

## ABSTRACT

FERRING, CASSANDRA LYNN. Estimates of Genetic Parameters for Sow Body Weight Loss During Lactation. (Under the direction of Dr. Mark Knauer).

The purpose of this study was to estimate genetic parameters among sow BW, sow BW loss during lactation, and reproductive traits. Data and pedigree information were available for Landrace (n = 3,310), York (n = 827) and Landrace × York F1 sows (n = 354) from The Maschhoffs (Carlyle, IL). Sows were housed in environmentally controlled facilities with slatted concrete flooring and had ad libitum access to water. Females were restricted fed during gestation based on a visual body condition score of 1 to 5 (1 = thin, 5 = fat). During lactation sows were fed ad libitum. Sow traits analyzed included body condition score at farrowing (FBCS), sow farrowing weight (SFW), total number born (TNB), number born alive (NBA), litter birth weight (LBW), litter weaning weight (LWW), number weaned (NW), body condition score at weaning (WBCS), sow weaning weight (SWW), and sow BW loss during lactation (WTA). Variance components were estimated using ASReml. All models included fixed effects of genetic line, parity, and contemporary group and random effects of animal (sow) and permanent environment. Covariates were included for SFW (days until farrowing), LBW (NBA), LWW (piglet age at weaning and number of piglets fostered), NW (number of piglets fostered), WBCS (lactation length), SWW (lactation length and days after weaning), and WTA (lactation length). Heritability estimates for FBCS, SFW, TNB, NBA, LBW, LWW, NW, WBCS, SWW, and WTA were 0.16, 0.27, 0.13, 0.15, 0.23, 0.15, 0.12, 0.15, 0.29, and 0.13 respectively. Permanent environment variance estimates for FBCS, SFW, TNB, NBA, LBW, LWW, NW, WBCS, SWW, and WTA were 0.0007, 25.2, 0.50, 0.25, 0.57, 2.65, 0.02, 0.0009, 40.5, and 1.29 respectively. Phenotypic variance

estimates for FBCS, SFW, TNB, NBA, LBW, LWW, NW, WBCS, SWW, and  $WT\Delta$  were 0.010, 185.6, 9.58, 8.91, 3.87, 95.04, 4.18, 0.010, 172.8, and 215.6 respectively. Genetic and phenotypic correlations between  $WT\Delta$  with FBCS, SFW, TNB, NBA, LBW, LWW, NW, WBCS, and SWW were  $-0.05$ ,  $0.27$ ,  $0.003$ ,  $-0.02$ ,  $0.50$ ,  $0.27$ ,  $0.05$ ,  $-0.21$ , and  $-0.37$  respectively, and  $0.04$ ,  $0.46$ ,  $0.06$ ,  $0.06$ ,  $0.26$ ,  $0.14$ ,  $0.14$ ,  $-0.04$ , and  $-0.47$  respectively. Continued selection for increased litter size would have minimal effect on body weight loss during lactation.

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Genetics of Sow Body Weight Loss during Lactation

by  
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## **BIOGRAPHY**

Cassandra L. Ferring was born on February 26, 1990 in Columbia, South Carolina. She was raised in a military family and moved frequently throughout her life. One constant throughout her life was her love of animals. Cassandra attended North Carolina State University where she received a B.S. in Animal Science and Zoology and a minor in Genetics. While at NC State, she was a part of the College of Agriculture and Life Sciences Honors Program where she participated in undergraduate research in quantitative genetics. It was during this undergraduate research that she developed an interest in swine genetics, which led to her pursuit of her Masters of Science Degree at North Carolina State University.

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## **Chapter 1: Literature Review**

## **Introduction**

The main means of profit by a sow is through her reproduction. Hence a sow's profitability increases the more piglets she has during her lifetime. If she was to become less efficient in reproducing, she is then more likely to be culled from the herd. Reproductive problems are the main reasons sows are culled (Anil et al., 2006). A major cause of reproductive problems is poor body condition due to an excess of weight loss during lactation (Lundgren et al., 2014).

Industry changes in body composition and reproductive throughput have perhaps increased the environmental sensitivity of the modern commercial sow herd. Consumer demand for leaner pork (Grandinson et al., 2005) has led to selection for pigs with less body fat (Vries and Kanis, 1994). Genetic selection for increased leanness has created sows that have fewer body reserves and are perhaps more difficult to maintain in ideal body condition. Besides reductions in body fat, swine producers continue to increase litter size (Knauer and Hostetler, 2013). A greater litter size increases the demand for milk production (Revell et al., 1998b), hence increasing a sow's sensitivity to reductions in lactation feed consumption.

