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Analysis Of Sources Of Variation And Relationships Among Sow Productivity Traits

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Date

ANALYSIS OF SOURCES OF VARIATION AND RELATIONSHIPS AMONG SOW
PRODUCTIVITY TRAITS

A Thesis

Submitted to the Faculty

of

Purdue University

by

Richard L. Cutshaw

In Partial Fulfillment of the

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of

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ABSTRACT

Cutshaw, Richard L., M.S. Purdue University, December, 2013. Analysis of the sources of variation and relationships among sow productivity traits. Major Professor: Allan P. Schinckel.

The swine industry has witnessed major changes in the past three decades in terms of selection tools and implementation of effective selection. As the pork industry continues to consolidate, it is increasingly important to be able to accurately predict and direct future performance toward increased overall profitability. Overall, sow productivity greatly affects a pork producer's ability to be profitable in the industry and have sufficient knowledge of production levels to improve the likelihood of remaining profitable into the future.

The relationships among sow productivity traits including total number born, litter birth weight, number weaned, preweaning survival, mean piglet birth weight, and litter weaning weight in purebred and crossbred litters and their relationships with growth performance and composition were evaluated. The initial study found that relationships among many commonly measured sow productivity traits have changed dramatically since the 1980's and selection for certain traits have been more effective than others.

The second study found that variation in birth and weaning weights in swine had a large positive effect on the days to market but litter effect on loin muscle area or backfat depth. Sow productivity traits such as litter, birth, and weaning weights have increased drastically in the past whereas threshold traits like survival percentage have not greatly

changed in the same time period. Many of the relationships observed in sow productivity were examined by their relationship between number of pigs the sow is allowed to nurse as well as the parity of the dam. These data suggest that genetic superiority for milk production potential may be expressed when the sows are subjected to litter sizes that are larger than average. As number of pigs born alive increases, the percentage of piglets that are light weight increases, competition for food resources increases, and the likelihood of a pig being weaned decreases. Maximum litter weight and number weaned were observed when sows were allowed to nurse 12 to 14 piglets. Above these levels of number of pigs nursed there was no increase in number of piglets weaned or litter weaning weight. Number weaned increased as number after transfer (NAT) increased in a linear fashion up to NAT equal to 10. After 10, there was a curvilinear relationship between number weaned and NAT until number weaned reached a maximum value at NAT equal to 12 to 13. In current studies, increasing litter size did not significantly increase the amount of variation in the piglet birth weights; nor did increasing the number of piglets allowed to nurse increase the variation in piglet weaning weights.

It is important to understand these relationships for adjustment of raw data to allow more accurate genetic evaluation. Overall, for most sow productivity traits, parity 2 sows had litters with the greatest birth and weaning weights. For other traits there were no differences from parity 2 sow litters to parity 3 through 5 sow litters. Both birth and weaning weight were found to be related to days to 250 pounds, backfat depth, and loin muscle area. Overall, birth and weaning weight had greater effect and accounted for more of the residual variation of days to 250 pounds (20.5 %) than backfat depth (2.4%) or loin muscle area (0.6%). Pigs with lighter than average birth and weaning weights required more days to achieve 250 pounds bodyweight. Pigs with the lightest birth weight had smaller loin muscle areas and slightly greater backfat depth than pigs with average and above average birth weights. Parity 1 dams required approximately 3 more days to achieve 250 pounds. When adjusted for linear-quadratic effects of both birth and weaning weight, the difference in days to 250 pounds was not significant. This suggests in these high health purebred herds, the increased days to 250 pounds of the parity 1 dams was accounted for by their decreased birth and weaning weights. Selection for

increased birth weight and increased preweaning survival has become more important than selection for increased litter size. Future selection must also consider the magnitude of variation for birth and weaning weight, along the percentage of lightweight piglets born as these traits are more closely related to piglet survival and post weaning performance.

CHAPTER 1 INTRODUCTION

Sow productivity is influential to the profitability of every swine producer. Sow productivity is a trait of the dam that can be defined in many ways, each of which is impacted by the total number of pigs born. Total number of pigs born is affected by 4 main components: ovulation rate, conception rate, embryonic survival, and the sow's ability to farrow live piglets (Gaugler et al 1984). Another measure of sow productivity that many producers in the industry inquire about is the number of pigs per sow per year (PSY), which takes into account the total number of piglets born per litter, and the number of litters the sow farrows in a given year. All of which are influenced by the sow's ability to rebreed in a timely manner and not mount up an undesirable number of unproductive sow days (Britt 1986).

Other measures that affect productivity should also be evaluated. One such trait is the sow's milking ability, which affects the size of its litters at weaning (Bereskin and Norton, 1982). It is the desire of every swine producer to wean as many large piglets as a sow can. Larger piglets farrowed and weaned lead to greater profits for producers since the piglets grow more efficiently, have lower mortality, and have decreased incidence of illness.

Over time the swine industry has continually selected animals that producers believed to be more profitable. Producers focus on one or two traits and select heavily for them, such as increasing PSY and litter weaning weights. Sows that have larger litters have an increased number of light birth weight pigs (LBWP) which grow more slowly, are less efficient, and have lower survivability than piglets that are much larger at birth (Le Dividich 1999). The current analysis will evaluate how swine producers have selected for sows that can produce larger litters, and the impact on the industry in terms

of number of pigs weaned (**NW**), piglet survival percentage (**%S**), litter weaning weights (**LWW**) over the past 3 decades.

1.1 Objectives

The objective of this research is to evaluate the relationships amongst sow productivity traits in modern swine production and gain a better understanding of how a change in one trait affects other economically important traits. Specifically, the effects of changing litter sizes, and the subsequent performance of litters will be evaluated, through various statistical models.

1.2 Literature Review

Sow productivity is defined by many measurable traits including: total number of pigs born (**TNB**), %S, NW, and LWW. Overall sow productivity affect's market animals in terms of the number of days to market, loin muscle area, and backfat depth. All of these variables are affected by the early growth of the newborn piglets and selection for sow productivity traits can have beneficial outcomes in the market animals (Dube et al., 2013).

Tables A and B are a survey of studies conducted from 1980 to 1992, and from 2007 to 2010 respectively, representing a subset of the population means for certain sow productivity traits. During the studies conducted in the 1980s weaning ages were not consistent, making comparisons between the two data sets difficult. It is possible however to adjust all weaning weights to the constant weaning age of 21 days with litters weaned after 21 days being assigned decreased levels of production the older the litter is at weaning.

Table A. Economically important productivity trait averages of studies in the 1980s

Study	N	TNB ^d	NW ^f	%S ^g	LBW ^e , kg	LWW ^h , kg
Drewry, 1980 ^b	380	12.0	8.8	73.3	15.1	68.0
Schneider, 1982 ^a	1,065	9.2	7.3	78.7	12.3	43.8
Gaugler, 1984 ^c	366	10.6	7.6	72.3	14.3	87.8
Britt, 1986	394	-	7.7	-	-	-
Stansbury, 1987 ^b	341	9.7	8.6	88.4	-	57.4
Kuhlers, 1989 ^a	182	11.0	9.1	82.3	16.6	46.7
Shurson, 1992 ^b	223	9.0	7.1	78.7	14.1	61.1
Average	2,557	10.0	7.8	78.3	13.7	57.2

^a weaning age of 21d; ^b weaning at age 35d; ^c weaned at 42d

^d Total Born possibly including stillbirths; ^e Litter birth weight

^f Number of piglets weaned; ^g Percentage of survival; ^h Litter weaning weight

Table B. Economically important productivity trait averages of studies in the 2000s

Study	N	TNB ^a	NW ^c	%S ^d	LBW ^e , kg	LWW ^b
Su, 2007	16,171	11.7	9.8	88.5	-	66.8
Lindemann, 2007	411	10.7	9.1	85.0	13.9	64.2
Darroch, 2008	381	10.3	9.0	86.8	15.5	56.3
Veum, 2009	-	9.1	8.9	97.5	-	63.2
Canario, 2010	15,109	12.6	-	-	-	-
Estienne, 2010	19	10.9	9.7	89.0	17.8	84.3
Wolf, 2010	122,859	11.1	10.0	90.4	-	-
Average	154,950	11.3	10.0	90.1	14.8	66.5

^a Total born not including stillbirths; ^b All weaning weights are at 21d;

^c Number of pigs weaned; ^d Percentage of survival; ^e Litter birth weight

1.2.1 Total Number Born

The largest proportion of mortality in any commercial or purebred swine operation occurs prior to weaning and survival is greatly affected by the birth weight of the individual piglets in any given litter (Fix, 2010b). Generally it is thought that simply increasing the

size of swine litters will allow for larger litters to be weaned; over time producers have tended to select for such relationships. Research conducted in the early 1980's by Drewry (1980), Schneider et al. (1982), and Gaugler et al. (1984) reported that the total number of pigs born ranged from 9.24 to 12.00. While data from later in the decade by Stansbury et al (1987), and Kuhlers et al (1989) had total number born that ranged from 9.68 to 11.03. Shurson et al., (1992) presented data that included 223 litters with an average of 8.96 piglets born. In the studies represented in table A, there was an average of 10.00 piglets born per litter for the time period from 1980-1992. It should be noted that the number of piglets born in these studies were not consistent in measurement in that some of the studies included stillborn piglets in there measurement, whereas later studies did not include these piglets in the analysis, also there were many different parity compositions for each study.

Over time selection along with better management has been successful at increasing litter size. Studies from 2007 by Su et al.; Lindeman found the number of piglets born to be 11.66 and 10.66 respectively. Data from Darroch et al. (2008), Bloemhof et al. (2008), and Veum et al. (2009) showed total piglet numbers ranging from 9.13 to 10.34 piglets per litter. However, research published in 2010 on a wider more international base showed an average of 11.09 (Wolf) pigs in Czech Landrace and Large White litters and 12.59 (Canario et al.) pigs in Norwegian Landrace litters. From the data collected in early 21st century there was an average of 11.29 piglets weaned which represented over 150,000 litters. This suggests that over time selection along with other factors such as increased management have increased swine litter sizes by 1 to 3 piglets per litter. Crossbred sow productivity has increased over time which could possibly be due to the selection for larger litters in the purebred sows (Cecchinato et al., 2010).

Increasing the total number of piglets born can greatly affect later growth of the newborn piglets as well as early survival. Studies have found that increasing litter sizes in general results in a decrease in average piglet birth weights (Foxcroft et al., 2007; Knol et al., 2010). Not only are piglets from larger litters smaller at birth, they have increased likelihood of being stillborn and increased competition for food resources (Rutherford et al., 2013). Increasing litter sizes through genetic selection generally has a negative

relationship with piglet survival (Roehe, 1999; Quiniou et al., 2002; Fix et al., 2010b). A later comprehensive study looking at sow productivity traits found that between 2005 and 2010 there has been a significant increase (1.21) in the number of piglets born (Knauer and Hostetler, 2013).

1.2.2 Number Weaned

The major goal of the swine producer is to wean a larger number of pigs by reducing the number of stillbirths and maximizing the survival of piglets born alive (Dividich, 1999). Weaning more piglets should give the producer a larger profit in the overall operation, since the costs associated with any individual litter is divided amongst more piglets. Britt (1986) determined that the average number of piglets weaned likely ranged from 7.2-7.9 pigs per litter, while also noting that management strategies play a key role in the productivity of the sows. The effects of environment were studied by Stansbury et al. (1987) who found that the least squares means for sow productivity with respect to weaning number was 8.2 on concrete floors with multiparous sows and as high as 9.2 for first parity sows raising their young on plastic flooring. Kuhlers (1989) showed similar results with sows weaning between 8.5 and 9.2 piglets per farrowing. Shurson (1992) showed that Duroc sows weaned between 5.5-6.8 piglets per litter whereas Landrace weaned between 7.1-8.75 piglets per litter.

Number of pigs weaned is a function of the number of pigs that are actually born, and over time the swine industry has selected animals that are capable of weaning more pigs per litter. While increasing litter size, the total number of piglets weaned has increased, reducing the cost of producing extra piglets at weaning. A Swedish study conducted by Kaufmann et al. (2000) found in 1,928 litters there were an average of 8.39 piglets weaned. Foxcroft (2008) observed that a highly prolific lines of swine averaged 10.8 pigs weaned and lower production non-selected sow lines averaged 9.4 pigs per litter. Although, selection for litter size alone leads to a negative trend in maternal genetic effects on individual birth and weaning weights of piglets and this relationship must be taken into account in breeding systems (Kaufmann 2000). Knauer and Hostetler

(2013) found in the United States there has been a significant increase in number of piglets weaned per litter from 9.30 pigs in 2005 to 10.08 pigs per litter in 2010.

1.2.3 Percent Survival

Litter size at weaning is one of the most important traits in swine production, and direct selection is generally restricted by the practice of cross-fostering (Su et al., 2007). Selection for increased litter size at birth in most breeding populations has been associated with an overall decrease in average piglet birth weight (Foxcroft, 2008). Baxter et al. (2008), stated that piglets with higher birth weight have greater neonatal survival rates than piglets with lighter than average birth weights. Drewry (1980) referred to survivability in a litter as the livability of the piglets and found that across 380 litters the average livability at 35 days of weaning was about 74%. Gaugler et al. (1984) reported similar results with breed means ranging from 64-87%. Changing environmental conditions can have a large effect on sow performance, especially piglet survival. Stansbury et al. (1987) found that the average mortality for litters varied from 6 to 20% depending on the temperature in the surrounding farrowing house and the type of flooring that was used in the facility. Shurson et al. (1992) found a strong breed effect on the preweaning survival. Duroc sows had preweaning survival rates of about 70% while Landrace sows had survival rates of approximately 80 to 87%.

Survival is reduced in low birth weight pigs, which have poor thermoregulatory abilities and may be slow at acquiring colostrum when born (Baxter, 2009). Fix (2010b) reported, as birth weight increased, the likelihood of pigs being born alive, surviving to weaning, and surviving through the nursery phase increased in a linear-quadratic fashion. With the increase in litter sizes observed in the past 30 years, there is an increased likelihood of litters having light birth weight pigs which will likely not survive to weaning and have greater mortality to weaning. Recent research shows that as litter size increased from 5 to 16 piglets the difference in survivability was about 30% with nearly 98% of pigs born in litters of 5 being weaned and less than 65% of piglets raised in litters of greater than 16 NAT. Recent studies found that over the past few years there has been

an increase in piglet mortality as total born has increased, and number of piglets born alive have increased simultaneously (Knauer and Hostetler, 2013).

