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Application of Pork Checkoff We Care Sustainability Principles To Pork Production: Water, Nutrition, and Biosecurity

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APPLICATION OF PORK CHECKOFF WE CARE SUSTAINABILITY PRINCIPLES TO PORK PRODUCTION: WATER, NUTRITION, AND BIOSECURITY

BY

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THESIS ACCEPTANCE PAGE

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This thesis is approved as a creditable and independent investigation by a candidate for the master's degree and is acceptable for meeting the thesis requirements for this degree. Acceptance of this does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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ABSTRACT

APPLICATION OF PORK CHECKOFF WE CARE

SUSTAINABILITY PRINCIPLES TO PORK PRODUCTION: WATER,

NUTRITION, AND

HANNAH MILLER

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The Pork Checkoff program was founded in 1986 as a means to strengthen U.S. pork in the market place (Pork Checkoff). Under this program all U.S. pork producers and importers pay $0.40 for every $100 worth of pigs is sold (Pork Checkoff). Funds are then used for pork promotion, research, and education for producers and consumers (Pork Checkoff). The Pork Checkoff program uses the We Care ethical principles as a means to address "continuous improvement in the pork industry's production practices and promote a strong record of responsible farming to those outside of the industry" (National Pork Board, 2018a). The six pillars of the We Care principles are food safety, animal wellbeing, public health, environment, people, and community. Under each of the main pillars are many overlapping subtopics. These include water, animal nutrition, manure management, disease prevention, along with many others. The We Care principles, under environmental stewardship, have the goal to improve water usuage. The current goal is to improve reporting and measuring of in-barn water usage (We Care, 2021). Under the environmental stewardship and animal care pillars are objectives for animal nutrition which include providing balanced and age appropriate diets which contribute to efficient growth (We Care). Proper management for both water and nutrition lead to improved manure management, with the goal to reduce manure output as well improving manure quality through the reduction in nutrient and ammonia output of the manure (We Care).

The We Care principles also outline objectives for disease prevention under the pillar of food safety. Part of normal practice in swine facilities is the use of biosecurity and sanitation to reduce the risk of disease. Foreign animal diseases are considered a threat to food safety and security. As a means of preparedness the Pork Checkoff has encouraged swine producers to create site-specific enhanced biosecurity plans which help maintain business continuity in the event of a foreign animal disease outbreak (We Care). Due to the relevance of sustainability, animal care, and food safety the following topics of water use, nutrient requirements, and enhanced biosecurity are further analyzed.

1.0 LITERATURE REVIEW

1.1 Water in Swine Production

Water Metabolism

Water is a fundamental requirement for all organisms as it fulfills many biochemical and physiological roles in the body, including maintenance of homeostasis, lubrication, transportation of nutrients, and suspension of biological structures in aqueous environments (Patience, 2012). Water is a small molecule with a dipolar structure, which enables it to easily dissolve other molecules linked by ionic bonds (Israelachvili and Wennerström, 1996; Patience, 2012). Water acts as a solvent to move nutrients into a cell and to remove metabolic end products (Patience, 2012)

Pigs source water through direct consumption, moisture in the diet, and metabolism (i.e., metabolic water). Seventy- five to eighty-six percent of the water in the pig is supplied through direct water consumption, while another 11% is acquired through metabolic water and moisture in the feed (Mroz et al., 1995; Shaw, 2003; Patience, 2012). Metabolic water is sourced from the oxidation of carbohydrates, amino acids and lipids (Patience, 2012). Every kilogram (kg) of air dry feed produces between 0.38 to 0.48 kg of metabolic water depending on the composition of the diet (Yang et al., 1984). More specifically the oxidation of 1 kg of fat, carbohydrate and protein produces 1190, 560, and 450 grams (g) of metabolic water, respectively (NRC, 2012).

Water loss occurs in the lungs through respiration, the skin via evaporation, the intestines through defection, and the kidneys through urination (NRC, 2012). Between 30 to 40% of water output is directed towards urine, feces accounts for 8 to 28% of output, while growth only accounts for 5 to 14%, with the remainder attributed to losses via the skin and lungs (Mroz et al., 1995; Shaw, 2003; Patience, 2012).

Homeostasis of Water

Body water is regulated through osmotic, ionic, hormonal and nervous signals (McKinley and Johnson, 2004). The hypothalamic-neurohypophysis-renal axis is the control center for water balance (Knepper et al., 2015). Urine is the primary regulator of water. Urination is largely controlled by arginine vasopressin (AVP) and total solute load (Robertson and Norgaard, 2002). Increases in plasma osmolality above the physiologic threshold triggers thirst and a feedback loop. After the signal of high plasma osmolarity, the feedback loop increases the secretion of AVP from vasopressinergic nerve endings in the neurohypophysis. Arginine vasopressin is an antidiuretic hormone, expressed in the neurons of the supraoptic and paraventricular nuclei of the hypothalamus. Arginine vasopressin binds to receptors in the kidneys, which signals to reduce the excretion of water and directs more filtered water back into the blood stream (Knepper et al., 2015). A study which restricted water intake in ratios of 1.5:1 or 3:1 relative to feed intake, found that pigs with the lower levels of water to feed ratio had increased concentrations of plasma urea nitrogen (PUN), relative to those with the higher water to feed ratio. By reducing water, urine output was also reduced. Reduction of urine led to increased reabsorption of urea and increasing PUN levels (Cai and Zimmerman, 1995). The feedback loop is complete once the reabsorption of renal water lowers plasma osmolality which in turns signals to reduce the secretion of AVP (Knepper et al., 2015).

Water and Feed

Water intake is influenced by feed intake, diet composition (salt and protein), environment (temperature and humidity), delivery system, stress, boredom, and hunger, making true requirements dificult to define (Nyachoti and Kiarie, 2011; NRC, 2012; Patience, 2012). Eighty-five percent of a pig's water consumption occurs within 10 minutes of eating (Patience, 2012). Water is recommended to be provided at 2.5-3 L/kg of feed (Almond, 1995). Cumby (1986) reported that when feed and water were freely given water intake was approximately 2.5 kg of water per kg of feed. This was supported by Shaw (2003), who reported a range of 2.1 – 2.7 kg of water per kg of feed. A minimum of 2 kg of water per kg of feed is recommend by NRC (2012) for pigs between 20 and 90 kg; when feed is restricted pigs will increase their voluntary water intake to 3.7 kg of water per kg of feed to aid in satiety (Yang et al., 1984; Cumby, 1986).

There are mixed conclusions on water intake and the influences on feed intake and thus pig performance. Brooks et al. (1989) state that water consumed by the pig affects voluntary feed intake and hence growth, and as water to feed ratio increases so does the biological performance of the pig. However, a study from Cai and Zimmerman (1995) found that lowering the water to feed ratio had no effect on gain or feed efficiency, and the "pigs grew as expected" even while water was limited. Additionally, in studies featuring a wet feeding system with water:feed ratios ranging from 1.5:1 to 3:1 increasing the water to feed ratio had little impact on performance or carcass quality (Barber et al., 1963). More recent work from Shaw et al. (2006) further supported a poor relationship between average daily feed intake and water intake.

While evidence for a clear relationship between feed and water intake is mixed, there is strong support for the impact of diet composition on water intake. Increasing the salt and protein content of a diet increases water intake (Almond, 1995; Shaw et al., 2006). Increasing the protein content of the diet increases circulating urea content, an end product of nitrogen metabolism. Animals drink enough water to eliminate excess salt and urea, so by increasing nitrogen content in the diet there is an increased need for water in order to eliminate the urea that is subsequently produced (Cai and Zimmerman, 1995). Lowering protein content in the diets to meet essential amino acids and to match pig performance decreases nitrogen excretion by 14 – 40%, which in turn will decrease water intake (Koch, 1990; Smith and Crabtree, 2005). Although reducing the nitrogen content of the diets below requirements does not have the same effect, and will not reduce water intake (Shaw et al., 2006).

Water and Temperature

The thermal neutral zone for growing-finishing pigs is between 18 to 21°C (Midwest Plan Service, 1982; Lammers et al., 2007a). It has been well established that water consumption increases with a rise in temperature (Almond, 1995; Schiavon and Emmans, 2000; Huynh et al., 2005; Nyachoti and Kiarie, 2011). When temperature elevated from 12-15°C to 30-32°C there is a greater than 50% increase in water consumption (Mount et al., 1971; Almond, 1995). Schiavon and Emmans (2000) reported that for every 1°C increase in temperature, there is a 0.1 L increase in water intake. Close et al. (1971) reported a change in behavior patterns with increased water intake. For example, pigs were observed to spill water in the pen to cool themselves. It may be concluded that the increase in water disappearance observed by others is not going only to water consumption but also to play and cooling. Water spillage for the purpose of cooling is due to pigs having limited ability to lose heat through the skin via evaporation;

the majority of water vapor is expired through the lungs. Increased loss of water through evaporation increases the quantity of water the pig needs to consume (Ingram, 1965; Nyachoti and Kiarie, 2011).

Relative humidity alone does not impact pig performance, water consumption, or water loss (Morrison et al., 1967; Patience, 2012); however, when humidity is coupled with high temperatures it can have a negative impact on performance and limits the pig's ability to cool itself through evaporative heat loss (Nyachoti and Kiarie, 2011). In high temperatures when relative humidity increased from 50% to 80%, the water to feed ratio doubled (Huynh et al., 2005; Patience, 2012). Providing water in the form of overhead misters, drippers, or sprinklers can aid in the pig's ability to stay cool and maintain performance when temperature and humidity is elevated (Nyachoti and Kiarie, 2011). It is important that misters are properly managed so they are not contributing to increased humidity in the barn but rather allow the pigs to cool themselves and loose heat through evaporation (Ingram, 1965).

Water Quality

Water quality is influenced by pH, hardness, total dissolved solids, nitrates and nitrites, sulfates, and bacteria load, all of which can impact water consumption and pig performance (Nyachoti and Kiarie, 2011; NRC, 2012).

Water pH for livestock should range between 6.5 and 8.5. Lower levels of pH may damage water delivery devices and water pipes, while higher levels of pH can lead to the scaling of water lines and limit rate of water passage (Nyachoti and Kiarie, 2011). Additionally, water outside of the normal range of pH may negatively impact medications which are often delivered through water lines (Nyachoti and Kiarie, 2011). Water hardness is defined as the sum of divalent cations in the water, usually comprised of calcium and magnesium salts (Nyachoti and Kiarie, 2011; NRC, 2012). Water is considered to be soft when the cation concentration is less than 60 ppm, and hard when in the range of 120-180 ppm (NRC, 2012). Similar to high pH levels, hard water can also cause scaling of the water lines and reduce the passage of water (NRC, 2012). If calcium content in the waters lines is high enough, phosphorus in the diets may need to be adjusted in order to balance for the increased calcium consumption from water intake (Kober, 1993).

The measure of total dissolved solids (TDS) in the water is an indicator of water quality and can impact swine health. Total dissolved solids is a measure of the salinity of the water; which measures the level of soluble salts like magnesium, calcium, sodium bicarbonate, chloride and sulfate forms present in the water sample (Thulin and Brumm, 1991; Kober, 1993). At 1,000 ppm TDS water is considered safe. (Nyachoti and Kiarie, 2011). The Canadian Council of Ministers of the Environment (1987) outlines a maximum of 3,000 ppm TDS appropriate for livestock consumption. Levels greater than 1,000 ppm may result in water refusal and in health concerns like temporary diarrhea (Kober, 1993; NRC, 2012).

High levels of nitrite and nitrate concentrations are often an indicator of bacterial contamination (Kober, 1993). Nitrites impair blood’s ability to carry oxygen, reduce hemoglobin to methemoglobin, and inhibit the use of vitamin A (NRC, 2012). Nitrates are less of an issue than nitrites, but through enzymatic reactions nitrates can be converted to nitrites (NRC, 2012). Nitrate-nitrogen concentrations of 290-940 ppm caused an increase in mortality in swine (Winks et al., 1950); although it has been reported that levels up to 333 ppm do not negatively impact pig performance (Kober, 1993).

Sulfate concentration has the biggest impact on water quality in North America (NRC, 2012). A 1991 study found that 25% of wells in Canada have excessive concentration of sulfates at 1,000 ppm or greater (McLeese et al., 1990). Concentrations are dependent on location, well depth as well as TDS concentration (NRC, 2012). Concentrations below 2,650 have no impact on performance (Veenhuizen et al., 1992; Maenz et al., 1994; Patience et al., 2004). Sulfate concentrations above 3,300 ppm cause a laxative effect, while concentrations greater than 7,000 ppm reduce performance and cause diarrhea (Anderson et al., 1994; NRC, 2012). For young pigs, whose immune system is compromised due to the stress of weaning, there is a lower tolerance for sulfates. Concentrations as low as 750 ppm have been reported to cause health issues (Nyachoti and Kiarie, 2011).

Water lines provide the ideal environment for bacteria to flourish. *Escherichia coli*, Salmonella, and Leptospira are the most prevalent types of bacteria found in water lines and drinking devices (Fraser et al., 1993). Water for livestock should not contain more than 5,000 coliforms per 100 mL (Bureau of National Affairs, 1973; Meek, 1996). This recommendation is highly dependent on the type of bacteria present as many are still benign at this concentration while others can be harmful at concentrations below this level (NRC, 2012). Regular disinfection of the waterlines can aid in reducing the bacteria load (NRC, 2012).

Water Delivery and Reducing Water Wastage

Globally, agriculture accounts for 92% of the freshwater footprint, with 29% of agriculture water use related to livestock production (Gerbens-Leenes et al., 2013). In the United States, swine production is estimated to use 156.3 million liters of water annually (Muhlbauer et al., 2010). Of that, finishing pig production uses 62-64% of the total water use. While gestating sows account for approximately 16%, nursery pigs 11% and animals in farrowing 9% of the total water use in the swine industry (Froese and Small, 2001; Muhlbauer et al., 2010). A survey of growing-finishing barns in Manitoba, Canada reported water disappearance ranging from 4.7 to 13.9 L/ pig/ day (Froese and Small, 2001). Differences in water disappearances can be attributed to wastage, which can be reduced through proper management of the water delivery system (Froese and Small, 2001; Patience, 2012). Currently, water in North America is largely abundant, with generally few costs or regulations (Patience, 2012). But due to increasing demand of water due to the rising human population, there may come a time when animal agriculture is faced with an increase in cost of water and a decrease in availability (Vörösmarty et al., 2000; Patience, 2012). Given the quantity of water used to produce finishing pigs relative to other sectors in swine production, there is plethora of opportunity to reduce water inputs through reevaluation of management practices. For example, water flow rate, drinker position, and type of drink all influence water usage.

Water flow rate is the rate at which water is delivered to the pig. Growing-finishing pigs drink at a rate of 1,422 mL/min when water flow rate is 2,080 mL/min (Brumm, 2019). A minimum of 250 mL/min is recommended, while it is advised to not exceed delivery rates above 1,000 mL/min (Brumm, 2019). Providing water at a rate of 650 mL/min versus 2,080 mL/min resulted in spillage of 8.6% and 23.2%, respectively

(Brumm, 2019). Work from Li et al. (2005) reported that pigs will consume the same amount of water regardless of the water flow rate. Increases in water disappearance between a low water flow rate of 500 mL/min versus a high water flow rate of 1,000 mL/min are attributed to water being wasted rather than being consumed by the pig (Li et al., 2005).

Water wastage can be also reduced by increasing the drinker height as the pig grows. Height adjusted waterers drinkers decreased water wastage by 15% compared to an unadjusted water drinker (Li et al., 2005). Patience (2012) echoes this, stating that wastage is highly dependent on water flow rate and method of mounting. Nipple water drinkers should be either at a 90° angle at shoulder height or at a 45° angle 20% above shoulder height (Patience, 2012). When nipple water drinkers are set too low the pig will turn to the side to drink. This results in up to 60% of the water exiting the side of the mouth (Gadd, 1988).

Drinker type can also greatly influence the quantity of water wasted. Brumm et al. (2000) studied the impact of different drinker types and the impact on water wasted and pig performance. The study was divided into 3 sections, first comparing wet-dry feeders to conventional dry feeders, second comparing swinging water nipple to a conventionally mounted nipple drinker, and finally comparing a swinging water nipple to a bowl drinker. Pigs using the wet-dry feeder were reported to have an increased average daily gain (ADG) as well as average daily feed intake (ADFI) but due to the increase in feed intake, feed conversion was poorer. Use of the wet-dry feeders reduced water usage by 26% and manure volume by 29.3%. Feeder type had no impact on carcass qualities. When comparing different styles of water drinkers there were no differences in pig performance in either of the two studies. Water was reduced by 11.1% with the swing drinker compared to the mounted drinker, while use of the bowl drinkers reduced water by 25% relative to the swinging water nipples. Results from Tavares et al. (2014) contrast work from Brumm et al. (2000) in that the nipple drinker had the lowest water disappearance when compared to a bowl drinker and a ball bite drinker. The authors suspect that the unexpected increase of water usage of the bowl drinker is due to position and the height of the bowl drinker which was not set appropriately for the age and size of pigs in the study (Tavares et al., 2014). When considering manure production, the ball bite drinker resulted in the highest manure output with no differences between the nipple or bowl drinker (Tavares et al., 2014). However, similarly to the result from Brumm et al. (2000), Tavares et al. (2014) also found no differences in body weight (BW), ADG or ADFI regardless of the type of drinker used.

Regardless of the water delivery and method or management there is little impact on pig performance, apart from the wet-dry feeders. With that in mind, advantages in improving water management come from being able to reduce water input at the pig level which in turn reduces costs associated with the water and manure handling.

Water and Manure

One finishing pig produces 8-9% of its BW in feces per day, or approximately 4.2 L of raw manure (Fleming et al., 1998; NRC, 2012); over a 114-day feeding period that equates to 620.7 L of slurry per pig (Fleming et al., 1998). Approximately 20% of water used in swine facilities is wasted (Fleming et al., 1998). The value of swine manure is determined by the nutrient content of the manure and the distance that the manure is hauled (Fleming et al., 1998). For swine manure to be a profitable form of fertilizer the delivery costs must be low enough to justify using it as a substitute for chemical fertilizer (Fleming et al., 1998). Swine manure is rich in nutrients like nitrogen, potash and phosphate (Fleming et al., 1998; Hatfield et al., 1998). Increasing the water content of the manure slurry reduces the concentration of these nutrients in the manure. Due to the high water content there is often a need to make multiple trips between the pumping site and the site of application (Hatfield et al., 1998). Increased water content of a slurry is often associated with storage and land application issues (Hatfield et al., 1998). Longer storage periods of the manure slurry minimizes application problems by allowing some water to evaporate off (Hatfield et al., 1998). By reducing wasted water, the manure pit does not fill as rapidly, and the slurry can be stored for a longer period. This in turn decreases the frequency of pumping and reduces the amount of water that must be transported and applied to a field and increases the value of the manure applied.

Conclusion

Water impacts sustainability, manure output and field application, as well as the well-being and performance of the pig. With recent goals announced by the Pork Checkoff to improve water usuage in pork production, there is an increase relevance to evaluate how water is being used in pork production. A 2019 survey of South Dakota pork producers found that a majority of producers provide water a flow rate that exceeds recommendation (Zeamer et al., 2021). Based on these findings the question was raised, how does water flow rate impact finishing pig performance during the summer months.

1.2 Using Pig Growth Models to Reevaluate Phase Feeding Programs

Growth Models

One of the objectives of the We Care principle is to improve the nutrition provided to the pig in a manner that contributes to efficient growth and reduces potential pollutants (We Care). Growth curves and models are a practical tool to help achieve this goal. Growth curves for swine production are used to predict pig performance under different management or environmental conditions. Application includes to demonstrate nutrient utilization, track pig performance, create a feeding program, reduce diet costs, improve feed efficacy, reduce the excretion of pollutants, set production goals, and improve management (Schinckel and de Lange, 1996; de Lange et al., 2001; Fraga et al., 2015). Using data such as pig BW and ADFI, along with current levels of nutrients being provided in the diet, a plethora of information can be extracted and analyzed in order to improve a number of production goals.

Body weight (Figure 1.1) and pig growth is best characterized by a sigmoidal function (Whittenmore and Green, 2002; Wellock et al., 2004; Strathe et al., 2010). Growth typically follows a pattern of slow initial growth, followed by a period of rapid gain (Whittenmore and Green, 2002). As the animal reaches maturity, there is an assumption that there is an upper limit to the growth potential and the growth rate will begin to decrease with the increase in age and BW (Whittenmore and Green, 2002; Wellock et al., 2004). The upper limit where the animal reaches their maximal growth rate, is referred to the point of inflexion (Wellock et al., 2004). There are multiple functions that can be used to accurately characterize pig growth. Schulls (2013) reported that Logistic, von Bertalanffy, Gompertz, Richards, Generalized Michaelis-Menten, Bridges and Polynomial, all accurately characterize BW, with R^2 values greater than 0.997. Wellock et al. (2004) reported as well that Gompertz, Logistic, von Bertalanffy, Richards, Black, and Bridges functions also accurately predict potential growth, with preference given to the Gompertz function. Preference was given to the Gompertz function as it has a lower number of parameters, includes an asymptote, includes monotonic decrease relative to the growth rate, has a point of inflexion, and is suitable to describe biological systems (Wellock et al., 2004). Strathe et al. (2010) gives preference to four parameter functions, like Lopez or Bridges function, over three parameter functions, like Gompertz or Logistic, for reporting extended periods of growth. Comparisons of the models were based on the model selection criteria of the Akaike information criterion, Bayesian information criterion and residual degrees of freedom. A potential reason for preference to the four parameter models is that this study tracked pig body weight for over 2 years begining from birth (Strathe et al., 2010). For practical application, 3 parameter functions maintain popularity due to increased ease of use and functionality of the model (Wellock et al., 2004). The Gompertz function, one of the most commonly used models, reaches a maximum growth rate at a fixed degree of maturity and linear decrease in the slope or rate of growth as the logarithm of the x-axis or time increases (Gompertz, 1825; Wellock et al., 2004).

Average daily gain (Figure 1.2). is typically characterized by a period of very rapid increase through the nursery and early grower phase. As pigs age, they become less efficient and ADG begins to decline. Models use to characterize ADG include gompertz, GMM, and Bridges. Schinckel et al. (2009) reports that the Gompertz model predicts reduced growth at d 32 to 60 of age, but a greater rate of gain at the inflection point, followed by a lower ADG after d 152, compared to the Bridges and GMM models. The GMM and Bridges functions predict similar patterns of growth (Schinckel et al., 2009). Schulls (2013) analyzed the predictability of Gompertz, Richards, GMM, Bridges, and polynomial equations. Polynomial equations provided a good fit for characterizing ADG for both barrows and gilts (0.96 and 0.92 respecitivly) (Schulls, 2013).

Work from Schulls (2013), shows that polynomial equations provide a good fit for characterizing feed intake (Figure 1.3) where quadratic and cubic models are best fit for average daily feed intake (ADFI) of barrows (Figure 1.3A) and gilts (Figure 1.3B), respectively ($R^2 = 0.99$). In this study barrows reached a greater maximal ADFI and had a greater subsequent decline of ADFI compared to gilts who maintain a more constant feed intake in the finsihing period (Schulls, 2013). Although Lorenzo Bermejo et al. (2003) suggests the use of logistic functions to describe ADFI, as polynomial equations lack the stabilization or plateau of feed intake that is often seen at the end of the finishing period. This contradicts work from Schulls (2013), who reported a decrease in feed intake after 120 kg.

Protein and Lipid Deposition

The information provided in the growth model (BW, ADG, ADFI, and GF) combined with dietary levels of protein and energy, information such as protein and lipid deposition can be calculated (Schinckel and de Lange, 1996; de Lange et al., 2001; Cai et al., 2011; NRC, 2012). The rate of protein and lipid deposition is dependent on dietary energy and dietary amino acid intake (Wagner et al., 1963; Kyriazakis and Emmans, 1991; de Greef and Verstegen, 1996; van Milgen and Noblet, 2003). In finishing pigs, the goal is to maximize the weight of sellable protein in the animal. Increasing protein supply in the diet will increase protein retention until energy supply becomes the limiting factor, which results in a lower ADG (Wagner et al., 1963; Black et al., 1986; van Milgen and Noblet, 2003). But when high protein diets are properly adjusted for energy, intramuscular fat and backfat decreases, while protein deposition increases (Wagner et al., 1963). On the other hand, when high energy diets are not adjusted for protein, this results in increased intramuscular fat, increased ADG, and improved feed efficency (Wagner et al., 1963). As energy intake increases the lipid : protein deposition ratio increases curvilinearly resulting in a lower lean protein deposition and an increase in fat deposition with higher energy intakes (Bikker et al., 1996). This is due to protein now being the limiting element and more energy being partitioned towards lipid deposition.

Before energy can be partitioned towards growth it must first meet the requirements for maintenance. Maintenance energy can be calculated from the exponent of BW (NRC, 2012).

Daily maintenance metabolizable energy (ME) requirement from BW in kg (Eq.8-19).

$$ME \left(\frac{kcal}{day}\right) = 197 \times BW^{0.60}$$

Daily protein deposition (Pd) for gilts and barrows between 25 and 125 kg can also be calculated from body weight using the following equation (NRC, 2012):

Protein deposition for gilts based on BW in kg (Eq. 8-22).

$$Pd, gilts \left(\frac{g}{day}\right) = 137 \times (0.7066 + 0.013289 \times BW - 0.00013120 * BW^2 + 2.8627 \times 10^{-7} \times BW^3)$$

Protein deposition for barrows based on BW in kg (Eq. 8-23).

$$Pd, barrows\ \left(\frac{g}{day}\right)$$

$$= 133 \times (0.7078 + 0.013764 \times BW - 0.00014211 \times BW^2 + 3.2698 \times 10^{-7} \times BW^3$$

Protein deposition rates are at their highest when pigs are very young, with a steady decline in Pd as the animal ages. As Pd decreases, the rate of lipid deposition (Ld) begins to increase (NRC, 2012). Protein deposition in gilts and barrows is described using different equations because during the finishing period the rate of gain, feed efficiency and protein accretion differ (NRC, 2012). Throughout the growing period, gilts have a higher rate of Pd than barrows of the same BW; after 23 kg barrows have a greater ADG than gilts (NRC, 2012). Barrows also have a greater ADFI, as a result barrows have a reduced feed efficiency compared to gilts (Lammers et al., 2007b). The limitation of the above Pd equations is that they only consider BW and are based on assumed ME intake. For example, as pointed out by Schinckel and de Lange (1996), these equations assume that environment or genetics does not influence lean protein deposition.

Lipid deposition (Ld) can be calculated using ME intake, maintenance ME and Pd (NRC, 2012).

Daily Ld based on ME intake, ME requirements and Pd (Eq. 8-31).

$$Ld\ \left(\frac{g}{day}\right) = (ME\ intake - maintenance\ ME\ requirements - Pd\ \times 10.6)\ /12.5$$

Phase Feeding

Growth curves and models can be used in the development of feeding programs. Using BW and feed intake as inputs for a model, daily nutrient requirements can be estimated for a given period of time and a phase feeding program can be developed (de Lange et al., 2001; NRC, 2012; Menegat et al., 2019b; Remus et al., 2021). The objective of phase feeding is to provide multiple diets throughout the animal's lifetime which matches the nutrient needs of its given physiological state (Han et al., 2000). Ensuring that nutrients are not provided in excess of the animals needs to optimal growth creates opportunities for cost savings as well as reducing environmental pollutants by reducing levels of excreted nutrients like N, Ca, or P (Hauschild et al., 2012; Pomar et al., 2015; Andretta et al., 2016). Depending on the capacity of the feed mill and the goals of the production system a phase feeding program may be very simple, with only a handful of phases to as complex as adjusting the diet daily in advanced precision feeding systems (Han et al., 2000; Menegat et al., 2019b). Programs that use fewer phases usually capitalize on compensatory gain (Menegat et al., 2019a). Compensatory gain is accomplished by restricting nutrients in the nursery or early grower phase of production and capturing additional gain in finishing period when the previously restricted nutrients are provided in adequate supply (Menegat et al., 2019a). As a means to ensure that the proper level of nutrients are provided to the appropriate age of pig, a feed budget is assigned to each of the diet phases (Menegat et al., 2019b). A feed budget considers ADFI over a range of BW or time of which the pig is allotted to consume an age-appropriate diet.

Lysine

One of the objectives of phase feeding is to provide nutrients at adequate levels, not in excess. Nutrients that are provided in excess are excreted (Han et al., 2000; Han et al., 2001; NRC, 2012; Pomar and Remus, 2019). Excess nitrogen is one of the biggest concerns of excreted nutrients from manure, because it is a factor for rate of land application of manure (Fulhage, 2018). Lysine is an essential amino acid, meaning that the body cannot synthesize it and it must be provided in the diet (NRC, 2012). When determining a phase feeding program, lysine is usually the first amino acid to be evaluated (Menegat et al., 2019b). Lysine is often the pinnacle which diets are built around as it is the first limiting amino acid. The term “first limiting amino acid” is used to describe an amino acid that is not provided in sufficient quantities and hinders performance, with the pig only growing to the potential of the limiting amino acid (NRC, 2012). While under providing lysine leads to poor performance, over providing lysine leads to excess nitrogen being excreted (NRC, 2012; Pomar and Remus, 2019). Lysine should be provided at a ratio of 0.019 to 0.020 g per gram of gain (Goodband et al., 2014; Orlando et al., 2021). Using modeled ADG and ADFI, diets can be formulated to more accurately meet lysine requirements. Inclusion of other amino acids are determined based on a ratio to lysine (NRC, 2012; PIC, 2021; Remus et al., 2021). As all other amino acids are formulated based on a ratio to lysine, by more precisely meeting lysine requirements the inclusion of other amino acids are similarly more precisely met reducing nitrogen content of the diet and hence nitrogen excretion (Han et al., 2001). Retained nitrogen only accounts for 30 – 60% of nitrogen consumed by the pig (Kirchgessner et al., 1994; Han et al., 2000; Han et al., 2001; Otto et al., 2003). For every 1% decrease in crude protein intake, there is a 6.7 – 8.7% decrease in nitrogen excretion (Kerr, 2003; Leek et al., 2005; Leek et al., 2007).

In addition to using lysine as a basis for the inclusion of other amino acids, lysine is also used to determine the proper ratio for energy. As explained in the prior section

“Protein and Lipid Deposition”, the ratio of protein and energy determines the body composition of the pig and the rate of deposition of either lean tissue or lipid. The inclusion of lysine and energy is of equal importance to growth of the pig.

Energy

Energy is one of the most expensive components of a diet (Velayudhan et al., 2015). Young pigs eat a small quantity of energy dense and expensive diets, compared to finisher pigs who eat a large quantity of less energy dense, more inexpensive diet (Niemi et al., 2010). As a pig grows, daily feed intake and energy requirement are increased. Because feed intake increases at a more rapid rate than whole body energy requirement, the calories provided per kg of feed is reduced as the pig grows. (Niemi et al., 2010; NRC, 2012; Pomar and Remus, 2019). Reducing dietary energy as feed intake increases, maximizes feed conversion and reduces diet costs (Fraga et al., 2015).

After development of a model and a phase feeding program with the appropriate nutrient requirements, feedstuffs, or ingredients of a pig’s ration can be combined to match the targeted nutrient profile. In the United States the most common feedstuffs in swine diets are corn and soybeans due to their abundance and complementary nutrient profiles (Ates and Bukoswski, 2021; McConnell, 2021). Other feedstuffs include vitamin and mineral premixes and specialty ingredients which typically appear in lower quantities compared to the standard corn and soybean meal.

Feedstuffs

Corn

Corn is the most commonly included cereal grain in swine diets in the United States. More than 90 million acres of U.S. cropland is dedicated to corn production (McConnell, 2021). Corn is comprised of 4 main parts: endosperm, germ or embryo, pericarp, and the tip cap (Gwirtz and Nieves Garcia-Casal, 2014). The endosperm, which makes up the majority of the corn is made up of starch; on a dry matter basis corn is 72% starch (Gwirtz and Nieves Garcia-Casal, 2014; Loy and Lundy, 2019). The germ or the embryo is the next largest portion of the corn. It is high in fat, enzymes and vitamins which aids in new plant growth. The pericarp is a barrier surrounding the endosperm and the germ. It is fibrous and is the source of bran. Finally, the tip cap, the smallest portion of the corn, is the entry point for moisture and nutrients (Gwirtz and Nieves Garcia-Casal, 2014). In swine diets corn is typically included at less than 25% in nursery diets, while up to 90% in growing and finishing pig diets (Iowa State University Extension, 1996). Nursery pigs have a lower feed intake which requires a more nutrient dense diet which is dificult to meet through corn only (Niemi et al., 2010; NRC, 2012; Pomar and Remus, 2019). This need for a diet that is dense in energy and protein results in nursery diets being complex with multiple feed ingredients. As the pig ages and the nutrient density of the diet decreases many of the specialty ingredients are removed and the inclusion of corn increases, which allows for a decrease in diet costs (Niemi et al., 2010).

Due to its high starch content, corn is used primarily as an energy source. Corn is comprised of 2 types of starch, amylose and amylopectin (Loy and Lundy, 2019). Amylose is made up of a compact single chain of glucose molecules bound together via α 1-4 bonds. While amylopectin, the more digestible of the two, is highly branched and contains glucose molecules bound by α 1-4 and α 1-6 bonds (Hamaker et al., 2019;

Reese, 2019). Corn is approximately 22% amylose and 78% amylopectin (Reese, 2019). The NRC (2012), reports ME and NE values of yellow dent corn to be 3,395 and 2,672 kcal/kg, respectively.

While corn is high in energy content, a pure corn diet would be deficient in many of the essential amino acids for pigs in the nursery and early grower phase of production. Corn has a crude protein value of about 8% (NRC, 2012) and is relatively high in the sulfur-containing amino acids, methionine (0.18%) and cysteine (0.19%), but low in essential amino acids like lysine (0.25%) and tryptophan (0.06%) (NRC, 2012; Loy and Lundy, 2019). Lysine levels in corn can range from 0.20 – 0.32% (Johnston, 1995). Lysine in corn is influenced by the soil type, variety, fertilization, moisture, and bushel weight, creating a lot of variability from one crop to the next (Johnston, 1995). Due to this variability, it is important to account for changes in corn lysine levels when formulating diets. Common methods to detect levels of lysine include near-infrared spectroscopy (NIR) which uses light absorption to predict AA content of the grain and high performance liquid chromatography (HPLC) (Hardy et al., 2008; Zhou et al., 2012; Varzaru et al., 2013). Near-infrared spectroscopy is a more rapid method to determine amino acid levels, making it more practical to sample new grain shipments, and adjust diets as needed (Hardy et al., 2008; Zhou et al., 2012).A higher level of lysine allows for a reduction in the inclusion of products like soybean meal or synthetic amino acids, which are more expensive ingredients relative to corn, and can help reduce diet costs (Johnston, 1995).

Corn is rich with several vitamins and minerals including, vitamin A, vitamin B complexes, vitamin E, choline, folic acid, pantothenic acid, pyridoxine, riboflavin, and thiamine (Gwirtz and Nieves Garcia-Casal, 2014; Loy and Lundy, 2019). Corn contains high levels of phosphorus, 85% of which is in the form of phytate. Phosphorus in phytate is bound by oxygen making the phosphorus unavailable to pig due to the inability to synthesize phytase which is required to breakdown phytate and release the phosphorus. (NRC, 2012). Less than 30% of the phosphorus in corn is usable by the pig (Loy and Lundy, 2019). The phytate present in corn also binds minerals such as calcium, magnesium, zinc, and iron and can limit their avaliability (Underwood, 1962; Momcilovic and Shahl, 1976).

Another consideration for corn-based diets is the potential for antinutritional factors such as mycotoxins. Mycotoxins are secondary metabolites produced by toxigenic molds that occur when the corn is grown or stored in warm conditions with high moisture (Shotwell, 1977; NRC, 2012; Loy and Lundy, 2019). The most common mycotoxins include aflatoxin, zearalenone, deoxynivalenol, T-2 toxin, fumonisin, and ochratoxin A (NRC, 2012). A seven year survey of mycotoxin presence in new corn crop found that the mycotoxin Fusaric acid and deoxynivalenol occurred in 78.1 and 75.7% of corn samples (Weaver et al., 2021). Signs that pigs have consumed feed containing mycotoxins include reduced growth, feed refusal, and reproductive failure (Loy and Lundy, 2019). The U.S. Food and Drug administration (FDA) sets out regulations, or "action levels" which imposes regulatory actions on the incorporation or feeding a feedstuff that contains mycotoxins above a given level. The FDA prevents providing feedstuffs that contain aflatoxins to young swine at levels greater than 20 ppm and 200 ppm for mature pigs greater than 45 kg.

Mitigation of mycotoxins can be done by including a mycotoxin binder. Mycotoxin binders are considered non-nutritive additives, made of inorganic binders such as silicate clays, activated carbon, or polyvinyl polyproline (NRC, 2012). Mycotoxin binders work by either deactivation of the mycotoxin through binding to other substrates, converting the mycotoxin to produce a less toxic metabolite, or by reducing the absorption and promoting the excretion of mycotoxins in feed (NRC, 2012).