The topics covered in this literature review include: first, phenotypic associations between sow body weight loss and reproduction; second, genetics of sow body weight loss; and finally, management strategies to minimize sow body weight loss.

### **Phenotypic associations between lactation sow body weight loss and reproduction**

#### *Litter weaning weight*

Sows with faster growing pigs mobilize more of their body tissues during lactation as compared to sows with slower growing piglets (Lundgren et al., 2014). Bergsma et al. (2007)

found that greater litter weight gain was associated with increased sow weight loss and backfat loss ( $r= 0.35$  and  $0.31$  respectively). Similarly, Lewis and Bunter (2011) and Ferguson et al. (1985) reported phenotypic correlations between litter weight gain and sow weaning weight of  $-0.17$  and  $-0.41$ , respectively. Lundgren et al. (2014) found a phenotypic correlation between litter weight at three weeks of age and body condition score of  $-0.15$ . Collectively these studies suggest that sows with heavier piglets at weaning lose more weight during lactation when compared to sows with smaller piglets.

### *Parity*

First parity sows tend to be more sensitive to weight loss in relation to subsequent reproduction when compared to multiparous females (Thaker and Bilkei, 2005). Thaker and Bilkei (2005) reported when females lost 11 to 15% of their body weight, multiparous sows had greater conception rate than parity one sows (71.8 vs. 68.7). Perhaps this is because first parity sows are not fully mature (Grandinson et al., 2005). When parity one sows lost an excess of 5% of their body weight, wean-to-service interval increased by one day, while this same increase in wean-to service interval was not seen in higher parity sows until weight loss during lactation exceeded 10% (Thaker and Bilkei, 2005).

### *Subsequent estrous and farrowing performance*

Mobilization of body tissues during lactation has been shown to impair subsequent estrous characteristics and farrowing rate. Sterning et al. (1990) reported that weight loss during lactation was associated with increased wean-to-estrus intervals ( $r=0.21$ ). Thaker and Bilkei (2005) found that sows who lost more than 20%, between 11 and 20%, and less than

10% of their body weight during lactation had farrowing rates of 60.4, 66.6, and 77.7%, respectively.

Sow condition at weaning, an indicator trait of sow body weight loss, has also been shown to have associations with subsequent estrous characteristics and farrowing rate. Lundgren et al. (2013) reported phenotypic correlations between body condition with wean-to-estrus interval and subsequent farrowing rate of -0.07 and 0.03, respectively, which indicates that as body condition decreases, wean-to-estrus interval increases and subsequent farrowing rate decreases. Lewis and Bunter (2011) reported first parity sows that had higher weight and fatness levels at weaning were more likely to farrow in their second parity ( $r=0.07$  and  $0.14$ , respectively). Taken together, excess body tissue mobilization increases wean-to-estrus and wean-to-farrow intervals. Thus the more time and money that is wasted due to poor rebreeding performance, the more likely the sow is to be culled.

#### *Subsequent litter size*

Losing excess weight or condition during lactation can have negative effects on subsequent litter size. Eissen et al. (2003) demonstrated that a reduction in sow body weight loss of 1 kg per day during first lactation increased subsequent litter size by 1.28 piglets. In agreement, Schenkel et al. (2010) showed sows that lost more than ten percent of their body weight during lactation had decreased subsequent litter size when compared to females that lost up to five percent (9.4 vs. 10.2). The same authors reported that a body condition score of 2 or less at weaning reduced subsequent litter size when compared to heavier conditioned sows (9.4 vs. 10.2). This same study also showed that an increase in backfat at weaning from 12mm to 16 mm increased second litter size from 9.4 to 10.2 piglets. Collectively, results

suggest that decreasing sow body weight loss or condition loss can increase subsequent litter size.

### **Genetics of sow body weight loss**

#### *Heritability of sow body weight loss*

Several investigators have estimated the genetic variation associated with sow body weight loss (Ferguson et al., 1985; Rydhmer et al., 1992; Grandinson et al., 2005; Bergsma et al., 2007; Lewis and Bunter, 2011). Heritability estimates for sow body weight loss and associated traits are reported in Table 1. Grandinson et al. (2005), Bergsma et al. (2007), and Lewis and Bunter (2011) reported similar heritability estimates for sow body weight loss of 0.20, 0.20, and 0.23, respectively. Ferguson et al. (1985) reported heritability estimates for sow body weight loss during lactation for Yorkshires and Durocs of 0.13 and 0.20, respectively. Rydhmer et al. (1992) found a relatively higher heritability for sow weight loss of 0.41. Hence previous estimates indicate moderate genetic variation exists for sow body weight loss during lactation.

