1.- INTRODUCTION

The globalization of the economy along with many other factors continue to have major impacts on swine production and feeding programs in the USA. Greater emphasis on feed and food safety is creating new government mandated regulations for feed mills. The Food Safety and Modernization Act (FSMA) is currently being implemented at feed mills and will continue to be phased in over the next 3 years. With the recent emergence of Porcine Epidemic Diarrhea virus (PEDv) in the US, a high level of scrutiny was focused on ingredient supply chain bio-security, particularly from China, due to the number of micro-ingredients originating in China and the genetic similarity of the PEDv strain identified to a recent PEDv outbreak in China. While slaughter weights have steadily climbed over the last 20 years, now approaching a national average of 130 kg, increased mortality from PEDv created a short-term jump in slaughter weights forcing feeding programs to be adjusted to accommodate heavier weight pigs. Biofuels production and the resulting volume of by-products (e.g. DDGS) available to the feed industry has begun to level off but still has a major impact on commodity (e.g. corn) prices and availability, diet cost, and in the case of DDGS, greater attention to iodine value as a measure of carcass fat quality. As the biofuel industry competes with the livestock and food industries for grain-
derived starch, the resulting increase in swine diet fiber content and cost increases interest in non-starch polysaccharide (NSP) enzymes, although their economic benefit is still uncertain.

Improvements in swine genetics, now more rapid than ever due to enhanced molecular selection techniques, challenge nutritionists to continually retest and refine nutrient requirements for optimum lean growth and production efficiency. Continued advances in rapid analytical tools such as a NIR for feed ingredient analysis allow more frequent updates to nutrient matrices which is more critical than ever as producers feed for maximum profit in rapidly changing commodity markets.

2.- SLAUGHTER WEIGHT

In May of 2013, a highly virulent strain of PEDv was found in the US and spread rapidly causing high mortality to nursing piglets, and mild to moderate diarrhea in nursery and grow-finish pigs. Affected sow farms commonly lost 100% of their production for 3-4 weeks creating a large hole in production. Total US pigs slaughtered decreased significantly in 2013 and 2014 as a result of the PEDv crisis. Attempting to compensate for lost revenue from selling fewer pigs, many producers fed pigs to heavier weights (Figure 1). Two key factors allowed this to happen: 1. Increased space available per pig due to fewer pigs entering finish barns, and 2. higher market prices resulting from the shift in pork supply made feeding pigs to heavier weight very attractive. During brief windows in 2014, profit per pig sold approached 100 USD for 100 kg carcasses. Highly profitable economics drove some producers to slaughter weights of 145 kg, even though feed conversion ratios at these weights would normally mean unprofitable conditions. The trend to higher slaughter weights over the last 15 years is not new but the abrupt changes in pig supply due to PEDv meant slaughter weights increased more quickly than normal. Space allowance becomes limiting for growth rate, generally after pigs reach 100 kg. Abrupt increases in slaughter weight create challenges to determine the most effective marketing strategy. A common strategy is to remove 5-10% of the heaviest pigs from each pen thus alleviating growth restrictive conditions. Often, a rapid increase in growth rate of the remaining pigs is observed immediately following the first marketing of pigs. The best method of marketing is often system-specific and influenced by factors such as split vs. mixed sex feeding, packer grids, whether the system is long or short on space, and of course feed cost and market price.
3.- PHYTASE

The phytase enzyme has been used commercially in grow-finish feeding programs for over 20 years. Its use has grown significantly from a set level of 300 FTU/kg diet when first introduced, to levels as high as 1-2000 FTUs when inorganic phosphorus prices peaked, to dynamic levels now adjusted depending on ingredient composition of the diet, stage of production, and phosphorus requirement. The use of phytase has generally increased over time, although its use has been challenged with increased use of corn distiller’s dried grains with solubles (DDGS). In the pre-fermentation process of corn to ethanol conversion, phytase is commonly used to improve starch availability for fermentation. Phytase is commonly used to improve starch availability for fermentation. Phytate phosphorus is released in this process and thus the phytate phosphorus content of DDGS is generally quite low. When DDGS comprises 30 to 40% of grow-finish diets, the need for phytase to help meet the pigs’ phosphorus requirement is greatly diminished and completely eliminated in some cases, especially in late finishing. Phytase has primarily been used to improve calcium and phosphorus digestibility of cereals and oilseed feedstuffs, and to decrease phosphorus excretion thus increasing its value as part of an overall environmental management tool. More recently the efficacy of phytase for improving amino acid digestibility has gained acceptance and the economic value of this benefit can be greater than the phosphorus benefit when protein prices are high. Energy digestibility can also be improved by feeding phytase but this may be limited to diets deficient in digestible phosphorus (Almeida et. al., 2013). In diets high in DDGS which provide adequate digestible phosphorus to meet pigs’ requirements, the use of phytase is likely over estimating nutrient release and thus economic value. Linear
modeling of nutrient release (e.g. phosphorus, AAs, energy) in feed formulation programs is common today but needs to evolve to more accurately reflect variation in phytate concentration as ingredients with varying phytate levels are used in diets.

