow-to-finish or a breed-to-wean operation encounters 3 options when culling a sow from the breeding herd. The first option is to sell cull sows immediately after weaning. This practice is discouraged as a \$11.00/100 kg price discount is commonly assessed against “wet” sows or sows that still possess mammary tissue

typically found on sows that have just been weaned, and fewer than 5% of sows are sold at weaning (USDA Market News, Louis Langell, personal communication). Housing sows for approximately 2 wk will allow involution of mammary tissue (Kim et al., 2001) sufficiently enough that they will not be discounted when marketed. However, increasing or decreasing energy and protein levels can extend or decrease the days required for mammary tissue involution to occur.

The second and third options are most commonly practiced by swine producers. Both options require housing and feeding sows which allows time for mammary tissue involution while taking advantage of compensatory BW gain and the possibility of the sow remaining in the breeding herd if mating is successful. The second and third options only differ in the amount of time the cull sow remains onsite. Sows identified for the second option will be removed from the herd after approximately 2 wk as compared to longer lengths of time to add BW to cull sows for option 3. At this point, the decision to add BW is dependent upon the ability of the producer to accurately assess the productivity of the cull sows. Thin sows that have recently weaned large litters of piglets could be candidates to add BW; whereas sows that have exhibited considerable feed intake variation (possibly due to stomach ulcers) or appear morbid and/or lame are ideal candidates for immediate marketing after weaning (option 1) or as soon as mammary tissue involution has occurred (option 2). Additionally, disease-laden sows pose a high mortality risk, and when mortality occurs, sows have no salvage value.

Finally, herd health must be incorporated into cull sow feeding decisions. In the present study, 8 sows required treatment for clinical signs including chronic lameness, metritis, and pneumonia. The cost for treating those 8 sows totaled \$35.51 for medication,

and did not include labor. Four of the sows represented 70% of the total individual treatment costs. Pork producers should carefully consider medications utilized for sow treatment as withdrawal periods extend the amount of time the sow remains onsite increasing mortality risk. Disease incidence can increase break even prices and affect the profitability of feeding cull sows.

IMPLICATIONS

Many factors unique to individual pork operations must be evaluated before producers should consider adding BW of cull sows. Foremost, the operation must be able to physically house prospective cull sows, and in this study, only inexpensive feed and depreciated facilities were profitable. Second, the producer must have current market condition knowledge and be able to predict, with some degree of certainty and associated, risk future market trends based on historical prices. Finally, each producer should evaluate their sow operation and determine (based upon sow health and feed prices) whether adding BW to cull sows will be a profitable decision. In this study, adding BW to cull sows could be profitable in the presence of \$0.11/kg feed prices and labor and housing costs of \$0.25/d per sow.

LIST OF TABLES AND FIGURES

Table 1. Composition and nutrient analysis of a gestation ration used in a study of adding BW to cull sows¹

Item	As fed
Ingredient	
Ground yellow corn, %	84.0
Soybean meal (44%), %	13.0
Gestation Vitamin-Mineral Mix ² , %	3.0
Calculated composition	
DM, %	88.55
CP, %	13.07
Lysine, %	0.59
Fat, %	3.73
Fiber, %	2.79
Ca, %	0.94
NaCl, %	0.54
Zn, ppm	110.21
I, ppm	0.69
Fe, ppm	86.97
Cu, ppm	6.06
Mn, ppm	19.19
Se, ppm	0.26
Vit A, KIU/kg	3663.9
Vit D, KIU/kg	482.37
Vit E, IU/kg	50.67

¹Feed cost of \$0.16/kg (as fed) on September 1, 2005²Kent Feeds, Inc., Muscatine, IA

Table 2. Mean values for tenth and last rib backfat measurements of cull sows as estimated by A-mode¹ and real-time² ultrasound

Body condition score (BCS)	Back fat, mm			
	10 th Rib		Last rib	
	A-mode ultrasound	Real-time ultrasound	A-mode ultrasound	Real-time ultrasound
BCS 1	12.9	12.2	9.2	8.3
BCS 2	19.4	21.4	14.0	12.9
BCS 3	25.6	31.1	18.1	19.4
BCS 4	30.9	39.4	23.3	26.0
BCS 5	35.8	46.0	27.9	31.3

¹Lean-Meater, Renco Corporation, Minneapolis, MN

²Aloka 500, Corometrics Medical Systems, Wallingford, CT

Table 3. Least squares means and SEM values of cull sow performance traits

Trait ²	Day on trial															
	0		14		28		42		56		70		84		96	
	Mean	SEM ¹	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
ADFI, kg																
MWC1 ³	-	-	3.66	0.53	4.32	0.49	4.73	0.50	4.90	0.51	4.82	0.54	4.50	0.58	4.03	0.65
MWC2	-	-	5.24	0.53	5.87	0.50	6.25	0.50	6.38	0.52	6.27	0.57	5.91	0.66	5.41	0.77
MWC3	-	-	5.11	0.50	5.53	0.45	5.71	0.46	5.64	0.52	5.33	0.62	-	-	-	-
MWC4	-	-	4.62	0.38	5.30	0.35	5.73	0.36	5.91	0.39	5.85	0.45	5.55	0.53	5.09	0.65
ADG, kg																
MWC1	-	-	1.42	0.24	1.11	0.17	0.87	0.14	0.71	0.12	0.62	0.11	0.61	0.13	0.65	0.21
MWC2	-	-	2.03	0.24	1.53	0.17	1.11	0.14	0.76	0.13	0.48	0.15	0.27	0.21	0.15	0.30
MWC3	-	-	1.35	0.24	1.04	0.16	0.80	0.14	0.63	0.21	0.54	0.32	-	-	-	-
MWC4	-	-	1.40	0.18	1.01	0.12	0.68	0.11	0.44	0.12	0.26	0.13	0.16	0.17	0.13	0.25
G:F																
MWC1	-	-	0.37	0.05	0.27	0.03	0.19	0.03	0.14	0.03	0.12	0.03	0.12	0.03	0.15	0.05
MWC2	-	-	0.41	0.05	0.28	0.03	0.17	0.03	0.09	0.03	0.04	0.03	0.02	0.05	0.01	0.07
MWC3	-	-	0.26	0.05	0.18	0.03	0.13	0.03	0.10	0.04	0.10	0.07	-	-	-	-
MWC4	-	-	0.28	0.03	0.17	0.02	0.10	0.02	0.05	0.02	0.03	0.03	0.03	0.04	0.05	0.06
N ⁴																
MWC1	5		5		5		5		5		4		4		4	
MWC2	5		5		5		5		5		3		2		1	
MWC3	6		6		6		6		6		1		-		-	
MWC4	10		10		10		10		6		4		2		2	

¹SEM = Standard error of the mean²ADFI, ADG, and G:F were independently calculated using regression analyses.³MWC = Market weight class (Agriculture Marketing Service, 2005). MWC1 = 136 - 205, MWC2 = 205 - 227, MWC3 = 227 - 250, MWC4 = 250 - 341 kg⁴Sows were removed from the trial upon reaching a body condition score 5. N = 29 total sows. All sows in MWC3 were removed from the study at 70 d after reaching a BCS 5.

Figure 1. Body weight gain curves of cull sows¹ by initial market weight class^{2,3}

¹N = 29; Three sows were removed from the analysis due to disease. Body weight gain was measured every 14 ± 2 d.

