Proceedings

of the

1st LONDON SWINE CONFERENCE

The Pork Industry and Public Issues

April 5-6, 2001

London, Ontario

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The Pork Industry and Public Issues

Edited by
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Proceedings of the London Swine Conference – The Pork Industry and Public Issues

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CHAIR'S MESSAGE

Welcome to the 1st London Swine Conference!

In April of 1999, six people gathered in a conference room at 1 Stone Road in Guelph to talk about, as it was referred to then, a "world-class annual swine conference in Ontario". We had been talking amongst ourselves for some time about the need for an internationally recognized educational event for the Ontario swine industry and felt it was time the idea was given serious consideration. And so the work began…

The people around the table at that inaugural meeting were Kees de Lange, Gary Koebel, Jim Morris, Andrew Pharazyn, Doug Richards and myself. Although the faces around the table have changed (and multiplied) in the two years since our first meeting, the original goals and objectives have not. Our intention now, as it was then, is to provide a platform to speed up the implementation of new technologies in commercial pork production in Ontario and to facilitate the exchange of ideas within the swine industry.

The London Swine Conference features internationally renowned speakers who are recognized authorities in their field. Through presentations, panel discussions and breakout sessions, these speakers will explore current and emerging issues and technologies that are relevant to commercial pork production. The theme of the conference**, The Pork Industry and Public Issues**, will provide participants with essential information on the challenges and opportunities that face our modern swine industry in 2001.

A conference such as this would be impossible to deliver without the hard work of volunteers, the support of industry partners, and industry-wide participation. I would like to thank Ontario Pork, the University of Guelph, and the Ontario Ministry of Agriculture, Food and Rural Affairs for providing the foundation for this conference to become a reality. Thank you to our very generous sponsors, who have shown their commitment to this initiative through their financial support. And to you, the participants, thank you for taking time from your busy schedules to participate in the 1st London Swine Conference.

Enjoy the conference!

Janice Murphy
Chair, Steering Committee
2001 London Swine Conference

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FOOD SAFETY – THE CONSUMER AND EMERGING TECHNOLOGIES

CHANGING DEMOGRAPHICS AND NUTRITION PATTERNS

Margaret Gill
Macaulay Land Use Research Institute
Aberdeen, Scotland

ABSTRACT

The predictions for the rate of increase in the human population have been revised downwards, slightly, but it is still estimated that the global population will reach 8 billion before 2030. The accompanying rapid increase in global consumption of livestock products in recent years is predicted to continue, albeit at a slower rate. The most rapid increase has been in meat consumption in Asia, particularly China. An extra 292 million tonnes of grain would be required annually by 2020 compared to the early 1990s if the increase in animal production is to be met from high concentrate diets, but more efficient use of human-edible feeds can be made if alternatives to grain are used. The energetic efficiency of animal production has been improved in recent years but there is potential for further increase to meet the increasing demand.

INTRODUCTION

The global human population is increasing at a rate of 78 million persons per annum. Estimates for the number of people expected to be inhabiting the earth in 2020 vary, but having passed the 6 billion mark in 1999, world population is expected to exceed 8 billion before 2030 (FAO, 2000). The rate of growth is slowing down, having peaked (at a global level) in the late 1960s at 2.1% per annum and fallen to 1.3% per annum by the late 1990s. However, the global data hide a highly significant variation, from zero or even negative growth in some developed countries to over 3% in countries in sub-Saharan Africa. Population growth is, however, only one of the many factors which influence nutritional patterns. Other demographic and cultural factors also interact with the quantity and type of food produced and access to food can be constrained by both physical and economic factors.

This paper starts by presenting variations in traditional food consumption patterns in different countries, then considers demographic and food consumption trends, follows by reviewing trends in animal production and swine production, and ends with a brief consideration of the contribution of research.

GLOBAL VARIATION IN DIETARY COMPONENTS

Meat, fish, milk and eggs provide on average 13.5% of daily energy intake on a global basis (Loftas, 1995), but this global average hides a wide variation between different countries as can be seen in Table 1. Part of the reason for these differences is due to climatic and ecological factors which limit the type of crops which can be grown and the potential for

livestock production, together with the extent of poverty in rural areas, which will limit access to, for example, seeds and fertilizers. Religion and culture have also been important traditionally, but with increasing global awareness and the mixing of cultures within countries, these effects may be diminishing.

Table 1. Percentage contribution to energy intake of major dietary components by country (Loftas, 1995).

	China	Mongolia	Mali	Zaire
Cereals	35	42	72	17
Meat, fish, milk & eggs	25	37	1	1
Oils, fats and sugars	25	14	4	5
Roots and tubers	0	1	1	60
Fruits, vegetables, pulses & nuts	0	1	18	16
Other foods	15	5	4	1

There is evidence (see later) for rapid changes in the local composition of diets in some countries (notably China) due to both demographic and economic trends and globalisation is predicted to increase the extent of trade in food commodities (FAO, 2000). These changes will have an impact not only on food production systems but also the extent of processing which food has to undergo to provide the increase in shelf-life required for food which has to be transported over long distances. This raises the importance of food safety issues.

DEMOGRAPHIC TRENDS

Dire predictions concerning the inability of the world to feed growing human populations have been made since the time of Malthus (in the 18th & 19th centuries), yet the world still has the capacity to feed its current population of 6 billion if food was evenly distributed. Recent estimates put the number of people suffering from malnutrition at around 800 million (Dyson, 1996), with 200 million children under the age of 5 suffering from malnutrition, which includes over 40% of children of that age group in, for example, India, Pakistan and Ethiopia (World Bank, 1997) due to inequalities in access to food. Yet, despite the increases in population indicated in Table 2, international agencies predict that, barring severe economic crisis and with appropriate investment in research and infrastructure, it should be possible to decrease child malnutrition overall in developing countries, although an increase is likely in sub-Saharan Africa (Rosegrant *et al.*, 1995; Rosegrant and Ringler, 2000).

Table 2. Annual increments (millions) of population growth by decade (FAO, 2000).

	1964/66 to '74/76	1974/76 to '84/86	1984/86 to '95/97	1995 to 2000	2010 to 2015
World	74	76	83	78	72
Developing Countries (DC)	64	68	75	72	69
DC as % World	86	89	90	92	96

It is worth noting from Table 2 that the rate of increase in the human population appears to have passed its peak, even in developing countries, although these countries now account for over 90% of the annual increment in population. However, the term 'developing countries' refers to a range of countries which are by no means homogeneous. The figures in Table 3 illustrate the continuing high population growth rate in sub-Saharan Africa. Data on predicated annual growth in GDP for the same regions are also given which show that previous indications that slowing population growth may increase economic growth are now weaker. This can in part be attributed to the impact of the AIDS epidemic in slowing population growth (FAO, 2000).

Table 3. Growth rates (% per annum) in developing regions in population and per caput GDP (FAO, 2000).

	Population		GDP
	1967 to '97	1995/'97 to 2015	1995/'97 to 2015
World	1.7	1.2	2.0
Developing countries	2.1	1.4	3.4
Sub-Saharan Africa	2.8	2.4	1.5
Latin America	2.1	1.4	2.3
South Asia	2.2	1.5	3.6
East Asia	1.7	0.9	4.9

Another demographic trend, that is exerting a major influence on patterns of food consumption is that of urbanisation. While 45% of the world's population were estimated to be living in urban areas in 1990, it is predicted that this figure will rise to 62% by 2020 (Dyson, 1996). There is evidence linking this trend towards urbanisation with increased income and increased consumption of animal products (e.g. Anderson *et al.*, 1997).

FOOD CONSUMPTION TRENDS

Global variation in diet composition was illustrated in Table 1, but the demographic changes presented in the previous section, together with economic globalisation are having a major impact on consumer demand for different food commodities. In particular there has been a rapid growth in the consumption of livestock products in Asia (Table 4).

There are also differences in the type of livestock product consumed in different countries. Thus, while China is predicted to dominate (45%) the developing world in relation to the increased demand for meat, India will dominate (41%) the demand for milk. These trends are based on FAO historical data (1983 to1993) and predictions from the IFPRI IMPACT model for the future. The IMPACT model has been described in detail by Rosegrant *et al.* (1995) and updated since then as described in the references quoted in the text.

Table 4. Estimated demand (kg/hd/yr) for meat in 1993 and projected demand in 2020 (Rosegrant and Ringler, 2000).

	1993	2020
Developed countries	78	83
Developing countries	4	7
South Asia (except India)	7	10
Southeast Asia	15	27
China	33	62
Other East Asia	44	79

The demand for different types of meat also varies between regions: beef currently constitutes 50% of total production in Latin America, 41% in sub-Saharan Africa and only 5% in China (Delgado *et al.*, 1998). Pork, in contrast, constitutes 59% of total meat production in China but is insignificant in West and North Africa. These variations reflect very different religions and cultures in different regions of the world and there has been little change in the relative proportions of beef : pork over the last decade, despite a doubling in total meat consumption in some developing regions (Delgado *et al.*, 1998).

TRENDS IN ANIMAL PRODUCTION

The geographical trends in consumption of animal products are closely mirrored by trends in production (Table 5). There was a 1.1% increase in total production of meat in the developed world, compared to a 5.4% increase in the developing world between 1983 and 1993. The rate of increase was greatest for poultry meat, followed by pork, with beef production mirroring population increases with no increase in per capita production (Table 5).

Table 5. Meat production, 1983 & 1993 (Delgado *et al.*, 1999)

	Total production (million tonnes)		Per capita production (kg)	
	1983	1993	1983	1993
Developed world				
Beef	36	35	27	26
Pork	35	37	29	29
Poultry	19	27	16	21
Developing world				
Beef	16	22	5	5
Pork	21	39	6	9
Poultry	9	21	3	5

However, there are significant differences between regions in the developing world in the distribution of monogastric animals as illustrated in Table 6. Pigs are concentrated in Asia and Latin America, with China having an estimated 44% of the world's pig population in 1993 and 38% of world production (Delgado *et al.* 1999). These figures represent a growth rate of 5.8% per year between 1983 and 1993 in pigs slaughtered in China, with the percentage growth rate for sub-Saharan Africa being higher (7.7%) but from a lower population base (Table 6).

Table 6. Global distribution (millions) of livestock, 1983 and 1993 (Delgado *et al.*, 1999).

	Pigs		Poultry	
	1983	1993	1983	1993
Developing world	442	562	4514	8408
Developed world	334	316	4166	4528
China	295	386	1302	3105
Southeast Asia	39	44	608	1423
Latin America	78	79	1042	1552
Sub-Saharan Africa	8	18	434	647

Future projections based on IFPRI's IMPACT model (Rosegrant *et al.*, 1995) suggest continued growth in meat consumption and production but at a slower rate (Table 7). Percentage growth will remain highest in sub-Saharan Africa (3.4%), but the absolute increase in production will remain highest in Asia, particularly China (Delgado *et al.*, 1999).

Table 7. Past and projected future trends in meat production (% growth/year) (Delgado *et al.*, 1999).

	1982-1994	1993-2020
Developed countries		
Beef	0.1	0.6
Pork	0.7	0.4
Poultry	3.2	1.2
Developing countries		
Beef	3.1	2.6
Pork	6.1	2.7
Poultry	7.8	3.0

Achievement of this predicted growth in production, however, depends on sufficient supply of feed and Delgado *et al.* (1999) predicted that an additional 292 million tonnes of cereals will be used as feed in 2020 compared to the early 1990s. Critics of meat consumption in developed countries (e.g. Brown, 1997) suggest that even current levels of grain use for

animals are morally unacceptable, but there is already global variation in the extent to which animals are in competition with humans for feed and there is potential for further decreasing that competition. In addition, the feeding of grain to animals provides a buffer for human grain supplies in that in years of high yield, grain is fed to animals, but when grain is scarce and more expensive, the use of grain in animal feeds decreases.

SWINE PRODUCTION

Globally, some 600 million tonnes of cereals are used as animal feed, with a further 119 million tonnes of brans, 133 million tonnes of oilseeds and cakes and 130 million tonnes of roots and tubers (Hendy *et al.*, 1995). Developing countries account for 31% of the total cereals used, but 75% of the brans and 59% of the roots and tubers. The conversion rates for grain to meat are shown in Table 8.

Table 8. Conversion of grain (million tonnes) to meat (million tonnes) 1992-93 (Hendy *et al.*, 1995 and CAST 1999).

	Beef, veal, buffalo	Sheep and goat meat	Pig meat	Poultry meat
Developing countries				
Production	22.2	6.1	38.5	18.8
Grain	5.8	2.0	67.8	29.6
Grain/Product	0.31	0.33	1.76	1.57
Developed countries				
Production	32.1	3.9	36.8	26.0
Grain	83.9	3.1	135.1	55.9
Grain/Product	2.61	0.78	3.67	2.15

The data in Table 8 indicate that the amount of grain used per kg of pig meat produced in developing countries is less than half that used in developed countries. For example in China roots and tubers are used in swine diets. Since (Table 1) they form a more important part of human diets than grains in some developing countries, development of new diets for swine with ingredients which do not compete with human use must take local human dietary traditions as well as local feed resources into account.

The CAST Task Force (CAST, 1999) calculated gross efficiencies of conversion of energy and protein for four countries with contrasting pig production systems (Table 9). Also in Table 9 are the efficiencies of energy and protein production of port and ham, based on human edible inputs, mainly cereals (CAST, 1999).

Table 9. Gross efficiencies of conversion of total and human-edible energy and protein in diets to meat in swine (CAST, 1999).

	Energy		Protein	
Country	Gross efficiency	Human-edible efficiency	Gross efficiency	Human-edible efficiency
Argentina	0.15	0.24	0.07	0.11
Mexico	0.13	0.25	0.08	0.21
South Korea	0.20	0.35	0.16	0.51
United States	0.21	0.31	0.19	0.29

The US has the highest gross efficiencies of energy and protein while South Korea has the highest efficiencies in human-edible terms, due to a relatively high percentage (20%) of by-product use in swine diets, compared to an 82% reliance on cereals in US swine diets. This suggests that there are options for increasing swine production which are not in direct competition with human food supplies.

CONTRIBUTION OF RESEARCH

Increased understanding of the optimum level of fibrous feeds in the diets of swine appropriate to the local resources and the demand for pork is one way in which research can help to meet future demand. However research has already contributed to an increased efficiency of conversion of grain to all kinds of meat (Table 10). Over the 10 years from 1983 to 1993, the efficiency of conversion increased by 15% in both developing and developed countries. There is no reason to think that this efficiency cannot be increased further, particularly in developing countries, where production levels are low.

Table 10. Improvement in the efficiency of conversion of feed grain to meat over time (CAST, 1999).

	Developed countries		Developing countries	
	1983	1993	1983	1993
Total meat (million tonnes)	88	99	50	89
Total feed grain (million tonnes)	453	443	126	194
Feed grain for meat (million tonnes)	290	284	74	114
Conversion Efficiency (unit meat/unit grain)	0.30	0.35	0.68	0.78

CONCLUSIONS

The demand for pork, particularly in Asia, is still increasing. In the past production has increased in response to demand, but 800 million people were estimated to be malnourished at the end of the twentieth century. There have been calls for a decrease in meat production in developed countries to enable grain to be used to feed the global population, but Rosegrant *et al.*, (1999) demonstrated that reduction in meat consumption in developed countries would be likely to have little impact on the nutritional status of poor people in developing countries.

However, in developing countries there are alternatives to the use of grain in pig production and, although these are not used so efficiently in gross energetic terms, they indicate the potential for a more balanced use of global food resources to meet both demand for livestock products and the total nutritional needs of the growing human population.

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IS OUR FOOD SAFE?

Honourable Eugene F. Whelan
Amherstburg, Ontario

There was a time before the deregulation of food safety and cuts to federal food and agriculture programs when I could say with confidence and pride that Canada had the safest food anywhere in the world.

There was also a time when we had the best independent scientific agricultural research in the world.

Is our food safe? I no longer feel I can answer an unqualified "Yes" to that question.

Let me talk to you today about some of the reasons why I and many other Canadians are worried about the safety of our food.

The reasons are familiar to anyone reading the papers or listening to the news: hog factories, Mad Cow disease, foot and mouth disease, beef hormones, antibiotic resistance, *E. coli* O157:H7, salmonella, listeria, genetically manipulated seeds.

Some say behind every food catastrophe of the past decade is the drive for cheap food.

It's time we had a good hard look at intensive farming policy and the promotion of overproduction of cheap food. Who says that more is better? Increasingly people are judging that more is not better. It is worse, for the animals, for the farms, for the farmers, for the water and for our health.

It's also time to question the bizarre notion that food regulation and enforcement by the industry is the way to maintain and improve food safety.

Public concern for food safety has to do with things like hog factories with manure lagoons, an overpowering stench, and God knows what in terms of drug residues. These hog factories are raising questions not only about water supplies and clean air but also about unsafe food. 75% of the aquifers in Iowa are polluted by the hog manure.

Canada had a major pork recall last August because the meat was contaminated with a dangerous cancer causing drug called carbadox. In November 1999 a new report appeared in the New England Journal of Medicine linking an outbreak of fatal salmonella in Denmark to the use of antibiotics in pigs.

Do any of you know how many pounds of valuable antibiotics are fed to animals every year in the United States? Twenty-five million pounds - roughly 70% of total U.S. antibiotic production - are fed to pigs, chickens, and cows. And this is for non-therapeutic purposes like growth

promotion. Meat producers use 8 times more antibiotics than human medicine, which is only 3 million pounds a year, according to a new report from the Union of Concerned Scientists.

Using antibiotics in pigs, cattle, chicken and even fish to increase growth rates has long been cited as a probable source of antibiotic resistance.

I want to say a word about BSE - mad cow disease. The disease is spread by feeding rendered animal parts back to cows. Now you farmers know that cows are designed by nature to feed on grass not other cows. But here we are still putting rendered animal protein in animal feed.

Worse than that, we imported animal feed from the U.K. **after** their mad cow disaster. Talk about asking for trouble. There was a newspaper report that said Canada was putting road kill and dead pets in animal feed. Is our meat safe? Is our beef safe? Well, Newsweek magazine recently did a cover story on Mad Cow disease spreading and asked "Should I stop eating beef?" The answer was: "That depends on your level of risk tolerance."

Some say mad cow disease is a warning shot across the bow of intensive farming practices, the worldwide distribution of animal feed and other animal products, and the demand for cheap food. Mad cow disease is nature's way of saying something's wrong. Mad cow disease is proof that biological boundaries are real. Animal, plant and human kingdom barriers can't be transgressed with impunity.

The practice of feeding rendered animal protein and poultry manure back to cattle is a fairly low-tech innovation. It does not compare with the complexity of putting human genes in pigs and other experiments in genetic engineering. The story of mad cow disease is a warning of the unpredictable dangers inherent in efforts to tamper with biology.

Mad cow disease is basically the result of commercial interests forcing the crossing of biological boundaries leading to a new disease. For economic reasons, grass eating animals were fed something they would never eat in nature.

No wonder the Canadian Food Inspection Agency has moved to a "risk-based" food system. We used to have a food system based on the precautionary principle. The shift in preventing harm from happening in the first place to managing the damage after the harm is already done, is a huge threat to the health of Canadians. The damage we are dealing with is illness and death.

I know something about agriculture and the food industry. And you know, some people try to discredit those of us who have different opinions than those of giant agribusinesses like Monsanto, Dupont, Novartis and Cargill.

My record still speaks for itself. Canada did more agricultural research in the 11 years I was Minister of Agriculture than they did in all the previous years. We had the biggest branch of government research. We knew what we were doing. We didn't have Monsanto or anyone else telling us what the science was. We had our own government scientists. And they were the best in the world.

We led independent research. That was possible because we had a Prime Minister in Pierre Trudeau who believed in public research for the public good. Today, it seems that the only research that gets done has a narrow commercial focus.

We have a Governor-General today who said in her government residence there will be organic food, and safe food, and Canadian food. See, at one time we had control of our total food system. We believed in food security. We believed in pure food. We didn't rely on hormones and antibiotics. Now it seems as if Agriculture Canada and several other federal departments are working to promote the concentration of food and agriculture into the hands of a few giant agribusinesses.

They pay sports stars more per box for their name on the box of cereal than the farmer gets per box. Farmers only get 4 cents from a box of Corn Flakes. And they say we can't pay for labelling to inform us stupid people about what we are eating. Proper labelling costs passed onto the farmer - phooey.

We are seeing today a North American-style collectivisation of farming that would rival the old Soviet system in the U.S.S.R. Corporate control over the food system is the corporate control over life. Farmers don't know where to turn. Governments aren't protecting their interests. Farmers are surrounded not only by concentrated market power from the companies that buy their crops and animals. Farmers are also surrounded by the companies that are selling expensive inputs like genetically modified seeds, fertiliser, hormones and antibiotics.

Farmers are on a capital-intensive treadmill. As farm prices dive, Monsanto and others are there to sell genetically modified seeds for corn, soybeans and canola to farmers who are desperate to try anything. The economic benefits of this technology has not been proven. While farmers are suffering from years of depressed prices, a few giants of agribusiness enjoy soaring profits from the same line of goods.

In Ontario, gross farm income increased an average of about $2.8 billion a year between 1974 and 1999. However during that same period, realised net farm incomes have actually declined, by an average of $92 million annually. Every cent that Ontario's farmers have gained from adapting to changing conditions has disappeared in increased costs (National Farmers Union figures).

Now it seems that <u>it's not government's business</u> to direct agricultural research and to tell industry what to do and what not to do. Now industry is telling government and telling us what's good for us and we don't have the right to challenge them. When I was Minister of Agriculture, I felt <u>it was my business</u>, all the time.

And the people working in Agriculture Canada when I was the Minister were trained in agriculture and they were serving the public. Now we have people running Agriculture Canada who don't know a cow from a sow. People are being brought in from the Privy Council Office, Treasury Board, Finance and International Trade to promote something called the "Life Science Industry".

Life science companies are playing God and manipulating the blueprint of life as if it were a machine they owned. Talk about arrogance. Life sciences are going to save us from Mother Nature by destroying nature. Some call it the new "Golden Calf". Others call it a Mad Cow!

We are being told that biotechnology must figure prominently in Canada's food production. There's never been a debate or a public discussion. This is something that has been "determined" by the upper echelons of government and industry.

Now all of a sudden food and drug regulations have to be revoked and replaced to facilitate this new industry and its biotech products. The first thing that has to go is the *Food & Drugs Act* because, and I'm quoting a Health Canada document here, "the Food & Drugs Act has too narrow a focus on safety".

I read in the paper where the assistant deputy minister of Health Canada told 50 pharmaceutical company representatives in California that the federal government plans to transform the Experimental Farm in Ottawa into a centre for biotechnology experiments. And what is the government of Canada offering these drug companies? Tax breaks and the fastest drug-approvals anywhere (Ottawa Citizen, December 13, 2000).

Canada now has genetically modified organisms mixed into 3/4 of our processed food: soya, corn, and canola. The U.S. had 74% of the global acreage of genetically modified crops, and Canada had 10% in 1998.

Scientists can insert genes into plants - the shotgun approach - to give them a natural insecticide or make them resistant to weed-killing chemicals. They can create supersized fish and animals. But there is trouble in GMO paradise. Some people can have allergic reactions to proteins in the new plants. One study raised concern that pollen from the new Bt corn is killing off the monarch butterfly larvae on milkweed in surrounding fields. There was an incident last fall where StarLink corn - not approved for human consumption - found its way into taco shells and other foods.

Common sense is the common trigger for the survival of the human species. And common sense says you don't eat a Bt toxin that kills monarch butterflies.

All this has happened in advance of long-term testing for human health and the environment. It has happened without anyone knowing because the government won't label the products.

Remember, these products are alive - bacteria, viruses, plants, and animals. They're alive. So they are inherently more unpredictable than chemicals or nuclear products. Secondly, these products reproduce. Third, they migrate. They proliferate. They mutate.

You can't recall them to the laboratory. So we have profound questions that have to be scientifically verified. We can't just "assume" everything is alright. In chemistry, we have a science called toxicology. It's not that good, but it allows you to judge some risk. In biotechnology, there is no comparable science that can assess the risk of releasing a genetically engineered organism into the environment or putting it in baby food.

There is no science. Remember it took 30 years of research on DDT before they established its hazardous side effects. When I chaired the Senate committee hearings into rBST, the bovine growth hormone, one of the shocking things that came to light was the fact that the regulator was all set to approve this drug without the health data required by law. They gagged their scientists. Files were stolen from the scientists reviewing the drug submission. This was in Ottawa not Moscow.

The heroes in that episode are the brave Health Canada scientists who spoke out and exposed the fact that there was no testing for human health effects of rBST.

I couldn't believe we had this medical doctor coming before our committee testifying that rBST was safe for humans - but couldn't produce a scrap of evidence to back it up. Then we had the veterinarian testifying that rBST was not safe for the animals. And now rBST is coming in with American products and is in baby formula.

I don't imagine that Monsanto has given up trying to get rBST approved by Health Canada. They just hired Health Minister Allan Rock's senior advisor to go work for them.