1.2.4 Litter Weaning Weight

Swine producers strive to produce as much product as possible and many producers will use the litter weaning weight as a good indicator of how to select to increase the total amount of product that they can produce. Litter weaning weight is the amount of total pounds of live piglets produced by a sow in a farrowing cycle, and can be used as a bioassay to evaluate the milk production potential of a sow. Litter weaning weight measurements have been modified many times in the past and the weights depend on the age at weaning of piglets. Piglets are typically weaned at 21 days in the industry but in the past pigs were weaned at 28, 35, and 42 days of age. Drewry (1980) reported a 35 day litter weaning weights of 68.0 kg, while Gaugler et al. (1984) reported litter weights ranging from 70 to 97.99 kg with a 42 day weaning. Stansbury et al., (1987) reported a 28 day weaning age and had weight ranges of 50.28-63.33 kg depending on the environmental conditions around the sow and litter. Kuhlert et al., (1989) found weights around 46.5 kg with either pasture gestation or conventional gestation stalls with a 21 day weaning age. Wood et al. (1990) suggested that standardizing weaning to 21 days of age would simplify the process and would give the producer the ability to select more efficiently for higher performing sows. Using a 39 day average lactation period (Duroc) and a 32 day lactation period (Landrace) while looking at the effect of breed on economically important production traits, Shurson et al. (1992) found Duroc litters weaned between 53-62 kg per litter, and Landrace would wean anywhere from 55-72 kg per litter.

Kaufmann et al. (2000) found in 1,928 litters an average of 64.3 kg litter weaning weight at 21 days of age and Veum et al., (2009) found litter weaning weights ranging from 59.6 to 63.2 kg. Lindermann (2007) looked at the effect of Vitamin A supplementation and found average litter weaning weights were 64.2 kg while weaning an average of 9.1 piglets per litter. Estienne et al., (2010) evaluated the performance

traits of gilts which were gestated in various conditions and showed that sows gestated under general commercial conditions weaned about 84.5 kg, about 86.3 kg when gestated in group pens, and 81.5 kg when the sows were kept in a combination system. From these studies, selection for increased LWW has occurred over the past 30 years in swine populations and producers wean more pounds of piglet, with a more standardized weaning age of 21 days.

In the US, average piglet weaning weights have increased over the past few years from 5.46 kg in 2005 to 5.86 kg in 2010 with more piglets being weaned (Knauer and Hostetler, 2013). These results suggest that producers have increased litter weaning weight through selection of both increased piglet weight and number of piglets weaned. It is also important to note that some of the increases in litter weaning weight are due to the ever evolving knowledge of swine nutrition and the increased nutrient requirements of essential amino acids, of sow during lactation (NRC, 2012).

1.3 Consequences of Selection

Over time selection has increased litter size while maximized the number and weight of piglets weaned. However, selection for increasing litter size has a few possible undesirable consequences that every producer should take into account. It is well documented that larger litters have large numbers and percentages of lightweight piglets, which are typically described as piglets weighting less than 1.0 kg at birth (Quesnel et al., 2008). The scale at which a pig light birth weight is considered light weight varies but at some point the size is small enough to cause a problem. This is likely due to the limited space inside the uterus of the sow. Increasing birth weight is associated with a reduced chance of mortality prior to weaning, and lighter birth weight pigs are more likely to be lower quality at weaning, and finishing (Fix, 2010b). Light birthweight pigs grow more slowly during all phases of production, and as a result are lighter at all fixed points in the production cycle (Schinckel et al., 2010a; Fix, 2010a). Although to what magnitude light weight pigs affect the economics of any production system are highly variable, it is a factor to consider when selecting solely for litter size in swine production systems.

Lighter birth weight pigs will take longer to market, thus requiring more feed resources and cost the producer more money (Schinckel et al., 2010a). It is in the best interest of the individual producer to find a balance as to what selection will become the most profitable for their operation. Selection and management should be targeted to increase litter size with no or small decreases in average piglet weaning weight (Boyd, 2012).

1.4 Effects of Variation

Within-litter birthweight variation is economically important in that it has a positive association with preweaning mortality (Wolf et al., 2008). In litters with a high level of variation in birth weight, the smallest piglets are not able to compete effectively with their larger littermates for food resources and they will consume a lower amount of colostrum. Their lower milk intake, will also lead to reduced growth to weaning and a poor acquisition of passive immunity (Quiniou et al., 2002). Additionally, litters with more variable birth weights have increased variation at weaning (Campos et al., 2011), and the small pigs will require additional management later in life as they will be far behind in growth as they approach market weight (Schinckel et al., 2010a).

Parity 1 sows have decreased litter size, lower litter birth weights, and lighter weaning weights (Schinckel et al., 2010b). Boyd et al. (2008) showed that in high health herds without accounting for birth weight variation there is an increase of approximately 3 days to market for pigs from parity 1 females but after adjustment for birth and weaning weight there is no significant difference in the number of days it takes the offspring to reach target BW. Selection across litters in which birth and weaning weight are not accounted for will result in a decreased likelihood of selection of females from litters of parity 1 dams, simply because they are typically lighter weight and are born in litters that are smaller.

Variation in birth weight and weaning weight accounts for approximately 20% of the total variation in growth to 113 kg. Variation in birth and weaning weight accounts for less variation in carcass characteristics such as: backfat depth and loin muscle area. Previous studies have found that within typical ranges (0.8-2.4 kg) of birth weight the

overall real-time ultrasound measurements of backfat depth at market decreased only 0.3 cm in barrows and 0.4 cm in gilts, also over that range loin muscle area only increased .15 cm in gilts, and <0.1 cm in barrows (Schinckel et al., 2010a). However differences in days to market over that same range of birth weight was approximately 20 days in gilts, and 25 days in barrows (Schinckel et al., 2010a), showing that BTW accounts for more variation in growth traits than carcass characteristics.

1.5 Genetic and Phenotypic Correlation

Increasing litter size alone can cause changes in additional economically important sow productivity traits. It is important to evaluate the genetic and phenotypic correlations between these traits to help determine the best processes of management for these traits. Genetic and phenotypic correlations between TNB and litter morality were examined by Bergsma et al. (2008) and found to be 0.39 and 0.23 respectively, additionally correlations between litter size and litter birth weights were 0.78 and 0.80, as well as 0.45 and 0.05 for litter size to litter weight gain to weaning. Additionally there is a negative phenotypic correlation between TNB and sow weight loss (-.11), sow fat loss (-.05), and sow protein loss (-.12) during lactation (Bergsma et al., 2008). Mesa et al. (2006) demonstrates that there is a positive direct genetic correlation between the farrowing survival of a pig to birth weight (0.83). Direct and maternal genetic effects to individual piglet birth weights have a moderately negative correlation of about -0.45 (Roehle et al., 2010). Generally there are larger negative correlations between individual piglet birth weight and postnatal survival than perinatal survival (Su et al., 2008). There is a negative correlation between the number of pigs born and the prenatal and preweaning survival in modern swine production (Lund et al., 2002).

1.6 Summary

Swine production has drastically changed in recent history and production has improved through selection and management techniques. The ability to realize the full benefit of selection and increased production is dependent on accounting for the negative impacts of increased litter sizes. In the future increasing litter sizes will require additional management, and without proper management of large litters the rewards of selection will not be fully realized.

CHAPTER 2 RELATIONSHIPS AMONGST SOW PRODUCTIVITY TRAITS WITHIN PUREBRED AND CROSSBRED LITTERS

2.1 Abstract

The purpose of this study was to evaluate the relationships of litter weaning weight (LWW), number weaned (NW), mean pig weaning weight (PWT), litter birth weight (LBW), and survival percentage (%S) with number after transfer (NAT) and number born alive (NBA) on purebred and crossbred litters. Data consisted of purebred Duroc (29,297), Landrace (34,177), and Yorkshire litters (40,301) as well as Yorkshire x Landrace (8,061) and Landrace x Yorkshire (4,028) crossbred litters. The data were distributed into 4 time periods of 1980 through 1997, 1998 through 2002, 2003 through 2008, and 2009 through 2011. All variables were initially modeled with the fixed effects of litter breed, period, NAT, farm, parity-age class (P-AC) groupings and interactions, and random effects of sow and contemporary group. Non-significant variables and interactions ($P > 0.05$) were removed from final models. Periods 1 and 2 as well as 3 and 4 were combined based on non-significant main effects and interactions. The effect of NAT on LWW differed by time period ($P < 0.01$) such that heavier litters were achieved at larger litter sizes ($NAT > 11$) in Landrace and Yorkshire litters ($P < 0.05$) in period 2. Mean PWT decreased as NAT increased with less effect on PWT during the second time period. Also %S decreased in a linear fashion from 6 to 12 NAT then decreased at an increasing rate for $NAT > 12$, with a slight increase in %S over time for all breeds. Number weaned increased in a linear fashion up to NAT equal to 11 then increased at a decreasing rate to a maximum value depending on breed; above that value of NAT, NW decreased. There were no significant ($P > 0.05$) NBA by parity interactions for traits that

were measured after processing and transfer. In every statistical analysis farm was a significant and major source of variation. Also %S, and NW were greatly affected by NAT, and LBW was greatly affected by total number of pigs born (TNB). The data suggest the effects of NAT on LWW, and PWT should be reevaluated periodically.

2.2 Introduction

Sow performance records are important for monitoring and quantifying commercial production levels and for genetic selection. Sows should farrow a greater number of live piglets (NBA) to reduce the cost of each piglet at birth, although increasing the litter size has an adverse effect on piglet birth weight (PBW) and weaning weights (PWT) (Roehe, 1999; Quiniou et al., 2002; Fix et al., 2010a). Swine producers aim to wean a larger number of pigs by reducing the number of stillbirths and maximizing the survival of piglets born alive (Le Dividich, 1999). Genetic improvement made in the past can be attributed to the development of statistical methods used to remove and overcome many non-genetic sources of variation from field data (Bourdon, 1998). Number weaned (NW) data has typically been adjusted by using a grouping that consists of the parity of the dam, as well as the NAT (Brubaker et al., 1994; Culbertson et al., 1997). An underlying trait associated with NW is the %S for the litter. Piglet survival is affected by several environmental factors (Stansbury et al., 1987; Kuhlers et al., 1989). Prewaning survival is a measure of the mothering ability of dam.

Heavy pigs at weaning tend to grow faster (Lawlor et al., 2002, Schinckel et al 2009c) than their lighter counterparts. Lighter pigs at birth and weaning tend to grow more slowly, and have a greater mortality rate from weaning to market than heavier pigs at birth and weaning (Fix et al., 2010b; Schinckel et al., 2010a). Litter weaning weight (LWW) must be adjusted to a standardized age to allow for accurate genetic comparisons of individual animals (Bereskin and Horton, 1982). For genetic selection of animals, LWW must be adjusted for number after transfer (NAT), and the age of the dam. Twenty-one day litter weight is a good indication of a sow's milking ability (Wood et al.,

1990). Litter size and milk production have steadily increased over the past decades (Revell et al., 1998; Bergsma et al., 2008).

It is important for producers to understand the relationships between these sow productivity traits to evaluate alternative management practices. Also non-genetic factors associated with sow productivity must be accounted for in genetic evaluation. An earlier study (Brubaker et al., 1994) suggested that the relationships amongst these traits have likely changed based on a variety of factors including, changes in management and genetic selection. Also the future direction of genetic selection programs should consider the relationships amongst these factors and sow performance to maximize the profitability of the pork production system (Stewart et al. 1991; Bergsma et al. 2008).

The objectives of this study were to evaluate the relationships amongst sow productivity traits in purebred and crossbred litters and to what extent the relationships have changed with time.

2.3 Methods

Data were collected from 14 of the largest US purebred swine producers. The data had been submitted to the STAGES program of the National Swine Registry (Stewart et al., 1991). The dataset consisted of purebred Duroc (29,297), Landrace (34,177), and Yorkshire litters (40,301) with Yorkshire sire by Landrace (8,061) and Landrace x Yorkshire (4,028) crossbred litters. The data was distributed into 4 time periods of 1986 through 1997, 1998 through 2002, 2003 through 2008, and 2009 through 2011. After initial analysis it was found the period 1 and period 2 as well as period 3 and period 4 were not significantly different and were combined to yield 2 time periods from 1986 through 2002 and 2003 through 2011. Data points that did not include birth date were deleted as were LBW's that were missing, and any litters that were determined to have a %S of greater than 1.00 were removed. The data were further edited to include only litters where the recorded value for number born alive (NBA), number after transfer (NAT), and total number born (TNB) were greater than 5 and a maximum value of 18 was used for NBA, 16 for NAT, and 10 for parity.

Sow productivity traits were NBA, litter birth weight (LBW), number of pigs weaned (NW), survival percentage (%S), piglet weaning weight (PWT), and litter weaning weight (LWW). Mean piglet weaning weight was calculated from the data as LWW/NW, %S was calculated by NW/NAT, and PBW was calculated similarly using LBW/NBA. Litter birth weight was collected on the farm as only piglets that were fully formed, live piglets. The breeding date of each sow was determined by taking the birth date of the litter and subtracting a constant of 114 days. A variable was created and called Parity-Age class grouping (P-AC) which was determined by taking the age of the sow at breeding and combining it with the parity for the sow. In preliminary analyses each parity-age group was split up into approximately 4 age classes. Different age groups that were not significantly different ($P > 0.05$) were combined.

Data was analyzed using the PROC MIXED procedure in SAS (SAS Institute Inc., Cary, NC). The models for the sow productivity traits of NBA, LBW, and PBW were modeled with main effects of farm, dam breed (DB), period (TIME), P-AC, TNB, with all two and three way interactions, later non-significant interactions were removed from final models.

The LWW data was adjusted for weaning age (wage) of the litter by the use of the equation based on the relationship of wage and the Least squares means of LWW:

$$LWW = \text{actual} * (2.3967 - 0.0951 * \text{wage} + 0.0014 * \text{wage}^2),$$

where LWW is the adjusted value for LWW, *actual* is the reported weaning weight of the litter; wage is the weaning age (d) of the litter. The regression of the least squares means for each weaning age had an R^2 value of 0.9962. The sow productivity traits of NW, %S, LWW, and PWT were modeled with main effects of farm, dam breed (DB), TIME, P-AC, and all two and three way interactions, later non-significant interactions were removed and least-squared means were estimated. Crossbred litter performance was analyzed following the same process with identical models where crossbred litter performance was significantly different than purebred data depending on sow breed means, using orthogonal contrasts to test differences.

2.4 Results

The individual breed means are outlined in Table C. The overall means of the sow productivity traits were 59.57 kg for the adjusted 21-d LWW, 9.18 piglets weaned per litter, and mean adjusted PWT of 6.51 kg. Across breed values for NBA were 10.20, 1.64 kg PBW, and 16.51 kg of piglet born per litter. Mean survivability for the entire data set was 91.2% with an average total number born of 11.06.