²MWC = Market weight class (Agriculture Marketing Service, 2005). MWC1 = 136 - 205, MWC2 = 205 - 227, MWC3 = 227 - 250, MWC4 = 250 - 341 kg

³The rate of increase in BW did not differ between cull sow market weight classes ($P = 0.18$)

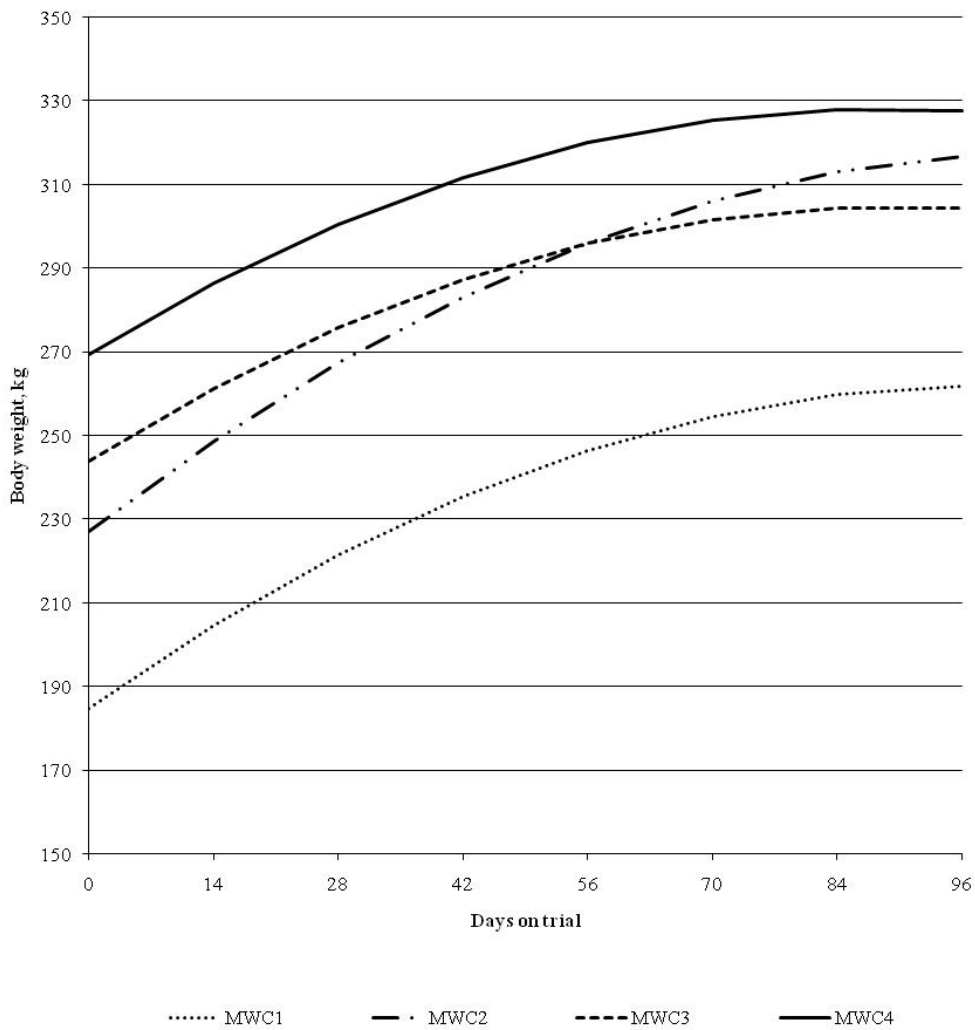


Figure 2. Change in revenue¹ from adding BW to cull sows of four initial market weight classes^{2,3}

¹ Revenue was calculated every 14 ± 2 d period by multiplying sow BW by the average price for each sows' market weight class. In this study, change in revenue refers to the revenue received above the cull sow salvage value at d 0 (approximately 7-14 d post weaning).

Average cull sow market prices for MWC1 through 4 were \$0.73, \$0.80, \$0.83, and \$0.87/kg, respectively.

²MWC = Market weight class (Agriculture Marketing Service, 2005). MWC1 = 136 - 205, MWC2 = 205 - 227, MWC3 = 227 - 250, MWC4 = 250 - 341 kg

³The rate of increase in revenue did not differ between cull sow market weight classes ($P = 0.32$).

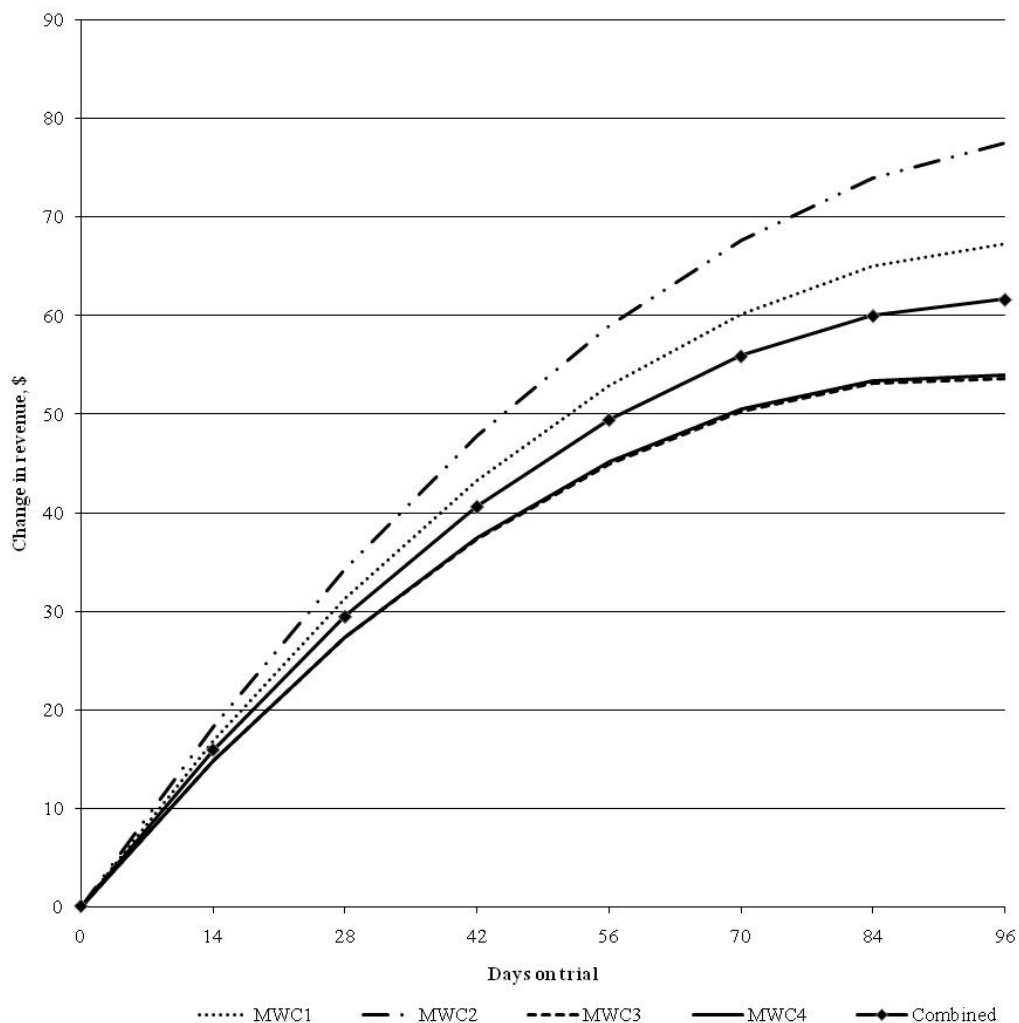


Figure 3. Estimated net return received from adding BW to culls sows¹ in four market weight classes² with \$0.11/kg feed cost and \$0.25/d fixed³ cost

¹ N = 29; Revenue, total costs, and BW gain were calculated 14 ± 2 d. Average cull sow market prices for MWC1 through 4 were \$0.73, \$0.80, \$0.83, and \$0.87/kg, respectively. Net return = gross revenue per period – (feed + fixed costs per period).