Today the federal government is an advocate of biotechnology and refuses to fund and conduct independent testing of genetically manipulated products. Because there is no testing and no science, Monsanto and the others can't get insurance on their products for long term catastrophe.

This is why the British Medical Association and others are calling for a global ban on the release of genetically modified materials until they can be proven safe. The precautionary principle should be applied because "adverse effects are likely to be irreversible".

I'm so worried about what we're doing - putting human genes in pigs and cattle - uncontrolled release of GMO's - no human or environmental testing. How about human genes in a rat bigger and more ferocious than before. I wake up in the night asking what in hell are we doing playing God with the blueprint of life?

My doctor in Ottawa wanted to talk to me. What did he want to talk about? He's got little kids and he wants to know what's going into their food. He said: "Do whatever you can to stop this crazy and dangerous science of shooting genes into plants using viruses and then feeding it to children and not letting parents know what's in the food."

You know, the Royal Society just came out with a report saying Canada's biotech regulators are in a conflict of interest with the biotech industry and that Canadians are being used as guinea pigs. This isn't some scare mongerer. This is the Royal Society of Canada's expert scientific panel on food biotechnology.

Why is Ottawa force-feeding Canadians unlabeled, untested, uninsured mutant food? Will Canadians swallow anything? What we are doing is bad. It has to stop.

Let me tell you a true story about the one scientist in the world that had a team of 18 scientists and a lab testing a genetically modified potato. His name is Dr. Arpad Pusztai. He published over 300 scientific articles in the field of plants. He is a member of the Royal Society of Edinburgh.

He developed a rigorous method for testing transgenic potatoes on rats. After only 10 days the rats developed a weakened immune system and abnormal development of the pancreas, intestines, prostate, testicles, liver, and brain development. The genetic instability of the potato was also startling. Within 2 days of making these findings known, he was fired, the team disbanded, the lab closed and all the data was confiscated. Everything was taken.

You would think that these kinds of preliminary results - his rat study was only for 10 days - would call for more research not less.

The Colorado Beetle dies if it eats the leafs of the plant and the tubers are supposed to be safe???

Dr. Pusztai said: "We are eating things which we have not eaten before. And I challenge anyone who can predict the consequences of this. Particularly for our immune system, which is there to protect us from any injury coming from the outside world. People feel very concerned about their food, not just for their sake, but for their children and grandchildren."

Testing of genetically modified organisms is commercially secret. The Canadian Food Inspection Agency and Health Canada tell us that all the technical and scientific data on all this technology is secret. Adverse effects on human health and the environment are secret. Well, I say that if it is all secret, then it isn't science. And that is what the Royal Society of Canada says too. You can't claim a regulatory system is science-based if it is not open to peer review and available for all to see.

The Royal Society says the level of secrecy surrounding testing of new GM food is unacceptable. The public must have access to the results of the tests - or else there is no science base to the approval system.

The Royal Society also spoke about the consequences for closing down all the independent research at Agriculture Canada, and those are the growing conflict of interest in the scientific community and the domination of the research agenda by private corporate interests.

The Royal Society spoke out and supported what Professor Ann Clark at the University of Guelph has been saying for years. Genetically manipulated organisms should not be presumed safe unless there is reliable, independent publicly available scientific data that demonstrates the safety.

This kind of scientific testing and verification has to replace the CFIA's reliance on what they call "substantial equivalence". Right now these GMO's are allowed on the market because the CFIA and Health Canada says they look the same as conventionally bred, plants and therefore

don't warrant testing. Some people think that "substantial equivalence" would be better named "substantial fraud".

Is genetically modified food safe? Well, if you asked Dr. Pusztai, he would say nobody knows and they won't let anybody find out. And by the way, you can read Dr. Pusztai's findings in the most prestigious medical journal in the world - *the Lancet* (16 October 1999).

I want to conclude with a few comments about Canada's food safety system in general and the Canadian Food Inspection Agency in particular. The Auditor General of Canada reported this February that the food safety agency is rife with serious shortcomings. The biggest problem is the conflicting mandate. One of the most important lessons learned in Europe is that you shouldn't put food safety functions and food promotion duties in the same agency. That is a conflict of interest. That's asking for trouble. Monsanto gave Ag. Canada $600,000 to develop a Roundup resistant wheat!

Here's some of what the Auditor General has to say: "Shifting from regulatory regimes to reliance on industry has been controversial. Some have expressed general concerns that public health and safety could be compromised because industry would place profit ahead of public health and safety."

A 1994 Health Canada study found that the need of a company to maintain consumer confidence and avoid lawsuits "does not cause manufacturers to adopt measures to avoid injuries, where the cost of the measure is greater than the cost of settling civil actions for an injury or death." I'm quoting from the Auditor General's Report, Chapter 24, paragraphs 29 and 30.

Is Canada's food safe? Well, the Auditor General is suggesting it won't be if you just rely on industry alone.

When the CFIA was established in 1997, they were told by the government to cut 10%. Nobody cared how or where, just make the cuts. So the senior managers at the CFIA decided to cut 200 professional field inspectors. I suppose this makes sense if you are moving to industry self-regulation. You wouldn't want vets out there inspecting operations. Four years later, the CFIA now has about 200 more employees but they are working at headquarters in Ottawa, not in the field.

In creating the CFIA, the mandate was to privatise the inspection system. They called it "alternate service delivery". This privatisation didn't work. It fell flat on its face but it left the inspectors demoralised. Everyone was waiting for their lay-off notice. To make professional morale even worse, senior management at the CFIA are not providing the proper support to the front-line inspectors.

There are meetings where managers refuse professional advice from their vets because it could mean the Department would be "liable". Those who promote science, proper inspection and in-depth understanding of food safety, human health, and animal health are sometimes

viewed by senior managers in Ottawa as “trouble-makers”. This has a devastating impact on morale.

I’m not making this up. Read the Auditor General’s Report on how the CFIA mishandled the largest outbreak of food-borne disease in Canadian history when 800 cases of salmonella were reported. 80% of those affected were children under 15 years of age. The CFIA to this day never reported on this incident and never provided key documents requested by the Auditor General of Canada.

The other mistake at the CFIA was the way they brought in a new meat inspection system in federally registered plants. It’s called, as you know, the Hazard Analysis and Critical Control Points - HACCP. Some food inspectors call it Have A Cup of Coffee and Pray! The program was implemented as a way to cut more professional staff and cut resources in the CFIA. So now what’s happening, is that inspectors are pulled off plant inspections in order to train and implement the new program. Instead of cutting 200 field staff, they needed to hire 200 to implement the HACCP program properly.

Can someone tell me why we think we can or should cut corners on food safety? Does anyone in Treasury Board or the Finance Department understand that spending money on a strong and independent food safety system will save billions of dollars in health care bills and will also save lives!

Canadians have a right to safe food. Canadians are willing to pay for safe food. No tax break can compensate for the essential work being done by government food inspectors in the field.

Is our food safe? No. Not as safe as it should be. Not as safe as it needs to be.

At the end of the day, food producers and the food industry in general will lose the confidence of consumers in their products if we continue down this road to food safety privatization and de-regulation.

Only a strong and independent food safety regulator doing its own independent safety research can restore the public confidence in the food we eat. If we let industry set the food safety rules, there will literally be no limit to what we’ll be swallowing from our plates.

Canadians want pure, clean, safe food and so does the world market. Let’s produce what consumers want and have a right to.

Farmers have suffered disaster in the last 20 years. People are losing confidence in the way their food is produced. We can’t continue like this. It’s time to get back to pure, safe farming practices.

Let’s produce in co-operation with Mother Nature.
Let’s farm with the family and not in a factory.

DEALING WITH FOOD SAFETY ISSUES

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INTRODUCTION

In recent years, food safety issues have received increased attention from consumers, industry groups and governmental agencies in the U.S. and throughout the world. Consumer assurance of the safety of pork is vital to ensure continued demand in pork producing countries. Countries that export pork must satisfactorily meet the expectations of the importing country's regulatory agency as well as their consumers.

INCREASED INTEREST IN FOOD SAFETY

There has been increased interest in food safety by the public globally for several reasons. Several prominent food safety situations throughout the world have led to this increased interest. They include:

- Bovine Spongiform Encephalopathy (BSE or Mad Cow Disease)
- *E. coli* O157:H7
- Dioxin contamination of animal feeds
- *Listeria* in ready to eat foods
- *Salmonella* in eggs
- *Salmonella* DT104

In addition, issues such as biotechnology, antimicrobial resistance, and irradiation have received heightened attention by the media worldwide.

FACTORS AFFECTING FOOD SAFETY

There are many factors that affect food safety and countries' responses. They include:

- Increased international movement of food products
- Cultural differences with regard to sanitation and food preparation
- Increased numbers of susceptible people to foodborne illness (young, aged, immune suppressed)
- Changes in lifestyle (food on the run)
- Lack of basic food preparation skills
- Emerging pathogens
- Consolidation of the food industry
- Increased number and visibility of consumer organizations
- Enhanced media coverage

These factors must be addressed as countries develop food safety regulations, industry programs, and consumer education.

NATIONAL PORK PRODUCERS COUNCIL'S (NPPC) FOOD SAFETY CHAIN APPROACH

While NPPC is a producer organization, we recognize that food safety is a continuum. Therefore, effectively addressing food safety requires a partnership among all of the participants in the food chain. To develop this partnership, NPPC established a Pork Safety Committee in 1994. All segments of the chain are represented on this Committee. The Committee's mission is to assure the safety of U.S. pork through coordinated science-based efforts throughout the pork chain. Its efforts are directed to decreasing the potential for foodborne illness associated with pork products and to improving product image with regard to safety among consumers worldwide.

NPPC has allocated significant resources to each segment of the chain in the areas of research, technology transfer, education, and policy development to develop a Pork Industry Food Safety System. The target audiences for program activities are producers, packers/processors, retail/foodservice and consumers.

HAZARD ANALYSIS AND CRITICAL CONTROL POINT (HACCP) AND PERFORMANCE STANDARDS

The U.S. Department of Agriculture's Food Safety and Inspection Service (FSIS) has established requirements for all meat and poultry plants to reduce the risk of foodborne illness associated with the consumption of meat and poultry products and to modernize the meat and poultry inspection system. Plants are required to develop HACCP plans. HACCP is part of a food safety management system where plants evaluate each step in their process to look for areas where potential food safety problems or hazards could exist. Based on these identified hazards and their potential to be controlled, plants identify Critical Control Points in the process.

HACCP implementation is based on seven principles. They are:

1. Conduct a hazard analysis.
2. Identify the Critical Control Points (CCPs) in the process.
3. Establish critical limits for preventive measures associated with each identified CCP.
4. Establish CCP monitoring requirements. Establish procedures for using the results of monitoring to adjust the process and maintain control.
5. Establish corrective actions to be taken when monitoring indicates that there is a deviation from an established critical limit.
6. Establish effective record-keeping procedures that document the HACCP system.
7. Establish procedures for verification that the HACCP system is working correctly.

Under HACCP, packers focus on three specific types of hazards: physical such as broken needles, chemical (antimicrobial and pesticides), and microbial. One of the areas for control that packer HACCP plans address is incoming animals. This has increased packer interest in on-farm production practices.

With regard to microbial hazards, packers are required to meet performance standards for generic *E. coli* and *Salmonella.* Packers are first taking steps within their plants to meet the microbial standards but there is increased interest in what can be done at the farm to reduce levels of potentially harmful bacteria.

PRODUCERS - PORK QUALITY ASSURANCE™ (PQA) PROGRAM

The most significant way that U.S. pork producers address their food safety responsibilities at the present time is through the PQA Program. Pork producers developed and implemented this voluntary education program beginning in 1989 to prevent antimicrobial residues and enhance herd health practices. Drug residue prevention is clearly a producer responsibility.

There are three levels to the program. PQA Level III™ is the highest level of the PQA program. The producer can only complete it after discussions with a third party verifier. Approved verifiers are veterinarians, agricultural education instructors, and U.S. Department of Agriculture (USDA) Extension personnel. The 1997 release of the program was designed to more clearly emphasise producers' responsibilities with regard to antimicrobial residue avoidance and to blend with packer Hazard Analysis and Critical Control Point (HACCP) plans. Considerable discussion took place with the Food Safety and Inspection Service (FSIS), Food and Drug Administration (FDA), and packers to ensure this revision meets packer and government expectations of producer responsibilities. Briefly, it consists of Ten Good Production Practices (GPPs) with the first six related to antimicrobial residue avoidance (food safety) and the last four addressing management to help minimise the use of animal health products (efficient, quality production).

Many packers are now requiring all of the producers that supply their plant to have completed the PQA Program. A new version of the PQA Program will be released in the summer of 2001. Some of the topics to be addressed with this revision are antimicrobial resistance, foreign animal disease avoidance, cleaning and disinfection, rodent control, avoidance of broken needles, *Trichinae* certification, *Toxoplasma* control, and pork quality. In addition, NPPC is focusing on enhancing the delivery of the education in a more uniform manner. Web-based applications are also being explored.

PRODUCERS - PHYSICAL HAZARD AVOIDANCE

NPPC has been conducting research to evaluate the breaking strength of injection needles and the detectability of currently available needles and prototype needles under development. NPPC organized a workshop in March 2000 with representation by producers, packers, needle manufacturers, and manufacturers of needle detection equipment. Each group is evaluating

ways to enhance their efforts to reduce the potential for this type of physical hazard in pork. This year NPPC implemented a new awareness campaign to reduce the possibility of physical hazards in pork products. Developed with the thought that no consumer should find a broken needle in his pork dinner, the "One Is Too Many"[sm] campaign provides information to producers, veterinarians and packers on how they can work together to eliminate this situation.

PRODUCERS - ANTIMICROBIAL USAGE

Recently, there has been heightened interest by the public health community, media, consumers, and industry in the potential for antimicrobial usage in animals to result in the transfer of resistant bacteria to humans. NPPC is committed to assessing the science of this issue. In 1997, in cooperation with the American Association of Swine Practitioners, a Pharmaceutical Issues Task Force was formed. This Task Force is reviewing the current science with regard to antimicrobial usage in animal agriculture and will be recommending a sustainable position for the pork industry. Research projects and educational programs for producers and veterinarians are currently underway.

In addition another advisory group is being formed to look at non-antimicrobial production enhancers. This group will look at the science and performance of products such as probiotics, competitive exclusion agents, enzymes, etc. A Manure Safety Working Group is helping the industry better understand what happens to bacteria and other agents after they are applied to the land from manure.

PRODUCERS – ON-FARM FOOD SAFETY CERTIFICATION PROGRAMS

In addition to the PQA Program, NPPC with the Agricultural Research Service, the Animal and Plant Health Inspection Service, and FSIS has been developing the framework for additional on-farm food safety certification programs. The first one to be implemented will be certification for the absence of the risk factors for trichinae infection. Though the prevalence of trichinae in U.S. swine is extremely low (0.013% on the 1995 USDA National Animal Health Monitoring System National Swine Survey) and the number of human cases due to the consumption of pork is small, it continues to be a perception concern for U.S. pork. The certification will be based on an on-farm audit conducted by specially trained veterinarians with USDA program oversight.

The proposed certification process includes the following elements:

1. Veterinarians trained in good production practices relative to trichinae work with their producers to ensure that trichinae risk factors are minimised on their farms.
2. The on-farm audit will serve as a method to document the absence of trichinae infection risks. The audit will evaluate feed integrity, source and storage; building construction and condition as it pertains to biosecurity; the integrity of rodent control programs; and general management and hygiene concerns as they pertain to rodent control, vermin attraction, and other issues.

3. On a regular basis, a statistical sample of the national trichinae certified herd will be tested at slaughter using diaphragm digestion or ELISA.
4. USDA veterinarians will conduct random "spot audits" of certifications.

Large-scale pilots with producers and packers began in 2000 with completion in early 2002.

PRODUCERS - PATHOGENS

With performance standards in place for processing plants, there is more interest in what can be done at the farm to reduce levels of potentially harmful bacteria. NPPC since 1994 has had a very aggressive on-farm food safety research program focused on the feasibility of Good Production Practices (GPPs) at the farm level for control of potential human pathogens. NPPC with its *Salmonella* Working Group is exploring development of GPPs to begin to address this potential pathogen. In addition, to ensure coordination of U.S. and international efforts, NPPC has been involved in the three international symposiums held on *Salmonella* in pork production.

PACKERS/PROCESSORS

In 1996, NPPC added a food microbiologist, to develop food safety programs from the plant to the consumer. Significant research programs have been funded to assist plants as they implement HACCP systems and meet performance standards. Two Pork Quality and Safety Summits have been held to provide timely research results to the packing industry. A Post-harvest Food Safety Technical Advisory Group composed of plant food safety personnel, academia, and researchers provides direction on research, education, and policy to the NPPC Pork Safety Committee.

Last March, NPPC developed the *Salmonella* Intervention Assistance Program (SIAP). This program provides help to small slaughter plants facing unique challenges meeting FSIS *Salmonella* Performance Standards. The program arranges for teams of professional meat scientists and microbiologists to evaluate these plants, suggest areas where improvements can be made, and provide the plants with information on how to control and prevent *Salmonella*. The SIAP is provided to the plants at no cost and results remain strictly confidential.

In conjunction with the American Meat Science Association, many fact sheets on food safety issues such as irradiation, HACCP implementation, and meat inspection have been developed. NPPC provides a monthly publication, Pork Plant Communicator, that includes the latest research results to over 250 key plant, government and industry personnel. In addition, research reports from producer funded research are posted on the NPPC web site (http://www.nppc.org/) as they are received.

RETAIL/FOODSERVICE

At the retail level, research has been funded to survey temperatures in meat cases to better inform the retail sector about the importance of temperature control for shelf life and food safety. NPPC also provides food safety information to retailers as requested and is currently working on a comprehensive literature review on enhanced and case ready pork products. For foodservice, ServSafe educational courses are sponsored along with the development of educational materials.

CONSUMERS

A food safety kit with a variety of educational messages including pork specific information has been developed. Thousands of these kits have been distributed. Website materials are also available. Food safety information is included with requests for pork recipes. For three years, we have directly reached consumers through a Food Safety Booth at the World Pork Expo. Consumers have the opportunity to take a food safety quiz, pick up food safety educational materials, and participate in a handwashing demonstration. NPPC also is a member of the Partnership for Food Safety Education "Fight Bac" campaign.

FUTURE FOOD SAFETY AREAS

Food safety assurances are and will increasingly be key components of food production chains. To reduce the potential for food safety problems, there will be more interest in qualified suppliers and traceability. Such systems are currently being developed. Each segment of the chain must understand what their contribution and responsibility is in addressing food safety. Consumers will continue to have an increased interest in how their food is produced.

Improved product quality including food safety is increasingly viewed as a cost of remaining competitive in the food production business rather than as a means to directly enhance profits for the producer or the rest of the chain. The integration of key features such as market responsiveness, strong process control and production audits into a credible food safety system will be key to an industry's competitiveness.

CONCLUSION

Effectively addressing food safety issues requires coordination of efforts throughout the food chain. Comprehensive food safety education and research "from the farm to the table" is needed. In addition, it is critical that pork producers throughout the world are aware of the evolving food safety issues and are preparing themselves to address their role and responsibilities in providing safe pork to consumers. There will be increasing expectations by global consumers for accountability and certification in food safety systems.

EMERGING PRODUCTION TECHNOLOGIES

NEW TECHNOLOGY FOR GENETIC IMPROVEMENT OF LIVESTOCK

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ABSTRACT

As the pig industry faces increasingly uncertain fortunes, the revolution in the science of genetics continues to gather pace. The challenge will be to judge the extent to which the new technologies can help the industry in the light of public reaction. Today DNA *microarrays* the size of a microscope slide can be used to test 30 000 genes at a time to show whether they are "switched on" in a given tissue. Prospects are therefore good for identifying any individual genes that might be useful in improving meat quality and disease resistance. Gene transfer (GM) remains difficult and risky, but may be rendered unnecessary by the science of *functional genomics* which will allow control of the expression of the animal's own genes. Genomic *imprinting* could allow genes for fatness and longevity in the dam that are not expressed in her slaughter progeny. There are good prospects for using antibodies in semen to produce a single-sex slaughter generation. In a few years advances in reproduction may allow the entire genetic selection process to take place using only sperm and eggs, without any live animals. Combining for example the *myostatin* gene with Meishan cross sows and semen sexing could improve production efficiency by up to 30%. Breeding organisations must balance research effort between present and future technologies. The correct strategy involves three priorities: (1) maintain maximum improvement using present BLUP technology, (2) ensure maximum expression of existing genetic potential by good nutrition, and (3) evaluate and be prepared to deploy the new molecular technologies if required for industry survival.

INTRODUCTION

For more than thirty years the partnership between genetics and nutrition has led to dramatic improvements in the efficiency of pig production. Selective breeding with the aid of computers has raised the genetic potential for lean growth, while nutrition has sought to ensure that the increased potential is realised on the farm. These technologies are well proven, acceptable to the public, and highly cost effective. They are extensions of traditional methods offering steady improvement for years to come.

However within a very short time this comfortable picture could be radically changed by the current revolution in biotechnology. The Year 2000 has already seen the first cloned pigs and the complete DNA sequence for the human genome. At present these technologies are both expensive and controversial. Yet in the longer term they offer the prospect of cheaper, healthier and safer pork. Taking the pig industry as an example, this paper reviews the new

genetic technologies, and examines their role in improvement programmes along with the implications for animal nutrition.

STATISTICS AND INFORMATION TECHNOLOGY

For over ten years cheap desktop computer power has allowed the application of BLUP (best linear unbiased prediction) in pig selection. By using family records this gives more accurate prediction of genetic merit for traits of low heritability, doubling the rate of improvement for example in litter size. However the greatest contribution of BLUP has been that, together with AI acting as the genetic link, it allows direct comparisons of genetic merit among animals measured in different environments. This ability to compare across herds has opened the way for larger more geographically diverse nucleus populations, greater selection differentials, and faster improvement.

Shipping breeding stock from a nucleus in one country for production in another is costly in terms of transport and health security, and runs the risk that market requirements may be very different. The solution is to establish separate nucleus populations in key countries selected for local objectives. Where necessary BLUP calculations now can be easily conducted on data transmitted over the Internet using centralised statistical expertise. New genotypes can be introduced via frozen semen or embryo transfer.

This decentralisation also brings the challenge to bring down overhead costs by reducing the size of each nucleus population. Conversely the more accurate the selection the faster the rate of inbreeding. Procedures are therefore now being developed to combine a BLUP prediction of merit with a measure of inbreeding to give a single selection criterion which balances the two (Grundy *et al*, 2000). Nevertheless BLUP does not overcome the problem that traits such as meat quality or disease resistance are difficult to measure in the live animal.

COMPOSITE LINES

Substituting a better breed or line will always be a faster method of genetic change than selection. After 30 years of intense selection, some populations of the traditional breeds such as Large White and Landrace are becoming very homozygous. Incorporating a third breed such as the Duroc to restore heterosis and hardiness in a cross greatly adds to the overhead nucleus cost. The dilemma is that unless populations of sufficient size can be maintained, the minority breeds will quickly fall behind.

The solution has been to combine the attributes of different breeds in new composite lines. For example, Cotswold has introduced 25% of its White Duroc line into each of Large White and Landrace type dam lines to give new composite lines. When crossed together these give a parent gilt containing 25% Duroc from two rather than three nucleus lines. The two larger nucleus populations result in faster selection. They are also cheaper to maintain, with better physical condition than pure breeds due to residual heterosis from the Duroc. Multipliers too benefit from heterosis in what would otherwise have been a purebred GP (GrandParent).

The Chinese Meishan offers eight extra pigs per sow per year, accompanied by very poor growth and carcase characteristics. Since 1987 Cotswold has been developing a 50% Meishan composite dam line by selection for lean growth. Trials at Cotswold's UK R & D Centre in alliance with Imperial College at Wye (London University) show an advantage for the resulting 25% Meishan parent females over non-Meishan parents of 3.8 piglets weaned per sow per year. Backfat of the resulting 12.5% Meishan progeny was increased by 0.7 mm on *ad lib* feeding to 95 kg live weight, feed efficiency was 1% worse and there was no difference in growth rate. Work continues to improve uniformity and lean distribution.

GENOME MAPPING

Completion of the human genome map will greatly accelerate understanding of the mechanism of inheritance at the level of DNA. In the pig the DNA is distributed over 19 pairs of chromosomes and organised into some 100 000 functional genes. The DNA code is made up of sequences of the four bases (A, C, G, T) and a typical gene would be some 5-20 thousand bases in length. Once the sequence for a gene is known, its presence can be detected using a DNA test as in the case of the halothane gene.

Research teams from the USA and Sweden as well as the EU-funded Pig Genome Mapping Project (PiGMaP) are collaborating to map the genome of the pig (Visscher and Haley, 1998). By locating genes on the chromosomes, the objective is to understand how genes are organised and interact with each other, and how they affect all aspects of performance. To date some 2000 DNA sequences showing genetic variation have been placed on the pig maps. These maps are freely accessible on the Internet, along with similar maps for cattle, sheep and chickens.