Table C. Means and standard deviation (SD) of sow productivity traits by breed

Trait	Landrace			Yorkshire	
	Duroc	Landrace	Cross ¹	Yorkshire	Cross ²
LWW ³	50.4 (12.8)	65.6 (13.6)	69.3 (11.0)	62.3 (14.9)	66.4 (14.9)
PWT ⁴	6.3 (1.2)	6.8 (1.1)	7.0 (0.6)	6.6 (1.2)	6.7 (1.1)
NBA ⁵	9.1 (2.2)	10.6 (2.7)	10.9 (2.7)	10.7 (2.8)	10.6 (2.9)
LBW ⁶	15.5 (3.8)	17.8 (4.3)	15.8 (3.6)	16.9 (4.4)	16.3 (4.2)
%S ⁷	90.8 (12.0)	91.7 (10.5)	91.9 (9.8)	90.9 (11.6)	91.4 (11.6)
TNB ⁸	10.0 (2.3)	11.4 (2.8)	11.8 (2.9)	11.6 (3.0)	11.6 (3.0)

¹Landrace dams bred to yorkshire sires, ²Yorkshire dams bred to landrace sires,

³ Litter weaning weight, ⁴ Piglet weaning weight, ⁵ Number of piglets born alive, ⁶ Litter birth weight, ⁷ Survival percentage, ⁸ Total number of piglets born

Parity age-class groupings varied depending on sow productivity trait (Table D). Parity 3 to 5 were not significantly different for all traits and were combined whereas parity 6, 7, and all others were statistically different ($P < 0.05$) and observed separately. For LWW the two older classes of parity 1 gilts were grouped together, and all Parity 2 sows grouped together based on significant differences. Parity-Class groupings for NW had a similar pattern in that Parity 2 animals are all grouped together but differ from LWW PA-C groupings as all four classes of Parity 1 gilts were statistically different.

Table D. Parity-age class groupings for each sow productivity trait examined

Parity	Age at Breeding	PWT LBW		
		NBA	LWW	NW
1	≤ 210	*	*	*
1	211-239	*	*	*
1	240-269	*		*
1	≥ 270	*	*	*
2	≤ 365	*		
2	366-424	*	*	*
2	≥ 425	*		
3 to 5		*	*	*
6		*	*	*
7		*	*	*
≥ 8		*	*	*

* Significant ($P < 0.01$) PA-C or parity effect for all models represented

Number born alive were affected by farm, DB, TIME, P-AC, with two way interactions of DB with TIME, DB with P-AC ($P < 0.01$, Figure 1 and 2). Yorkshire litters were larger than either Duroc or Landrace litters in this study ($P < 0.01$). Duroc litters were consistently smaller than either Landrace or Yorkshire litters ($P < 0.05$). Maximum NBA from 1986 to 2002 (Figure 1) was observed in the Duroc (9.79) and Yorkshire (10.69) litters with parity 3 to 5 sows, while maximum NBA was found in parity 6 dams in the Landrace breed (10.80). Maximum NBA in the Yorkshire breed was 11.25 with parity 3 to 5 sows from 2003 to 2011 (Figure 2). Landrace litters were maximized at 11.16 for parity 3 to 5 sows during period 2. Duroc litters were largest (9.52) for parity 3 to 5 sows during period 2. The relationship between parity and NBA was very similar for both Landrace and Yorkshire litters with an increase in size as parity increased until parity = 3 to 5 then the number of pigs born alive began to decrease as parity increased past 6. Duroc litters also had consistently fewer piglets born alive as parity increased above 5. Overall Yorkshire litters were 0.1 pig greater ($P < 0.05$) than

Landrace litters, and 1.14 pigs larger than Duroc litters ($P < 0.01$). The results from this study directly contradict previous studies by Anderson et al. (2011) which found not significant difference in the number of pigs born to different parity sows. Other studies have found increases in litter size up to the fourth and fifth parities (Fernandez et al., 2008; Garcia et al., 2012).

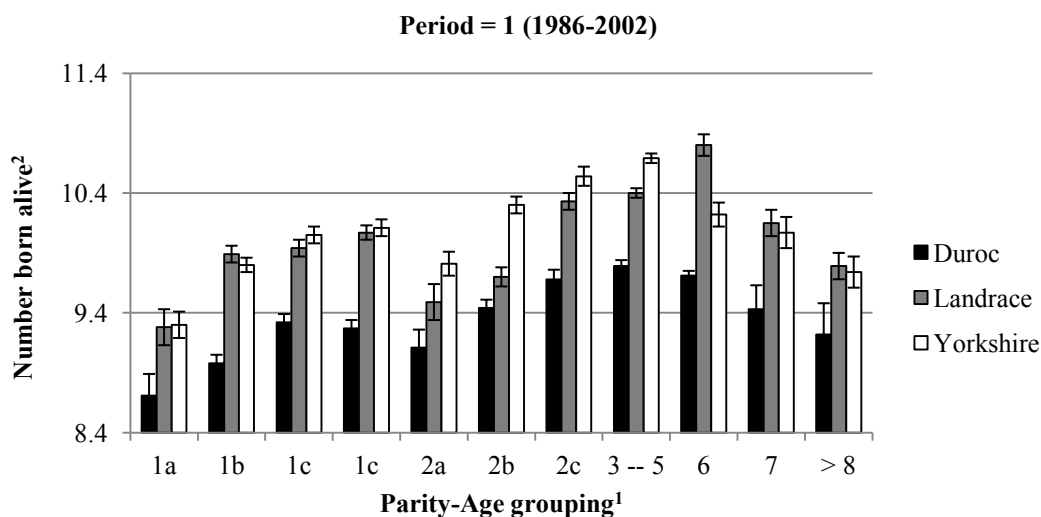


Figure 1. Number born alive with parity-age grouping, in 1986 to 2002 by breed of sow.

¹ Parity 1 sows ages (a= ≤ 210 , b= 211-239, c= 240-269, and d= ≥ 270 days), Parity 2 sows ages (a= ≤ 365 , b= 366-424, and c= ≥ 425 days) at breeding

² Significant fixed effects of DB, PA-C, TIME, farm, DB x TIME, DB x PA-C, and DB x TIME x PA-C ($P < 0.05$)

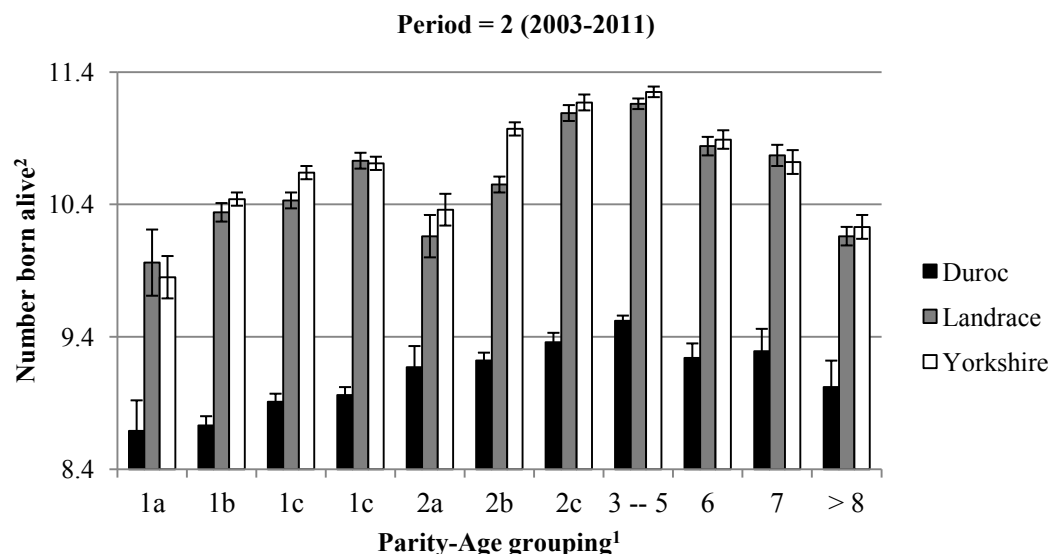


Figure 2. Number born alive with parity-age grouping, in 2003 to 2011 by breed of sow.

¹ Parity 1 sows ages (a= ≤ 210 , b= 211-239, c= 240-269, and d= ≥ 270 days), Parity 2 sows ages (a= ≤ 365 , b= 366-424, and c= ≥ 425 days) at breeding

² Significant fixed effects of DB, PA-C, TIME, farm, DB x TIME, DB x PA-C, and DB x TIME x PA-C ($P < 0.05$)

Litter birth weight and PBW were affected by farm, DB, P-AC, total number born (TNB), along with the significant two-way interactions of DB*P-AC, DB*TNB, and P-AC*TNB ($P < 0.01$, Figure 3). Litter birth weight was not affected by period ($P > 0.05$). Landrace dams with large litters (TNB > 11) had heavier piglets at birth ($P < 0.05$) than either Duroc or Yorkshire sows with large litters. Duroc and Yorkshire litters were had similar LBW as litter size increased. The regression of litter birth weight least squares means were fitted to a linear-quadratic function ($R^2=0.997$) to TNB. Although, LBW increased 11.17 kg from 5 to 17 TNB, average PWT decreased 0.64 kg as litter size increased from 5 to 17. Other studies have found negative relationships between litter size and the average piglet birth weight (Foxcroft et al., 2007, Knol et al., 2010). Beaulieu (2010) reported that increasing litter size decreased piglet birth weight by 0.033 kg per piglet, which is slightly less than the 0.053 kg/pig found in this study.

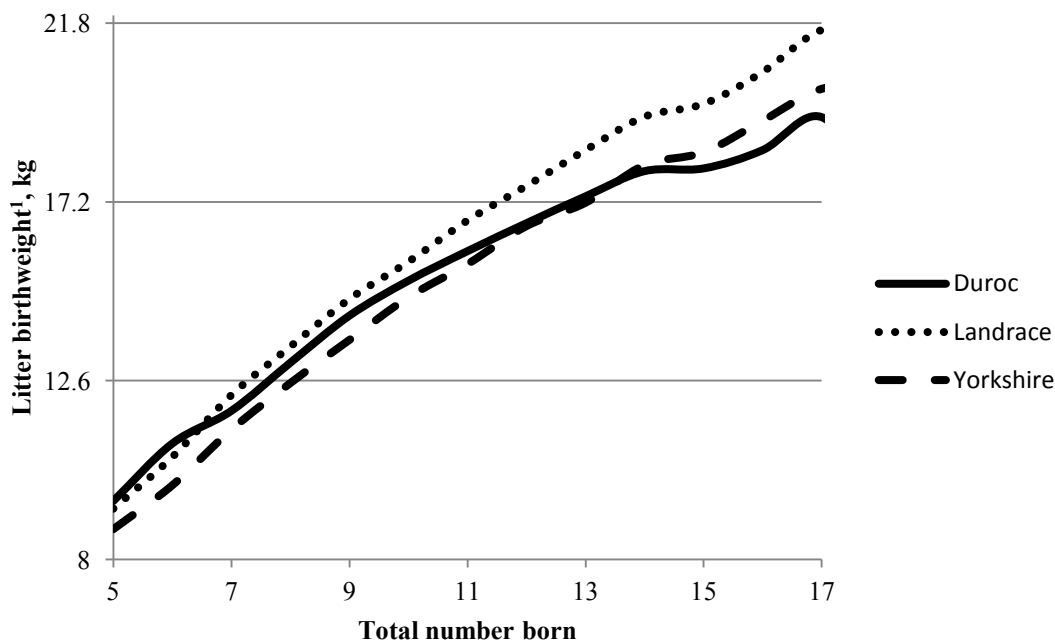


Figure 3. Relationship of total number born (TNB) with litter birthweight (LBW) by breed of sow.

¹ Significant fixed effects of DB, PA-C, farm, DB x PA-C, DB x TNB, and PA-C x TNB ($P < 0.05$).

Number of piglets weaned was affected by farm, DB, P-AC, NAT, TIME ($P < 0.05$), two-way interactions of DB*P-AC, DB*TIME, NAT*TIME with three way interactions of DB*NAT*TIME (Figure 4 and 5). The regression of the least squares means of the NW were fitted to a linear-quadratic relationship with NAT ($R^2 = 0.99$). For both periods, NW for smaller litters (< 10 NAT) were not significantly different among breeds ($P > 0.05$). At litter sizes greater than 11 NAT, litters from Landrace and Yorkshire dams were greater ($P < 0.05$) than Duroc litters. Litters from Landrace dams were 0.54, and 0.14 pigs larger ($P < 0.05$) than Duroc and Landrace litters. Maximum NW was observed in period 1 (Figure 4) when NAT = 14 for the Landrace (10.56) and Duroc litters (10.07), and at NAT = 15 for the Yorkshire litters (10.33). Maximum NW in period 2 (Figure 5) was achieved at NAT = 15 for all breeds (9.68 for Duroc, 11.18 for Landrace, and 10.89 for Yorkshire). These results are in agreement with previous

adjustment studies that found an increasing linear relationship between NAT and NW between 3 and 13 NAT (Brubaker et al., 1994). Maximum NW of 8.54 (Duroc), 9.11 (Landrace), 9.01 (Yorkshire) were found in the study in parity 2 sows. Studies conducted on similar data during the first time period found a very similar relationship of parity and NW with maximum NW being with parity 2 sows (Brubaker et al., 1994). Landrace litters increased in NW by 0.16 pigs while Yorkshire litters increased by 0.21 pigs from period 1 to period 2 in the study.

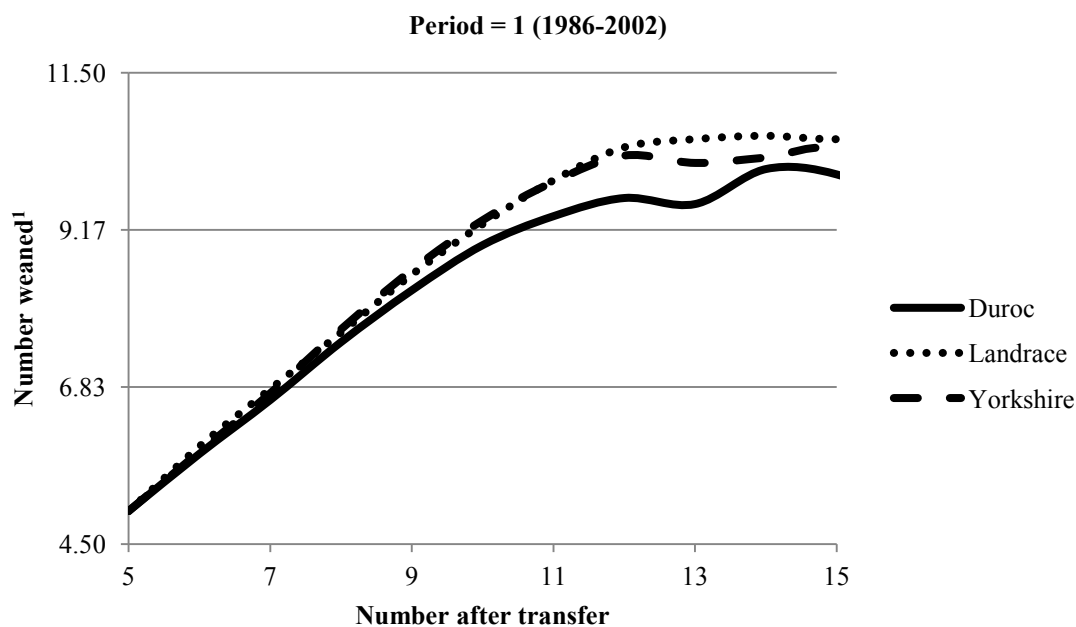


Figure 4. Relationship of number after transfer with number weaned (1986 to 2002) by breed of sow.

¹ Significant fixed effects of DB, PA-C, TIME, farm, NAT, DB x PA-C, DB x TIME, PA-C x NAT, NAT x TIME and DB x NAT x TIME ($P < 0.05$).