²MWC = Market weight class (Agriculture Marketing Service, 2005). MWC1 = 136 - 205, MWC2 = 205 - 227, MWC3 = 227 - 250, MWC4 = 250 - 341 kg

³ Fixed cost was \$0.25 (\$0.10/d cost for debt free, depreciated facilities + \$0.10/d labor + \$0.05/d utilities).

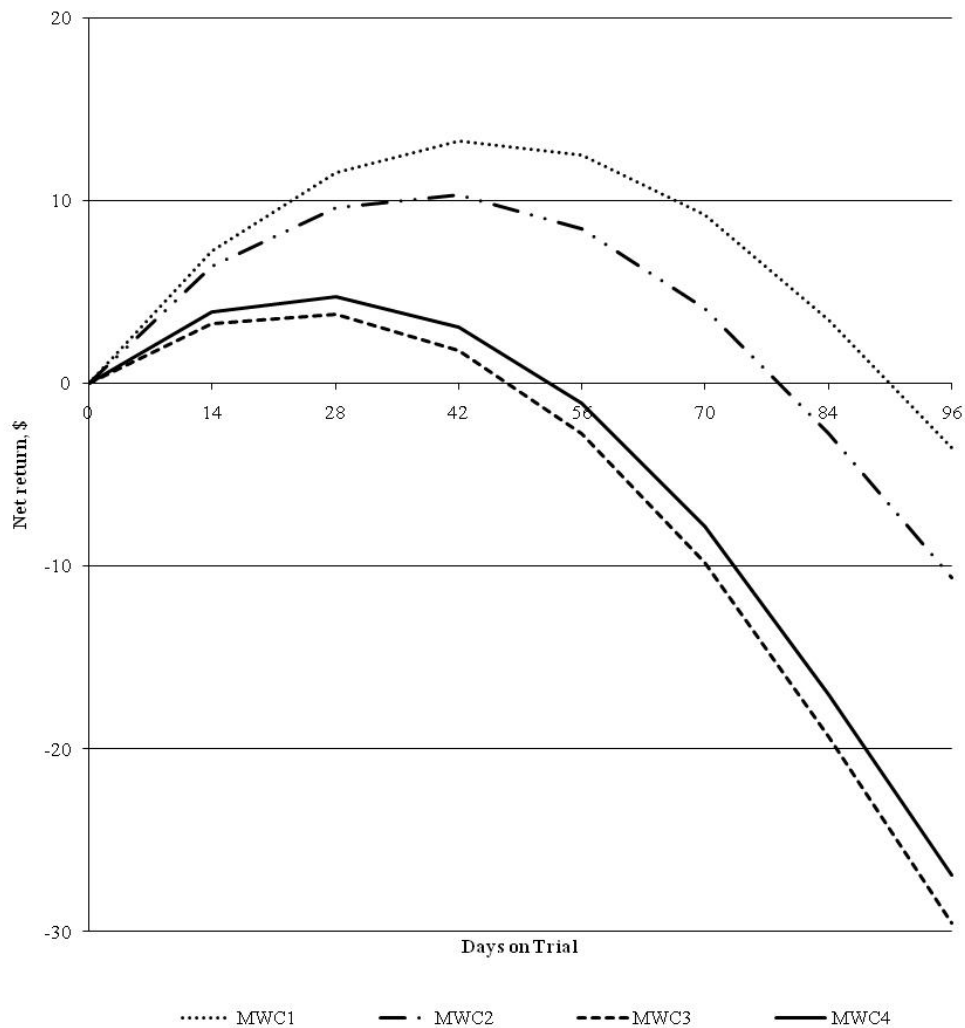


Figure 4. Estimated profit received from adding BW to culls sows¹ in four market weight classes² with \$0.20/kg feed cost and \$1.00/d fixed³ cost

¹ N = 29; Body weight gain was measured every 14 ± 2 d.

²MWC = Market weight class (Agriculture Marketing Service, 2005). MWC1 = 136 - 205, MWC2 = 205 - 227, MWC3 = 227 - 250, MWC4 = 250 - 341 kg

³ Fixed cost was \$1.00 (\$0.85/d cost for newly constructed sow facility + \$0.10/d labor + \$0.05/d utilities)

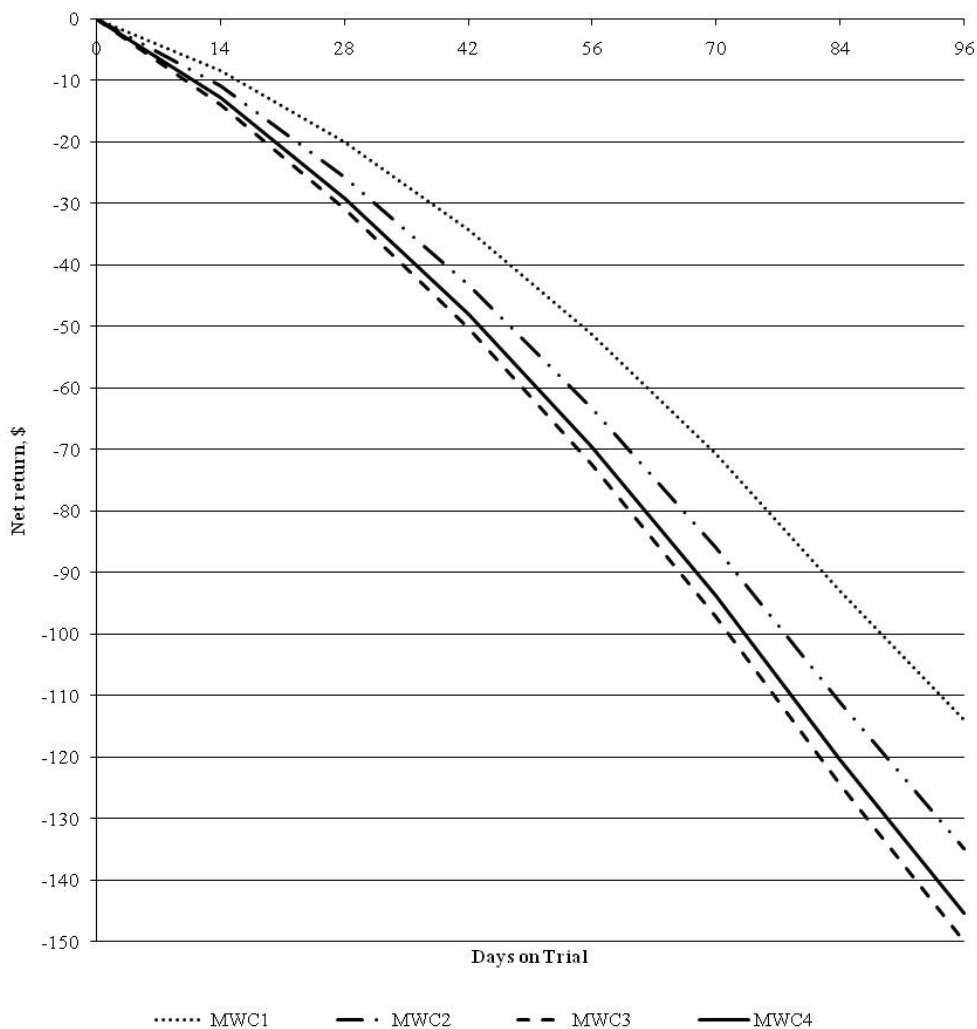


Figure 5. Average monthly cull sow prices¹ for 4 market weight classes² from 1996 through 2005