Ferguson et al. (1985), Grandinson et al. (2005), Bergsma et al. (2007) and Lewis and Bunter (2011) investigated traits similar to sow body weight loss. Bergsma et al. (2007) reported that body weight at the beginning of lactation was the most heritable of the body weight traits with a heritability estimate of 0.45. Similarly, Ferguson et al. (1985) evaluated Yorks and Durocs and found sow farrowing weight was highly heritable with heritability estimates of 0.72 and 0.85, respectively. Grandinson et al. (2005) showed the heritability of weight at farrowing was relatively lower (0.19). Lewis and Bunter (2011) reported that sow weaning weight and farrowing weight had heritability estimates of 0.33 and 0.24,

respectively. Similarly, Ferguson et al. (1985) showed that dam weaning weight was highly heritable with heritability estimates of 0.42 and 0.87 for Yorks and Durocs, respectively.

Grandinson et al. (2005) and Bergsma et al. (2007) investigated sow fat loss traits. Grandinson et al. (2005) and Bergsma et al. (2007) found similar heritability estimates for backfat loss during lactation of 0.10 and 0.05, respectively. Grandinson et al. (2005) showed the heritability of backfat at farrowing was 0.47.

#### *Genetic correlations between sow body weight loss with sow weight and body condition*

Sow body weight loss has been reported to have associations with sow farrowing and weaning weight. Ferguson et al. (1985) and Lewis and Bunter (2011) reported a sow's weight at 110 days of gestation was associated with weaning weight, with genetic correlations of 0.93 and 0.70, respectively. Ferguson et al. (1985) also found negative genetic correlations between sow body weight loss with weight at 110 days of gestation and sow weaning weight of -0.63 and -0.30, respectively. Bergsma et al. (2008) found a negative genetic correlation between sow weight at farrowing and sow body weight loss of -0.27.

There are also associations between sow body weight loss with fat and protein loss. Bergsma et al. (2008) found relatively high correlations between weight loss with fat loss and protein loss of 0.86 and 0.99, respectively.

#### *Genetic correlations between sow body weight and condition with reproduction*

Genetic associations between sow farrowing weight and condition with reproduction have been reported by Ferguson et al. (1985) and Grandinson et al. (2005). Ferguson et al. (1985) reported genetic correlations between sow weight at 110 days of gestation with litter birth weight, litter weaning weight, number weaned, total number born, and number born

alive (0.68, 0.45, 0.42, 0.32, and 0.37, respectively). Grandinson et al. (2005) found genetic correlations between piglet birth weight with weight at farrowing and amount of backfat at farrowing of 0.67 and -0.31, respectively.

Genetic correlations between sow weaning weight and body condition with reproduction have been estimated by Ferguson et al. (1985), Hermesch et al. (2008), Lewis and Bunter (2011), and Lundgren et al. (2014). Phenotypically, Hermesch et al. (2008) showed that large body reserves at farrowing can withstand a 31 kg weight loss without a decrease in subsequent reproductive performance, while low body reserves at farrowing are more sensitive to weight loss when it comes to reproduction. Sow weaning weight has been shown to have a negative genetic correlation with litter weight gain to day 10 (-0.38, Lewis and Bunter, 2011). Ferguson et al. (1985) found genetic correlations between sow weaning weight with litter birth weight and total number born (0.62 and 0.34, respectively). Lundgren et al. (2014) found a positive genetic correlation between sow body condition at weaning and pregnancy rate and the ability to farrow a second litter (0.18).

#### *Genetic correlations between sow body weight and condition loss with reproduction*

Genetic associations between sow body weight and condition loss with reproduction have been reported by Ferguson et al. (1985) and Grandinson et al. (2005). Ferguson et al. (1985) found that weight loss during lactation was genetically correlated with number born alive, number weaned, litter birth weight, and litter weaning weight (-0.58, -0.81, -0.46, and -0.92, respectively), meaning that as reproductive throughput increased, weight loss increased. In agreement, Grandinson et al. (2005) reported maternal genetic correlations between

weight loss and backfat loss with piglet survival of 0.45 and 0.75, respectively, and growth to weaning of -0.85 and -0.80, respectively.

### **Management strategies to minimize sow body weight loss**

#### *Lactation feed intake*

Lactation feeding is key to minimizing the mobilization of body tissues during lactation. Increasing lactation feed intake can minimize weight loss, increase litter weight gain and decrease the probability of a delayed wean-to-estrus interval (Anil et al., 2006). Similarly, Bergsma et al. (2007) found that an increase in daily feed intake decreased the loss of body weight and fat and increased litter weight gain. Lewis and Bunter (2011) reported primiparous sows that were fed ad libitum during lactation had a 23% increase in body weight and 28% increase in body condition by the end of lactation when compared to those limit fed. Besides weight loss, high lactation feed intake can also reduce backfat loss during lactation (Maes et al., 2004). Noblet and Etienne (1987) stated that a sow requires between 460-490 kJ of energy per day per kg of sow body weight in order to maintain weight and body condition during lactation.