Soybean meal

Soybean meal is the most widely used protein source in swine diets around the world (Cromwell, 1999; Lammers et al., 2007c; Stein et al., 2014). In 2020, the United States planted 83.5 million acres of soybeans and harvested 4.1 billion bushels (Ates and Bukoswski, 2021). Soybean meal is a by-product of soybean oil production. Hexane is used as solvent to extract the oil from the whole soybean. Heat is then applied to evaporate the solvent. After processing and removing the oil, what is left is a product that is high in protein (particularly lysine) and low in fat (Cromwell, 1999; Lammers et al., 2007c; Stein et al., 2014). Soybean meal has a crude protein concentration between 44-48%, and a lysine concentration around 3% (Cromwell, 1999; NRC, 2012; Stein et al., 2014). Soybean meal also contains high levels of tryptophan (0.66%), threonine (1.86%), isoleucine (2.14%), and valine (2.23%). Due to its highly digestible profile of proteins, soybean meal is a good counterpart to corn, which tends have a low concentration of these key amino acids (Cromwell, 1999; NRC, 2012; Stein et al., 2014).

Soybeans have several anti-nutritional factors, some of which are eliminated through further processing (Cromwell, 1999). Anti-nutritional factors found in soybeans include allergenic proteins, oligosaccharides, trypsin inhibitors, lectins, and phytate.

Soybeans contain antigenic proteins which causes an allergic response of inflammation in the intestine (Cromwell, 1999). This reaction is critical as high levels of soybean meal in nursery diets can lead to digestibility issues like increased incidences of diarrhea, deformed intestinal villi, immature enterocytes on the villus, and increased immunological activity on the intestinal wall (Dunsford et al., 1989). Glycinin and β-conglycinin are the primary antigen proteins which contribute to hypersensitivity (Engle, 1994; Wang et al., 2012). Sensitivity to soy proteins occurs 3 to 4 day after exposure, with recovery occurring 7 to 10 days after exposure (Stokes et al., 1986). During the time of sensitivity, pigs experience reduced growth, low feed intake, and changes in intestinal morphology (Miller et al., 1948b, a; Friesen et al., 1991; Wu et al., 2016). Changes in intestinal morphology are a result of increased enterocyte turnover and a reduction in villus height, elongated crypts, and lower enzymatic activity at the brush border (Miller et al., 1948b, a; Hampson and Kidder, 1986; Stokes et al., 1986; Li et al., 1990; Friesen et al., 1991; Li et al., 1991; Engle, 1994). These changes reduce a pig's ability for nutrient absorption and are more prone to *E. coli* colonization, and diarrhea (Miller et al., 1948b; Stokes et al., 1987; Friesen et al., 1991; Li et al., 1991)). Oligosaccharides also present a challenge when included in diets of newly weaned pigs. Oligosaccharides are short-chain carbohydrates that are undigestible and lead to slowed growth and diarrhea (Cromwell, 1999; Stein et al., 2014). Due to the many anti-nutritional factors, soybean meal inclusion should be limited in newly weaned pig diets to not more than 20% (Stein et al., 2014).

Unprocessed soybeans contain trypsin inhibitors (TI), which limits the pig's ability to properly digest proteins and amino acids (Cromwell, 1999). Trypsin inhibitors work by binding trypsin and chymotrypsin, a protein digesting enzyme (Yen et al., 1977;

Stein). There are two types of inhibitors: Kunitz and Bowman-Birk (Rackis, 1972; Chen et al., 2020). Trypsin inhibitors are deactivated by high amounts of heat, which occurs during the processing of soybean meal (Li et al., 1998; Cromwell, 1999; Stein, 2012; Chen et al., 2020). After heat processing, soybeans may still retain 20% of their trypsin inhibitors (Friedman and Brandon, 2001) . Soybeans that have a TI value of less than 7 units are considered to be sufficiently processed and of good quality (Stein, 2012). The quantity of TI after processing is dependent on soybean particle size, sample homogeneity, and extraction method (time and temperature) (Chen et al., 2020). When soybean meal was included at 38% of the diet of growing pigs, increasing the levels of TI from 2.51 mg/g to 8.78 mg/g significantly reduced apparent ileal digestibility (AID) of all essential AA by 13.3 to 26% (Chen et al., 2020). Work from Herkelman et al. (1992) supports this, reporting that as level of TI were reduced AID improved. Pig performance also improved with the reduction of TI.

Soybeans contain high concentrations of potassium, magnesium, and sulfur (Stein et al., 2014). Like most plants, soybeans also contain high levels of phosphorus, but it is bound in the form of phytate making it mostly unavailable to the animal.

Further Processed Soybean Meal

Due to the many antinutritional factors commonly found in soybean meal, different further processing techniques of soybean meal have been developed to remove these antinutritional factors. Common further processing methods include fermentation or treating the soybean meal with a blend of enzymes. This further processing results in a soybean meal product that typically lacks oligosaccharides and sugars, has a higher crude protein content (53%), and increased digestibility of proteins (Pahm, 2008; Stein, 2008).

enzymatically treated soybean meal (ESBM) is often included in newly weaned pig diets as an alternative to not only traditional soybean meal, but other more expensive protein sources like fish meal or plasma protein. There are mixed results on the benefits of including ESBM and the ideal level of inclusion. Work from Zhu et al. (1998) showed that in nursery pigs fed diets containing 10% ESBM improved feed to gain and resulted in higher average daily feed intake. This study also resulted in a tendency for improved amino acid digestibility with the inclusion of ESBM. Yang et al. (2007) also reported that diets with ESBM improved ADG, ADFI, and G:F in newly weaned pigs compared to diets with soybean meal. Enzymatically treated soybean meal also resulted in improved digestiblity of all essential amino acids, apart from methionine, when compared to soybean meal. On the other hand, work from Ruckman et al. (2020) and Jordan et al. (2014) showed reduced pig performance. Pigs fed a diet with either 7% or 10% inclusion of ESBM had reduced BW, ADG, and ADFI compared to pigs fed 3.5% or 0% inclusion of ESMB (Ruckman et al., 2020). Jordan et al. (2014) also reported lower ADFI in newly weaned pigs fed ESBM. It is speculated that the reduced ADFI may be due to the high water holding capacity of ESBM which increases gut fill and reduces feed intake and hence subsequent growth (Ruckman et al., 2020).Water holding capacity measures a feedstuffs ability to hold water (Giger-Reverdin, 2000). A high water holding capacity means that while in the gut the feed may expand and reduce further feed consumtion (Kyriazakis and Emmans, 1995; Anguita et al., 2007; Ndou et al., 2013). This is a major potential limitation of including ESBM in nursery diets as newly weaned pigs often struggle with low feed intakes.

When considering gut health, there was no difference in villus height in pigs fed ESBM or soybean meal (Yang et al., 2007; Ruckman et al., 2020). Ruckman et al. (2020) reported a tendency for decreased crypt depth with pigs fed 10% inclusion of ESBM while Yang et al. (2007) reported no difference. Inclusion of ESBM did however improve fecal scores and fecal dry matter which indicates that inclusion of ESBM may reduce incidences of diarrhea (Ruckman et al., 2020). Despite some of its limitations, inclusion of ESBM has become increasingly popular in nursery diets, mainly due to its increased digestibility and reduction in antinutritional factors.

Synthetic Amino Acids

As mentioned in prior sections, in the corn-soybean meal diets typically fed across North America, lysine is the first limiting amino acid. The introduction of synthetic amino acids allows amino acid requirements to be more precisely met, reduce diet costs, and increases the efficiency of the nitrogen provided in the diet, which reduces the amount of nitrogen excreted (Easter and Baker, 1980; Han and Lee, 2000; Osada et al., 2011). Followed by lysine, the most commonly included synthetic amino acid is methionine (Han and Lee, 2000; Ratliff, 2008-09). The inclusion of synthetic amino acids reduces the crude protein content of the diet, creating what is called a low protein diet (Easter and Baker, 1980). When energy and individual amino acids are met there is no reduction in growth or feed intake in pigs fed low protein diets (Easter and Baker, 1980; Kerr et al., 2003; Osada et al., 2011). Work from Aarnink and Verstegen (2007) states that supplementation of synthetic amino acids can account for up to 20% of the protein content without a loss in productivity. Synthetic amino acids have the advantage of being highly digestible which allows for improved absorption and deposition of protein (Han and Lee, 2000). Undigested nitrogen is excreted in the feces which can have a negative environmental impact (Han and Lee, 2000). The addition of 0.1 – 0.2% of synthetic amino acids can reduce crude protein levels by 2 – 4% (Easter and Baker, 1980; Han and Lee, 2000). This reduction in nitrogen content in the diet leads to a reduction in excretion of nitrogen (Han and Lee, 2000; Osada et al., 2011). In addition, synthetic amino acids provide a potential cost savings. While synthetic amino acids are considerably more expensive than other protein sources because a small inclusion is able to replace a larger portion of other protein sources (for example, soybean meal) there is often a cost savings associated with including synthetic amino acids (Kerr et al., 2003).

Vitamin and Mineral Premixes

Vitamins and minerals are essential for many metabolic functions, including maintaining the electrolyte balance, homeostasis, pH level, a cofactor for enzymes, nutrient absorption, structural functions, and efficiency of use of other nutrients (Coelho, 1991; NRC, 2012; PIC, 2021). Of the minerals, the NRC states that pigs require calcium, chlorine, chromium, copper, iodine, iron, magnesium, manganese, phosphorus, potassium, selenium, sodium, sulfur, zinc, and cobalt. Vitamins are classified as either water or fat soluble. Fat-soluble vitamins include A, D, E, and K while water-soluble vitamins include the B-vitamin complexes (biotin, choline, folacin, niacin, pantothenic acid, riboflavin, thiamin, B6, B12) and vitamin C (NRC, 2012). In swine diets most vitamins and minerals are included as pre-mixes. This is done to reduce error at the feed mill due to their low inclusion levels. Vitamins are organic compounds and can quickly loose activity when not stored in the proper conditions (Shurson et al., 2011; NRC, 2012). Vitamins also lose activity when stored with minerals, with constant exposure to light with extended periods of storage, or are exposed to high humidity or heat (which oven occurs when feed is being extruded or pelleted) (Shurson et al., 2011). Deficiencies can occur if degradation of vitamins in not considered when formulating diets; this can lead to reduced growth and deficiencies (Coelho, 1991; Shurson et al., 2011). To account for the loss of activity vitamin premixes are often included with a margin of safety based on vitamin costs, presence of trace minerals, storage time, feed processing and predicted rate of degradation (Shurson et al., 2011; Flohr et al., 2016). Across the swine industry in the United States, it is common to provide vitamins and minerals at levels that exceed requirements (Flohr et al., 2016). A 2014 survey of swine producers found that in the wean to finish vitamin concentration ranged from 0.4 to 11.6 times the NRC (2012) recommendation, while minerals were provided at a rate of 1.0 to 31.6 times the recommendation (Flohr et al., 2016). Extreme inclusion of the minerals can sometimes be attributed to copper and zinc often being provided at pharmacological levels to improve performance (Flohr et al., 2016).

Minerals such as zinc can be fed at levels above the NRC (2012) recommendation of 80 ppm when phytase is included in the diet as a way to promote growth, improve gut health, and reduced incidences of post weaning diarrhea in the early nursery pigs (Hanh and Baker, 1993; Carlson et al., 1999; Hill et al., 2000). Zinc is normally provided in the form of zinc oxide as it has proven to provide consistent positive results and is less toxic than other forms of inorganic zinc (Hanh and Baker, 1993; McCully et al., 1995; Schell and Kornegay, 1996). Pharmaceutical levels of zinc oxide can be fed up to 3,000 ppm (Hill et al., 2001; Sales, 2013). Although several authors have shown that lower levels can be just as effective. Hill et al. (2001) report increased growth response with the addition of zinc oxide but saw a plateau in growth once concentrations increased past 1,500 ppm. Sales (2013) report that ADG or ADFI did not continue to increase once dietary levels of zinc exceeded 2,250 ppm. Inorganic zinc is poorly absorbed by the pig; it is best practice to feed it at its lowest effective level to prevent the excretion excess zinc, which can potentially pollute soil and water when manure is not properly applied to a field (Sales, 2013).

Calcium (Ca) and phosphorus (P) are macrominerals that are essential for proper lean tissue and skeletal growth, along with several metabolic functions (NRC, 2012; PIC, 2021). It has been well established that Ca and P use is dependent on ratio as well as proper dietary inclusion (Vipperman et al., 1974; Peo, 1991). Deficiencies of Ca or P lead to poor growth and bone mineralization which can ultimatly lead to the development of rickets or osteomalacia (NRC, 2012); providing Ca and P in excess leads to excretion of pollutants, poor growth, and reduced nitrogen retention (Vipperman et al., 1974; PIC, 2021). The NRC (2012) recommends Ca and P be provided at a ratio of 1:1 to 1.25:1. Urinary excretion of Ca is reduced when dietary levels of Ca are equal or slightly exceed levels of dietary P (Vipperman et al., 1974). Retention of P, more so than Ca retention, is impacted by the Ca:P ratio (Vipperman et al., 1974). When dietary P is included at a lower level, rate of gain is reduced when ratios exceed 1.3:1 (Reinhart and Mahan, 1986). However, when P inclusion is increased rate of gain does not decrease until Ca and P reached a ratio of 2:1 (Reinhart and Mahan, 1986). Vipperman et al. (1974) supports this stating that the retention of P decreases as concentration of Ca increases. Due to this relationship it is recommended that Ca levels are defined after inclusion of P is defined (PIC, 2021). Sources of Ca in the diet include limestone, gypsum, oyster shell flour, bone meal, skim milk powder, aragonite, marble dust, calcium gluconate, and calcium sulfate (NRC, 2012). Products like mono-, di-, and tricalcium phosphate provide both phosphorus and calcium to the diet.

Phytase

Plant based feedstuffs, like corn and soybean meal, are relatively high in phosphorus although it is largely unavailable to the pig. Between 60 – 75% of phosphorus in plant based diets are bound in the form of phytate (NRC, 2012). This requires either additional supplementation of inorganic phosphorus or the inclusion of phytase (Cromwell, 1999; NRC, 2012; Stein et al., 2014). Phytase is an enzyme, which works by cleaving the phosphorus from the phytate molecule, making it available to the pig (Cromwell, 1979). Phosphorus is the third most expensive nutrient in swine diets in addition to being a major environmental pollutant (PIC, 2021). Inclusion of phytase reduces the need for inorganic P inclusion as well as reducing P excretion by 30 – 60% (NRC, 2012). In low P diets the inclusion of phytase improved rate of gain and bone strength (Cromwell et al., 1993). In addition to better P utilization inclusion of microbial phytase improves the bioavailability of calcium, iron, zinc, and protein. (Pallauf et al., 1992; Ketaren et al., 1993; Lei et al., 1993; Young et al., 1993; Mroz et al., 1994; Kemme et al., 1995; Biehl and Baker, 1996; Stahl et al., 1999).

Fats and Oils

Fats and oils are highly digestible and are included in the diet to increase energy, aid in the absorption of fat soluble vitamins, provide essential fatty acids, improve palatability, and reduce the production of dust (Azain, 2001; van Milgen et al., 2001;

NRC, 2012; Lin et al., 2013). There are several sources of lipids in swine diets, the most common in North America include choice white grease, soybean oil, corn oil and tallow. Pig age, rate of inclusion, lipid source and type all influence the impact lipids has on the pig (NRC, 2012). Mahan (1991) reported no differences in pig performance in the first 2 weeks post wean betweeen diets that were supplemented with oil, although from day 15 to 35 the addition of oil did improve ADG and feed efficiency. It has been reported that newly weaned piglets have low luminal lipase activity indicating that the addition of triglycerides in the initial diets post wean will have little impact on performance (Leibbrandt et al., 1975; Atteh and Leeson, 1983; Cera et al., 1988b, a, 1990b, a; Howard et al., 1990). Further it has also been reported that vegetable oils have better digestibility than animal fats in nursery pigs. Although these differences quickly diminish as the pig ages (Cera et al., 1989). In finishing diets, the addition of lipids increased ADG, backfat thickness, and carcass weight in pigs fed corn-based diets (Brooks, 1972). In the finishing period the type of lipid is important to pork quality. Lipids can generally be placed into one of two categories, saturated and unsaturated. Unsaturated fatty acids are comprised of at least one cis double bond, while saturated fatty acids contain only single bonds (Kerr et al., 2015). Generally, vegetable oils are high in unsaturated fatty acids while animal fats, such as tallow and choice white grease, are high in saturated fatty acids (Sewell and Miller, 1965; Cera et al., 1988b, 1989). The level of inclusion of either saturated or unsaturated fatty acids in the diet has a direct impact on the composition of the pork fat (NRC, 2012). An increased presence of unsaturated fats in the diet just prior to marketing increases the presence of “soft fat” on the pig (NRC, 2012). This “soft fat” is particularly troublesome as it creates issues with processing bellies, reduces the pork shelf life, and increases oxidative rancidity (NRC, 2012). To prevent "soft bellies" diets can be formulated based on iodine value (IV) (NRC, 2012). Iodine value is the measure of grams of iodine per 100 g of fat and is a measurement of double bonds present. A higher IV indicates more unsaturated fatty acids and a softer fat content in the pork (NRC, 2012). Soft bellies can also be prevented by including more saturated fatty acids, chemically hydrogenated fats, or conjugated linoleic acids (Thiel-Cooper et al., 2001; Averette et al., 2002a; Averette et al., 2002b; Wiegand et al., 2002; Dugan et al., 2004; Averette et al., 2005; Carr et al., 2005; Averette et al., 2006; Lampe et al., 2006; Weber et al., 2006; Martin et al., 2007; Latour et al., 2008; Apple et al., 2009; Jiang et al., 2009; Larsen et al., 2009; White et al., 2009; Cordero et al., 2010).

Select fatty acids, of the n-6 and n-3 series, are essential for lipid metabolism, cell division, and immune response (NRC, 2012). Essential n-6 fatty acids include linoleic and arachidonic acids while n-3 fatty acids include α – linolenate, eicosapentaenoate, and docosahexaenote (Palmquist, 2009). Arachidonic acid can be synthesized from linoleic acid; similarly n-3 polyunsaturated fatty acids can be synthesized from α – linolenate (Jacobi et al., 2001; NRC, 2012). True deficiencies of essential fatty acids are dificult to create. High ratios of n-6:n-3 can be problematic as it limits the production of anti-inflammatory fatty acids (Wall et al., 2010). Esner (1984) reported normal performance in nursery pigs when fed diets of 0.1% linoleic acid. The Agriculture Research Council (1981) recommends essential fatty acids to be 3.0% of dietary digestible energy for pigs under 30 kg and 1.5% for pigs between 30 to 90 kg. Adequate levels of linoleic and α – linolenic acids are usually present in cereal-based diets (NRC, 2012).

Inclusion of fat can aid in the digestion and absorption of other nutrients. Apparent ileal digestible values of arginine, valine, leucine, histidine, isoleucine, and phenylalanine improved with the inclusion of soybean oil or choice white grease (Kil and Stein, 2011). Inclusion of oil slows down the process of digestion, this also increases the time the proteins have to be digested and absorbed which would improve digestiblity (Kil and Stein, 2011).

In the summer months feed intake is often reduced due to the excessive heat. The reduction of feed intake leads to a reduction in energy consumption. To compensate for this reduction in energy, fat is commonly included in the diet to increase the concentration of energy. For every 1% inclusion of fat ME intake increases 0.2 – 0.6% (Stahly, 1984).

Beyond improving performance, inclusion of fats in a diet can also aid in dust suppression. Mankell et al. (1995) reported that the addition of 1 to 3% of soybean oil would aid in the suppression of dust from swine feed. The greatest improvement of dust suppression was seen when oil was added after grinding of the feed (Mankell et al., 1995). The reduction of dust can improve the quality of life in swine and improve employee working conditions.

Oats

Oats are a highly palatable cereal grain; high in crude protein (11.5%), lysine (0.4%), and crude fiber (12%) (Myer, 2008). However, oats are much lower in energy content compared to corn (Myer, 2008; Azain et al., 2017). While oats are not a major feedstuff in swine diets, they are commonly included in nursery diets. Inclusion in nursery diets at rates between 10 – 20%, can minimize incidences of diarrhea (Medel et al., 1999; Paulicks et al., 2000; Myer, 2008). In young pigs, feed conversion and ADG improved linearly with the inclusion of oats (De Goey and Ewan, 1975). Work from Azain et al. (2017) supports this where pigs fed diets that included oats from day 0 to 28 post-wean had improved rate of gain and improved feed efficiency. Oats contain both fermentable and nonfermentable fibers which stimulates fermentation in the hind gut (Stein, 2007). The fermentation of fiber increases the production of short chain fatty acids and lactic acid, which improves the immune system and may lead to improved performance (Bach Knudsen and Canibe, 2000; O'Connell et al., 2005; Pie et al., 2007). Due to its high fiber content, oats are too bulky to be a major portion of the diet (Myer, 2008). For pigs under 27 kg, oat inclusion should not exceed 25% or 40% for growing – finishing pigs (Myer, 2008).

Lactose Based Products

At weaning pigs are placed under several stressors. One of these is transitioning from a liquid diet consisting of milk from the sow to a completely solid diet, consisting largely of corn and soybean meal. Lactose is the main disaccharide present in milk, which is broken down by the enzyme, lactase into glucose and galactose (Vente-Spreeuwenberg et al., 2003). Lactase is highly prevalent up to weaning, at which point it begins to decline as the pig transitions to a solid diet (Pluske et al., 2003). Inclusion of whey or other forms of milk, which contain lactose can positively impact newly weaned pig performance as lactose is more easily digestible than other feedstuffs like corn and soybean meal (Tokach et al., 1989; Lepine et al., 1991; Fukuda et al., 2011; Jawad et al., 2011; NRC, 2012) . Inclusion of whey in newly weaned pig diets improved ADG, ADFI, and gut health

(Lepine et al., 1991; Nessmith et al., 1997; Konstantinov et al., 2004; Bach Knudsen, 2012; Tran et al., 2012; Zhao et al., 2019). The inclusion of lactose in the feed improves palatability, increasing feed intake and hence subsequent gain (Nessmith et al., 1997). Lactose is also highly digestible by young pigs and lacks antinutritional factors that are common in soybean meal that hinder growth (O'Doherty et al., 210; Mahan, 1992). Inclusion of lactose in the diet improves gut health by increasing the production of lactic acid and volatile fatty acids which increase the acidity of the large intestine and suppress the growth of *E. coli* and increase the presence of *Lactobacillus*: an indicator of good gut health (Konstantinov et al., 2004; Bach Knudsen, 2012; Tran et al., 2012; Zhao et al., 2019). While inclusion of lactose improves the microbiome of the large intestine, other indicators of good gut health such as villus height, crypt depth, or fecal score did not improve with the addition of lactose (Pierce et al., 2006; Jang et al., 2021). There is evidence that inclusion of lactose at too high of a concentration for too long of time can have negative effects on the pig. Several sources state that inclusion of lactose past two weeks post wean have no advantage and can even lead to increased incidence of diarrhea as lactase activity quickly declines as pigs begin consuming solid foods (Pluske et al., 2003; Pierce et al., 2005; Yang et al., 2016; Zhao et al., 2021). For newly weaned pigs there is no inclusion limit of lactose due to the high lactase activity, but rate of gain has been shown to be optimized when inclusion is at 15%, while feed intake is optimized when lactose is included at 30% (Zhao et al., 2021).

Animal By-Product Proteins

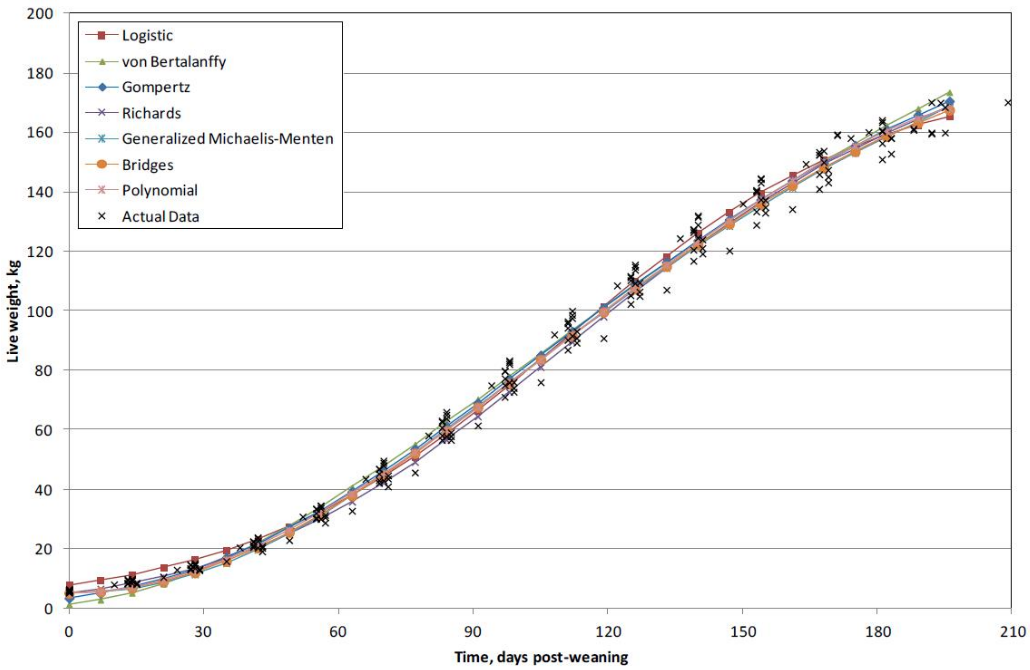
Specialty proteins such as blood meal, spray dried plasma, and fishmeal are commonly included in nursery pig diets. These products are a by-product of the human food industry and provide easily digestible proteins to the young pig (Miller, 1990). Animal by-product proteins are relatively expensive sources of protein and hence are usually only included in nursery diets. The high energy and lysine levels makes animal by-products ideal for inclusion in corn-soybean meal diets (Miller, 1990). Blood meal contains 8.6% lysine and has a metabolizable energy of 3,773 kcal/kg. Plasma contains 6.9% lysine and 4,017 kcal/kg ME, while fishmeal has 4.56% lysine and 3,528 kcal/kg ME (NRC, 2012). While high in energy and proteins such animal by-products tend to be low in many vitamins and minerals, apart from blood meal which contains high levels of iron (1494 ppm) (NRC, 2012). Inclusion of porcine plasma at 10.35 or 13.4% the first 2 weeks post weaning had improved ADG and ADFI compared to pigs fed corn-soybean meal based diets with only skim milk or whey supplementation (Hansen et al., 1993). Gatnau and Zimmerman (1990) also reported pigs have greater ADG when porcine plasma was included in their diets.

Conclusion

Input such as BW, ADFI, and feed conversion can be used to develop or improve a phase feeding program. Phase feeding can reduce diet costs and improve nutrient utilization by providing the correct nutrients to the appropriately aged pig and aids in determining the proper inclusion of different feedstuffs. All of this works together to help achieve the We Care principle of improving nutrition to better pig performance and sustainability. As a part of evaluation and improvement of sustainability of the South Dakota State University (SDSU) swine unit, nutritent requirements of the On-site wean-to-finish herd were established to reformulate the current standard diets.

Figure 1. 1 Sigmoidal curve of the predicted live weights of barrows (A) and gilts (B) using various equations. From Schulls (2013) (Figure 22 and 23)

A.



B.

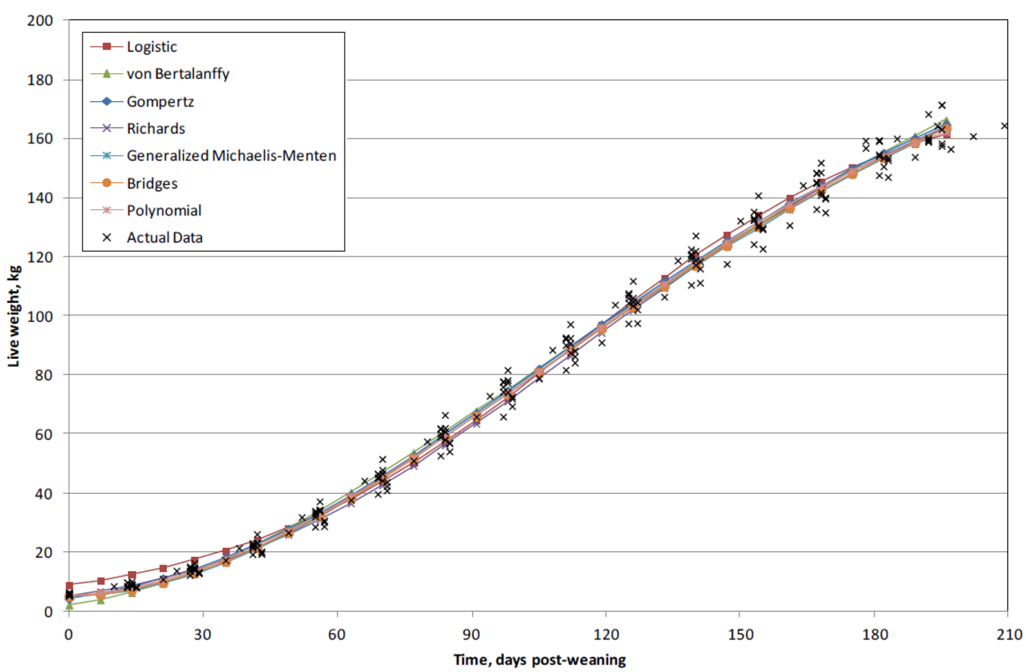
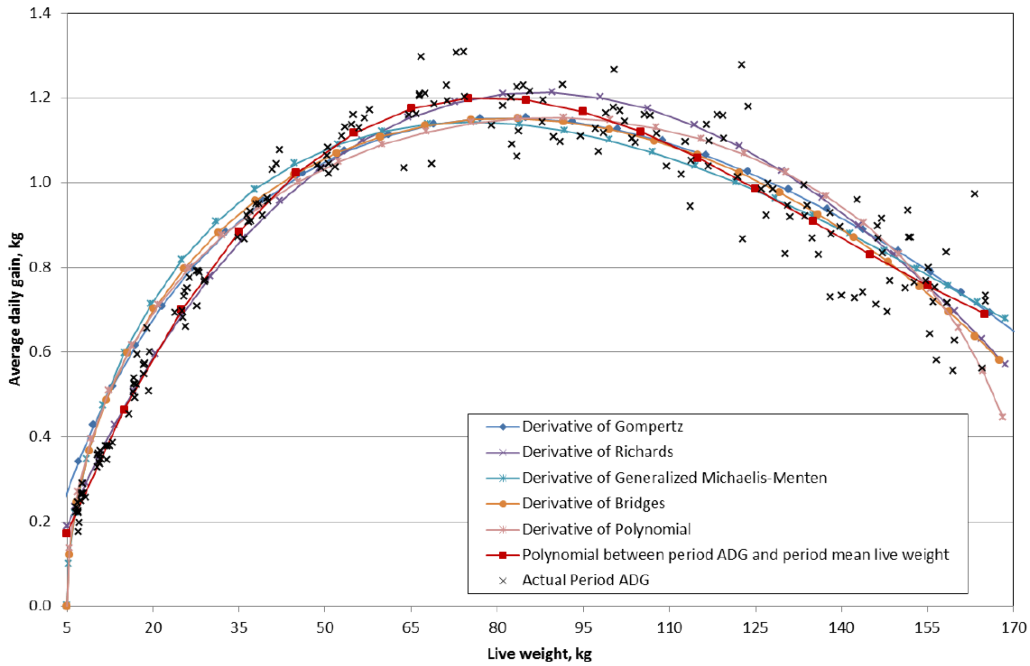


Figure 1. 2 Predicted average daily gain over live weight for barrows (A) and gilts (B) using various equations. From Schulls (2013) (Figure 24 and 25).

A.



B.

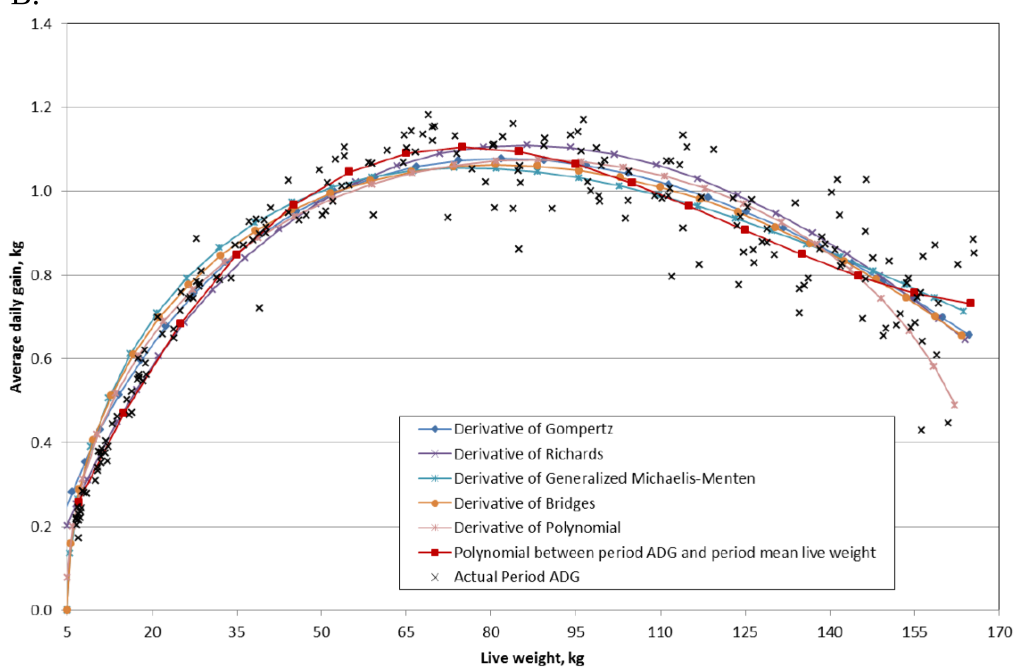
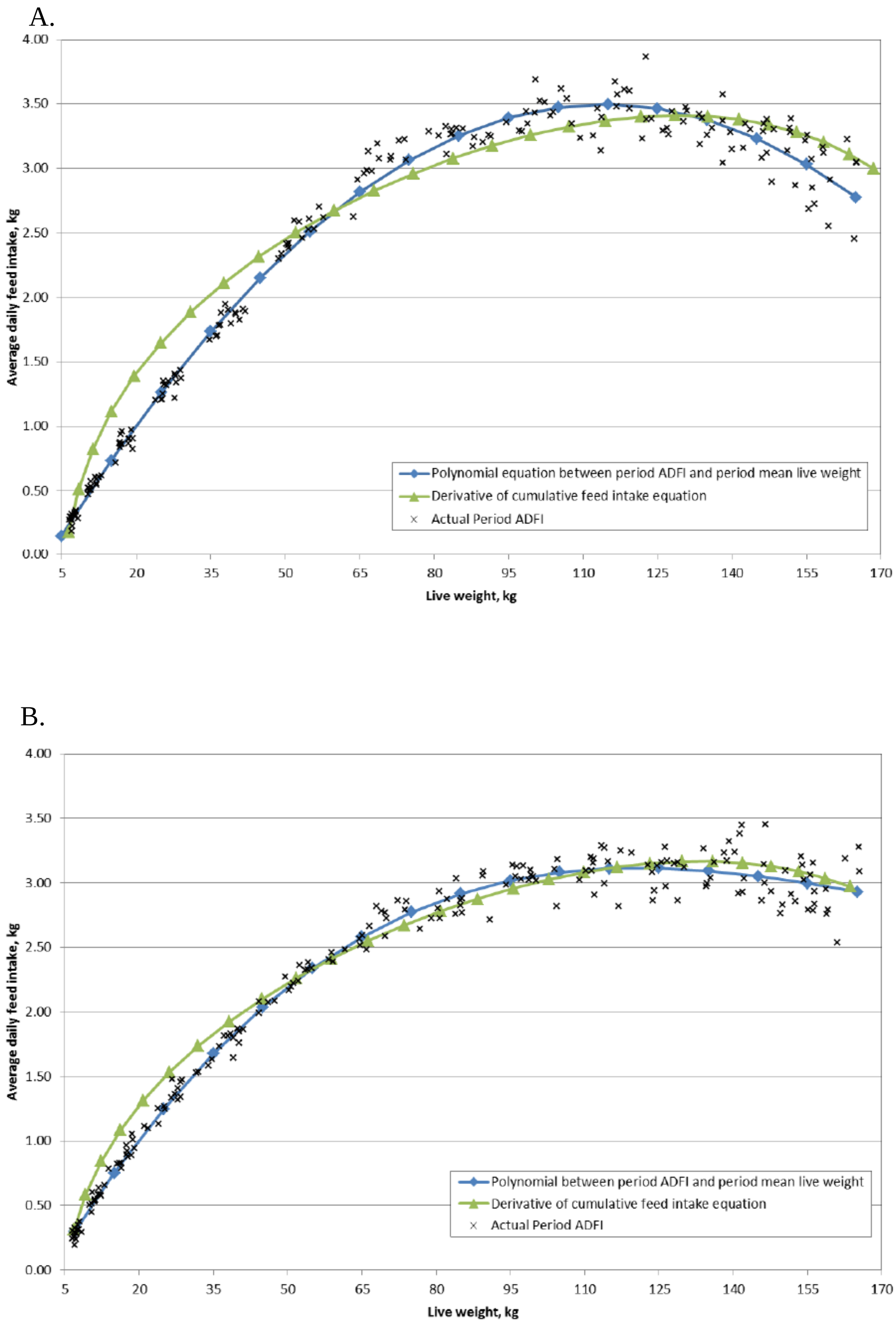


Figure 1. 3 Predicted average daily feed intake over live weight for barrows (A) and gilts (B) using various equations. From Schulls (2013) (Figure 26 and 27)



1.3 Secure Pork Supply Plan

Foreign Animal Diseases

A foreign animal disease (FAD) is any disease that is not currently present in the United States or one of its territories (USDA, 2016b). Foreign animal diseases are also considered communicable diseases, meaning that if a FAD is suspected it should be reported to the Veterinary Official and the State Animal Health Official. Signs and symptoms that are considered suspicious include high morbidity and mortality, unexplained abortions, respiratory conditions, vesicular lesions, pox or lumpy skin, poor or no response to treatment, encephalitis, atypical necropsy findings and other unusually signs of illness. These symptoms are usually paired with knowledge of personnel or visitors with recent foreign travel history, receiving a foreign parcel, and recently imported animals, embryos, or semen. Reportable multi-species diseases include Brucellosis, Crimean Congo hemorrhagic fever, foot and mouth disease (FMD), heartwater, Japanese encephalitis, new world screwworm, old world screwworm, rift valley fever, rinderpest, surra, and vesicular stomatitis. Swine specific FAD include classical swine fever (CSF), African swine fever (ASF), Nipah virus encephalitis, porcine cysticercosis, swine vesicular disease and Teschovirus encephalomyelitis. Of the diseases listed FMD, CSF, and ASF, pose some of the biggest threat to the swine industry due to their prevalence in other countries, economic impact, and rapid ability to spread (USDA, 2021b).

