Factors Driving the Improvement of Average Daily Gain
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Introduction
While many factors contribute to the overall profitability of a given pork production facility, throughput would be high on most manager’s lists. Faster growth rate, and thus increased building throughput, reduces both fixed and variable costs of production. Faster growing pigs not only use less barn space in their lifetime, but they also eat less feed and usually require less care. Furthermore, it has been amply demonstrated that faster growing pigs can produce pork that is of at least equal quality to that produced by slower growing pigs (Ellis and Keith, 1993).

At its simplest, growth rate is affected by two factors, namely feed intake and the efficiency with which that feed is utilized for growth. Assuming feed efficiency remains constant, increasing feed intake will increase growth rate; conversely, if feed intake remains the same, improving feed efficiency will improve growth rate. This intimate relationship among growth rate, feed intake and feed efficiency provides insight into the factors that drive growth rate; however, at a more fundamental level, it creates confusion, because it is difficult to differentiate the primary as opposed to secondary effects on each component.

Growth Defined
Before discussing the factors that affect growth in the pig, understanding some of the basic principles will provide a basis for further discussion of constraints and their solutions. Modelling growth is a relatively recent undertaking, having been pioneered by Whittemore and Fawcett (1976) less than a quarter century ago. In general terms, growth in the pig consists of lean tissue (largely protein and water), lipid and ash. Protein accretion increases linearly as dietary protein supply increases, until another nutrient, generally energy, becomes limiting. Dietary protein supplied in excess of this upper limit is wasted, as it cannot be retained as protein tissue per se. It is generally accepted that under all but the most ideal circumstances, maximal protein accretion is below the intrinsic maximum of the animal (Whittemore, 1998).

Predicting growth under commercial circumstances has proven to be more difficult than initially imagined. Fundamentally, five pieces of information are required: 1) the intrinsic potential of the pig for protein deposition at a given weight or point in time, 2) the maintenance requirement for energy and amino acids, 3) the partitioning of energy intake in excess of maintenance between protein and lipid accretion, 4) daily nutrient intake and 5) the efficiency with which energy and amino acids are utilized for growth (adapted from Schinkel and de Lange, 1996) and . Unfortunately, this information is often not readily available. For example, most genotypes are poorly characterized with respect to potential for protein deposition and feed intake under commercial conditions is rarely readily available, at least not with sufficient accuracy for these purposes. The maintenance requirement for energy and amino acids has been defined with a reasonable degree of accuracy, although further clarification of some issues is required. The metabolic parameters, namely the nature of partitioning of energy between adipose and lean tissue, and the efficiency with which amino acids and energy are utilized for growth are poorly defined. Predicting animal performance under commercial conditions has been frustrating, although there are a number of laboratories around the world working on this important topic.

There are at least two intrinsic limitations to protein accretion. First, there appears to be a minimum lipid:protein ratio that is applied to growth, and which appears to differ among genotypes. In modern genotypes, under conditions of excellent feed intake, the lipid:protein ratio in the empty body rise from 1.0 at 50 kg to 1.6 to 1.8 at 120 kg. Under conditions of less ideal feed intake, the lipid:protein ratio at 120 kg is only about 1.3 to 1.5:1 (Patience, unpublished data). Second, there is an intrinsic upper limit to protein accretion, which is not only characteristic of individual genotypes, but which is also affected by gender. Energy supplied in excess of that required to maximize protein deposition and the intrinsic minimum lipid:protein ratio will be used for fat deposition (Gerrits, 1996).
It has been estimated that only about one-third of the protein consumed in the diet will be retained in the body as protein. The rest will contribute to the circulating nitrogen pool, most of which is eliminated in the urine, and to the energy currency of the body.

**Genetics**

With the tremendous improvements in the genetic make-up of the modern pig, it is sometimes hard to accept that with this progress, we may have also inherited some constraints to performance. For example, it is well understood that selection for leanness, if not linked to selection for feed intake, can lead to animals with reduced appetite, and thus growth potential.

Interestingly, selection for leanness also tends to select for animals with a higher mature body weight. Selection for younger age at puberty tends to select for animals with a lower mature body weight (Currie, 1988). Since modern pork production seeks leaner animals, but also selects for animals that achieve puberty at a younger age, conflicting objectives emerge.