The study by Lewis and Bunter (2011) found sows that consumed more during lactation had more and heavier piglets. For every kg per day increase in feed intake there was an increase of 0.30 pigs per litter at day 10 and an increase of 0.72 pigs per litter at day 21. Eissen et al. (2003) found a similar result where increasing lactation feed intake had decreased weight loss and increased litter weight gains, but they found that the effects on backfat and body weight were smaller when the sows were nursing large litters.

A decrease in feed given during gestation is commonly associated with increased voluntary feed intake during lactation (Mullan and Williams, 1989). When there is increased feeding during gestation, the sows tend to have higher fat and weight at farrowing and this seems to be associated with the decrease in feed intake in lactation (Dourmad, 1991). Revell et al. (1998a) concluded sow backfat impacted feed intake of the sow. This impact was most prevalent in the first two weeks of lactation, while intake during the last two weeks was impacted more by other factors such as the content of the feed. When sows are allowed to build up their body fat stores during gestation, they tended to eat less when they enter into lactation and lose more weight throughout lactation (Williams and Smits, 1991). Managing feed and feed intake during gestation is one of the best ways to minimize weight loss during lactation.

#### *Diet composition*

Another piece to the lactation feeding puzzle is composition of the lactation diet. Brendemuhl et al. (1989) showed the amount of energy fed had a significant effect on change in backfat during lactation. The weight of the sow was more influenced by protein intake than by energy intake. The same authors reported protein restriction was more deleterious than energy restriction to the wean-to-estrus interval of the sow. Reese et al. (1984) showed a significant difference between body fat change and the loss of weight and backfat during lactation in sows fed high and low energy diets.

Within the amino acids that make up protein, optimum dietary lysine levels help mitigate sow body weight loss. A study by Touchette et al. (1998) showed that with an increase in the amount of dietary lysine there was a decrease in weight loss during lactation.

It is also worth noting that first parity sows are more likely to suffer from body weight loss and may need a more concentrated feed to support their litter (Anil et al., 2006). Besides lactation feeding management, there are other environmental strategies that can be used to help minimize weight loss during lactation.

### *Temperature*

One environmental management strategy that is linked with feed intake is temperature in lactation. Makkink and Schama (1998) reported that when temperature increased from 20 to 30° C, sows decreased their feed intake by about 2 kg per day. The same authors propose sows reduce feed intake during periods of heat stress to minimize heat production due to digestive processes. In order to keep producing milk at the same rate, sows mobilize more body reserves and lost about 20 kg more weight under heat stressed conditions.

### *Lactation length*

Another management technique that can reduce weight loss during lactation is to decrease lactation length. A study by Anil et al. (2006) demonstrated that sows with shorter lactation lengths tended to lose less weight and also have fewer high nutrient demands in the short term. In contrast, Tantasuparuk et al. (2001) showed that an increase in lactation length by 1 day decreased relative weight loss by 0.6%.

Taken together, studies show that lactation body weight loss is a problem Yet there are management and genetic strategies that can be used to avoid excessive weight loss and resulting impaired subsequent reproduction.

## **Conclusion**

There is sufficient evidence as to the causes of weight loss and its effects on reproduction. Increased sow body weight loss causes an increase in the wean-to-estrus interval and a decrease in subsequent litter size. Yet increased sow body weight loss is associated with increased litter size at weaning and litter weaning weight. Management strategies to limit weight loss include; increased feeding during lactation, increased dietary lysine, a shortened lactation length, and maintaining optimal farrowing room temperatures to encourage increased feed intake. These strategies are beneficial, but combating weight loss through genetic selection may increase the effectiveness of these management strategies and allow producers to more easily maintain sow weight and condition.

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**Table 1.1:** Heritability estimates for sow body weight loss and associated traits<sup>1</sup>

Traits	Bergsma et al. (2007)	Lewis and Bunter (2011)	Ferguson et al. (Yorks) (1985)	Ferguson et al. (Durocs) (1985)	Grandinson et al. (2005)	Rydhmer et al. (1992)	Gilbert et al. (2012)
WL	0.20	0.20	0.13	0.20	0.20	0.41	0.13
SFW	0.45	0.28	0.72	0.85	0.17		0.16
SWW		0.35	0.42	0.87			0.23
BFL	0.05	0.11			0.10		0.14
BFF	0.52				0.47		0.40
BFW							0.38