MARKER GENES

Most quantitative traits such as growth rate are controlled by many hundreds of genes, each with a small effect. A gene with a large effect such as the halothane gene is very much the exception. Nevertheless, much research is now under way to identify possible genes with useful effects on performance. The function of most of the genes so far detected is unknown. They may however be situated on the chromosome close to a gene that does affect performance, for example growth rate, but for which no DNA test exists. Due to genetic linkage, the gene which can be detected will then show an association with growth rate, which is actually caused by its neighbour.

In this case, the DNA tested gene is known as a *marker*, because it marks a section of chromosome affecting performance. The gene whose presence it detects is known as a *quantitative trait locus* (QTL), with linkage between the marker and the QTL (Figure 1).

Possible markers have been reported for all the important traits, and many have been mapped. The 'hot spots' from world-wide pig research are shown in Figure 2. Hot spots for litter size exist on chromosomes 1, 8 and 16; lean growth on 4 and 7; and meat quality on 1, 6 and 15.

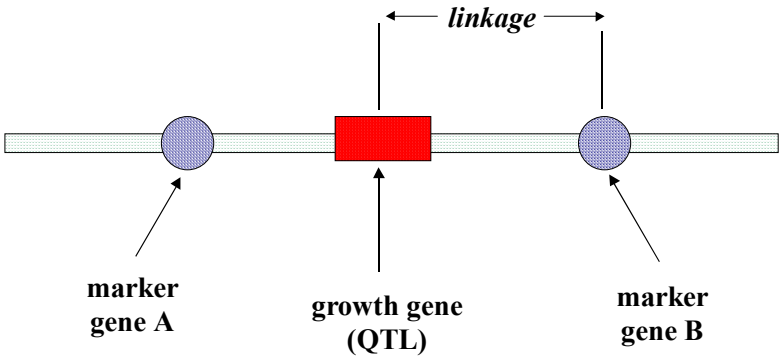

Figure 1. **Flanking marker genes A and B used to predict the presence of a growth gene or QTL (*quantitative trait locus*).**

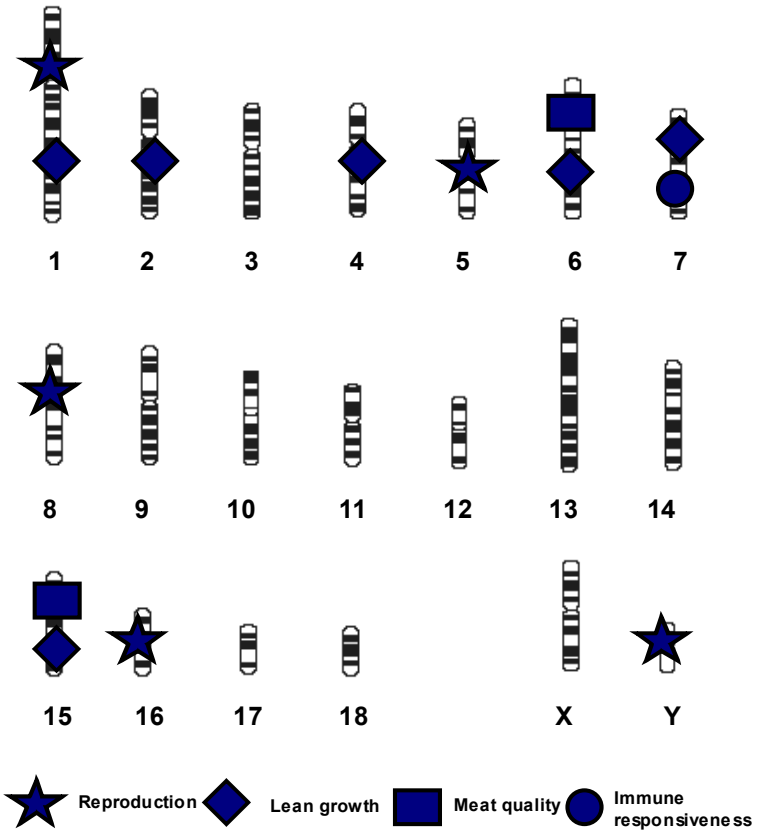

Figure 2. **Hot spots on pig chromosomes affecting reproduction (*Courtesy of P R Bampton*).**

MARKER ASSISTED SELECTION

In the process of *marker assisted selection*, DNA testing for the marker can be used to increase the frequency of the QTL and lead to an improvement in a production trait. The main benefit would be in traits such as meat quality or disease resistance which are difficult or expensive to measure in the live pig, or in reproduction which occurs late in life in one sex only. There are however a number of problems:

- DNA testing is still relatively expensive in relation to the small benefits of most markers on performance.
- There is no further benefit after the marker has been made homozygous
- Marker effects are often inconsistent between lines and even families
- Due the high number of candidates and traits, there is a statistically high chance of false positive markers. Already the number of markers reported would explain more than 100% of the genetic variation for some traits.
- Selecting on markers causes a loss of selection on other traits.
- Markers may have unknown harmful as well as beneficial effects. There may therefore be good reasons why selection has not fixed apparently favourable QTLs at 100% in these populations.

Current thinking is that the interaction of genes with each other is probably more important than originally recognised, so the implications of changing the frequency of any gene with a large effect may be difficult to predict from one population or even family to the next. A further difficulty is that the information from hundreds of markers of small effect may be difficult to collate. At this stage, the use of markers is therefore risky, whereas BLUP selection is already proven and cost-effective.

MARKER ASSISTED INTROGRESSION

As an alternative to selection within a line, a marker can be used to introduce a QTL from one line into another by *marker assisted introgression*. Suppose for example that a single gene for prolificacy is to be introduced from Meishan into Landrace. An F1 cross of the two is then backcrossed to Landrace over several generations, gradually increasing the proportion of Landrace while selecting for the desirable gene. In the absence of a DNA test, this is the method by which Cotswold introduced the dominant white coat colour gene from the Large White into its White Duroc line.

By the same principle other markers can be used to reduce the proportion of background genotype from the undesirable line, for example fatness from Meishan, hastening a commercially viable result. A further application might be the use of markers to retain maximum heterozygosity in any closed population. The risk of introgression is that it takes several generations. During this time the linkage with the marker could break down, selection on other traits may be lost, and the intermediate Meishan crosses could be over-fat and costly. The benefit of the QTL in improved performance would therefore need to be large.

NEW TYPES OF MARKERS

The main disadvantage of existing markers is their high cost and low accuracy. The majority are random segments of DNA of the form CACACA (*microsatellites*) that show genetic variation in the number of repeats. The inaccuracy stems from the weakness of the linkage in predicting the presence of the QTL. Either closer markers are needed or ideally a method of detecting the QTL directly. Several new options are now appearing:

- **AFLPs** Amplified fragment polymorphisms can be generated by enzymes which cut the chromosomes only at specific sequences. The presence of different genes results in DNA fragments of different length, which can be correlated with performance traits. Patented by KeyGene NV in the Netherlands and applied in plants, this has the advantage of producing a set of markers specific to one line. It also overcomes any patents on published markers.

- **SNPs** Single nucleotide polymorphisms are changes in a single specific coding unit of the genetic code. They are easy to detect and usually occur within the functional gene. Unlike microsatellites SNP tests can be automated on DNA *microarray* chips.

- **ESTs** Expressed sequence tags allow genes to be detected when they are 'switched on'. This would allow selection for animals expressing rapid early growth, earlier puberty, or perhaps for immune response. ESTs will provide the key to how genes are organised and controlled.

As the number of mapped genes increases, AFLPs are likely to provide alternative markers for QTLs or hot spots that are already known. *Microarray* technology already allows 30 000 SNP DNA tests to be conducted on a single chip the size of microscope slide, making this the most likely method for the future. This technology is therefore likely to be both powerful and cheap.

CANDIDATE GENES

Rather than searching at random for markers, the candidate gene approach uses knowledge of physiology to identify likely QTLs with a major effect. Equally, QTLs from human, mouse or other species maps would be candidates for investigation in the pig. Patents have been filed on some markers, but can often be overcome using others that are near to the QTL.

The halothane gene RYR1 appears to be the functional gene or QTL responsible for all the effects on lean growth and stress susceptibility. In Germany Cotswold has developed a very lean Pietrain-type composite sire line which is approaching homozygosity for the absence of the halothane gene. The oestrogen receptor ESR which affects litter size in some populations but not others appears to be a marker rather than the QTL responsible. H-FABP was discovered to affect intramuscular fat in Durocs and is currently being trialed under licence in other populations (Gerbens *et al.*, 1998). Candidate genes to control boar taint arising from skatole and androstenone are being investigated by several groups (Davis and Squires, 1999).

As an example, Cotswold is co-sponsoring a study at Glasgow University in which a knowledge of myosin heavy chain muscle protein polymorphisms is being used to deduce likely sequences of DNA that could act as markers within the genes affecting eating quality (Beuzen *et al.*, 2000). Certainly markers represent an important opportunity to accelerate genetic improvement, and Cotswold is very actively continuing its programme of in-house evaluation with exploratory selection on a combination of markers and BLUP.

GENOMIC IMPRINTING

In violation of the simple laws of Mendel, the expression of some genes can be switched on or off in the progeny depending on whether the gene was transmitted through the mother or father. This process of *imprinting* occurs by methylation of C (*cytosine*) units in promoter regions of genes carried by either sperm or eggs, shutting off their function. It may have evolved as a means of resolving conflicting requirements of mother and offspring. At least 34 genes showing imprinting are already known in the mouse (Ruvinsky, 1999).

In humans and mice the Igf2 gene (*insulin-like growth factor 2*) affecting growth appears to be maternally imprinted, and is thus expressed only when inherited from the father. By contrast, the corresponding receptor gene Igf2r is paternally imprinted and expressed only when transmitted by the mother. In pigs the Igf2 gene on chromosome 15 appears maternally imprinted and expressed only via the sire (Nezer *et al*, 1999). A marker for Igf2 in Pietrain crosses has been patented and is used by one breeding company. There have also been some reports of maternally imprinted genes for fat in the pig. This would allow higher levels of fat in the dam, allowing a long reproductive life, with no adverse effect on the carcase fat of the commercial progeny.

GENE TRANSFER

Gene transfer in animals between individuals and species has been possible for some years. The method of microinjection of DNA into the fertilised egg had a low success rate and could not control where and how many copies of the DNA sequence were incorporated. Dolly type cloning makes gene transfer much easier and cheaper, allowing DNA to be incorporated into cloned cells before transfer into the embryo. The first cloned pigs were announced by PPL Therapeutics in the USA this year.

First attempts to add extra copies of pig or human growth hormone genes brought adverse publicity due to undesirable effects on fertility and physical soundness. Methods are now being developed to control the number of copies, site of insertion, and the degree of expression. The technology of gene transfer is being driven by the use of the pig as a donor of hearts and other organs for humans (*xenotransplantation*). Human genes are added and pig genes 'knocked out' to avoid rejection of the heart as 'foreign'.

GENES FOR TRANSFER

What are the opportunities for gene transfer in pigs? Take as an example the *myostatin* gene, a naturally occurring mutation, which is the cause of double-muscling in Belgian Blue Cattle. When this gene is 'knocked out' of laboratory mice, lean growth rate is doubled and ham weight tripled (McPherron *et al.*, 1997). In a pure Meishan line with eight extra pigs per sow per year, a similar knockout might restore the very fat carcase to normal with dramatic consequences for productivity. Other opportunities might include:

- Lean growth (*e.g. leptin, Igf*)
- Boar taint (*e.g. androstenone, skatole*
- Meat quality *(muscle proteins)*
- Disease resistance *(major histocompatibility complex)*
- Gender determination *(SRY on Y-chromosome)*
- Pollution control (*e.g. phytase)*

Genes for androstenone and skatole might be knocked out to control boar taint. The SRY region has a major role in determining maleness. Transfer of this onto one of the non-sex chromosomes might allow sires which produce only male or female offspring.

Guelph University has produced pigs transgenic for phytase, which emit less phosphate pollution. In rats attempts have been made to introduce *cellulase* genes to improve digestion of plant material. This raises the issue of which genotype should be chosen for manipulation: the animal, the fodder plant, or the gut flora. The animal itself should probably be the last choice. An even better long-term solution will be to control the expression of the existing genes and avoid gene transfer altogether. This is a prime area where plant and animal geneticists could work together.

GENE THERAPY

Gene transfer involves a permanent change to the germ line by manipulation in the embryo. Gene therapy attempts to change the individual phenotype by adding genes to the tissues of the live animal, for example to replace an enzyme that is missing due to a naturally occurring mutation. These genes are not passed to the next generation. Genes can be introduced by a number of methods from injection to being fired through the skin adsorbed onto gold particles.

Researchers at the Baylor College of Medicine, Houston, have recently used this approach to introduce a modified GHRH (growth hormone releasing hormone) gene into the young pig (Draghia-Akli et *al*, 1999). The DNA sequence in the GHRH gene was altered to greatly extend its life by preventing normal breakdown by protease enzymes. The modified gene was introduced into three-week old pigs by a single injection. An electric current was then passed (*electroporation*) to integrate the DNA into the cells.

After 65 days the treated animals showed a 37% increase in growth rate with no penalty in body composition. In future the cost of such a treatment might well justify its use in

commercial production. While it would not be classified as GM, it would still be open to concerns of ethics and welfare for animals growing 'unnaturally' fast.

DISEASE RESISTANCE

This major source of loss in pig production has attracted strangely little genetic research. The existence of genetic variation in immune responsiveness within and between breeds has only recently been demonstrated. At Guelph, selection on a BLUP index for high or low immune responsiveness was successful in creating a genetic difference (Mallard *et al.*, 1992). At Iowa State, Durocs showed greater resistance to PRRS virus than other breeds (Halbur *et al.*, 1998).

However, a line with higher immune responsiveness would be expected to show a correlated reduction in lean growth every time the immune system was triggered (Baker and Johnson, 1999). This is a natural defense in response to infection, and is mediated by the cytokines such as interferon and interleukin. One challenge for molecular genetics would be to break this association so that high immune responders could continue to grow normally.

REPRODUCTIVE TECHNOLOGIES

Improvements can be expected in the reproductive technologies such as frozen semen, frozen embryos, and non-surgical embryo transfer (ET). As pigs already have large litters the main benefit of ET will be in establishing and updating nucleus populations, obtaining 100% of the desired genotype with minimum health risk. Cloning the slaughter generation would give 100% uniformity from top pigs in the nucleus, but cloning would need to be repeated each year to keep pace with genetic improvement. Genetic variation would of course need to be maintained in the nucleus to allow continued improvement by selection, which may well cause the nucleus to lag behind the cloned commercial population in genetic merit.

In vitro fertilisation (IVF) together with ET will be *enabling technologies* for gene transfer. *In vitro* meiosis to produce sperm and eggs would be the final step that would allow successive generations to be produced entirely *in vitro*. IVF would be used to produce cloned embryos from which cells would be sampled to conduct marker assisted selection. *In vitro* meiosis would then give the next generation of sperm and eggs directly from cells of the embryo allowing IVF to be repeated (Haley and Visscher, 1998). Genetic improvement could thus proceed at 5-10 times the pace without the need for any live pigs.

SEMEN SEXING

The idea of raising antibodies to remove unwanted X or Y sperm is not new. However, a recent breakthrough in Guelph now offers the prospect of a commercial method for doing this within 3-5 years. Based on the knowledge that the DNA on the X chromosome of all mammals is very similar (Ohno's Law), it assumes that proteins on the surface of the sperm must also be very similar between species. If so, then injecting male porcine material into a

male rabbit will not raise antibody to male-specific proteins, but will raise antibodies to non-sex-specific proteins. These antibodies can then be used to remove the non-sex-specific proteins, leaving the male-specific molecules available for retrieval. From these, sex-specific antibodies can be raised by injection into the opposite sex (Blecher *et al,* 1999). The plan is to prepare monoclonal antibodies that will be added in solution to the semen. Sperm of the unwanted sex can then be made to clump together and filtered off using glass wool.

The main benefit of semen sexing lies in improved feed efficiency and carcase lean content. Compared with a castrate, a gilt has up to 15% better feed efficiency and 3% more lean. An entire boar shows roughly the same advantage again over a gilt. For an industry practicing castration, switching to 100% gilts would give an annual advantage of over $60 per sow place. Switching to 100% entire boars could give over $180 per sow place. Single sex production also avoids the need for split-sex feeding, better meeting nutritional requirements and improving uniformity.

Through its owner Ridley Inc, Cotswold has made a strategic investment of $1 million in the Guelph University spin-off company Gensel Biotechnologies Inc set up to commercialise this process. The strategic investor for cattle is Genus, and Monsanto is a collaborator for protein biochemistry. If successful the semen sexing technique will be easy and cheap to apply for on-farm AI collection. It involves no genetic manipulation, and is safe and acceptable to the public. In the short term sex determination probably represents the greatest single potential step forward in pig production and is therefore well worth the risk. The slower method of physically sorting stained sperm by laser (*flow cytometry*) would not be fast enough to supply the high numbers of sperm per insemination in pigs.

FUTURE GENETIC OBJECTIVES

The pig industry will continue to compete on the low cost per kilo of lean meat. With the move to larger more integrated production pyramids serving specific needs of retailers, there will be increased emphasis on the quality and uniformity of the meat. The way meat is produced will come under closer public scrutiny, including of ethics, naturalness, traceability, the environment, sustainability and animal welfare.

In the pig industry today arguably some 20-30% of genetic potential is not realised on the farm. There are two main reasons for this. The first is poor herd health, with multifactorial diseases such as porcine respiratory syndrome in which PRRS, ‘flu and pneumonias act in concert. The second reason is *incomplete knowledge or application of the nutritional needs of the modern improved genotype*. Genetic objectives are therefore twofold: to continue to raise genetic potential, but also to increase the probability that this potential can be realised on the farm.

A GENETIC CHALLENGE FOR NUTRITION

Genetics and nutrition will need to work together in three areas. First, the nutritional requirements of the modern pig must be understood and met more closely. Second, the correct choice of selection objectives for future improvement will depend on a better understanding on the biology of the pig. Third, the potentially large changes in lean growth, offered for example by the *myostatin* gene, must not be attempted without a nutritional strategy to exploit them.

Taking a simple view, the daily feed intake of a pig is converted to product in the form of saleable lean and fat. In the past, pigs have been fat because daily intake exceeded daily lean deposition. The ideal animal for *ad libitum* feeding would need to have its feed intake genetically linked to lean growth potential (a genetic correlation of 1.0). Serial dissection studies on Cotswold sire lines suggest that dissectable lean growth rate is much higher than expected in the young growing pig, exceeding 400 g per day by 40 kg live weight. This means that before about 60 kg live weight feed intake is the limiting factor, but after 60 kg genetic potential for lean deposition is limiting.

Trials now under way at Cotswold's UK R & D Centre (Wye) suggest that boosting energy and protein levels by 5% above current commercial practice can increase lean growth rate by 10% with very little increase in fat. Increasing the energy alone and leaving the protein unchanged seems to give 90% of this increase. This confirms the view that energy intake rather protein intake is the limiting factor in the early growth of the modern pig (de Lange, 1997). With continued genetic improvement of lean growth potential, and in the absence of a matching increase in feed intake, one of the greatest challenges for nutrition will be to formulate an affordable diet which can actually supply this early energy requirement.

NUTRITION AND BREEDING OBJECTIVES

With no sign of a decline in genetic variation, selection can be expected to continue to increase lean growth at the present rate for some years. Up to now, feed efficiency has largely been improved by substituting lean for fat. As pigs become leaner, further improvements in efficiency will increasingly depend on raising the rate of lean growth itself. The longstanding question remains of how much selection emphasis if any should be placed on voluntary feed intake. Is it realistic to expect intake to increase as a consequence of selection on lean growth?

In practice it appears that lean growth potential and feed intake are highly dependent on diet, health and other environmental conditions. For example, feeding a whey-based liquid diet can far exceed what seemed to be the maximum lean growth on the highest-quality solid diet. The concept of a genetic potential level for lean growth and intake therefore only appears useful for a specific set of husbandry conditions. The excellent long-term study in Edinburgh confirms the existence of genotype x nutrition interactions in lines selected for different objectives (Cameron, 1997).

Certainly it appears that a genetic increase in early feed intake is required, but with very little increase beyond 60 kg. In lean genotypes, intake is very highly genetically correlated with growth rate. Increased early intake is therefore most easily achieved by increasing the selection emphasis on early versus late growth. It is not necessary to incur the expense of individual measures of feed intake by using electronic feeding stations. Genetic improvement can only proceed alongside the appropriate nutritional changes: *genetics and the environment must change together.* Computer models allow alternative strategies to be evaluated.

PUTTING THE TECHNOLOGY TOGETHER

The new technologies could be brought together to revolutionise the pig industry. Suppose for example that a Meishan type containing the *myostatin* knockout could give single line production with an acceptable carcase and 32 pigs per sow per year. Semen sexing could be used to give 100% entire male offspring, and androstenone/skatole knockouts could remove boar taint. This would immediately improve production efficiency by some 30%.

Another possibility would be to produce surrogate mothers from an F1 cross of say Meishan with Fengjing. These would receive cloned and frozen embryos from a dedicated sire line containing *myostatin*. Dam lines would be bred only for uterine capacity and the sire lines only for slaughter pig attributes. As well as 32 pigs per sow per year this could give better lean growth with faster genetic improvement of finishing traits.

Of course no one is advocating these methods, but their adoption by rival industries could pose a threat in terms of lower production cost. On the other hand there could be a huge benefit for the animal and human by manipulating genes for say disease resistance or sustainability.

RISKS OF GENETIC MANIPULATION

So what are the risks of gene transfer in animals? The nightmare scenario would be genetic modification of pathogens (bacteria or viruses) which might then cause an epidemic, perhaps lethal, in man or across a range of species. Production of toxins or allergens would be relatively easy to avoid on any scale by judicious trials in advance of widespread release. Any accident causing sterility would of course be self-eliminating. Risks to animal welfare clearly exist from production stress or physical malfunction. Whilst these risks are very small, those involving pathogens at least have the potential to affect a much larger proportion of the population than say mountaineering or air travel.

The real risk surely lies in the fact that our knowledge of the molecular mechanisms of inheritance, and particularly of the way genes interact with each other, is still rudimentary. Sexual reproduction is set up to produce new genetic variation and is therefore inherently unpredictable. It is therefore difficult to predict the consequences of inserting a gene with 100% certainty. In the event that some undesirable genetic transformation did occur, there is the danger that the knowledge needed to avert a disaster would simply not exist. The *prion*

factor causing BSE and the absence of a solution to cancer would be seen by some as examples of gaps in knowledge. As soon as there is complete understanding of the mechanisms of gene action, the risk will evaporate.

FUTURE GENETIC STRATEGY

So what strategy should be adopted for future genetic improvement and research? There are three components:

- Maintain maximum rates of improvement using existing BLUP methods.
- Close the gap between genetic potential and actual performance on farm.
- Secure access to the new technologies and be prepared to quickly deploy them if required to defend the competitive position of the industry.

To close the achievement gap Cotswold has a large investment in better understanding the nutrient requirements of modern genotypes, especially of the young growing pig where energy intake may be limiting lean growth. There is also a need to increase research on the immune system of the pig.

To access the new technologies Cotswold has developed an international science base run by its five full-time PhD geneticists. As well as in-house research this is supported by research fellowships and alliances, collaborative research agreements and research contracts with biotech companies, and shareholdings in semen sexing company Gensel and DNA typing company Rosgen. The aim is to be closely informed on new ideas and technology with the opportunity for early experimentation where appropriate.

SOME CONCLUSIONS

Through gene mapping, gene therapy, gene transfer, and the control of gene expression, the new technology of molecular genetics has the potential to revolutionise the process of livestock breeding. Today the main contribution of genetic maps and markers is to understand how genes operate. Methods of gene transfer are being developed for medical applications and will inevitably become available to the livestock industry. As these new methods are being evolved, it is important to realise that modern selective breeding programs have been both successful and cheap.

In pigs the immediate challenge for genetics and nutrition is to deliver to the farmer a higher proportion of the genetic potential for lean growth that already exists. The next challenge is to provide diets that can meet the nutritional requirements at ever increasing rates of growth. To help the breeder choose the correct objectives for genetic change, more understanding will be required of the basic biology of pig growth, and in particular factors determining feed intake.

For the pig industry the goal remains the production of high quality lean meat at minimum cost, but with increasing regard for public approval, animal welfare, wholesomeness and the environment. The breeding companies will be integrators of a range of technologies, providing a package of genetic services to the food chain of which a full knowledge of nutritional requirements will be an integral part. At this stage the knowledge does not exist to fully assess the risks of genetic manipulation in livestock. In the meantime genetics and nutrition must work together to ensure that the industry has access to whatever new technology is needed to compete in the future.