Foot and Mouth Disease

Foot and mouth disease is a highly contagious virus which affects most species of livestock: cattle, swine, sheep, goats, and other cloven-hoofed ruminants (OIE, 2013) but does not pose a threat to human health. There are seven types (A, O, C, SAT1, SAT2, SAT3, and Asia1) and 60 subtypes of FMD (OIE, 2013; APHIS, 2021). Unfortunately, immunity from one type or subtype does not grant immunity to another. This lack of cross-protection immunity makes vaccination dificult and preventative vaccination in nonendemic areas is often impractical (OIE, 2013; APHIS, 2021). Symptoms of FMD include high fever, depression, hypersalivation, loss of appetite, reduction in growth, weight loss, and low milk production. The most notable symptom is the development of blister-like sores along the tongue, lips, mouth, teats and between the hooves (OIE, 2013). Morbidity is usually high, commonly infecting an entire population. Mortality of mature populations tend to be low (1-5%), while mortality of young animals can quickly exceed 20% (OIE, 2013). Foot and mouth disease is spread when the virus is aerosolized and enters the animal via the respiratory or oral route. Naïve animals can come into contact with FMD through infected animals, contaminated facilities or transport vehicles, feed, people with footwear or clothing containing the virus, consumption of infected meat and virus in the air (OIE, 2013). Foot and mouth disease can spread through semen and milk for up to 4 days before the animal begins to show symptoms (OIE, 2013).

Classical Swine Fever

Classical swine fever is caused by a RNA virus in the genus *Pestivirus* (Risatti and Borca, 2020). Symptoms of CSF include fever, ataxia, vomiting, hemorrhages, lethargy, and cyanosis of the skin ears, lower abdomen and extremities. Classical swine fever has an incubation period of 3 to 7 days with death usually occurring after 10 days of infection (Risatti and Borca, 2020). Classical swine fever does not survive long outside of its host, and is easily inactivated when aerosolized for extended periods, although it does have increased survival in cooler temperatures (Risatti and Borca, 2020). Classical swine fever can also infect naïve pigs through swill feeding, or feeding of contaminated animal products, contact with infected equipment, vehicles, and clothing of personnel, and carrier pigs who do not show clinical symptoms (Risatti and Borca, 2020). In 1978 CSF was eradicated from the United States (APHIS, 2020). In countries where the disease is endemic the vaccine is highly effective, while nonendemic countries use depopulation methods to prevent the spread of disease (Risatti and Borca, 2020).

African Swine Fever

African swine fever is a virus that infects both domestic and feral swine populations, although it has much more devastating effects on the domestic pig populations (OIE, 2019; APHIS, 2022). African swine fever is not a public health or food safety concern (APHIS, 2022). Symptoms of ASF present very similar to other swine diseases making it dificult to detect without laboratory analysis. Symptoms include high fever, reduced appetite, weakness, red and blotchy skin, lesions on the skin, diarrhea, vomiting, coughing, and difficulty breathing (APHIS, 2022). African swine fever is able to spread through contact of infected animals, soft bodied ticks, clothing of people, contaminated transport vehicles, and swill feeding of uncooked infected pork to other pigs (APHIS, 2018).

ASF has been of particular concern for swine producers in the United States recently. In July and September 2021, ASF was confirmed in the Dominican Republic and Haiti, respecitivly (Cima, 2021). While it is less of a threat to the mainland of the United States there is increasing worry about the possibility of entry to Puerto Rico, a territory of the United States. According to International Standards, if ASF enters into the borders of a territory or island belonging to the United States it would close all pork exports from the territory or island as well as the countries mainland, resulting in grave economic loss (https://www.oie.int/en/what-we-do/standards/)

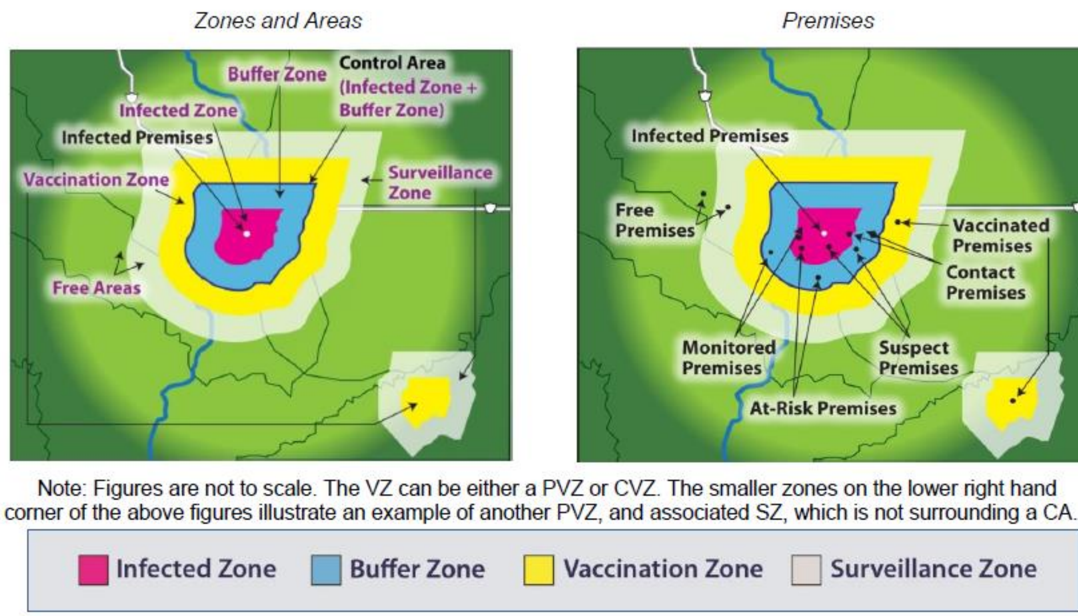
Outbreak Event

Foreign animal diseases are associated with huge economic losses due to increased animal culling, loss of sick animals and limited ability to export meat and animal products. Due to this the USDA has outlined a plan of action in the event of FAD outbreak. The three primary objectives are containment, control and finally eradication. In the first 24 hours after detection a stop movement will be enacted, and quarantine measures will be put into place. During this time frame, initial depopulations will begin along with increased biosecurity measures. Depending on the scale of the outbreak, restrictions are placed by either local, state, tribal, or federal authorities. In order to identify the source of the outbreak the process of epidemiological tracing and identifying the virus type will also begin. Data and information will be collected and entered to the Emergency Mangement Response System (EMRS). In the 24 to 48 hours following the outbreak, depopulation, disposal, epidemiological tracing, enhanced biosecurity measures, and data collection and entry to the EMRS efforts will continue. Quarantine and movement controls will be reevaluated and adjusted based on the given scenario. Businesses and livestock operations should initiate their continuity of business (COB) or enhanced biosecurity plans. In this time frame public awareness campaigns will have begun. In the following 48 to 72 hours post outbreak, depopulation, disposal, data entry in the EMRS, surveillance and tracing, increased biosecurity, public awareness campaign, and COB plans are continued. After the initial 72 hours, activities continue as appropriate throughout the FAD response (USDA, 2015).

The establishment of quarantines and controlled movement includes establishing 7 types of zones (Figure 1.4): infected zone, buffer zone, control area, surveillance zone, free area, containment vaccination zone, and protection vaccination zone. The size of each zone or area is dependent upon the FAD, geography, and jurisdictional area. Each zone may be modified based on circumstance. Within the seven areas or zones are six different types of premises: infected premise, contact premise, suspect premise, at-risk premise, monitored premise, vaccinated premise, and free premise (USDA, 2015).

Infected zone is the area immediately surrounding the infected premise, or the location of the confirmed or presumptive positive case. Infected zones include all confirmed or assumed positive premises and contact premises which contain susceptible animals. The infected zone should be at least 3 km beyond the infected premise. Buffer zones surround the infected zone and should be at least 7 km from the infected zone. A containment area is composed of an infected zone and a buffer zone and should be at least 10 km from the infected premise. Within the containment area are contact premises, at-risk premises, and monitored premises. Contact premises are locations with animals that may have directly or indirectly been exposed to the FAD. Contact premises are subject to disease control measures such as quarantine, movement controls, surveillance requirements, and possible depopulation. At-risk premises are susceptible animals but show no symptoms of having contracted the FAD. At-risk premises may move animals if proper procedures and biosecurity measures are followed, although movement outside of the control area is not permitted. Monitored premises have proven that they are not an infected contact, or an at-risk premise. Monitored premises are able to move animals outside of the control area. Surveillance zones are outside of the control area. The width of the surveillance zone should be at least 10 km, although may be much larger. The purpose of the surveillance zone is to define the most at-risk areas within the free area. The free area includes the surveillance zone although may extend past the surveillance zone. Within the free area are free premises. Free premises have the fewest restrictions although careful surveillance and monitoring should take place to prevent the introduction of the FAD onto a premise. Containment vaccination zone and protection vaccination zone are secondary zones. Containment vaccination zones are zones inside of the control areas while protection vaccination zones are in the free area. Vaccinated premises are located in one of the two vaccination zones. Vaccinated premises are locations which emergency vaccination has been performed. Suspect premises are located in the infected zone, buffer zone, surveillance zone or vaccination zone. This is a short-term identification, as these locations are under investigation for potential FAD infection. Suspect premises are subject to quarantine, movement controls, surveillance requirements, and strict biosecurity measures (USDA, 2015).

Figure 1. 4 Example of zones, areas, and premises. (From USDA (2015) *APHIS Foreign Animal Disease Framework Response Strategies: Foreign Animal Disease Preparedness & Response Plan.* https://www.aphis.usda.gov/animal_health/emergency_management/downloads/documents_manuals/fadprep_manual_2.pdf)



Specific protocols related to zones and areas dictate the five potential response strategies: stamping out, stamping-out modified with emergency vaccination to kill, stamping-out modified with emergency vaccination to slaughter, stamping-out modified with emergency vaccination to live, and emergency vaccination to live without stamping-out. The stamping-out strategy includes depopulation of all animals on infected premises and contact premises. Stamping-out modified with emergency vaccination to kill includes depopulation of all infected animals and vaccinating all at-risk animals with eventual depopulation of the vaccinated animals. Vaccinations are distributed to high risk areas in the infected or buffer zone. Stamping-out modified with emergency vaccination to slaughter includes depopulation of all infected animals and vaccinating all at-risk animals with eventual slaughter and processing of vaccinated animals if eligible. Again, vaccination is distributed to the most susceptible populations within the infected or buffer zone. Stamping-out modified with emergency vaccination to live includes depopulation of all infected animals and vaccination of at-risk animals with the intent for vaccinated animals to continue with their intended use (breeding, milking, slaughter). The goal of this method is to vaccinate non-infected livestock, targeting first valuable genetic stock and reproducing livestock. Under this plan vaccine zones should remain free of diseases, which increased surveillance and restriction of animal movement and transportation. Finally, emergency vaccination to live includes vaccinating all animals without depopulation of infected animals or vaccinated animals. The goal of the final strategy is to protect susceptible animals from infection. With all strategies, monitoring the movement of vaccinated animals is enforced (USDA, 2015).

Continuity of Business and Enhanced Biosecurity Plans

In the event of a FAD, part of the emergency strategy is for livestock producers to implement COB or enhanced biosecurity plans (USDA, 2016b). These are voluntary plans, created prior to a FAD outbreak (Secure Pork Supply, 2020). In the event of an outbreak they allow non-infected premises to continue movement of slaughter of animals even if they are located in a control area (USDA, 2016a; Secure Pork Supply, 2020). Creation of a COB plan creates preparedness for stakeholders and allows for identification of gaps in biosecurity and response planning (USDA, 2016b). Benefits of COB include being able to sustain a secure food supply, maintain herd health, reduce disruption in production, lessen the negative economic impacts of a FAD, and increase understanding of the needs of stakeholders in the event of a FAD (USDA, 2016b). Secure Food Supply Plans have specific COB plans for each of the major food species, poultry, swine, milk and beef (USDA, 2016a).

Mass Depopulation

Depending on the FAD outbreak, some degree of stamping out process or mass depopulation is very plausible, and in the past has been the most common means for livestock disease control in the past (Arruda et al., 2020). The American Veterinary Medical Association lists their preferred means for mass depopulation as lethal injections, inhalation of gas like cardon dioxide, or physical methods such as a captive bold gun, shot gun or blunt force trauma for suckling pigs. (AVMA, 2020). Under constrained circumstances or incidences of emergency methods such as oral administration of sodium nitrate or ventilation shutdown may be used. Although these methods are not preferred as they do not result immediate unconsciousness or an immediate death without distress (Arruda et al., 2020; AVMA, 2020). After mass depopulation comes the question of proper disposal. In a time of an FAD outbreak mortalities will most likely exceed the capabilities of landfills and rendering facilities, additionally, moving carcasses off a premise creates a biosecurity risk (Costa and Akdeniz, 2019). Other practices like below ground burials are limited to land size and run the risk of potential contamination of groundwater and soil, while incineration would potentially aerosolize infectious particles (Costa and Akdeniz, 2019). Composting is seen as the preferred method as it results in the breaking down of organic material and denaturing of viruses and other harmful bacteria (Wilkinson, 2007; Costa and Akdeniz, 2019).

Beyond welfare concerns for the animals ensuring an immediate and painless death there is also a welfare concerns related to the stockpersons carrying out these duties. Mass depopulation takes a financial and emotion toll on farmers and herdsmen who care for and own these animals (Marchant-Forde and Boyle, 2020). A survey conducted among dairy farmers in the Netherlands after the 2001 FMD outbreak found that farmers suffered from increased stress, depression and would describe themselves as being in a state of permanent crisis and unable to adapt (Van Haaften et al., 2004). A FAD outbreak results in an increase in authorities and regulations for daily processes. During the Netherland FMD crisis farmers felt they lost their autonomy which increases feelings of hopelessness and helplessness (Van Haaften et al., 2004). The creation of an enhanced biosecurity plan can help remove some of the immediate decision making during the initial panic of an FAD outbreak. Additionally, it provides protection for the herd and may allow for continuity of business.

Conclusion

To improve safety and security of the swine herd an enhanced biosecurity plan for both SDSU swine facilities have been created. In the event of a FAD outbreak, it is essential that the SDSU swine facilities be able to continue to operate and be a sourced of outreach, education, and research, especially during a time of crisis.

2.0 IMPACT OF WATER FLOW RATE ON FINISHING PIG PERFORMANCE

H.E. Miller, K. McClellan, J.Y. Perez-Palencia, R.S. Samuel, C.L. Levesque, and R.C. Thaler

2.1 Abstract

A survey of 23 South Dakota pork producers in 2019 reported that sixty-eight percent of the waterers in finishing barns had water flow rates above the recommended rate of 500 to1,000 mL/min. The objective of the two studies was to determine the impact of water flow rate on finishing pig performance in the summer months. Study 1 used a total of 396 pigs in two groups in a 77-day trial (34.6 to 103.8 kg BW) with 6 pigs/pen and 1 cup waterer/pen. Study 2, conducted in a commercial style barn, used a total of 1,227 pigs in an 84-day trial (61 to 111 kg BW) with 26 pigs/pen and 2 cup waters/pen. Pens were assigned to one of three water flow rates (high, medium, low) based on the 3-hole settings of the water nipples (2.0, 1.0, and 0.8 mm; n = 22 and 16 pens/treatment for Study 1 and 2, respectively). Room temperature, outside temperature and relative humidity were recorded daily for both studies. In Study 1, water disappearance was recorded daily, and individual pen water flow rates were recorded every two weeks. At every diet phase change (26 ± 2.6 days), feed disappearance and individual pig body weights were recorded. Water flow rates averaged 1846 ± 188, 906 ± 214, 508 ± 100 mL/min for high, medium, and low flow settings, respectively. In Study 2, individual pen water flow rate, water disappearance, BW, and feed disappearance were recorded every two weeks. Water flow rates averaged 1565 ± 96, 1115 ± 265, and 605 ± 203 mL/min for high, medium, and low flow settings, respectively. In both studies, there were no differences in final BW, cumulative ADG, or G:F. Due to the variability of water flow rate within a setting, data was further analyzed using regression with flow rate as the

independent variable. Apart from average daily water disappearance (adj. $R^2 = 0.87$), there was a low relationship between pig performance and water flow rate (adj. $R^2 < 0.09$). The low R^2 values associated with pig performance and the high association with water disappearance suggests that water flow rate above current recommendations has little impact on finishing pig performance but does contribute to water wastage and its associated costs.

Keywords: finishing pigs, summer, water flow rate

2.2 Introduction

Water is a vital part of all livestock production and is an important component for pig performance, cost of production, and environmental impact (Muhlbauer et al., 2010; Gerbens-Leenes et al., 2013). A recommended water flow rate has been outlined by the National Swine Nutrition Guide (NSNG, 2010) which states that water delivery for finishing pigs should be between 500 to 1,000 mL/min (Brumm, 2010). However, more recent work has shown that growing-finishing pigs can perform well on delivery rates as low as 250 mL/min (Brumm, 2019). The same report (Brumm, 2019) describes water flow rates of 1,000 mL/minute as “more than adequate”. A 2019 survey of South Dakota Pork Producers reported that 68% of the waterers tested had water flow rates above the recommend 1,000 mL/min water flow rate (Zeamer et al., 2021).

There is little evidence supporting that excess water consistently translates to improved pig performance. Pigs fed liquid diets with water to meal ratios ranging from 2:1 to 3.5:1 with supplementary water, responded with an increase in daily gain as water content in the meal increased, but no changes in feed intake were observed (Gill et al., 1986). Brooks et al. (1989) reported that increasing delivery rate (300 to 900 mL/min) increased water disappearance by 80% but it had no impact on daily gain or feed intake. Li et al. (2005) demonstrated in an experiment with growing-finishing pigs that neither drinker height nor water flow rate had an impact on feed intake or daily gain.

Water wasted from the water drinker accounts for 25 to 40% of the total water used in swine facilities (Li et al., 2005). Water nipples with higher flow rates tend to have increased water wastage and water spillage; for example, waterers set to 2,000 mL/min in a grow-finish trial had over 2 times the amount of water spillage compared to waterers within the recommended flow rate (Li et al., 2005). Muhlbauer et al. (2010) reported that pigs given free access to water consumed similar amounts of water, regardless of other factors including drinker height and design. Differences in water disappearance can most likely be attributed to wastage, rather than consumption (Muhlbauer et al., 2010). When comparing average water usage of growing-finishing pigs from farms in Canada, United States and Netherlands, the data shows dramatic differences in water usage between the three countries (7.0, 17.0 and 4.6 L/pig/day, respectively) (DGH Engineering Ltd., 1999; North Carolina Cooperative Extension Service, 1999; Prairie Swine Centre, 2000; Froese and Small, 2001). The lower water usage of the Dutch pigs indicates that proper conservation techniques can reduce water usage without negatively impacting pig performance. Alternatively, excess water disappearance also increases production costs associated with manure handling and storage costs (Mroz et al., 1995; Fleming et al., 1998; Muhlbauer et al., 2010).

The actual water flow rate of a drinker is a combination of external supply and internal variables. The water source may have limited ability to alter external supply; however, adjustments to the water flow rate can be made from different internal control points, including water pressure in the line as well as adjustments of valves and pumps and at the water nipple. We hypothesize that increasing the water flow rate beyond the recommendation of 1000 mL/min will not impact finishing pig performance. Therefore, due to the potential impact on pig growth performance, cost of production, and sustainability, this study was conducted to evaluate the impact of water flow rate on finishing pig performance.

2.3 Materials and Methods

Study 1

The experimental protocol used in this study was approved by the South Dakota State University Institutional Animal Care and Use Committee (IACUC 2006-028E) and followed the Guide for the Care and Use of Agricultural Animals in Research and Teaching (3^{rd} edition, 2010). The experiment was performed in the wean-to-finish barn at SDSU Swine Education and Research Facility, located in Brookings, SD 57006, USA.

Animals and housing

A total of 396 barrows and gilts (35 kg ± 4.6; 6 pigs/pen; 0.66 m^2 per pig) in two groups in separate rooms, were utilized in a 77 ± 3.4-day trial until pigs reached a final weight of 104.3 kg. Pens were allocated to three different water setting groups, with a total of 22 replicates pens per group. All pens contained one 2-space dry feeder and one cup waterer for ad libitum access to feed and water. The base of each water cup was approximately 10 cm above the slats (Figure 2.1).

Data collection began June 2020 and concluded September 2020 for Group 1 and began July 2020 and concluded October 2020 for Group 2. The barn was mechanically ventilated; at the beginning of each group, the temperature setpoint was 19.4°C and then decreased 0.06°C daily until reaching 14.4°C. High, low, and average room temperatures were recorded between 0600 and 0800 h daily. Outside temperature and relative humidity was collected through the Brookings Mesonet station (#BKMS2).

Throughout the trial, feed disappearance was monitored for each pen. All animals received common grow-finish diets in three phases, with 26 ± 2.6 days/phase (Table 2.1). Feed disappearance and body weight (BW) were measured at the end of each diet phase to determine average daily gain (ADG), daily feed intake (ADFI), and gain-to-feed ratio (G:F).

Daily animal monitoring included observations of individual pigs, room environment, and facility conditions, as well as records of veterinary treatment on a per pen basis including number of pigs treated/pen, drug administered, dosage, duration, reason for pig removal (i.e., dead, untreatable health issue such as umbilical prolapse, morbidity), and evidence of health concerns (i.e., lameness, coughing).

Water Settings

The three water settings were defined as low, medium, and high based on the three-hole diameters (0.8, 1.0, and 2.0 mm respectively; Figure 2.2) of the commercial water nipples (Koca USA Inc., Des Moines, IA 50313) used in the facility. Recommended water flow rate for grow-finish pigs is between 500 – 1,000 mL/min (Brumm, 2010). For purpose of the study medium setting was considered within the range of the recommended water flow rate. Low and high settings were considered to be outside of the recommended water flow rate. Water flow rate of the cup waterer in each pen was recorded every two weeks by the same technician. Water flow rate was measured by letting the water overflow the water cups into a basin below and measuring the volume of water collected in 30 seconds, and then adjusted to one-minute flow rates.

Each room was equipped with 4 water lines, and each line fitted with an individual water meter (Dwyer Instruments Inc., Michigan City, IN 46361). Water for all pens on a given water nipple setting was supplied by a designated water line. From the meter, total water disappearance for each of the 3 settings was recorded daily.

Study 2

The South Dakota State University Institutional Animal Care and Use committee approved the protocol (IACUC 2106-037E) used in this study. The experiment was conducted at the SDSU commercial wean to finish research facility, located in Flandreau, SD 57028, USA.

Animal housing

In the second study, 1,227 barrow and gilts (60.9 kg ± 4.4; 26 pigs/pen; 0.82m^2 per pig) were utilized in an 84-day trial, with a final body weight (117.4 kg) recorded on day 91, on day prior to the first marketing event. Pens within a block were randomly assigned to one of the three different water settings, with 16 pens per setting. Pen dimensions were 3.1 m x 6.9 m and each pen contained one 5-slot stainless steel dry feeder and two cup waters placed 1 m apart on the same side of the pen and within 1 m of the feeder. The same model of drinker was used as in Study 1 (Figure 2.1). Daily animal observations followed same protocol as Study 1.

Data collection began June 2021 continued through September 2021. The barn was mechanically ventilated with temperature setpoints at 20.5, 18.3, 16.7, and 16.1C on day 0, 27, 55, and 77, respectively. High, low, and average room temperature was recorded between 0600 and 0800 daily. Outside temperature and relative humidity was recorded through the Flandreau Mesonet Station (#FLNS2).

All pens received a common grow-finish diet (Table 2.2). Pen feed disappearance and BW were measured every 2 weeks for calculation of ADG, ADFI, and G:F.

Water settings

Water flow rate was recorded every 2 weeks in the same manner as study 1. Each pen was equipped with an individual water meter and pen water disappearance was recorded every 2 weeks. Average daily water disappearance was calculated for each period in the study.

Total water usage during the 84-d experimental period per water setting was recorded, and water disappearance on a per pig basis was calculated. Information regarding water cost for livestock use was sourced from Mid Dakota Rural Water System (mdrws.com/billing/waterrates/).

Statistical analysis

The UNIVARIATE procedure of SAS (SAS Inst., Inc., Cary, NC) was used to confirm the homogeneity of variance and to analyze for outliers. Data was analyzed using the PROC MIXED procedure in SAS. In the model, water flow was considered the main effect and pen the experimental unit. For study 1, room was the blocking factor. Because mixing of pens of pigs can negatively impact performance due to fighting and establishment of hierarchy (Li and Wang, 2011), pens were not remixed at the start of the trial to balance for gender. However, a sex ratio of gilts:barrows was created for each pen and included as a random effect. Location in the room was the blocking factor in Study 2. For both studies, Tukey's adjusted means test was used to detect differences between water settings; data reported as least squares means +/- SEM. Results were considered significant at $P \leq 0.05$ and a tendency at $0.05 < P \leq 0.1$ for all statistical tests.

For Study 1, average daily barn water consumption per kg of BW and high barn temperature was analyzed using a regression model in SAS with room temperature as the independent variable. For both studies, water flow rate and pig performance were analyzed using regression model in SAS, with water flow rate as the independent variable. All regression models were tested under linear, quadratic, and cubic responses to corresponding variables. Responses were considered significant at $P \leq 0.05$.

2.4 Results

Study 1

Over the entire experimental period of Study 1, average daily barn temperature was 22.8°C (*SD* = 3.3°C) with daily average high temperature of 29.0°C (*SD* = 3.7°C), and daily average low temperature of 20.5°C (*SD* = 2.9°C). The average outside temperature and relative humidity, for the entire experiment period was 20.0°C (*SD* = 4.9°C) and 73.1% (*SD* = 7.9%), respectively. Water flow rates were 508 ± 100, 906 ± 214, and 1856 ± 188 mL/min for low, medium, and high settings, respectively. Daily water disappearance for the high, medium, and low settings were 6.8 ± 3.6, 2.3 ± 1.1, 1.3 ± 0.8 liters/pig/d, respectively. Average daily water disappearance per kg BW and daily high room temperature (Figure 2.3) demonstrates the pattern of increase and decrease in daily water consumption per water flow setting. The pattern of increased water disappearance with increased room temperature was especially prevalent for the high water setting with the medium and low setting maintaining a much more consistent daily water disappearance. A cubic regression ($P < 0.0001$) described the relationship between high barn temperature and water disappearance per kg of BW for each of the separate water settings (Figure 2.4). Adjusted R^2 values of each cubic regression for high, medium, and low water settings are 0.60, 0.14, and 0.14, respectively.

The ADG was greater ($P = 0.04$) for pens on the high water flow setting compared to low setting with the medium setting intermediate in Period 1 (Table 2.3). During this period, ADFI was also greater for pens on high setting ($P = 0.05$) compared to pens on the low water setting. There were no differences in G:F during period 1. In Period 2, there were no differences in BW and ADG. However, ADFI was greater ($P = 0.04$) in pens on the high water flow setting than for pens on the low water settings. This resulted in improvements in G:F ratio ($P = 0.04$) for pigs on the low water setting compared to pigs on the high water setting. In period 3, there were no differences in final BW, ADG, ADFI, or G:F. From d 0 – d 77, there was no difference in ADG or G:F. Conversely, cumulative ADFI ($P = 0.02$) was greater for pens on the high water compared to pens on the low setting, with the medium water setting intermediate (Table 2.3).

Due to the variability in water flow rate within a setting, regression analysis was conducted to compare pen water flow rate and pig performance for each trial period. In Study 1 (Figure 2.5), there was no relationship between water flow rate and final BW

(Figure 2.5A), cumulative ADG and ADFI (Figure 2.5B), or G:F (Figure 2.5C). Regression of performance within each weigh period are provided in Supplemental Figures 7.1 to 7.10 in the appendix.

Study 2

In Study 2, barn temperature averaged 25.5°C (*SD* = 2.3 c), with a daily average high temperature of 28.5°C (*SD* = 2.8°C) and daily average low temperature of 23.1°C (*SD* = 5.8°C). Outside average temperature was 21.4°C (*SD* = 2.8 °C) and relative humidity was 73.9% (*SD* = 9.7%). Average water flow rates for the low, medium, and high setting were 605 ± 203, 906 ± 209, and 1115 ± 98 mL/min, respectively.

Differences in growth performance were only detected in Period 3 where there was a 2 kg reduction (P = 0.03) in BW between the low and the other two water settings with no difference in BW between pigs on the medium and high water setting (Table 2.4). Similarly, ADFI was lower for pigs on the low water setting relative to the other two settings (P = 0.02). Both ADG and G:F were greater (P < 0.05) for pigs on the high setting compared to pigs on the low and medium settings.

In all periods and for over the entire trial, there were differences in average water disappearance on a per pig basis between all waterer settings (P < 0.0001), specifically in Periods 1, 2, 3, 5, and 6. In Period 4, the low setting had the lowest water disappearance, but there was no difference between the high and medium settings. From d 0 to 84, water disappearance (P < 0.0001) increased with the water nipple settings such that pigs on high water setting used 1.14 liters more per day than pigs on medium setting and 3.70 liters more per day than pigs on low setting. Over the 84-day experimental period pigs on the low, medium, and high settings used a total of 25,977, 114,080, and 151,350 liters, respectively

Similar to Study 1, regression of water flow rate against performance parameters were conducted. Regression of performance within each weigh period and d 91 BW are provided in Supplemental Figures 7.1 to 7.10. In study 2 (Figure 2.6) there was a linear increase in final BW (Figure 2.6A), cumulative ADG, and ADFI (Figure 2.6B) with increase water flow rate (P <0.05; R^2 =0.08, 0.09, 0.06, respectively). There was no relationship between G:F (Figure 2.6C) and water flow rate. While there was a positive quadratic relationship between water disappearance (Figure 2.7) and water flow rate (P <0.0001 R^2 = 0.87).

2.5 Discussion

The objective of these studies was to evaluate the impact of water flow rate on finishing pig performance. As referenced in the Swine NRC (2012) water consumption "generally has a positive correlation with feed intake" and, hence, pig BW. A study from (Li et al., 2005) reported no differences in water or feed intake due to water flow rate (between 500 to 1,000 mL/min) or nipple height. Additional water disappearance was attributed to water wastage. In the current studies, water disappearance increased as the water nipple setting increased. Results from Study 1 indicated a difference in cumulative ADFI between the high and low water settings, but similar to Li et al. (2005), this did not translate in an increase in final BW. From this it can be concluded that providing water above recommendation does not result in improved pig performance.

In the studies presented herein, variation in individual pen water flow rate within treatment may have reduced the ability to detect treatment differences. To address this, regression was used to evaluate the relationship between growth performance and pen water flow rate. The resulting low R^2 values (i.e., <0.09) for all performance parameters, apart from water disappearance, supports the conclusion that water flow rate above current recommendation had little impact on pig performance.

It should be noted that Study 1was terminated at 104.3 kg BW and not at a market weight of 130 kg. It is possible that if pigs had been followed for an extended period of time, there could have been greater impact on performance at the heavier pig weights. However, given the lack of difference in gain in phase 3 of Study 1 and the resulting regression curve for ADFI and BW, it is unlikely that longer tracking of pig performance would have resulted in significant differences in growth. In addition, growth of pigs in Study 2 was followed through to market and the lack of difference provides further support to the conclusion that water flow rate above current recommendations does not improve pig performance. Similar to Li et al. (2005), the lack of improved pig performance in our trials suggest that the greater water disappearance on the high water setting could be considered wasted, rather than consumed by the pig, and thus added to the pit volume.

Producer manuals recommend finishing pigs receive 7 to 12 L of water per day (National Pork Board, 2018b). Others, like Almond (1995) and Yang et al. (1981), also recommend a higher level of water for finishing pigs (8 to 12 L/pig/day and 60 mL per kg of body weight, respectively). In these studies, even pigs on the high water setting utilized considerably less water than that of the recommendations from production manuals. In three experiments conducted by Li et al. (2005), the grow-finish pigs also had lower water disappearances (1.94 L to 7.31 L) than the above recommendations. This is most likely due to water requirements often being over-estimated and water wastage is not always considered (NRC, 2012). Due to the importance of water in many metabolic functions and the many variables that contribute to the level of intake, defining true requirements has proven challenging (NRC, 2012).

Throughout the duration of these studies, average barn temperature was well above thermal neutral zone for finishing pigs (Midwest Plan Service, 1982; Lammers et al., 2007a). Higher ambient temperatures can lead to increased water consumption (Nienaber and Hahn, 1984; Li et al., 2005). Almond (1995) states that there is a greater than 50% increase in water consumption when temperatures increase from 12 to 15 ºC to 30 to 32 ºC. The same study found that during warmer temperatures, providing water at a higher flow rate may help to compensate for low ADFI typically associated with heat stress associated with the high ambient temperatures of the summer months (Almond, 1995). In a study utilizing pigs from 10 to 14 weeks of age, Nienaber and Hahn (1984) also reported that as temperature and water flow rate increased, so did water consumption. Based upon observations from this study, usage from the high water setting appeared to follow a similar pattern of increasing as the room temperature increased, while pens on the medium or low water flow rate had lesser daily fluctuation in water disappearance, regardless of temperature. One possible explanation for this is that the pigs on the high water setting were using the water for other purposes besides consumption, for example, play or dispersing water to cool themselves on especially warm days.

High water usage is associated with increased water wastage (Nienaber and Hahn, 1984; Li et al., 2005). It is estimated that finishing pigs may waste up to 60% of the water used (Brooks, 1994). While water management and resources to conserve water (i.e. the introduction of the cup waterer) has improved over the years, water management still holds relevance to the industry today as demonstrated in a producer survey conducted by Zeamer et al. (2021), which shows the majority of swine producers providing water in excess. In Study 2, the regression curves and ANOVA table show how increasing pen water flow rate increases daily pen water disappearance. Increases in water usage has the potential to add additional costs for the producer without improving pig performance. Sourced from Mid Dakota Rural Water System (at mdrws.com/billing/waterrates on April 2022), a barn's yearly water usage cost per liter is divided into 3 water usage categories, where fee per liter increases with greater water use (i.e. < 1.1 million liters, 1.1 to 2.6 million liters, and ≥ 2.6 million liters equate to $1.06, $1.32, and $1.91 USD per 1,000 liters, respectively). Using average water consumption data from Study 2, a single turn of 2400 head grow-finish barn, in a 125-day period, would use approximately 1.3 million, 996,000, or 228,000 liters of water, if the pigs had access to water settings equivalent to the high, medium, and low settings in this study. In this example, pigs on the high water setting would incur a 1.3 times greater water cost per pig ($1.06) relative to those on the medium water setting ($0.79), and a 10.6 times greater water cost per pig compared to those on the low water setting ($0.10).