<sup>1</sup>WL= weight loss, SFW= sow farrowing weight, SWW= sow weaning weight, BFL=

backfat loss, BFF= farrowing backfat, BFW= weaning backfat

## **Chapter 2: Estimates of genetic parameters for sow body weight loss during lactation**

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## Abstract

The purpose of this study was to estimate genetic parameters among sow BW, sow BW loss during lactation, and reproductive traits. Data and pedigree information were available for Landrace (n = 3,310), York (n = 827) and Landrace × York F1 sows (n = 354) from The Maschhoffs (Carlyle, IL). Sows were housed in environmentally controlled facilities with slatted concrete flooring and had ad libitum access to water. Females were restricted fed during gestation based on a visual body condition score of 1 to 5 (1 = thin, 5 = fat). During lactation sows were fed ad libitum. Sow traits analyzed included body condition score at farrowing (FBCS), sow farrowing weight (SFW), total number born (TNB), number born alive (NBA), litter birth weight (LBW), litter weaning weight (LWW), number weaned (NW), body condition score at weaning (WBCS), sow weaning weight (SWW), and sow BW loss during lactation (WTΔ). Variance components were estimated using ASReml. All models included fixed effects of genetic line, parity, and contemporary group and random effects of animal (sow) and permanent environment. Covariates were included for SFW (days until farrowing), LBW (NBA), LWW (piglet age at weaning and number of piglets fostered), NW (number of piglets fostered), WBCS (lactation length), SWW (lactation length and days after weaning), and WTΔ (lactation length). Heritability estimates for FBCS, SFW, TNB, NBA, LBW, LWW, NW, WBCS, SWW, and WTΔ were 0.16, 0.27, 0.13, 0.15, 0.23, 0.15, 0.12, 0.15, 0.29, and 0.13 respectively. Permanent environment variance estimates for FBCS, SFW, TNB, NBA, LBW, LWW, NW, WBCS, SWW, and WTΔ were 0.0007, 25.2, 0.50, 0.25, 0.57, 2.65, 0.02, 0.0009, 40.5, and 1.29 respectively. Phenotypic variance estimates for FBCS, SFW, TNB, NBA, LBW, LWW, NW, WBCS, SWW, and WTΔ were

0.010, 185.6, 9.58, 8.91, 3.87, 95.04, 4.18, 0.010, 172.8, and 215.6 respectively. Genetic and phenotypic correlations between  $WT\Delta$  with FBCS, SFW, TNB, NBA, LBW, LWW, NW, WBCS, and SWW were  $-0.05$ ,  $0.27$ ,  $0.003$ ,  $-0.02$ ,  $0.50$ ,  $0.27$ ,  $0.05$ ,  $-0.21$ , and  $-0.37$  respectively, and  $0.04$ ,  $0.46$ ,  $0.06$ ,  $0.06$ ,  $0.26$ ,  $0.14$ ,  $0.14$ ,  $-0.04$ , and  $-0.47$  respectively. Continued selection for increased litter size will have minimal effect on body weight loss.

## **Introduction**

Industry changes in body composition and reproductive throughput have perhaps increased the environmental sensitivity of modern commercial sow herds. Consumer demand for leaner pork (Grandinson, 2005) has led to selection for pigs with less body fat (Vries and Kanis, 1994). Selection for increased leanness has created sows that have fewer body reserves and are perhaps more difficult to maintain in ideal body condition. Besides reductions in body fat, swine producers continue to increase litter size (Knauer and Hostetler, 2013). A greater litter size increases the demand for milk production from the sow (Revell et al., 1998), hence increasing her sensitivity to reductions in lactation feed consumption.

Continued strategies to mitigate sow body weight loss during lactation should be developed. Past research has identified increased lactation feed intake, increased lactation dietary lysine, and shortened lactation lengths as successful management strategies to alleviate lactation body weight loss (Touchette et al., 1998; Eissen et al., 2003; Maes et al., 2004; Bergsma et al., 2007; Lewis and Bunter, 2011). Yet few genetic approaches to lessen sow body weight loss during lactation have been investigated. Therefore, the objective of this study was to estimate genetic parameters among sow body weight, sow body weight loss during lactation, and reproductive traits.

## **Materials and Methods**

### *Animals and Facilities*

Data from Landrace (n=3,310), Yorkshire (n=827), and Landrace Yorkshire F1 sows (n=354) were provided by The Maschhoffs (Carlyle, IL). Sows were housed in environmentally controlled facilities with slatted concrete floors with one sow per pen in both gestation and lactation. All females had ad libitum access to water. In gestation, gilts and sows were fed twice daily, the feeding level for gilts depending on breeding weight and for sows based on visual body condition score. In lactation, sows were provided ad libitum access to feed and water. All diets met or exceeded NRC requirements (NRC, 2012).