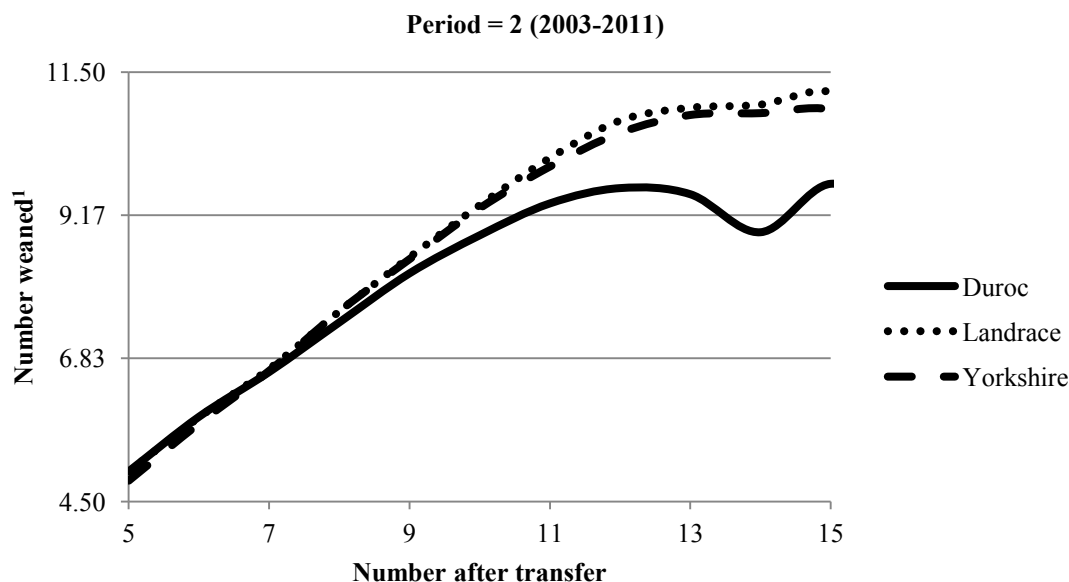


Figure 5. Relationship of number after transfer with number weaned (2003 to 2011) by breed of sow.

¹ Significant fixed effects of DB, PA-C, TIME, farm, NAT, DB x PA-C, DB x TIME, PA-C x NAT, NAT x TIME and DB x NAT x TIME ($P < 0.05$).

Prewaning survival was affected by the significant fixed effects of farm, DB, parity, NAT, with two-way interactions including DB*NAT (Figure 6), DB*parity(Figure 7), farm*DB, and farm*parity. Survival was not affected significantly by period for the study ($P > 0.10$). Over the entire range of NAT, %S ranged from nearly 100% (NAT =5) to 59.5% for the Duroc breed when NAT = 16 (Figure 6). Survivability decreased in a linear fashion until NAT = 11 then it continued to decrease at an increasing rate as NAT increased above 11. The lowest %S was found in Duroc litters for every parity ($P < 0.05$) while the greatest survival occurred in Landrace litters ($P < 0.05$). Parity 2 litters had the greatest %S ($P < 0.05$) and as parity increased %S decreased (Figure 7). These results are in agreement with previous studies by Cecchinato et al. (2010) that found a similar relationship with parity 2 dams having the highest %S with a decrease in %S as parity increased for both crossbred and purebred litters.

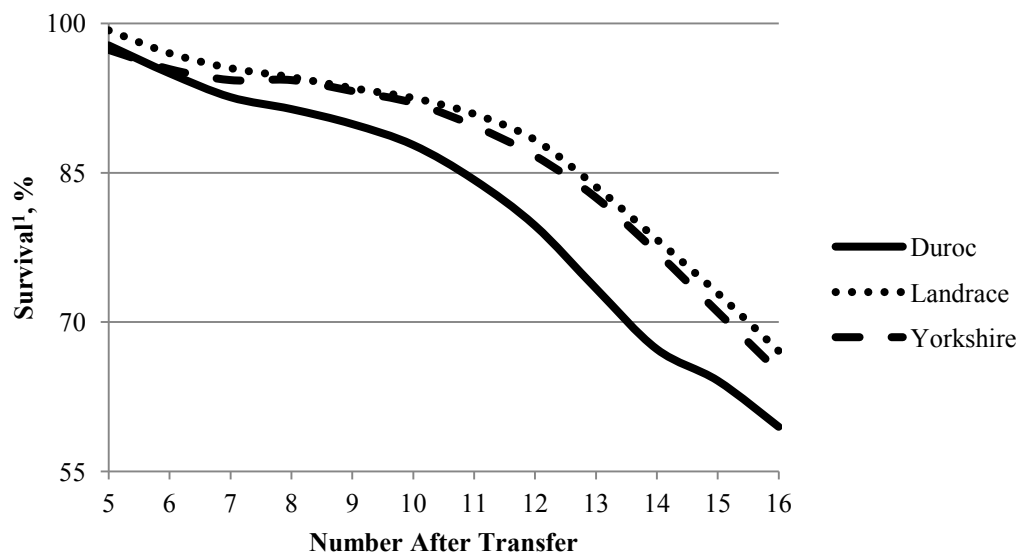


Figure 6. Effect of number after transfer on survival percentage by breed of sow.

¹ Significant effects of DB, farm, parity, NAT, DB x parity, DB x NAT, farm x DB, and farm x parity ($P < 0.05$)

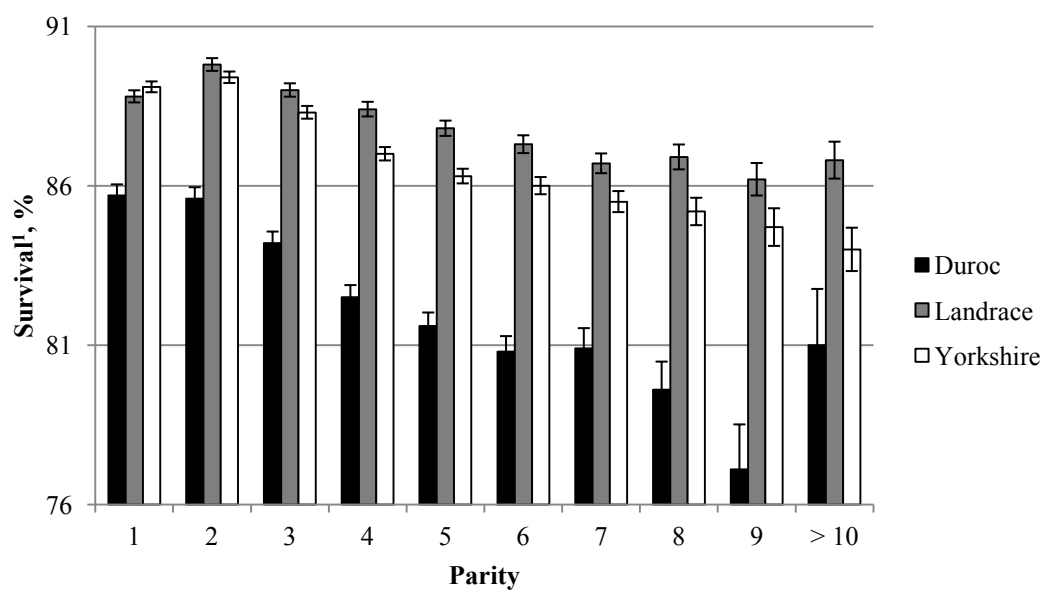


Figure 7. Effect of parity on survival percentage by breed of sow.

¹ Significant effects of DB, farm, parity, NAT, DB x parity, DB x NAT, farm x DB, and farm x parity ($P < 0.05$)

Average piglet weaning weight was affected by LB, P-AC, TIME, NAT, farm grouping, two way interactions between LB with P-AC, LB with NAT, P-AC with TIME, TIME with NAT, and the significant ($P < 0.05$) three way interactions of LB*TIME*NAT (Figure 8 and 9), and LB*P-AC*TIME (Figure 10 and 11). As NAT increased PWT decreased in a linear fashion up to approximately 13 NAT and with NAT > 13 there was no significant increase in PWT ($P > 0.05$). Pigs from Landrace litters (6.84 kg) were heavier than Duroc (6.16 kg) and Yorkshire (6.48 kg) pigs over the entire range of NAT ($P < 0.05$). Yorkshire pigs were heavier than Duroc pigs overall. However, as NAT increased standard errors of the means increased and Yorkshire and Duroc pigs were no longer statistically different at $\text{NAT} \geq 13$ ($P > 0.05$). The standard errors were greater for the Duroc litters as they had fewer records at every NAT. Inconsistent trends in PWT relative to NAT in Duroc litters were due to the decreased number of observations. Overall mean PWT increased ($P < 0.01$) from period 1 (6.58 kg) to period 2 (6.99 kg). Maximum PWT occurred for Landrace litters in period 2 (8.04 kg, Figure 9) and the lightest overall mean PWT was found at $\text{NAT} = 15$ in the Duroc litters in period 1 (5.30 kg, Figure 8).

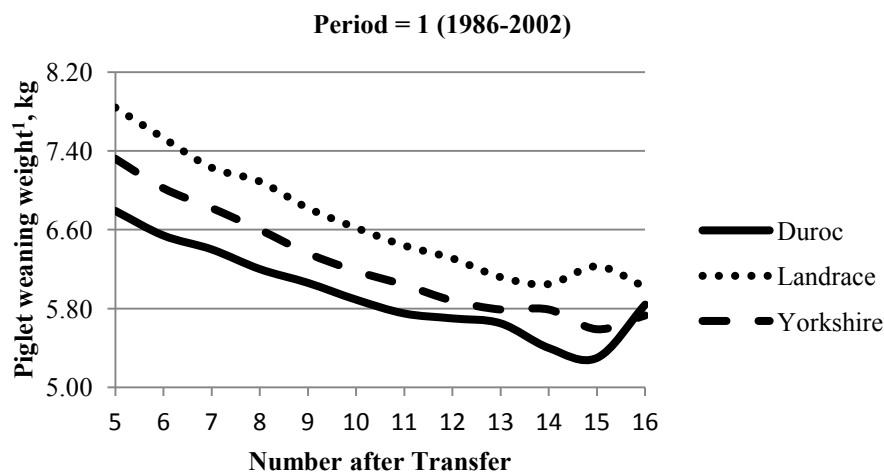


Figure 8. Effect of number after transfer on piglet weaning weight (1986 to 2002), in purebred litters by breed of sow.

¹ Significant effects of LB, PA-C, TIME, NAT, farm, LB x PA-C, LB x NAT, PA-C x TIME, NAT x TIME, LB x TIME x NAT, and LB x PA-C x TIME ($P < 0.05$).

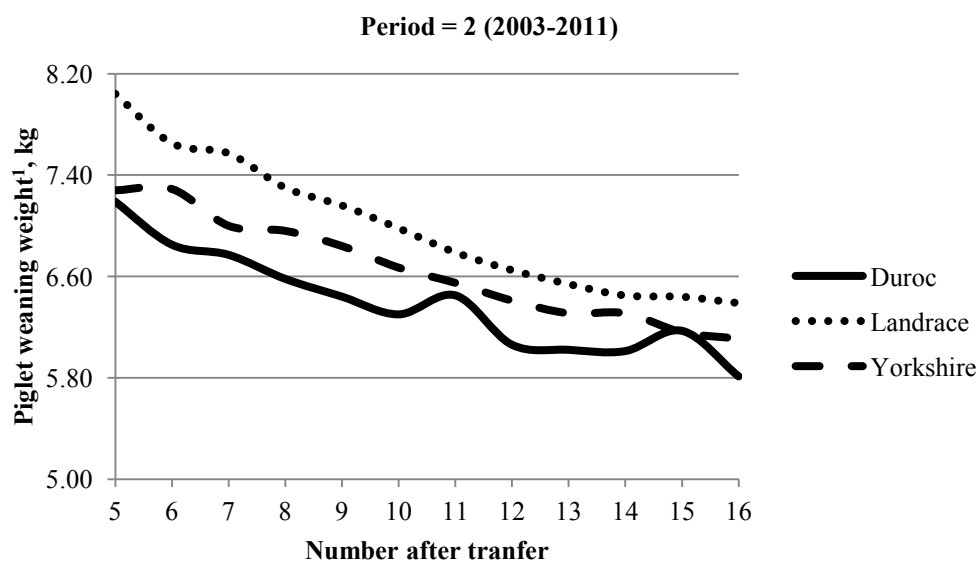


Figure 9. Effect of number after transfer on piglet weaning weight (2003 to 2011), in purebred litters by breed of sow.

¹ Significant effects of LB, PA-C, TIME, NAT, farm, LB x PA-C, LB x NAT, PA-C x TIME, NAT x TIME, LB x TIME x NAT, and LB x PA-C x TIME ($P < 0.05$).

Maximum PWT in purebred litters were found in period 1 in Landrace litters when parity =2 and age of breeding was ≥ 425 days (6.99 kg) (Figure 10), and maximum PWT were found in period 2 in Landrace litters when parity = 2 and age at breeding was between 366 and 424 days (7.25 kg, Figure 11).

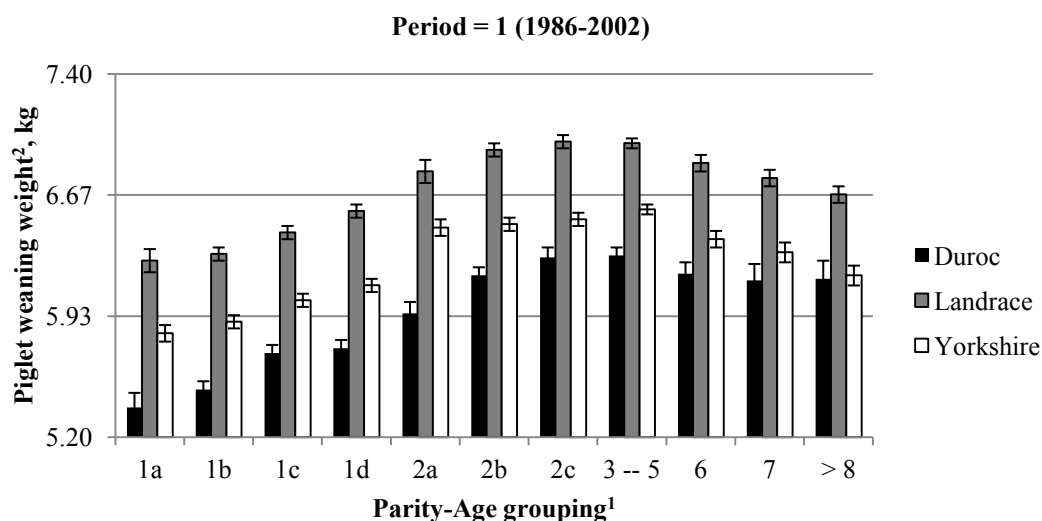


Figure 10. Effect of parity on piglet weaning weight (1986 to 2002). in purebred litters by breed of sow.