The concept of “super dosing” phytase has been promoted recently as providing “extra-nutritional” benefits through an undefined mechanism. Phytase levels of 1500 to 2500 FTU/kg diet are now being promoted to improve gain and feed conversion. Data from our own lab confirm that in young pigs (below 12 kg BW), super dosing can improve growth performance (Table 1, Cargill, unpublished data). But the data in grow-finish pigs is not consistent. Wilcock et al. (2014) reported an improvement in ADG and feed conversion as phytase increased from 500 to 2000 FTU/kg diet, well above a level needed to meet the pigs’ phosphorus requirement. However, a study in our own research facilities using 1000 grow-finish pigs fed from 25 to 125 kg live weight failed to show any improvement in growth performance as phytase increased from 600 to 1800 FTU/kg diet. Whether consistent improvements in grow-finish performance can be consistently achieved with super-dosed levels of phytase when loading values for amino acids and energy (in addition to calcium and phosphorus) are already being applied needs to be clarified.

Table 1.- Effect of super dosing phytase in nursery pigs from weaning to 21 days post weaning

<table>
<thead>
<tr>
<th>Criteria</th>
<th>0</th>
<th>1500</th>
<th>3000</th>
<th>4500</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed:Gain, g/g*</td>
<td>1.129</td>
<td>1.105</td>
<td>1.090</td>
<td>1.086</td>
</tr>
<tr>
<td>ADG, g**</td>
<td>334</td>
<td>328</td>
<td>333</td>
<td>333</td>
</tr>
</tbody>
</table>

*Cargill, unpublished data.
*Treatment effect, P<0.01.
**Treatment effect, P>0.10.

4.- NSP ENZYMES

The use of corn DDGS has become common in grow-finish diets with levels ranging from 5 to 50% of the diet. The NDF content of DDGS is approximately 27-30% and thus the interest in NSP enzymes to improve energy digestibility is significant. The most commonly evaluated NSP enzyme is xylanase, likely due to its relatively low cost and some substrate specificity. In vitro studies clearly show an improvement in arabinoxylan degradation in both wheat products and DDGS with xylanase use. Other studies in pigs demonstrate an improvement in energy digestibility in diets containing...
DDGS (Nortey et al., 2014). However, in larger scale commercial trials, the consistency of an actual feed conversion response, and thus confidence in assigning an energy loading value to xylanase for grow-finish pigs has been poor (Asmus et al., 2012). The other main sources of arabininoxylans in US grow-finish diets are wheat and wheat by-products, most commonly wheat middlings. Recently, Boyd and Rush (2015) reported that adding wheat middlings to grow-finish diets, may increase mortality under commercial conditions. But, when xylanase was added to these diets, mortality returned to control levels. This response was then tested in a large-scale commercial trial involving over 2100 pigs fed from 12 to 138 kg. Diets in this study contained 15% corn DDGS and 10% wheat middlings. A xylanase dose titration was performed with levels of 0, 3000, 6000, and 9000 units/ton. Mortality was improved from 3.99 to 2.25% as xylanase increased from 0 to 6000 units (Table 2) consistent with previous observations. Feed per unit of live weight gain was not significantly affected by xylanase, but carcass yield tended to increase with increasing xylanase and therefore feed per unit carcass weight gain improved significantly.

A brief review of other studies with a different source of xylanase suggested the improvement in mortality was not specific to one xylanase. The mode of action for xylanase to improve mortality is not known but may involve shorter chain xylo-oligomers acting as prebiotics in the gut to improve the intestinal microbiome (Damen et al., 2011).