Sow traits analyzed included body condition score at farrowing (FBCS), sow farrowing weight (SFW), total number born (TNB), number born alive (NBA), litter birth weight (LBW), litter weaning weight (LWW), number weaned (NW), body condition score at weaning (WBCS), sow weaning weight (SWW), and sow BW loss during lactation (WT $\Delta$ ). Sow farrowing weight was adjusted to account for both placental weight and number of piglets born using the equation:  $SFW \text{ (kg)} = -19.75 + 0.973 \times \text{pre-farrow weight} - 1.09 \times \text{number of pigs born}$  (Rosero et al., 2013).

### *Statistical Analysis*

Variance components were estimated using ASReml (Gilmour et al., 1996). All models included fixed effects of genetic line, parity, and contemporary group and random effects of animal (sow) and permanent environment. Covariates were included for SFW (days until farrowing), LBW (NBA), LWW (piglet age at weaning and number of piglets fostered), NW (number of piglets fostered), WBCS (lactation length), SWW (lactation length

and days after weaning), and WTΔ (lactation length). Standard errors for heritability estimates and genetic and phenotypic correlations were calculated in ASReml (Gilmour et al., 2002).

## **Results and Discussion**

### *Heritability Estimates*

Estimates of variance components for sow body condition, sow weight, and litter traits are shown in Table 1. In the current study, the heritability for SFW was 0.27. In agreement, Grandinson et al. (2005) and Lewis and Bunter (2011) reported heritability estimates for SFW of 0.19 and 0.23, respectively. Yet Ferguson et al. (1985), Bergsma et al. (2008), and Gilbert et al. (2012) reported relatively different heritability estimates (0.72, 0.45, and 0.16, respectively). In the present study, the heritability estimate for SWW was 0.29. Similarly, Lewis and Bunter (2011) and Gilbert et al. (2012) found heritability estimates of 0.33 and 0.23, respectively. Ferguson et al. (1985) reported a higher heritability for SWW of 0.42. The heritability estimate for WTΔ in the current study was 0.13. In accordance, Ferguson et al. (1985) and Gilbert et al. (2012) reported estimates for WTΔ of 0.13 and Grandinson et al. (2005), Bergsma (2008) and Lewis and Bunter (2011) found estimates of 0.20, 0.20, and 0.23, respectively. In contrast, Rydhmer et al. (1992) reported a relatively greater heritability estimate for WTΔ of 0.41. Collectively, these heritability estimates suggest SFW and SWW would respond to selection faster than WTΔ.

Heritability estimates for FBCS and WBCS were 0.16 and 0.15, respectively. Similarly, Lundgren et al. (2013) reported a WBCS heritability of 0.17. Sow body condition score is a composite trait of weight, backfat, and muscling (Knauer and Baitinger, 2015). An

indicator trait of sow body condition, sow backfat has also been shown to be heritable. Lewis and Bunter (2011) reported estimates for farrowing and weaning backfat of 0.33 and 0.35, respectively. Similarly, Gilbert et al. (2012) reported estimates of 0.40 and 0.38, respectively, for the same traits. Grandinson et al. (2005) and Bergsma et al. (2008) reported estimates for farrowing backfat of 0.47 and 0.52, respectively. Collectively, these results suggest sow backfat has a greater heritability than sow body condition score. Perhaps this is because sow backfat is a more objective measure than visual sow body condition. This is supported by Fitzgerald et al. (2009) who found the perceived “ideal” target for sow body condition varies between individuals.

Heritability estimates for reproductive traits LBW, TNB, NW, and LWW (0.23, 0.13, 0.12, and 0.15, respectively) were consistent with literature estimates (0.24, 0.11, 0.08, and 0.14 respectively, Rothschild and Bidanel, 2011). The heritability estimate for NBA (0.15), was relatively greater than those reported in the literature (0.10, Rothschild and Bidanel, 2011).

### *Correlation Estimates*

Estimated genetic and phenotypic correlations among sow body condition, sow weight, and litter traits are shown in table 2. Phenotypic and genetic correlations between SFW and  $WT\Delta$  were 0.46 and 0.27, respectively. Ferguson et al. (1985) reported phenotypic and genetic correlations between SFW and  $WT\Delta$  of 0.38 and 0.63, respectively. These correlations indicate sows that are heavier at farrowing lose more weight during lactation. Hence farms should properly manage sow condition during gestation and optimize sow farrowing weight in order to help mitigate weight loss during lactation. The current study

found a genetic correlation of -0.37 between SWW and WTΔ. This correlation is comparable to the genetic correlation reported by Bergsma et al. (2008) (-0.27). In contrast, Ferguson et al. (1985) reported a correlation between SWW and WTΔ of 0.30. The current study and Ferguson et al. (1985) reported genetic correlations between SFW and SWW of 0.82 and 0.93, respectively, indicating SFW and SWW are quite similar traits. Collectively, results suggest selection for WTΔ would not have a great effect on sow body weight at farrowing or weaning.