¹ Parity 1 sows ages (a= ≤ 210 , b= 211-239, c= 240-269, and d= ≥ 270), Parity 2 sows ages (a= ≤ 365 , b= 366-424, and c= ≥ 425) at breeding.

² Significant effects of LB, PA-C, TIME, NAT, farm, LB x PA-C, LB x NAT, PA-C x TIME, NAT x TIME, LB x TIME x NAT, and LB x PA-C x TIME ($P < 0.05$).

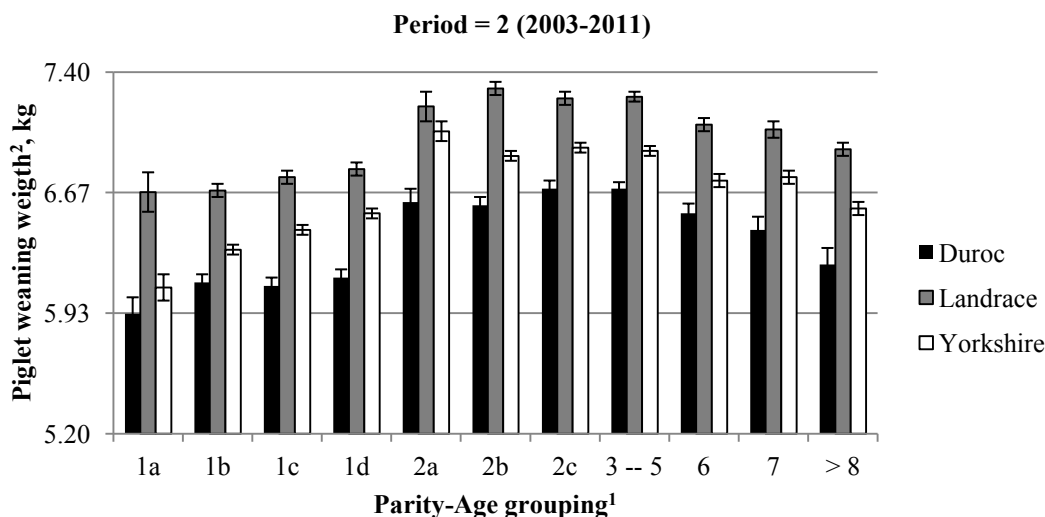


Figure 11. Effect of parity on piglet weaning weight (2003 to 2011), in purebred litters by breed of sow.

¹ Parity 1 sows ages (a= ≤ 210 , b= 211-239, c= 240-269, and d= ≥ 270), Parity 2 sows ages (a= ≤ 365 , b= 366-424, and c= ≥ 425) at breeding.

² Significant effects of LB, PA-C, TIME, NAT, farm, LB x PA-C, LB x NAT, PA-C x TIME, NAT x TIME, LB x TIME x NAT, and LB x PA-C x TIME ($P < 0.05$).

Overall LWW was affected by LB, P-AC, TIME, NAT, farm grouping, the significant interactions ($P < 0.05$) between LB with P-AC, LB with TIME, LB with NAT, P-AC with TIME, TIME with NAT, and three way interactions of LB*TIME*NAT (Figure 12 and 13), and LB*P-AC*TIME (Figure 14 and 15). As NAT increased LWW increased to a point (NAT = 12) then there was a decrease in LWW at NAT ≥ 13 ($P < 0.05$) (Figure 11 and 12). Maximum LWW from period 1 to 2 increased in the Duroc (1.57 kg), Landrace (5.76 kg) and Yorkshire (7.68 kg) litters. Maximum LWW was achieved at greater NAT in both the Landrace and Yorkshire litters over the two time periods. Litter weaning weights across periods were not significantly different with NAT > 10 within breeds. When NAT > 11 litters in period 2 were significantly heavier ($P < 0.05$) within each breed. Landrace litters were significantly heavier than either Yorkshire ($P < 0.01$) or Duroc ($P < 0.01$) litters.

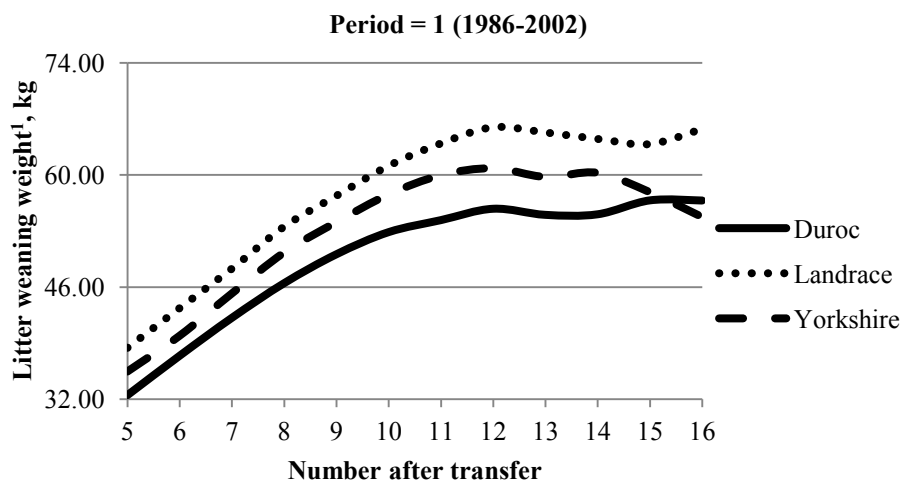


Figure 12. Effect of number after transfer on litter weaning weight (1986 to 2002), in purebred litters by breed of sow.

¹ Significant fixed effects of LB, PA-C, TIME, NAT, farm, LB x PA-C, LB x TIME, LB x NAT, PA-C x TIME, NAT x TIME, LB x TIME x NAT, and LB x PA-C x TIME ($P < 0.05$)

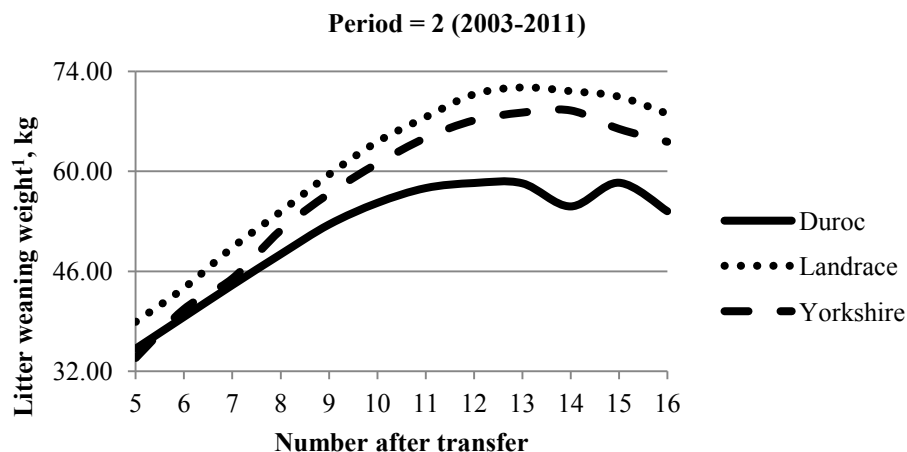


Figure 13. Effect of number after transfer on litter weaning weight (2003 to 2011) in purebred litters by breed of sow.

¹ Significant fixed effects of LB, PA-C, TIME, NAT, farm, LB x PA-C, LB x TIME, LB x NAT, PA-C x TIME, NAT x TIME, LB x TIME x NAT, and LB x PA-C x TIME ($P < 0.05$).

The heaviest litters were found in parity 2 dams in all breeds in the study for both periods. Older parity 1 dams (≥ 270 days at breeding) had significantly heavier litters than younger parity 1 dams (< 240 d, $P < 0.05$, Figure 14 and 15). Landrace litters were heavier than either Duroc or Yorkshire litters at every PA-C grouping in the study ($P < 0.05$). As parity of dam increased (parity ≥ 6), LWW decreased. This relationship is in agreement with previous studies that found that LWW from parity 2 sows were significantly heavier at weaning than other parity sows across Duroc, Landrace, and Yorkshire genetic lines (Brubaker et al., 1994; Culbertson et al., 1997).

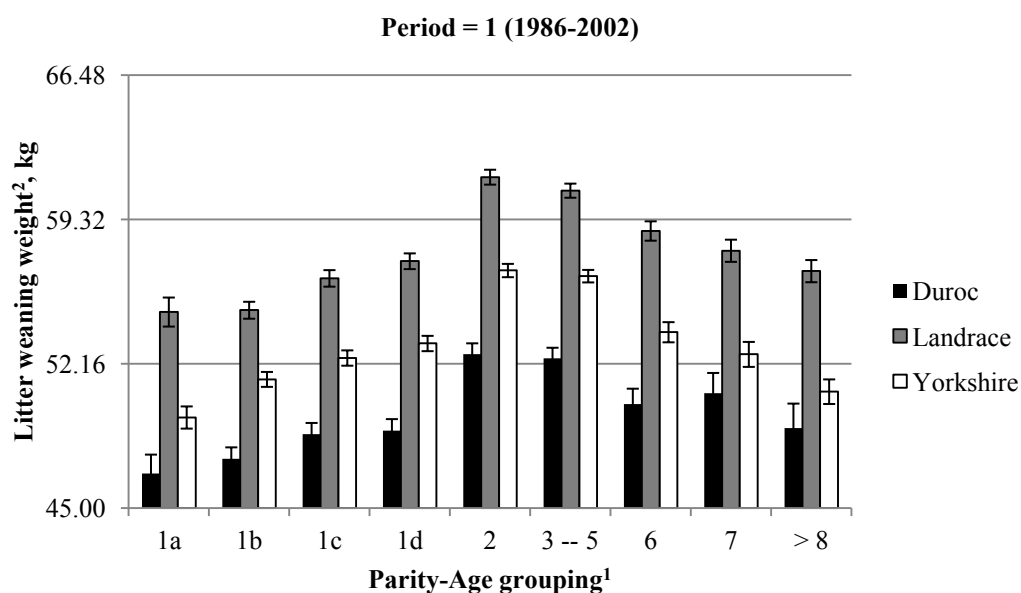


Figure 14. Effect on parity on litter weaning weight (1986 to 2002) in purebred litters by breed of sow.

¹ Parity 1 sows ages (a= ≤ 210 , b= 211-239, c= 240-269, and d= ≥ 270) at breeding

² Significant fixed effects of LB, PA-C, TIME, NAT, farm, LB x PA-C, LB x TIME, LB x NAT, PA-C x TIME, NAT x TIME, LB x TIME x NAT, and LB x PA-C x TIME ($P < 0.05$)

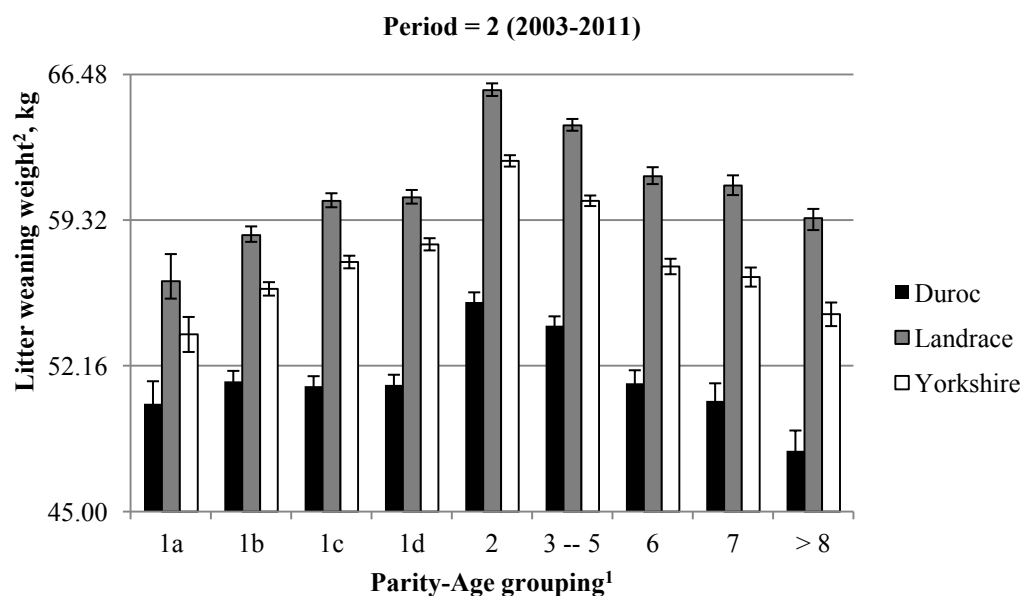


Figure 15. Effect of parity on litter weaning weight (1986 to 2002) in purebred litters by breed of sow.

¹ Parity 1 sows ages (a= ≤ 210 , b= 211-239, c= 240-269, and d= ≥ 270) at breeding.

² Significant fixed effects of LB, PA-C, TIME, NAT, farm, LB x PA-C, LB x TIME, LB x NAT, PA-C x TIME, NAT x TIME, LB x TIME x NAT, and LB x PA-C x TIME ($P < 0.05$)

Crossbred LWW's were greatly affected by NAT ($P < 0.01$, Figure 16), PA-C ($P < 0.01$, Figure 17), litter breed, and two way interactions between litter breed with PA-C, and litter breed with NAT. Crossbred PWT's were greatly affected by NAT ($P < 0.01$, Figure 18), PA-C ($P < 0.01$, Figure 19), NAT, and interaction between breed with parity, breed with NAT ($P < 0.05$). Period 1 LWW means for the crossbred litters were not estimable due to small numbers of observations. Crossbred litters from Landrace sows were not significantly heavier than crossbred litters with Yorkshire dams ($P > 0.05$). Landrace sow litters when NAT= 12 were 3.21 kg heavier than Yorkshire sow litters ($P < 0.05$, Figure 16). Also for parity 3 to 5 sows, LWW for Landrace sow litters were 2.16 kg greater than litters from Yorkshire sows ($P < 0.05$, Figure 17).

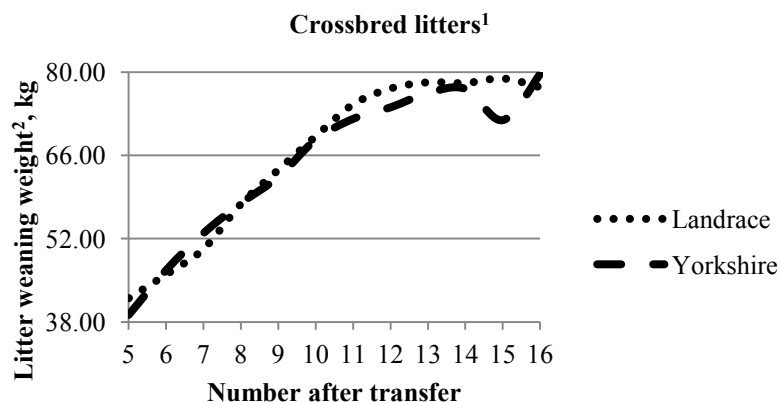


Figure 16. Effect of number after transfer on litter weaning weight (2003 to 2011), in crossbred litters by breed of sow.