¹USDA Market News, Louis Langell, personal communication

²MWC = Market weight class (Agriculture Marketing Service, 2005). MWC1 = 136 - 205, MWC2 = 205 - 227, MWC3 = 227 - 250, MWC4 = 250 - 341 kg

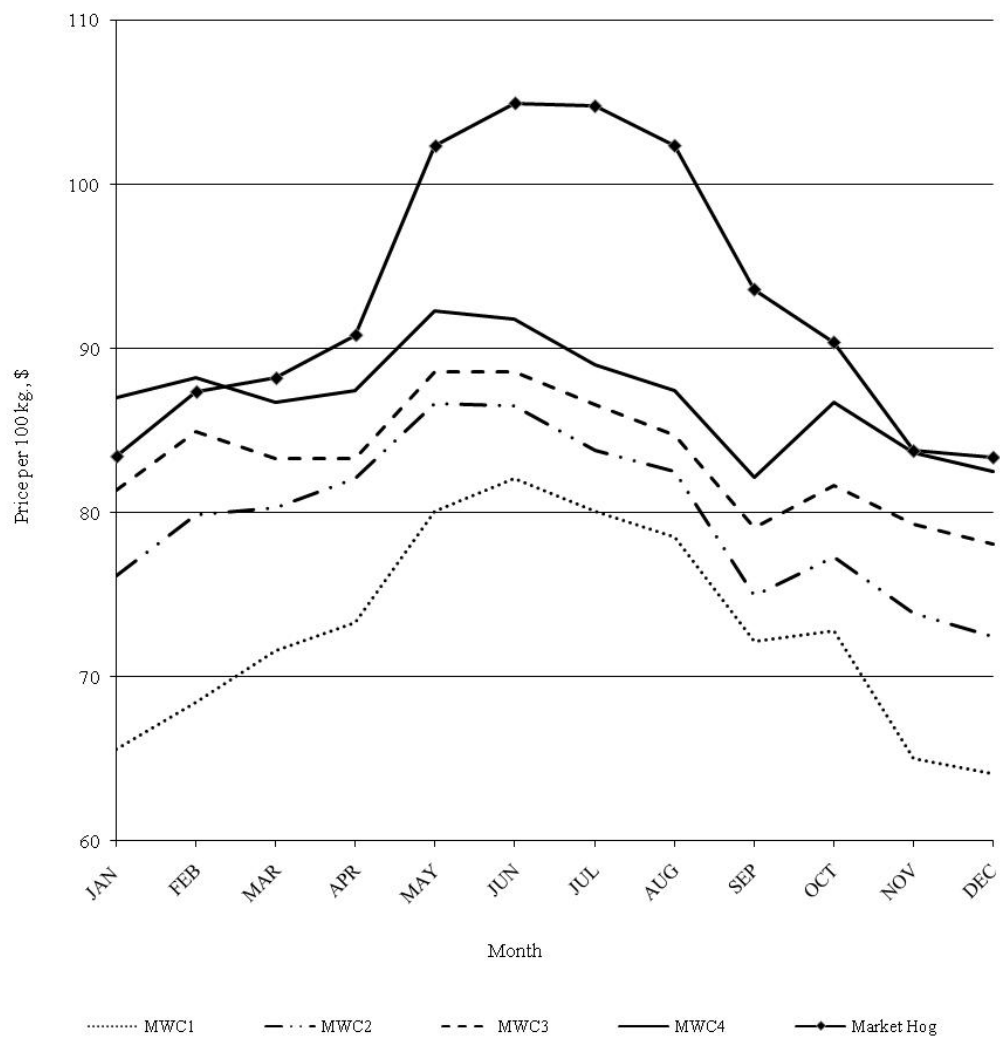


Figure 6. Average yearly cull sow prices¹ for 4 market weight classes² from 1996 through 2005

¹USDA Market News, Louis Langell, personal communication

²MWC = Market weight class (Agriculture Marketing Service, 2005). MWC1 = 136 - 205, MWC2 = 205 - 227, MWC3 = 227 - 250, MWC4 = 250 - 341 kg

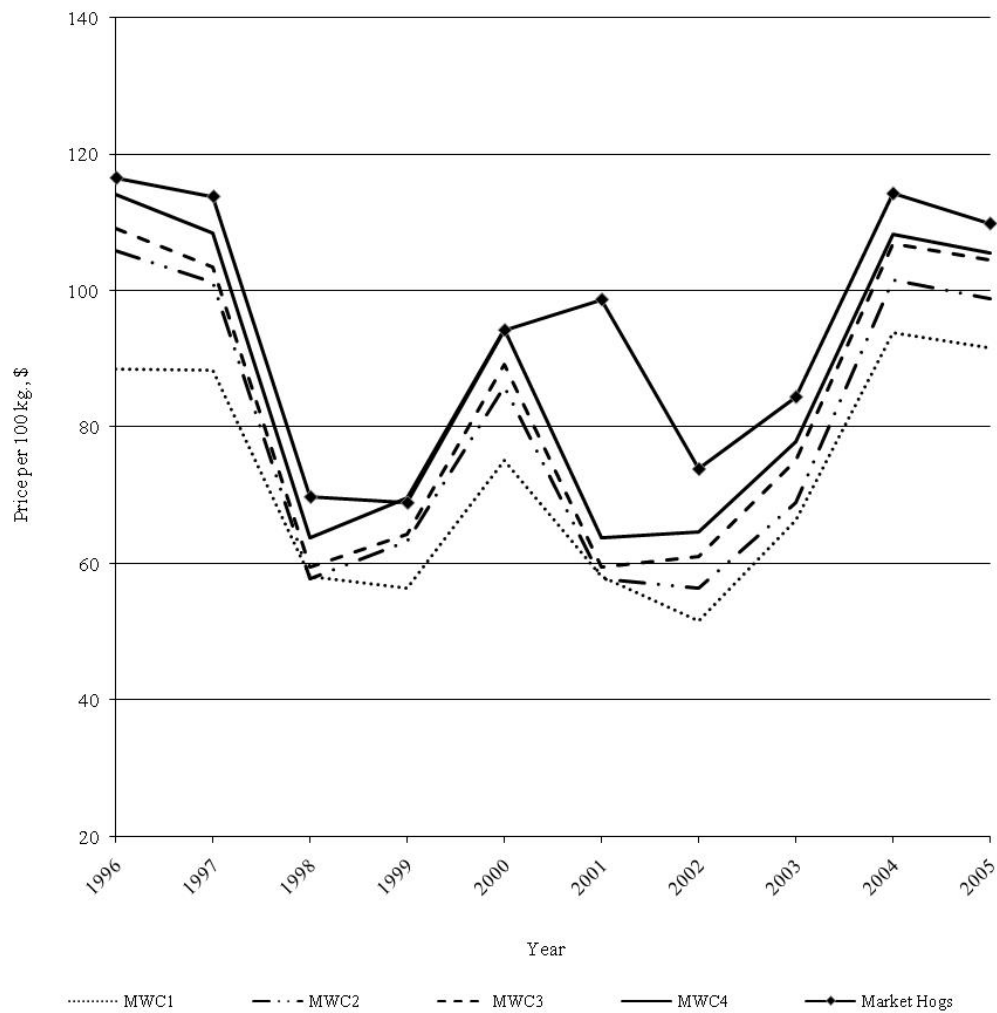


Figure 7. Monthly price¹ differential² between 4 price classes of culls sows from 1996 through 2005