> *From fertilized egg to newborn, thousands of genes twinkle on and off in the delicate dance of creation.*
>
> *(Huang, 2000)*

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EMERGING REPRODUCTIVE TECHNOLOGIES IN PIG PRODUCTION

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ABSTRACT

Without question, the implementation of artificial insemination (AI) has been the greatest achievement in swine reproductive technology during the last decade. Because AI in swine is not a new technology, the underlining technological enhancements of this procedure are most likely responsible for its recent popularity. It is widely accepted that reproductive performance as a result of AI can be as good and at times better than from the use of natural service. However, the major limitation of AI is the increased number of procedures associated with its use. These procedures are often associated with inconsistent reproductive performance in many herds. Although there are many factors that can effect the outcome of an artificial mating, the aims of this paper are to discuss the reproductive technologies that have had a positive contribution to on farm AI, their constraints to improvement, and the future need and application of new reproductive technologies in this and other areas of swine reproduction.

ARTIFICIAL INSEMINATION

Semen Analysis and Fertility Assessment

One of the advantages of utilising AI is that each boar ejaculate is assessed for some aspects of quality prior to being used in the breeding process. Generally, there are five parameters that are measured to evaluate boar semen quality: visual assessment, concentration, motility, morphology and acrosome integrity. Of these, concentration and motility are most routinely used for sorting ejaculates prior to processing. Measuring semen concentration or total numbers of spermatozoa in an ejaculate does not appear to be a valuable estimate of the overall fertility of the ejaculate (Flowers, 1997), but more so, as a tool to monitor the health an productive output of the boar. However, this parameter serves as the primary feature in processing boar ejaculates for optimising the genetic potential of a single individual.

Visual estimation of the percentage of motile and morphologically normal spermatozoa by light microscopy is the most widely used and acceptable method of semen quality assessment. The limitation to this procedure is the accuracy of the generated values. Fortunately, the fact the neither parameters are highly related to fertility and generally a surplus of spermatozoa is inseminated, allows for this inexpensive and relatively simple procedure to be currently used as means to evaluate ejaculates. Currently however, it would seem that to improve the efficiency of a boar ejaculate (produce more doses/collection), an accurate method to determine the number of viable sperm numbers in a dose would be of great benefit. Although Computerized Sperm Analyzers (CPA) are not new, they potentially are the best tools for

analysing sperm motility and in the near future, morphology. Like visual assessment, the generated results are highly dependent on the operational settings of the equipment as well is handling and care of the submitted sample. The major limitation to the widespread use of CPAs, like other technologies, are costs and repeatability. CPAs can be expensive and although they provide an objective measurement of semen quality, they remain disadvantaged compared to visual assessment because of the extra time required to process samples.

The search for *in vitro* methods and criteria to predict the fertilising ability of semen has been, and will continue to be, the subject of many investigations. It is likely that in the near future diagnostic approaches to assessing the fertility of an ejaculate will be developed in a manner similar to testing samples for pathogens with a simple diagnostic based test (PCR). However a strong correlation to a specific component or characteristic of the sperm cell or seminal fluid to fertility must first be determined (William Flowers, Personal Communication).

Semen Preservation

Developments in semen extenders for extended storage of semen have played a pivotal role in the development of AI procedures. Artificial insemination doses containing 40 x 10^9 spermatozoa (whole ejaculates) were commonly used during the early years of AI. However, these AI doses were seldom stored for more than one day without suffering a drop in reproductive performance (Rigby, 1966; First, *et al.*, 1968). Today, most semen extension media types are able to storage spermatozoa for up to three days without a drop in reproductive performance. Within most operations, this period of time is sufficient since: 1) semen can be collected and shipped to the sow farm on the same day or the day thereafter, and 2) in the case of the sow, estrus can be accurately predicted based on weaning. Semen can be collected on farm, but the centralisation of boars and modern delivery systems for semen has perhaps contributed to the growth of AI as much as any technology. Unfortunately, the major limitation in the widespread use of superior boars is the inability to store semen for more that 3 days without a drop in reproductive performance. The ability to store extended semen for longer periods of time is becoming more important because: 1) on-farm semen collection and processing is declining, and 2) AI implementation is being adapted world-wide and the demand for superior genetics is high in remote locations. In the latter, the benefits are obvious in meeting the goals of producing a high quality protein source in countries where other technologies for improving pork quantity and quality are not as widely available. Concerning the first, most commercial sow farms in the U.S. are not equipped to produce the required amount of semen during times when delivery of stud derived semen is not possible. As to not suffer a drop in reproductive performance, a viable supply of frozen semen would be of great value in most operations, however, most producers are not satisfied with the 20-30% drop in conception rates that can be expected from using frozen semen compared to fresh extended semen. Because a large number of spermatozoa are required for a swine AI and it is difficult to cryopreserve pig sperm, an increase in frozen semen on commercial farms as an alternative to fresh semen is not foreseeable in the near future.

There have been few changes in developing a “long” term fresh semen extender, however, some recent developments in boar semen freezing may be of some benefit to the distribution of pig semen in the near future. One of the obstacles for freezing boar semen is actually not

the extension medium, but the ability to freeze large numbers of sperm (3-5 billion) in a single container at a controlled rate. Boar semen doses have traditionally been frozen in either a pelted form or in a round 5 ml straw with modest success. Eriksson and Rodriguez-Martinez (1999) have developed a new type of flat plastic package for frozen boar semen. The Flatpack is a single flattened straw, which, similar to freezing small quantities, equalised the freezing rate throughout the whole cell population. Their system is slight modification to traditional freezing techniques and the potential gains in fertility rates appears to range from 70-80% compared to 50-60% associated with the round 5 ml straw. IMV International has recently implemented techniques to freeze boar semen in 0.5-ml straws, which improves the freezing rate of cell samples. It appears that, as a result, the viability and resulting fertility rates from the use of these frozen sperm is improved. The limitations of this technique are that 6-10 straws are handled per dose, and the equipment needed to efficiently process many collections can be expensive.

Semen Sexing

The potential benefits of pre-breeding sex determination are numerous when considering:

1. The inefficiency of castrated males within a meat producing system, and

2. The value of male or female offspring in a terminal or maternal seed stock multiplication system.

The Beltsville Sperm Sexing Technology (Johnson and Welch, 1999) has been proven as the only effective means of altering the sex ratio of offspring in livestock and humans. Commercial application of the technology will become apparent in the next few years, but this application strongly hinges on the ability of this research to develop faster technologies to sort sperm cells. Considering that just in the last 5 years the sort speed has increased over 10 fold (0.6 million/h vs. 10 million/h), this technology is still too slow to produce the enormous numbers of sperm needed for conventional AI (~2 billion). However, in cattle and horses this technology is beginning to be adapted since smaller numbers of sperm are needed for AI and bull and stallion sperm can be frozen with little complications. In the event that the sort rates continue to increase, boar semen cyropreservation technologies are improved, or practical methods to inseminate with low numbers of sperm evolve, this technology will certainly make a dramatic impact on the swine industry.

The Beltsville Sperm Sexing Technology has been perhaps the most publicised technique for sexing semen, however, other technologies could be on the market in the near future that appear to be even more promising. A new approach to immunologically sex semen has recently been reported. This technique is a non-invasive method that utilises differences in protein characteristics to sort X and Y using antibodies specific to each sperm class. It is presumable that both technologies for sorting sperm will become commercially available in the near future. The costs for utilising this technology will be initially a major limiting factor, but pork producers should be prepared to utilise this process in production areas where altering the sex ratio could be of most benefit, such as gilt multipliers or nuclease farms.

GAMATE TRANSFER TECHNIQUES

Low Dose Inseminations

Some studies have suggested that as little as 1 billion inseminated spermatozoa can maximise fertility rates in optimal conditions. However, most farms increase this number to nearly 6 billion cells per dose to mask sub-optimal breeding conditions present on most farms that cause inconsistencies in reproductive performance after inseminating with low numbers of sperm (Baker *et al.*, 1968; Steverink *et al.*, 1997). Most farms today inseminate sows with 2-5 billion sperm cells, and an obvious benefit to lowering the ultimate numbers needed for AI would be in optimising boar usage and stud efficiencies. There are three limitations to applying on farm low dose inseminations: (1) sperm transport is highly inefficient in the pig, (2) optimal insemination conditions are consistently required (technique), and (3) semen evaluations are too imprecise to accurately ensure that a required population of fertile sperm are actually inseminated.

Recent reports suggest that as few as 10 million sperm cells can be inseminated surgically without significant drops in fertility (Rath *et al.*, 1999), and similar results have been obtained using non-surgical deep uterine insemination with specialized equipment (Struthers Inc. 2000; Vazquez *et al.*, 1999). These approaches are being developed to achieve reasonable fertility when using biotechnologies such as sperm sorting where larger numbers of sperm are not available. Obviously, the time required to perform an insemination and the inconsistencies in reproductive performance resulting from these procedures, limit the on farm use of these technologies. Their application in the future will greatly depend on the advancements and costs of the equipment needed to quickly perform a deep uterine insemination. There have been numerous press releases related to the development of a fiber optic scope for performing a deep uterine insemination with low numbers of sperm (Gourley Scope) that bears mention. Although the Gourley scope may hold a small competitive advantage today, researches in Germany have shown that the success of a low dose insemination is not dependent on a specific placement in uterine horn and that the only obstacle for improving sperm viability remains the cervix and the major uterine body. Therefore, placement of semen at the beginning of the uterine horn should yield similar results as placement of semen much deeper in the uterine horn cavity. Although there is no published evidence of performance improvements due to insemination beyond the cervix, it is conceivable that a 20 to 40% improvement in sperm survival or overall AI efficiency from adapting this technology is possible. Because it is not that difficult to transverse the cervix with a small catheter, I anticipate that within the next year a disposable apparatus that serves the same function as the Gourley scope for insemination will be introduced to the market. Producers should be aware that regardless of this technique becoming affordable, more skill is required to perform this procedure and if conducted inappropriately, a loss in reproductive performance will occur due to the sensitive nature of uterine tissues to abrasion. Producers should definitely consider their technician's ability before rapidly adapting this technology.

Reductions in Inseminations

As an alternative to semen placement techniques, methods to improve the viability of the sperm deposited into the uterus using the traditional insemination technique seem more promising. Although spermatozoa capable of fertilising an egg have been recovered from the reproductive tract of the sow nearly 2 weeks following insemination, the fertile lifespans of sperm are generally considered to only be 12-36 h following deposition (Polge, 1978). Our current knowledge of the limiting factors to prolonged sperm survival in the pig has only recently become expanded. Accumulating evidence from our laboratory suggests a post-breeding uterine inflammatory response, which appears to be vital for clearance and preim-plantation preparation, may also be one on the most significant limiting factors for prolonged sperm survival in the female tract as well (Rozeboom *et al.*, 1999). Sperm are only viable in the female reproductive tract for about 24 h and, thus, insemination intervals shorter than 24 h may not be necessary on most farms if each AI is performed with a sufficient population of fresh, viable sperm. However, viability or longevity of sperm in the female tract appears to be dependent on the components of the insemination dose. Seminal fluid, which is often diluted extensively during semen processing, seems to protect inseminated spermatozoa and may reduce the potentially negative impacts of inadvertent inseminations performed at the end of estrus. Our *in vitro* data suggests that a minimum of 10-12 % of the entire AI dose should consist of seminal plasma to protect and improve the viability of spermatozoa once it is in the female reproductive tract. Therefore, we suggest that boar studs and/or producers collect the entire ejaculate, because the entire fluid portion in an ejaculate is seminal plasma, and dilute semen to reach target seminal plasma volumes in AI semen doses. Future applications of synthetic seminal components to AI doses are inevitable, since reduced external shelf life (storage) is a major constraint to large volumes of natural seminal plasma present in AI doses.

Embryo Transfer

Embryo transfer in other species (cattle, horses) has been for some time a very affordable and successful means of genetic dissemination. In pigs, however, the need to implement this tech-nology into practice has only recently surfaced. In light of pork production's health related challenges, the means to preserve genetics while eliminating devastating diseases has now become a higher priority. There have been recent reports of successful embryo transplants using non-surgical approaches. A reliable means to transfer pig embryos non-surgically will greatly increase this practice in critical situations of genetic multiplication where health issues can influence large numbers of breeding stock throughout the swine industry. Surgical transfer of pig embryos remains the most reliable choice for embryo transfer in pigs. A team of Canadian researchers is at the front of this emerging reproductive technology to enable producers to improve the health status of existing genetic lines and multiply the genetic potential of superior sow lines (Rohman, 2000). It is important to note that in the past these procedures relied mainly on the practice of transplanting freshly recovered frozen embryos, since pig embryos have been notoriously difficult to cryopreserve. However, research in this area in a variety of locations (Dobrinsky, 2000) has made tremendous strides in improving the embryo transfer success rates of frozen pig embryos. During the next decade, one should expect this technology to be practical for genetic companies to improve health status, and to preserve and distribute existing female lines here and throughout the world.

BIOTECHNOLOGIES

In Vitro Fertilisation, Embryo Cryopreservation, and Cloning

One may argue that these technologies have very little place in commercial swine production since pigs are a litter bearing, highly fertile domesticated species where genetic progress can be made rather quickly because of a short generation interval. However, two of the limitations to the widespread use of swine genetics throughout the world are: (1) the current health status of most of the world swine population, and (2) the transportation costs associated with the transfer of genetics (Pollard and Plante, 1998). From a discovery standpoint, advances in the development of *in vitro* produced embryos should ultimately lead to better research on fertility and embryo survival issues that directly impact swine production and efficiency. Developments in this area have been slow and its impact on the swine industry is not likely in the near future. Methods in female gamete transfer and long term storage have rapidly progressed during the last decade. Pregnancy rates associated with these procedures are at least now measurable (~40-50%) and may be applicable to swine systems in the near future. Their potential benefits may include: rapid development of genetically superior lines of animals, the eradication of certain pathogens in developing disease free operations, international sales of genetics through frozen embryo transport, and the development of transgenetic animals for the use in human xenotransplantation medicine. Commercial application of all these technologies is limited, however, to advancements in procedural efficiency. Most of the procedures involved in these technologies often require expensive laboratory equipment, surgical expertise, indirect costs and time for trial and error.

It is also important to recognise the potential medical applications of the swine species that are evolving through cloning and organ transplant research. It has now been reported that two separate teams have successfully cloned pigs, a tricky accomplishment that opens the door to breeding herds of genetically engineered pigs to farm for organ transplants to people. But other scientists said they had found tough barriers to such an attempt -- saying they had shown that human cells could be infected with potentially dangerous viruses from pigs. So far sheep, cattle, goats, mice and monkeys have been cloned. One idea is to breed genetically identical farm animals that can produce human products such as proteins for use in medicines. They have also been seen as a potential source of organs and tissue for transplant into people.

PREGNANCY DIAGNOSIS, INSEMINATION TIMING, AND UTERINE PRIMING

Pregnancy Testing

Historically, daily boar exposure is the earliest and the best means to diagnose open sows and gilts. The development of ultrasound techniques for pregnancy diagnosis was a great stride in improving overall herd reproductive performance, since daily boar exposure does not catch all open sows and gilts in heat. The most common types of ultrasonic equipment for these purposes are A-mode and Doppler ultrasound. A-mode ultrasound machines are programmed to emit a beep in response to fluid in the reproductive tract, confirming pregnancy. Doppler machines allow the user to actually hear movement associated with the fetal heartbeat and the

pulsing blood flowing through the uterine artery, indicative of pregnancy. They are accurate beginning around day 28 to 35 of gestation (day 0=day of first breeding), however, each has limitations. Both instruments are 'yes' or 'no', there is little room for judgement. As a result, each may yield erroneous diagnoses.

Within the last decade, the use of another means of pregnancy diagnosis, real-time ultrasound (RTU), has become more widely applicable. Similar to other methods, RTU utilises the same principles of emitting and receiving sound waves. However, RTU displays the resulting information as a two-dimensional image allowing the user to see the reproductive tract and its contents, thereby reducing the chance for diagnostic error. This may impact producers as earlier diagnosis has the potential to decrease non-productive days and reduce the time-spent heat checking, positively altering animal flow. RTU's major disadvantage is cost, but its accuracy (nearly 100% at 23 d) and benefits in reducing non-productive sow days are significant in most herds of reasonable size (>600 sows). It is also important to note that other technologies are also emerging as potential low cost, simple and accurate means to diagnose pregnancy in swine. A competitive inhibition-type enzyme-immunoassay (EIA) has been developed for direct measurement of hormone levels in swine urine. In a field trial with a group of 387 sows (7 in estrus, 16 non-pregnant and 364 pregnant sows at several stages post service), it was shown that the assay is potentially an accurate pregnancy test in assessing the viability of the fetoplacental unit from day 23 up to day 30-post service. This type of assay is potentially well suited for routine testing, particularly as a swine early pregnancy diagnosis test since urine sampling is easier and does not disturb the animal, while in the present assay there is no restriction in the time of sampling and the sample storage conditions (Stefanakis *et al.*, 2000).

Techniques to Improve Insemination Timing

In addition to pregnancy testing, real time ultrasound has also helped define insemination strategies by characterising ovulation patterns in the sow retrospectively. Initially, some researchers have felt that it may be useful in tracking follicular growth, and hence, use this technology in a prediction model for ovulation and subsequent timing of a single fixed time AI. Unfortunately, it does not appear to be effective in predicting ovulation ahead of time, that is, when ovulation will occur, and this is a major constraint in using this technology. Nevertheless, countless hours of research have been conducted on retrospective analysis of the moment of ovulation and on defining relationships between the time of ovulation relative to estrus behaviours. These relationships have ultimately led to methods that allow producers to more accurately time inseminations. Even though there is large variation in the time that ovulation occurs after estrus is first detected, ovulation consistently takes place at a relatively fixed two-thirds of estrus length in most herds and females. Thus, even if a female's estrus length is known, then we have a pretty good idea when ovulation will occur. However, there is some variation in ovulation time relative to estrus length, but this response can be verified using real time ultrasonography. Briefly, once estrus is detected transcutaneous flank ultrasonography (Weitze *et al.*, 1989) can be performed using an ultrasound machine, preferably with a with a 5 MHz micro-convex probe (Universal Medical Systems, Bedford Hills, NY) to detect the presence (pre-ovulation) or absence (post-ovulation) of tertiary follicles greater than 6 mm in diameter. When pre-ovulatory follicles are present, ultrasound should be repeated

morning and afternoon until these follicles disappear. The absence of large follicles indicates that ovulation occurred. Females should then be checked for estrus at the same interval until they are no longer in standing heat. Subtract 6 h from each time (ovulation and estrus length) and an estimation of ovulation relative to estrus length can be accurately established in this herd. The number of females required to accurately establish this relationship should be around 10 % of the total population of the breeding herd. This description has been developed from subcutaneous ultrasonography, whereas, some researchers have suggested that rectal sonography can allow faster and more detailed means of assessing fine reproductive structures of varying echogenicity (Knox *et al.*, 1999). We have in our laboratory, however, used only subcutaneous ultrasonography, since rectal sonography requires specialised transducer rods and our current system up to now only requires a gross structural evaluation of the ovaries. It is become increasingly evident in our research program that ultrasonography is perhaps a more valuable as a tool in retrospective analysis of established insemination timing schedules than as a tool for predicting when to inseminate.

Uterine Priming

Priming the uterus for mating before or during insemination with either synthetic or natural products to enhance subsequent fertility has been attempted through various means during the past 25 years. Leucocytes, estrogens, oxytocins, and prostaglandins have been either added to semen or injected into the female as a strategy to enhance reproductive performance of artificial matings. The effectiveness of additions of these types of compounds has yielded only small improvements or no positive effect in most published trials. In most instances where improvements have been noted, the positive effect has been attributed to masking or covering up sub-optimal fertilisation conditions such as old or poor quality semen, poor AI techniques, and poor estrus detection (Flowers and Esbenshade, 1993). There has, however, recently been a renewed interest in this area because of recent reports of a positive influence of "priming" the uterus with dead semen or synthetic seminal plasma during the estrus period just prior to mating. In both cases, these reports have reported about a 0.5 pig advantage to this technique, however, there is no scientific literature to support these claims as of yet and one could perhaps expect that the advantages to implementing these types of programs across many farms would yield highly variable results. Nevertheless producers should expect further publicity of these types of insemination technologies and, as with most new procedures, approach them with optimistic caution, since simple changes in either estrus detection, or AI procedures that can yield similar results without sacrificing extra labor or product costs would certainly be considered more cost effective. However, a positive cost/beneficial procedure like this could be easy implemented on most sow farms and therefore should never be overlooked.

Hormonal Therapy

Historically, gonadotropins and progestens have been used with limited success to improve reproductive performance in swine and this author does not recommend using them on a routine basis. Nevertheless, application of these hormones in specific swine management areas has helped reduce the reproductive lag associated with these recent management trends that can potentially improve sow reproductive performance. Two hormonal strategies using

PG600® (400 I.U. PMSG + 200 I. U. hCG) and Regumate® (progesterone) have been introduced to counteract the negative effects of shortening lactation lengths. PG600® can be injected at weaning to stimulate follicular growth, speed return to estrus intervals and reduce the incidence of anestrus. However, costs are a major limitation and therefore this approach may only be beneficial in herds where extended wean to estrus lengths (>10d) or high frequencies of anestrus are occurring. Some producers only treat problem groups of sows such as those with low lactation feed consumption or of low parity to improve the efficiency of this technology.

Extended weaning to estrus intervals and anestrus following weaning in parity 1 sows are probably the most noticeable effects of poor lactational feed intake, short lactation lengths, and heat stress on reproduction. The combination of heat stress, parturition, lactation, and poor feed intake contribute to poor reproduction in all sows; however, P1 females also have a metabolic demand for growth. One strategy to minimise these impacts on overall herd reproduction is to adjust female replacement schedules to avoid large numbers of P1 farrowings during July and August. It may also be possible to treat this subpopulation of females with hormonal therapy during lactation and at the time of weaning to stimulate the reproductive system. A single injection of PG600® at the time of weaning has been effective in reducing weaning to estrus interval in sows. However, a recent field report suggests that a vulvular injection of 1/2 cc. of Estrumate (not currently labeled for swine use) within 24 hours after farrowing in conjunction with PG600® at weaning may be even more effective at reducing weaning to estrus interval and the incidence of anestrus than the use of either of these components alone.

Continual feeding of Regumate® suppresses follicular growth and estrus until withdrawn. Its usage appears to be useful in estrus synchronization of cycling females and as a strategy to improve reproduction performance after a short lactation length (feed throughout lactation and withdraw at weaning). In addition to costs, the delivery system is a major limitation. Regumate® is currently produced in an oil-base form that is difficult to handle and constrain.

CONCLUSIONS

Reproductive technologies have and will continue to benefit swine production systems. I would argue that in the advent of large scaled operations with a lack of skilled labour and management, the recent application of both new and old technologies actually masks the potential losses associated labour deficiencies. It is with certainty that other reproductive technologies will continue to be developed in addition to the ones mentioned here. The impact of present, developing and other conceptual technologies is certainly dependent of the cost/benefit relationship of their application directly on the sow or boar unit. When developing new reproductive technologies for the new millennium, I urge science to ask the right questions. What is the problem in the production unit (industry, operation or female) that needs improvement and will the benefits of the technology outweigh the limitations in terms of time, money and market influences? Traditionally, the application of reproductive technologies into swine production is slow and one must understand that there are very few technologies that can or will make dramatic changes in a short period of time.

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EMERGING ENVIRONMENTAL TECHNOLOGIES

WHERE LIES THE PUBLIC INTEREST?

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ABSTRACT

Swine farm operators need to be aware of the interplay between the public interest and the current legislative scheme in existence in Ontario so that they can take steps to self regulate their operations and avoid excessive regulation by the government in the future. This paper reviews the current legislation affecting swine operations and discusses how the public interest plays a role in the application of the legislation.

> "Whereas the *Farming and Food Production Protection Act, 1998* is intended to promote farm practices in a way that balances the needs of the agricultural community with provincial health, safety and environmental concerns; pursuant to subsection 9(1) of the Act I direct that an agricultural operation proposed to be carried on in an area which is the subject of an interim control by-law under the Planning Act shall be deemed not to be carried on as a normal farm practice until a by-law providing for nutrient management planning, minimum distance separation and manure storage has been passed"[1]

By this Directive, the Minister of Agriculture, Food and Rural Affairs gave notice that public interest considerations under the *Planning Act* have precedence to the right to continue established normal farm practices.

This was done in the context that agriculture is the second largest industry in Ontario and annually contributes $25 billion to the economy in this Province[2]. Farming operations vary from the smaller "family farm" to larger operations that have been termed "intensive" agricultural operations. The growing national concern about the environment, along with a rash of media attention to specific environmental problems caused by farming operations, is shifting the scope and focus of the regulatory regime of these agricultural operations. As the above Directive released June 26th, 2000 from the Minister suggests, the government is prepared to give increasing weight to the public interest in developing agricultural policy and laws.

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[1]Ontario Ministry of Agriculture, Food and Rural Affairs, Directive from the Minister of Agriculture, Food and Rural Affairs, Ernie Hardeman dated June 26th, 2000 found at http://www.gov.on.ca/OMAFRA/english/about/directive.html

[2]Ontario Ministry of Agriculture, Food and Rural Affairs, Discussion Paper on Intensive Agricultural Operations in Rural Ontario, July 11, 2000 found at http://www.gov.on.ca/OMAFRA/english/agops/discussion.html

Swine operations in particular are a matter of public interest for a variety of reasons. As the number of intensive livestock operations increases, the issues surrounding manure management and how failure to manage manure properly poses a threat to the environment and human health have also increased.