¹ Litters denoted by breed of sow farrowing the litter

² Significant fixed effects of LB, PA-C, TIME, NAT, farm, LB x PA-C, LB x TIME, LB x NAT, PA-C x TIME, NAT x TIME, LB x TIME x NAT, and LB x PA-C x TIME ($P < 0.05$).

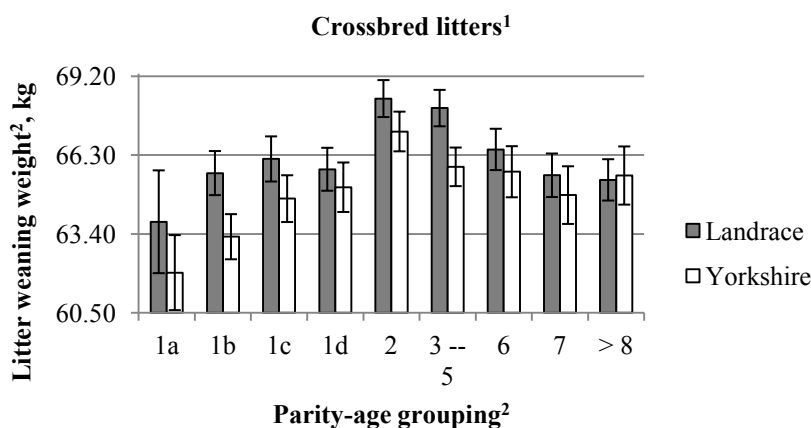


Figure 17. Effect of parity on litter weaning weight (2003 to 2011), in crossbred litters by breed of sow.

¹ Litters denoted by breed of sow farrowing the litter.

² Parity 1 sows ages (a= ≤ 210 , b= 211-239, c= 240-269, and d= ≥ 270) at breeding.

³ Significant fixed effects of LB, PA-C, TIME, NAT, farm, LB x PA-C, LB x TIME, LB x NAT, PA-C x TIME, NAT x TIME, LB x TIME x NAT, and LB x PA-C x TIME ($P < 0.05$).

Relationships of LWW to NAT and PA-C were very similar in both crosses. Average PWT in crossbred litters followed similar relationship with NAT as in purebred litters with crossbred litters consisting of significantly heavier piglets ($P < 0.05$). Increasing NAT in period 2 decreased LWW in crossbred litters from Landrace sows averaging 0.17 kg heavier than piglets from Yorkshire dams ($P < 0.05$, Figure 18). Maximum PWT was found in the Landrace sows from parity 3 to 5 (7.62 kg), and in the Yorkshire dam's in older parity 2 sows (≥ 270 days at breeding, 7.58 kg, Figure 19).

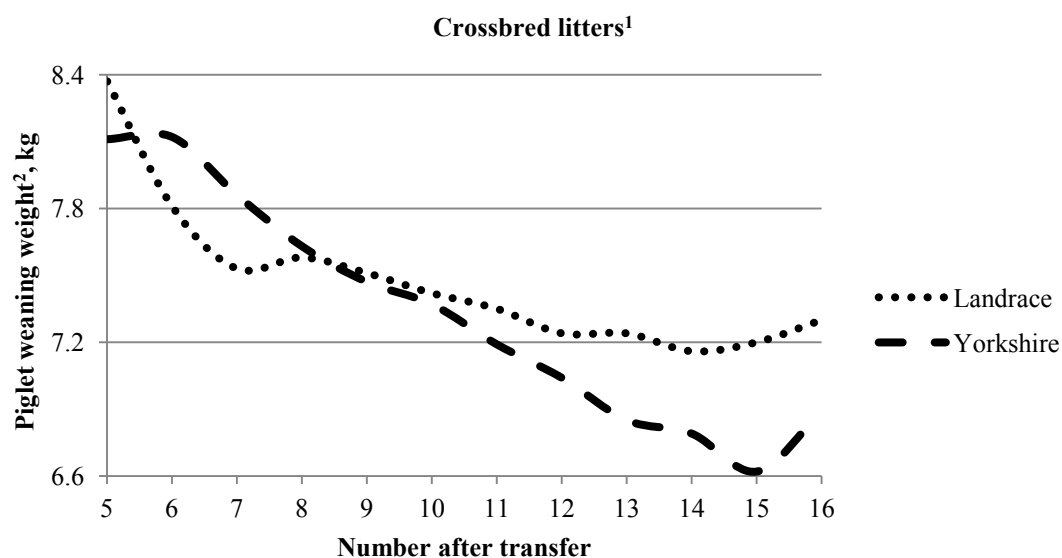


Figure 18. Effect of number after transfer on piglet weaning weight (2003 to 2011), in crossbred litters by breed of sow.

¹ Litters denoted by breed of sow farrowing the litter

² Significant effects of LB, PA-C, TIME, NAT, farm, LB x PA-C, LB x NAT, PA-C x TIME, NAT x TIME, LB x TIME x NAT, and LB x PA-C x TIME ($P < 0.05$).

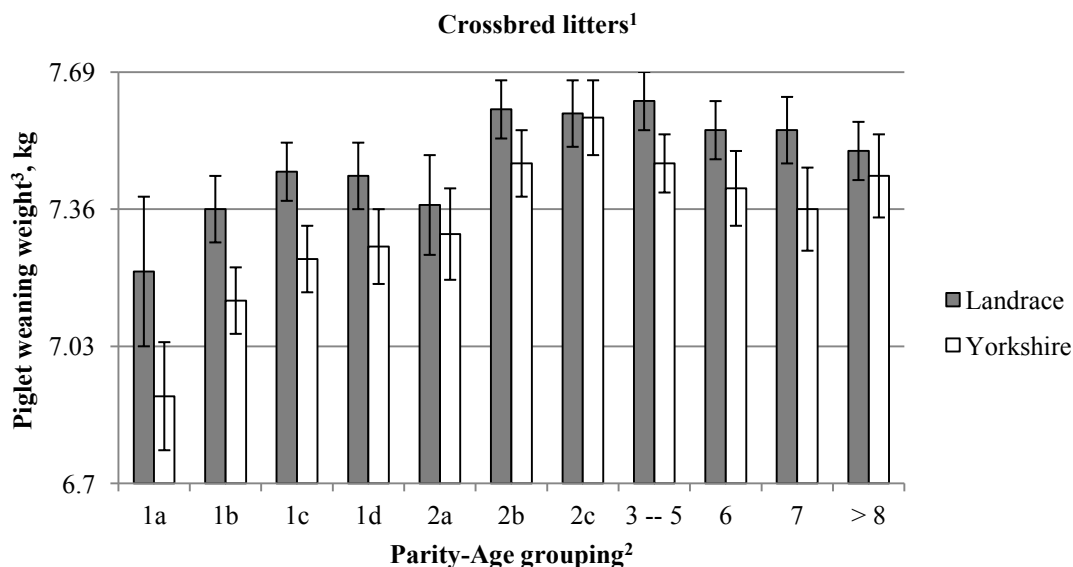


Figure 19. Effect of parity on piglet weaning weight (2003 to 2011) in crossbred litters by breed of sow.

¹ Litters denoted by breed of sow farrowing the litter

² Parity 1 sows ages (a= ≤ 210 , b= 211-239, c= 240-269, and d= ≥ 270), Parity 2 sows ages (a= ≤ 365 , b= 366-424, and c= ≥ 425) at breeding

³ Significant effects of LB, PA-C, TIME, NAT, farm, LB x PA-C, LB x NAT, PA-C x TIME, NAT x TIME, LB x TIME x NAT, and LB x PA-C x TIME ($P < 0.05$).

There was a significant increase in performance of the crossbred litters in the study ($P < 0.05$) in terms of LWW and PWT. Crossbred litters exhibited approximately 11.6 % heterosis in LWW and 9.1% in PWT. This estimation of heterosis is consistent with previous studies by Johnson (1981) and Sellier (1976) reporting across breed litter heterosis of 16.7 % and 10.0 % respectively. Cassady et al. (2002) using breeds with similar traits found a direct litter heterosis of around 14.8 %. Estimates by Johnson (1981) found PWT heterosis to be approximately 2.8 %.

2.5 Discussion

Over time, sow productivity has improved due to improved management practices and genetic selection (Knauer and Hostetler, 2013). For the majority of traits measured there were significant increases in performance levels over previous National Swine Improvement Federation (NSIF, 1988) adjustment factors which indicated that LWW and NW did not increase as litters exceeded 10 pigs NAT. Selection for sow productivity traits has occurred in maternal lines in terms for LWW, NBA, NW, and PWT, while the increases in performance over time for traits such as survival have not improved over time.

The data indicates that the relationships for PWT and LWW have changed for NAT greater than 10. The maximum LWW is achieved at greater NAT, while PWT is not greatly reduced with $NAT > 10$. The small reduction in PWT as NAT increases is expected since at larger litters ($NAT > 10$) the NW does not increase a significant amount. This selection for 21 day LWW has increased the genetic potential for milk production which is only observed when sows are allowed to nurse large litters. The increased milk production potential of current maternal line sows may not be realized at $NAT < 10$. Bourdon (1998) explained that offspring that can effectively challenge their dams by consuming all available milk, force their dam to fully express her genetic potential for milk production, but offspring that do not offer a challenge their dam allow her to only express a portion of her genetic potential. Also, nutritionists based research and modeling recommend lactation diets in swine with a greater lysine concentration which allow greater LWW's to be achieved (Boyd, 2002; NRC, 2012). Without a significant increase in NW over time the increases in LWW seen are due to increased piglet weaning weights.

Prewaning survival of pigs has improved to a small extent, however the survival of pigs to weaning with $NAT > 13$, may require a combination of genetic selection and management changes. As NBA increases, NAT will ultimately increase resulting in a decrease in preweaning survival (Knol et al., 2010). Studies have shown that although BTW is the most influential in piglet survival other behavioral factors such as vitality and vigor of piglets at birth do contribute to the overall likelihood of the offspring surviving

(Baxter et al., 2010). Birthweight is highly correlated with NBA and increasing litter size by selection results in a higher proportion of still-born pigs (Foxcroft et al., 2007), but selection for increased survival will lead to a decrease in variation of piglet birth weight (Knol et al., 2002). Piglet survival is an outcome of very complex interactions between the piglets, the sow, and the environment in which the animals are raised (Edwards, 2002).

There have been an increase in NBA through selection and the result is an increase in NW and preweaning mortality (Knauer and Hostetler, 2013). As litter size increases, the proportion of light LBW offspring increases, this results in more pigs having their long-term robustness impaired (Rutherford et al., 2013). With selection for increased NBA, resulting in greater number of sows nursing 12 to 14 pigs, a greater relative emphasis should be placed on preweaning survival. There is a direct genetic correlation between birth weight and survival although survival traits are more influenced by other genetic effects (Roehe et al., 2010). Genetic approaches to management of large litters (NAT > 14) are only somewhat effective at mitigating the effect of the large litter for most survival-type traits only 0-15% of the variation is genetic whereas 85-100% is environmental (Baxter et al., 2013).

2.6 Conclusions

It is important that these relationships of the sow productivity traits and factors including parity, NAT, weaning age be evaluated to refine selection and management practices. The economically important sow productivity traits such as NBA, LWW, and NW have been selected for effectively. As litter size increases, greater emphasis should be placed on preweaning survival. With the current performance levels known it is simple to develop adjustment factors for the sow productivity traits that allow a producer to adjust raw data to the highest performance level for every trait.

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CHAPTER 3 SOURCES OF VARIATION IN PUREBRED PIG GROWTH, LIVE ULTRASOUND BACKFAT, AND LOIN MUSCLE AREA

3.1 Abstract

The purpose of this study was to evaluate in purebred pigs the sources of variation in birth weight (BTW) and weaning weight (WW) and relationships of BTW and WW with performance traits: Days to 113.4kg (DAYS), ultrasound backfat depth (BF), and loin muscle area (LMA). Data consisted of BTW and WW records (Duroc, n=26,260; Landrace, n=31,209; Yorkshire, n=53,037), and off test records (Duroc, n=10,103; Landrace, n=9,478; Yorkshire, n=18,647). Mean piglet BTW and WW decreased as total born and number weaned increased ($P < 0.05$). Models included significant effects of parity, sex, farm, and random effects of contemporary group and sow. Covariates of BTW, BTW^2 , WW, and WW^2 were included to evaluate their effects. Mean DAYS for pigs from parity 1 dams were 2 to 3 d greater than pigs from parity 2 and 3 dams ($P < 0.05$). However, when BTW and WW were included as covariates to the model, DAYS were not different for parity 1 dams pigs vs. older sows. Birth weight (linear and quadratic) and WW (linear and quadratic) accounted for approximately 20% of the residual variance in DAYS within each breed. Backfat depth and LMA were affected ($P < 0.05$) by BTW and WW. However, inclusion of BF and LMA as covariates to the models produced only small reductions in residual variances. Pigs that were lighter at birth or weaning had smaller LMA, greater BF, and greater DAYS. Pigs with lighter BTW and WW, are more common in parity one litters and large litters, and had poorer postweaning growth, BF and LMA than heavier pigs at birth and weaning.

3.2 Introduction

It is important to understand the relationships between early piglet growth and future growth to market BW (King, 1999; Schinckel et al., 2009a). Some of the variation in post weaning pig growth is due to variation in birth and weaning weight (Le Dividich, 1999; Klindt, 2003; Schinckel et al., 2009b). Colostrum intakes along with many other environmental factors influence the variation in pre-weaning growth (Quesnel et al., 2012).

Selection for increased litter size in maternal lines of pigs has been successful (USDA-NASS, 2011; Jones et al., 2012; Nielsen et al., 2013). However as litter size and number of pigs nursed increases, the mean piglet birth and weaning weights decrease (Roehe, 1999; Quiniou et al., 2002; Fix, 2010b). As litter size increases, the within litter variance in birth BW also increases such that the percentage of light birth BW pigs with decreased survival rates also increases (Kapell et al., 2011).

Overall, crossbred pigs with lighter birth BW's have decreased growth rates and decreased carcass lean percentage (Rehfeldt and Kuhn, 2006; Schinckel et al., 2007a, 2010a). The relationships of birth and weaning weight to subsequent pig performance have not been evaluated within purebred populations. The selection criterion for both maternal and terminal sire lines of pigs includes postweaning traits (Stewart et al., 1990). The objective of this study was to identify sources of variation in birth weight (BTW) and weaning weight (WW), and evaluate the relationships of BTW and WW with the postweaning performance traits: days to 113.4kg (DAYS), real-time ultrasound backfat depth (BF), and loin muscle area (LMA).

3.3 Methods

Data collected from two farms from February 2010 to July 2013, consisting of 3 breeds: Duroc, Landrace, and Yorkshire, and 14 contemporary groups based on the off-test weigh date. The WW records were adjusted to 21 d of age using the equation:

Where WW is the adjusted weaning weight, *actual WW* is the actual weaning weight, and Wage is the age at weaning for the pig.

The BF measurements were adjusted to 113 kg BW using the following equation:

Where BF is the adjusted backfat measurement, *actual BF* is the actual backfat measurement, and offw is the offtest weight of the pig (NSIF, 1998).