Current genetic improvements have resulted in an increase in the lean growth rate of up to 3% per year (Hall et al. 2000). As the lean content of the pig increases, feed efficiency improves. Nutrient intake must also increase through increased feed intake or diets higher in energy and nutrient concentration in order for the genetic potential of future pig generations to be expressed (Hall et al. 2000). However, selection for feed efficiency can indirectly result in reduced feed intake and thus growth rate.

### Average growth rate and feed conversion in Dutch (NL) and Norwegian (N) pigs from 1980 to 1995

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<tbody>
<tr>
<td>Growth (g/d) (NL)</td>
<td>646</td>
<td>654</td>
<td>693</td>
<td>718</td>
<td>717</td>
<td>729</td>
</tr>
<tr>
<td>Growth (g/d) (N)</td>
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<td>888</td>
<td>897</td>
<td>936</td>
<td>960</td>
<td>956</td>
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<tr>
<td>FC (NL)</td>
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<td>2.98</td>
<td>2.93</td>
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<tr>
<td>FC (N)</td>
<td>2.54</td>
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<td>2.45</td>
<td>2.31</td>
<td>2.26</td>
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Adapted from Rauw et al. 1998

**Physical Environment**

The pig's physical environment is clearly a major determinant of growth rate. This is a complex subject, because of the interactions among and between thermal (e.g. temperature, humidity, air speed) and non-thermal factors (e.g. air contaminants, floor space).

The thermal comfort zone is that range in ambient temperature between the lower and upper critical temperatures across which the animal maintains a constant core temperature without having to resort to changes in heat production or metabolic rate. The thermal comfort zone is about 10ºC wide. Within any living thing, there is a minimum amount of heat generated by the processes included in basal metabolism; there are also obligatory losses of heat. The amount of heat generated will be dependent on resting metabolism, plus the additional heat generated by muscle activity associated with movement, eating, etc. The balance of heat production and heat losses will determine the upper and lower critical temperatures for a given animal.

The nature and extent of heat loss is often misunderstood. For example, the pig loses heat to its surroundings by both sensible (radiation, convection, conduction) and insensible (evaporation) mechanisms. Certain losses or gain of heat, such as through radiation, are difficult to measure, and therefore not as obvious as conductive and convective mechanisms. Even the latter are often poorly understood. For example, while many people refer to subcutaneous fat as highly protective against chilling, the reality is that fat tissue is 16 times more effective than air in conducting heat (Currie, 1988). The impact of adipose tissue rests more with its poor vascularization than its insulation properties.

Under practical circumstances, one should be considering the “effective” ambient temperature when considering the effects of elevated temperature. As an example, wet floors and slats have the effect of
lowering the effective ambient temperature by 5 to 10ºC. On the other hand, the presence of dry bedding elevates effective ambient temperature by about 4ºC (Verstegen et al., 1984).

Growth rate may not be maximized within the thermal comfort zone of the pig. Rather, a slightly lower temperature will stimulate feed intake to the point that growth rate increases, and the benefit of this increased feed intake is only partly off-set by a lower feed efficiency.

**Heat Stress**

The single most important effect of heat stress is reduced feed intake. This results from the stimulation of peripheral thermal receptors which signal the appetite centre of the hypothalamus. Heat stress also increases heart rate and reduced feed intake, leading to a drop in growth rate (Lopez et al., 1991a,b; Hyun et al., 1998; Becker et al., 1993).

While temperatures above the thermal comfort zone reduce feed intake, changes in feed intake alter the thermal comfort zone. For example, pigs with a reduced feed intake experience a higher thermal comfort zone, due to the reduction in metabolic heat production. This becomes a particular concern in newly-weaned pigs, which due to a temporary reduction in feed intake, often become chilled at temperatures that would otherwise provide adequate comfort.

The impact of thermal stress will affect, and be affected by, the presence of other stressors. For example, a study by Hyun et al. (1998) showed that the effects of different stressors (high temperature, restricted space allowance and regrouping) on average daily gain, feed intake and feed conversion, when presented together, are additive.

**Cold Stress**

Verstegen et al. (1984) suggest that the main factor influencing growth and development of young pigs is feed intake, which is increased as temperature decreases. If feed intake is not allowed to increase, the result is a reduced rate of gain as the cold increases heat loss and therefore energy gain. Herpin et al. (1987) suggest that heat production is increased as environmental temperatures fall, which has the effect of reducing fuels available for growth.