When manure is spread on agricultural land it can be beneficial. Inept practices in application of manure and inattention when doing so, however, give rise to the potential for contaminants to enter both ground water and surface watercourses with resultant risk to human health and safety. How swine operations manage the volumes of waste they produce and how they work to prevent contributing to other environmental concerns are issues that will continue to come to the forefront if the swine industry does not take a strong and proactive role in regulating themselves.

The Canadian Pork Council's voluntary environmental Code of Practice for hog farmers is one example of standards hog farmers could follow to promote self regulation.

In the wake of Walkerton, the public's concern over farming practices is growing, and in turn, the public interest is being given more attention both by the media and by Government. Whether it is deserved or not, incidents such as the Walkerton disaster make it inevitable that farmers will experience more regulation in their practices in the future. Farmers' efforts at achieving a safe operation at the earliest opportunity will go a long way in giving farmers the ability to shape how their operations are guided by Government, instead of having the Government impose formal legal regulations.

The swine industry is a target of regulation. In fact, pig farmers have probably been the target of more regulatory legislation than any other agricultural industry over concerns about pig manure and its potential effect on the environment. As one swine researcher has said: "Pig manure is a potential environmental pollution problem that may impair the growth of Ontario's pork industry"[3]. No matter how important the agriculture industry is to Ontario, the public is being heard when they express their concerns. The public interest will be a more powerful force than the right-to-farm advocates if there is a conflict. The burden of avoiding that conflict rests upon the swine industry; however unfair that may seem to some, that is the political reality.

A recent Task Force Report prepared for the Ministry of Agriculture, Food and Rural Affairs suggests that more restrictive legislation is on the way for Ontario farmers[4]. There are several pieces of legislation in Ontario already in existence which regulate farming activities, and if operators of livestock facilities are not prepared to regulate themselves by keeping their operations within the boundaries of the current regulations and through taking preventative

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[3]de Lange, K. Winter 1998. Calculate nutrient balances on your own pig farm. PigPens. Vol. IV No.1

[4]Ontario Ministry of Agriculture, Food and Rural Affairs, Task Force on Intensive Agricultural Operations in Rural Ontario, Consultation, February 21, 2001 found at www.gov.on.ca/OMAFRA/english/agops/report.html

steps to avoid the pollution hazards that are potential problems in swine farming, the public interest may direct the legislation in a manner with which the agricultural industry will not be happy.

Certain federal and provincial laws are designed to address the public interest and protect resources of land, water and air from environmental contaminants. Swine farmers should be familiar with the current regulations in place that impact on their operations. A better understanding of the role that the public interest plays in the laws that already exist in Ontario will help those operators who wish to avoid excessive regulation achieve that goal in the best way possible. The following is a summary review of the current legislation which impacts on the balance between the rights of farmers and the rights of the public. An understanding of that balance should provide swine farmers with some insight into the legislative policies which impact upon their operations and suggestions on how swine farmers can be proactive in self regulating their own operations.

BUILDING CODE ACT, 1992[5]

The *Building Code Act* is of interest to any farmer who is preparing to construct a new swine operation or expand an operation already in existence by building new structures, including barns and manure storage facilities. The *Building Code Act* does not address the public interest, per se, because subsection 8(2) states that a building permit must be issued if the proposed structure complies with all applicable law.

There is little or no discretion which the building inspector or chief building official can bring to the decision about whether or not to issue a permit. If the proposal complies with "applicable law", the permit must be issued.

The public interest, however, is a product of the "applicable law", most pertinent of which are usually Zoning By-laws passed by local municipalities under the *Planning Act* and manure management By-laws passed under the *Municipal Act*.

PLANNING ACT[6]

The *Planning Act* gives municipalities the authority to create Zoning By-laws which regulate the location, type and dimensions of buildings. Official Plans are also creatures of the *Planning Act* which are, in turn, implemented through Zoning By-laws passed pursuant to section 34 of the *Planning Act*.

Zoning By-laws and Official Plans often incorporate minimum distance separation formulae which are standards set by the Ministry of Agriculture, Food and Rural Affairs requiring

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[5]S.O. 1992, c.23.

[6]R.S.O. 1990, c.P.13.

certain separation distances between agricultural operations and their neighbours. Regulation of livestock density upon a lot and limitations upon the size of any intensive livestock operations are also issues that are starting to show up in Zoning By-laws and Official Plans.

Zoning By-laws and Official Plans can be appealed to the Ontario Municipal Board. The Board brings to it's deliberations many policy considerations but over arching all is a question of the public interest. In the recent decision of the O.M.B. in the case of West Perth Township's Zoning By-law[7], the Board did not speak of the public interest, per se, but for the reasons set out in that decision, the Board endorsed provisions in the Zoning By-law which restricted the size of intensive livestock operations to 600 livestock units per lot. The Board also approved a section which prescribed that 30% of the land base required for a livestock operation must be owned by the livestock operator.

These regulations then feed back to a building inspector who cannot issue a building permit unless such provisions are complied with.

The *Planning Act* also provides for site plan control. This permits a municipality to regulate site grading for the disposal of waste waters from the lands and buildings, including facilities used for the storage of manure. This site plan control authority is not usually exercised by municipalities for agricultural operations. If there is a need, however, whether real or perceived, this is a tool that is available when nutrient management, including contingency planning, is not satisfactorily managed by the agricultural industry itself. Again there are appeals to the Ontario Municipal Board in connection with site plan approvals and development agreements imposed as conditions of plan approval.

The ultimate weapon in a municipality's *Planning Act* arsenal is an Interim Control By-law passed under subsection 38(1). This is akin to a Zoning By-law that prohibits certain types of uses of land, such as intensive livestock operations, without notice, process or hearing from those affected. It is a short term, maximum two year measure (see subsection 38(2)) which gives a municipality a chance to study a perceived problem, putting a stop to any development in the interim. This is the sort of By-law which is addressed by the Minister of Agriculture, Food and Rural Affairs in the Directive quoted at the beginning of this paper.

A Interim Control By-law passed by Ashfield Township in Huron County with respect to nutrient management plans has been recently upheld in Court.[8]

Interim Control By-laws are subject to appeal to the Ontario Municipal Board.

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[7] *Re West Perth (Township) Zoning By-Law No. 100-1998*, [2000] O.M.B.D. No. 707.

[8] *Country Pork Ltd. v. The Corporation of the Township of Ashfield and Chief Building Official of the Corporation of the Township of Ashfield*, (October 2000) Leitch J. (unreported) Court File No. 30858

MUNICIPAL ACT[9]

The *Municipal Act* is probably of primary importance in a growing number of swine operations as municipalities are passing By-laws which call for nutrient management and manure storage plans. These Nutrient Management By-laws also tend to regulate new construction by incorporating the Minimum Distance Separation calculations published by Minister of Agriculture, Food and Rural Affairs. Often these MDS calculations parallel provisions in a Zoning By-law.

Section 102 of the *Municipal Act* authorizes By-laws for the health safety, morality and welfare of the inhabitants of the municipality in matters not specifically provided for in the Act, and joined with section 210 every municipality in Ontario has the authority to pass By-laws for Nutrient Management Plans, Minimum Distance Separations and Manure Storage By-laws. If this statutory authority was found to be inadequate for these purposes by a Court, recourse could be had to the business licensing provisions of the *Municipal Act*.

It is doubtful, however, that the statutory authority for a Nutrient Management By-law will be challenged because many farmers are voluntarily preparing these plans. The other reason is that the response to a successful Court challenge will be a legislative one by the Government which will respond to the public interest by legislating formal Nutrient Management Plans. Such legislative initiatives are already in contemplation and it would not serve the interests of the swine industry to precipitate an over-reaction to a successful Court challenge.

It is worth noting that *Municipal Act* By-laws usually have application to existing operations. Existing land uses and building are protected from the application of Zoning By-laws under the *Planning Act* by what is known in the vernacular as "legal non-conforming" status. The notion of a legal non-conforming use simply does not apply to a *Municipal Act* Nutrient Management By-law.

It is also worth saying that, in the majority of cases, when a municipal council passes a By-law under the *Municipal Act* in accordance with what it perceives to be the public interest, there is no appellate supervision by the Municipal Board. The only real recourse is through the ballot box - the ultimate test of the public interest.

THE CANADIAN PORK COUNCIL GUIDELINES

The Code of Practice developed by the Canadian Pork Council is a series of guidelines that swine farmers are encouraged to follow so their production practices are continually reviewed to ensure that they are in harmony with the environment.[10]

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[9] R.S.O. 1990, c. M.45.

[10] Canadian Pork Council. Canadian Code of Practice for Environmentally Sound Hog Production found at http://www.cpc-ccp.com/codeeon.html

The Canadian Pork Council has stated that a principal objective in their design of these guidelines was to provide "provincial and local governments with a code of environmentally sound practices which can be incorporated into regulations affecting hog practices"[11].

It further recognizes the need for farmers to develop their industry in a manner which shows respect for society's concerns over pollution. If farmers accept and adopt these guidelines for their operations, their efforts to self regulate their industry will be strengthened. The Code is also a valuable tool for use in nuisance complaints which fall under the *Farming and Food Production Protection Act, 1998* as it can be used by a swine farmer to show that their operation was in accordance with "normal farm practices".

FARMING AND FOOD PRODUCTION PROTECTION ACT, 1998[12]

The *Farming and Food Production Protection Act, 1998* is the "right to farm" legislation and it stands for the proposition that it is in the Provincial interest that in agricultural areas, agricultural uses and normal farm practices be promoted and protected in a way that balances the needs of the agricultural community with provincial health, safety and environmental concerns.

While that has the appearance of identifying the public interest it does not.

The Act establishes a Normal Farm Practices Protection Board and has given this Board the authority to protect "normal farm practices" from Court actions for nuisance and municipal by-laws that restrict such practices. Once it can be established that something is a normal farm practice, the Board has no basis for introducing a public interest factor.

It is true, therefore, that the Code of Practice developed by the Canadian Pork Council can be used by swine producers to establish a normal farm practice before the Board. The problem is that, if the practice is at odds with sound land use planning as endorsed by the Ontario Municipal Board or an interim control by-law passed under the *Planning Act* or basic common sense, the Normal Farm Practices Protection Board has no jurisdiction to take those matters into account. That is why the Minister issued the Directive quoted at the top of this paper that was issued on June 26th, 2000.

In effect the Code of Practice becomes a self-fulfilling situation. If enough swine operators follow the Code of Practice for a year or so, it becomes the norm and is, on that account, protected by the Normal Farm Practices Protection Board. If the Code finds public acceptance then it will have served the swine industry and the public interest well. If not, the public interest will prevail and those who obtain the protection of the Board's jurisdiction will find it gone.

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[11] Ibid. found at www.canpork.ca/introe.html

[12] S.O. 1998, c.1.

Regardless of the Board's jurisdiction, the *Farming and Food Production Protection Act, 1998* provides no protection from behaviours and practices which contravene the *Environmental Protection Act*[13], the *Ontario Water Resources Act*[14], the *Drainage Act*[15] and the *Fisheries Act*[16].

ENVIRONMENTAL PROTECTION ACT

Of these, this paper will touch only on the *Environmental Protection Act*.

Environmental pollution is the most discussed issue with respect to swine operations. The public's interest in both a healthy environment and pollution control are priorities in the *Environmental Protection Act*.

This Act prohibits the discharge of contaminants into the environment in concentrations greater than the prescribed amounts along with those which cause or are likely to cause an adverse effect (subsections 6(1), 14(1)). However, these sections do not apply to the application of manure to land which is being done in accordance with normal farm practices (subsections 6(2) and 14(2)).

Again normal farm practices represent a defence to pollution charges, but if those practices are conspicuously out of step the public perception of what should be done, the defence will be eroded. It would not take much imagination to guess the result of such a "normal farm practice" defence in a Walkerton scenario.

At the moment, swine farmers are more likely to find themselves caught by the provisions of this the *Environmental Protection Act* in situations where the environmental standards of their operations are far below safe levels. The *Environmental Protection Act* deals directly with issues of spills in sections 92 and 93 where it states that spills must be reported to the Ministry of the Environment, the owner and surrounding neighbours and also requires that the spill be cleaned up to prevent any adverse affects if possible.

There are suggestions of potential future requirements for "environmental farm plans"[17] where farmers will be required to assess potential environmental farm risks on their farm and prepare a plan which addresses those concerns. Many farmers across the Province are already

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[13]R.S.O. 1990, c. E.19.

[14]R.S.O. 1990, c. O.40.

[15]R.S.O. 1990, c. D.17.

[16]R.S.C. 1985, c. F.14.

[17]Canada-Ontario Agriculture Green Plan, Ontario Environmental Farm Plan Program found at http://res2.agr.ca/london/gp/efp/efpmenu.html

doing this on a voluntary basis, but if disasters similar to the Walkerton one continue to appear, these plans may end up becoming a focus of new laws.

CONCLUSION

Swine farmers will not be immune to increased regulation in the coming years, as the public's interest in keeping hog operations environmentally safe is not going unheard by the media and in turn, the politicians. Farmers should be well aware of the laws already in existence which allow the public's concerns to be heard. The swine industry should be placing pressure on itself to increase awareness among its members as to steps they can take to self regulate in the hopes of avoiding excessive regulation by the government. A failure to comply with the regulatory schemes in existence will only serve to increase the regulatory measures the government has to take to respond to the demand of the public.

TECHNOLOGIES TO ADDRESS ENVIRONMENTAL ISSUES

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THE ISSUES

In Canada, environmental issues are the only reasons used by the news media to discuss the livestock industry, when for most other industries, economic issue are of much greater interest. The controversy in this fact, is that the Canadian livestock industry grosses annually over $15 billion which is as much if not more than many other industries. Furthermore, its environmental impact has not been worse than that of other industries, such as the pulp and paper industry using our major rivers to transport its logs, and the electronic industry sending annually to landfills, tons of obsolete systems rich in heavy metals.

The Canadian livestock industry has therefore been quite successful in resolving its environmental issues, improving the quality of our soil, water and air resources. Although modern intensified livestock operations do concentrate wastes and offer a large point source of waste, their manure management is more cost effective. The large quantities of manure justify the purchase and operation of equipment concentrating manure nutrients and reducing odours.

The present paper will therefore review the technologies that have been developed to handle the manure produced by intensive livestock operations, with minimum impact on our resources, soil, air and water. Intensive livestock operations can be found under two circumstances:

1. those enterprises surpassing the size of the average farm by a factor of 5 or more, and
2. regions where livestock intensify exceeds 1 large animal unit (AU)/tillable ha.

THE LIVESTOCK INDUSTRY

The North American livestock industry has not grown significantly in numbers but rather in enterprise size and in production level (Table 1), and this over the past 30 years. Cattle and sheep numbers have dropped by 17% while hog and chicken numbers have increased by 7.5% and 34%, respectively. Nevertheless, net production has greatly increased, especially for milk and eggs, (20% and 30%), indicating that yield per animal has increased even more as a consequence of heavier feeding regimes with higher feed protein and mineral content. The quantity of manure produced has increased exponentially with higher feed nutrient, because of the low digestion capability of most livestock.

As a result, livestock manure accounts for 69% of the total dry mass of organic waste produced on an annual basis in Québec (Table 2), which also reflects the North American situation. In Canada alone, livestock manure contains some 1 080, 675 and 1 120 million tons

of nitrogen, phosphorous and potassium, respectively. Although some of this nitrogen is lost through handling, all the phosphorous and potassium remain (Garcia Moreno 1993).

Table 1. Evolution of livestock numbers and animal production in North America from 1975 to 1995 (Encyclopedia Britannica inc., 1989 and 1999).

Livestock	1975	1985	1995
Cattle and sheep, 1 000 head	143,2	127,7	122,8
Hogs, 1 000 head	58,9	63,0	67,7
Milk, 1 000 tons	62,0	73,4	79,3
Eggs, 1 000 tons	4 115	4 369	4 907
Chickens, 1 000 head	1 006	1260	1692

Table 2. Organic waste production in Québec (dry matter basis) (CQVB 1991).

Source	Organic waste production, Dry 1000 tons/yr	Percentage (dry mass basis) %
Domestic waste		
- food waste	550	1,6
- cardboard	660	1,9
- garden waste	220	0,6
- total	1 430	4,1
Institutional and commercial waste	2 000	5,8
Wastewater sludge	5 100	14,7
Pulp and paper		
- bark	930	2,7
- sludge	1 070	3,0
- ashes	70	0,2
- floating residues	125	0,4
- total	2 195	6,3
Livestock	24 000	69,1%
Total	34 725	100%

1. Problems of Localised Waste Surpluses

The intensification of the livestock industry has created manure surpluses in some regions of Canada: the B.C. Fraser Valley; the region of Lethbridge, Alberta; and the regions of St Hyacinthe, L'Assomption and Beauce in Québec. Québec is the Canadian Province with the highest livestock density per tilled surface.

Nevertheless, Canada is not the country with the highest average livestock (Animal Unit = AU) density. Among the countries with the highest livestock densities are China, Denmark, The Netherlands, and Japan (Table 3). In these countries, average livestock densities exceed 1 AU per ha, when the average density in Canada is 0.19 AU/ha. In some regions of Canada, though, average livestock densities exceed or come close to exceeding 1 AU/ha. For example,

in the Provinces of Ontario and Québec, such livestock densities are found in the Southern region of Ontario and in the Regions of Lanaudière (North East of Montréal), Estrie (Eastern Townships) and Chaudière-Appalaches (South of Québec City) (Table 4).

Table 3. World livestock densities (1990) expressed in large animal units (AU) (Statistics Canada 1990; Encyclopedia Britannica inc. 1999).

Province or Country	Cattle 10^3 AU	Hog 10^3 AU	Sheep 10^3 AU	Poultry 10^3 AU	Total 10^3 AU	Tilled land 10^3 ha	Density AU/ ha
	Cattle	Hogs	Sheep	Poultry	Total		
Canada	6145.9	2106.4	95.0	170.7	8518	45485	0.19
- Maritime	169.4	70.4	6.9	15.2	261.9	520	0.50
- Québec	706.5	595.0	14.8	29.1	1345.4	2115	0.64
- Ontario	1125	636.2	26.9	63.7	1851.8	4050	0.46
- Prairies	3775	758.0	39.1	41.6	4611.2	37910	0.12
- B.C.	370	46.8	7.3	21.1	445.2	890	0.50
China	58 230	93 611	16 586	24 084	19 551	166 902	1.17
Denmark	1015	2220	21	154	3410	2 728	1.25
France	10 332	2 993	1 308	1 852	16 485	30 060	0.55
Germany	7 880	4 857	291	822	13 850	17 344	0.80
Japan	2 375	1 962	2	2 472	6 811	5 038	1.35
Spain	2 957	3 854	2 998	1 008	10 817	30 816	0.35
USA	50 730	11 234	992	12 424	75 380	393 471	0.19
Argentina	27 300	640	2 050	440	30 430	177 440	0.17
Brazil	80 500	6 280	2 300	7 200	96 300	376 300	0.26
Chili	1 880	350	470	560	3 260	8 746	0.37
Peru	2 350	510	1 700	640	5 200	14 900	0.35

These high livestock densities lead to excess amounts of manure nutrients for the tilled land base. Thus, applying this amount of manure to the regional land base leads to the accumulation of excessive amounts of nutrients (nitrogen (N), phosphorus (P) and potassium (K)) and the pollution of soils, which in turn produce sediments and drainage contaminating our water resources. The only solution out of this situation is to concentrate the manure nutrients to export them to outer regions, with no manure surpluses or to transform the manure into a by-product. This last solution has produced much controversy especially since the incident of mad cow disease, which developed in the United Kingdom.

The impact of high livestock densities on manure application rates is illustrated in Table 5. To further demonstrate the level of livestock manure applied, the N, P and K requirements for corn and cereals are added at the bottom of the Table. In Canada and the USA, manure application rates are well under that required by corn, the main crop. In Europe, where cereals are the main crop, manure N, P and K levels exceed that up-taken by the plant. In such a case, manure nutrients accumulation in the soil and eventually leach with drainage to contaminate water resources.

Table 4. Livestock densities in Ontario and Québec (1995) expressed in large animal units (Statistics Canada 1995).

Region	Cattle 10^3 AU	Hog 10^3 AU	Sheep 10^3 AU	Poultry 10^3 AU	Total 10^3 AU	Land 10^3 ha	Density AU/ ha
Ontario							
Niagara	248.9	259.8	6.8	15.9	531.3	1191	0.46
South	619.5	378.3	16.4	15.9	1030.1	1073	0.96
West	226.2	19.1	6.2	15.9	267.3	379	0.71
Central	285.6	22.7	7.3	15.9	331.4	487	0.68
East	85.9	2.8	1,6	-	90.3	123	0.73
Québec							
Montérégie	184.4	129.3	2.7	63.0	379.7	527.8	0.72
Mauricie Bois Franc	176.3	53.9	3.2	27.5	260.9	314.1	0.83
Laurentides	31.4	2.6	0.3	3.8	38.1	69.8	0.55
Estrie	101.9	16.2	4.6	3.4	126.1	128.7	0.98
Lanaudière	37.4	23.6	1.6	70.1	132.7	107.8	1.23
Gaspésie	8.0	0.024	1.0	0.036	9.1	18.7	0.49
Chaudière Appalaches					300.0	230.2	1.30
Bas St Laurent					99.1	184.3	0.54
Québec	28.3	2.3	0.55	9.1	41.3	60.6	0.68
Lac St Jean	53.2	0.7	1.07	4.2	59.7	119.1	0.50
Outaouais	55.7	0.04	0.62	0.12	58.8	80.75	0.73

2. Characteristics of Livestock Manures

Along with an increase in production, livestock enterprises have been specialising and consolidating to remain competitive with the opening of world markets. Livestock enterprises now house a greater number of head under the same roof and, to facilitate manure management, it is diluted to a water content exceeding 92%. Typical swine and dairy manure water levels out of the barn are 93 and 95% whereas handled as a solid, the water content of this manure would exceed 80%. Once stored over the winter in an open outdoor pit, this manure has a water content of 95 and 97%. This additional water dilutes the manure nutrient concentrations and increases transportation costs during land spreading, by as much as 25 to 30% (Barrington 2000). The value of manures, as produced on the farm, is summarised in Table 6.

Table 5. Manure nutrient loading of world tillable land (1990) (Statistics Canada 1990; Encyclopedia Britannica inc. 1999).

Province or Country	N Kg/ha/yr	P Kg/ha/yr	K Kg/ha/yr
Canada	9.4	2.4	7.9
- Maritime	25.6	6.6	20.2
- Québec	31.6	8.4	23.6
- Ontario	23.0	6.0	18.0
- Prairies	6.2	1.5	5.4
- B.C.	25.7	6.3	22.5
China	57.2	16.2	35.8
Denmark	49.5	14.0	31.2
France	27.8	7.2	21.6
Germany	40.4	10.6	30.5
Japan	78.5	23.2	43.1
Spain	15.4	4.2	10.5
USA	10.3	2.7	7.8
Argentina	8.5	2.0	8.0
Brazil	13.3	3.3	11.5
Chili	18.8	5.0	14.1
Peru	15.4	4.0	12.0
Corn requirements	100-150	20	50
Cereal requirements	50-100	15	30

Table 6. Typical manure nutrient values and management costs.

Manure	Storage cost	Handling Cost	Spreading Cost	Total Cost	Nutrient value[1]
Dairy cow	$55.00	$25.00	$55.00	$135.00	$80.00
Grower hog	$2.60	$0.50	$2.50	$5.60	$ 4.25
Laying hen	$0.80	$0.25	$0.45	$1.50	$ 0.50

[1]The manure nutrient value assumes that 80% of the nitrogen is conserved during land spreading. The manure is transported over a distance of 1 to 2 km. Costs and values are expressed per animal.

To minimise the costs of spreading manure, enterprises have been using two techniques:

1. use equipment which minimises the spoilage of water in the barn and produce manures of lower water content in the range of 88 to 90%, for swine and cattle respectively;
2. concentrate manure solids by removing water;
3. removing some of the volatile elements such as carbon and nitrogen.

These intensive enterprises generate gases know to produce odours (Sweeten 1995), greenhouse effects and acid rain (Oosthoek and Kroodman 1990). Several of the 300 or so gases emitted by manure are detectable at concentrations of one part per billion. Therefore, large distances are required to dilute these below their detection threshold at the property lines

(O'Neil and Philip 1992). But, most system concentrating manure nutrients also reduce manure odour emission. Nevertheless, manure odours induce a psychological response from human beings and completely attenuating odours may still leave complaining neighbours. The livestock industry must therefore improve its public image now that it has the technology to environmentally manage its manures.