Table 2.- Effect of xylanase dose in grow-finish pigs fed diets with DDGS and wheat middlings on mortality and full value pig percent

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Xylanase Dose, units/kg diet</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Mortality, %*</td>
<td>3.99</td>
</tr>
<tr>
<td>Full Value Pigs, %**</td>
<td>96.0</td>
</tr>
</tbody>
</table>

*Adapted with permission from Boyd and Rush, 2015

**P<0.13

**P=0.35

5.- DDGS

The fatty acids in corn oil are mostly unsaturated consisting of 60% linoleic acid (C18:2). The typical fat content of DDGS has been 8-10% until recently and meant that for every 10% DDGS in the diet, a 1% increase in corn oil was achieved. Feeding unsaturated fat to pigs is known to increase the amount of unsaturated carcass fat. Because unsaturated fat is “softer” than saturated fat, a high level of unsaturated fat in the diet of a pig can lead to soft bellies and undesirable processing characteristics of wholesale cuts. Research has
demonstrated a significant increase in the iodine value of pork carcass fat in response to feeding DDGS (Whitney et. al., 2006). When fed in combination with liquid fat sources such as “animal/vegetable” blends, diets containing high levels of DDGS can create extremely soft carcass fat. This creates a limitation for DDGS inclusion in late finishing where the impact of diet iodine value has the largest impact on carcass iodine value. Carcass iodine value restrictions are imposed by slaughter plants and typically range from 72 to 76 maximum target for most of the industry. This means that DDGS feeding may be limited in cases where a packing plant has strict limits on the carcass iodine value.

More ethanol plants are removing a portion of the “free” corn oil from DDGS for sale in other markets thus creating “low fat” DDGS with 5-6% oil. The energy value of low fat DDGS makes it a less valuable ingredient vs. high fat DDGS. But, removal of free oil in DDGS is becoming an industry standard. Also, low fat DDGS may allow a producer more flexibility on DDGS inclusion level and feeding to heavier weights due to its lower iodine value.

6.- DIET FORM

With increased availability and consistency of DDGS, acceptance and inclusion rate has increased when economically favorable. When management of diet iodine value is not a concern and DDGS price relative to corn is favorable, DDGS inclusion rate in some feeding programs will reach 50% of the diet. The value of pelleting diets for grow-finish pigs is well known and is likely due, at least in part, to improved energy digestibility, particularly of the fat portion. Pelleting diets high in DDGS results in similar improvement in feed conversion and daily gain to those observed when corn-soy diets are pelleted. While pelleting clearly improves growth and feed conversion, negative aspects of pelleting such as increased rate of gastric keratinization and ulcer development exist. We recently observed a significant increase in carcass iodine value resulting from pelleting diets with DDGS. This further limits the level and duration of DDGS feeding when iodine value is of importance.

7.- NET ENERGY

The cost of energy ingredients in North America region have been at historical high level during the last 10 years. Therefore, proper evaluation of the energy of feedstuffs is increasingly important in feed formulation. Theoretically, the most accurate energy system is the net energy (NE) system. It accounts for not only fecal, urinary, and gaseous losses of
energy, but also heat produced (heat increment). It is the energy retained by the animal to be used for productive purposes, such as protein and fat deposition and milk production. Because losses in energy due to heat loss are accounted for in NE system, this energy system is especially valuable when considering alternative ingredients. When ingredients contain high levels of fiber, more energy is lost as heat, and the NE system can more accurately account for this reduction in energy efficiency. Moreover, because less heat is produced by dietary fat during digestion, it is given a higher value under the NE system.

While the NE system has been in existence for many years, nutritionists in the U.S. have just started to adapt this technology. The main issue has been the lack of studies evaluating the NE value of ingredients and validation supporting its use in U.S. style feeding program. However, with the increasing use of by-products in swine diets, more universities, feed companies, and large animal producers have started to evaluating, validating, and using the NE system. The traditional process of measuring net energy value for ingredients is very expensive and tedious and requires special equipment (metabolic chambers). In contrary, validation of the NE of ingredients in using a growth assay (sometimes referred to as “effective energy”) is more commonly being used in the US swine industry. Recent studies that revealed NE values of various feed ingredients have used both methods.

Fat, an important ingredient in swine diets, theoretically should have a relatively higher value vs. corn or starch under the NE system vs. the ME system. Kil et al. (2011) reported the NE value of soybean oil is 5,073 and 4,679 kcal/kg at 5% or 10% inclusion respectively, whereas the NE of choice white grease is 5900 kcal/kg at 10% inclusion using a comparative slaughter procedure. However, a growth assay by Boyd (2012) revealed that the NE value of choice white grease is around 7,600 kcal/kg in a typical U.S. diet. The difference might be due to the different metabolic fates of fat at different dietary inclusion levels. Incorporated into body fat would be the primary fate at lower inclusion levels, whereas at higher inclusion levels, the metabolic fate for some fat would also be metabolized as energy. In theory, the energetic efficiency of lipids for ATP production is 66%, whereas the efficiency is 90% if they are directly incorporated into tissue fat.