Beyond the potential additional costs associated with greater water usage, pigs on the high water setting have the potential to incur more costs by adding water to the manure pit volume. Greutink (1993), Mroz et al. (1995), and Li et al. (2005) all found that as water disappearance increased, so did manure volume. Wasted water from drinkers and washing may increase manure volume by 10 to 30% (Chastain et al., 1998), resulting in a greater volume that needs to be removed from the pit and decreasing nutrient concentrations in the slurry. The nutrient content of a manure slurry combined with delivery and handling cost is what determines its value (Fleming et al., 1998). By increasing the water content of the manure slurry an increased quantity of a less nutrient dense product is produced.

Overall, water provided at a flow rate above current recommendation provides little benefit to pig performance. In both studies, there was no difference in cumulative feed conversion, ADG or final BW. Pigs on the high water setting did have a higher water disappearance than those on the medium and low water setting. It may be concluded that the additional water disappearance is attributed to play and wastage rather than being consumed by the pig. This ultimately adds to the manure pit volume which can lead to additional costs to the producer either through increasing the water bill and cost of manure handling. Due to costs of production and concerns related to increasing water wastage, swine producers are encouraged to frequently measure nipple flow rate and adjust when outside of accepted limits.

Table 2. 1 Composition of Study 1 grow-finisher diets

	Phase[1]		
Item	1	2	3
Ingredients, %			
Corn	79.25	83.3	86.54
Soybean meal, 46.5%	17.68	13.83	10.77
L-Lysine HCl	0.40	0.38	0.36
L- Threonine	0.13	0.12	0.11
DL-Methionine	0.08	0.07	0.04
L-Tryptophan	0.01	0.01	0.01
Monocalcium phosphate	0.98	0.85	0.76
Limestone	0.97	0.94	0.91
Salt	0.30	0.30	0.30
Nursery Vitamin premix[2]	0.05	0.05	0.05
Trace Mineral premix[3]	0.15	0.15	0.15
Total	100.0	100.0	100.0
Calculated analysis			
ME, kcal/kg	3333	3341	3346
NE, kcal/kg	2469	2500	2522
CP, %	15.3	13.9	12.7
Ca, %	0.62	0.57	0.54
P, %	0.27	0.24	0.22
Available P, %	0.27	0.23	0.21
SID[4] amino acids, %			
Lys	0.94	0.84	0.75
Ile:Lys	0.55	0.55	0.55
Leu:Lys	1.36	1.42	1.51
Met:Lys	0.33	0.33	0.32
Thr:Lys	0.63	0.63	0.65
Trp:Lys	0.16	0.15	0.16
Val:Lys	0.65	0.65	0.67

[1] Phase 1, 2, and 3 diets were fed from d 0 to 25, d 25 to 53, d 53 to 77 of the experiment, respectively

[2] J & R Distributing Inc. 518 Main Ave, Lake Norden, SD 57248 - USA. Minimum provided per kg of diet: Calcium 55 mg, Vitamin A 11,000 IU, Vitamin D3 1,650 IU, Vitamin E 55 IU; Vitamin B12 0.044 mg, Menadione 4.4 mg, Biotin 0.165 mg, Folic Acid 1.1 mg, Niacin 55 mg, d-Pantothenic Acid 60.5 mg, Vitamin B16 3.3 mg, Riboflavin mg, 9.9 Thiamine 3.3 mg.

[3] J & R Distributing Inc. 518 Main Ave, Lake Norden, SD 57248 - USA. Minimum provided per kg of diet: Copper 16.5 ppm, Manganese 44.1 ppm, Selenium 0.03 ppm, Zinc 165 ppm.

[4] SID = Standard ileal digestible

Table 2. 2 Composition of Study 2 grow-finisher diets

	Phase[1]			
Item	1	2	3	4
Ingredients, %				
Corn	74.85	78.53	80.75	85.44
Soybean meal	12.65	9.15	9.63	7.50
DDGS	10.00	10.00	7.50	5.00
Limestone	0.925	0.87	0.82	0.80
Monocalcium Phosphate	0.15	0.07	0.05	0.11
Salt	0.50	0.50	0.5	0.50
Lysine-HCl	0.49	0.47	0.40	0.35
Threonine	0.165	0.15	0.12	0.10
DL-Methionine	0.05	0.03	-	-
Vitamin and Mineral Premix[2]	0.15	0.15	0.15	0.15
L-Tryptophan	0.04	0.04	0.03	0.025
Copper Chloride	0.025	0.025	0.025	0.025
Total	100.00	100.00	100.00	100.00
Calculated analysis				
ME, kcal/kg	2497	3303	3310	3317
NE, kcal/kg	3296	2518	2533	2559
CP, %	14.95	13.57	13.25	11.88
Ca, %	0.45	0.40	0.38	0.38
P, %	0.39	.37	0.34	0.34
Available P, %	0.12	0.12	0.13	0.12
SID[3] amino acids, %				
Lys	0.90	0.80	.75	0.65
Ile:Lys	1.14	1.16	1.15	1.15
Leu:Lys	1.51	1.60	1.67	1.77
Met:Lys	0.77	0.80	0.79	0.81
Thr:Lys	1.10	1.12	1.12	1.13
Trp:Lys	0.27	0.27	0.27	0.28
Val:Lys	1.57	1.61	1.60	1.61

[1] Phase 1, 2, 3, and 4 diets were fed from BW 60 to 73 kg, 73 to 90 kg, 90 to 105 kg and 105 kg until marketing, respectively

[2] Provided per kilogram of the diet: 1,998 FTU phytase, 3,522 IU vitamin A, 1,101 IU vitamin D3, 22 IU vitamin E, 3.0 mg vitamin K3, 26.4 mg niacin, 17.6 mg pantothenic acid, 5.2 mg riboflavin, 23.8 ug vitamin B12, 30 mg Mn from manganous oxide, 100 mg Zn from zinc hydroxychloride, 80 mg Fe from ferrous sulfate, 12 mg Cu from copper chloride, 0.40 mg I from ethylenediamine dihydroiodide, and 0.30 mg Se from sodium selenite.

[3] SID = Standard ileal digestible

Table 2. 3 Effect of water flow rate on Study 1 finishing pig performance[1]

Item	Water flow rate setting			SEM	*P*-value
	Low	Medium	High		
Avg water flow rate (mL/min)	500	900	1800		
Standard deviation	100	214	188		
Initial BW, kg	35.11	34.99	35.04	0.80	0.994
Period 1, d 0 to 25					
BW, kg	54.96	55.37	56.29	1.05	0.614
ADG, kg/d	0.82^{b}	0.85^{ab}	0.87^{a}	0.01	0.040
ADFI, kg/d	1.46^{b}	1.51^{ab}	1.59^{a}	0.04	0.049
G:F	0.59	0.59	0.57	0.02	0.676
Period 2, d 25 to 53					
BW, kg	78.49	78.44	79.98	1.31	0.548
ADG, kg/d	0.85	0.84	0.86	0.01	0.528
ADFI, kg/d	2.21^{b}	2.24^{ab}	2.34^{a}	0.04	0.011
G:F	0.38^{a}	0.38^{ab}	0.37^{b}	0.004	0.037
Period 3, d 53 to 77					
BW d 77, kg	103.18	103.24	105.91	1.35	0.251
ADG, kg/d	1.00	1.01	1.05	0.02	0.120
ADFI, kg/d	2.81	2.79	2.89	0.05	0.206
G:F	0.36	0.36	0.36	0.01	0.897
Period 1-3, d 0 to 77					
ADG, kg/d	0.88	0.88	0.91	0.01	0.203
ADFI, kg/d	2.16^{b}	2.18^{ab}	2.27^{a}	0.04	0.024
G:F	0.41	0.40	0.40	0.004	0.278

[1] Pigs were assigned to one of three water settings with 22 pens per treatment and 6 pigs per pen

[a, b] Least square means in the same row with different superscript letters differ ($P < 0.05$)

Table 2. 4 Effect of water flow rate on Study 2 finishing pig performance[1]

Item	Water Flow Setting Low	Medium	High	SEM	P-value
Avg Water Flow Rate (mL/min)	605	906	1115		
Standard Deviation	203	209	98		
Initial BW, kg	27.40	28.31	27.94	0.427	0.3568
Period 1, d 0 to 14					
BW, kg	36.70	37.54	37.45	0.497	0.4511
ADG, kg/d	0.65	0.66	0.68	0.010	0.2688
ADFI, kg/d	1.42	1.44	1.46	0.017	0.2208
G:F	0.46	0.46	0.46	0.005	0.6991
liters / pig /day	0.10[c]	0.51[b]	0.79[a]	0.038	<.0001
Period 2, d 14 to 28					
BW, kg	51.37	53.00	52.34	0.592	0.1669
ADG, kg/d	1.10	1.08	1.08	0.015	0.769
ADFI, kg/d	1.78	1.81	1.82	0.015	0.1781
G:F	0.61	0.60	0.60	0.009	0.3375
liters / pig /day	1.02[c]	3.10[b]	4.53[a]	0.220	<.0001
Period 3, d 28 to 42					
BW, kg	65.49[b]	67.54[a]	67.83[a]	0.629	0.0267
ADG, kg/d	1.01[b]	1.03[b]	1.11[a]	0.020	0.004
ADFI, kg/d	2.24[b]	2.19[a]	2.26[a]	0.017	0.0212
G:F	0.46[b]	0.46[b]	0.49[a]	0.009	0.0318
liters / pig /day	0.76[c]	2.83[b]	4.29[a]	0.280	<.0001
Period 4, d 42 to 56					
BW, kg	80.27	81.90	81.56	0.589	0.1366
ADG, kg/d	0.99	1.02	1.02	0.023	0.6702
ADFI, kg/d	2.43	2.45	2.47	0.021	0.4391
G:F	0.42	0.42	0.41	0.006	0.686
liters / pig /day	0.73[b]	4.50[a]	4.77[a]	0.306	<.0001
Period 5, d 56 to 70					
BW, kg	94.74	96.65	96.69	0.819	0.1756
ADG, kg/d	1.09	1.05	1.08	0.027	0.5963
ADFI, kg/d	2.71	2.71	2.71	0.027	0.9742
GF	0.40	0.39	0.40	0.008	0.4503
liters / pig /day	0.30[c]	0.97[b]	1.29[a]	0.091	<.0001
Period 6, d 70 to 84					
BW, kg	109.61	111.68	111.78	0.963	0.2371
ADG, kg/d	1.12	1.07	1.08	0.018	0.241
ADFI, kg/d	2.91	2.89	2.90	0.030	0.804
G:F	0.38	0.37	0.37	0.004	0.2427
liters / pig /day	1.05[c]	3.89[b]	5.31[a]	0.276	<.0001
Period 1-6, d 0 to 84					
ADG, kg/d	0.98	0.99	1.00	0.010	0.1444
ADFI, kg/d	2.24	2.25	2.27	0.015	0.3936
G:F	0.37	0.37	0.37	0.006	0.9934
liters / pig /day	0.76[c]	3.32[b]	4.46[a]	0.216	<.0001
BW Day 91	115.81	118.14	118.08	1.001	0.1892

[1] Pigs were assigned to one of three water settings with 22 pens per treatment and 16 pigs per pen

[a, b] Least square means in the same row with different superscript letters differ significantly ($P < 0.05$)

Figure 2. 1 Dimensions of the water nipple and water cup.

Figure 2. 2 Size comparison of water nipple setting orifice diameter

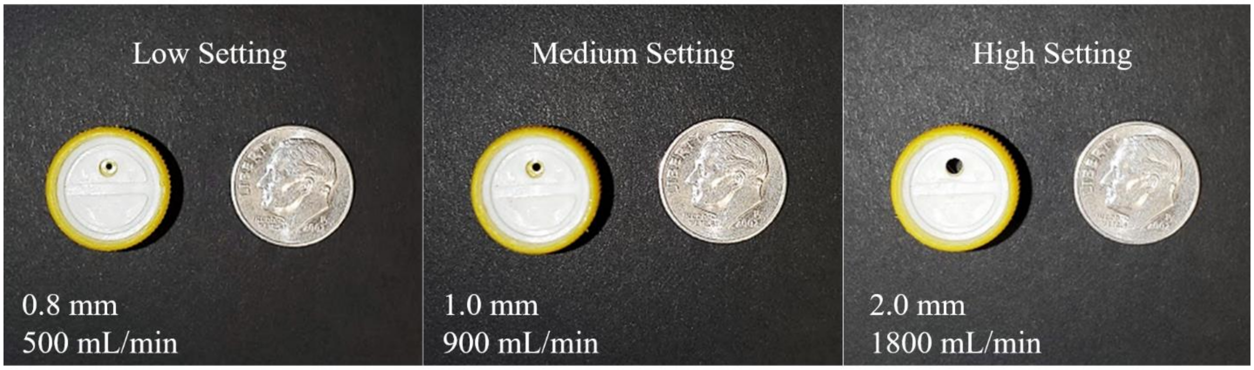


Figure 2. 3 Average daily water disappearance per kg BW and high room temperature over time in Study 1.

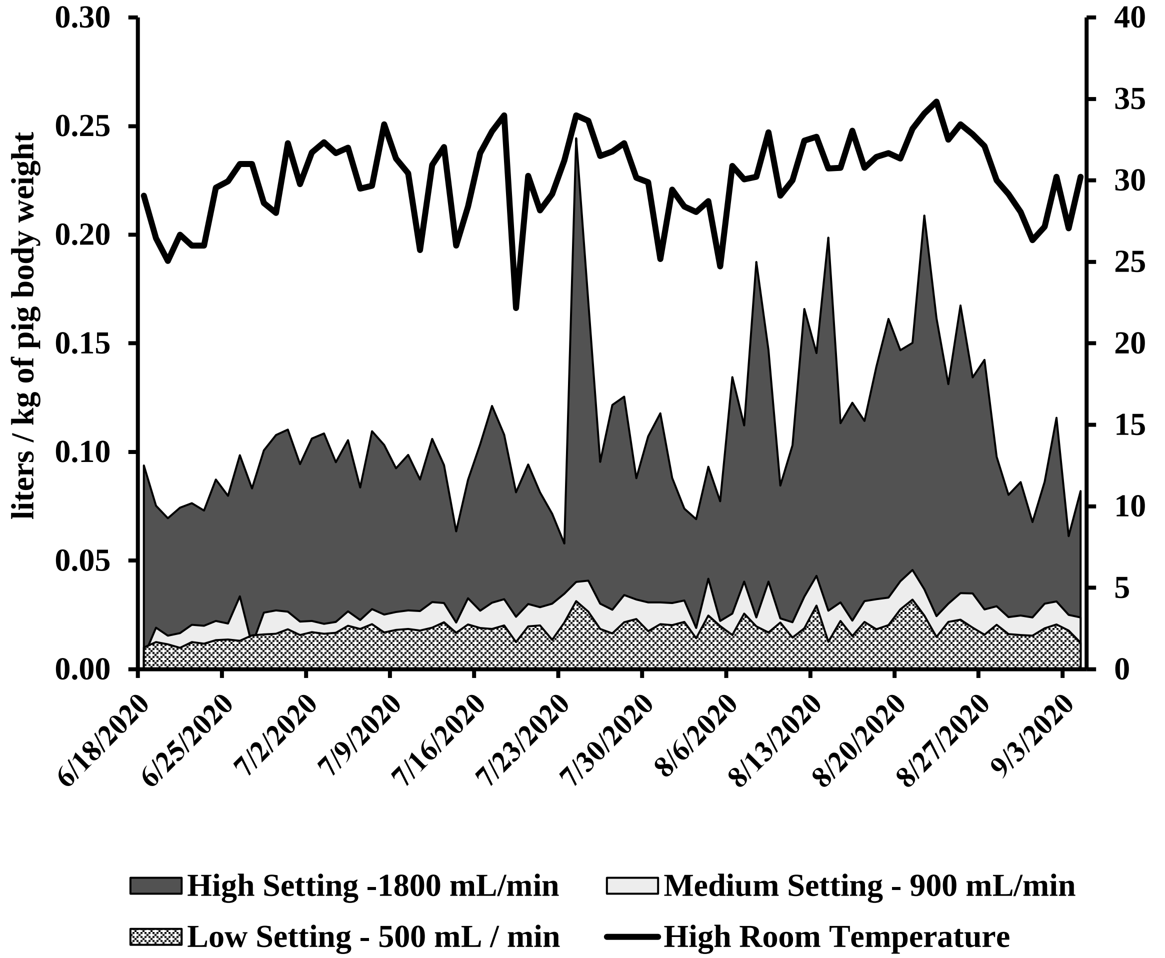
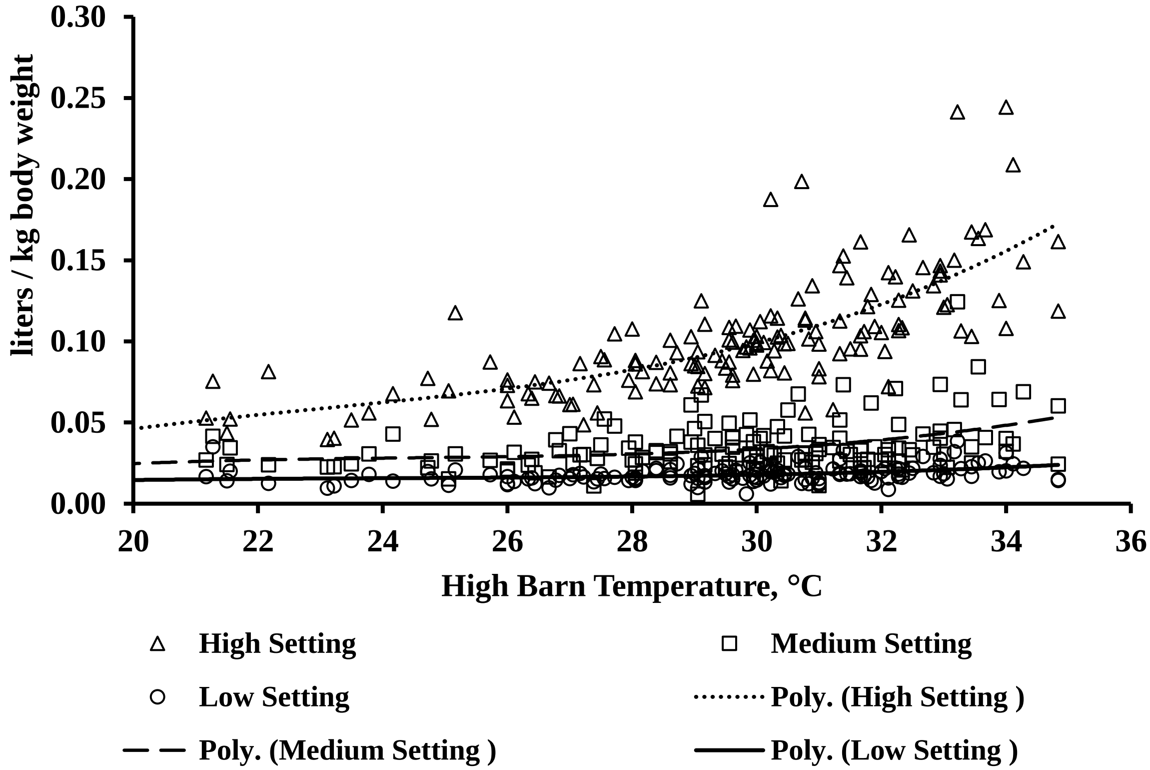


Figure 2. 4 Regression of water usage per pig on the high, medium, and low water settings against daily high room temperature in Study 1.



	High	Medium	Low
Observations	153	153	153
Parameters	3	3	3
Error DF	149	149	149
M SE	0.02	0.03	0.02
P-value	<.0001	<.0001	<.0001
R-Squared	0.60	0.16	0.16
Adj R-Square	0.59	0.14	0.14

Figure 2. 5 Regression of cumulative pig performance vs waterflow rate during Study 1. A = final body weight; B = cumulative average daily and feed intake; C = gain:feed ratio. Barn temperature ranged from 15.4 to 34.8 °C. High barn temperature averaged 29.0 °C for the entire trial period. Linear regression: body weight, P = 0.05, R^2 = 0.04; average daily gain, P = 0.041, R^2 = 0.05; average daily feed intake, P = 0.007, R^2 = 0.09. Cubic regression: gain:feed ratio, P = 0.190.

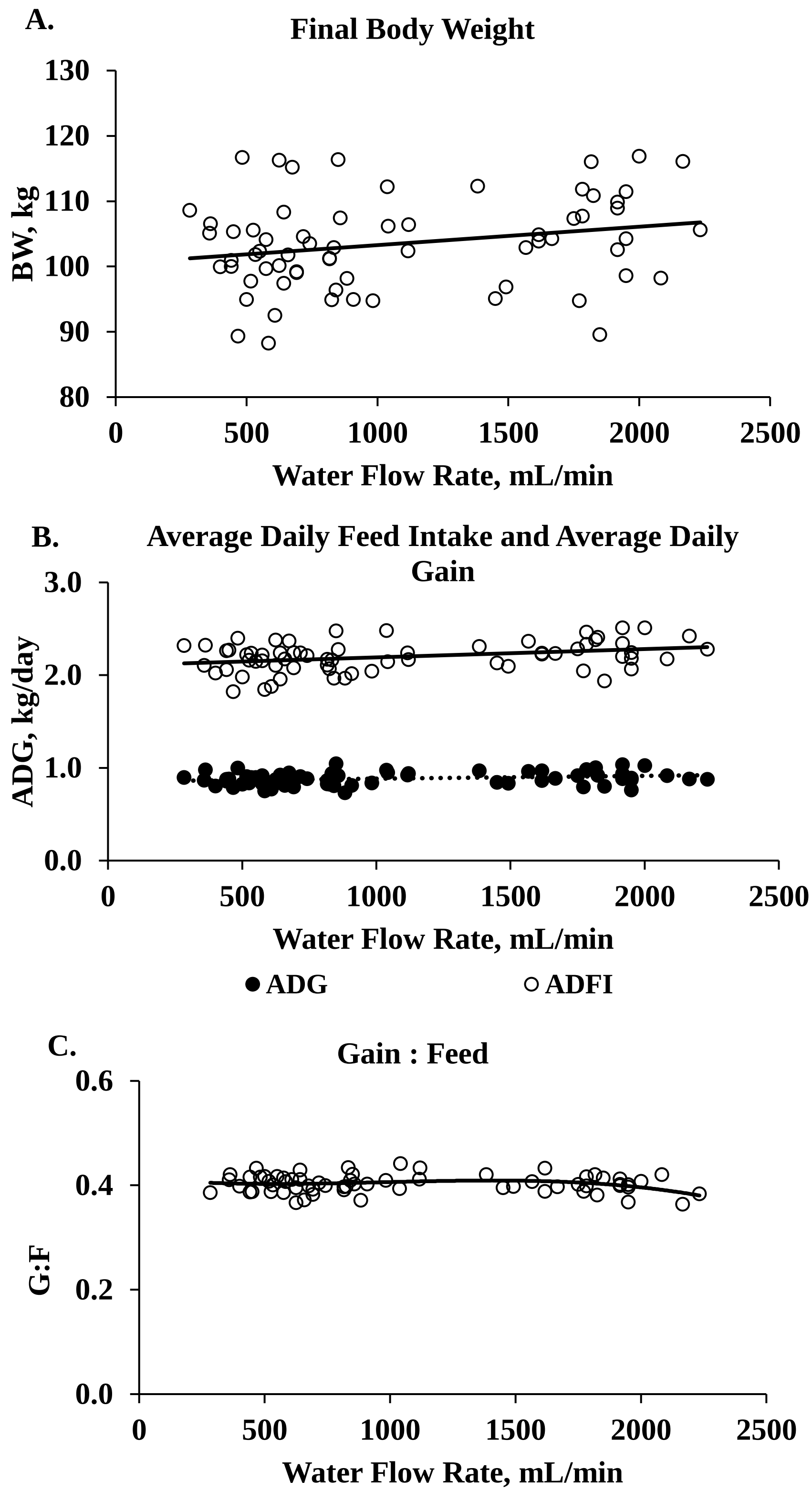


Figure 2. 6 Regression of cumulative pig performance vs waterflow rate during Study 1. A = final body weight; B = cumulative average daily and feed intake; C = gain:feed ratio. Barn temperature ranged from 18.3 to 38.2 °C. High barn temperature averaged 28.5 °C for the entire trial period. Linear regression: body weight, $P = 0.11$; average daily gain, $P = 0.01$, $R^2 = 0.09$; average daily feed intake, $P = 0.05$, $R^2 = 0.06$. Cubic regression: gain:feed ratio, $P = 0.79$.

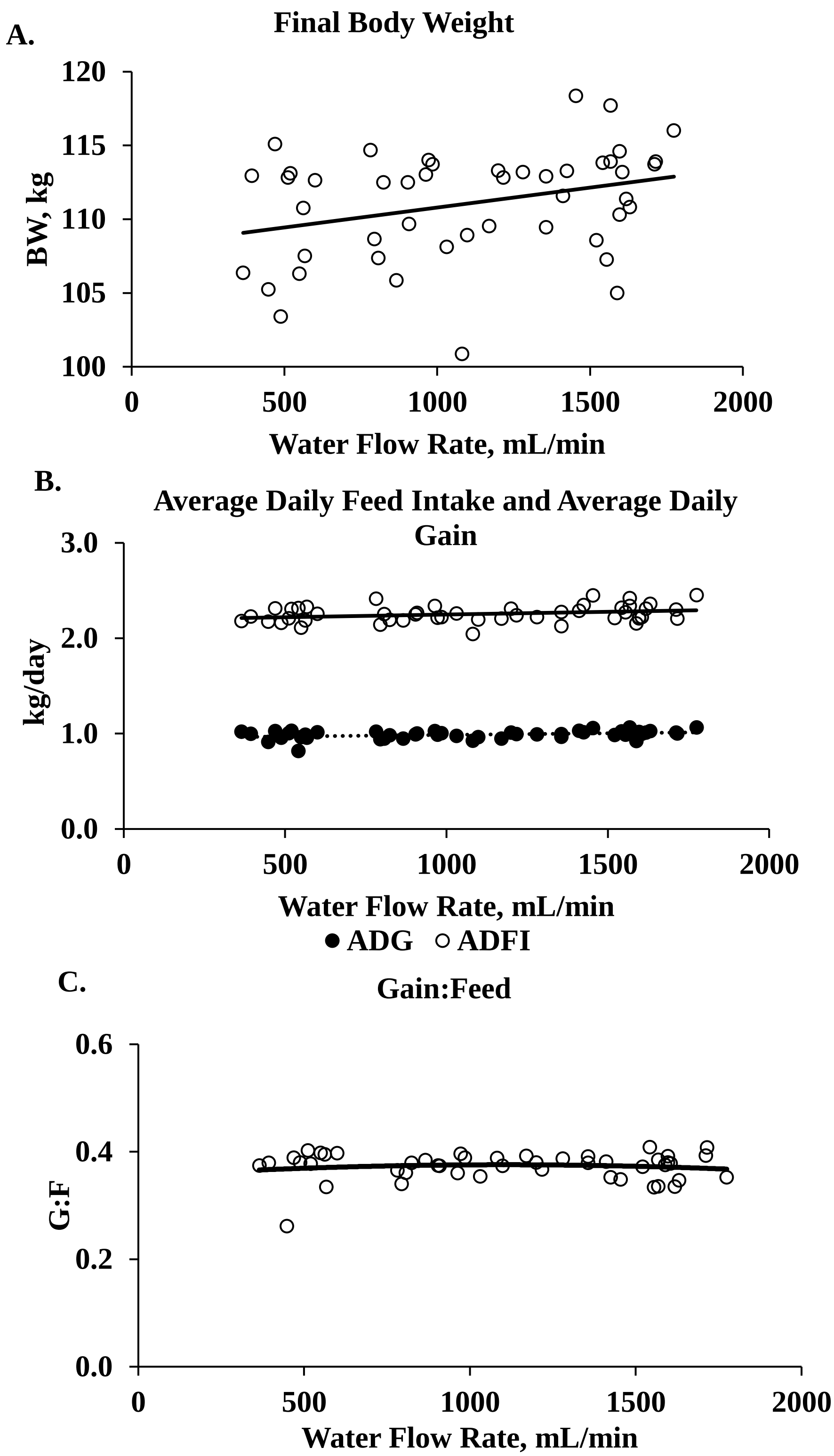
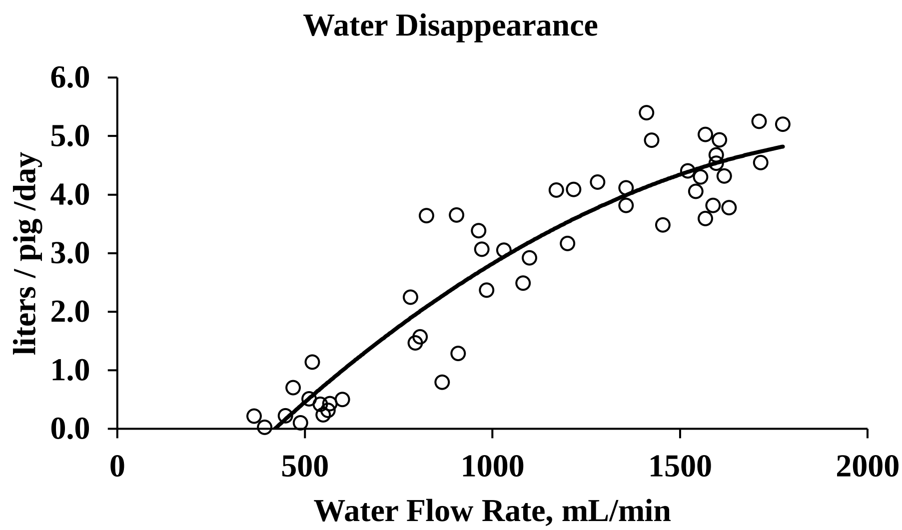


Figure 2. 7 Regression of cumulative water disappearance in liters/pig/day from Study 2. Quadratic regression, *P* <0.0001, R^2 = 0.87



3.0 EVALUATION AND REFORMULATION OF SDSU ON-SITE WEAN TO FINISH DIETS THROUGH MODELING OF GROWTH PERFORMANCE

3.1 Introduction

Precision animal nutrition is defined as a part of precision livestock farming which uses feeding techniques to allow the proper amount of feed of suitable composition to be supplied in a timely manner to a group of animals (Parson et al., 2007; Cangar et al., 2008; Pomar et al., 2017). Over the last 30 years, phase feeding, a form of precision nutrition, has become the standard for feeding growing pigs (Han et al., 2000). The goal of phase feeding is to feed more precisely for the age and physiological state of the animal, which in turn increases profitability, efficiency, and sustainability (Han et al., 2001; Hauschild et al., 2012; Pomar and Pomar, 2012; Pomar et al., 2017). Modeling pig growth and feed intake are tools that can assist in creating a feeding program that is specific to the production scenario (Fraga et al., 2015; Menegat et al., 2019b). Different genetic lines perform differently in response to the environment and management practices. Determining the specific growth profile for a given production system can improve feed efficiency and reduce diet costs and excretion of pollutants (Fraga et al., 2015).

Voluntary feed intake, which is heavily influenced by genetics and the pigs' environment, determines nutrient intake, which impacts growth, feed efficiency, caracass quality and profitability (Nyachoti et al., 2004). Swine diets are typically formulated on a percentage basis. If feed intake deviates from the predicted value this can result in either the over or undersupplying of nutrients. Between 0.019 – 0.020 g of lysine is needed per g of gain (NRC, 2012; Goodband et al., 2014). Providing lysine above this recommendation does not provide any additional benefit to the pig and results in excess nitrogen being excreted in the feces (Han et al., 2000). Pigs only use 30 to 35% of ingested nitrogen (Jongbloed and Lenis, 1992), which further emphasizes the importance of not over providing nutrients. On the other hand, not meeting the lysine: gain ratio could hinder pig growth performance (Wagner et al., 1963; van Milgen and Noblet, 2003). Both under providing and over providing lysine result in additional costs and greater inefficiencies. By meeting nitrogen requirements more precisely for a given grower-finisher production unit, nitrogen output can be reduced by as much as 14% (Koch, 1990).

The current diets fed at SDSU On-Site Wean-to-Finish (WTF) facility were formulated to meet the standards outlined in the National Swine Nutrition Guide for wean to finish pigs. The SDSU feeding program consists of 8 phases, formulated using least cost formulation software. At the time the phases were formulated there was no historical data on which to determine facility specific grow rates and hence dietary nutrient needs. Over the past 5 years since opening of the unit, there have been numerous research trials conducted at the unit where pig performance (growth and feed intake) was recorded regularly. The objective of this work was to use historical data to model barn-specific pig performance and reevaluate the Wean-to-Finish feeding program of the SDSU swine unit.

3.2 Materials and Methods

Wean to Finish performance data.

Data from nine previous studies, conducted at the South Dakota State University On-Site Wean-to-Finish facility between 2016 to 2021 were used to model pig growth, ADG, cumulative feed intake, ADFI, and feed conversion.

Commerical pig performance data (BW, ADG, and cumulative feed intake) was sourced from Compart Family Farms, the sire sources of the SDSU swine herd. Data from Compart, along with performance data provided by PIC (the maternal source) in the 2019 *Wean to Finish Manual*, were used as reference points to compare the unit specific growth to the maternal and paternal genetic lines used at the swine unit.

Modelling performance

All data was modeled in RStudio (Rstudio, PBC, Boston, MA) to fit either a Gompertz, logistic, or quadratic model. Ideal model was based upon recommendation from previous work by Lorenzo Bermejo et al. (2003), Wellock et al. (2004), Schinckel et al. (2009), and Schulls (2013) which details the ideal fit for each of the observed performance parameters in this study.

Predicting nutrient requirements and diet formulation

The SDSU standard diets were compared to lysine consumption and targeted gain recommended by NRC (2012) and PIC (2019). Inefficiencies of lysine for whole body growth were targeted based on the 0.019 – 0.020 g of lysine consumption per 1 g increase of pig BW (Goodband et al., 2014; Orlando et al., 2021). Inefficiencies in lysine use was adjusted for each diet phase. Inefficiencies in lysine: gain are indicated when the actual lysine: gain ratio is outside the targeted ratio of 0.019 to 0.020. Based on the new lysine values, targeted amino acids and energy requirements were adjusted to meet recommended lysine to amino acid or energy recommendations. Levels of vitamins and minerals were included to meet or exceed NRC (2012) recommendation and fit within the rate of inclusion of the designated vitamin and mineral premixes.

Diets were formulated using least cost diet formulation software (Concept5. Tech Services, Inc., Staples, MN) to the eighth limiting amino acid, lysine, threonine, tryptophan, isoleucine, valine methionine, cysteine, and leucine. Amino acids methionine and cysteine were considered together as total sulfur amino acids rather than individually.

3.3 Growth Model

A Gompertz model was used to pattern pig body weight (Figure 3.1) from time of weaning (0 weeks post wean) to time of marketing (22 weeks post wean) for the SDSU herd. Similarly, pig BW from PIC and Compart datasets (Figure 3.2 and Table 3.1) was also modeled to serve as benchmarks for the SDSU data. Starting weight was similar for all data sets at 5.7, 6.1, and 5.9 kg, respectively for SDSU, Compart, and PIC. By 2 weeks post weaning the PIC genetics exceeded both SDSU and Compart by 0.9 and 1.3 kg, respectively. Around 4 weeks post wean the Compart line begins to slow down relative to SDSU and PIC. Beyond that Compart and PIC are two different genetic lines which may have differences in rate of growth, other explanations for reduced growth include factors such as management or nutrition. It is also possible that differences may be due to frequency of data collection. Compart data was sourced from commerical closeout data which does not provide the same frequency or range of data points which is provided by the PIC or SDSU data. By week 6, there is a rapid increase in rate of gain as pigs exit the nursery phase. By 22 weeks post wean, pigs weighed 119.2, 107.4, and 127.2 kg for SDSU, Compart, and PIC respectively.

For the SDSU herd, ADG was best represented by a quadratic model (Figure 3.3 and Table 3.2).

Equation 3.1 Average Daily Gain for the SDSU swine herd.

$$y = -0.0028x^2 + 0.1028x + 0.0999$$

Over the entire period ADG was 0.79 kg/day. In the initial week following weaning, ADG begins at 0.20 kg/day. At week 18 ADG peaks at 1.03 kg/day where it begins to decrease, dropping to 0.99 kg/day by 22 weeks post wean. Prior work suggests that models such as Gompertz, GMM, and Bridges can also be used to characterize ADG (Schinckel et al., 2009; Schulls, 2013). Most prior work uses nonlinear equations to characterize ADG, as it begins with a period of rapid increase and then plateaus as pigs age. In the SDSU data set, ADG begins to plateau around 17 weeks post wean (1.03 kg/day) , and then begins to slightly decrease after 19 weeks post wean.

Average daily feed intake was modeled using a polynomial model (Figure 3.4 and Table 3.2).