The LMA measurements were adjusted to 113 kg BW using the following equation:

Where LMA is the adjusted loin muscle area measurement, *actual LMA* is the actual loin muscle area measurement, and offw is the off test weight of the pig (NSIF, 1998).

All data were analyzed using the PROC MIXED procedure of SAS (SAS Institute Inc., Cary, NC). The BTW data of each breed were analyzed using a model with significant fixed effects of parity, sex, and total number of piglets born (TNB), along with random effect of dam and contemporary group. Numbers of piglets born alive (NBA) data were analyzed with a model including the significant fixed effect of parity and random effects of dam and contemporary group. The proportion of piglets born in each

of the four BTW categories (≤ 0.85 kg, greater than 0.85 kg and ≤ 1.0 kg, greater than 1.0 kg and ≤ 1.15 kg, and greater than 1.15 kg) were determined based on TNB. The total number of piglets was broken into 7 separate categories including TNB of ≤ 5 , 6-7, 8-9, 10-11, 12-13, 14-15, and litters ≥ 16 piglets. A Chi-squared test was used to determine if TNB affected the proportion of piglets in each BTW category. Adjusted WW data were analyzed using a model with fixed effects of parity, sex, farm, and BTW (linear and quadratic), random effects of dam and contemporary group and BTW linear and quadratic as covariates. Also BTW and WW data were fitted to a model including a random effect of litter to evaluate the magnitude of the within litter variation. The residuals from this model were sorted by NBA and parity to evaluate their effect on the magnitude of the within-litter variance in BTW and WW.

The DAYS, BF, and LMA data for each breed were fitted with a model that included the fixed effects of parity, sex, and farm with random effects of the contemporary group and dam. The initial models were then evaluated with the linear and quadratic effects of BTW and WW which were included based on Akaike information criterion (AIC) values. The regression coefficients of the model were used to quantify the predicted change in each measure of pig performance over the range of BTW and WW. Following completed analysis and removal of all non-significant fixed effects, R^2 values were determined for the models including and not including BTW and WW covariates.

3.4 Results and Discussion

The mean birth weights were 1.63 kg for Duroc, 1.56 kg for Landrace, and 1.53 kg for Yorkshire. Mean adjusted weaning weights ranged from 5.80 kg for Duroc, 5.90kg for Landrace, and 5.66 kg for Yorkshire. Mean adjusted values for the Duroc pigs were 169.0 d, 0.81 cm, and 42.99 cm² for DAYS, BF, and LMA respectively. The mean values for the Landrace were 166.3 d, 0.74 cm, and 42.02 cm², and the Yorkshire pigs averaged 166.5 d, 0.74 cm, and 43.15 cm², respectively.

Overall least-squares means, SE, and variance components for the number of piglets born are represented in Table E. Litters from parity 3, 4, and 5 dams were significantly larger than any other parity group for most breeds in this study ($P < 0.05$). The smallest litters were always from parity 1 dams ($P < 0.05$) and litters from parity 5 dams or greater were also smaller. The variance due to dam accounted for the greatest proportion of the overall variation for every breed for number of piglets born alive. These results agree with previous reports (Boyd, 2006) which stated that litters from parity one dams were smaller. Other studies found that number of piglets born alive is not significantly different for litters from parity 4 through 7 (Brubaker et al., 1994), while the largest litters at weaning were for Parity 2 dams. The smaller litter size could be due to the decreased ovulation rates and embryonic survival of gilts (Foxcroft et al., 2006).

Table E. Least-squares means and variance components for number of piglets born.

	Duroc			Landrace			Yorkshire		
	N	Mean ¹	SE	N	Mean	SE	N	Mean	SE
Parity	P < .001			P < .001			P < .001		
1	6,723	10.55	0.15	7,890	11.63	0.15	12,124	11.91	0.12
2	5,811	10.95	0.15	5,790	11.97	0.15	10,117	12.27	0.12
3	4,827	11.66	0.15	4,985	12.28	0.15	9,231	12.66	0.12
4	3,976	11.88	0.15	4,227	12.61	0.15	8,084	12.70	0.12
5	3,151	12.20	0.16	3,279	12.55	0.15	7,139	12.93	0.13
>6	5,448	12.05	0.16	9,705	12.72	0.15	14,864	12.74	0.13
Variance estimations									
Contemporary group	0.281			0.259			0.192		
Dam	4.647			6.209			5.194		
Residual	3.522			3.250			3.552		

¹Model included fixed effect of parity (P < 0.001) and random effects of dam and contemporary group

Overall least-squares means, SE, and variance components for piglet BTW are shown in Table F. At birth, males including animals to be kept as intact boars and future barrows, were significantly heavier than females for all breeds (P < 0.05). The pigs not castrated and left as boars had great BTW than barrows (P < 0.01). Most likely caused by visual selection for the heaviest male pigs in each litter. Pigs that were later castrated to become barrows and gilts had similar BTWs. Piglets born to parity 1 dams were significantly lighter although being born in smaller litters at birth (P < 0.01) than piglets from any other parity dam. Piglets from parity 1 dams were 0.16 kg lighter (P < 0.01) at birth than pigs from parity 2 dams. Past research found piglets from parity 1 dams have a lower mean piglet BTW (0.15 kg) than parity 2 dams in purebred Yorkshire litters (Milligan et al., 2002). Contemporary group accounted for a small amount of the overall piglet BTW variation whereas dam had a much larger impact.

Table F. Least-squares means and variance components for the average piglet birthweight.

	Duroc			Landrace			Yorkshire			
	N	Mean ¹	SE	N	Mean	SE	N	Mean	SE	
Sex		P < .001			P < .001			P < .001		
Male ²	15,386	1.66	0.01	18,367	1.60	0.01	31,850	1.56	0.01	
Barrow	11,581	1.62	0.01	9,645	1.57	0.01	20,773	1.52	0.01	
Boar	3,805	1.78	0.01	8,722	1.65	0.01	11,077	1.62	0.01	
Female ²										
Gilt	14,544	1.60	0.01	17,507	1.57	0.01	29,702	1.51	0.01	
Parity		P < .001			P < .001			P < .001		
1	6,723	1.55	0.01	7,890	1.51	0.01	12,123	1.46	0.01	
2	5,811	1.71	0.01	5,790	1.67	0.01	10,115	1.62	0.01	
3	4,827	1.73	0.01	4,985	1.64	0.01	9,231	1.60	0.01	
4	3,976	1.69	0.01	4,227	1.60	0.01	8,084	1.58	0.01	
5	3,150	1.68	0.01	3,278	1.60	0.01	7,138	1.55	0.01	
>6	5,443	1.64	0.01	9,704	1.55	0.01	14,864	1.51	0.01	
Variance components										
Contemporary group		0.001			0.001			0.0005		
Dam		0.023			0.029			0.027		
Residual		0.106			0.103			0.101		

¹Model included fixed effects of parity, sex, linear tnb ($P < 0.001$) and random effects of dam and contemporary group

²Significant difference between Male and Female ($P < 0.001$)

There was no increase in within litter variation for piglet birth weight as total born increased from 7 to 15 pigs ($P < 0.05$) (Table G). The within litter SD for WW only marginally increased as number weaned increased from 7 to 15 pigs per litter. The within litter standard deviation of BTW was less ($P < 0.001$) for parity one gilts than older parity sows. Previous studies found that piglets from parity 1 and 2 dams had significantly less variation in birth weight than older parity litters (Milligan et al., 2002).

Table G. Within litter residual standard deviation by total number born and parity.

	Birth weight ¹			Weaning weight ¹		
	Duroc	Landrace	Yorkshire	Duroc	Landrace	Yorkshire
TNB						
≤ 5	.251	.257	.254	.888	.888	.912
6-7	.296	.254	.274	.973	.892	.920
8-9	.292	.293	.289	.963	.942	.959
10-11	.297	.285	.290	.969	.933	.948
12-13	.308	.290	.296	.980	.959	.968
14-15	.309	.304	.293	1.02	.995	.965
≥ 16	.304	.304	.301	.992	1.02	1.01
Parity						
1	.251	.242	.254	.818	.818	.841
2	.298	.290	.291	.967	.944	.949
3	.312	.308	.300	1.04	1.01	1.00
4	.325	.308	.309	1.03	1.01	1.01
5	.330	.311	.309	1.07	1.03	1.02
≥ 6	.322	.320	.309	1.04	1.06	1.02

¹Model included random effect of litter

These results contradict previous reports from Quiniou et al. (2002) that the within litter standard deviation increased as litter size increased. Others research has found that within litter variation did not increase as litter size increased (Beaulieu et al., 2010). Controlling within-litter BTW variation is economically important because it's unfavorably correlated with pre-weaning mortality (Wolf et al., 2008). Litters with greater variation have small piglets not able to compete with their heavier litter-mates for resources. Subsequently the smaller piglets at birth consume less colostrum and have lower milk intake leading to a poor acquisition of passive immunity and low nutritional status (Quiniou et al., 2002).

The proportion of small piglets in a litter that could be considered either extremely light (≤ 0.85 kg), moderately light (≤ 1.0 kg), or light (≤ 1.15 kg) are outlined in table H. There was an increase in the proportion of piglets that fell into each light

weight category as litter size increased. Litter size greatly affected the proportion of piglets that were in each light category ($P < 0.001$) with the least number of pigs that were light when TNB was less than 5 piglets. These results agree with Quinoiu et al. (2002) that found the proportion of small pigs increased as litter size increased. Le Dividich (1999) reported increasing litter size from 7 to 16 pigs lead to a reduction of 0.36 kg in average BTW, and increased the % of pigs born less than 1.0kg from approximately 5 to 15 %.

Table H. Effect of total number born on the proportion of small live piglets.

	$(\leq .85 \text{ kg}), \%^1$			$(0.85 < x \leq 1 \text{ kg}), \%^1$			$(1 < x \leq 1.15 \text{ kg}), \%^1$			$(\geq 1.15 \text{ kg}), \%$		
	Duroc	Land	York	Duroc	Land	York	Duroc	Land	York	Duroc	Land	York
TNB ¹												
≤ 5	1.11	1.20	0.70	.56	1.93	1.68	1.10	1.69	1.82	97.23	95.18	95.80
6-7	0.84	0.30	0.93	2.22	1.12	2.13	2.22	1.22	2.45	94.27	97.36	94.49
8-9	1.14	1.17	1.53	1.57	2.34	2.10	2.50	2.30	2.92	94.79	94.19	93.45
10-11	1.62	1.87	2.42	2.75	2.56	3.51	3.36	3.29	3.87	92.27	92.28	91.20
12-13	2.78	2.86	3.43	3.50	4.39	4.28	4.69	4.40	4.92	89.03	88.35	87.37
14-15	3.50	4.56	4.43	4.73	5.66	5.90	5.89	5.57	5.94	85.88	84.21	83.73
≥ 16	6.19	6.51	7.89	7.23	7.55	8.50	7.40	7.15	8.43	79.18	78.79	75.18

¹Means of proportion of piglets in body weight categories

²Proportion of piglets in each category different ($P < 0.001$)

The overall effects of parity and sex on WW are outlined in Table I. Parity 1 dams had piglets with lighter WWs ($P < 0.01$, 0.49 kg not adjusted for BTW, and 0.32 kg adjusted for BTW) than parity 2 dams. Maximum WWs were produced by parity 3-4 dams ($P < 0.01$). There was no significant difference in WW in respect to sex, male vs. female ($P > 0.05$), but animals kept intact and tested as boars were significantly heavier at weaning than females ($P < 0.05$). Males selected to remain boars had greater than average BTW and WW's than barrows. Selection of the male pigs tested as boars should result in selection of pigs with greater direct genetic merit for BTW, and WW. However, continued selection for increased litter size at birth and at weaning will result in decreased BTW and WWs.

Table I. Effect of parity on adjusted piglet weaning weight with and without birthweight accounted for.

	Birth weight excluded ¹						Birth weight included ²					
	Duroc	SE	Land	SE	York	SE	Duroc ³	SE	Land	SE	York	SE
Parity												
1	6.22	.06	6.53	.04	6.32	.04	6.30	.05	6.56	.04	6.39	.04
2	6.73	.06	7.07	.04	6.78	.04	6.62	.05	6.87	.04	6.63	.04
3	6.78	.06	7.11	.04	6.76	.04	6.70	.06	6.96	.04	6.65	.04
4	6.75	.06	6.98	.04	6.77	.04	6.69	.06	6.93	.04	6.69	.04
5	6.69	.06	6.94	.04	6.66	.04	6.66	.06	6.87	.04	6.45	.04
≥ 6	6.64	.06	6.82	.04	6.59	.04	6.66	.06	6.81	.04	6.61	.04
Sex												
Male ⁴	6.65	.06	6.92	.03	6.66	.04	6.59	.05	6.82	.04	6.59	.03
Barrow	6.36	.06	6.77	.04	6.46	.04	6.39	.05	6.72	.04	6.46	.03
Boar	7.09	.06	7.10	.04	6.95	.04	6.92	.05	6.94	.04	6.78	.04
Female ⁴												
Gilt	6.45	.06	6.86	.04	6.54	.03	6.51	.05	6.83	.04	6.57	.03

¹Model included fixed effect of parity, sex, farm ($P < 0.001$) and random effects of dam and contemporary group

²Model included fixed effect of parity, sex, farm, (linear and quadratic) BTW ($P < 0.05$) and random effects

³Model included fixed effect of parity, sex, farm, (linear) BTW ($P < 0.001$) and random effects

⁴No significant difference in sex, Male vs. Female ($P > 0.05$) with BTW included, significant difference between Boar vs. Gilt ($P < 0.05$)

There were only marginal increases in within litter SD for WW as number weaned increased from 7 to 15 pigs and parity increased from 2 to 6. The SD for piglet WW's were less ($P < 0.05$) for smaller litters and in parity 1 dams. Other researchers have found within-litter variation in WW increased as litter size increased (Milligan et al., 2002; Quesnel et al., 2008). Litters from greater total number born and number born alive had greater rates of preweaning mortality. However, this increase in mortality and greater variability in WW may be due to a greater number of piglets with low BTW (Milligan et al., 2002) rather than to greater competition between piglets (Milligan et al., 2001).

Regression coefficients that represent the relationships of WW to BTW are outlined in Table J. Weaning weight had a linear relationship with BTW for Duroc pigs while linear-quadratic relationships of WW to BTW were found for Landrace and Yorkshire pigs. Thus, an increase in BTW from 1 to 2 kg resulted in estimated increases in WW of 1.33 kg (Duroc), 1.69 kg (Landrace); 1.63 kg (Yorkshire). Likewise, an increase from 2 to 3 kg in BTW resulted in a WW increases of 1.33 kg (Duroc), 1.26 kg (Landrace), and 1.46 kg (Yorkshire). The increases in WW seen in this study are less than previous studies that found increases in BTW of 0.1 kg increased WW by 0.35 to 1.07 kg (Rousseau et al. 1994; Dunshea et al., 1997; Le Dividich, 1999). Schinckel et al. (2007a) which found a linear-quadratic relationship between BTW and 20-day BW, and that the change in WW per unit change in BTW decreased as BTW increased.