CONCENTRATING MANURE NUTRIENTS AND REDUCING ODOURS

Large volumes of manure can be environmentally managed by disposing of them on a land base where all nutrients will be up-taken by the crop within the growing season. To achieve this, manure nutrients must be concentrated as most manures are handled under a liquid form, indicating that their water content is at least 90%. Several solutions have been introduced to concentrate manure nutrients:

1. mechanical separators consisting of a screen, a press or a centrifuge, removing the large particles of solids from the manure slurry;
2. chemical systems adding a flocculent to the manure, preferably after being mechanically separated. The chemicals agglomerate the manure solids which can then be removed by either gravitational precipitation, by pressurising into a filter press or by centrifuging;
3. aerobic (biological) treatment where microbes degrade the manure solids, volatilise some of its carbon and nitrogen, and form a sludge concentrated in phosphorous;
4. anaerobic treatment where the microbes volatilise mostly carbon and produce a sludge rich in nitrogen and phosphorous;
5. ultra filtration where membranes are used to remove solids and salts from manure slurries once mechanically separated;
6. drying where the water content of the manure is reduced to 5% or less.

THE EUROPEAN TECHNOLOGIES

Such modern treatment systems are emerging in Europe, where livestock densities are high and phosphorous must be spread under limited rates. Membrane filtration accompanies the anaerobic and aerobic treatment of the systems to complete manure separation, and the liquid produced from the treatment is clean enough to be dumped directly into a watercourse. A Denmark group (BIOSCAN A/S inc., Table 7) is presently promoting such a system offering a minimum capacity of 41 m^3 per day, a capacity equivalent to the manure production of 5000 grower hogs. To resolve the complex problem of operating such a system, they promote the purchase of a such a system by a group of farm enterprises along with a service contract. This system is said to treat swine manure at a net cost of $8/$m^3$. This net cost involves subtracting the system's capitalisation and operating costs from the benefits equated to the lower transportation costs and the conservation of manure nutrients.

Table 7. Efficiency of BIOSCAN A/S Separation Technology (BIOSCAN A/S 2000)[1].

Fraction	Mass	N	P	K	Solids
Solids (compost)	2.9% (1.2 tons)	41.0% (83 kg)	10.0% (6.2 kg)	2.6% (3.1kg)	17.2% (0.42 t)
N concentrate	5.1% (2.1 tons)	82% (168kg)	--	--	--
P concentrate	16.2% (6.6 tons)	--	33% (19.8 kg)	84% (99 kg)	--
Water	68.6% (28.0 tons)	0.03% (0.06kg)	0.3% (0.5kg)	2.7% (2.24kg)	--
Biogas					840 m^3
Total Output (over input)	92.8% (37.9 tons)	123% (251 kg)	43.3% (26.5 kg)	89.3% (104.3kg)	--

[1]Input daily : 40.8 tons at 6% TS, with N, P and k content of 5, 1.5 and 2.9 kg/ton. Percentages calculated from process description (BIOSCAN A/S, Odense, Denmark)

In France, the accent is still focused on nitrogen pollution. The government has therefore encouraged the development of treatments scrubbing nitrogen and separating the solid and liquid fractions. To achieve this objective, several consulting groups have applied municipal wastewater systems to manure treatment. These systems are producing, unfortunately, three by-products, which for the typical livestock enterprise, complicate the handling of their manure (Table 8): a solid fraction to store inside a building, which can be composted; a thick sludge stored in an exterior concrete tank; and a separated liquid with a high salt content, but poor in N and P (Barrington 1998). Such systems use techniques of primary separation and of aeration to achieve their means, at a cost of $8 to $10/$m^3$.

Table 8. Efficiency of French Separation Technologies (Barrington 1998).

Fraction[1]	Volume	N	P	K
Solids	6%	8%	15%	6%
Sludge	25%	20%	70%	26%
Remaining liquid	62%	2%	15%	62%

[1]Fraction extracted by municipal systems developed for the treatment of swine manure.

Another French group has developed a treatment using flocculation and mechanical pressure separation. It produces a cake containing the solids (14% of the volume; 50% of total N (TN); 90% of total P (TP) and 10% of total K (TK)) and, a liquid fraction (96% of the volume; 50% of the N; 10% of the TP and 90% of the TK). This liquid fraction is still too concentrated be released directly into a watercourse. Again, the cost ranges from $8 to $10/$m^3$. Finally, a third French technology uses lime to precipitate manure solids and produce a sludge as well as a separated liquid. This system also costs $8 to $10/$m^3$ of manure treated.

Because no water reducing techniques are encouraged in the barn, the separated liquid fractions contain a very large portion of the TK, which removes some of the transportation advantages of the separation.

THE CANADIAN TECHNOLOGIES

Since the early 1970s, manure treatment systems have been developed and tested in British Columbia, Québec and Ontario. Such investigation was triggered by the rapid expansion of the swine and poultry industry. At that time, manure nitrogen scrubbing was the main objective as nitrogen was the primary element limiting the land application of manure. British Columbia researchers (Lo and colleagues at UBC since 1980) have been innovative in introducing the sequential batch reactor. In Ontario and Québec, mesophilic anaerobic treatments and oxygen ditches have been tested (Ogilvie and colleagues at the McGill and Guelph University, from 1975 to 1985). The Québec Ministry of Environment tested a municipal wastewater treatment facility in the Beauce County in the early 1980s to abandon it three years later because of the cost and complexity of operating such a system. These first systems where generally as efficient as those found today in France. They were not widely accepted because of their high operating costs.

Manure treatment was not a pre-occupation in Canada from 1980 to 1995, because the livestock population had stabilised. In 1995, many swine producers saw interesting and large market opportunities in Asia and the renewed expansion of the swine industry, for the second time, had to re-address manure treatment. This time, manure odour and phosphorous were of prime interest. Soils being richer in phosphorous, manure application rates were now limited by this element. Agriculture Canada (Massé and colleagues since 1995) promoted the use of two psychrophilic anaerobic sequential batch reactor operated in sequence for the treatment of livestock manures on the farm. The system is presently under trial on two Canadian farms. Such installation can treat swine slurries at a cost of approximately $\$5/m^3$, for an operation with an annual capacity of at least 3 600 finished grower hogs. The operational costs are low, energy being required for the transfer of manure only. Nevertheless, a technician visits the livestock operation once every two weeks to feed the digesters and verify the performance of the system. The treatment is effective in reducing manure odour during storage and in producing a sludge with concentrated levels of N and P.

This concept had been previously investigated by many American researchers who demonstrated that the use of aerobic and anaerobic treatments, in sequence, can reduce fecal coliform levels by a factor of 1000, COD and suspended solids (SS) by 93 and 98%, and nitrogen by 99%.

The CRIQ (Centre de Recherche Industriel du Québec) developed a swine manure treatment facility called BIOSOR inc. (Table 9) consisting of:

1. a separator removing the large manure solids;
2. an anaerobic tank for the primary settling of more manure solids;
3. a bio-filter for the treatment of the digested liquid which is also used to reduce the odours produced by the piggery;

4. a membrane filtration system for the final scrubbing of the manure liquids and their disposal into a water course.

Table 9. Efficiency of BioSor inc. Separation Technology (BioSor inc., 2001).

Fraction[1]	Volume	N	P	K	Solids
Solids Sludge	N/A	3.8% (4.3 kg/ton)	2.1% (2.4kg/ton)	0.9% (1.0 kg/ton)	(11%)
Discharged Liquid	N/A	(365mg/l)	(52 mg/l)	N/A	(225mg/l)

[1]Fraction extracted by municipal systems developed for the treatment of swine manure.

BIOSOR inc. is presented especially as a biofilter that treats manure liquids treated by settling in an anaerobic tank. Such a system requires an investment of $7.50/m^3 for an operation finishing at least 5 000 hogs annually. The operation of the system represents an additional cost of at least $2.50/m^3 and the expertise of a technician on a regular basis to verify the performance of the complex pumping and control systems. The long-term maintenance of the bio-filtration system is also questioned.

Atrium is another treatment plant located near Farnham, in the Province of Québec. It uses high efficiency dryers to convert manure slurries into dry organic fertiliser. It will be in full operation by spring 2001. Livestock producers can deliver their manure to the plant and paying a tipping fee of $4.50/m^3. Atrium plans to sell this dry fertiliser at a cost valued at $10.00/m^3 of raw manure slurry delivered. Atrium claims that there is an important market for such dried organic waste.

Purin-Pur is another Québec system (Table 10) using membrane filtration and operating on a farm. The system consists of initially removing all large particles using a mechanical separator. Then, the liquid is treated through the membrane system, where the pressure is automatically controlled to regularly start the membrane flushing operation. The system represents an investment of $5.00/m^3 for an operation producing between 3 000 and 4 000 finished hogs annually. The operation costs of $2.50/m^3 must be added to this investment cost, for a total cost of $7.50/m^3. This system does not control odours.

Table 10. Efficiency of Purin-Pur 2500 Separation Technology (Consumaj 2001).

Fraction[1]	Volume	N	P	K	Solids
Solids	2.0%	29.3% (2.2g/l)	12.8% (6.6g/l)	4.9% (7 g/l)	14.3% (22.7% dm)
Sludge	53.8%	68.6% (0.6mg/l)	87.2% (2.2 g/l)	94.9% (4mg/l)	85.5% (5.2%)
Discharged Liquid	44.4%	2.1% (87mg/l)	0.01% (0.7g/l)	0.2% (12.6mg/l)	0.2% (181mg/l)

[1]Fraction extracted by municipal systems developed for the treatment of swine manure.

LOW COST TECHNOLOGIES

Canadian livestock enterprises are located in regions where manure is not produced in surpluses. Thus, many livestock enterprises can benefit from simple solutions such as a preliminary separation. For agricultural purposes, such separators should not require an important level of energy to dry out the separated solids. Increasing the dry matter content over 15% does not change the volume to transport, only the weight. Barrington (1999) found that the solids' dry matter content influenced their bulk density as follows, for swine manure:

$$\text{Bulk density } (10^3 \text{ kg/m}^3) = 1.44 - 0.031 \text{ (dry matter content, \%)}$$

For a cost effective separation system, the enterprise must treat the manure from an annual hog finishing operation of at least 5 000 hogs, or the equivalent. The cost of separating is on the order of $1.50/m^3 while the separation effectiveness depends on the feed type and wastage, the dilution level of the manure and the separator screen size. Generally, 30 to 40% of the solids can be removed, while reducing the volume of manure by 10%.

CONCLUSION

Present intensive livestock operations are adopting new technologies allowing them to manage their manure with minimum environmental impact. These technologies consist of concentrating manure nutrients while, in many instances, reducing manure odour emissions. Nevertheless, these new technologies have increased the management cost of the operations, and this cost depends on the size of the enterprise. Large intensive enterprises are in better position to use such technologies more effectively and economically. The cost of improving manure management in regions of high livestock densities or for intensive livestock operations range from $1.50 to $10.00/finished hog or per m^3 of manure produced.

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COMMUNICATIONS AND MEDIATION AROUND ENVIRONMENTAL ISSUES

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ABSTRACT

Economics is the study of the optimal allocation of resources to maximise the welfare of people. The diverse desires of people include livestock products and environmental quality. Conflict over the relationship between livestock production and environmental quality requires communication and mediation to develop socially desirable policy. This paper includes an economics perspective on policy development. Observations from the development of the pig farming sector in North Carolina are offered to illustrate the need for communications and the role of mediation.

INTRODUCTION

The author is not an expert in mediation and his experience in communication is that of an agricultural extension specialist rather than a public relations expert. His perspective on this topic is based on seventeen years as an extension and research economist in North Carolina working with and studying the pig farming sector. The author is currently immersed in economic evaluation of technology and policy regarding pig farms and environmental protection.

Currently evolving policy regarding the relationship between pig farming and environmental quality is the primary determinant of the economic viability of the pork sector in North Carolina. Agribusiness accounts for roughly 24 percent of North Carolina's economy and pigs account for about 20 percent of cash receipts from farming in North Carolina. The future of the pork sector in North Carolina has strong implications for the income, employment, and property tax base in several counties in eastern North Carolina. Clear communications, mediation, and rational policy development are needed.

A few themes emerge in this paper. First, the notion of 'socially optimal' policy is presented and used as a reference point for communications and strategy. Policy seems to be the guideline for satisfying to the maximum extent possible, the many desires and needs of a diverse population. Another theme is that policy made under conflict and adversarial behaviour may be less rational and balanced than policy developed under more consensus-building conditions. Adversarial behaviour may include attempts to sway public opinion with strong allegations and propaganda. Adversarial behaviour may also include promotion of policy options that go far beyond the stated policy goals and may be punitive to the adversary, create long term power for the promoter, and create a source of revenue for the promoter and benefits for political allies. Pleas for 'science based' policy may arise in response to

rhetorical and political gains by an adversary. Communications and mediation can play roles in shifting the policy-making process toward consensus building and toward rationality.

AN ECONOMIST'S VIEW OF OPTIMAL POLICY … AND CONFLICT[18]

Policy regarding environmental management and livestock production can be evaluated in the framework of welfare economics. This section presents a very brief overview of the basic economics of social choice and a few basic conditions for social welfare maximising decisions.

Society's preferences can be represented as a social welfare function comprising the combination of individuals' preferences. A simple social welfare *isoquant* representing various combinations of environmental quality and economic activity that are equally desirable to society is presented in Figure 1. The curvature of the isoquant depicts the idea that the marginal value of an additional unit of a good or service declines as the quantity consumed of that good increases. A second welfare isoquant is also presented in Figure 1. All combinations of goods and services on the higher welfare isoquant are preferred by society to those on the lower isoquant. Individuals and society seek to maximise their level of welfare.

Individuals' and society's maximum welfare is constrained by the endowment of resources available and by the technology available to convert those resources to desirable goods and services. The maximal combinations of economic activity and environmental quality that can be produced are represented in Figure 1 as a technical possibilities curve. The curvature of the technical possibilities curve depicts the idea that the marginal cost of producing another unit of a good increases as the total quantity produced of that good increases. The maximum obtainable level of social welfare lies somewhere on the technical possibilities curve. An upward and outward shift of the technical possibilities curve illustrates the effects of new, improved technology.

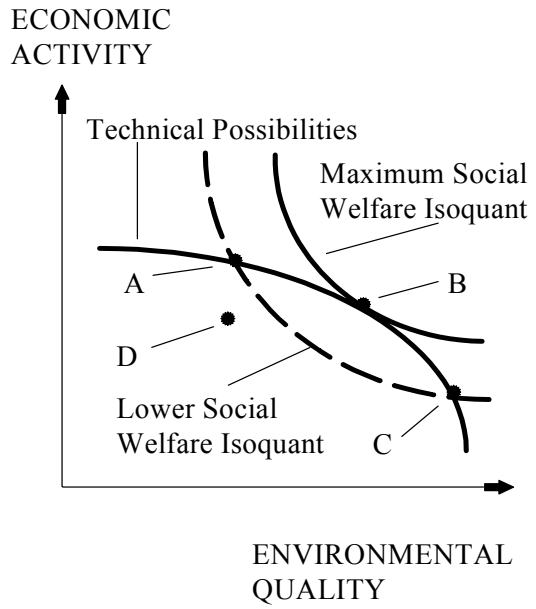
A combination of goods and services is <u>technically</u> efficient if it lies on the technical possibilities curve. Points A, B, and C in Figure 1 are technically efficient. A combination of goods and services is technically inefficient if it lies below the technical possibilities curve (for example, point D in Figure 1). Technical inefficiency means that society could have more of both goods and hence be at a higher level of social welfare.

A combination of goods and services is <u>economically</u> efficient if it lies on the technical possibilities curve and the maximum attainable social welfare isoquant. Point B in Figure 1 is economically efficient. A combination of goods and services is economically inefficient if it lies on the technical possibilities curve but below the maximum attainable social welfare isoquant or if it is technically inefficient (for example, points A, C, and D in Figure 1). Economic inefficiency means that society could have a higher level of social welfare by producing a different combination of goods and services.

[18] Earlier versions of this section of the paper were presented in Zering, 1999a, and 1999b.

Policy with respect to environmental management is based on social choices such as the one depicted in Figure 1. Most individuals and society as a whole would prefer a combination of environmental quality and economic activity that is technically efficient (point A, B, or C rather than point D in Figure 1). Education, design and performance standards, best management practices, regulation and enforcement, cost share and tax incentives are among policy instruments employed to encourage technically efficient production. Point B in Figure 1 is the socially optimal combination of environmental quality and economic activity. Point A in Figure 1 represents more economic activity and less environmental quality than point B. Point A may be preferred to point B by some individuals or communities with a stronger preference for economic activity. Similarly, point C might be preferred by individuals or communities with a stronger preference for environmental quality. Points A and C both result in a lower level of social welfare than point B based on society's preferences.

Figure 1. Socially Optimal Production



Source: Marra and Zering

Conflict arises in several ways. First, individuals or groups may have different preferences from each other and from society (for example, points A and C). Second, individuals or groups may have different perceptions of the technical possibilities or the current point of production (example, D versus B). In other words, they may not agree on the level of pollution or environmental quality currently being obtained or the change in economic activity that would be required to improve environmental quality.

Conflict can also arise from change. Change in technology, change in market structure, change in land use and residential development, and change in policy can all create conflict. Conflict arises from change when individuals perceive they have been made worse off or failed to benefit sufficiently while others have benefited greatly. A change is defined as welfare increasing if the value of benefits exceeds the costs or losses. Change that makes one or more people better off and makes no person worse off is called *Pareto improving*. Conceptually, welfare increasing change can be Pareto improving change if the beneficiaries of change compensate the losers in change. Two basic principles of environmental public policy design arise from this abstract model of social welfare maximisation. First, the value of environmental benefits derived from any policy or regulation should exceed the net direct and indirect cost it imposes. Otherwise, society is made worse off. A second principle is that any environmental benefit should be achieved at the lowest net direct and indirect cost possible. Otherwise, society could have enjoyed the same benefits at lower cost and have been better off.

MEDIATION IN CONFLICT RESOLUTION

One definition of mediation is "a dispute resolution process through which an impartial party (mediator) assists the parties in developing a voluntary settlement of their differences" (Public Issues Education (PIE) web page). A prominent example of a conflict resolution program is the Public Issues Education program of the Cooperative Extension System in the U.S.A. More information on this program is available at the following URL: http://www.ces.ncsu.edu/depts/agecon/PIE/resdir/introduc.htm

The process employed by the PIE program includes the following steps (Danielson and Perrin, 2000):

a. convene a group with representatives of citizens and private and public groups,
b. establish goals and procedures understood and agreed upon by all participants,
c. gather facts and information and dispel false perceptions to the extent possible,
d. establish and communicate each party's interest (rather than their position),
e. attempt to make decisions that all members of the group can support.

The process outlined above can take the form of mediation or an education program or a policy development program. In any case, it gives participants the opportunity to learn each others views, to gather facts, and to discuss options. The PIE program provides trained individuals to facilitate the process.

Dr. Steve Smutko in the PIE program in the department of Agricultural and Resource Economics at North Carolina State University reports mediation efforts in Craven and Beaufort counties in North Carolina regarding county policy development with respect to pig farms (Danielson and Perrin, 2000). Those county governments had imposed moratoriums on new or expanded pig farms in 1997 after a period of rapid growth and increasingly heated conflict over a proposed new farm. An Intensive Livestock Operations Moratorium Study Committee was formed in each county and asked to submit a consensus set of recommendations to their county commissioners on how the county should regulate livestock farms. Each committee contained representatives of agriculture, environmental groups, the public at large, and public health agencies. Among lessons learned, Dr. Smutko lists: the need to reach agreement within the group on the types and sources of information to be acquired, the need to talk to each group member prior to meeting to learn how an agreement might be reached, the need to develop a written charter of how the group will operate, and the need to develop a process for getting the recommendations implemented once they are delivered. The outcomes of the process in two counties include: Craven county accepted the committee's recommendations, adopted some of them and added some of their own, Beaufort county accepted the recommendations but did not pass an ordinance, many experts were brought before the committees and members received information and formed their own opinions, consensus was reached on the recommendations but could not be reached on all issues.

Mediation can play a valuable role in collecting and sharing information, in exploring the views and interests of diverse groups, and in reaching consensus on some set of points and recommendations. Mediation may not be able to overcome strong differences between groups and may not achieve consensus on some issues. Governments may or may not act on the

recommendations of mediation groups depending on factors such as the similarity of the mediation group's views to those of the general public, the legality and implications of the recommendations, and the government officials' understanding of the issues and the recommendations.

OBSERVATIONS ON COMMUNICATIONS

The author spoke to a few individuals who have been directly involved in the debate over pig farms in North Carolina and used their comments and his own observations to compile the following list.

Openness in communications and public relations is critical to maintaining the trust of the media and the general public. Early in the development of an issue, openness and a willingness to confront uncomfortable issues may avoid creation of an adversarial political conflict. In later stages of a conflict lack of openness creates suspicion and gives credibility to adversary's claims. Issues such as exposure to odour and the possibility of manure contamination of surface water or groundwater have been present in North Carolina since the number of large pig farms began rapidly increasing.

Fear of the unknown may be much worse and unbounded than knowledge of actual risks. Failure to communicate the risks clearly to the media and general public creates a void for fear to enter.

In periods of rapid change, existing technical standards and regulatory systems may be suddenly obsolete. It is a challenge for those directly involved in change to be actively engaged in expansion and to be initiating the dialogue to avoid conflict. As odour and water contamination fears became evident in North Carolina, some contract companies imposed voluntary minimum setback requirements for new farms. Nonetheless, a farmer that failed to meet their standard built a farm for another contractor and promptly became the defendant in a highly publicised nuisance suit. Similarly, the general statement that 'anaerobic lagoons do not leak' proved to be a point of mistrust for the pig farming sector. New standards requiring compacted clay liners for lagoons built in permeable soils were adopted in December, 1992 in North Carolina. However, one highly publicised claim of pig farm adversaries in 1995 was that 'half of the anaerobic lagoons were leaking at high rates into the groundwater.' This claim was based on a university study of a small sample of lagoons comparing seepage from unlined lagoons in sandy soil (built prior to 1993) to those with clay liners or built in soils with low permeability. This claim seemed to catch the pig farming sector in a false statement. After the governor ordered free well water testing of all wells within a half mile of a pig farm lagoon, and nearly 1,000 wells were tested, it was determined that 2 or possibly 3 older pig farms had contaminated neighbouring wells. One of those farms had an unlined lagoon in highly permeable soils and was determined to have contaminated several shallow wells within 250 feet of the lagoon. Another farm with an undersized overloaded sprayfield was determined to have contaminated a shallow well at the edge of the field. The sprayfield on a third farm was found to have contaminated a neighbouring well but that finding was contested. In general, the seepage from anaerobic lagoons (even the unlined lagoons in

permeable soils) seems to have no significant impact on well water in eastern North Carolina with a very few exceptions. Failure to communicate the possibility of contamination and the actual risk of a problem gave adversaries and a suspicious media group the opportunity to cast doubt on the pig farming sector.

On the local level, clear communication with neighbours about plans for new farms is critical. Dispelling fear of the unknown, giving neighbours the opportunity to voice concerns and ask questions are viewed as building trust and granting some control. In another highly publicised nuisance suit in North Carolina, a neighbour claimed to be very upset that the owners of the new farm had deceived her about their intentions. While complete openness may not overcome all objections, it eliminates an important source of mistrust and suspicion by the general public.

Once an issue becomes adversarial and public, and once the media become suspicious or adversarial, a few highly visible events can be used to create widespread public suspicion of the targeted group. In North Carolina in 1995, a Pulitzer Prize winning series of newspaper articles in a Raleigh newspaper was followed a few months later by the spill of the lagoon contents at Oceanview farm into the New River near Jacksonville. Pictures of the ruptured dyke of the former lagoon circulated around North America. The spill killed about 5,000 fish valued at about $6,000. Nonetheless, it provided the highly visual 'smoking gun' that adversaries needed to illustrate their claims that lagoons are a threat to the environment. A few months later, millions of fish (primarily menhaden) died in the Neuse River estuary near New Bern. Pig farm adversaries said 'we know it's the pigs' and the media gave the issue prominent coverage over the next several months. A national magazine, a national television news tabloid program, a northeastern U.S. newspaper chain, and eventually a senate agriculture committee minority paper came to refer to 'pig farm lagoon spills and the associated massive fish kills in North Carolina'. After five years and millions of dollars of water quality research, there is still no indication that any pig farm lagoon spill had any effect on fish kills in the Neuse River.

Once an issue becomes public and adversarial, it is important to provide timely and factual responses to allegations. This process becomes very expensive if the media are suspicious of your group and are sympathetic to your adversary. After the events of 1995, a state 'Blue Ribbon Panel' report in 1996 and new legislation in each of those years, a group of pig farming companies and others formed Farmers for Fairness to launch a publicity campaign to counter their adversaries' success in shaping public opinion. At considerable expense, they purchased television, radio, and newspaper advertising to point out that pig farms had very few spills that reached surface waters in the state and that permitted municipal discharges contributed tons of nutrients to the state's rivers each year. This campaign seemed to succeed in raising public doubt about the claim that 'it's the pigs'. The suspicious media group, adversaries and some state agencies attacked the campaign as funded by corporate hog producers and therefore lacking credibility. New laws regulating pig farms continued to be adopted including a moratorium on new and expanded pig farms that remains in effect today. Impressions created in 1995 have not been completely dispelled. A '500 year flood' following a series of hurricanes in 1999 produced new 'visuals' in North American media of

drowned pigs in North Carolina and calls for new regulatory action. Many of the general public and elements of the media in North Carolina still view pig farms with suspicion.