Equation 3.2 Average Daily Feed Intake for the SDSU swine herd.

$$y = 3E-05x^4 - 0.0017x^3 + 0.0311x^2 - 0.0121x + 0.286$$

Overall ADFI averaged 1.9 kg/day. ADFI slows immediately prior to weaning as pigs adjust to their new environment and the new source of food, and average 0.282 kg/day in the first week. By 3 weeks post wean, ADFI begins to rapidly increase until week 17, after which the rate of ADFI begins to slow down. By 22 weeks post wean pigs have a ADFI of 3.11 kg/day. Both polynomial and logistic functions can be used to describe ADFI (Lorenzo Bermejo et al., 2003; Schulls, 2013). The disadvantage to the provided polynomial equation is that if extended out beyond 22 weeks post wean, it would predict a drop in feed intake. Although, work from Schulls (2013) did report a decrease in feed intake after 120 kg. Lorenzo Bermejo et al. (2003) disagrees and places preference on the logistic model which results in a plateau in ADFI as pigs enter towards the marketing phase. The SDSU swine herd functions on a fixed time system, so there is rarely a need to predict ADFI beyond 22 weeks post wean. Due to this the polynomial equation can be justified to predict ADFI of the SDSU swine herd.

Feed conversion was found by dividing the predicted ADG by predicted ADFI and fitted to a polynomial equation (Figure 3.5).

Equation 3.3 Feed conversation for the SDSU swine herd (Figure 3.5 and Table 3.2)

$$y = -2E - 07x^6 + 1E - 05x^5 - 0.0004x^4 + 0.007x^3 - 0.058x^2 + 0.1796x + 0.5827$$

For the entire period G:F averaged 0.51. In the first week post wean, G:F increased as newly weaned pigs adjusted to their new environment and had low intake. Feed conversion peaked at 2 weeks post wean at 0.76. From 4 to 9 weeks post wean there is a steep decline in G:F, 0.723 to 0.496, respectively. Feed conversion continues to decrease after week 9 although at a much slower rate. By week 22 G:F ratio reaches 0.32. The method of calculating G:F through the division of the predicted values is also the method used by Schulls (2013) and Schinckel et al. (2009). Using predicted values of ADFI and ADG to calculate G:F has been shown to provide a simple and accurate method to create a predictive model (Schulls, 2013).

3.4 Predicting Nutrient Requirements

The calculated analysis of the previous and new diets are displayed on Table 3.3 and 3.4, respectively. Feed budget for each of the dietary phases was calculated based on the ADFI for each of the targeted BW ranges. The number of phases and targeted ME levels are similar to prior diets.

Performance values were used to determine the targeted lysine content of the 8 diet phases are shown in Table 3.5. Between 0.019 to 0.020 g of lysine is needed per g of gain (Goodband et al., 2014; Orlando et al., 2021). Phases 5 and 6 (Table 3.5) in the original diets had elevated lysine: gain ratios (0.0213 and 0.0212, respectively). Because providing lysine above 0.020 g lysine per g gain does not provide any additional or improved gain, the elevated lysine : gain ratio seen in phases 5 and 6 indicate inefficient use of lysine in the old diets. Potential solutions to address this include increasing energy or decreasing the lysine provided in the diet. One of the goals of the reformulation was to keep ME content similar to the original diets (3300 kcal/kg) as recommend by NRC (2012). Phase 2 and 3 had the lowest lysine : gain ratio (0.0172 and 0.0175, respectively) in the original diets. Based on ADFI in phase 1, 2, and 3 the new determined lysine level was originally calculated to be 1.42%, 1.52%, and 1.42% respectively (Table 3.5). To have a more gradual decrease in levels of lysine between phases, targeted lysine levels were adjusted to 1.52%, 1.42%, and 1.30% for phases 1, 2, and 3 respectively (Table 3.6). Phases 2 and 3 lysine levels were set at slightly lower than the calculated requirement, which has the potential benefit of improved gut health and creates opporunity to capture compensatory gain in later phases. Feeding high protein diets to newly weaned pigs is associated with increased incidences of diarrhea and increased presence of pathogenic bacteria in the gut (Pluske et al., 1997). Additionally, after a period of restricting amino acids, when pigs are provided with adequate levels of amino acids they experience a period of improved or compensatory growth. Totafurno (2018) reports that 3 weeks of a 40% lysine restriction of newly weaned pigs resulted in lighter pigs, but when fed a diet with adequate levels of lysine by week 9 the same final BW and body composition was achieved as non-restricted pigs.

Targeted amino acid to lysine ratios (Table 3.7) are based on recommendation from NRC (2012) and PIC (2021). These values are used to calculate the targeted inclusion of amino acids. Amino acids not provided at the proper ratios can lead to deficiencies, toxicity, antagonisms, and imbalances (Harper et al., 1970; D'Mello, 2003). The sulfur amino acids, methionine and cysteine, are some of the most toxic of the amino acids when provided in excess, due to their interference with metabolic functions (NRC, 2012). Amino acid antagonism occurs when amino acids that are structurally or chemically similar compete with one another, leading to an increase in catabolism and reduced absorption of the first limiting amino acid (NRC, 2012). Antagonisms most commonly occur in the branched chain amino acids leucine, isoleucine, and valine (Langer and Fuller, 2000; Langer et al., 2000; Witafsky et al., 2010). Recommendation for amino acid to lysine ratios vary on the physiological state of the pig (NRC, 2012). To ensure amino acid imbalances do not occur, such that pig growth is optimized, amino acid ratios should be properly balanced.

3.5 Diet Formulation

Calculated dietary nutrient content and dietary composition of new diets are displayed in Table 3.4 and 3.8, respectively.

Corn and soybean meal are major energy and protein sources for swine and are typically included in all diets (Lammers et al., 2007c). Synthetic amino acids such as Lysine HCl, DL-Methionine, L-Threonine, and L-Tryptophan, are all included in the reformulated diets and are some of the most commonly included synthetic amino acids. Inclusion of synthetic amino acids can help to reduce diet costs and allows diets to meet the pig's amino acid profile more closely (Han and Lee, 2000). Inclusion of synthetic amino acids at levels as low as 0.1 to 0.2% can reduce crude protein levels by as much as 4% (Sharda et al., 1976; Kerr, 1993; Han, 1996; Han and Lee, 2000). In the revised diets, Lysine HCl has the highest inclusion rate (0.20 – 0.34%) of the synthetic amino acids.

Ingredients like salt, vitamin, and mineral premixes, larvicide, and phytase are included at a fix rate. Targeted dietary mineral and vitamin levels (Table 3.6) were calculated from a fixed inclusion level of the vitamin and mineral premix, 0.050 and 0.150%, respectively. Most commerical diets include vitamin and mineral at an inclusion level well above NRC requirements as a margin of safety to account for potential degradation or reduced bioavailability (Flohr et al., 2016). Salt is added to the diet for electrolyte balance and acid-base status of the pig (NRC, 2012). In the presented diets salt is included at a rate of 0.40% resulting in Na concentration of 0.18 to 0.34%, and Cl concentration of 0.24 to 0.59%. Varying concentrations of Na and Cl levels among the different phases, despite a consistent inclusion of salt, can be attributed to the inclusion of whey in phases 1 and 2, which has a higher level of Na and Cl compared to corn or soybean meal.

Phytase is included to increase the avaliability of P in the diet. The majority of P in plant-based diets are bound in the form of phytate and are mostly unavailable to the pig (Cromwell et al., 1993; NRC, 2012). Phytase is measured in phytase units/ kg. Depending on the amount of phytate in the diet and inclusion level of phytase in the diet, STTD P release can range from 0.06 to 0.16% (Gebhardt et al., 2021). Phytase is included in the new diets at 0.02% and has a 0.13% STTD P release with 500 phytase units/kg. Inclusion of phytase also increases the avaliability of Ca in the diets (Igbasan et al., 2001). Which allows for a reduction of inorganic sources of P and Ca like monocalcium phosphate and limestone. In the new diets STTD Ca and STTD P are provided in a ratio of 1.17:1 to 1.29:1 which is within the ideal Ca:P ratio. Because of the inclusion of phytase, when compared to the original diets monocalcium phosphate was reduced in all of the new diet phases and limestone was reduced in phases 3 through 8.

To meet the high energy and protein requirments of young pigs, nursery diets typically contain several types of specialty feed ingredients, like oats, whey, ESBM, spray dried plasma, zinc oxide, and soybean oil. As the pig ages, diets are reduced in complexity to lower diet cost, and in response to changes in the pig's digestive ability, changes in nutrient requirements, and increases in feed intake which allow them to consume a larger quantity of less nutrient dense diet.

Oats are a highly palatable feedstuff and tend to be higher in fiber and protein than corn (Myer, 2008; Azain et al., 2017). Although they only have an energy value that is about 80% that of corn (Myer, 2008). In phase 1 oats are included at 21%. Inclusion at this level is within the range which can help to reduce incidences of diarrhea (Medel et al., 1999; Paulicks et al., 2000; Myer, 2008). Oats contain fermentable fibers which increase fermentation in the hind gut and the production of short chain fatty acids and lactic acid which can improve the immune system along with piglet performance (Bach Knudsen and Canibe, 2000; O'Connell et al., 2005; Pie et al., 2007; Stein, 2007). While fiber of the oats have many benefits for gut health of the pig, they also increase the bulk density of the ingredient and can have potential negative effects on ADFI, which is especially critical in the newly weaned pig (Myer, 2008). Due to this caution should be taken when formulating as to not to have too high of inclusion of oats.

Some form of lactose, in this instance whey, is typically included in the nursery diets to help with the transition from an all-liquid, high lactose diet to a solid plant-based diet after weaning. Inclusion of lactose improves post-weaning performance, as the lactose is more easily digestible than other carbohydrates (Tokach et al., 1989; Lepine et al., 1991; Zhao et al., 2021). While there is no true limitation to lactose inclusion in the period just after weaning, inclusion at 15% has been shown to improve ADG while 25 to 30% inclusion improves ADFI (Lepine et al., 1991; Zhao et al., 2021). Whey inclusion in phase 1 is at 25% with a lactose level of 18%; in phase 2 whey is included at 10% with a lactose level of 8%. Inclusion of 25% and 10% whey in phases 1 and 2, respectively, was based on inclusion in the previous diet and was decided to be continued in the new diets. By phase 3 whey has been completely removed from the diet due to enzymatic changes in the pig. Shortly after weaning lactase activity sharply declines, limiting the pig's ability to digest lactose and products like whey (Pluske et al., 2003). Additionally, prolonged inclusion of lactose can increase incidences of diarrhea (Pierce et al., 2005).

Due to its benefits for improved performance, increased digestibility of amino acids, and reduced antinutritional factors (Yang et al., 2007; Stein, 2008), ESBM is included at 10% in phase 1 and 2, after which it is removed from the diet. Very few studies have looked at the impact of including ESBM at levels above 10%. Due to this and some potential limitations associated with reduced feed intake (Jordan et al., 2014; Ruckman et al., 2020), inclusion was determined to not exceed 10%.

Spray dried plasma is high in amino acids such as lysine, tryptophan, and threonine (Coffey and Cromwell, 2001). Additionally, it is high in ME compared to many plant-based feedstuffs. For optimal performance inclusion of spray dried plasma is recommended to be between 4 to 8% (Coffey and Cromwell, 2001; van Dijk et al., 2001; Torrallardona, 2010). In the diet formulator parameters for spay dried plasma were set to include up to 4% in phase 1 and up to 2.5% in phase 2. Due to the functions of the least cost formulator, phase 1 spray dried plasma is included at 3%. Spray dried plasma has been removed from the diet in phase 2 as ESBM is continues to be included at 10% as an alternative protein source.

Pharmaceutical levels of zinc oxide (1,000 to 3,000 mg Zn/kg of diet) are commonly included in the first couple of weeks after weaning to improve piglet performance (Hill et al., 2001; Sales, 2013). In phase 1 zinc oxide is included at 0.25% providing zinc at 1984.82 mg/kg of feed. In phase 2 zinc oxide is reduced to 0.15%, providing zinc at 1272.73 mg/kg, by phase 3 zinc oxide has been removed from the diet. Zinc oxide has been reduced from the original diets which included zinc oxide at 0.42% (3220 mg/kg) and 0.28% (2214 mg/kg) in phase 1 and 2, respecitivly. Several authors have shown that the positive effects of zinc oxide can be achieved at lower levels (1,500 – 2,250 mg/kg) (Hill et al., 2001; Sales, 2013). Additionally, zinc oxide provided at high level presents several challenges such poor absorption, toxicity, palatability, and interference with other minerals. Zinc oxide is not well absorbed by the pig thus it is excreted into the manure and can be considered a pollutant if field application is mismanaged (NRC, 2012; Sales, 2013). Additionally, feeding zinc for an extended period at high levels, can result zinc toxicity which can lead to reduced performance (Grimmett et al., 1937; NRC, 2012). Zinc also has low palatability, which can lead to reduction in feed intake if included at too high of levels (Reynolds, 2008). Finally, zinc oxide interacts with other minerals if provided in too high of quantities can lead to deficiencies. Walk et al. (2013) reported a linear decrease in P and Ca serum concentrations with increasing zinc oxide levels in the diet. Further, zinc oxide can from zinc-phytate complexes which limits the ability of phytase of cleave the bound phosphorus in phytate (Blavi et al., 2017).

Soybean oil is also included in phase 1 at 3.05%, phase 2 at 2.86%, and phase 3 at 2.5% increase the energy density of the diet and meet the higher energy requirements of the first 3 phases. The nursey diets also contain products like oats and whey which are lower in energy than corn or soybean meal, which requires that a more energy dense product be included into the diet. A disadvantage of soybean oil is that it is a relatively expensive ingredient. Animal fats tend to be cheaper than vegetable oils, making it a popular choice in commerical diets. From the April 22, 2022, USDA Animal By-Product Feedstuff Report, choice white grease and soybean oil priced at $1.43 and 1.79 per kg, respectively. Although more expensive, vegetable oils have a higher digestiblity than animal fats during the initial weeks post week, making soybean oil a better choice for the nursery diets over choice white grease or tallow (Cera et al., 1989).

Most specialty feed ingredients are considerably more expensive than that of either corn or soybean meal, which limits their inclusion in the diet. Based on reports from April 1, 2022, oats (Trading Economics, 2022), soybean oil (USDA AMS Livestock, 2022b) and whey (Dairy Market News, 2022) cost $0.50, 1.75, and 1.67 per kg, respecitivly. While yellow dent corn (USDA AMS Livestock, 2022c) and soybean meal (USDA AMS Livestock, 2022b) cost $ 0.32 and 0.49 per kg, respectively. Limiting the inclusion of these specialty ingredients can greatly reduce diet costs.

Beyond costs, these ingredients are also removed due the pig's ability to consume larger quantities of feed. Feed ingredients such as plasma proteins, ESBM, oats, and soybean oil are added because they add either energy or protein to the diet at a higher rate than what can be provided by either or corn or soybean meal. Due to nursery pigs' limited ability to consume large quantities of feed, they require a diet that is more nutrient dense than that of an older pig. Voluntary feed intake increases at a more rapid rate than protein and energy requriements (Niemi et al., 2010; NRC, 2012; Pomar and Remus, 2019). Due to this, nutrient density per kg of feed is reduced to match the pigs voluntary feed intake. This results in an older pig eating more of a cheaper, simpler, less nutrient dense diet than a nursery pig but still consuming higher levels of dietary nutrients. The decreasing complexity of the new diets is presented in Table 3.8. After phase 3, protein is reduced which causes a reduction in the inclusion of soybean meal and an increase in the inclusion of corn.

With growth models, pig performance and the feed program can be evaluated and improved to reduce diet costs, improve pig performance, and increase sustainability.

Table 3. 1 Body weights of the SDSU swine herd from wean to 22 weeks and body weights of PIC and Compart from weaning to 25 weeks.

	BW, kg		
Weeks Post Wean	SDSU	Compart[1]	PIC[2]
0	5.7	6.1	5.9
1	6.9	7.0	7.3
2	8.6	8.2	9.5
3	10.7	9.8	12.2
4	13.4	11.8	15.4
5	16.7	14.2	19.8
6	20.6	17.2	24.7
7	25.1	20.6	29.9
8	30.2	24.5	35.4
9	35.8	28.9	41.3
10	41.8	33.8	47.5
11	48.1	39.0	54.0
12	54.8	44.6	60.5
13	61.6	50.5	67.3
14	68.5	56.7	74.1
15	75.4	63.0	81
16	82.3	69.4	87.8
17	89.0	75.9	94.6
18	95.6	82.4	101.4
19	101.9	88.8	108
20	108.0	95.2	114.5
21	113.8	101.4	121
22	119.2	107.4	127.2
23	-	113.2	133.2
24	-	118.8	139.1
25	-	124.2	144.8

[1]Sourced from close out data provided by Compart Family Farms
[2] PIC (2021) Nutrition and Feeding Guidelines

Table 3. 2 Daily gain (ADG), feed intake (ADF), and feed conversion (G:F) of the SDSU swine herd.

Weeks Post Wean	ADG, kg/day	ADFI, kg/day	G:F
1	0.200	0.282	0.709
2	0.294	0.386	0.762
3	0.383	0.504	0.759
4	0.466	0.644	0.723
5	0.543	0.805	0.675
6	0.614	0.985	0.624
7	0.680	1.182	.576
8	0.741	1.389	0.533
9	0.795	1.602	0.496
10	0.844	1.813	0.466
11	0.887	2.015	0.440
12	0.925	2.203	0.420
13	0.957	2.373	0.403
14	0.983	2.523	0.390
15	1.003	2.653	0.378
16	1.018	2.762	0.369
17	1.027	2.853	0.360
18	1.031	2.928	0.352
19	1.029	2.989	0.344
20	1.021	3.038	0.336
21	1.007	3.077	0.327
22	0.988	3.108	0.318

Table 3. 3 Calculated dietary nutrient content for the previous SDSU wean to finish diets

	Phase							
	1	2	3	4	5	6	7	8
BW, kg	wean to 7	7-11	11-22	22-40	40-60	60-80	80-105	105-280
Budget, kg	1.95	6.0	12.7	36.8	47.3	52.7	58.6	82.7
ME, kcal/kg	3504.6	3396.8	3300	3315.4	3328.6	3337.4	3341.8	3348.4
NE, kcal/kg	2499.2	2503.6	2367.2	2417.8	2466.2	2497.0	2519.0	2545.4
Calcium and Phosphorus								
Available P	0.55	0.45	0.37	0.32	0.27	0.23	0.21	0.19
Digestible P	0.51	0.42	0.36	0.31	0.27	0.24	0.22	0.20
Analyzed Ca	0.85	0.85	0.75	0.70	0.62	0.57	0.54	0.50
SID AA, %								
Arginine	1.27	1.18	1.19	1.00	0.83	0.72	0.63	0.53
Histidine	0.55	0.49	0.47	0.41	0.36	0.32	0.006	0.26
Isoleucine	0.91	0.77	0.72	0.62	0.52	0.46	0.41	0.35
Leucine	1.74	1.59	1.56	1.41	1.28	1.19	1.13	1.05
Lysine	1.51	1.31	1.25	1.08	0.94	0.84	0.75	0.65
Methionine	0.57	0.46	0.43	0.36	0.31	0.28	0.24	0.21
Phenylalanine	0.95	0.86	0.86	0.74	0.64	0.58	0.53	0.47
Threonine	0.94	0.81	0.78	0.68	0.59	0.53	0.49	0.43
Tryptophan	0.28	0.25	0.21	0.17	0.15	0.13	0.12	0.10
Valine	0.99	0.85	0.81	0.70	0.61	0.55	0.50	0.45
Minerals								
Sodium, %	0.29	0.14	0.16	0.14	0.14	0.14	0.14	0.14
Chloride, %	0.44	0.22	0.26	0.23	0.23	0.23	0.23	0.23
Magnesium, %	0.15	0.19	0.20	0.19	0.17	0.16	0.16	0.15
Potassium, %	1.07	0.99	0.87	0.75	0.64	0.57	0.523	0.46
Copper, ppm	25	25	24	23	22	21	21	20
Iodine, ppm	0.44	0.42	0.40	0.40	0.40	0.39	0.39	0.39

Iron, ppm	315	346	354	328	301	285	273	262
Manganese, ppm	44	48	49	47	45	43	42	41
Selenium, ppm	0.55	0.49	0.43	0.41	0.40	0.39	0.39	0.38
Zinc, ppm	3220	2214	197	194	192	190	189	187
Vitamins								
A, IU/kg	1405.8	1449.8	1476.2	1267.2	1278.2	1284.8	1291.4	1295.8
D, IU/kg	132	132	132	110	110	110	110	110
E, IU/kg	19.8	22	22	15.4	17.6	17.6	17.6	17.6
Biotin, mg/kg	0.154	0.132	0.132	0.110	0.110	0.088	0.088	0.088
Choline	1023	1364	1234.2	1095.6	972.4	891.0	829.4	756.8
Folic acid, mg/kg	0.572	0.55	0.506	0.440	0.374	0.308	0.286	0.242
Niacin, mg/kg	29.26	311.68	32.34	27.72	27.94	27.94	28.16	28.16
Pantothenic acid, mg/kg	22.66	17.6	13.64	11.00	10.34	10.12	9.90	9.46
Riboflavin, mg/kg	9.9	6.16	3.52	3.3	3.08	3.08	3.08	3.08
Thiamin, mg/kg	3.08	3.3	3.3	3.3	3.3	3.3	3.3	3.52
B12, mg/kg	0.022	0.022	0.0	0.0	0.0	0.0	0.0	0.0
B6, mg/kg	4.4	50.6	5.28	5.28	5.06	5.06	5.06	5.06
Linoleic acid, %	2.7	2.2	1.4	1.5	1.6	1.7	1.7	1.8
Lactose, %	18	7.2	0	0	0	0	0	0

Table 3. 4 Calculated dietary nutrient content for the new SDSU wean to finish diets.

	Phases							
	1	2	3	4	5	6	7	8
BW, kg	wean to 7	7 – 11	11 – 22	22 – 40	40 – 60	60 – 80	80 – 105	105 – 280
Feed Budget, kg	2	6.2	17	29.2	42.2	52.8	59.8	107.3
ME, kcal/kg	3,498	3,454	3,399	3,300	3,300	3,300	3,320	3,325
NE, kcal/kg	2,278	2,309	2,534	2,483	2,519	2,519	2,551	2,571
Calcium and Phosphorus								
Available P	0.39	0.30	0.37	0.26	0.28	0.24	0.21	0.18
STTD P	0.53	0.45	0.45	0.34	0.35	0.31	0.28	0.25
STTD Ca	0.63	0.56	0.58	0.44	0.43	0.39	0.33	0.32
SID AA, %								
Lysine	1.52	1.42	1.30	1.10	0.84	0.84	0.70	0.60
Methionine + Cystine	0.88	0.82	0.75	0.68	0.47	0.49	0.44	0.41
Threonine	0.97	0.92	0.85	0.72	0.55	0.55	0.46	0.40
Tryptophan	0.30	0.27	0.24	0.20	0.15	0.15	0.13	0.11
Isoleucine	0.93	0.91	0.81	0.67	0.54	0.54	0.48	0.42
Valine	1.03	0.97	0.88	0.75	0.63	0.63	0.57	0.51
Methionine	0.53	0.50	0.45	0.41	0.23	0.25	0.21	0.20
Cysteine	0.35	0.32	0.30	0.27	0.24	0.24	0.22	0.21
Leucine	1.67	1.74	1.65	1.48	1.31	1.31	1.23	1.14
Minerals								
Sodium, %	0.339	0.240	0.179	0.179	0.179	0.179	0.178	0.178
Chloride, %	0.586	0.377	0.240	0.238	0.238	0.238	0.237	0.236
Magnesium, %	0.191	0.201	0.185	0.172	0.159	0.159	0.151	0.147
Potassium, %	0.191	1.295	0.975	0.816	0.666	0.666	0.596	0.526
Copper, ppm	24	24	24	23	22	22	22	21

Iodine, ppm	0.40	0.38	0.36	0.36	0.36	0.36	0.36	0.36
Iron, ppm	266	257	244	231	222	223	213	213
Manganese, ppm	63	60	59	56	54	54	53	52
Selenium, ppm	0.40	0.44	0.44	0.42	0.40	0.40	0.40	0.39
Zinc, ppm	1,985	1,273	192	190	187	187	186	185
Vitamins								
A, IU/kg	11000	11000	11000	11000	11000	11000	11000	11000
D, IU/kg	1650	1650	1650	1650	1650	1650	1650	1650
E, IU/kg	58	55	55	55	55	55	55	55
Biotin, mg/kg	0.24	0.27	0.30	0.28	0.27	0.26	0.26	0.25
Choline, mg/kg	981	1080	1322	1156	992	992	918	841
Folic acid, mg/kg	1.56	1.57	1.67	1.57	1.47	1.47	1.43	1.38
Niacin, mg/kg	65	72	77	78	78	78	78	78
Pantothenic acid, mg/kg	68	68	69	69	68	68	68	67
Riboflavin, mg/kg	11	11	12	12	11	11	11	11
Thiamin, mg/kg	5.81	5.81	6.48	6.63	6.66	6.66	6.69	6.70
B6, mg/kg	5.60	7.42	8.49	8.53	8.43	8.43	8.41	8.36
B12, mg/kg	4.41	4.41	4.41	4.41	4.41	4.41	4.41	4.41
Linoleic acid, %	0.31	0.88	1.13	1.27	1.35	1.34	1.39	1.43
Lactose, %	20	8						

Table 3. 5 Lysine to gain ratios

	Phase							
	1	2	3	4	5	6	7	8
BW, kg	Wean to 7	7 – 11	11- 30	20- 40	40-60	60-80	80-105	105 to Market
ADG, g/day	300	338	464	708	885	967	1016	1011
ADFI, g/day	282	445	651	1290	2010	2438	2756	3053
Previous Diets SID Lysine, % in Diet	1.51	1.31	1.25	1.08	0.94	0.84	0.75	0.65
SID Lysine consumed, g/day	4.25	5.83	8.14	13.93	18.90	20.48	20.67	19.85
Previous SID Lysine, g/day : ADG, g	0.0213	0.0172	0.0175	0.0197	0.0213	0.0212	0.0203	0.0195
Targeted SID Lysine, g/day : ADG, g	0.0200	0.0200	0.0200	0.0200	0.019	0.019	0.019	0.019
Calculated SID Lysine, % in Diet	1.42	1.52	1.42	1.10	0.84	0.75	0.60	0.63

Table 3. 6 Targeted dietary specifications for the SDSU wean to finish diets.

	Phase							
	1	2	3	4	5	6	7	8
BW, kg	wean to 7	7-11	11-22	22-40	40-60	60-80	80-105	105 to market
Budget, kg	2.0	6.2	17.0	29.2	42.2	52.8	59.8	107.3
ME, kcal/kg	3500	3450	3400	3300	3300	3300	3300	3300
NE, kcal/kg	2500	2500	2450	2400	2400	2400	2400	2400
Calcium and Phosphorus								
STTD P	0.50	0.45	0.45	0.40	0.35	0.31	0.28	0.25
Available P	0.45	0.42	0.39	0.34	0.30	0.27	0.24	0.22
STTD Ca	0.63	0.56	0.56	0.50	0.44	0.39	0.35	0.31
Available Ca	0.56	0.56	0.49	0.42	0.37	0.34	0.30	0.27
SID AA, %								
Arginine	1.52	1.42	1.30	1.10	0.84	0.75	0.70	0.60
Histidine	0.53	0.48	0.44	0.38	0.29	0.26	0.24	0.21
Isoleucine	0.78	0.73	0.67	0.57	0.44	0.40	0.37	0.32
Leucine	1.52	1.42	1.30	1.11	0.84	0.76	0.71	0.61
Lysine	1.52	1.42	1.30	1.10	0.84	0.75	0.70	0.60
Methionine	0.88	0.82	0.75	0.64	0.49	0.44	0.41	0.35
Phenylalanine	0.89	0.83	0.76	0.66	0.50	0.45	0.42	0.36
Threonine	0.99	0.92	0.85	0.72	0.55	0.49	0.46	0.40
Tryptophan	0.29	0.27	0.23	0.20	0.15	0.14	0.13	0.11
Valine	1.03	0.97	0.88	0.75	0.57	0.51	0.48	0.41
Minerals								
Sodium, %	0.40	0.35	0.28	0.25	0.25	0.25	0.25	0.25
Chloride, %	0.50	0.45	0.32	0.25	0.25	0.25	0.25	0.25
Magnesium, %	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15

Potassium, %	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Copper, ppm	16.50	16.50	16.50	16.50	16.50	16.50	16.50	16.50
Iodine, ppm	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36
Iron, ppm	165	165	165	165	165	165	165	165
Manganese, ppm	44.10	44.10	44.10	44.10	44.10	44.10	44.10	44.10
Selenium, ppm	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Zinc, ppm	165	165	165	165	165	165	165	165
Vitamins								
A, IU/kg	1405.8	1405.8	1405.8	1405.8	1405.8	1405.8	1405.8	1405.8
D, IU/kg	132	132	132	132	132	132	132	132
E, IU/kg	19.80	19.80	19.80	19.80	19.80	19.80	19.80	19.80
K, mg/kg	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88
Biotin, mg/kg	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Choline	1023	1023	1023	1023	1023	1023	1023	1023
Folic acid, mg/kg	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10
Niacin, mg/kg	55.0	55.0	55.0	55.0	55.0	55.0	55.0	55.0
Pantothenic acid, mg/kg	60.5	60.5	60.5	60.5	60.5	60.5	60.5	60.5
Riboflavin, mg/kg	9.92	9.92	9.92	9.92	9.92	9.92	9.92	9.92
Thiamin, mg/kg	3.30	3.30	3.30	3.30	3.30	3.30	3.30	3.30
B12, mg/kg	0.0441	0.0441	0.0441	0.0441	0.0441	0.0441	0.0441	0.0441
B6, mg/kg	3.30	3.30	3.30	3.30	3.30	3.30	3.30	3.30
Linoleic acid, %	2.70	2.20	1.40	1.50	1.60	1.70	1.70	1.80

Table 3. 7 Targeted amino acid ratios.

	Phase							
	1	2	3	4	5	6	7	8
Arginine	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Histidine	0.347	0.341	0.341	0.347	0.344	0.342	0.342	0.344
Isoleucine	0.513	0.511	0.512	0.520	0.525	0.532	0.534	0.541
Leucine	1.000	1.000	1.000	1.010	1.005	1.007	1.014	1.016
Lysine	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Methionine + Cysteine	0.580	0.580	0.580	0.580	0.580	0.580	0.580	0.580
Phenylalanine	0.587	0.585	0.585	0.602	0.601	0.601	0.603	0.607
Threonine	0.650	0.650	0.650	0.650	0.650	0.650	0.650	0.660
Tryptophan	0.190	0.190	0.180	0.180	0.180	0.180	0.180	0.180
Valine	0.680	0.680	0.680	0.680	0.680	0.680	0.680	0.680

Table 3. 8 Dietary composition of new SDSU wean to finish diets.

	Phase							
Item, % inclusion	1	2	3	4	5	6	7	8
Corn	9.87	44.69	59.02	71.05	79.00	81.28	84.42	87.15
Soybean Meal, 47.5%	24.99	29.41	35.02	26.21	18.00	16.51	14.66	11.01
Whey Permeate, 80%	25.00	10.00						
Oat Groats	21.00							
Further Processed Soybean meal	10.00	10.00						
Spray Dried Plasma	3.00							
Soybean Oil	3.05	2.86	2.6821					
Lysine HCl	0.301	0.324	0.350	0.363	0.300	0.220	0.213	0.20
DL-Methionine	0.238	0.191	0.157	0.147	0.071			
L-Threonine	0.168	0.163		0.137		0.035	0.029	0.017
L-Tryptophan				0.007				
Salt	0.400	0.400	0.400	0.400	0.400	0.400	0.400	0.400
Mineral Premix	0.150	0.150	0.150	0.150	0.150	0.150	0.150	0.150
Vitamin Premix	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
Limestone	1.130	0.994	0.974	0.770	0.500	0.680	0.532	0.593
Monocalcium Phosphate		0.218	0.802	0.313	0.500	0.281	0.143	0.031
Zinc Oxide	0.250	0.150						
Phytase	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
Mycotoxin Binder	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250
Larvicide	0.130	0.130	0.130	0.130	0.130	0.130	0.130	0.130

Figure 3. 1 Body weight of the SDSU herd versus weeks post wean

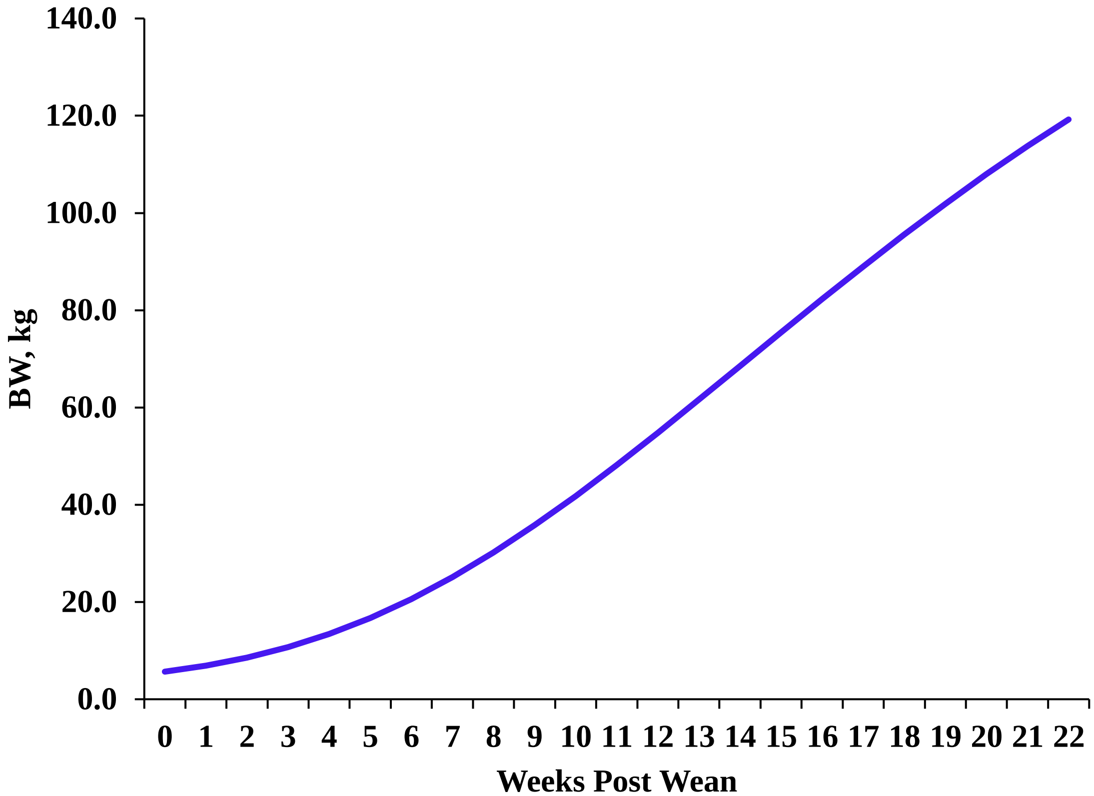
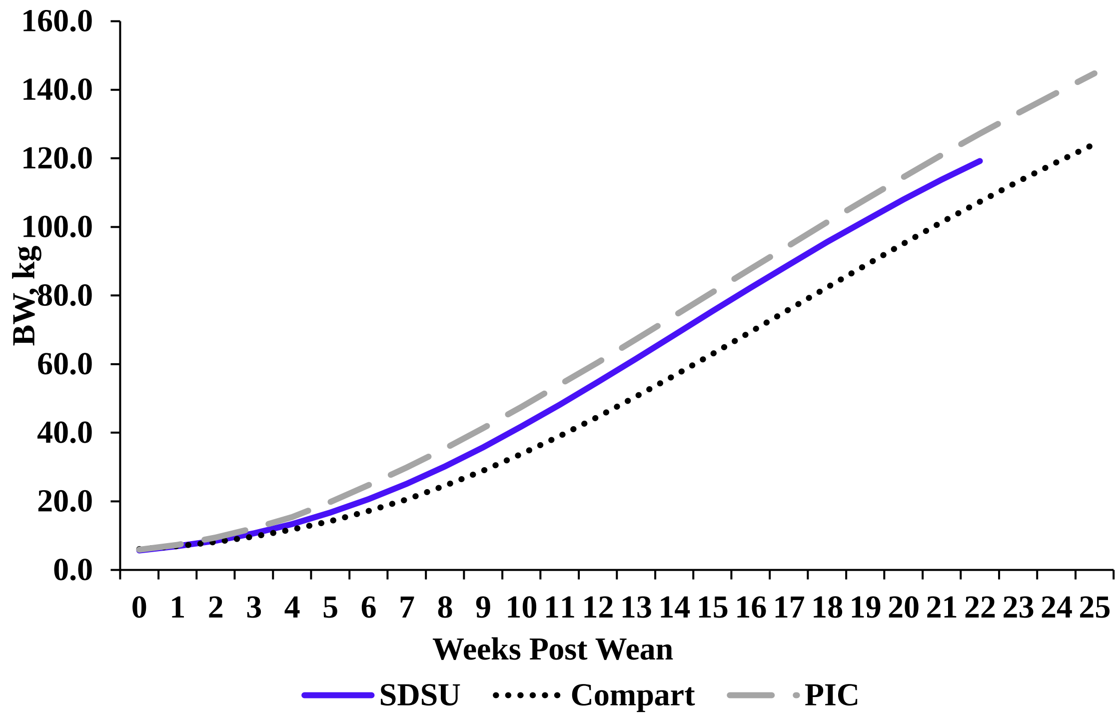


Figure 3. 2 Plot of pig BW from weaning to market of the SDSU swine herd and the two genetic sources, Compart[1] and PIC[2] used at SDSU.