Differences in WW occur because there is variation in BTW. In this trial, BTW increased the R^2 values of the model by 20.5%. Previous studies found R^2 values ranging from 0.24 to 0.44 for the regression of WW on BTW (Schinckel et al., 2007a, 2007b, 2010b). The greater preweaning growth rate in pigs is a result of larger piglets having greater milk intakes consuming approximately 30% more milk than smaller piglets (Pluske et al., 1996). Other variables such as colostrum intake and environmental factors influence the variation of pig mortality and pre-weaning growth (Quesnel et al., 2012).

Table J. Regression coefficients, residual variance, and residual standard deviation of birthweight on weaning weight models.

Breed	Model	b ₀	b ₁	b ₂	Residual Variance ³	Residual Variance ⁴	R ²	Derivative at mean BTW ⁵
Duroc	BTW ²	4.10	1.33		0.969	1.545	0.373	1.33
Land	BTW ¹	3.55	2.32	-0.212	0.893	1.418	0.371	1.66
York	BTW ¹	3.72	1.88	-0.084	0.917	1.435	0.361	1.63

¹Models included fixed effects of parity, sex, farm, BTW (linear and quadratic, P < 0.001)

²Model excluded BTW quadratic, P > 0.05

³Residual variance with covariate of BTW included

⁴Residual variance with BTW excluded

⁵Change in WW with unit change in BTW from mean BTW

The results of the regression analysis of postweaning performance traits (DAYS, BF< and LMA) on BTW and WW are shown in Table K. Models for DAYS are labeled as either simple (parity, sex, and farm, and random effects of contemporary group and dam), S + BTW (simple plus BTW linear and quadratic), S + WW (simple plus WW linear and quadratic), or a model that was the simple model and both BTW, and WW (linear and quadratic).

Table K. Variance, residual standard deviation, and regression coefficients of days to 113kg, backfat depth, and loin muscle area.

Breed	Model	b values of BTW			b values of WW		Resid	Resid	R ²
		b ₀	b ₁	b ₂	b ₁	b ₂	Var	SD	
Duroc									
DAYS	Simple ¹						118.21	10.56	0.403
	S+BTW	210.9	-35.27	6.19			97.56	9.60	0.507
	S+WW	194.6			-4.86	0.16	108.73	10.13	0.451
	S+B+W	221.7	-33.31	6.18	-2.68	0.09	94.78	9.46	0.521
BF, cm	Simple						0.165	0.393	0.632
	S+B+W	2.91	-0.61	0.13	0.08	-0.006	0.161	0.388	0.641
LMA,cm ²	Simple						16.46	3.93	0.578
	S+B+W	38.34	0.66		0.90	-0.056	16.36	3.92	0.580
Landrace									
DAYS	Simple						108.85	10.14	0.337
	S+BTW	204.8	-33.95	6.23			91.19	9.28	0.444
	S+WW	199.3			-6.49	0.25	98.53	9.65	0.400
	S+B+W	223.1	-30.05	5.69	-5.30	0.28	88.62	9.15	0.460
BF, cm	Simple						0.199	0.432	0.510
	S+B+W	2.46	-0.41	0.063	-0.011		0.195	0.428	0.519
LMA,cm ²	Simple						20.14	4.35	0.378
	S+BTW	41.30	0.44				20.13	4.35	0.378
Yorkshire									
DAYS	Simple						118.34	10.56	0.335
	S+BTW	213.9	-44.15	9.07			97.00	9.56	0.455
	S+WW	195.6			-5.16	0.13	105.33	9.96	0.408
	S+B+W	224.2	-39.54	8.54	-3.03	0.09	93.72	9.39	0.473
BF, cm	Simple						0.171	0.400	0.583
	S+B+W	2.33	-0.38	0.079	-0.007		0.169	0.397	0.588
LMA,cm ²	Simple						17.66	4.08	0.423
	S+B+W	42.23	3.23	-0.95	-0.56	0.043	17.63	4.07	0.424

¹Models included fixed effect of parity, sex, farm, (P < 0.001) and random effects of dam and contemporary group additional models included significant (P < 0.05) linear and quadratic effects of BTW and WW

For each breed, the residual variance for DAYS was reduced by approximately 20% with the inclusion of BTW and WW to the model. When all significant BTW and WW covariates were added to the model the residual variances for both BF, and LMA decreased, although the decreases were small (1.8% for BF, and 0.3% for LMA). This implies that while BTW and WW have an impact on later carcass characteristics their roles are small (Schinckel et al., 2009a). Models for BF included the linear and quadratic relationships of BTW and WW for Duroc pigs, but linear and quadratic BTW with linear WW for the Landrace and Yorkshire pigs. Models of LMA varied greatly by breed in that Duroc linear BTW and linear-quadratic WW were significant, for the Landrace pigs only the linear relationship of BTW was significant, but a complete model of the Yorkshire pigs included both linear and quadratic terms for both BTW and WW. Loin muscle models differed greatly depending on the breed of animal as pigs of the Duroc and Yorkshire breeds were more greatly impacted by the WW along with the BTW of the pig, whereas the Landrace pigs were much more greatly affected by BTW.

Days to 113 kg was more greatly affected by BTW and WW than the ultrasonic BF and LMA measurements. As pig BTW and WW decreased in value from their mean values, the functions predicted that the pigs would require every increasing days to achieve 113 kg BW. Pigs at the same WW but with lighter BTW have increased DAYS. The results of this study were in agreement with studies (Schinckel, et al., 2007b; Fix et al., 2010a) stating that pigs that were lighter at birth were lighter at fixed time points throughout development. In general, pigs from parity 1 dams which have lighter BTW are less profitable and require additional days to market than pigs from sows with greater parities (Moore, 2001; Boyd, 2008; Schinckel 2010a).

The effect on the variation in growth performance after birth may be pre-programmed during fetal development in the uterus, and the effects range from muscle development as well as organ size and functionality (Foxcroft and Town, 2004; Harding et al., 2006). Previous studies have indicated that pigs with lower BTW may have altered regulation of energy metabolism, and leptin concentrations (Poore and Fowden, 2004; Gondret et al., 2005, 2006). Piglets of light BTW have a decrease in LMA,

increase in fat deposition, poorer feed efficiency, and lower % lean for both male and female pigs (Schinckel et al., 2010a). Piglets with light BTW are slower growing to market and less efficient (Smit et al., 2013). Fetal growth retardation resulting from low BTW and decreased number of skeletal muscle fibers cannot be compensated for during postnatal growth of pigs (Rehfeldt and Kuhn, 2006). Selection for lean tissue growth in pigs does possess possible difficulties that may result in a negative effect on several factors that can ultimately affect piglet survival at birth, such as body and tissue composition, metabolic and hormonal states, as well as fat metabolism at birth (Herpin et al., 1993).

Overall Landrace and Yorkshire pigs required 2.5 and 2.7 fewer days to achieve 113kg than Duroc pigs ($P < 0.05$) (Table L). Increasing the birth weight two SD for each breed resulted in a decrease of 7.2 d (Duroc), 6.7 d (Landrace), and 6.3 d (Yorkshire) to market. Alternatively decreasing BTW by 2 SD resulted in increases of 13.5 (Duroc), 12.2 (Landrace), and 14.7 d (Yorkshire) to 113 kg BW. Birth weight had a greater impact for DAYS for each breed than WW in this study.

Table L. Birthweight and weaning weight affect on predicted days to 113kg.

	Birth weight					Wean weight				
	-2SD	-1SD	Mean	1SD	2SD	-2SD	-1SD	Mean	1SD	2SD
Duroc	182.7	175.1	169.2	164.8	162.0	176.7	172.6	169.0	165.9	163.3
Land	178.7	171.9	166.5	162.4	159.8	174.8	170.2	166.3	163.1	160.6
York	181.4	173.0	166.7	162.5	160.4	175.4	170.8	166.7	162.8	159.4

¹Mean predicted DAYS at mean BTW, and WW as well as plus or minus 2SD for each

Pigs from parity 1 dams required approximately 2.0 more DAYS to reach 113 kg than pigs from parity 2 dams ($P < 0.05$) (Table M). When BTW and WW were accounted for however, there was no significant difference in DAYS between any parity groups ($P > 0.05$). This is in agreement with a previous study (Boyd et al., 2008) that found pigs from high health herds from parity 1 dams took approximately 3 days to market than pigs from older parity dams, but after adjusting for BTW and WW there were no differences in days to achieve target market BW. Pigs with lighter BTW have a

greater feed: gain values than piglets that were larger at birth (Mroz et al., 1987; Schinckel et al., 2010a). Heavier BTW pigs have a competitive advantage in terms of early feeding and remain heavier throughout their lives within any given group (King et al., 1999; Le Dividich, 1999).

Table M. Effect of parity on days to 113kg by breed.

	Simple model ¹				Birth and Weaning weight included								
	Duroc	SE	Land	SE	York	SE	Duroc	SE	Land	SE	York	SE	
Parity													
1	169.2	1.54	165.7	1.35	164.4	1.18	168.3	1.55	166.0	1.34	164.1	1.24	
2	166.5	1.54	163.5	1.35	162.9	1.18	168.2	1.55	166.5	1.34	164.2	1.24	
3	166.0	1.54	162.9	1.35	161.6	1.18	167.7	1.55	165.3	1.34	163.5	1.24	
4	166.3	1.54	163.7	1.36	162.1	1.18	167.7	1.55	165.2	1.35	163.9	1.24	
5	166.8	1.56	164.6	1.37	163.1	1.19	168.1	1.56	166.3	1.36	164.2	1.25	
≥6	168.8	1.55	165.2	1.35	164.4	1.18	169.5	1.55	166.4	1.34	165.2	1.24	

¹Model included fixed effects of parity, sex, farm and random effects of dam and contemporary group, additional model included significant ($P < 0.05$) linear and quadratic effects of BTW and WW

Weaning weight also has an impact on DAYS. Increasing the WW by two SDs resulted in decreased DAYS of 5.7 d (Duroc), 5.7 d (Landrace), and 7.7 d (Yorkshire). Decreasing WW by two SDs resulted in increased DAYS of 7.7 d (Landrace), 8.5 d (Landrace), and 8.7 d (Yorkshire).

Pork production systems can be represented by complex bio-economic models (Quinton et al., 2006). The profitability of pork production is greatly affected by the total number of piglets born and weaned. As the number of piglets per litter increased, BTW decreased, which increased the probability of piglet being stillborn (Pedersen et al., 2011). Following birth, light BTW piglets may not be able to maintain a homeothermic balance in cold due to a greater surface to body mass ratio, are more prone to hyperthermia, and being overlain by the sow (Herpin et al., 2002). Others have found that the lightest weight pigs at birth have a decreased chance of survival to weaning (Fix et al., 2010b). With curvi-linear relationships between growth variables and BTW,

differences in postweaning performance is greatly affected by the variation and distribution of BTW within each group of pigs (Schinckel et al., 2010a). Others recently found that as CV for BTW increased, the CV for WW increases and survival decreases (Zindone et al., 2013).

Lower BTW pigs are slower growing to market and are overall less efficient (Schinckel et al., 2007a; Smit et al., 2013). Decreasing BTW also results in increased likelihood of inferior quality pigs at weaning, finisher placement, and near the conclusion of finishing (Fix et al., 2010b). Pigs with carcass weights that fall below the optimal range are discounted by processors (Boland et al., 1993; Boys et al., 2007).

Selection objectives must ultimately include changes in survival, market BW, growth performance, and value of carcass, which is produced biologically by selection for increased litter size (Stewart et al., 1990; Schinckel et al. 2010a). Selection and management should be targeted to increase litter size with no or small decreases in average piglet WW (Boyd, 2012). Pigs with less than average WW and early post weaning growth rates will take longer to achieve an acceptable market BW (Schinckel et al., 2009d).

3.5 Conclusions

Overall, variation in BTW and WW will affect the subsequent growth and performance of piglets, as litter size and number of pigs nursed to weaning increases mean piglet BWT and WW decreases. Decreasing piglets BTW and WW often results in decreased survival and post weaning performance. As litter size increases, and the number nursed increases, especially in maternal lines, variation the pigs' mean performance will increase while overall performance will decrease. Pigs with below average BWT and WW have reduced probability of being selected if the selection includes DAYS, BF, and LMA, with an objective to increase lean growth rates or feed efficiency. Selection practices should include a balanced approach to not only increase litter size but not decrease piglet BTW and WW. With such complex relationships between the measured variables, bio-economic models of pig production which account for sources of pig to pig growth are needed.

3.6 Chapter References

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CHAPTER 4 CONCLUSIONS

Overall swine production has changed in terms of performance levels with most changes having positive effects on the system as a whole. Selection has been successful in achieving gains in traits that directly affect the overall profitability of swine production. Traits such as litter weights have increased as a result of selection of total number of piglets born while not sacrificing the survival of the piglets. Up to this point selection has successfully increased litter size and the number of pigs weaned along with the size of those pigs. In the future it will increasingly be important to make successful and accurate selection for traits that will further the swine industry and not be detrimental to the survival and wellbeing of the offspring that are produced. Selection of animals that may not be the most extreme in any given category in production but have a good balance of traits will allow a producer to continue to make improvements to their herd while also allowing them to prevent some problems that arise from single trait selection.

The biological system of sow productivity is very complex and many traits should be taken into account when making selections as to not decrease performance in any trait while also continuing to make progress in many other traits at each selection point. This will allow the producer to see improvements in traits for many generations. Index selection allows for a system in which a producer must assign a weighted value for each measurable trait that is present. The producer must then implement the selections that the index tells them to make as to not put subjective evaluation for animal since this will hinder the improvements that can be made in the system.

In conclusion the single trait selection of litter size alone possesses too many down sides to be a viable selection program long term. Producers should know the relationships between all of the economically important traits and used balanced selection to make the most genetic progress, and producers using index methods of selection must

only select on animals that are the best based on the indexes or the genetic progress will be slowed or even stopped altogether. As litter size increases, greater emphasis should be placed on preweaning survival.

From the studies represented in this thesis there has been an increase in many economically important traits such as litter weaning weights, piglets weaning weights as well as sizes of litters at weaning. Increasing weaning weights and the number of piglets in a litter increases the profitability of a swine operation. The costs associated with each litter will be more distributed across a larger number of pigs. Additionally it has been found that increasing the weaning weights of pigs will reduce the amount of days it takes pigs to reach a target market weight. The faster pigs reach the target market weight the less it will cost to take the animal to market in terms of feed and building costs.

Furthermore variation in birth and weaning weight will ultimately affect the growth and performance of piglets and as litter size increase the number of pigs nursed will increase and birth and weaning weight will decrease. Decreases in birth and weaning weights will result in decreased survival and poorer post weaning performance (Schinckel et al., 2010a). Increased litter size also results in increased variation in birth and weaning weights and overall performance of the herd may decrease. Selection practices will need to be made based on the complex relationships between all measured variables in the system and the most accurate records obtainable. Furthermore in the future the selection tools afforded to producers will continually increase in complexity and it will be the individual producer's job to use the information as they see fit to allow for further growth of their operations.

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