Professional public relations based on open communications, rapid knowledgeable accurate response to new stories, regular releases of accurate positive news, and an on-going relationship with the media, political leaders, adversaries, and other interest groups have proven very constructive for pig producers in North Carolina in recent years.

CONCLUSIONS

The economics perspective on socially optimal policy development raises a few goals for communications and mediation. First, there must be clear understanding of the facts including the current level of environmental quality and economic activity and the effect on environmental quality and economic activity that might arise from a change. Communication and mediation are also useful in exposing people to the views and interests of others. In some cases, mediation can result in consensus on facts and on policy changes.

The economic approach also defined change as socially desirable when benefits are valued more highly than costs and Pareto improving when one or more are made better off and no one is made worse off. An implication of this definition is that to achieve socially acceptable change, maximise the number of people who view the change as beneficial, maximise the value of net benefit they perceive, and minimise the number of people who perceive the change as costly. Communications can play a role in making people aware of the benefits, in discovering the costs that people perceive and taking steps to minimise the costs or compensate those bearing costs.

The potential for mediation declines and the required investment in mediation and communication increases as issues become more polarised. Avoid polarisation by confronting issues, building policy, and building consensus and trust through communications. Adversarial policy making seems much riskier and less rational than policy making through mediation and consensus.

In some cases polarisation is inevitable for adversaries so the conflict becomes a battle for public perception and political support. Trends in society can create new potential for deep conflict where there was less significant or no conflict previously. Where change is of sufficient scale and impact beyond its immediate location, unexpected adversaries may join the fray. In times of dramatic change, consensus building and conflict avoidance become more important …although easily overlooked. Past peace is not a reason to ignore establishment of good communications.

The required investment in communication and mediation increases as public perception is shaped/hardened. Fear of the unknown can be far more destructive than knowledge of uncomfortable facts. Once the pariah factor is established, accusations are cheap to tack on and expensive to debunk or disprove. A ‘grain of truth’ to accusations seems sufficient to extend fear and suspicion. These are among strong arguments for investment in professional

public relations and openness in communicating with neighbours, the general public and the media.

In summary, regular, knowledgeable, accurate communications appear to be a necessity in development of rational equitable environmental policy. The mediation process offers a mechanism for orderly discovery of facts, exchange of views and interests, and the establishment of consensus on some points. Agriculture and most other groups in society must be prepared to communicate with political leaders, the general public, and the media in order to protect their interests in the policy making process and work toward socially optimal policy.

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STRATEGIES FOR SUCCESS

TOP 10 PROFIT DRIVERS IN U.S. PORK PRODUCTION

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ABSTRACT

As I view them, the top 10 profit drivers in the U.S. Pork Industry are:1) cost of production; 2) productivity and throughput; 3) structure of your marketing program; 4) genetic supply; 5) sustainability of your system; 6) quality of labour force; 7) outside forces (animal welfare, environment, etc.); 8) production system design and flow; 9) access to information and knowledge; and 10) continually challenging the system.

INTRODUCTION

Compiling a list of 10 top profit drivers is an interesting experience. If you asked every producer and industry advisor in the U.S. to compile their top 10 list, I doubt that you would ever get two lists that are identical. I asked several people for their top 10 list and will include a few of my favourite responses before providing my composite list. Some of the responses only listed 4 or 5 main profit drivers while others listed 10 drivers, but many of the drivers could have been subheadings of the main drivers.

Favourite Response 1: This was my favourite "inside the farm gate" response.

1. Weight of top hogs (excluding cull weight) sold/sow/year
   (essentially a measure of a system's throughput of quality product)
2. Feed ingredient procurement.
3. Feed manufacturing and delivery costs ("Appropriate" & Real-Time Formulation)
4. Carcass value - Genetic potential for carcass value.
5. Marketing agreement. (i.e. how you are paid & constraints or lack there of in how your product generates value including carcass windows, sort loss, other premium structures or fixed premium arrangements, etc.)
6. Debt load and overhead costs
7. Marketing product to maximise system margin per year. (i.e. optimising potential of marketing agreement, sale weights, etc.)
8. Operating cost management:
   a. Utilisation of nutrients (feed) delivered to the farm.
   b. Facility costs per pounds sold.
   c. Labour cost per pounds sold.
9. System location
   a. Proximity to slaughter
   b. Proximity to feedstuffs
   c. Proximity to other pigs
10. System design (i.e. production flow)

Favourite Response 2: This respondent listed some "inside the farm gate" issues and several "outside the farm gate" factors that could influence whether you are in business or not in the future.

1. Low cost producer -- two major factors influencing this are (a) efficient use of fixed assets (i.e. facility throughput) and (b) maximise production efficiency (i.e. p/s/y, f/g, etc.).
2. Labour availability
3. Environment -- cost of compliance will continue to increase but also legal costs associated with lawsuits, etc.
4. Public perception -- if the groups that are preparing to start filing lawsuits against all "pig factories" are successful, this could have a big impact on long run profitability for the industry.
5. Animal welfare – move to outlaw gestation crates and/or farrowing crates could greatly reduce potential for future profit in industry
6. Health/diseases -- obviously I'm not a vet so the other guys will tell you what is important here, but the fact that there always seems to be something "new" popping up will continue to make this an important issue.
7. Bio-security -- this will be an issue for health reasons at the production level but also increasing food safety concerns will lead to "trace back" requirements so producers will need to have a tight control of this area.
8. Information/knowledge -- we are increasingly seeing how large crop and livestock farms gain advantages when buying inputs and selling crops which is do to both economies of size but also knowing the right people and having more/better information.

Favourite Response 3: This was my personnel manager response.

1. Good people - find them, retain them.
2. Cheap feed, fed properly
3. No PRRS
4. Sharing information (i.e. records, marketing, etc.) so you know if you are competitive

Favourite Response 4: An excellent "What is not important!" response

Listing the top 10 profit drivers is a tough topic! I might take a bit different tack and try to list some things that producers erroneously believe to be important and are not. Once you know the NOT list, flip it over and you have 10 of the top profit drivers.

Top NON-profit drivers:

1. Growth promoters in feed in the finisher
2. Holding pigs until all reach some specific break point on weight to minimise sort loss
3. Confusing risk management of marketing with profit assurance
4. Using heaps of vaccine in the belief that it is 'insurance' somehow
5. Buying on personal relationship bases rather than market price discovery (especially feed)
6. Borrowing money from vendors (i.e. feed, equipment, veterinarians, etc.) through various accounting methods or just charge accounts

7. Hiring and firing at will because anybody can work in a pig barn

Favourite response 5: I call this the accountant response.

1. Feed cost
2. Feed cost
3. Feed cost
4. Feed cost
5. Feed cost
6. Feed cost
7. Facility cost
8. Facility cost
9. Labour cost
10. All other costs

These responses all provide different, but excellent thought provoking ideas on the most important profit drivers in the U.S. Industry. Several common themes can be found in all lists and are the cornerstones of the top profit drivers (in my opinion). In reality, a great portion of the difference in profitability between different production systems can be explained by the difference in cost of production and throughput (The top 2 profit drivers in my list presented below). Most of the other 8 items on my list are support items to allow you to attain low cost of production and high throughput.

1) You must be a low cost producer (attack costs vigorously)
2) You have to be good at pig production (throughput)
3) Structure of your marketing program
4) Genetic supply (health/disease susceptibility/carcass value/meat quality)
5) Your system must be sustainable (part of a system, facilities, markets, not overly dependent on outside capital, etc.)
6) People need to like working for you
7) Outside forces (animal welfare, environment, etc.)
8) Production system design and flow
9) Information/knowledge
10) Challenge the system – be an early adopter of technology

WHAT ABOUT MARKET PRICE?

"What about market price? Isn't it becoming more important than cost of production?" The answer is NO! Market price has received considerable attention in the last few years and rightfully so. I don't have to remind anybody that we recently experienced the lowest prices in 60 years; however, has cost of production or market price been the long-term winner? To help answer this question, my colleague, Dr. Steve Dritz, evaluated Agrimetric summaries to compare the impact that market price or cost of production has on net profit. Agrimetrics is a business firm that conducts cost analysis for many of the major pork producing companies in the U.S. to allow them to compare their costs with other producers in the group. The results of Steve's analyses are shown in Figures 1 and 2. Market price only explained 15% of the

difference in net profit between the firms for the 2-year period of the analysis. Cost of production explained 65% of the difference in net return. Analysis by agricultural economists of several other data sets (Iowa Enterprise records, Kansas Farm Management Data) reveals similar results: Cost of production is king. This does not mean that market price is not important. The relative importance of market price depends on your equity position. Several studies have demonstrated that use of futures or packer contracts to control the price received for your pigs will not increase the long-term price. If this is the case, why do some producers need contracts and futures? If a producer does not maintain a great enough equity position that they have leeway to allow loans when prices are low, they must protect themselves from down markets with contracts or through the futures market. The exact level of equity needed to allow a producer to ride through lows in the market may be variable, but is probably in excess of 50%. Two important points should be made about protecting prices with futures or a packer contract. First, your goal should not be an attempt to increase market price. Rather, you should be using the protection to limit losses. The second point is do not base your decision on whether to use price protection on another producers decision. The other producer may have an entirely different equity level, risk tolerance, and lender agreement. Your decision has to be made considering the facts surrounding your business.

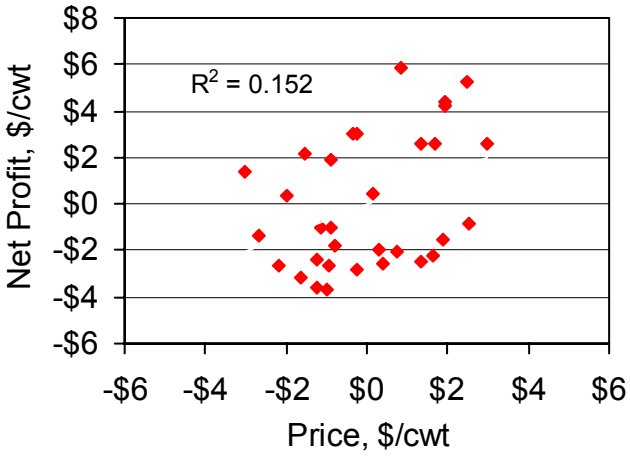

Figure 1. Relationship between market price and net profit.

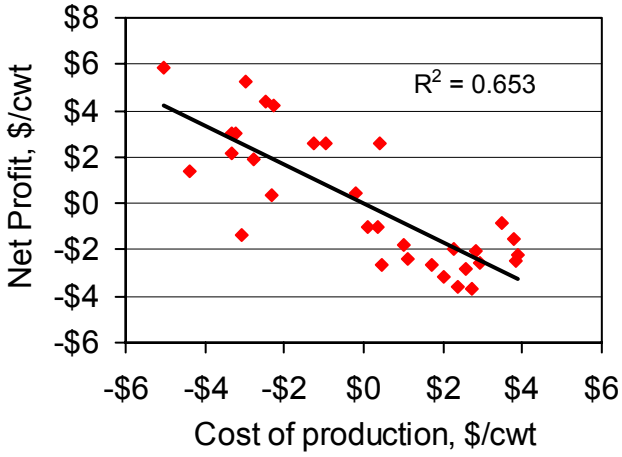

Figure 2. Relationship between cost of production and net profit.

If people are better able to separate their product from the competition and create a higher value product, price received may rise in importance in the future. This day will probably come. However, systems that are trying to capture higher value still have to prove their ability to do so. The important point to remember is: while striving for higher prices is don't forget that you still need to be a low cost producer

REASONS FOR MY TOP TEN PROFIT DRIVERS

1. Cost of production

The importance of cost of production has been downplayed in recent years with increased discussion about market price, packer contracts, pork quality, and retail value. Some leading advisors to the swine industry have discussed that continual focus on costs alone will lead to a spiralling down in the producers share of the retail value of pork. Also, products are often sold with the notion that they will increase cost slightly, but will enhance returns thus increasing net profit. Certainly, these technologies can exist. For example, we have added fat to some swine diets in the field to increase daily gain, market weight, and, thus, market value. At the same time, feed cost and cost of gain also can increase slightly, but not as great as the market value. These examples do exist, but they are few and far between. Approach offers of enhanced return with slightly higher cost with great scepticism. Usually, cost is increased with insufficient return to offset the higher costs. Bottom line is that lower cost has almost always won in the past and will continue to separate the profitability of producers in the future.

The steps to take in lowering cost of production sound rather simple, but many producers do not follow them to the degree necessary. First, every cost must be clearly and accurately documented. Second, the costs need to be benchmarked against others in the industry. Third, each cost centre must be fully explored for ways of reducing expense. Obviously, the items that have the greatest opportunity for increased profit should be attacked first. Remember the "accountant" response (Favourite response 5) listed above when tackling cost. Feed cost is approximately 60% of cost of production, facility cost is 20%, labour cost is 10%, and everything else is the remaining 10%. Because other costs are only 10% doesn't mean they are not important, just keep these percentages in mind when deciding where to spend your greatest energy.

2. Throughput

Another major point to make concerning lowering cost is productivity or throughput. In the modern swine industry, it is virtually impossible to reach a low cost of production without excellent productivity. Increasing productivity spreads the fixed costs over more pigs or pounds to lower per unit cost of production.

You have to be careful not to focus too much on a single measure of throughput or productivity. Focusing on a single measurement, like pigs/sow/year, can lead you to make decisions that reduce the overall profitability of your swine operation. For example, selling low productivity sows or those with a late return to estrus will increase your pigs/sow/year; however, total pigs produced from the system will also be reduced if you do not have another sow or gilt ready and able to replace them in the production flow. So, what is the best way to measure throughput on a whole farm basis? The answer to this question will depend on the type of production system. For example, if you produce weaned pigs as part of a system, the answer is probably not number of total pigs produced in the year, but rather a measure of the consistency of production of high quality pigs (i.e. > 3.6 or 4 kg without defect).

With any measure of productivity, you have to closely consider any increased cost that comes with the increased production. Although productivity is very important, spending extra money

in an attempt to increase productivity should be done with great care and consideration. However, for many production systems, increased throughput can be found without a lot of extra cost. An example is finishing barn utilisation. In the U.S., we have some production systems that market pigs from the finishing barn over an extended period of time in order to minimise sort loss and increase gross value of their pigs. The problem is that this will reduce the total pounds of pork produced by the production system. Producers forget that the goal is not to minimise sort loss, but to maximise profit from the production system.

3. Structure of your marketing program

The allowable weight window, cost of sort loss for heavy and light pigs, method of determining base price, and how premiums or discounts are applied all have a major impact on profitability. If the allowable weight window is wide, the number of pulls needed from a finishing barn is greatly reduced and the total weight marketed out of the barn is increased. The cost of sort loss also alters the marketing scheme. If sort loss is very expensive for light pigs, market weights are increased and an alternative market must be found for the slow growing pigs. If sort loss is expensive for the heavy pigs, total weight marketed from the barn is reduced because pigs have to be sold lighter. If sort loss is expensive on both ends, your competitiveness compared to another producer with a wide sort window can be severely hindered because it will force reduced throughput for your facilities because you will have to market over an extended period of time. The method for determining base price is a big concern in the U.S. at the current time. The proportion of pigs being priced on a formula based on some open market continues to increase. The problem is that the number of pigs that are actually sold on the open market continues to decrease. On some days, a small number of pigs sold on the open market will determine the value of all the other pigs being purchased on that same day. Some producer groups determine their price based on the average of prices paid during the previous week. Some smaller producers have really used this to their advantage and pushed marketings forward in a declining market and by holding pigs for an extra week during a rising market. Finally, the applicable premiums and discounts can have a big impact on decisions made in the production system. For example, some of our largest producers have contracts with their packer to sell pigs on a live weight basis. While you can argue that the packer knows the quality of their pigs well enough that they don't have to waste the time and money in determining all of the carcass parameters on these pigs, it greatly changes the decisions made by the production system. If these systems are examining a nutrient change or production decision that would increase carcass yield or improve backfat, their decision is much different than if they were being paid on a carcass weight basis or subject to premiums or discounts for backfat.

4. Genetic supply

The genetic supply is key for two very important reasons. First, genetics set the baseline for production (ADG, F/G, pigs/sow/year, etc.) and carcass parameters (backfat, loin area, yield, meat quality, etc.). For example, if two boar lines produce offspring with a 6% difference in ADG and 5% difference in F/G, the profitability of the production system is greatly altered. Unfortunately, few of our producers have the necessary data to analyse various boar lines and make an informed decision.

The other reason that genetic supply is important is that most diseases introduced into the herd come from upstream sources through their genetic supplier. Sure there are other methods of disease transmission, but vertical transmission of disease from the genetic supplier is the predominant way that new diseases find their way into a production system. The genetics also dictate the relative response of the pig when presented with a disease.

5. Sustainability of your system

By sustainability, I am referring to your ability to adapt to changes in market conditions, packer matrixes, feed prices, or other factors. As an example, if you are highly leveraged without a packer contract, your farm probably won't have the capital necessary to weather an extended period of low market prices (like the fall of 1998). Do you have the type of facilities that will allow you to adapt to future changes in the industry that are hard to predict. For example, if you had to produce antibiotic free pigs, would your facilities and production flow allow you to do this? Does your production flow allow you to apply new technology as it is introduced? If a new product was introduced to the market that increased net profit by $3 per pig when fed for only the last three weeks before market, would you be able to do this in your system or do the number of feed lines or groups of pigs in your facility limit your ability to capture all of the profit? A few of our producers have recently discovered that they are at an economic disadvantage because their system will not allow them to capture the value of Paylean, a beta-agonist recently introduced to the market in the U.S.

Another part of sustainability is whether you are part of a system. It is difficult to achieve some of the advantages of size to low costs and negotiate prices without being part of a system or part of several systems. Numerous examples could be given, but I will use one of our producers in Kansas as my example of somebody that leverages system involvement as an individual, relatively small producer. This individual owns one of eight shares in a sow unit in order to receive 600 weaned pigs every eight weeks. Joining this system allowed him enough scale to achieve all-in, all-out production, split sex feeding, phase feeding, and enough pigs to market semi-loads at market. This system also allows him to compare his production numbers to others in the group for continued improvement. The second system that he joined was to purchase inputs, which gave him the necessary scale to lower his costs. The third system that he joined was a marketing group that has negotiated a higher base price and bigger sort window than he was previously receiving on his own.

6. Labour

Many producers remaining in the swine industry are large enough that they have to rely heavily on hired labour. The importance of a high quality labour force cannot be over-emphasised. Many of the points that have been made above concerning throughput and low cost of production are not achievable without a high quality labour force. Because unemployment is low for much of North America and employees are difficult to find, you have to develop a reputation as the type of farm where people like to work. A good reputation is necessary to attract high quality employees and to retain them once they are on the job.

7. Outside forces can have a major impact on your profitability in the future

Although we often want everything to be under our control, some things are not. The swine industry is facing some very serious issues from outside forces that will impact your profitability and may dictate whether or not you stay in production in the future. A major change in animal care regulations (e.g. banning of gestation crates) may require changes that are not economically feasible or practical for your current production system. The cost of environmental compliance due to real or perceived problems also will cause some producers to exit the industry. The precaution that we must take as producers in the swine industry is to adhere to the highest standards possible concerning animal welfare and the environment to reduce the potential reasons for new regulations.

8. Production system design and flow

The reason that the design of the production system is important is because it dictates the ability of the system to adopt technology, achieve high throughput, and manage disease problems. For example, can you adopt simple technologies like split sex or phase feeding. For larger systems, advantages can be gained by filling sites or barns with a single sex in order to have the gilts on feed for 7 to 14 days longer than the barrows without sacrificing barn utilisation. The design of the system also influences the amount of disease that is transferred from one group of pigs to the next and your ability to remove a disease from the production system without excess expense.

9. Information and knowledge

The quality of information collected within your production system and your access to information and knowledge from others is a major driver of profitability. High quality information is essential to quantify your costs and throughput. Access to numbers from others is essential to know which of your cost or productivity measures need to improve. Also, as a greater and greater portion of practical, production research is being conducted on a confidential basis, your ability to access the information becomes key. The information can be accessed in two ways. First, many producers have joined systems that support their own production research. Second, either yourself or somebody else in your system has to build the relationships with people in other systems to share information. One of the reasons that some people don't have access to proprietary information is that they are not seen as having anything to reciprocate in exchange.

10. Challenge the system

The most profitable producers or production systems that I know are always challenging conventional wisdom. Instead of just accepting their current costs or productivity, they are always exploring new ways to improve their situation. They challenge themselves and their employees to continually review all procedures and to scrutinise all costs for new ways to increase profitability or to improve their employees and animals' environment.

CRITICAL CONTROL POINTS OF COST CONTAINMENT AND FINANCIAL MANAGEMENT FOR SWINE PRODUCTION

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ABSTRACT

Cost control on a modern swine unit can be managed by carefully monitoring and controlling certain critical areas. The authors believe that the key issues in cost control can be divided into three principal areas. These are production, expense and debt management. These key elements are the principal generators of Return on Equity, the global measure of long-term financial performance. This paper traces the important production, expense and debt variables through a model of impact on Return on Equity as a way to suggest a hierarchy of issues that render the greatest payoff to managerial attention.

EVALUATING PRODUCTION ON THE FARM

Evaluation of a farm production system is necessary in the following cases: 1) the owner desires to sell the farm, 2) potential investors are considering purchasing the farm, 3) the farm is in financial trouble and needs to determine the source of the shortfall, 4) the farm is expanding and needs the information for loans and to determine the best way to expand, and 5) the producer wants to improve productive performance.

Evaluation of a farm production system requires the ability to observe and assess a number of interrelated factors simultaneously. The three questions that must be considered are: 1) what are the main limiting factors on this specific farm? 2) where are the biggest potential impacts made in this system? and 3) what are the best answers, both short-term and long-term, for this individual farm?

Evaluation of the production system includes comparisons to some standard, as well as to the farm's internal goals. In most cases it is necessary to ask if the goals are appropriate. An outdoor breeding herd with a farrowing rate goal of 92% may need adjustment. A farm with capacity to finish 5,000 pigs with a goal of 6,000 may have problems. Once the goals and standards for comparison are established, then evaluation of production can take place.

We begin the evaluation by collecting baseline data on the farm. The first consideration in the evaluation is the endpoint - how many pigs are produced on an annual basis? At typical levels of production, throughput is more important than most measures of efficiency. Once throughput is established, measures of efficiency become more important and are evaluated. The following list gives some thumb rule indicators of herd performance based on experience and the performance levels reported from various databases. Farms that perform at these levels are usually successful.

The two parameters that overshadow all others in importance on most farms are throughput (total annual sales), and feed cost per pound of gain. Evaluations of farm productivity should start with these two parameters.

Beginning Benchmarks of Efficiency

The list given here provides beginning benchmark indicators of herd performance, and is used in the initial assessment of a hog farm. These items are not necessarily the final goal for the farm, simply a beginning point to assess high quality production.

1. **Annual total sale**s -- should approach or exceed 20 times the average sow inventory.
2. **Litters/sow/year --** should be close to 2 for pen-mated and pen gestated sow herds, >2.3 for confinement, hand-mated/artificially inseminated, individually-housed sow herds.
3. **Pigs weaned/sow/year --** has to be 21 or more to sell 20.
4. **Farrowing rate --** target > 80%. It is never as high as people without records think it is. Producers with outdoor and pen mating systems usually over-estimate farrowing rate, and don't account for first service performance.
5. **Days to market --** databases show average to be around 200 days and decreasing. Many "close-out" systems show days to market from 170 - 180. These closeouts account only for those animals which go to market at the first close-out. Producers without good records usually underestimate days to market because they do not account for "tail-enders" that pull the average up drastically. It is difficult to accurately account for days to market in continuous flow production systems. Conversion to AIAO will improve accuracy of producer estimates, but is still not as accurate as a detailed record system.
6. **Nonproductive Sow Days (NPD) --** NPDs are any days a sow is not either lactating or gestating. PigCHAMP data shows that the best herds can achieve 30 to 35 days; good herds 40 to 45 days; average herds are in the range of 70 days; and many herds are over 70 days.
7. **Feed cost per pound of gain --** The Swine Graphics database shows some producers at $.19, the average at $.21, and the target at $.20 (1991 data, US dollars).
8. **Feed efficiency --** $\leq$ 3.1 for inside finishing (50 to 250 lb.), $\leq$ 3.5 for outside finishing (3.8 is typical). Nursery FE for single-site farms should be < 2.0. For SEW nurseries should be around 1.5.
9. **Mortality figures--** a. breeding herd < 4% in confinement, < 8% outside. Sow mortality in outside herds and in many confinement herds is higher than we think.
   b. preweaning -- ballpark figure = 10%. Average is around 14%.
   c. nursery -- < 2%; grow-finish < 3%; less than 2% "tail-enders" in confinement production; < 5% in outside production.
10. **Feed consumption --** The challenge in grow-finish is to increase feed consumption and minimise feed waste. Measuring disappearance is the best we can do on most farms. Feed "consumption" should average 4.5 lb./day or more from weaning to market for reasonable growth performance. Many nursery/grow/finish diseases

(especially respiratory diseases) exert their worst effects on performance by decreasing appetite and thus growth.