In the current study, phenotypic and genetic correlations between FBCS and WBCS were 0.61 and 0.92, respectively. In accordance, Lewis and Bunter (2011) reported phenotypic and genetic correlations between sow backfat at farrowing and backfat at weaning of 0.63 and 0.91, respectively. Taken together, these genetic correlations indicate that body condition at farrowing and weaning are genetically similar traits. The positive phenotypic associations between body condition at farrowing and weaning suggest sow body reserves at farrowing can be used as a management tool to help prevent poor body condition at weaning. Yet excessive body reserves at farrowing is detrimental to WTΔ, especially for first parity sows (Revell et al., 1998). Hence optimal sow condition at farrowing is needed to enhance sow condition at weaning yet prevent excessive WTΔ during lactation. Bryan et al. (2014) reported optimal sow condition targets in relation to subsequent reproduction.

Genetic correlation estimates between SFW with TNB, NBA and NW were 0.10, 0.09 and -0.02, respectively. In agreement, Lewis and Bunter (2011) reported genetic correlations between SFW with TNB and NBA of -0.07 and 0.01, respectively. Ferguson et al. (1985) reported relatively greater genetic correlations between SFW with TNB, NBA, and NW

(0.32, 0.37, and 0.42, respectively). The current study found genetic correlations between SWW with LBW and TNB of 0.10 and -0.10, respectively. In contrast, Ferguson et al. (1985) reported relatively greater genetic correlations between SWW with LBW and TNB of 0.62 and 0.34, respectively. Genetic correlations in the current study between WTΔ with NBA, LBW, LWW, and NW were -0.02, 0.50, 0.27, 0.05, respectively. In agreement, Ferguson et al. (1985) and Bergsma et al. (2008) reported similar genetic correlations between WTΔ and LBW of 0.46 and 0.56, respectively. Yet Ferguson et al. (1985) reported relatively greater genetic correlations between WTΔ with NBA, LWW, and NW of 0.58, 0.92, and 0.81, respectively. Results from the current study indicate selection for litter size traits would have little impact on SFW, SWW, or WTΔ. Yet selection for LBW would somewhat reduce increase WTΔ.

*Selection to mitigate sow weight loss during lactation*

Given the heritability estimate for WTΔ is relatively lower than SFW or SWW, indirect selection for WTΔ warrants further investigation.

The formulas for direct and indirect selection are as follows:

**Direct Selection for WTΔ:**  $\Delta G_{WT\Delta} = h_{WT\Delta} * i * \sigma_{WT\Delta}$

**Indirect Selection for WTΔ through:**  $\Delta G_{WT\Delta * SWW} = r_g * h_{SWW} * i * \sigma_{WT\Delta}$

Where  $h_{WT\Delta}$  is the square root of heritability of the trait of interest (WTΔ),  $h_{SWW}$  is the square root of the heritability of the trait used for indirect selection (SWW),  $r_g$  is the genetic correlation between the two traits WTΔ and SWW,  $i$  is the selection intensity and  $\sigma_{WT\Delta}$  is the standard deviation of the trait of interest WTΔ.

By solving these equations it can be determined whether direct or indirect selection would increase genetic gain more rapidly. Using the previous equation,  $i$  and  $\sigma_{WT\Delta}$  cancel out since they occur in both equations.

$$\frac{\Delta GW_{T\Delta}}{\Delta GW_{T\Delta} * SWW} = \frac{h_{WT\Delta} * i * \sigma_{WT\Delta}}{r_g * h_{SWW} * i * \sigma_{WT\Delta}} = \frac{h_{WT\Delta}}{r_g * h_{SWW}}$$

Next, the numbers from tables 1 and 2 below can be inserted to calculate the genetic change in both of the situations.

$$\frac{\Delta GW_{T\Delta}}{\Delta GW_{T\Delta} * SWW} = \frac{\sqrt{0.13}}{-0.37 * \sqrt{0.29}} = \frac{0.36}{-0.19} = -1.81$$

As these numbers show, direct selection is a better method for creating genetic change for  $WT\Delta$  than indirect selection using  $SWW$  to make genetic change in  $WT\Delta$ . In fact, direct selection is almost twice as effective as indirect selection.

In conclusion, it appears possible to reduce the amount of body weight sows lose during lactation using genetic selection. Results suggest that continued selection for litter size traits will have minimal effects on sow  $WT\Delta$  over the course of lactation.