¹USDA Market News, Louis Langell, personal communication

²Price differential equals the heavier market weight class minus the lighter market weight class. MWC = Market weight class (Agriculture Marketing Service, 2005). MWC1 = 136 - 205, MWC2 = 205 - 227, MWC3 = 227 - 250, MWC4 = 250 - 341 kg

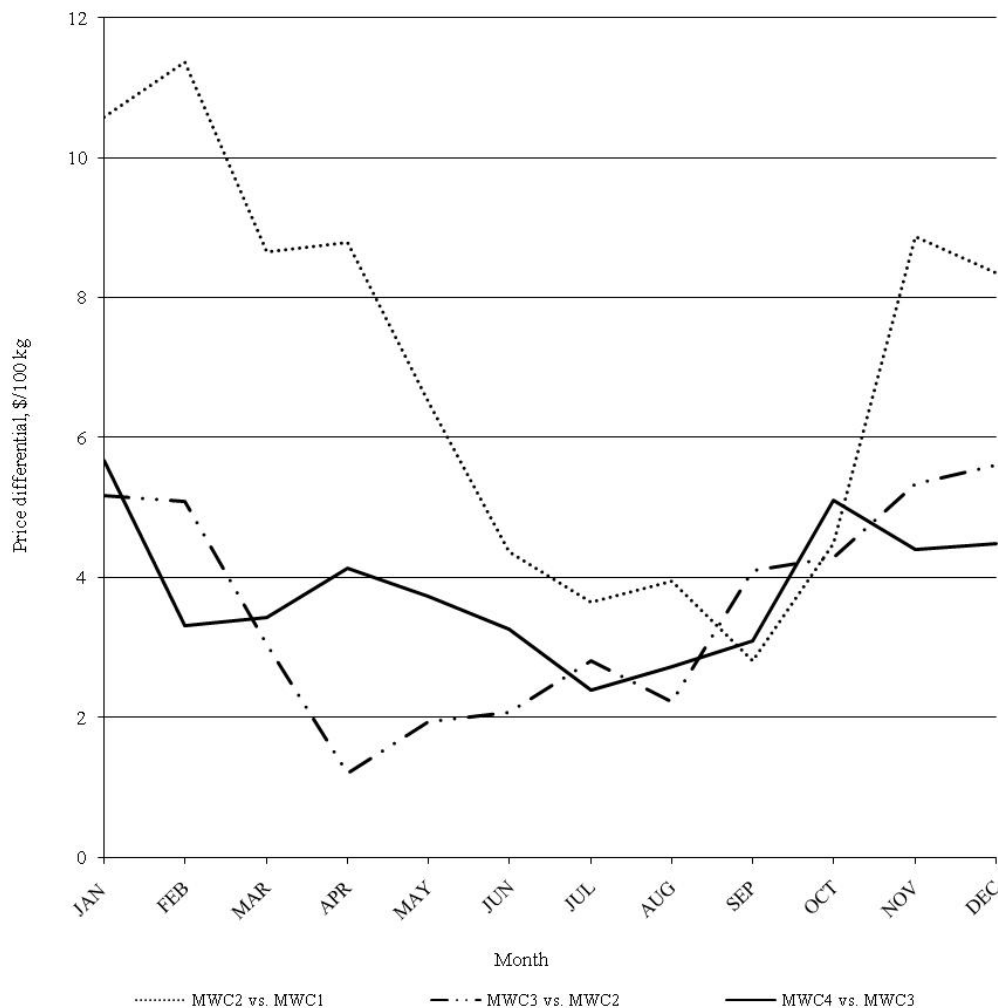
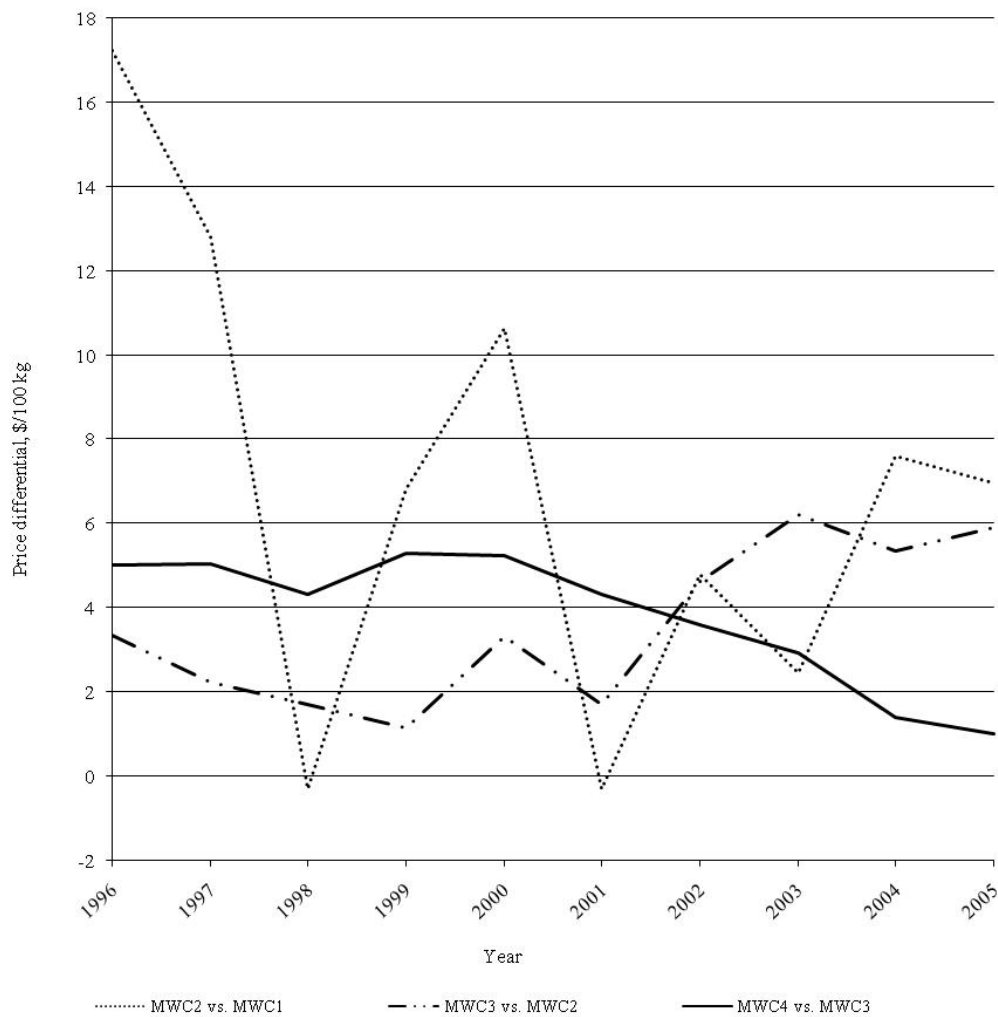