Another major ingredient, soybean meal, has also been studied recently. Zier-Rush et al (2011) demonstrated the NE value of soybean meal is close to the value reported in the 2012 Swine NRC using a growth assay.

Several recent papers have also studied the NE value of alternative ingredients. Stewart et al. (2013) has determined that the NE value of soybean hulls and wheat middlings using comparative slaughter procedure, was 603 kcal/kg and 987 kcal/kg,
respectively. These values are relatively lower compared with the value reported by Sauvant et al. (2004). De Jone et al. (2014) reported that increasing inclusion of wheat middlings reduced gain and gain:feed. However, when assigned the NE energy value reported by Sauvant et al. (2004), 10% inclusion of wheat middlings did not affect gain and gain:feed suggesting that a more accurate value was reported by Sauvant et al. (2004). A recent growth assay from Cargill research facility also demonstrated that the NE value of wheat middlings is greater than the value reported by Stewart et al. (2013).

Corn DDGS has been used extensively over the last decade in swine diets. However, a relatively small number of researchers have studied the NE value of corn DDGS. Kerr et al. (2014) recently reported the NE value for corn DDGS is 2,133 kcal/kg DM, being lower than the 2,622 kcal/kg DM reported in the 2012 Swine NRC. A follow-up growth assay by Kerr et al. (2014) confirmed the lower NE value of corn DDGS. A recent growth assay from Cargill research facility suggested the NE value of reduced-oil corn DDGS is close to the value reported in the 2012 Swine NRC.

Furthermore, studies have confirmed the advantages of the NE system over the ME system in U.S. style feeding program, in terms of growth performance prediction and financial results in animal production (Boyd et al., 2012; Patience, 2014; Cargill, unpublished data Figure 2).

Figure 2.- Effect of increasing low-fat DDGS level in grow-finish diets formulated on an equal ME vs. NE basis

![Figure 2](image-url)
8.- AMINO ACID RESEARCH

In the swine industry, crystalline amino acids have been widely used to replace soybean meal in swine diets. In a typical corn and soybean meal diet, lysine, threonine, and methionine are the first three limiting amino acids. However, tryptophan becomes the second limiting amino acid in diets containing high levels of corn DDGS. With the extensive utilization of corn DDGS in swine diets during the last decade, the optimal Trp:Lys ratio becomes more critical for practical diet formulation.

However, the optimal SID Trp:Lys ratio remains controversial due to the variability among trial results over the last 10-15 years. Historical studies from North America and Europe have reported a range of 14.5 to 23.1% SID Trp:Lys ratio requirements across various pig body weights. Thus, recent studies have been focused to determine the optimal SID Trp:Lys ratio for various stages of pig growth in a corn-soybean meal-corn DDGS diet. Nitikanchana et al. (2011) reported the optimal SID Trp:Lys ratio was 20.3% for 6 to 10 kg nursery pigs. Goncalves et al. (2015) reported the SID Trp:Lys requirement for 11 to 20 kg pigs fed 30% corn DDGS ranged from 16.6% for G:F to 21.2% for maximum ADG. Barnes et al. (2010) has demonstrated an optimal SID Trp:Lys ratio of greater than 18% in diets containing 30% corn DDGS for pigs greater than 73 kg of body weight. In a follow up study, Nitikanchana et al. (2012) confirmed the optimal SID Trp:Lys was around 20% in diets containing 30% of corn DDGS for the same weight of pigs. Increasing SID Trp:Lys ratio by adding crystalline tryptophan or increasing soybean meal both increased growth performance of pigs. Goncalves et al. (2015) reported the estimated requirements for SID Trp:Lys for 30 to 125 kg pigs fed 30% corn DDGS ranged from 16.9% for gain:feed to 23.6% for ADG. Greiner et al. (2015) demonstrated optimal SID Trp:Lys ratio for ADG in grow-finish pigs was between 18.0 and 21.4, whereas the optimal ratio for gain:feed was between 15 and 19.5. In general, recent studies on Tryptophan suggest a higher SID Trp:Lys ratio is necessary to optimize growth efficiency in pigs vs. levels used in typical North American corn-soy diets. Validation studies have also been conducted at Cargill research facility. Our data largely agrees with the published data and supports a higher ratio is needed when feeding moderate to high levels of corn DDGS.