Typically, lower average daily gains and higher feed intake occurs among pigs in a cold environment (Lopez et al., 1991). However, in some studies, notably in younger pigs, low temperatures did not affect feed intake, so that only growth rate and feed conversion were compromised (Maenz et al., 1994). As a thumb rule, one can estimate that for every Centigrade degree below the thermal comfort zone, growth rate will decline by 10 to 22 g/d (Verstegen et al., 1984).

**Social Interation**

**Space Allocation**

While the response to floor space by pigs in confinement appears to have received considerable attention, many questions remain. It is well understood that reducing floor space allowance reduces both feed intake and growth rate and lead to behavioural vices, such as tail-biting (Edmonds et al., 1998). However, the changing nature of pig housing combined with a more thorough investigation of the subject has resulted in more questions arising on this topic. It is now clearly understood that floor space allowance is best expressed as a function of BW^{0.667} and that maximum growth occurs when floor space allowance for finishing pigs is set at 0.039 m² BW^{0.667} (Gonyou and Stricklin, 1998). However, the economic optimum lies somewhat below this standard.

While crowding is known to reduce growth rate and feed intake, increasing the density of the diet to achieve equivalent daily nutrient intake is not successful in returning the performance of crowded pigs to that achieved by non-crowded pigs (Brumm and Miller, 1996).

**Regrouping**

In order to maintain efficient use of barn space, regrouping of animals may be required from time to time. It may be practiced during the nursery and weaning stages to utilize pen space most efficiently; it may
also be practiced as pigs within a pen reach market weight and a portion of the slower growing animals remain behind. Stookey and Gonyou (1994) determined that mixing or re-grouping of animals within two weeks of marketing led to decreases in weight gain in the range of 11%. The setback also increased days to market and would result in loss of revenue, as animals did not have sufficient time to compensate. Some studies showed a significant reduction in re-grouping aggression when escape areas were provided. This also translated to a slight improvement in gain for a two-week period following re-grouping. It is therefore clear that regrouping of pigs must be done with care, and a clear understanding of what the implications may be.

**Group Size**
The number of pigs housed within a pen will affect barn design as well as construction cost. Hence, there is growing interest in the expansion of group size to double or triple that which seemed optimal less than a decade ago.

There has been some inconsistency in findings on the effect of group size on performance (Gonyou and Stricklin, 1998; McGlone and Newby, 1994). Most recently, it has been determined that if all other factors are equal, it appears that group size up to at least 80 animals is completely viable (Schmolke and Gonyou, 1999).

**Feed Presentation**
Feed presentation is an extremely important aspect of pork production. Various studies have concluded that the choice of feeder can influence growth rate by more than 10%. The information that is available on the subject provides useful insight into the design of the feeder, and the importance of the nature of the feed that they contain. For example, by far the majority of all aggression in pigs is associated with feeding (Ewbank and Meese, 1971). McGlone et al. (1983) suggested that providing adequate space for feeding based on size of the pig and with an additional social space allocation, should minimize aggression during feeding. Baxter (1989) concluded that group feeding with provisions for structural dividers between feeding spaces greatly reduces the need for defensive behaviour. The research also indicates that wastage was reduced 10-fold when structural dividers were included for head and shoulders.

The form of the feed is also important. Feed offered in a mash will result in lower feed intake than when offered in pellet form. Wet and/or wet/dry feeding will also increase feed intake (Gonyou and Lou, 2000).

**Health**
In response to pathogens, the immune system is activated to synthesize the components of the defense mechanism. These processes require energy; thus, the health of the animal becomes important not only in the growth of the animal but also in the efficiency of that growth. The increase in cytokine production decreases feed intake and consequently reduces feed efficiency (Williams et al., 1997). Minimizing the level of chronic immune system activation can enhance the rate and efficiency of pig growth (Williams et al., 1997). Williams et al. (1997) suggested that pigs with a highly activated immune system are more affected by dietary amino acid requirements above that needed to meet the lean tissue growth rate than pigs with a low level of immune system activation.

Effect of immune system (IS) activation and dietary lysine percent on pig daily growth (kg/d) from 7 to 112 kg.