Figure 8. Yearly price¹ differential² between 4 price classes of cull sows from 1996 through 2005

¹USDA Market News, Louis Langell, personal communication

²Price differential equals the heavier market weight class minus the lighter market weight class. MWC = Market weight class (Agriculture Marketing Service, 2005). MWC1 = 136 - 205, MWC2 = 205 - 227, MWC3 = 227 - 250, MWC4 = 250 - 341 kg



ACKNOWLEDGEMENTS

The authors would like to express appreciation to M. Knauer, S. Frankovich, S. Harrison, T. Hargens, R. Schaefer, and other graduate and veterinary students that assisted with the project.

LITERATURE CITED

- AMS. 1996-2005. U.S. Direct Slaughter Sow Report. USDA Agriculture Marketing Service Market News and Transportation Data, Nashville, TN. Available at: <http://www.ams.usda.gov>. Accessed April 1, 2008.
- Bates, R. O., and L. L. Christian. 1994. The National Swine Improvement Federation Guidelines for Ultrasonic Certification Programs. Fact Sheet NSIF-FS16, Cooperative Ext. Service, Perdue Univ., West Lafayette.
- Edwards, W. 2002. 2002 Building rental and contracting rates. Ag Decision Maker C2-17, Iowa State Univ. Ext., Ames.
- Fix, J. S., D. J. Hanson, E. van Heugten, J. P. Cassady, and M. T. See. 2007. Carcass traits of 1980 vs. 2005 pigs when fed 1980 or 2005 feeding programs. Midwestern Section ASAS and Midwest Branch ADSA 2007 Meeting, Des Moines, IA. Abstract # 44.
- Hill, G., D. Rozeboom, N. Trottier, D. Mahan, L. Adeoli, T. Cline, D. Forsyth, and B. Richert. 1998. Tri-State Swine Nutrition Guide. Available at: http://ohioline.osu.edu/b869/b869_44.html Accessed Jan. 05, 2007.
- Iwasawa, T., M. G. Young, T. P. Keegan, M. D. Tokach, S. S. Dritz, R. D. Goodband, J. M. DeRouchey, and J. L. Nelssen. 2004. Comparison of heart girth or flank-to-flank measurements for predicting sow weight. Pages 17-22 in 2004 Swine Day, Kansas State Univ., Manhattan.
- Kim, S.W., R.A. Easter, and W.L. Hurley. 2001. The regression of unsuckled mammary glands during lactation in sows: The influence of lactation stage, dietary nutrients, and litter size. *J. Anim. Sci.* 79: 2659-2668.

- Maes, D., G. Janssens, P. Delputte, A. Lammertyn, and A. de Kruif. 2004. Back fat measurements in sows from three commercial pig herds: relationship with reproductive efficiency and correlation with visual body condition scores. *Live. Prod. Sci.* 91:57-67.
- NASS. 2006. U.S. & All States Data – Hogs & Pigs, Sows and Gilts USDA. Natl. Agric. Stat. Serv., Washington, DC. Available: <http://usda.mannlib.cornell.edu/usda/nass/HogsPigs/2000s/2006/HogsPigs-12-27-2006.txt> Accessed Feb 09, 2008.
- Olson, S. PigCHAMP Benchmarking summaries: USA. Available: http://www.pigchamp.com/summary_archives.html. Accessed Feb 09, 2008.
- Rodriguez-Zas, S. L., C. B. Davis, P. N. Ellinger, G. D. Schnitkey, N. M. Romine, J. F. Conner, R. V. Knox, and B. R. Southey. 2006. Impact of biological and economical variables on optimal parity for replacement in swine breed-to-wean herds. *J. Anim. Sci.* 84:2555-2565.
- Wiseman, T. G., D. C. Mahan, S. J. Moeller, J. C. Peters, N. D. Fastinger, S. Ching, and Y. Y. Kim. 2007. Phenotypic measurements and various indices of lean and fat tissue development in barrows and gilts of two genetic lines from twenty to one hundred twenty-five kilograms of body weight. *J. Anim. Sci.* 85:1816-1824.
- Young, M., M. Tokach, R. Goodband, J. Nelssen, and S. Dritz. 2001. The relationship between body condition score and backfat in gestating sows. Pages 5-9 in 2001 Swine Day, Kansas State Univ., Manhattan.

CHAPTER 7. GENERAL SUMMARY

Sow productive lifetime has been described as a multi-factorial challenge due to numerous factors that can influence the amount of time she remains in the herd. Those factors may be related to reproduction, nutrition, behavior, or management. Sow productive lifetime refers to the ability of the sow to remain productive in the breeding herd for a period of time before being removed, culled, euthanized, or dies. If sow operations are to maintain sow populations at some level, each sow culled or removed from the herd must be replaced. Thus, producers incur some cost of replacing culled sows, either through purchasing replacement sows from a breeding company or conducting in-house multiplication systems. Culling can be classified into two categories, voluntary or involuntary culling. Voluntary culling is a term describing the situation where the owner or manager of a swine operation has the opportunity to make a conscious choice to retain or cull a breeding herd female. Such decisions may be based on a lack of productivity after a single parity or over multiple parities relative to the productivity of herd mates. Further, voluntary culling may result from the sow displaying an undesirable behavior i.e. aggression towards the caretaker, her piglets, or other sows. Involuntary culling occurs when a producer does not make or have a choice to cull a sow if the operation is to maintain productivity at a pre-determined level, as would be the case when a sow fails to cycle, conceive, or becomes severely lame.

Behaviors identified to be detrimental to sow productive lifetime were stereotypical behaviors such as bar biting, aggression between sows through lower feed intake (Andersen et al. 1999), aggression toward caretakers, and piglet savaging and cannibalism. Good maternal ability in gilts and sows can be characterized by rapid piglet growth rate (though sow's milk supply), small weight variation within the litter, little to no piglet mortality

(Wülbers-Mindermann et al., 2002) and short parturition duration (85 to 180 min producing an average litter size of 10.6 piglets per litter; Jensen, 1986).

Most of the hoof cracks in the present study were localized to the hind feet; however, cracks varied in the length and severity (Chapter 4). The longest recorded hoof crack was 5.1 cm in length, and a clear separation in the outer hoof wall was observed in most of the severely scored cracks. In these cases, these cracks would allow bacteria and other pathogens to infect the hoof, potentially affecting other body organ systems. Similarly, most claw size differences and all overgrown hooves were confined to the hind feet. This observation is supported by numerous researchers. However, there has been limited research that identifies specific reasons why the prevalence of these lesions is higher in the hind feed. In stall-housed sows, the front and hind feet have different micro-environments. The front feet are typically housed on solid concrete flooring and the hind feed on slatted flooring. Further, although not evaluated, moisture levels are typically greater for the rear of the stall where manure and urine accumulate.