The relative higher cost of soybean meal and the continued availability of crystalline amino acids in the last few years has strengthened the importance of using high crystalline amino acids. With lysine, methionine, threonine, tryptophan, valine, and isoleucine commercially available, the limitation of using high crystalline amino acid comes from a minimum requirement of the non-essential amino acids or crude protein. Availability of corn DDGS, as a relatively cheap crude protein source, has partly solved the minimum requirement of crude protein economically and expanded the use of...
crystalline amino acids. However, knowing the exact minimum crude protein levels of various stages of pigs feeding corn-soybean meal-corn DDGS diets could expand the use of crystalline amino acids even more and save dietary costs. Several studies have evaluated the minimum crude protein requirement for pigs fed corn-soybean meal-corn DDGS diets. Recent findings allow us to take full advantage of using synthetic amino acids.

9.- INTERCONNECTED SYSTEMS

Rising feed costs mean that every point of feed conversion is worth significantly more money. For 100 kg live weight gain, every 0.05 change in feed conversion alters total feed usage by 5 kg. Table 3 shows the relationship between feed cost per ton and the value of changes in feed conversion ratio. Using this relationship, when the average cost per metric ton of feed is $250, a change of .05 in FCR is worth $1.25/pig. As feed costs rise by $100/ton, this changes the value of .05 FCR by $0.50 per pig.

Table 3.- Impact of FCR on change in feed cost per pig for 100 kg of live weight gain with varying costs per metric ton feed

<table>
<thead>
<tr>
<th>Feed cost, $/metric ton</th>
<th>Value ($/pig) per pig of .01 change in FCR</th>
<th>Value ($/pig) of .05 change in FCR</th>
<th>Value ($/pig) of .10 change in FCR</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>0.10</td>
<td>0.50</td>
<td>1.00</td>
</tr>
<tr>
<td>150</td>
<td>0.15</td>
<td>0.75</td>
<td>1.50</td>
</tr>
<tr>
<td>200</td>
<td>0.20</td>
<td>1.00</td>
<td>2.00</td>
</tr>
<tr>
<td>250</td>
<td>0.25</td>
<td>1.25</td>
<td>2.50</td>
</tr>
<tr>
<td>300</td>
<td>0.30</td>
<td>1.50</td>
<td>3.00</td>
</tr>
<tr>
<td>350</td>
<td>0.35</td>
<td>2.75</td>
<td>3.50</td>
</tr>
<tr>
<td>400</td>
<td>0.40</td>
<td>2.00</td>
<td>4.00</td>
</tr>
<tr>
<td>450</td>
<td>0.45</td>
<td>2.25</td>
<td>4.50</td>
</tr>
<tr>
<td>500</td>
<td>0.50</td>
<td>2.50</td>
<td>5.00</td>
</tr>
</tbody>
</table>

Rising feed costs may increase how aggressively by-product ingredients with greater nutrient variability are utilized. More aggressive use of by-product ingredients to control feed costs can increase the risk of greater variability in nutrient supply in the final diet. Rapid and frequent analysis of ingredients to capture nutrient variability is more critical than ever and certainly more important as ingredients with higher nutrient variability constitute a higher proportion of the diet. Using static book values for nutrient content of ingredients is not adequate to remain competitive and ensure the correct nutrient
supply is given to pigs each day to meet their requirements. Furthermore, providing diets and therefore nutrients for the best economic outcome is rarely consistent with maximum biological performance of the pig. Systems which connect rapid nutrient analysis of ingredients with diet formulation, biological modeling, and economic inputs and outputs can greatly improve a producer’s ability to respond rapidly to changing ingredient supply, nutrient content variation, ingredient cost and availability, pig market price, and packer matrix changes affecting premiums and docks for weight, back fat, and other factors.

10.- SUMMARY

Change is happening faster than ever. Our global supply chain in the pork industry means that diseases may spread more quickly and impact the economics of pig production dramatically, almost overnight in some cases, requiring nutritionists to respond with updated feeding programs just as fast. Genetic progress is now more rapid than ever due in part to molecular selection techniques. Revaluation of growth curves and corresponding amino acid requirement every 3-5 years is no longer frequent enough but more frequent evaluation using empirical growth assays may not be practical. This continues to push the industry to use systems and growth models which are robust but practical enough that critical inputs can be captured easily at the farm level. Ingredient market shifts in one geography can have immediate impacts on commodity markets in another part of the world. Integrated systems which combine nutrient analysis with formulation, modeling, and economic projections will be critical for future competitiveness.

11.- REFERENCES