[1]Sourced from close out data provided by Compart Family Farms

[2] PIC (2021) Nutrition and Feeding Guidelines

Figure 3. 3 ADG of the SDSU herd versus weeks post wean

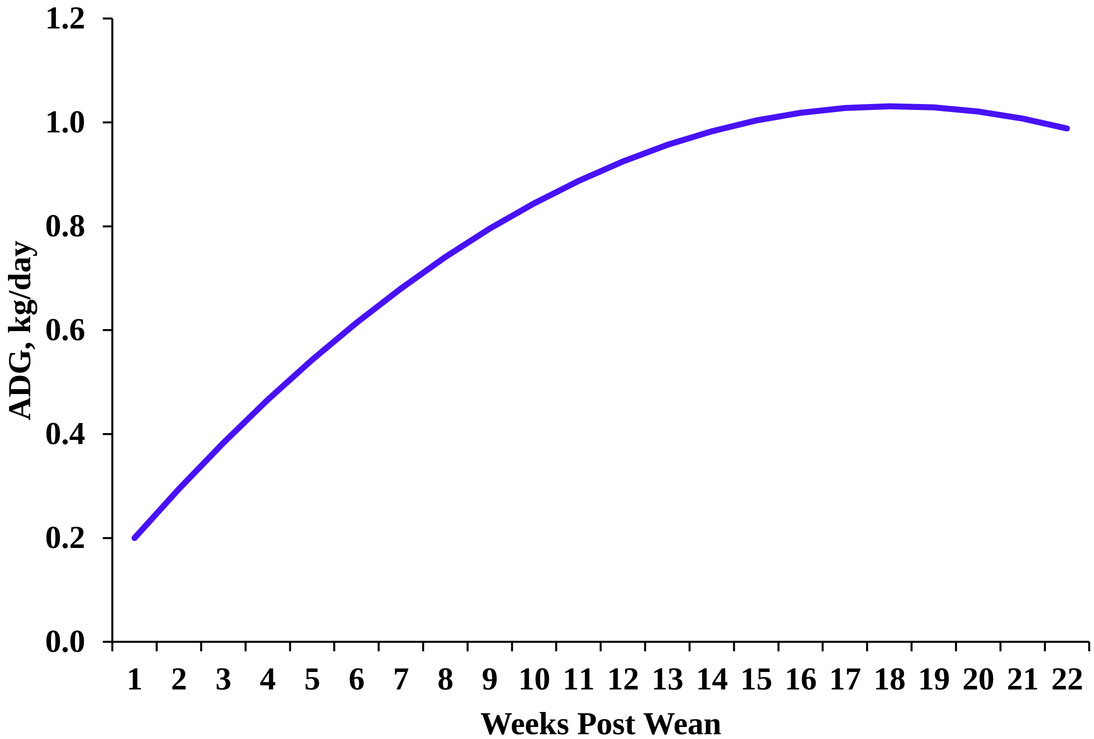


Figure 3. 4 ADFI of the SDSU herd versus weeks post wean

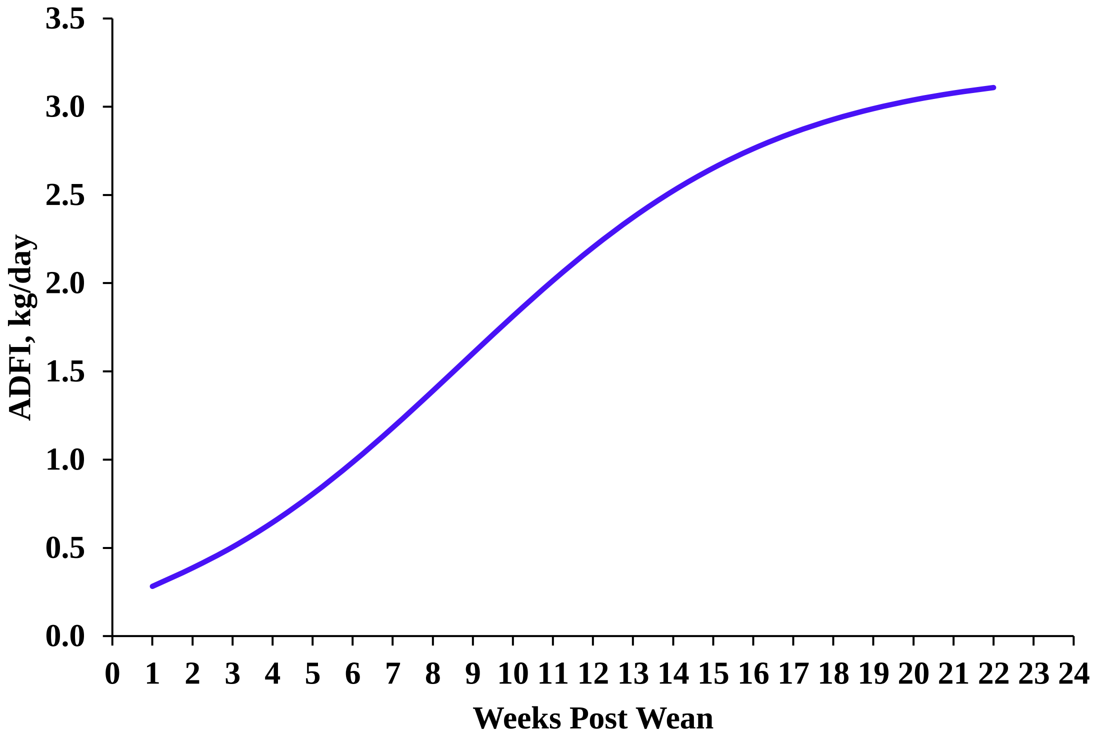
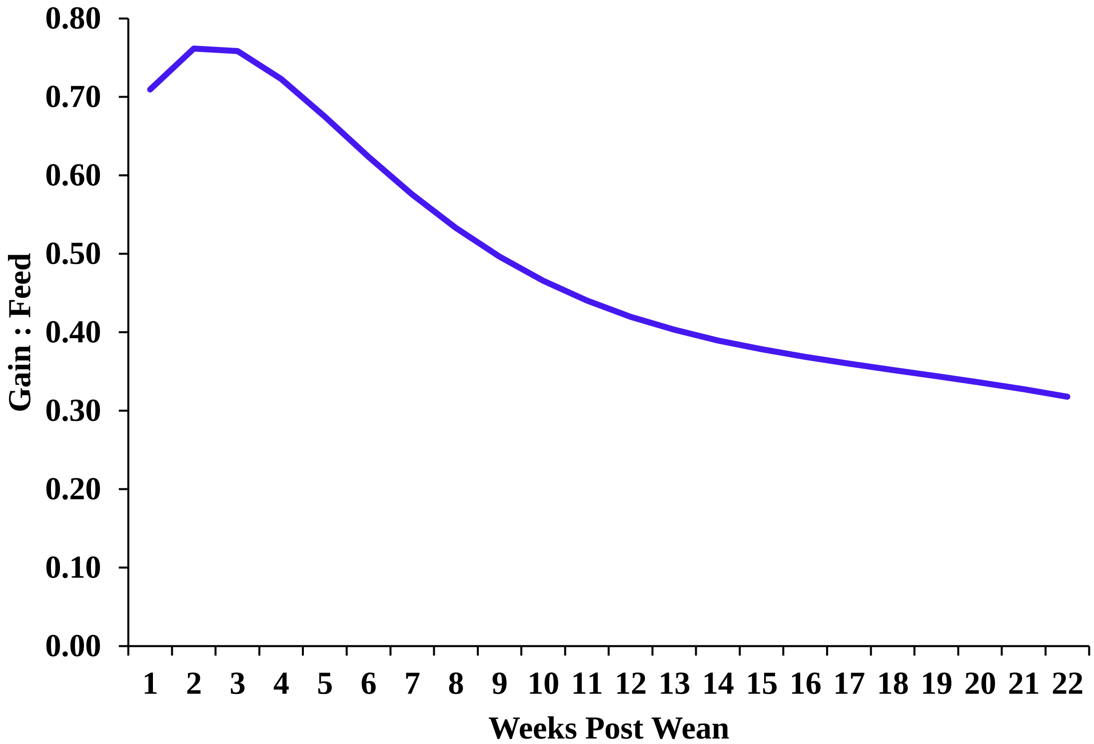


Figure 3. 5 Feed conversion versus weeks post wean



4.0 SECURE PORK SUPPLY PLAN

4.1 Introduction

Entry of a FAD, such as classical swine fever, African swine fever, or foot and mouth disease, to the United States would have a major impact on swine production, movement of animals, and trade (Secure Pork Supply, 2020). To minimize the impact of an outbreak, reduce risk, and to prepare for such an event the Pork Checkoff and the USDA have created a voluntary continuity of business plan called Secure Pork Supply Plans (Secure Pork Supply, 2018). These plans outline enhanced biosecurity protocols that would be implemented during the event of an outbreak. If a site can prove to authorities that they are following these enhanced biosecurity protocols and have animals that are free of disease, they can continue movement and selling of animals even in a controlled area (Secure Pork Supply, 2020).

South Dakota State University has 2 swine unit facilities. The Off-site facility, located 1 mile from the interstate, near the Ward rest area, is a 1,200 head wean to finish barn. The second site, or the On-site facility, is a farrow to finish facility with 2 animal buildings, the Sow Teaching and Research unit and the Wean to Finish Research unit, with a classroom adjoined to the sow unit. The On-site can house 150 sows, 200 – 300 suckling piglets, and 1,200 weaned pigs. The On-site is located 2 miles north of campus's Animal and Veterinary Sciences buildings, and 1 mile north of Highway 14. As a leader and advocate for the swine industry and due to the proximity of each unit to high traffic areas, Secure Pork Supply Plans were created for the two swine facilities at SDSU.

4.2 Materials and Methods

A valid premise identification number (PIN) is required to create an enhanced biosecurity plan through the Secure Pork Supply Plan. The PIN is included in the enhanced biosecurity plan. In the facilities used in this review the PIN was obtained from the PQA Plus® site assessment.

Aerial maps of both facilities were obtained from Google Maps (https://www.google.come/maps, last accessed February 2022) using the coordinate of the facilities.

The Secure Pork Supply Plan’s Information Manual for Enhanced Biosecurity for Pork Production: Animals Raised Indoors (2017) requires all maps to be clearly marked (Figure 4.1) with the following items: Perimeter Buffer Area (PBA), Line of Separation (LOS), Designated parking area, Carcass disposal/ pickup location, Cleaning and Disinfecting Station (C&D), PBA Access Points, LOS Access Points, Carcass removal pathway, Vehicle movement, and site entry.

The PBA is defined as the outer boundary around the buildings. It is designated by a light blue perimeter in the map. Individuals are able to perform their daily activities within the bounds of the PBA. Deliveries and other activities not essential to the daily operation should occur outside of the PBA. Individuals must enter the PBA through the PBA Access Point and its designated biosecurity measures.

The LOS is a second boundary of control within the PBA. Designated by a red line on the map. Walls of buildings and other permanent structures are often indicators of

LOS. The LOS may only be entered through controlled LOS Access Points and its assigned biosecurity measures.

The Designated Parking Area should be located away from animal areas. It is for vehicles that will not be entering the PBA and have not been cleaned or disinfected. Parking is indicated by a green line.

Carcass disposal and pickup location should be located away from PBA to prevent contamination from rendering trucks and other vehicles hauling deceased animals. Carcass disposal should be managed in such a way as to prevent the attraction of wildlife and scavengers. On the map carcass disposal is indicated by a dark blue perimeter.

The C&D station is used for vehicles that will be entering the PBA. All items entering the PBA should clear of all contamination and be disinfected. The C&D station should be operated by trained individuals. The C&D stations should follow local regulations, be located away from water ways, and avoid livestock housing or on-farm traffic. The C&D station is designated by a green diamond outlined in red on the map.

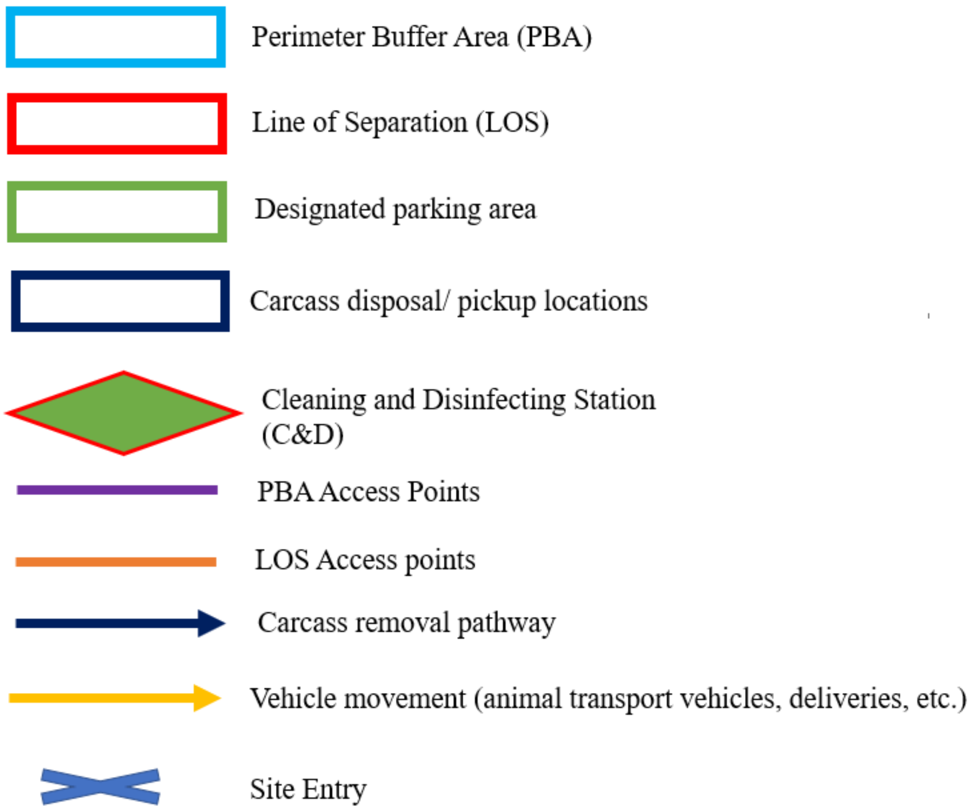
The PBA Access Point and LOS Access Point control the entry of the PBA and LOS, respectively. The PBA Access Points are marked purple, while LOS Access Points are marked orange on the map. The PBA and LOS Access Points should be marked with a sign. PBA Access Points should be protected by a physical barrier, such as a rope, gate, chain, or cable. Objects, people and animals crossing the LOS Access Point should follow the designed biosecurity measures and should be recorded in a logbook.

Vehicles for animal transport and deliveries as well as carcass removals should follow the designed paths outlined in the enhanced biosecurity plan. Vehicle movement is marked with a yellow arrow while carcass removal pathway is marked with a dark blue or black arrow on the map.

Entrance to facilities is restricted to a limited number of site entries. Entry points should be protected with a lockable barrier like a gate, chain, rope or cable. Site of entry should also be accompanied with a sign, denoting that access is restricted. On the map site entry is marked with a blue “X”.

After identifying and delineating the respective areas on a map of the property, a site-specific enhanced biosecurity plan is created using a customizable template provided from Secure Pork Supply (https://www.securepork.org/pork-producers/biosecurity/, last accessed February 2022). This plan consists of 10 sections which outlines protocols regarding proper entry into perimeters and lines of separation for animals, people, vehicles, and equipment, carcass disposal, manure management, pest control, and feed entry. The site map and the and the site-specific enhanced biosecurity plan together constitute a complete enhanced biosecurity plan.

Figure 4. 1 Legend of the items denoted on an Enhanced Biosecurity Plan.



4.3 South Dakota State University Off-Site Facility Enhanced Biosecurity

Plan for FAD Prevention in South Dakota

Date: 03/29/2022

This Biosecurity Plan is based off of the Secure Pork Supply (SPS) Self-Assessment Checklist for Enhanced Pork Production Biosecurity: Animals Raised Indoors, [August 2017] and was developed using guidance from the SPS Information Manual for Enhanced Biosecurity: Animals Raised Indoors. All documents are available at www.securepork.org. In the Plan below, all items have been implemented except those indicated which will be implemented prior to requesting an animal movement permit.

Scope of Biosecurity Plan

- National Premises Identification Number (Prem ID or PIN): 00N5GGN
- Premises Address: 47292 223rd street Flandreau, SD
- Premises GPS Coordinates: 44.15333544487447, -96.75126671604035
- Animals* on primary premises: 1,200 head wean to finish pigs
- Other business operations on premises? No
- Secondary premises** locations (PIN, 911 address, or GPS coordinates): N/A
    - Will be provided to Responsible Regulatory Officials if this premises is located in an FAD Control Area
    - *Work with your State Animal Health Official to determine if separate PINs are needed for all of your associated premises.

*Animals that are susceptible to FMD include cattle, pigs, sheep, goats, and elk. For biosecurity guidance for dairy cattle and beef cattle, see www.securemilksupply.org and www.securebeef.org.
**Work with your State Animal Health Official to determine if separate PINs are needed for all of your associated premises. When a premises becomes infected, all premises with the same PIN number will be considered to be infected.

Biosecurity Manager and Written Plan

The **designated Biosecurity Manager** for this site and their contact information follows:

NAME: Dr. Ryan Samuel
PHONE: 859-221-7218
EMAIL: ryan.samuel@sdstate.edu

In the event the Biosecurity Manager is away from the site, **their designee's** contact information is:

NAME: Juan Castillo Zuniga (assistant manager)
PHONE: 605-592-4048
EMAIL: juan.castillo@sdstate.edu

The Biosecurity Manager's contact information is posted in the barn office.

Dr. Ryan Samuel and Juan Castillo Zuniga have the written authority to ensure compliance with biosecurity protocols and take corrective action as needed.

Hannah Miller developed the site-specific biosecurity plan with the assistance of:

- Dr. Scott VanderPoel, a licensed veterinarian whose contact information is:
  PHONE: 508-820-0914
  EMAIL: scott.vanderpoel@pipestone.com

- Dr. Bob Thaler, a consultant with South Dakota State University whose contact information is:
  PHONE: 605-695-6444
  EMAIL: robert.thaler@sdstate.edu

The Biosecurity Manager or their designee:

- ☒ communicates with and/or trains individuals entering on biosecurity measures to follow;
- ☒ reviews the biosecurity plan at least annually and updates it whenever the site goes through a change affecting biosecurity;
- ☒ ensures that all individuals entering the site frequently (weekly or more often) have access to a copy of the biosecurity plan;
- ☒ is capable of implementing the written plan if FMD, CSF, or ASF is diagnosed in the U.S.; and
- ☒ has the authority to take corrective action, as needed, when biosecurity protocols are not followed.

A labeled premises map is included at the end of this plan and can be found on the premises at: the barn office

Training

The people in the positions listed below are trained at least once about the biosecurity measures necessary to keep an FAD out of the herd. This training is documented and available for review upon request.

Manager, Assistant Manager, Student Employees, Graduate students, and Faculty

The Biosecurity Manager(s) informs individuals entering the site of the biosecurity measures they are to follow in a language they understand. Individuals are aware of the biosecurity concepts and procedures that apply to their specific areas of responsibility. Our required training is described below.

All individuals entering must understand how to:

- ☒ Contact the Biosecurity Manager(s)
- ☒ Respect the Perimeter Buffer Area (PBA)

☒ Cross the Line of Separation (LOS), if required, following arrival and biosecure entry
requirements
☒ Perform biosecurity measures for their specific job duties

In addition, employees must:
☒ Undergo biosecurity training prior to starting to work at the site;
☒ Understand the importance of biosecurity;
☒ Review the entire biosecurity plan;
☒ Review the labeled premises map;
☒ Know who to report to if they see someone not complying or something preventing compliance; and
☒ Recognize the consequences for not complying with biosecurity protocols.

Communication occurs with drivers, delivery and service personnel, veterinarians, livestock transporters, and visitors through the following methods:
☒ phone calls, text messages, emails, faxes

Protecting the Pig Herd

Site Entry

Entry to the site (such as driveways) is restricted to one site entry and each are labeled on the premises map at the end of this plan.

- Each entry point, including unused entries, is protected with a suitable barrier consisting of rope and/or snow fence to restrict entry.

The entry point is secured with rope and/or snow fence.

Signs written in these languages, English, are posted at the site entry that including the following contact information, manager and assistant manager.

Perimeter Buffer Area (PBA)

The Perimeter Buffer Area is labeled on the premises map at the end of this plan. The PBA is marked on-site with rope and/or snow fence.

PBA Access Point(s)

Entry to the PBA is restricted to 2 controlled PBA Access Point(s) and each are labeled on the premises map at the end of this plan. The PBA Access Points are clearly marked with a suitable barrier of rope and/or snow fence to restrict entry.

Signs written in these languages, English, are posted at all PBA Access Points that include the following contact information: manager and assistant manager.

All movements (animals, vehicles, equipment, people) which enter the PBA are recorded and these documents are kept in the barn office and are available for review upon request.

Deliveries are made outside of the PBA at the SDSU Animal Science office.

Vehicles and equipment entering the PBA Access Points are cleaned to remove visible contamination and then disinfected at the Cleaning and Disinfection Station.

People and items crossing through the PBA Access Points follow appropriate specific biosecurity steps, described under Biosecure Entry Procedure in this plan.

Cleaning and Disinfection (C&D) Station

There is an operational, clearly marked, and equipped C&D station(s) located southwest of the main facilities, and it is labeled on the premises map at the end of this plan. The wash pad for the C&D station is made of gravel and slopes away from animal housing, feed receiving or storage areas, waterways, and on-farm traffic areas. This site uses drainage ditch to manage runoff from the C&D area to ensure susceptible animals are not exposed. Runoff from the C&D Station is managed following all state and local regulations.

This site has access to all the equipment and supplies needed to successfully operate the C&D Station. The SOP for the C&D process is available upon request.

The following individuals have received documented training in proper selection and use of personal protective equipment, the principles of C&D to avoid introducing an FAD virus on the site and are able to effectively operate the C&D Station.

- Manager
- Assistant manager

In the case of inclement weather (freezing temperatures, thunderstorms, high winds) when the C&D Station cannot be operated, we have the following contingency plans to ensure vehicles do not bring visible contamination onto our site:

- A high-pressure power washer utilizing warm water with a disinfectant metered in will be used in freezing temperatures at the C&D station. Since thunderstorms and high winds are usually gone in a day, we will wait until they have passed before using the C&D station.

Designated Parking Area

The designated parking area is clearly marked onsite with rope and labeled on the premises map at the end of this plan. It is located outside of the PBA and away from animal areas.

Line of Separation (LOS)

The Line of Separation is labeled on the premises map at the end of this plan.

LOS Access Point(s)

Entry to the LOS is restricted to 5 controlled LOS Access Point(s) and each are labeled on the premises map at the end of this plan. The LOS Access Points are clearly marked with bench entry way and showers in the employee entry building; brightly colored spray paint on the floor indicating LOS access points at the north and south end of the barn.

Signs written in these languages English are posted at all LOS Access Points that include the biosecurity protocol required for each entry.

All movements (animals, equipment, supplies, people) which cross the LOS are recorded and these documents are kept in the barn office and are available for review upon request.

The designated animal loading/unloading area is labeled on the premises map at the end of this plan, and this is NOT used for a people entry point unless there is no alternative.

People crossing the LOS Access Points follow appropriate specific biosecurity steps, described under Biosecure Entry Procedure in this plan.

Biosecurity measures taken when food, personal items, equipment, and supplies cross the LOS include disinfecting or passing under a UV box prior to entry and exit and double bagging items that cannot be directly disinfected.

Securing the Buildings

Manager and assistant manager is/are responsible for ensuring the buildings are locked.

Vehicles and Equipment

Vehicles and Equipment (non-animal transport)

All vehicles and equipment not containing live animals are cleaned to remove visible contamination and effectively disinfected prior to crossing the PBA; otherwise, entry is prohibited.

☒ Equipment used on this site is not shared with equipment from other sites.

Livestock Trucks/Trailers (animal transport vehicles)

All empty animal transport vehicles are cleaned and disinfected prior to arrival at the site (outgoing loads) or before animals are loaded for delivery to the site (incoming loads).

Animal transport vehicles containing animals that are not being unloaded at this site are not allowed to cross the PBA. (Pick one, modify, cross out the other)

☒ The PBA is relocated while animals are unloaded. After the truck leaves, the PBA is re-established and the surface is C&D. If surface is cannot be C&D, then adequate amount of time is applied to cover the area.

Personnel

Prior to Arriving at the Site

The Biosecurity Manager ensures that everyone who needs to cross the LOS has been instructed on how to arrive at the site:

- with a clean vehicle interior (free of all animal manure/excrement) that has not become contaminated by soiled clothes, footwear, or other items
- having showered and wearing clean clothing and footwear since last contacting susceptible animals.
    - For individuals living off-site, after showering and changing into clean clothes and footwear, they must NOT contact animals, live or dead, or facilities where they are held at least 48 hrs or greater prior to arrival at the site.
- Individuals will put on disposable boots as they leave the vehicle and before stepping on the ground
- Individuals will be informed of the biosecurity measures they are to take once they arrive.

These individuals have a signed Employee and Visitor Arrival Agreement on file agreeing to follow our biosecure entry procedures (described below).

Entry Logbook

Everyone crossing the LOS Access Point(s) completes the entry log, which is located in the site office, unless they are a scheduled worker.

The entry log is monitored by manager/ student manager on the site to ensure accurate completion.

The contact information and work schedule records for all workers are maintained and posted at the following location barn office.

Biosecure Entry/Exit Procedure

When entering the PBA, all individuals must:
- Put on disposable or disinfectable footwear
- Put on gloves or apply hand sanitizer

All deliveries and items entering the PBA are recorded in the office log.

Vehicles and equipment entering the PBA need to be cleaned and disinfected (Vehicles are addressed in Section 6: Vehicles and Equipment).

All individuals crossing the LOS must:
- Shower in and shower out (delete if does not apply to this site)

- Put on site-specific coveralls or clothing and footwear at the LOS Access Point.
    - Absolutely no street clothes not completely covered by site-specific coveralls/hats/accessories are allowed past the LOS.
- The same procedure is in reverse when crossing back across the LOS from the pig side of the LOS, leaving site-specific clothing or coveralls and footwear inside the LOS.

Animal Movement

Incoming Animals and Semen

Pigs come only from sources with documented, enhanced biosecurity practices that align with our biosecurity practices and have no current or previous evidence of the FAD viruses. Diagnostic testing of animals as requested by the Responsible Regulatory Officials is negative.

Pre-movement Isolation Period

☒ We do not accept animals from operations within an FAD Control Area.

Contingency Plan for Interrupted Animal Movement

In the event animal movement is stopped for several weeks, this is our plan for managing animals in a biosecure manner:

☒ Cull animals will be humanely euthanized and properly disposed of on the operation (described under Carcass Disposal below).

☒ Housing, feed, and healthcare equipment are available for 1,200 head of market ready pigs for a period of a few weeks. A contingency plan has been established for ration formulation, transport and market of animals that are at, approaching, or have exceeded market weight.

☒ Our plan to manage weaned or nursery aged pigs:

☒ There is enough housing and feed available for 1,200 head of pigs for a period of a few weeks, depending on the circumstances .

☒ Humane euthanasia equipment and supplies are available if needed.

Loading Animals

Animals leaving the site only move in one direction across the LOS at an Access Point labeled on the premises map at the end of this plan. All areas inside the LOS that become contaminated by individuals or animals loading are cleaned with detergent and effectively disinfected by trained personnel after loading is complete. The SOP for the C&D process is available upon request.

☒ The animal loading/unloading area is NOT a people entry point.

The following individuals have received documented training in proper selection and use of personal protective equipment, the principles of C&D to avoid introducing an FAD virus to the site, and are able to effectively C&D the loading area:

- Manager
- Assistant manager

Carcass Disposal

In an FAD outbreak, dead animals (normal mortality numbers) are disposed of by composting in a way which prevents the attraction of wildlife, rodents, and other scavengers, and is in accordance with state and federal laws. Routes for carcass movement and disposal are labeled on the premises map at the end of this plan.

☒ Dead animals are disposed of onsite but outside of the PBA.

☒ Rendering trucks and other vehicles hauling dead animals to a common disposal site do not enter the PBA.

In the event of a large number of mortalities unrelated to the FAD infection (toxicity, heat stress, etc.), dead animals will be disposed of by composting which also prevents the attraction of wildlife, rodents, and other scavengers, and is in accordance with state and federal laws.

Manure Management

Manure is stored in deep pits

In the event of a prolonged outbreak, we can store manure for several months, depending on timing of an outbreak. After that time, the method for manure removal is application to fields utilizing a dragline to decrease the amount of traffic into the PBA. This will prevent exposure of susceptible animals and meet state, local and Responsible Regulatory Officials regulations.

☒ All manure handling vehicles and equipment from other sites is cleaned to remove all manure and disinfected with either heat or a chemical disinfectant followed by drying. In the event that manure handling equipment from another location cannot be effectively C&D, a plan to temporarily modify the PBA near the manure storage facility during manure removal is in place. The affected areas are cleaned and disinfected before returning to the original PBA.

All manure handling personnel must have showered and changed into clean clothes and footwear prior to arriving at the site. These expectations have been communicated to contract companies and signed and dated when read. This communication is kept on file in the off-stie office.

Rodent, Fly, Wildlife, and Other Animal Control

Rodent and Fly Control

The following rodent and fly control measures are in place

☒ This site utilizes bait stations to discourage rodent movement and has designated assistant manager / designated student employee as the rodent control monitor responsible for implementing the rodent control plan. Bait is checked monthly by assistant manager / designated student employee and replaced as needed. This protocol is in accordance with state and local regulations for controlling rodents.

☒ This operation utilizes flytraps and aerosol pesticides for fly control and has designated the assistant manager as the fly control monitor responsible for implementing the fly control plan. This protocol is in accordance with state and local regulations for controlling flies.

☒ Weeding and grass control is done as needed.

☒ The sanitation of general office areas is completed weekly.

☒ Trash is removed on an as need basis from the facility to the dumpster located outside Animal Science building. In an outbreak, the garbage truck would not cross the PBA.

Wildlife and Other Animal Control

The following control measures are in place to minimize an animal from entering the buildings.

☒ This operation utilizes enclosed buildings to discourage animal entry and has designated the assistant manager as the individual to monitor.

☒ Dogs, cats, and other pets are NOT allowed to enter the buildings.

☒ The buildings are totally enclosed so birds cannot enter.

Feed

Grain and feed commodities are delivered in trailers that are covered during transport.

In an outbreak, feed trucks delivering feedstuffs or finished feed would

☒ Feed is augured into feed bins or bagged feed is unloaded without feed trucks entering the PBA.

Feed spills are cleaned up and disposed of as soon as possible to minimize attraction of wildlife and rodents.

Feed spills clean-up and disposal is monitored by manager and assistant manager.

Labeled Premises Map

Premises Address: 47292 223rd St, Flandreau, SD
PremID or PIN: 00N5GGN

Perimeter Buffer Area (PBA)

PBA Access Point(s)

Line of Separation (LOS)

LOS Access Point(s)

Vehicle cleaning and disinfection (C&D) station(s)

Designated parking area

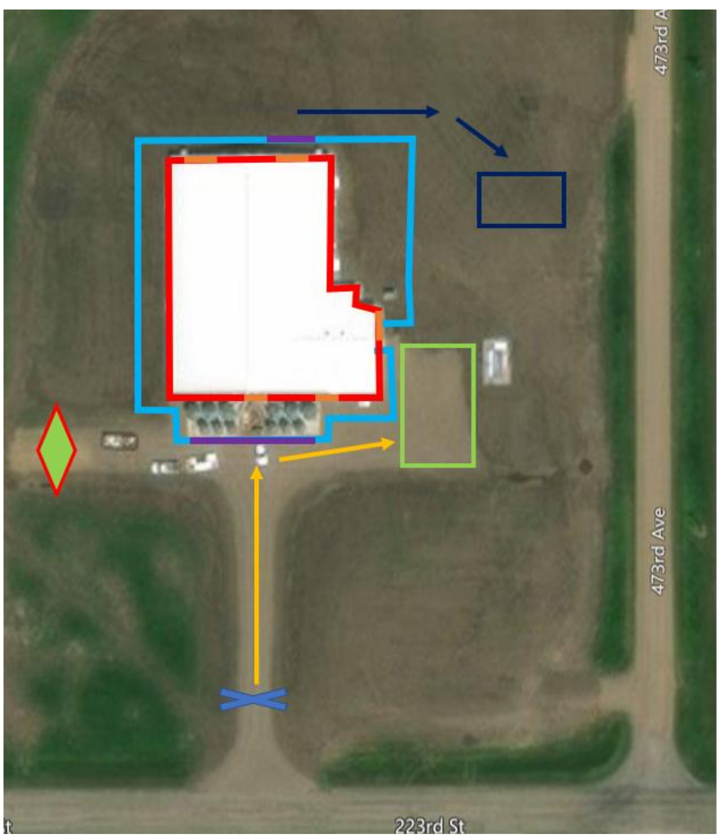
Carcass disposal/pickup location

Carcass removal pathways

Vehicle movements (animal transport vehicles, deliveries, etc.)

Site Entry

Figure 4. 2 Map SDSU Off-Site Facilities



4.4 South Dakota State University On-Site Facilities Enhanced Biosecurity

Plan for FAD Prevention in South Dakota

Date: 03/29/2022

This Biosecurity Plan is based off of the Secure Pork Supply (SPS) Self-Assessment Checklist for Enhanced Pork Production Biosecurity: Animals Raised Indoors, [August 2017] and was developed using guidance from the SPS Information Manual for Enhanced Biosecurity: Animals Raised Indoors. All documents are available at www.securepork.org. In the Plan below, all items have been implemented except those indicated which will be implemented prior to requesting an animal movement permit.

Scope of Biosecurity Plan

- National Premises Identification Number (Prem ID or PIN): 00JMJCB
- Premises Address: 2221 Medary Ave, Brookings SD 57006
- Premises GPS Coordinates: 44.331889, -96.794547
- Animals* on primary premises: 150 sows , 1,200 head wean to finish (with the ability to also house 300 nursery pigs and 50 replacement rebreeding stock in the original sow barn)

*Animals that are susceptible to FMD include cattle, pigs, sheep, goats, and elk. For biosecurity guidance for dairy cattle and beef cattle, see www.securemilksupply.org and www.securebeef.org.
**Work with your State Animal Health Official to determine if separate PINs are needed for all of your associated premises. When a premises becomes infected, all premises with the same PIN number will be considered to be infected.

Biosecurity Manager and Written Plan

The **designated Biosecurity Manager** for this site and their contact information follows:
NAME: Aaron Prinz
PHONE: 760-532-5667
EMAIL: aaron.prinz@sdstate.edu

In the event the Biosecurity Manager is away from the site, **their designee's** contact information is:
NAME: Dr. Jeffery Clapper
PHONE: 706-224-2262
EMAIL: Jeffery.clapper@sdstate.edu

The Biosecurity Manager's contact information is posted in the barn offices.

Aaron Prinz and Dr. Jeffery Clapper have the written authority to ensure compliance with biosecurity protocols and take corrective action as needed.

Hannah Miller developed the site-specific biosecurity plan with the assistance of:

- Dr. Scott VanderPoel, a licensed veterinarian whose contact information is:
  PHONE: 508-820-0914
  EMAIL: scott.vanderpoel@pipestone.com

- Dr. Bob Thaler, a consultant with South Dakota State University whose contact information is:
  PHONE: 605-695-6444
  EMAIL: robert.thaler@sdstate.edu

The Biosecurity Manager or their designee:

- ☒ communicates with and/or trains individuals entering on biosecurity measures to follow;
- ☒ reviews the biosecurity plan at least annually and updates it whenever the site goes through a change affecting biosecurity;
- ☒ ensures that all individuals entering the site frequently (weekly or more often) have access to a copy of the biosecurity plan;
- ☒ is capable of implementing the written plan if FMD, CSF, or ASF is diagnosed in the U.S.; and
- ☒ has the authority to take corrective action, as needed, when biosecurity protocols are not followed.