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<tr>
<th>Lys %</th>
<th>LOW IS</th>
<th>HIGH IS</th>
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<tr>
<td></td>
<td>BW (kg)</td>
<td>BW (kg)</td>
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<tr>
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<td>102</td>
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<tr>
<td>1.20</td>
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<td>.375</td>
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<td>1.50</td>
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<td>7</td>
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<tr>
<td>1.20</td>
<td>.789</td>
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Adapted from Williams et al., 1997.
Diet

Diet Composition
Other speakers in this session will address issues of diet composition, so they will only be briefly addressed herein. Clearly, diet composition is one of the most easily altered aspects of pork production, as nutritionists seek to enhance performance at the lowest possible cost. However, it is an over-simplification to assume that increasing nutrient density will increase performance; while this is certainly true in many instances, it is not universal and care must be taken to avoid the temptation to increase nutrient density – and thus feed cost – to overcome other more fundamental constraints in the production system. Not only is it costly, it may be ineffective.

Considerable attention is directed at selecting the appropriate nutrient levels in the diet, but there appears to be less interest in addressing how those nutrient specifications will be met. This may be a more serious matter than previously thought. For example, Fairbairn et al. (1999) reported that the energy concentration in barley varies by 15% or more; other studies have revealed similar or larger variation in other ingredients. Clearly, the same degree of precision must be applied to meeting nutrient specifications as was applied in the development of those specifications.

Diet Processing
The reduction in particle size of feed ingredients improves feed efficiency and nutrient digestibility (Wondra et al., 1995a, 1995b). Efforts are still being made to find the optimum particle size of grain ingredients. Healy et al. (1994) found that optimum particle size of the diet was 600 µm in nursery pigs and Wondra et al. (1995a) found that a particle size of 600 µm, or slightly less, was optimal for corn in diets for finishing pigs. The reduction of particle size exposes more surface area to enzymes in the gut of the pig, allowing more of the nutrients to be digested and absorbed. However, there is an increased incidence of gastric ulcers with decreased particle size (Wondra et al., 1995a, 1995b) which must be considered when determining the optimum particle size of grains in a diet.

Benefits of using pelleted diets include decreased segregation, increased bulk density, reduced dustiness, improved handling and transportation characteristics, improved palatability and thermal modification of starch and protein (Chae and Han, 1998). Wondra et al. (1995a) found that pigs fed pelleted diets digested 3% more DM and 10% more N each day than pigs fed meal diets. The improvement was attributed to the increased digestibility of DM and N, rather than increased daily intake of these nutrients, because ADFI was actually less for the pigs fed pelleted diets.

Water Quality
Water quality can affect performance, and is generally described in terms of dissolved solids (TDS), suspended solids (organic matter) and microbiological content. Microbial contamination of water can result in pathogen transmission to an animal and therefore affect productivity. Water hardness increases with mineral content (TDS) (McLeese et al., 1991).

Water is often blamed for poor performance, but the data supporting these claims is often lacking. Wahlstrom (1981) reported that at TDS levels as high as 6900 ppm, water consumption increased, but salinity had no effect on gain, feed consumption or feed efficiency. This is in agreement with an earlier study by Paterson et al. (1979) who found no significant differences in average daily gain or feed efficiency between pigs drinking water with 3000 ppm added sulfate and those provided water with no added sulfate. Adding nitrate to drinking water up to a rate of 2000 ppm had no negative effects on growth, feed intake or feed utilization (Sorensen et al., 1993). Maenz et al. (1994), Patience (1997) and Patience et al., (1997a,b) reported that water with very high levels of sulphate result in an osmotic diarrhea, but has no effect on animal performance.

Anti-nutritional Factors
Increasing average daily feed intake through the use of palatable ingredients for pigs will ultimately increase average daily feed intake. However, many ingredients used in swine diets have antinutritional
factors (ANFs) associated with them, which will impede the performance of the pig by affecting ADFI and feed efficiency.

Known ANFs present in peas, common beans and soybeans are protease inhibitors, haemagglutinins or lectins, tannins, alpha-amylase inhibitors, allergens or antigenic proteins, phytases, goitrogens, antivitamins and saponins. Antinutritional factors decrease feed intake as well as decrease feed efficiency through interference in the digestive process.

Summary
In summary, a multitude of intrinsic and extrinsic factors affect growth in the pig. It is only by addressing each, individually and as a whole, that animal growth can be optimized. What is clear is that pork production, while achieving extraordinary gains in the past 4 decades, has yet to fully utilize the tremendous genetic potential of the pig. This is apparent by the variation in performance which occurs among groups of pigs within a barn, and by the diversity of results experienced among producers. It is equally clear that the financial returns which will accrue from achieving higher levels of performance are substantive.

References


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Red Deer, Alberta, Canada