This study (Chapter 4) indicates that litter weaning weight adjusted for on-test weight and number of piglets at crossfostering was negatively associated with lesion score increases in overgrown toes (OG; $P = 0.03$), hoof cracks (CK; $P = 0.07$), and toe length differences (TS; $P = 0.39$) sows. Each lesion score increase for sows in the OG group was significantly associated with 2.1 kg less adjusted litter body weight at weaning. For the 22 OG sows in this study, this would equal 71.3 kg less piglet weight at weaning. Multiplying the partial regression coefficients for each treatment group times the number of sows within each severity score [an average of TS and CK coefficients was used for TK sows (sows with both toe size difference and hoof cracks)], 144 treatment sows weaned a total of 215 kg less piglet

body weight compared to control sows. Commercial sow operations frequently record the number of piglets weaned per litter, piglet mortality during lactation, and other easily obtained measurements for sows during lactation and use that data for culling criteria. However, most farms do not weigh individual litters at weaning due to the expense associated with obtaining that data. Thus, the adjusted litter weaning weight might have the most unnoticed consequence of hoof lesions in many commercial swine production systems.

There was no evidence that sows with hoof lesions produced fewer number of piglets born alive (Chapter 4). Sows with overgrown toes were associated with standing less time after feeding, and this result is consistent with previously reported findings. Increased piglet mortality during lactation was associated with an increase hoof crack and toe length difference severity score, and thus, sows from those treatment groups weaned fewer piglets per litter. Sows spent between 3.3 and 9.1 % (mean = 5.7%) of the day eating (Chapter 4). Only one sow was observed to eat while sitting. Also, eating was the primary activity performed while standing, ranging from 55 to 91%. Sows appeared to have a preference for the side when lying laterally, after successfully lying down, and some sows had difficulty when lying down. Sows in the control, CK, TS, OG, and TK groups completed 89.3, 80.9, 93.1, 100.0, and 77.4 % of the 525 attempted lying down events. The number of attempts required when lying down above those that were defined as completed ranged from 0 to 6 per observation for all sows. Sows averaged 1.9 successful lying down events. Including all attempts, sows averaged 2.3 lying events during the observation period. Producers should identify sows standing for an excessive amount of time after feeding and confirm that there are no environmental impediments that prohibit sows from lying down.

Accurate sow body condition estimates are essential so that pork producers can provide sows with an appropriate feed volume needed to replenish body reserves during gestation so they are more likely to be productive in the subsequent farrowing and lactation. Thus, it is important for swine producers to have the skills necessary for accurate and repeatable quantification of body condition scores so that feed rations can be adjusted accordingly. Participant BCS₅ and BCS₉ deviation evaluations from BCS derived from objective backfat measurements revealed a tendency for participants to overestimate BCS in some sows and underestimate BCS in others. Repeatability, a measure of variance attributed to individual participants between rounds of scoring, was the largest contributor (70.6 %; lower values are more desirable) to the total test variability. One plausible way to reduce repeatability error would be to average multiple, independent scores by the same participant on the same sow. Reproducibility, a measure of variance attributed to BCS assigned by multiple participants, only accounted for 29.4 % of the total test variation, suggesting that participants were adequate in their estimation of BCS in sows. Because participant variance only accounted for 16.3 % of the total test variance, much more opportunity exists to reduce repeatability variance as compared to variance associated with consistently over- or under-estimating BCS. Averaging over all participants, the ultrasonic trait of last rib backfat yielded the greatest correlation (0.58) with BCS₉, followed by tenth rib backfat (0.51), tenth rib loin eye area (0.47), and last rib loin eye area (0.43). Similar trends were observed for the BCS₅ scale. Therefore, practice assigning independent BCS should lower repeatability variance, but training to calibrate specific participants may only influence total test variance to a relatively small degree.

Further, participants tended to assign BCS on their own scale and had individual specific biases towards over- or underestimating BCS in sows. Therefore, producers and employees on sow operations need training assigning condition scores against an objective standard in order to remove personal bias. Additionally, a designated person from the farm workers needs to be responsible for overall sow body condition on the farm, thus minimizing observer bias and inconsistency.

Once sows are culled from the herd, either as a result of sow welfare or productive reasons, many factors unique to individual pork operations must be evaluated before producers should consider adding BW of cull sows (Chapter 6). Foremost, individual pork operations must be able to physically house prospective cull sows, and in this study, only inexpensive feed and depreciated facilities allowed a decision to add weight to cull sows to be profitable. Second, pork producers must have current market condition knowledge and be able to predict, with some degree of certainty and associated risk, future market trends based on historical prices. Finally, each producer should evaluate their sow operation and determine (based upon sow health and feed prices) whether adding BW to cull sows is likely to be a profitable decision. In this study, adding BW to cull sows could be profitable in the presence of \$0.11/kg feed prices and labor and housing costs of \$0.25/d per sow. The maximum profit increase above salvage value was observed for MWC1 at \$13.01 per sow at 42 d. At that point, sows had gained 50.7 kg of BW since trial initiation. Revenue equaled total cost at approximately 90, 80, 45, and 53 d on trial for MWC1 through 4, respectively, using the lowest feed and fixed costs.

CHAPTER 8. REFERENCES CITED

- Bane, D. P., R. J. Meade, H. D. Hilley, and A. D. Leman. 1980. Influence of d-biotin and housing on hoof lesions. In: Proc. Int. Pig Vet. Soc. p 334.
- Boyle, L. 1996. Skin lesions, overgrown hooves and culling reasons in individually housed sows. M.S. Thesis. University College, Dublin.
- Bonde, M., T. Rousing, J. H. Badsberg, and J. T. Sorensen. 2004. Associations between lying-down behaviour problems and body condition, limb disorders and skin lesions of lactating sows housed in farrowing crates in commercial sow herds. *Livest. Prod. Sci.* 87:179-187.
- Brooks, P. H., D. A. Smith, and V. C. Irwin. 1977. Biotin-supplementation of diets: The incidence of foot lesions, and the reproductive performance of sows. *Vet. Rec.* 101:46-50.
- Budsberg, S. C., M. C. Verstraete, R. W. Soutas-Little, G. L. Flo, and C. W. Probst. 1988. Force plate analyses before and after stabilization of canine stifles for cruciate injury. *Am. J. Vet. Res.* 49:1522-1524.
- Clayton, H. M. 2005. The force plate: established technology, new applications. *Vet. J.* 169:15-16.
- Corr, S. A., C. C. McCorquodale, R. E. McGovern, M. J. Gentle, and D. Bennett. 2003. Evaluation of ground reaction forces produced by chickens walking on a force plate. *Am. J. Vet. Res.* 64:76-82.
- Cunha, T. J., D. C. Lindley, and M. E. Ensminger. 1946. Biotin deficiency syndrome in pigs fed desiccated egg white. *J. Anim. Sci.* 5:219-225.
- Dourmad, J. Y., M. Etienne, and J. Noblet. 1996. Reconstitution of body reserves in multiparous sows during pregnancy: Effect of energy intake during pregnancy and mobilization during the previous lactation. *J. Anim. Sci.* 74:2211-2219.
- Engblom, L., N. Lundeheim, A.-M. Dalin, and K. Andersson. 2007. Sow removal in Swedish commercial herds. *Livest. Prod. Sci.* 106:76-86.