A labeled premises map is included at the end of this plan and can be found on the premises at: the sow barn office and wean to finish barn office

Training

The people in the positions listed below are trained at least once about the biosecurity measures necessary to keep an FAD out of the herd. This training is documented and available for review upon request.

Manager, Assistant Manager, Student Employees, Graduate students, and Faculty

The Biosecurity Manager(s) informs individuals entering the site of the biosecurity measures they are to follow in a language they understand. Individuals are aware of the biosecurity concepts and procedures that apply to their specific areas of responsibility. Our required training is described below.

All individuals entering must understand how to:

- ☒ Contact the Biosecurity Manager(s)
- ☒ Respect the Perimeter Buffer Area (PBA)

☒ Cross the Line of Separation (LOS), if required, following arrival and biosecure entry
requirements
☒ Perform biosecurity measures for their specific job duties

In addition, employees must:
☒ Undergo biosecurity training prior to starting to work at the site;
☒ Understand the importance of biosecurity;
☒ Review the entire biosecurity plan;
☒ Review the labeled premises map;
☒ Know who to report to if they see someone not complying or something preventing compliance; and
☒ Recognize the consequences for not complying with biosecurity protocols.

Communication occurs with drivers, delivery and service personnel, veterinarians, livestock transporters, and visitors through the following methods:
☒ phone calls, text messages, emails, faxes
☐ a premises map highlighting the route drivers are to follow upon entering the site

Protecting the Pig Herd

Site Entry

Entry to the site (such as driveways) is restricted to one site entries and each are labeled on the premises map at the end of this plan.

- Each entry point, including unused entries, is protected with a suitable barrier consisting of rope and/or snow fence to restrict entry.

The entry point is secured with rope and or snow fence.

Signs written in these languages English are posted at the site entry that including the following contact information Manager and Assistant Manager.

Perimeter Buffer Area (PBA)

The Perimeter Buffer Area is labeled on the premises map at the end of this plan. The PBA is marked on-site with rope and/or snow fence.

PBA Access Point(s)

Entry to the PBA is restricted to eight controlled PBA Access Point(s) and each are labeled on the premises map at the end of this plan. The PBA Access Points are clearly marked with a suitable barrier of rope and/or snow fence to restrict entry.

Signs written in English are posted at all PBA Access Points that include the following contact information: manager, assistant manager, and overseeing faculty.

All movements (animals, vehicles, equipment, people) which enter the PBA are recorded and these documents are kept in the site office and are available for review upon request.

Deliveries are made outside of the PBA in the swine classroom.

Vehicles and equipment entering the PBA Access Points are cleaned to remove visible contamination and then disinfected at the Cleaning and Disinfection Station.

People and items crossing through the PBA Access Points follow appropriate specific biosecurity steps, described under Biosecure Entry Procedure in this plan.

Cleaning and Disinfection (C&D) Station

There is an operational, clearly marked, and equipped C&D station(s) located East of the classroom and designated parking area and it is labeled on the premises map at the end of this plan. The wash pad for the C&D station is made of gravel and slopes away from animal housing, feed receiving or storage areas, waterways, and on-farm traffic areas. This site uses drainage ditch to manage runoff from the C&D area to ensure susceptible animals are not exposed. Runoff from the C&D Station is managed following all state and local regulations.

This site has access to all the equipment and supplies needed to successfully operate the C&D Station. The SOP for the C&D process is available upon request.

The following individuals have received documented training in proper selection and use of personal protective equipment, the principles of C&D to avoid introducing an FAD virus on the site, and are able to effectively operate the C&D Station.

- Manager
- Assistant Manager

In the case of inclement weather (freezing temperatures, thunderstorms, high winds) when the C&D Station cannot be operated, we have the following contingency plans to ensure vehicles do not bring visible contamination onto our site:

- Equipment will temporarily be washed in the hoop barn.

Designated Parking Area

The designated parking area is clearly marked onsite with rope and labeled on the premises map at the end of this plan. It is located outside of the PBA and away from animal areas.

Line of Separation (LOS)

The Line of Separation is labeled on the premises map at the end of this plan.

LOS Access Point(s)

Entry to the LOS is restricted to 9 total controlled LOS Access Point(s) (3 in the Wean to Finish and 6 in the Sow Teaching and Research building). Each are labeled on the premises map at the end of this plan. The LOS Access Points are clearly marked with the exterior walls of the buildings.

Signs written in these languages English are posted at all LOS Access Points that include the biosecurity protocol required for each entry.

All movements (animals, equipment, supplies, people) which cross the LOS are recorded and these documents are kept in the Sow Teaching and Research office and are available for review upon request.

The designated animal loading/unloading area is labeled on the premises map at the end of this plan, and this is NOT used for a people entry point unless there is no alternative.

People crossing the LOS Access Points follow appropriate specific biosecurity steps, described under Biosecure Entry Procedure in this plan.

Biosecurity measures taken when food, personal items, equipment, and supplies cross the LOS include disinfecting or passing under a UV box prior to entry and exit or double bagged if it cannot be properly disinfected.

Securing the Buildings

The barn manager and assistant manager is/are responsible for ensuring the buildings are locked.

Vehicles and Equipment

Vehicles and Equipment (non-animal transport)

All vehicles and equipment not containing live animals are cleaned to remove visible contamination and effectively disinfected prior to crossing the PBA; otherwise, entry is prohibited.

Concerning the sharing of equipment with other sites:

- ☒ Equipment used on this site is not shared with equipment from other sites.

Livestock Trucks/Trailers (animal transport vehicles)

All empty animal transport vehicles are cleaned and disinfected prior to arrival at the site (outgoing loads) or before animals are loaded for delivery to the site (incoming loads).

Animal transport vehicles containing animals that are not being unloaded at this site are not allowed to cross the PBA.

- ☒ The PBA is relocated while animals are unloaded. After the truck leaves, the PBA is re-established and the surface is C&D. If surface is cannot be C&D, then an adequate amount of lime is applied to cover the area.

Personnel

Prior to Arriving at the Site

The Biosecurity Manager ensures that everyone who needs to cross the LOS has been instructed on to arrive at the site:

- with a clean vehicle interior (free of all animal manure/excrement) that has not become contaminated by soiled clothes, footwear, or other items
- having showered and wearing clean clothing and footwear since last contacting susceptible animals.
  - For individuals living off-site, after showering and changing into clean clothes and footwear, they must NOT contact animals, live or dead, or facilities where they are held prior to arrival at the site.
- informed of the biosecurity measures they are to take once they arrive.

These individuals have a signed Employee and Visitor Arrival Agreement on file agreeing to follow our biosecure entry procedures (described below).

Entry Logbook

Everyone crossing the LOS Access Point(s) completes the entry log, which is located at the pass through window in the Sow Teaching and Research facility and outside of the locker room in the Wean Finish Research Facility , unless they are a scheduled worker.

The entry log is monitored by barn manager on the site to ensure accurate completion.

The contact information and work schedule records for all workers are maintained and posted at the following location: online with a physical copy in each of the barn offices.

Biosecure Entry/Exit Procedure

When entering the PBA, all individuals must:

- Put on disposable or disinfectable footwear
- Put on gloves or apply hand sanitizer

All deliveries and items entering the PBA are recorded in the entry log, which is located in the sow teaching and research office.

Vehicles and equipment entering the PBA need to be cleaned and disinfected (Vehicles are addressed in Section 6: Vehicles and Equipment).

All individuals crossing the LOS must:

- Shower in and shower out
- Put on site-specific coveralls or clothing and footwear at the LOS Access Point.
  - Absolutely no street clothes not completely covered by site-specific coveralls/hats/accessories are allowed past the LOS.

- The same procedure is in reverse when crossing back across the LOS from the pig side of the LOS, leaving site-specific clothing or coveralls and footwear inside the LOS.

Animal and Semen Movement

Incoming Animals and Semen

Pigs come only from sources with documented, enhanced biosecurity practices that align with our biosecurity practices and have no current or previous evidence of the FAD viruses. Diagnostic testing of animals as requested by the Responsible Regulatory Officials is negative.

The Biosecurity Manager will ensure that any semen **arriving** after the FAD has been diagnosed in the U.S. will be handled as follows:

- ☒ Semen is purchased only from sources with documented biosecurity practices that align with our biosecurity practices.
- ☒ Semen has tested negative for the virus.
- ☒ Semen arrives in containers that can be cleaned and disinfected effectively to minimize the risk of virus contamination.
- ☒ The source herd documents Active Observational Surveillance for at least 7 days prior to movement of product.

The Biosecurity Manager will ensure that any semen **collected** after the FAD has been diagnosed in the U.S. will be handled as followed:

- ☒ Frozen or chilled semen is held on the site until the semen tests negative for the virus by PCR. If the animals are healthy and the semen tests negative for the virus, the semen may be shipped.
- ☒ Semen is transported in disposable containers or those with exteriors that can be cleaned and effectively disinfected as it crosses the LOS.
- ☒ The source herd must document Active Observational Surveillance for at least 7 days prior to movement of product.

Pre-movement Isolation Period

- ☒ We do not accept animals from operations within an FMD Control Area.

Contingency Plan for Interrupted Animal Movement

In the event animal movement is stopped for several weeks, this is our plan for managing animals in a biosecure manner:

- ☒ Cull animals will be humanely euthanized and properly disposed of on the operation (described under Carcass Disposal below).

- ☒ Housing, feed, and healthcare equipment are available for 1200 head of market ready pigs for a period of a few weeks. A contingency plan has been established for ration formulation, transport and market of animals that are at, approaching, or have exceeded market weight.

- ☒ Our plan to manage weaned or nursery aged pigs:
  - ☒ There is enough housing and feed available for 1200 head of pigs for a period of a few weeks.
- ☒ Humane euthanasia equipment and supplies are available if needed.

Loading Animals

Animals leaving the site only move in one direction across the LOS at an Access Point labeled on the premises map at the end of this plan. All areas inside the LOS that become contaminated by individuals or animals loading are cleaned with detergent and effectively disinfected by trained personnel after loading is complete. The SOP for the C&D process is available upon request.

☒ The animal loading/unloading area is NOT a people entry point.

The following individuals have received documented training in proper selection and use of personal protective equipment, the principles of C&D to avoid introducing an FAD virus to the site, and are able to effectively C&D the loading area:

- Manager
- Assistant manager

Carcass Disposal

In an FAD outbreak, dead animals (normal mortality numbers) are disposed of by composting in a way which prevents the attraction of wildlife, rodents, and other scavengers, and is in accordance with state and federal laws. Routes for carcass movement and disposal are labeled on the premises map at the end of this plan.

- ☒ Dead animals are disposed of onsite but outside of the PBA.
- ☒ Rendering trucks and other vehicles hauling dead animals to a common disposal site do not enter the PBA.

In the event of a large number of mortalities unrelated to the FAD infection (toxicity, heat stress, etc.), dead animals will be disposed of by composting which also prevents the attraction of wildlife, rodents, and other scavengers, and is in accordance with state and federal laws.

Manure Management

Manure is stored in pits and in a manure tank

In the event of a prolonged outbreak, we can store manure for several months to a year, depending on time of outbreak. After that time, the method for manure removal is pumping and field application via a dragline. This will prevent exposure of susceptible animals and meet state, local and Responsible Regulatory Officials regulations.

☒ All manure handling vehicles and equipment from other sites is cleaned to remove all manure and disinfected with either heat or a chemical disinfectant followed by drying. In the event that manure handling equipment from another location cannot be effectively C&D, a plan to temporarily modify the PBA near the manure storage facility during manure removal is in place. The affected areas are cleaned and disinfected before returning to the original PBA.

All manure handling personnel must have showered and changed into clean clothes and footwear prior to arriving at the site. These expectations have been communicated to contract companies and signed and dated when read. This communication is kept on file here: Sow Teaching and Research Office.

Rodent, Fly, Wildlife, and Other Animal Control

Rodent and Fly Control

The following rodent and fly control measures are in place

☒ This site utilizes traps and bait boxes to discourage rodent movement and has designated undergraduate staff as the rodent control monitor responsible for implementing the rodent control plan. Bait is checked monthly by undergraduate employees and replaced as needed. This protocol is in accordance with state and local regulations for controlling rodents.

☒ This operation utilizes tape and aerosol pesticide for fly control and has designated manager and assistant manager as the fly control monitor responsible for implementing the fly control plan. This protocol is in accordance with state and local regulations for controlling flies.

☒ Weeding and grass control is done every 2-3 weeks or as needed.

☒ The sanitation of general office areas is completed weekly.

☒ Trash is removed every month. In an outbreak, the garbage truck **would not** cross the PBA.

Wildlife and Other Animal Control

The following control measures are in place to minimize an animal from entering the buildings.

☒ This operation utilizes enclosed buildings to discourage animal entry and has designated manager and assistant as the individual to monitor.

- ☒ Dogs, cats, and other pets are NOT allowed to enter the buildings.
- ☒ The buildings are totally enclosed so birds cannot enter.

Feed

Grain and feed commodities are delivered in trailers that are covered during transport.

In an outbreak, feed trucks delivering feedstuffs or finished feed would

- ☒ Feed is augered into feed bins or bagged feed is unloaded without feed trucks entering the PBA.

Feed spills are cleaned up and disposed of as soon as possible to minimize attraction of wildlife and rodents.

Feed spills clean-up and disposal is monitored by the barn manager.

Labeled Premises Map

Premises Address: 2221 Medary Ave, Brookings SD
PremID or PIN: 00JMJCB

Perimeter Buffer Area (PBA)

PBA Access Point(s)

Line of Separation (LOS)

LOS Access Point(s)

Vehicle cleaning and disinfection (C&D) station(s)

Designated parking area

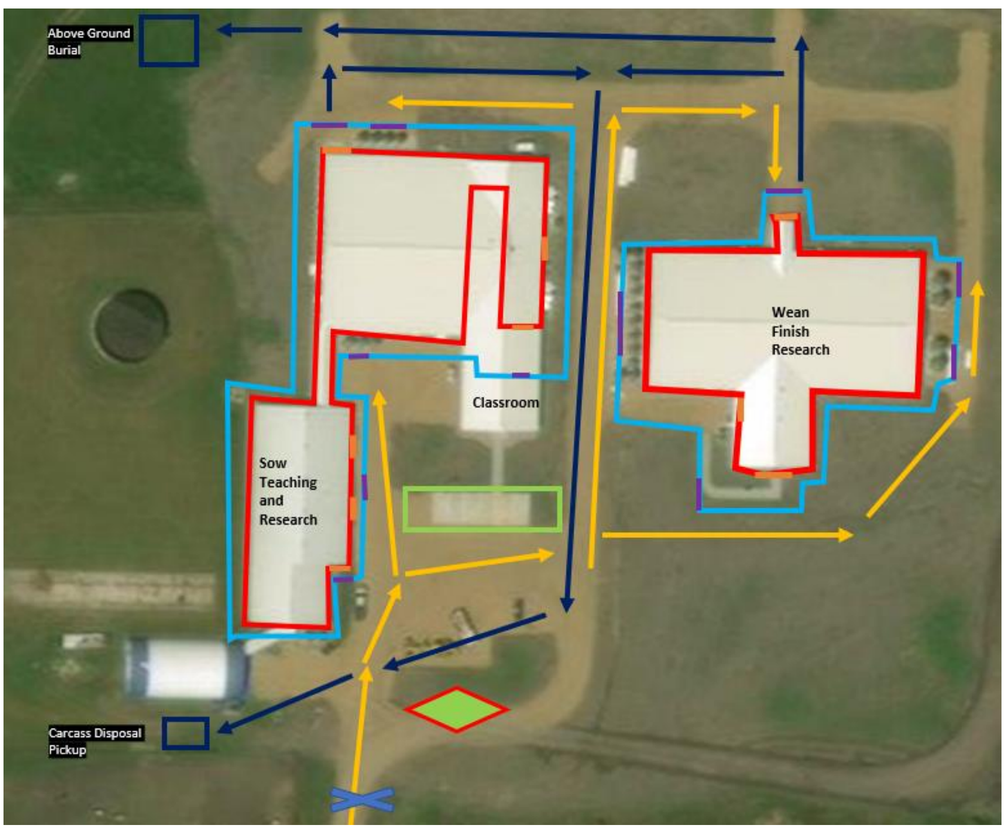
Carcass disposal/pickup location

Carcass removal pathways

Vehicle movements (animal transport vehicles, deliveries, etc.)

Site Entry

Figure 4. 3 Map of SDSU On-site Facilities



4.5 Considerations for the South Dakota State University Secure Pork Supply Plans

Above is the Secure Pork Supply Plans for the SDSU swine facilities. These plans are in the process to be approved by the South Dakota Animal Industry Board.

Both the Off and On-site facilities are located near very high traffic areas, making plans such as these pertinent to have in place. Both units in the event of an outbreak will utilize either rope or snow fence to mark the PBA. While neither facility currently owns these materials, they were chosen as they are easy to access in the even of a FAD outbreak. Potential limitations to the outline enhanced biosecurity plans include the C&D stations, entrance of livestock trucks and trailers and re-establishment of the PBA, and carcass disposal. For both locations it has been outlined for the wash stations to be made of gravel. Gravel was chosen as it is easy to access in the event of an emergency. Although there is the possibility that loose gravel could catch debris of contaminated vehicle and get transferred to another vehicle or piece of equipment if debris is not properly flushed from the C&D station after each use. For the Off-site this will be located west of the facilities. In the event of inclement weather, there is no good alternative location for a wash station. This requires that any cleaning and disinfecting that needs to occur during poor weather to have to wait. The On-site C&D station is located east of the Swine Unit classroom. One limitation to this location is that there is a pasture that occasionally houses horses. Both horses and pigs are susceptible to disease such as FMD. Care should be taken to ensure that run off is directed away from the horse pasture to prevent the spread of disease. During inclement weather the C&D station will be moved to the hoop barn. This will require temporary movement of the farm truck, trailer and other equipment that is usually stored in this location.

For both facilities the PBA will be re-established after the movement of animals to or from a truck and/or trailer. After movement of animals is complete the PBA access point should be properly cleaned and disinfected. If disinfection is not possible, the area should remain unused and quarantined until appropriate time has passed for the area to be free of virus. Perimeter Buffer Area access points at the Off-site are located on the north and south ends of the facility. On-site PBA access points are located in front of each of the grain bin storage areas, outside the classroom to access deliveries, and in front of each livestock load out, and in front of the main entrance of the Sow Teaching and Research unit.

Disposal and rendering of carcasses also pose another challenge. The Off-site carcass disposal is located northeast of the main facility, outside of the PBA. Care should be taken to ensure that cross traffic contamination does not occur between the path of the rendering vehicle and vehicles and equipment that are to enter in or near the PBA. In the event of a large number mortalities occur that exceeds the capacity of the rendering facilities an above ground burial can be implemented which is an effective means to compost carcasses and has been approved by the USDA (2021a). The On-site in the past has utilized a above ground burial of carcasses and could easily do so again the future. This site is located just west of the Sow Teaching and Research unit. Mortalities for rendering pick up are located east of the hoop barn. Care should be taken for disposal of the carcasses as the vehicle used to transport mortalities will have to cross traffic paths mapped out for feed deliveries and animal transport vehicles. The carcass disposal location east of the hoop barn arguably has the greatest risk for contamination as rendering vehicles will also have contact with this site. Equipment that is used to transport mortalities from the barns to the carcass disposal location should be properly cleaned and disinfected to ensure there is no cross contamination between other vehicle traffic.

Enhanced biosecurity plans allow for swine producers to be more prepared and protect their herd in the event of a FAD outbreak. This plan brings value to the universe by allowing continuity of business of the SDSU swine herd. This allows for teaching and research to continue even in the event of a FAD crisis.

5.0 FINAL DISCUSSION

Sustainability has become a topic of increasing interest among both consumers and producers. The We Care principles from the Pork Checkoff outline goals for food safety, animal wellbeing, public health, environment, people, and community, all in relation to pork production. The objective of this thesis is to evaluate 3 subtopics of sustainable pork production: water, nutrition, and biosecurity.

Over 2 studies it was determined that providing water flow rate above the recommendation of 1,000 mL/min does not improve pig performance. However, increasing water flow rate did increase water disappearance. One limitation to the studies was the inability to measure water wastage. Due to the lack in response of pig performance, it is assumed that increasing water disappearance resulted in more water entering the manure pit. Not only are there cost savings associated with water conservation, but it is environmentally responsible. In the 2021 Sustainability Report, the Pork Checkoff records the goal to increase water data, begining by measuring in-barn water use. They also state the goal to improve water efficiency through implementation of best management practices and “aggressive implementation of on-farm water-use targets” (We Care, 2021). With the majority of surveyed swine producers providing water in excess (Zeamer et al., 2021), this work demonstrates that there is great potential for improvements in water conversation in grow-finish barns.

The feeding program of the SDSU On-site Wean to Finish was re-evaluated with the use of growth models. Growth models and consideration for ingredients can improve utilization of the nutrients provided in the diets and reduce nutrients excreted in the manure. It was determined that lysine was being over provided in relation to growth in phases 1, 5, 6, and 7. Decreasing excess levels of lysine, can reduce the level of excreted N. Excess N can result in production of ammonia which is an environmental pollutant that can reduce air quality (United States Environmental Protection Agency, 2021b). Additionally, if not properly managed during field application, can alter plant growth and cause harm to the soil and waterway (United States Environmental Protection Agency, 2021b). Beyond amino acid adjustment, another major improvement of the diets is the inclusion of phytase. The addition of phytase allows for a reduced of inorganic P which can lead to a reduction of P excreted. Additionally excess P can have negative effects when field application is mismanaged: limiting nutrient uptake of other micronutrients by the plants, or reducing oxygen levels in bodies of water (Provin and Pitt, 2014; United States Environmental Protection Agency, 2021a). The re-evaluation of the SDSU feeding program is in alignment with the We Care ethical principle, environmental stewardship. Under this principle is the goal to improve manure quality and management by formulating diets that not only allow for efficient growth of the pig but also reduce nutrients excreted in the manure.

Finally, biosecurity, which falls under the pillars of food safety and animal well-being, is address with the development of enhanced biosecurity plans for the SDSU swine facilities. The development of these plans allows for the continuity of business in the event of a FAD outbreak. This means that SDSU can continue to not only contribute to the pork supply chain but continue its teaching and research efforts in the middle of an animal disease crisis.

This thesis only reviewed three of the many topics under the We Care principles. There is boundless work that can be done to evaluate and improve pork production regarding the six outlined principles and sustainability.

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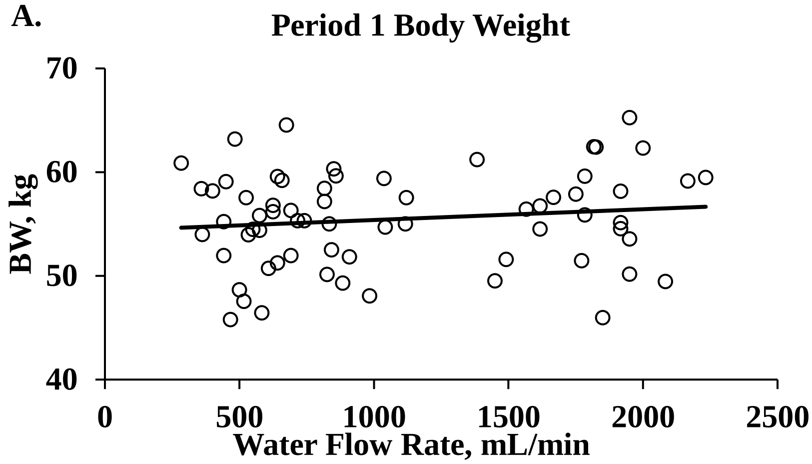
7.0 APPENDIX

7.1 Impact of Water Flow Rate Flow Rate on Finishing Pig Performance:

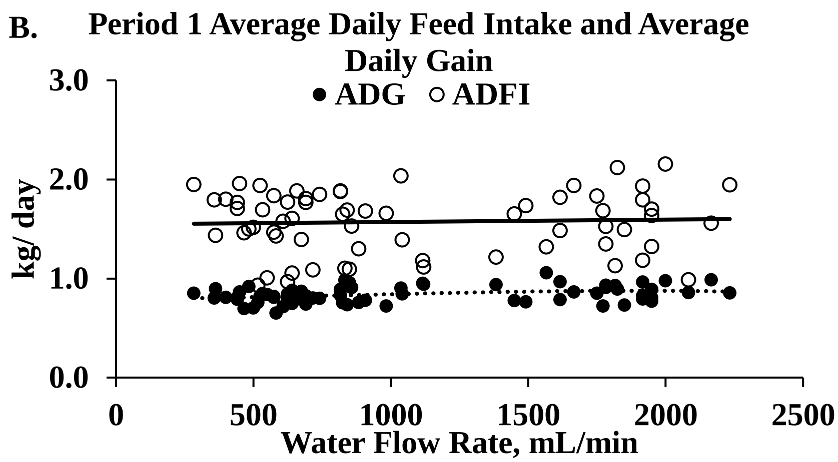
Supplemental Figures

Figure 7. 1 Day 0 to Day 25 (Period 1), regression of pig performance vs waterflow rate during Study 1. A = body weight; B = average daily feed intake and gain; C = gain:feed. High barn temperature averaged 29.7 °C. Linear regression: body weight, *P* = 0.39; average daily gain, *P* = 0.44. Cubic regression: average daily feed intake, *P* = 0.28; gain:feed, *P* = 0.30.

A.



B.



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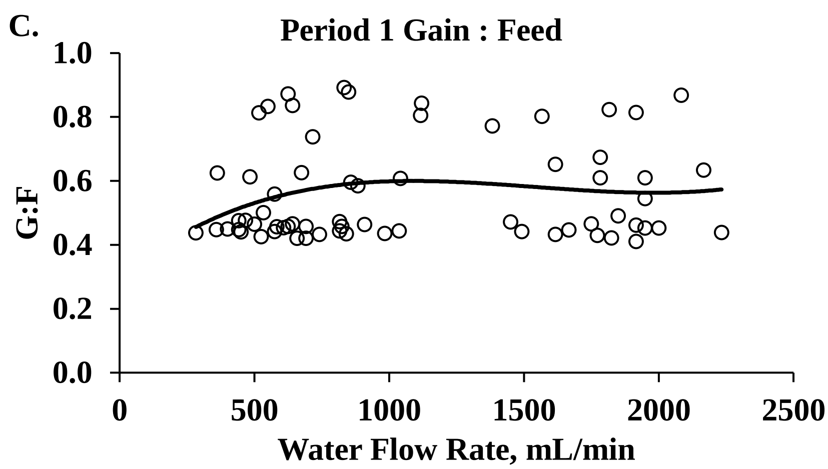


Figure 7. 2 Day 25 to Day 53 (Period 2), regression of pig performance vs waterflow rate during Study 1. A = body weight; B = average daily gain and feed intake; C = gain:feed. . High barn temperature averaged 29.2 °C. Linear regression: body weight, P = 0.21; average daily gain P = 0.32; average daily gain, P = 0.005, R^2 = 0.10; gain:feed, P = 0.02, R^2 = 0.08

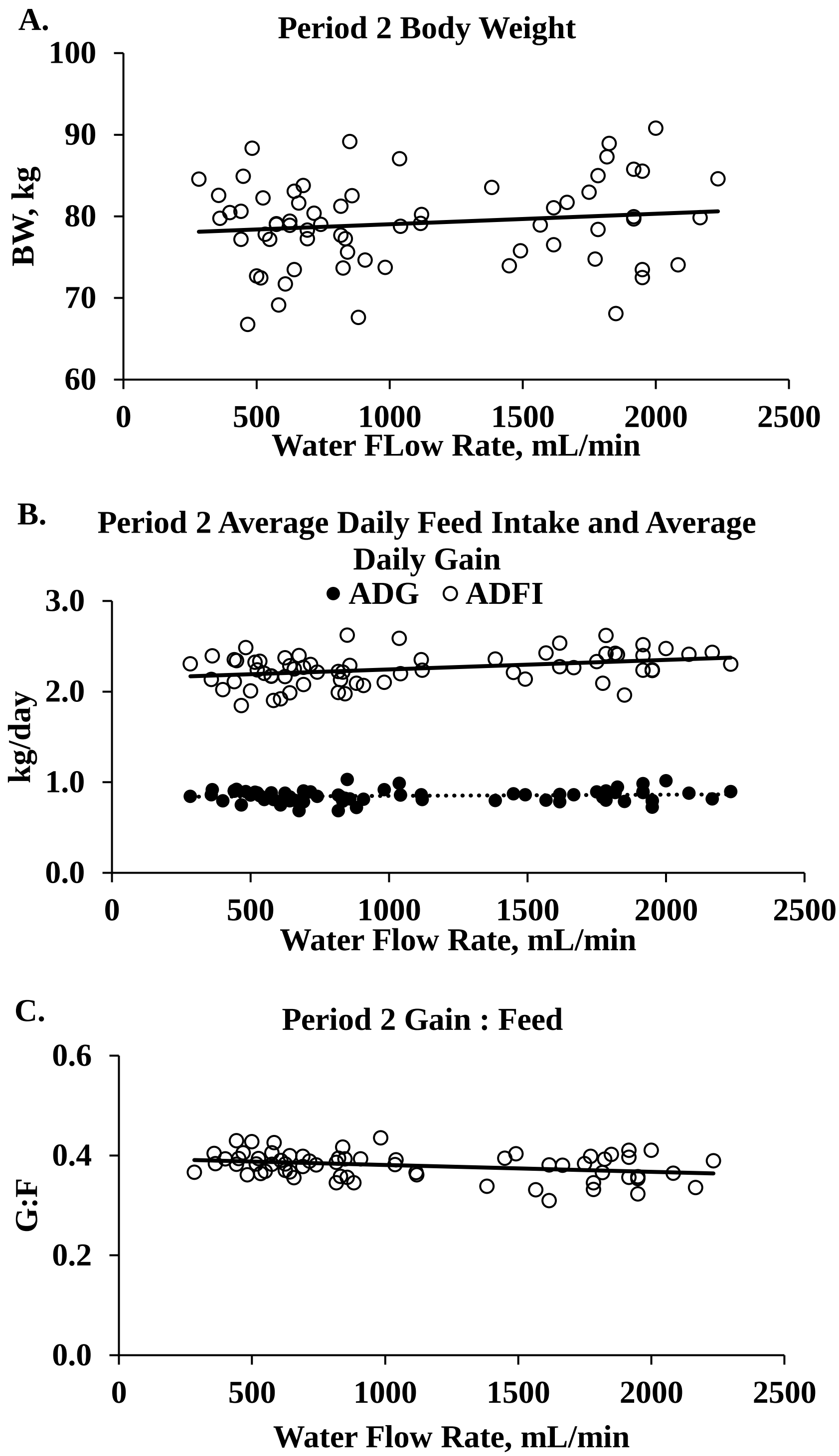


Figure 7. 3 Day 53 to Day 77 (Period 3), regression of pig performance vs waterflow rate during Study 1. A = body weight; B = average daily gain and feed intake; C = gain:feed. High barn temperature averaged 27.9 °C. Linear regression: body weight, P = 0.05, R^2 = 0.04; average daily gain, P = 0.05, R^2 = 0.05; average daily feed intake, P = 0.64; gain:feed, P = 0.96.

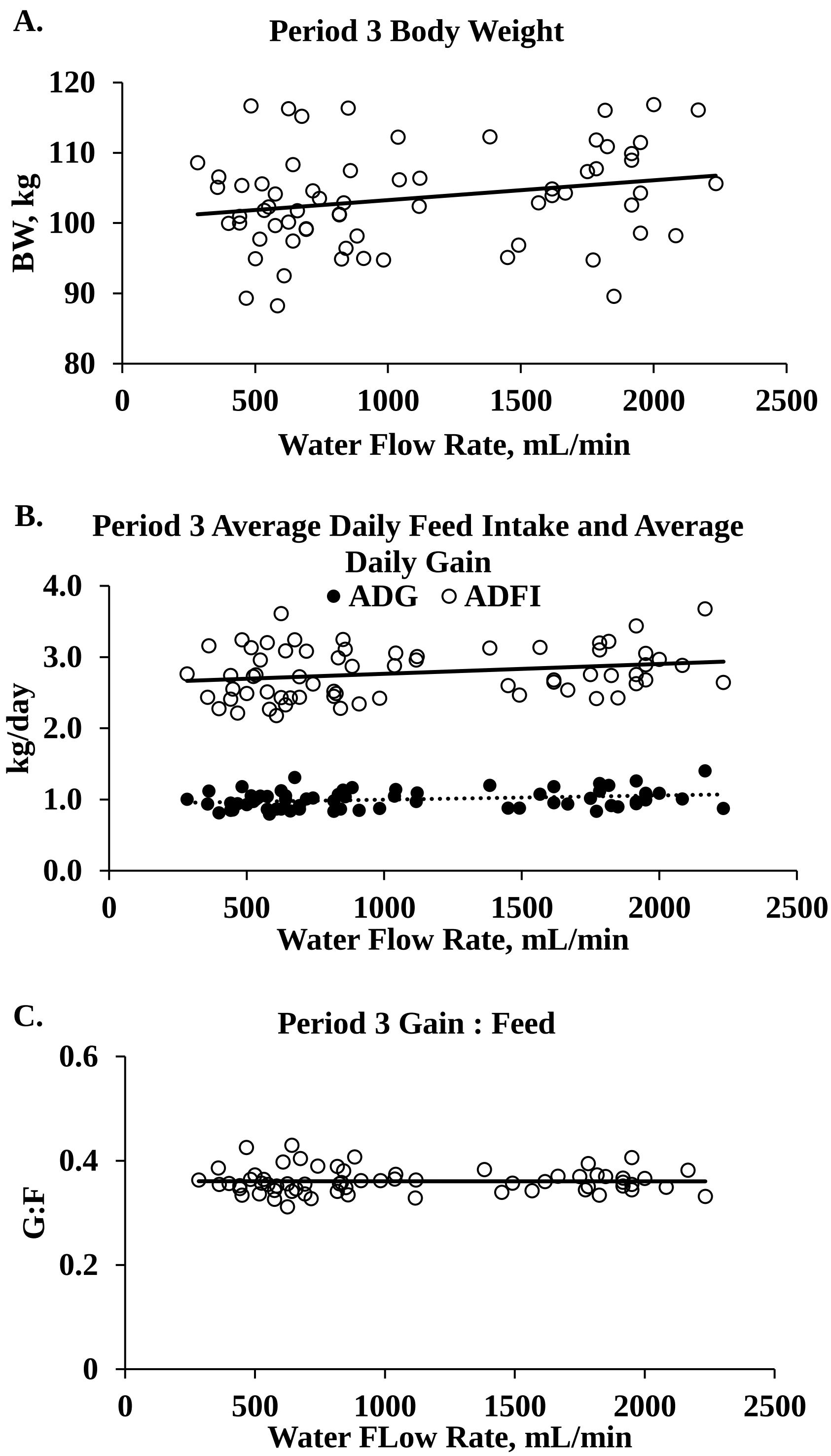


Figure 7. 4 Day 0 to Day 14 (Period 1), regression of pig performance vs waterflow rate during Study 2. A = body weight; B = average daily gain and feed intake C = gain:feed; D = water disappearance. High barn temperature averaged 31.3°C. Linear regression: body weight, P = 0.34; average daily gain, P = 0.32; average daily feed intake, P = 0.03, R^2 = 0.07, water disappearance, regression P <0.0001, R^2 = 0.84. Quadratic regression: gain:feed, P = 0.55.