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**Table 2.1:** Heritability estimates for sow body condition, sow weight, and litter traits.

<i>Trait</i>	$\mu$	$\sigma_P^2$	$\sigma_A^2$	$\sigma_{PE}^2$	$h^2$	<i>SE</i>
<i>FBCS</i>	3.04	0.010	0.0030	0.0007	0.16	0.03
<i>SFW, kg</i>	192.1	185.6	91.7	25.2	0.27	0.04
<i>TNB</i>	11.8	9.58	1.56	0.50	0.13	0.03
<i>NBA</i>	10.7	8.91	1.61	0.25	0.15	0.03
<i>LBW, kg</i>	15.7	3.87	1.52	0.57	0.23	0.04
<i>LWW, kg</i>	46.8	95.04	16.97	2.65	0.15	0.03
<i>NW</i>	9.74	4.18	0.56	0.02	0.12	0.02
<i>WBCS</i>	3.03	0.010	0.004	0.0009	0.15	0.04
<i>SWW, kg</i>	188.8	172.8	87.5	40.5	0.29	0.04
<i>WTA, kg</i>	-3.28	215.6	33.0	1.41	0.13	0.03

$\mu$ = phenotypic mean,  $\sigma_P^2$ = phenotypic variance,  $\sigma_A^2$ = additive genetic variance, PE= permanent environmental variance,  $h^2$ = heritability, SE= standard error; FBCS= body condition score at farrowing, SFW= sow farrowing weight, TNB= total number born, NBA= number born alive, LBW= litter birth weight, LWW= litter weaning weight, NW= number weaned, WBCS= body condition score at weaning, SWW= sow weaning weight, WTA= sow body weight loss.

**Table 2.2:** Estimated genetic (above diagonal) and phenotypic (below diagonal) correlations among sow body condition, body weight, and litter traits

Trait	FBCS	SFW	TNB	NBA	LBW	LWW	NW	WBCS	SWW	WTΔ
FBCS		0.69 (0.08)	-0.03 (0.16)	-0.06 (0.15)	0.12 (0.14)	-0.07 (0.16)	-0.22 (0.15)	0.92 (0.05)	0.63 (0.09)	-0.06 (0.16)
SFW	0.33 (0.02)		0.10 (0.13)	0.09 (0.12)	0.39 (0.11)	0.29 (0.14)	-0.02 (0.14)	0.68 (0.10)	0.82 (0.14)	0.27 (0.12)
TNB	-0.01 (0.02)	-0.02 (0.02)		0.94 (0.02)	-0.23 (0.13)	0.37 (0.14)	0.73 (0.07)	-0.09 (0.21)	-0.10 (0.14)	0.003 (0.16)
NBA	-0.007 (0.02)	-0.01 (0.02)	0.92 (0.002)		0.70 (0.07)	0.56 (0.12)	0.88 (0.03)	-0.10 (0.20)	-0.06 (0.13)	-0.02 (0.16)
LBW	0.05 (0.02)	0.32 (0.02)	-0.42 (0.02)	0.77 (0.009)		0.62 (0.10)	0.12 (0.15)	0.13 (0.20)	0.10 (0.13)	0.50 (0.12)
LWW	0.03 (0.02)	0.13 (0.02)	0.36 (0.02)	0.49 (0.02)	0.46 (0.02)		0.67 (0.09)	-0.24 (0.23)	-0.05 (0.15)	0.27 (0.16)
NW	0.009 (0.02)	0.007 (0.02)	0.72 (0.009)	0.85 (0.005)	0.16 (0.02)	0.71 (0.01)		-0.20 (0.19)	-0.02 (0.14)	0.05 (0.17)
WBCS	0.61 (0.01)	0.36 (0.02)	-0.04 (0.02)	-0.04 (0.02)	0.02 (0.03)	0.008 (0.03)	-0.04 (0.03)		0.78 (0.09)	-0.21 (0.19)
SWW	0.29 (0.02)	0.58 (0.01)	-0.10 (0.02)	-0.08 (0.02)	0.07 (0.02)	-0.02 (0.02)	-0.14 (0.02)	0.43 (0.02)		-0.37 (0.12)
WTΔ	0.04 (0.02)	0.46 (0.02)	0.06 (0.02)	0.06 (0.02)	0.26 (0.02)	0.14 (0.02)	0.14 (0.02)	-0.04 (0.02)	-0.47 (0.02)	

Standard errors are located within parenthesis; FBCS= body condition score at farrowing,

SFW= sow farrowing weight, TNB= total number born, NBA= number born alive, LBW=

litter birth weight, LWW= litter weaning weight, NW= number weaned, WBCS= body

condition score at weaning, SWW= sow weaning weight, WTΔ= sow body weight loss.