- Evans, R., C. Horstman, and M. Conzemius. 2005. Accuracy and optimization of force platform gait analysis in Labradors with cranial cruciate disease evaluated at a walking gait. *Vet. Surg.* 34:445-449.
- Fitzgerald, R., K. Stalder, L. Karriker, C. Johnson, L. Layman, and A. Johnson. 2008. Developing and utilizing visual tools to assist pork producers in employee training in the evaluation of sow body condition. *J. Ext.* 46:2T0T7.
- Flower, F. C., and D. M. Weary. 2008. *Gait assessment in dairy cattle.* Animal. Cambridge University Press.
- Gjein, H., and R. B. Larssen. 1995a. 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.* 36:433-442.
- Gjein, H., and R. B. Larssen. 1995b. Housing of pregnant sows in loose and confined systems-a field study. 3. The impact of housing factors on claw lesions. *Acta Vet. Scand.* 36:443-450.
- Hegsted, D. M., M. C. Mills, G. M. Briggs, C. A. Elvehjem, and F. B. Hart. 1942. Biotin in chick nutrition. *J. Nutr.* 23:175.
- Hegsted, D. M., J. J. Oleson, M. C. Mills, C. A. Elvehjem, and F. B. Hart. 1940. Studies on a dermatitis in chicks distinct from pantothenic acid deficiency. *J. Nutr.* 20:599.
- Jevens, D. J. et al. 1996. Use of force-plate analysis of gait to compare two surgical techniques for treatment of cranial cruciate ligament rupture in dogs. *Am. J. Vet. Res.* 57:389-393.
- Johnston, L. J., J. E. Pettigrew, S. K. Baidoo, G. C. Shurson, and R. D. Walker. 2003. Efficacy of sucrose and milk chocolate product or dried porcine solubles to increase feed intake and improve performance of lactating sows. *J Anim. Sci.* 81:2475-2481.
- Kestin, S. C., T. G. Knowles, A. E. Tinch, and N. G. Gregory. 1992. Prevalence of leg weakness in broiler chickens and its relationship with genotype. *Vet. Rec.* 131:190-194.
- Knauer, M. 2006. *Factors influencing sow longevity.* M.S. Thesis. Iowa State University, Ames.

- Kornegay, E. T., K. L. Bryant, and D. R. Notter. 1990. Toe lesion development in gilts and sows housed in confinement as influenced by toe size and toe location. *Appl. Agric. Res.* 5:327-334.
- Lameness. 2008. Merriam-Webster Online Dictionary. Available at: <http://www.merriam-webster.com/>. Accessed December 1, 2008.
- Leonard, F. C., I. Stienezen, and P. B. Lynch. 1997. Behaviour of sows with overgrown hooves in the farrowing house Agricultural Research Forum, Faculty of Agriculture, U.C.D Belfield, Dublin.
- Maes, D. G. D., G. P. J. Janssens, P. Delputte, A. Lammertyn, and A. de Kruif. 2004. Back fat measurements in sows from three commercial pig herds: relationship with reproductive efficiency and correlation with visual body condition scores. *Livest. Prod. Sci.* 91:57-67.
- MAFF. 1981. Injuries caused by flooring: A survey in pig health scheme herds, *Pig Vet. Soc.* p 119-125.
- Main, D. C. J., J. Clegg, A. Spatz, and L. E. Green. 2000. Repeatability of a lameness scoring system for finishing pigs. *Vet. Rec.* 147:574-576.
- Manson, F. J., and J. D. Leaver. 1988. The influence of concentrate amount on locomotion and clinical lameness in dairy cattle. *Anim. Prod.* 47:185-190.
- McLaughlin Jr., R. M., C. W. Miller, C. L. Taves, T. C. Heam, N. C. Palmer, and G. I. Anderson.. 1991. Force plate analysis of triple pelvic osteotomy for the treatment of canine hip dysplasia. *Vet. Surg.* 20:291-297.
- Mill, J. M., and W. R. Ward. 1994. Lameness in dairy cows and farmers' knowledge, training, and awareness. *Vet. Rec.* 134:162-164.
- NASS. 2006. U.S. & All States Data – Hogs & Pigs, Sows and Gilts USDA. Natl. Agric. Stat. Serv., Washington, DC. Available at: <http://usda.mannlib.cornell.edu/usda/nass/HogsPigs//2000s/2006/HogsPigs-12-27-2006.txt>. Accessed Feb 09, 2008.
- Penny, R. H., A. D. Osborne, and A. I. Wright. 1963. The causes and incidences of lameness in store and adult pigs. *Vet. Rec.* 75:1225-1237.

- PigCHAMP. 2007. Benchmarking 2007 annual summary of US herds. Available at: http://www.pigchamp.com/summary_archives.html. Accessed March 25, 2009.
- Quinn, M. M., N. S. Keuler, Y. Lu, M. L. Faria, P. Muir, and M. D. Markel. 2007. Evaluation of agreement between numerical rating scales, visual analogue scoring scales, and force plate gait analysis in dogs. *Vet. Surg.* 36:360-367.
- Ritter, L. A., J. Xue, G. D. Dial, R. B. Morrison, and W. E. Marsh. 1999. Prevalence of lesions and body condition scores among female swine at slaughter. *J. Am. Vet. Med. Assoc.* 214:525-528.
- Smith, B. 1988. Lameness in pigs associated with foot and limb disorders. *In Pract.* 10:113-117.
- Stalder, K. J., M. Knauer, T. J. Baas, M. F. Rothschild, and J. W. Mabry. 2004. Sow longevity. *Pig News Inf.* 25:53N-74N.
- Stienezen, I. 1996. Welfare of confined sows with overgrown hooves in the farrowing house. M. S. Thesis. Moorepark Dairy Production Research Institute, Fermoy, Ireland.
- Thomsen, P. T., L. Munksgaard, and F. A. Togersen. 2008. Evaluation of a lameness scoring system for dairy cows. *J. Dairy Sci.* 91:119-126.
- Tomlinson, D. J., C. H. Mulling, and T. M. Fakler. 2004. Invited review: formation of keratins in the bovine claw: roles of hormones, minerals, and vitamins in functional claw integrity. *J. Dairy Sci.* 87:797-809.
- Vaughan, L. C. 1969. Locomotory disturbance in pigs. *Brit. Vet. J.* 125:345-365.
- Wells, G. A. H. 1984. Locomotor disorders of the pig. *In Pract.* 6:43-53.
- Wells, S. J., A. M. Trent, W. E. Marsh, and R. A. Robinson. 1993. Prevalence and severity of lameness in lactating dairy cows in a sample of Minnesota and Wisconsin herds. *J. Am. Vet. Med. Assoc.* 202:78-82.
- Welsh, E. M., M. Gettinby, and A. M. Nolan. 1993. Comparison of a visual analogue scale and a numerical rating scale for assessment of lameness, using sheep as a model. *Am. J. Vet. Res.* 54:976-983.

- Whay, H. 2002. Locomotion scoring and lameness detection in dairy cattle. In Pract. 24:444-449.
- Whay, H. R., D. C. J. Main, L. E. Green, and A. J. F. Webster. 2002. Farmer perception of lameness prevalence. In: 12th International Symposium on Lameness in Ruminants, Orlando, FL. p 355-358.
- Young, M. G., M. Tokach, R. D. Goodband, J. L. Nelssen, and S. S. Dritz (Editors). 2001. The relationship between body condition score and backfat in gestating sows. Pages 5-9 in Swine Day. Kansas State University, Manhattan.