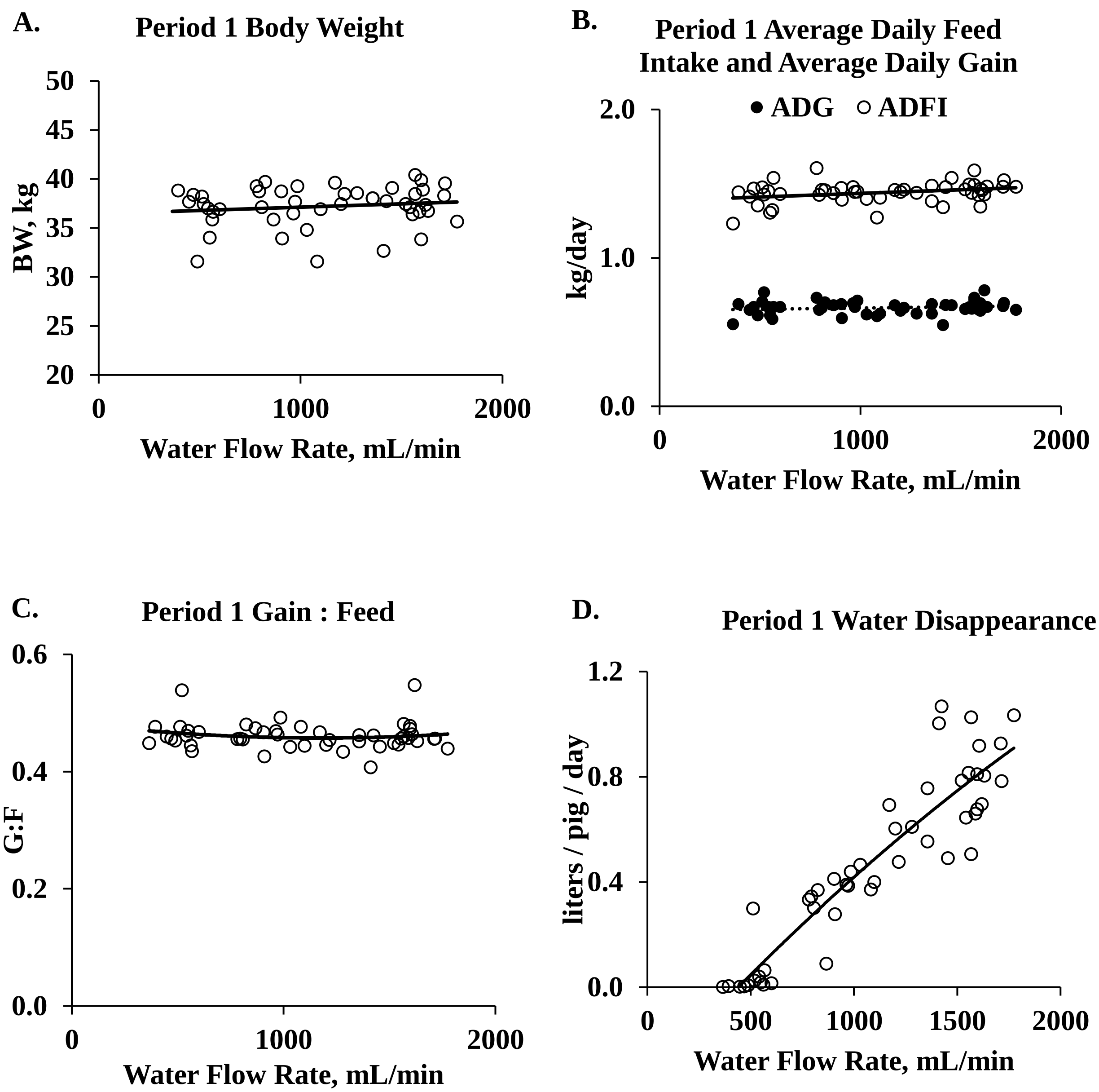


Figure 7. 5 Day 14 to Day 28 (Period 2) regression of pig performance (BW (a), ADG (b), ADFI (c), G:F (d), water disappearance (e) vs waterflow rate during Study 2. A = body weight; B = average daily gain and feed intake C = gain:feed; D = water disappearance. High barn temperature averaged 28.5°C. Linear regression: body weight, $P = 0.12$; average daily gain, $P = 0.57$; average daily feed intake, $P = 0.05$, $R^2 = 0.06$; gain:feed, $P = 0.10$; water disappearance, $P < 0.0001$, $R^2 = 0.81$.

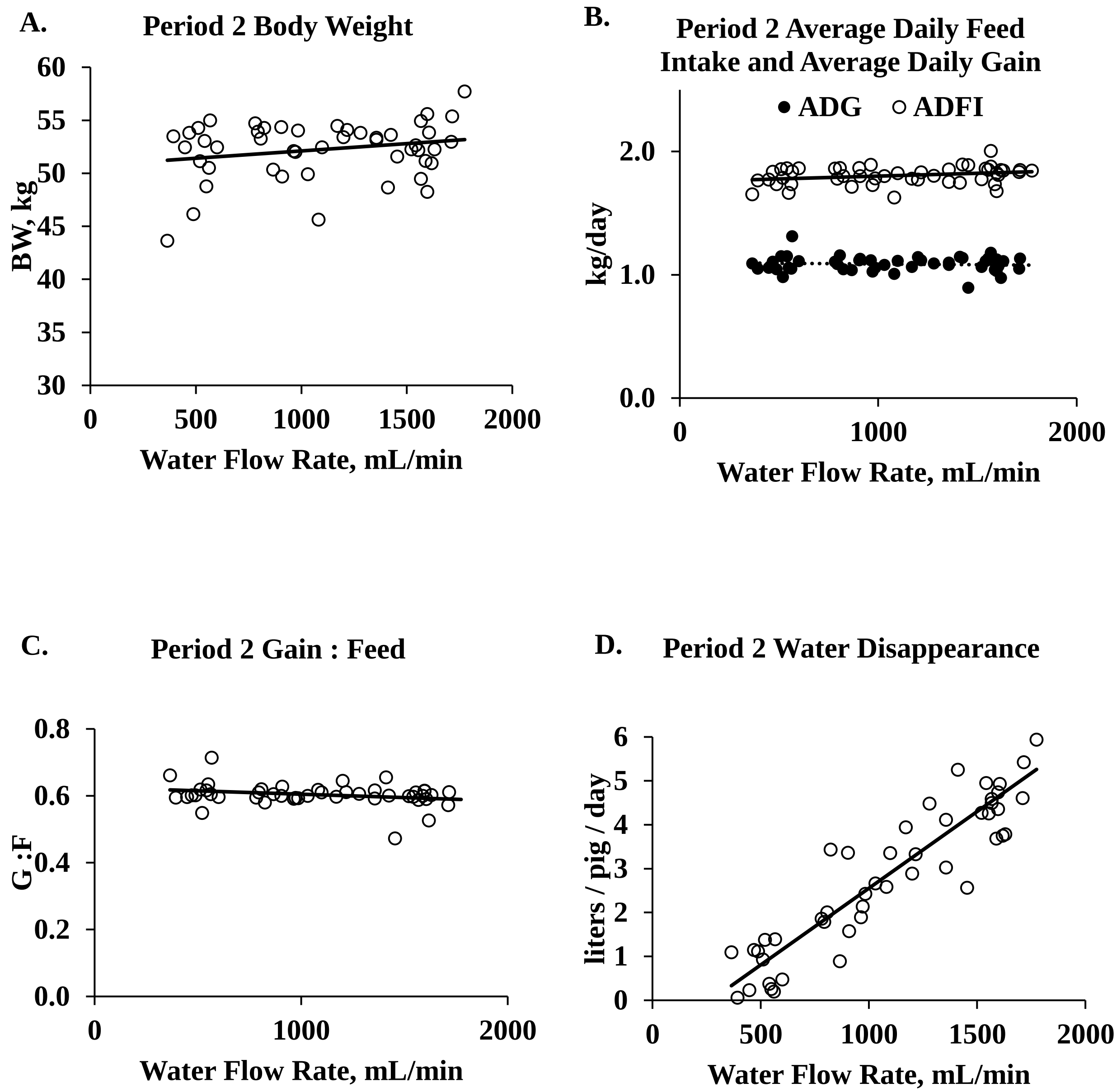


Figure 7. 6 Day 28 to Day 42 (Period 3) regression of pig performance vs waterflow rate during Study 2. A = body weight; B = average daily gain and feed intake; C = gain:feed; D = water disappearance. High barn temperature averaged 25.9°C. Linear regression: body weight, P = 0.008, R^2 = 0.12; average daily feed intake, P = 0.003, R^2 = 0.16. Cubic regression: average daily gain, P = 0.03, R^2 = 0.27; gain:feed, P = 0.006, R^2 = 0.19; water disappearance, P <0.0001, R^2 = 0.81.

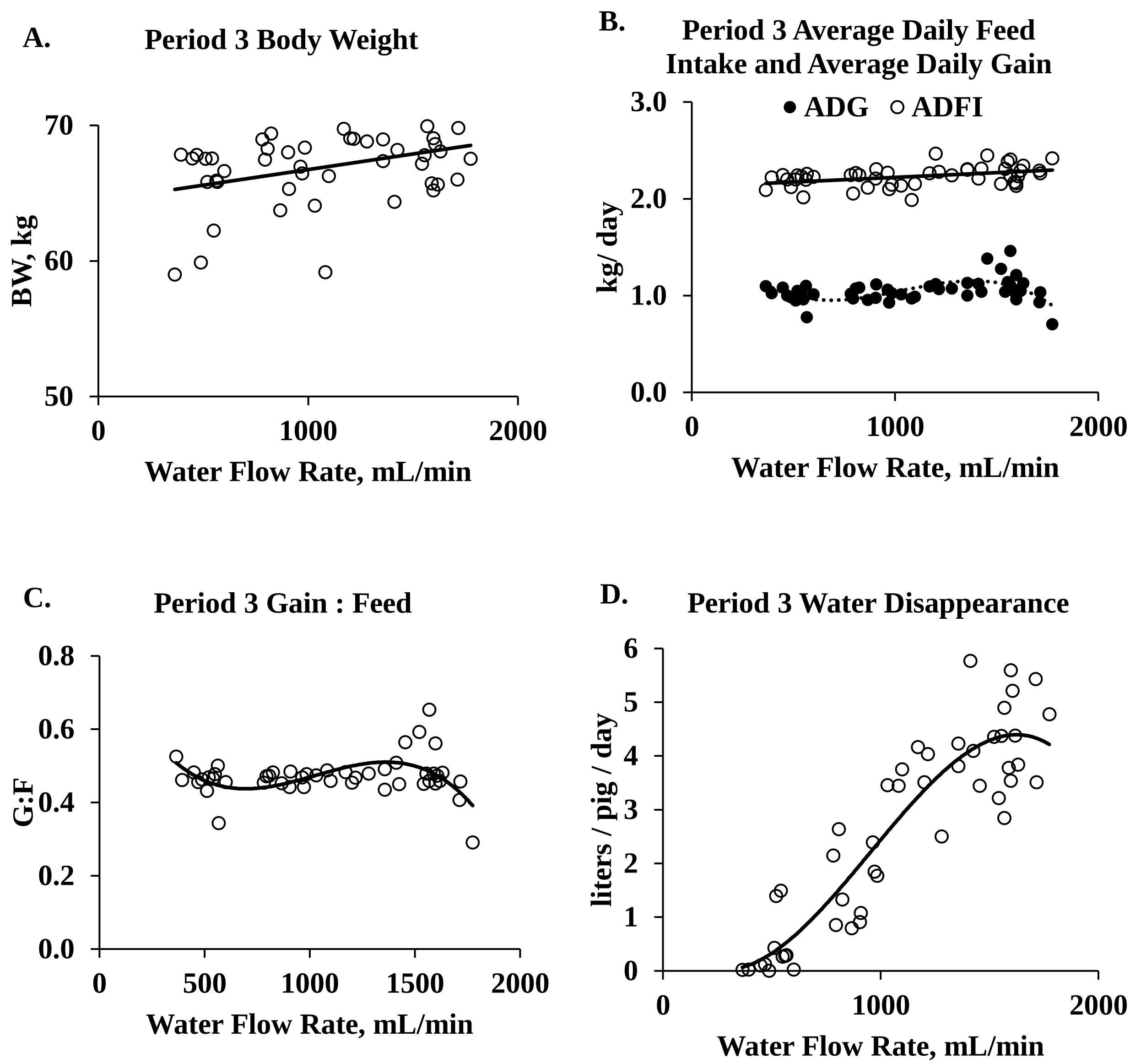


Figure 7. 7 Day 42 to Day 56 (Period 4) regression of pig performance vs waterflow rate during Study 2. A = body weight; B = average daily gain and feed intake C = gain:feed; D = water disappearance. High barn temperature averaged 28.2°C. Linear regression: body weight, P = 0.0041, R^2 = 0.28; average daily feed intake, P = 0.14. Quadratic regression: average daily feed intake, P = 0.19; gain:feed, regression P = 0.23; water disappearance, P <0.0001, R^2 = 0.61.

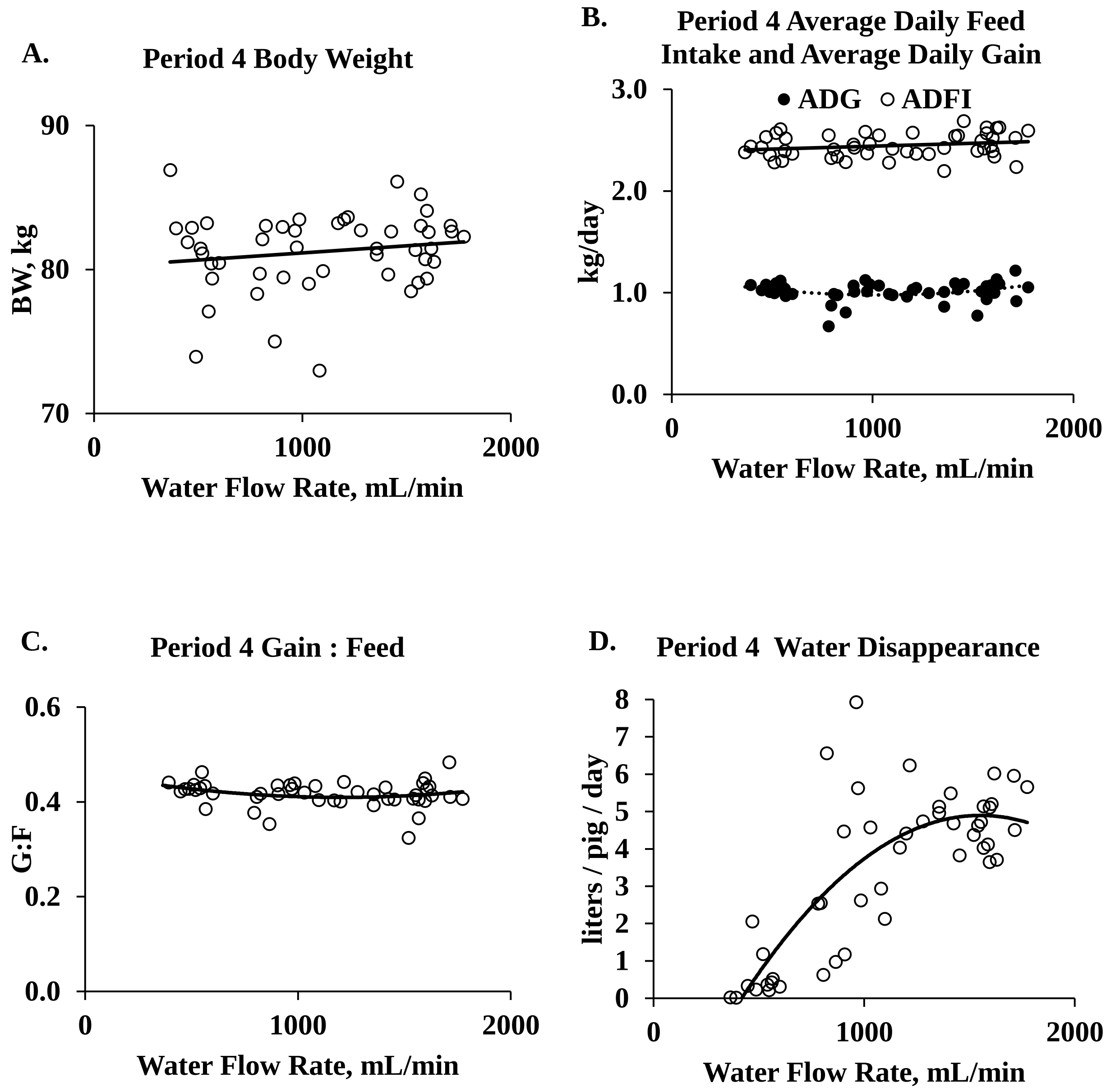


Figure 7. 8 Day 56 to Day 70 (Period 5) regression of pig performance vs waterflow rate during Study 2. A = body weight; B = average daily gain and feed intake; C = gain:feed; D = water disappearance. High barn temperature averaged 28.0°C. Linear regression: body weight, P = 0.04, R^2 = 0.07. Cubic regression: average daily gain, P = 0.57; average daily feed intake, P = 0.34. Quadratic regression: gain:feed, P = 0.87; water disappearance, P <0.0001, R^2 = 0.68.

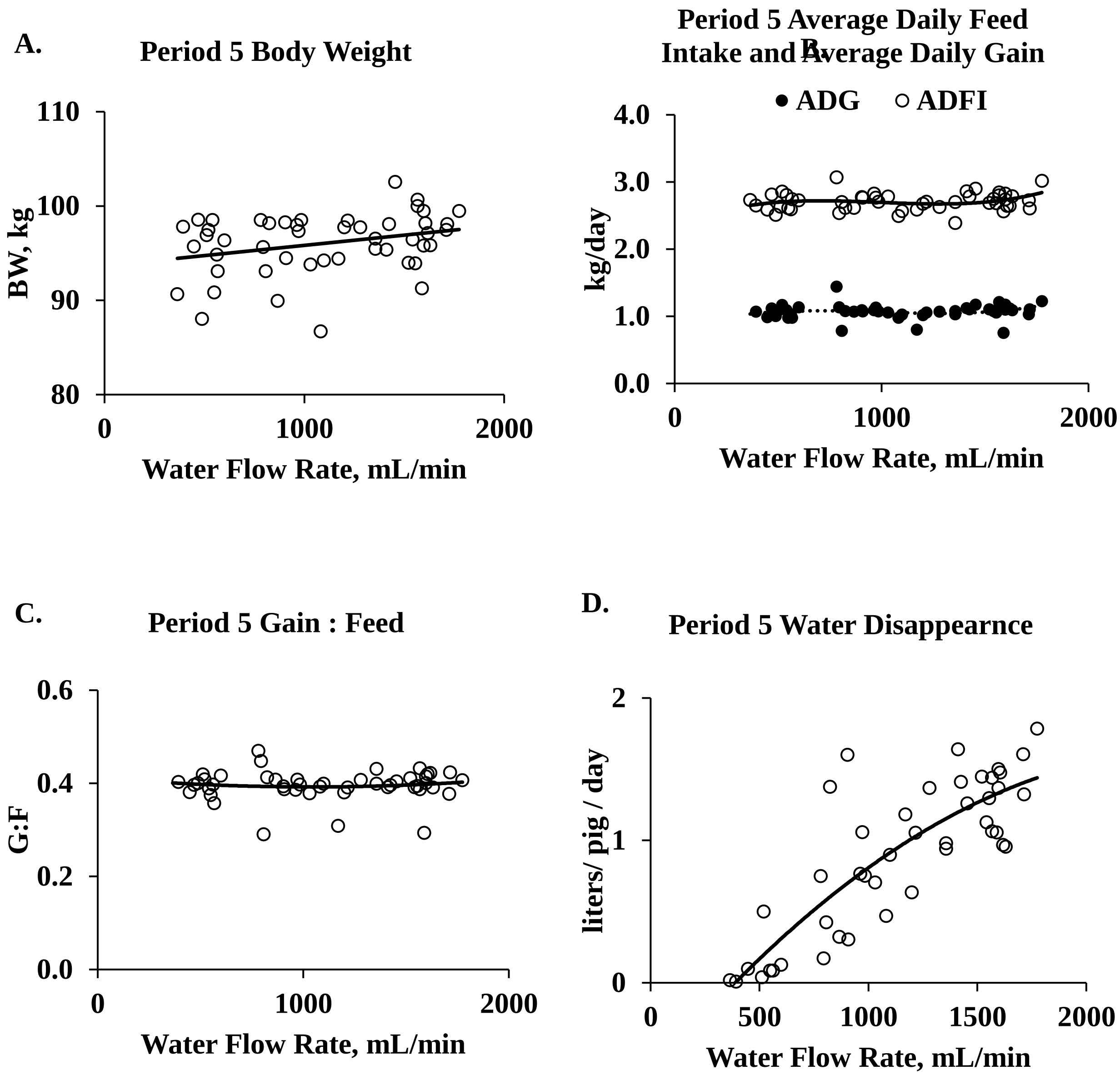


Figure 7. 9 Day 70 to Day 84 (Period 6) regression of pig performance vs waterflow rate during Study 2. A = body weight; B = average daily gain and feed intake; C = gain:feed; D = water disappearance. High barn temperature averaged 27.7°C. Linear regression: body weight $P = 0.03$, $R^2 = 0.08$; gain:feed $P = 0.28$. Quadratic regression: average daily gain, $P = 0.23$; average daily feed intake $P = 0.20$. Cubic regression: water disappearance, $P < 0.0001$, $R^2 = 0.82$.

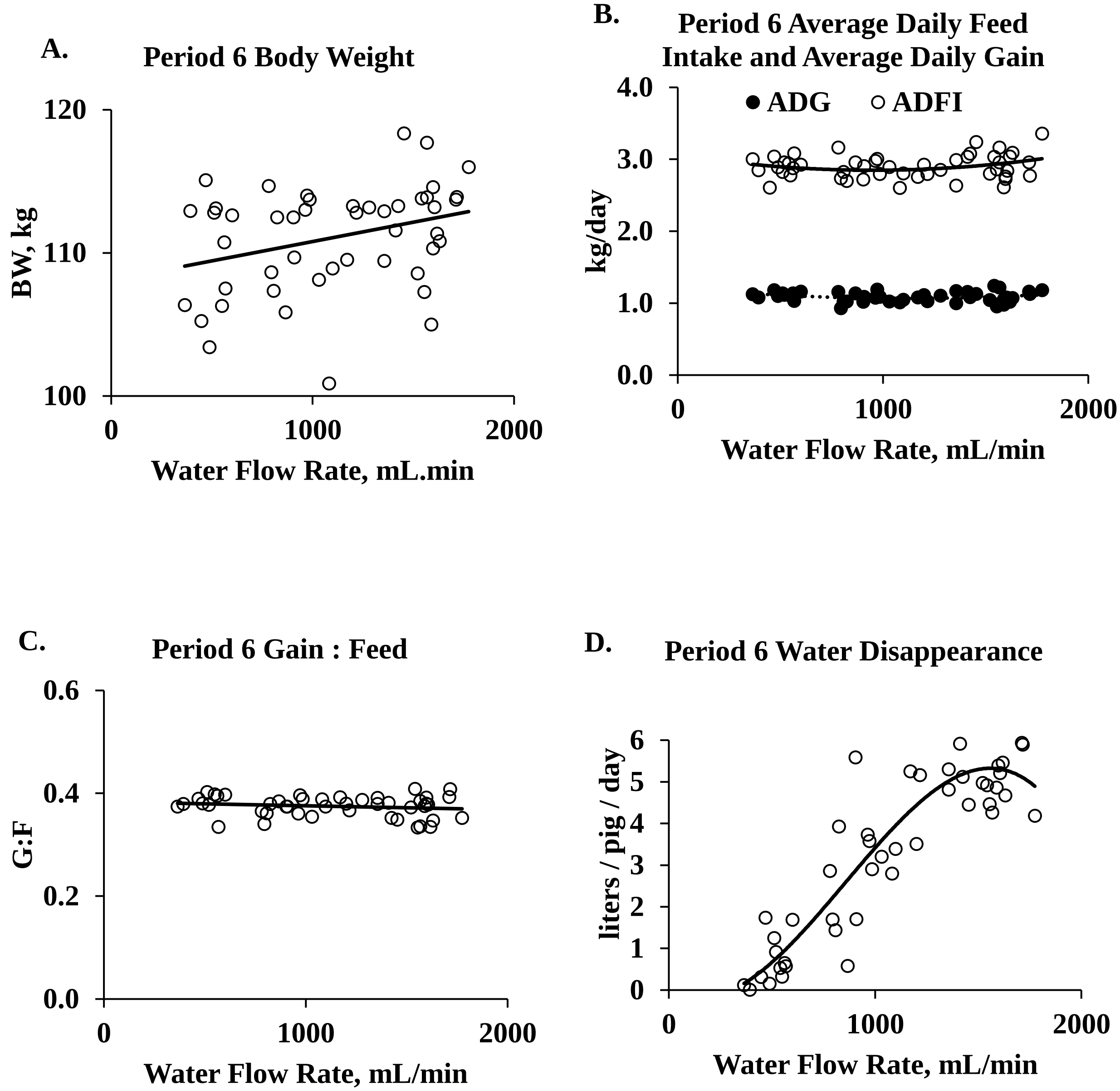
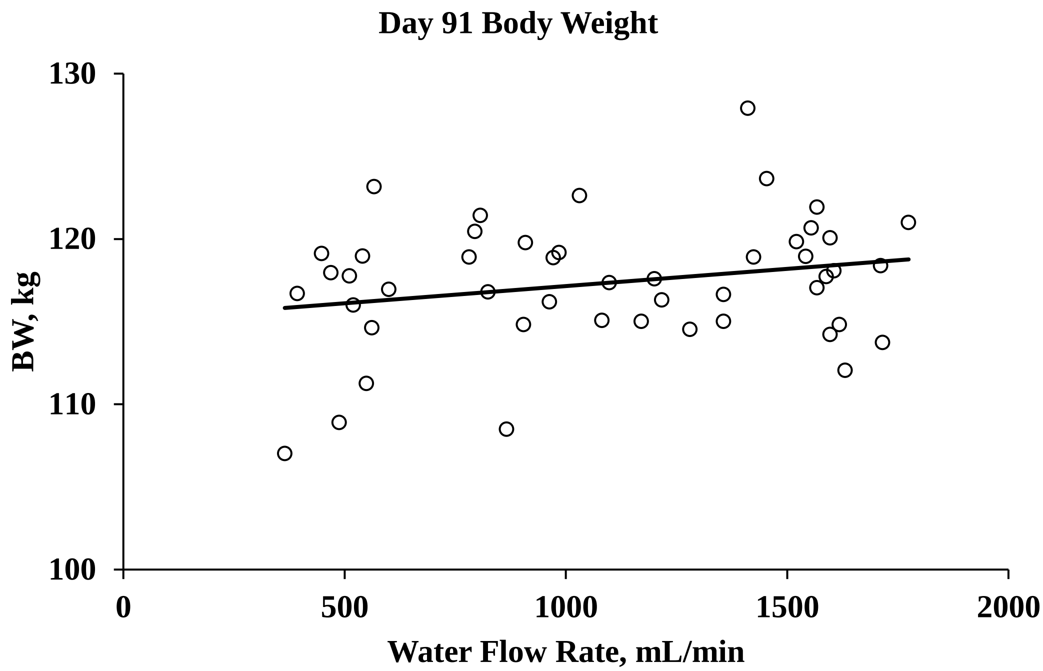


Figure 7. 10 Regression of D 91 BW. Linear regression: *P* = 0.11



7.2 Evaluation of Student Employee Satisfaction at the South Dakota State University On-Site Swine Unit

Introduction

Under the We Care principles of the Pork Checkoff is the principle of 'Our People'. The objective of this principle is to provide effective education and training to herdsmen in order to create a safe and ethical work place (We Care).

The On-site swine facility at SDSU employs between 8 to 10 students per semester. Since the opening of the facilities in 2016 has been a high turnover rate of undergraduate students. While a high turnover rate is expected as students are consistently coming in and graduating, the current turnover rate was perceived as being higher than expected. In order to address this, a survey was conducted among current student employees and a formalized training process was developed.

Materials and Methods

A survey (Table 7.1) was sent out in April 2021 to 9 undergraduate employees via QuestionPro. The survey requested basic information such as major, year in school, and approximate start date at the swine unit. Students were then asked to rank 17 statements about their experience and perception about working at the swine unit and the effectiveness of 8 learning styles on a Likert scale followed by six open ended questions.

Results

Results of the survey are displayed in Table 7.2. Of the nine student employees there were six responses. Sixty-six percent of the respondents were freshman, while 33.33% were sophomores with no juniors or seniors responding to the survey (actual employee distribution is 55.6% freshman, 33.3% sophomores, and 1.1% juniors). Of the respondents, the average employee had been employed at the swine unit for 7 months. Most of the students hope to pursue a career in the swine industry (33% agree and 50% strongly agree) and majority agree that working at the swine unit has increased their desire to work in the swine industry. All surveyed students either agreed or strongly agreed that their knowledge and understanding of the swine industry and pig production has grown since starting at the unit. Additionally, all agree or strongly agree that they have learned or gained a skill that will benfit them in the future.

All students either agreed or strongly agreed that the work they do at the swine unit is important to them, although there is less conviction that their work is valued by others. Thirty-three percent strongly agreed that their work at the swine unit is important to the SDSU Animal Science Department, with 50% agreeing, and 16% neither agree nor disagree. While 16% strongly agree that their work is important to the swine industry, with 66% agreeing, and 16% neither agree nor disagree. Finally, 66% of students agree with the statement that feel like their work is valued and appreciated while 22% neither agree nor disagree.

There is a strong consensus that communication between employees is clear and positive, with 66% agreeing and 16% strongly agreeing, while feelings towards communication with management is not as strong with 50% answering neither agree nor disagree, 16% neutral and 33% strongly agree. When asked about their preparedness to complete new tasks 50% responded neither agree nor disagree while 50% responded as agree.

For training, partner pairing and shadowing the supervisor were perceived as the most beneficial forms of training, followed by scenarios, case studies and real-life examples. Technical skills test, one time in person walk through, and classroom / lecture ranked last. In the open-ended portion of the survey common themes included student employees expressing an interest in learning more about record keeping, nutrition, research, pregnancy checks, pig flow, ventilation, and being more involved during farrowing.

Improvements to Training

One of the takeaways from this survey was student's preparedness and access to resources when asked to complete tasks. While the barn already had some signage with the outlined protocols available for students to reference, most of the protocols had been altered making the current documentation of little use. Creation of new reference material was based on management's experience on commonly asked questions during daily activities. One of the first steps included updating reference materials found in the record books. New information included a few written and photographed examples of the commonly seen illnesses for that stage of production and the recommended course of action and treatment. Also included was a medication guide which included the name of the medication, indication for its usage, dosage, and number of days for withdrawal. Specific to the Wean to Finish barn was information about pan covering and when adjustments to the opening of the feeder are needed. Instructions for powering on and off the powerwasher were created and displayed near each of the machines.

At the beginning of the school year in 2021, an introduction and review for new and returning student employees was held. While the survey indicated that a classroom style approach to learn was considered one of the least effective, it was decided that this was the best approach to reach all student employees at once and create the opportunity to have a group conversation about common questions or scenarios that arise in the barn. Students were encouraged to contribute and provide their own experiences in response to questions prompted by other students.

Conclusion

Measuring the impact of the training presented and the additional resources provided proved to be dificult as the barn broke with porcine reproductive and respiratory syndrome which resulted in the depopulation of the swine herd and the releasing of many of the student employees. Despite having any measurable data to compare, it is worth noting that during the training presenation students were actively contributing to conversation and asking questions throughout, indicating that students were attentive and engaged. Further work needs to be done to establish a more formalized routine training program.

Table 7. 1 Student employee survey example.

Major:

Year:

Approximate Start Date at the Swine Unit:

Please rate the following statements

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
I hope to have a future career in the swine industry or an associated /allied industry	1	2	3	4	5
Working at the swine unit has increased my desire to work in the swine industry	1	2	3	4	5
My knowledge and understanding of the swine industry have grown since starting at SDSU's swine unit	1	2	3	4	5
My knowledge and understanding of pig production have grown since starting at the swine unit	1	2	3	4	5
I feel that the work I do is valued and appreciated	1	2	3	4	5
I feel that the work I do at the swine unit is important to the swine industry	1	2	3	4	5
I feel that the work I do at the swine unit is important to South Dakota State University	1	2	3	4	5
The work I do at the swine unit is important to me	1	2	3	4	5
I plan to stay at my current job position for as long as possible	1	2	3	4	5
There is little to gain by staying at the swine unit	1	2	3	4	5
I feel that I have learned a skill or gained experiences	1	2	3	4	5

that will benefit me in the future					
I feel that I have been given the opportunity to grow and pursue my interests at work	1	2	3	4	5
I feel that my communication/contact between other employees is clear and generally positive	1	2	3	4	5
I feel that my communication/contact between the current supervisor is clear and generally positive	1	2	3	4	5
As I was assigned new responsibilities, I feel I was adequately trained and had access to the proper tools to complete the task	1	2	3	4	5

How effective were the following styles of training you may have experienced at SDSU swine unit at helping you learn/perform your daily duties as an employee?

	Very Ineffective	Ineffective	Neither Effective nor Ineffective	Effective	Very Effective	
Shadowing your supervisor	1	2	3	4	5	Was not implemented
Partner Pairing (following around a more experienced employee)	1	2	3	4	5	Was not implemented
On the job (learn as you go)	1	2	3	4	5	Was not implemented
One time in person walk through	1	2	3	4	5	Was not implemented
Scenarios/ Case Studies with supervisor (real life examples)	1	2	3	4	5	Was not implemented
Technical Skills Test	1	2	3	4	5	Was not implemented
Classroom / Lecutre Style	1	2	3	4	5	Was not implemented

Rate how effective you believe the following training styles would be

	Very Ineffective	Ineffective	Neither Effective nor Ineffective	Effective	Very Effective
Shadowing your supervisor	1	2	3	4	5
Partner Pairing (following around a more experienced employee)	1	2	3	4	5
On the job (learn as you go)	1	2	3	4	5
One time in person walk through	1	2	3	4	5
Scenarios/ Case Studies with supervisor (real life examples)	1	2	3	4	5
Technical Skills Test	1	2	3	4	5
Classroom / Lecutre Style	1	2	3	4	5

Approximately, how many hours did you spend in training?

Do you feel you would benefit from ongoing training?

What areas or skills would you like more training in to help you to be more confident in your job?

What technical skills would you like to learn more about that you feel would help you long term (preparation for future career or internship) (ex. Introduction to different areas of swine production, nutrition, genetics, gilt development, pig flow, etc.)?

What soft skills would you like to learn more about that you feel would help you long term (preparation for future career or internship) (conflict resolution, problem-solving, time management, adaptability, decision-making, etc.)?

What else do you need? What should your supervisor know to help you best do your job?

Table 7. 2 Likert scale responses on a percentage basis (n=6).

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
I hope to have a future career in the swine industry or an associated /allied industry	16.67	0.00	0.00	33.33	50.00
Working at the swine unit has increased my desire to work in the swine industry	0.00	0.00	33.33	50.00	16.67
My knowledge and understanding of the swine industry have grown since starting at SDSU's swine unit	0.00	0.00	0.00	50.00	50.00
My knowledge and understanding of pig production have grown since starting at the swine unit	0.00	0.00	0.00	66.67	33.33
I feel that the work I do is valued and appreciated	0.00	0.00	33.33	66.67	0.00
I feel that the work I do at the swine unit is important to the swine industry	0.00	0.00	16.67	66.67	16.67
I feel that the work I do at the swine unit is important to South Dakota State University	0.00	0.00	16.67	50.00	33.33
The work I do at the swine unit is important to me	0.00	0.00	0.00	83.33	16.67
I plan to stay at my current job position for as long as possible	0.00	16.67	16.67	33.33	33.33
There is little to gain by staying at the swine unit	16.67	66.67	16.67	0.00	0.00
I feel that I have learned a skill or gained experiences that will benefit me in the future	0.00	0.00	0.00	66.67	33.33
I feel that I have been given the opportunity to grow and pursue my interests at work	0.00	16.67	33.33	50.00	0.00

I feel that my communication/contact between other employees is clear and generally positive	0.00	0.00	16.67	66.67	16.67
I feel that my communication/contact between the current supervisor is clear and generally positive	0.00	0.00	50.00	16.67	33.33
As I was assigned new responsibilities, I feel I was adequately trained and had access to the proper tools to complete the task	0.00	0.00	50.00	50.00	0.00

On a scale of 1 to 5, with 1 being very ineffective and 5 being very effective please rank the following styles of training you may have experienced at the SDSU Swine Unit at helping you learn/perform your daily duties as an employee. If a specific training style was not utilized, please select was not implemented

	Very Ineffective	Ineffective	Neither Effective nor Ineffective	Effective	Very Effective	Was not implemented
Shadowing your supervisor	0.00	0.00	16.67	50.00	33.33	
Partner Pairing (following around a more experienced employee)	0.00	0.00	0.00	66.67	33.33	
On the job (learn as you go)	0.00	0.00	33.33	33.33	33.33	
One time in person walk through	0.00	16.67	50.00	33.33	0.00	
Scenarios/ Case Studies with supervisor (real life examples)	0.00	0.00	50.00	33.33	0.00	16.67
Technical Skills Test	0.00	16.67	50.00	16.61	0.00	16.67
Classroom / Lecutre Style	0.00	33.33	33.33	16.67	0.00	16.67

Rate how effective you believe the following training styles would be

	Very Ineffective	Ineffective	Neither Effective nor ineffective	Effective	Very Effective
Shadowing your supervisor	0.00	0.00	0.00	50.00	50.00
Partner Pairing (following around a more experienced employee)	0.00	0.00	0.00	50.00	50.00
On the job (learn as you go)	0.00	0.00	33.33	66.67	0.00
One time in person walk through	0.00	33.33	33.33	33.33	0.00
Scenarios/ Case Studies with supervisor (real life examples)	0.00	0.00	33.33	66.67	0.00
Technical Skills Test	0.00	16.67	50.00	33.33	0.00
Classroom / Lecutre Style	0.00	33.33	50.00	16.67	0.00