11. **Health products and feed additive costs** -- are excessive on many farms. A target of < $3.50 per pig for all health related products (vaccines, injectables, and feed additives). Feed additives in most cases should be < $1.50 to $2.00 of the total per pig marketed.

COST OF PRODUCTION RELATED TO EFFICIENCY

High Productivity/Low Variance Production Systems

Developing a high productivity/low variance production system involves coordinating all the facets of production and enabling them to reach their potential in a synergistic fashion so that overall production is consistently optimised. The production areas that must be coordinated to produce a high output/low variance outcome are: 1) throughput, 2) the health assurance program, 3) the genetics/breeding program, 4) the facilities and buildings, and 5) the nutrition technology employed. Details on each of these areas are now addressed:

Throughput

Throughput is primarily a manufacturing term and refers to the amount of finished product generated by a production process in a given period of time. On-farm, throughput refers to volume of production appropriate for the fixed assets that are in place. The first consideration is sow inventory relative to the number of gestation and farrowing spaces that are planned or available. Secondly, mating targets must be established and achieved for each breeding group. Historical records that establish a track record for each month throughout the year are required to establish seasonal targets.

The record-keeping system also needs to be able to project farrowing rates and gilt needs 4 months in advance. The farrowing rate report should account for sows that have fallen out of the breeding groups on a weekly to biweekly basis, depending on the frequency of data entry. Historical trends are important here as well, as farms that have a history of pregnancy loss late in gestation will need to account for those when placing gilt orders. Gilt pool numbers and management are ultimately the major consideration in assuring high throughput. Mating targets cannot be reached unless the required numbers of gilts is available for each breeding group. There must be adequate space for the number of gilts required during each season of the year. During the summer months, it may be necessary to house twice as many gilts as during other seasons of the year. Gilts must be managed such that a predictable number are available for breeding in each group. This includes proper feeding and boar exposure at the appropriate times.

Genetics/Breeding Program

The pig genotype that is used must allow the production system to meet its production and financial goals, and allow the system to produce in a high throughput/low variance manner. The selected genotype must be able to meet the system's goals for reproductive performance, growth,

and carcass quality. The genetic source should be able to supply the required number of animals in a timely manner and ideally from only one source herd. The genetic source should provide the purchaser with evidence of its commitment to research, development, and long-term genetic improvement. Assurance that the product is going to be available on a long-term basis and that continuous improvements will be made is a minimum qualifying condition for choosing a genetic supplier. Carcass lean of 50 - 52% is now becoming slightly below average in today's market. Evidence suggests that improvement to 54%+ in the next few years will be occurring. Lean improvement beyond this point requires careful assessment of the entire quality bundle to assure losses in other desired traits do not offset the value of increased lean muscle.

Available breeding systems include rotational crosses, rota-terminal crosses, internal grandparent programs to allow terminal crosses for the market pigs, and terminal cross programs in which all gilts are purchased. Breeding management programs include pen-mating, hand-mating, or the use of artificial insemination (AI). Breeding systems and breeding management programs must allow the system to meet throughput targets and carcass quality targets. Some type of terminal program with hand-mating or Al are the only options for high throughput/low variance systems. AI can allow producers to take advantage of faster genetic improvement and better quality boars. Al has more potential for reducing variation than any other technology available today. Because fewer boars can be used over the same number of sows, variation should be reduced.

A routine pregnancy monitoring program, including 21- and 42-day heat checks, 30- and 50-day ultrasound checks, and 65- and 90-day visual appraisals should be conducted. Vigilant detection of open sows at the earliest possible time will not only assist in reducing non-productive days, but will also help reduce variation in the number of sows farrowed. Finally, the housing system should be consistent with the chosen genotype and the production targets, allowing high productivity and low variance. Although other systems may be able to fulfill these requirements, individual gestation stalls are the housing system that gives the highest productivity and lowest variance in the hands of most managers.

Since reproductive performance is so important to "in-control" production throughout the rest of the production process, it is important to understand how to interpret and use the major reproductive measures listed below.

Interpreting specific reproductive parameters:

1. ***Wean-to-Service Interval (WSI)*** -- is an often-overlooked indicator of reproductive performance. Percent sows bred by 7 days gives some idea of the variation involved in WSI. Normally, the average WSI should be 5 - 6 days and the percent bred by 7 days should be 90%.

2. ***Entry to First Service Interval (EFSI)*** -- can be deceptive. Many herds enter gilts into the record system on the day they are mated, therefore EFSI is low. In order to accurately assess and control the gilt pool, however, gilts should be entered into the herd the day they would have otherwise been marketed, or in the case of purchased gilts, the day they enter the farm.

3. ***Pigs born alive per litter --*** biologically is a function of total born minus stillbirths and mummies. In practice, it depends on the ability of the person recording the data to

distinguish between live-born and stillborn pigs. It is not unusual to see the proportion of live-borns vs. pre-weaning mortality change with a change in farrowing house personnel.

4. ***Farrowing Rate (FR)* --** is an over-rated measure of reproductive performance. It is essential to know FR in order to set targets, however, litters/sow/year and non-productive days are better measures of reproductive efficiency.

5. ***Litters per Sow per Year (LSY)*** -- This figure is determined primarily by the lactation length that has been determined for the farm, and the ability to find recycle and open sows early in gestation. Herds with hand-mated, individually housed sows and lactation of approximately 21 days should accomplish > 2.3. Many sows go through their lifetimes averaging 2.5 litters per year. A relatively small proportion of sows keep most herd averages down.

6. ***Non-productive Days (NPDs)* --** As with LSY, a small proportion of sows often contribute a high proportion of total NPDS. NPDs are influenced by the conventions used for gilt entry and sow culling. Some herds remove sows from the breeding herd the day the culling decision is made, others wait until the sow actually physically leaves the herd.

7. ***Pigs Weaned per Lifetime Female (PWLF)*** -- is a good combined measure of sow productivity and sow longevity. A herd that weans 9.5 pigs and averages 4 parities per female should have 38 PWLF.

8. ***Sow inventory*** -- may fluctuate as efficiency changes, but must be kept at a level that will allow meeting mating targets. In most herds it should increase during the summer months.

9. ***Pigs weaned per sow per year*** -- A good measure for assessing the reproductive efficiency of the sow, and if inventories are kept in line, gives a reasonable estimate of facility use. It is a function of pigs weaned per litter and litters per sow per year, with LSY having a greater impact in almost all herds.

Health Assurance Program

The health assurance program is of primary importance in promoting high productivity/low variance production. Once sow inventory, mating targets, and mating management are being properly managed, diseases, both primary and secondary, become significant contributors to variation in performance. The health assurance program should address both external and internal biosecurity. It should minimise the opportunity for diseases to enter the herd for the first time (external biosecurity), as well as minimising the effects of diseases within the herd (internal biosecurity).

New breeding animals should be obtained from one source whose existing health status is compatible with the receiving herd. If a start-up is being planned, the source-herd health status should be evaluated critically for the presence of diseases that are of particular concern in start-up herds: (parvovirus, streptococcal and staphylococcal organism, and porcine reproductive and respiratory syndrome (PRRS)). By working closely with the source-herd veterinarian, less than ideal start-ups won't be avoided entirely, but in many cases they can be smoothed out. The source herd should be negative for all diseases of regulatory concern. Suppliers should be willing to provide the results of any regular herd surveillance programs, including clinical

observations, serological screenings, and slaughter checks. Communications between source-herd and recipient-herd veterinarians should be conducted as needed.

A high productivity/low variance production system will use an appropriate isolation and quarantine protocol for new breeding animals, worked out in conjunction with their consulting veterinarian. The plan will include some type of isolation facility located at least 200 feet from the main farm in the case of a mechanically ventilated building, and at least 200 yards from the farm in the case of a naturally ventilated building. The external biosecurity plan will include an external barrier such as a fence, so that wandering people and animals are discouraged. Visitor policies will be rigidly enforced, possibly including a set number of "pig-free" days. A shower-in, including a change of clothes into those provided by the farm, will be a part of the biosecurity plan. Load-in and load-out procedures that minimise the potential for pigs re-entering the loading chute or building after entering the truck are necessary. Delivery areas for feed ingredients or complete feeds should be provided so that delivery personnel do not need to enter the farm. The biosecurity program of the feed supplier, and the manner in which they handle feed ingredients and their quality assurance program should be investigated and understood as well.

Internal biosecurity, or the prevention of the spread of disease organisms within the herd, is critical to a high throughput/low variance system. All-in, all-out production should be practiced by room as minimum, preferably by building, and by site if the production system is large enough. Each production area must be cleaned, disinfected, and allowed to dry before a new group of pigs is brought in. Finally, the farm personnel should be certified at level III of the NPPC Pork Quality Assurance Program established by the National Pork Producers Council (NPPC) or its equivalent and the farm should be using an independent health consultant on a regular basis.

Facilities/Building Types

Pigs are resilient creatures and can be produced in a variety of facilities and building types. High productivity/low variance production, however, requires some standardisation of building types within a system. Standard systems today may be either mechanically- or naturally-ventilated. Manure may be handled by flushing under slats or wire, by a pit recharge system, or by a hairpin gutter. Stocking density and space allowances per pig should be within normally accepted ranges within the industry and should allow for pig performance that is consistent with pro-jections and industry standards. In any production system, "tail-ender" pigs are inevitable, and provisions must be made for accommodating them. They must not be allowed to violate the integrity of age-segregated groups.

Ideally, the separation of the various phases of production onto different sites can be accomplished. Although our research has shown that there is no advantage to removing pigs from a high-health sow herd, separate-site production allows for the specialisation of labour, it encourages all-in, all-out production, and it provides for a depopulation of the building or site between production groups. Separate-site production provides an insurance policy, in that the potential exists for "breaking" the transmission of a disease should an outbreak occur. Separate site production promotes higher productive efficiencies without the expense and down-time of

repopulation in those herds in which chronic diseases have reached a level at which production is impaired. Buildings must provide a reasonable environment for the people who work in them, and routine maintenance schedules must be observed.

Nutrition Technology, Feed Efficiency and Feed Costs

The feeding program in a high productivity/low variance system must be designed to economically optimise the genotype of pig employed, and must allow performance consistent with projections. If feed is mixed on the farm, quality control is in the hands of the manager and the feed mill operator. They must assure that ingredient quality and feed biosecurity meet their requirements. The farm must have adequate feed-milling technology and management skills to ensure a consistent feed product that will support the expected performance. If feed is not mixed on the farm, bids to supply the feed can be solicited. These should be based on written specifications that require narrow tolerances of ration ingredients that are consistent with the genetic requirements and performance expectations of the herd.

Between 55 and 65% of the total cost of production for a market hog is feed. That means about 45% of its earned income (at slaughter) must go for nutrition.

Expert nutritional assistance is needed to prescribe the correct diets. As much as is practical, given the facilities and management capabilities, this will mean a phased feeding approach which seeks to match the rations with the changing nutritional needs of the pig as it grows. Once the rations have been chosen, obtaining them in the most economical fashion becomes critical. Regardless of how careful you are to price or bid rations, annual fluctuations in the price of grains can have dramatic impacts on your ration cost. These costs are outside of management control yet can dramatically influence the overall cost of production.

Benchmarking 90th percentile farms also reveals they pay attention to quality, including feed related bio-security. These farms typically work with a nutritional consultant, their feed supplier and their genetics source to make sure the feeding program does not limit the productivity and growth or contribute to increased variation in carcass quality. Most of these farms employ split-sex feeding to avoid overfeeding expensive ration elements to animals that do not require them. Lastly, these farms subject both ingredients and complete feeds to periodic analysis by an independent lab to ensure quality control. It seems doubtful we will ever get the pig to consume as little a percentage of its total lifetime earnings on food as we do. Moving in that direction will produce more profits and long-term staying power in this changing industry.

To summarise, the farm needs to work with an independent nutrition consultant, their feed supplier, and the genetic supplier to ensure that the feeding program does not limit productivity and contribute to variation in growth rate and carcass quality. Ration composition, ingredient source, phase feeding, and separate-sex feeding of barrows and gilts all need to be considered. In most cases, barrows and gilts should be fed separately. Ration changes should be phased as frequently as practical and economical in order to supply the right feed mix to each category of pigs. Feed ingredients and complete feeds should be subjected to periodic, regular analysis by an independent laboratory.

Feed Efficiency

Several factors influence feed efficiency in swine. Gary Allee, Professor of swine nutrition at the University of Missouri lists the following key determinants of feed efficiency:

1. Feed Wastage
2. Particle Size of Cereal Grains
3. Space-pig Density
4. Health Status
    a. multiple source pigs
    b. AIAO vs continuous flow
    c. mortality
5. Market Weight
6. Temperature
7. Energy Density
8. Feed Additives
9. Genetics
10. Improper Formulation and Mixing

Allee notes that Illinois researchers determined the wastage from 10 popular styles of feeders under carefully controlled conditions. The wastage ranged from 1.5 - 7.7%. Adjusting feeders, using pelleted rations and the use of wet/dry feeders conserve both feed and water. We will demonstrate the financial impact of reducing waste and increasing feed efficiency.

Feed Costs and Gain

Feed costs are the greatest single cost of production. Grow-finish feed costs are the single most significant portion of the total feed bill. The issue is not as simple as getting the cheapest feed possible. A combination of input costs and management affect the bottom-line. Single efficiency measures such as cost-of-feed-per-CWT of gain are affected by feed costs, genetics, management, facilities employed, and diets utilised. Some of these are outside management control while others can be directly affected. When we judge feed costs as too high for a farm, it is important to realise that the solution is not always simply cutting ingredient costs or costs of the final product. The challenge is to economically optimise the feeding program with the genetics employed on the farm. The process begins by understanding the genetic capabilities of the animal on the farm in combination with its grow-finish environment (facilities) and management system.

Feed costs can be evaluated as feed costs per ton, feed costs per pound of gain, or feed costs per pound of lean gain if the required level of detail is available in the record-keeping system. Feed costs per ton can be deceptive, particularly if higher feed costs are directly correlated with better performance in the form of lean gain. While this may sometimes occur, the primary ingredients in most swine diets in the U.S. are still corn and soybean meal. For diets other than starter diets, these components will be 60 to 90 % of the diet. Corn, soybean meal, major minerals, vitamins and trace minerals, and crystalline amino acids will be the ingredients in most diets. Ingredient costs plus grind, mix, and deliver costs make up the per ton costs of feed. Costs of each

component need to be analysed routinely in order to control per ton feed costs without sacrificing performance.

The components of feed cost per pound of gain are feed costs per ton, feed efficiency, and average daily gain. Feed costs per pound of gain will fluctuate as ingredient costs fluctuate, however, year-in and year-out, farms with good cost control programs manage to keep feed costs around $0.22 per pound or less. To be at this level, a 250-pound market hog could incur $55.00 in feed costs. If whole herd feed efficiency is 3.3 pounds of feed per pound of gain, 825 total pounds of feed went into producing the pig to market weight. To stay within the feed budget, feed would have to average $0.067 per pound, or $133.00 per ton. Feed costs per pound of lean gain can be evaluated similarly, except that the percent lean measurement from the packer kill sheet is required. Feed costs per pound of lean gain includes the impact of carcass quality as well as feed costs per ton, feed efficiency, and average daily gain.

Personnel Recruitment, Training and Management

The final key ingredient in developing a high productivity/low variance system is recruiting good people, training them in the system of production, and managing them to their potential. The farm must be known as a good place to work. Employees that are trainable and that can contribute to the system of production should be recruited. Benefits such as true bonuses (not production incentives), health care, and retirement plans can contribute to the ability to recruit and retain people. Written job descriptions and a written employee procedure manual contribute to high productivity and low variance. Regular performance appraisal interviews, a fair and reasonable work schedule, and a competitive pay scale relative to other job opportunities in the area also contribute to employee recruitment and retention.

A "cost driver" is shorthand for a variable that substantially impacts cost as it changes. A cost driver is an especially important variable to monitor on a continuing basis. Costs will always be creeping toward to unacceptable unless vigilance is maintained. A surprising percentage of total cost is accounted for by a few variables. For most modern farms, the primary cost drivers are feed and its related efficient use, labour cost, building and equipment, cost of debt, genetic cost, and veterinary costs. Several of these six costs are inter-related and can increase together such as labour, vet and feed costs.

TYPICAL PATTERNS OF COST AND EFFICIENCY

Note that farms that are performing well across a wide variety of cost drivers are less susceptible to wide swings in total cost of production when one factor gets out of line. Note also that the effect on lower performing farms is not necessarily linear when a key driver changes along a given path. The effect can (and often is) best be described by a curve or exponential function. This is primarily because of the escalating interest costs and working capital shortages which develop on these farms. When a working capital shortage develops due to temporary drops in market prices of hogs or increases in input costs, the farm may often have to borrow money on a short-term basis to pay debt or interest. This results in an exponential impact for low performing producers as costs get out of control.

Caution must be used in interpreting costs of production and comparing them from farm to farm. Some farms may report *costs of goods sold* as their costs of production. Costs of goods sold include direct costs associated with acquiring and producing an inventory during a specified reporting period. Other operating expenses, such as administrative overhead, may not be included as costs of production. Likewise, non-operating expenses, such as interest expense, may not be included in some reported costs of production.

OTHER IMPORTANT COSTS

Labour costs are the second or third greatest cost of production on most farms. Labour costs per market hog have a wide range from farm-to-farm, but farms that have reasonable performance along with good cost control come in at $10.00 to $11.00 per head. These costs can vary by region. Facility costs (depreciation + interest) are a major cost of production, especially on new farms. Depreciation and interest costs may range as high as $16.00 to $20.00 per market hog on new state-of-the art farms that are highly leveraged. Utility and facility/equipment maintenance vary somewhat by region, but also with the age and condition of the facilities. Per head costs of $1.00 to $4.00 are not unusual. Veterinary and medicine costs are major costs on some farms. While costs as high as $10.00 per head are sometimes observed, a competitive level is $3.50 per head or less, for feed and non-feed medications. Administrative overhead costs vary with the accounting practices used, but may be a substantial part of total costs of production in some systems of production. They should be evaluated carefully in a financial evaluation.

FINANCIAL EFFICIENCY

The magnitude of investment required by modern production technologies coupled with the increased sophistication of pig production systems demands a high level of production and financial management. While many producers have invested the time to keep accurate production and financial records, most will admit they lack a systematic method of using the data collected to make effective and profitable decisions.

Many producers, along with consultants and lenders, fall into the trap of examining only a few, favourite pet indicators of production efficiency like litters/mated-female/year or pigs weaned/sow/year. On the financial side, cost of production and a few balance sheet ratios are used to get a "quick and dirty" understanding of the underlying financial performance of the farm.

Likewise, farm magazines and the popular pig press typically only focus on a few measures that become a popular list of "benchmarks" for producers. Unfortunately, these measures usually focus on only a single dimension of the business such as feed to gain or preweaning mortality. These measures, while providing important information to the producer, are not comprehensive assessments of system production or financial performance although they are often used that way. They are actually subsystem measures.

Return on Assets (ROA) and Return on Equity (ROE) are true system measures of financial efficiency. This is so because every subsystem on the farm (breeding herd, nursery, and finisher) is fully represented in the numbers used to calculate ROA and ROE.

Let's take a look at how to calculate and interpret these system efficiency measures:

ROA = (Accrual Net Income + Interest Payments)/ Average Total Assets

ROA can be thought of as the underlying return of the operation without considering the impact of the level of debt. Notice that interest is added back to Net Income so regardless of the amount of debt the farm has, it will not effect the calculation of ROA. ROA is a function of the system you have created on your farm. This includes the choices you've made regarding genetics, nutrition, environment/housing, management practices, efficiency, prices of inputs and marketing of your animals.

ROA is a true system variable since it includes comprehensive information about both the production and financial performance of the farm. Information from both the income statement and the balance sheet is needed to calculate ROA and ROE.

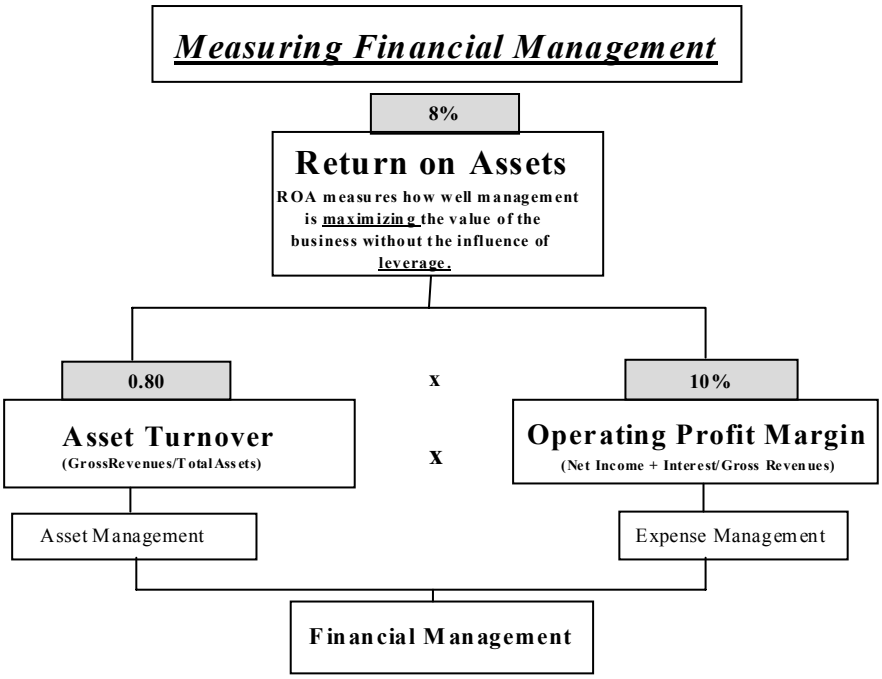
ROE is very similar to ROA except that interest is now included in the calculation. The formula for ROE is:

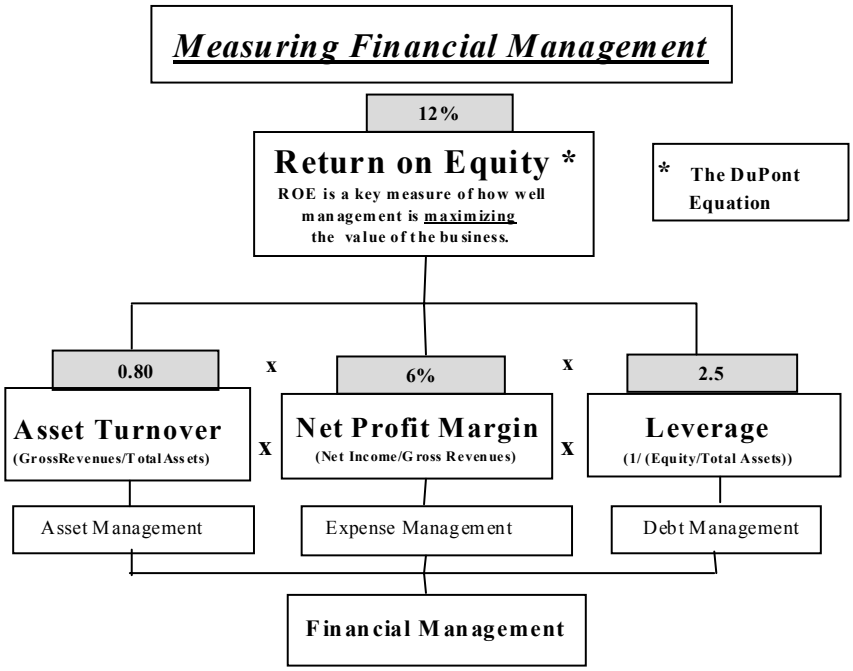
ROE = Accrual Net Income/Average Farm Equity

ROE is a comprehensive measure of system production and financial performance that specifically accounts for the effect of the level of debt used.

Accrual net income reflects the complete revenue and expense performance of all subsystems on the farm. Both measures (ROA and ROE) also use a category from the balance sheet, either assets or equity. By combining both income and expense performance from the income statement and a measure from the balance sheet, ROA and ROE capture all of the available production and financial information about your production process in one number.

Now that we've rolled all this information into one or two key numbers we have a problem. If the value of ROE is determined to be mediocre, there is no additional information available to diagnose what area or specific problem is causing the less the desirable performance. We can unpack ROE using a construct called the DuPont equation to develop a means to diagnose and address substandard performance.





The DuPont equation breaks ROE into three parts, providing a way to audit three key areas of farm management and their contributions to ROE. The three components of ROE evaluate asset management, expense management and debt management. Managing all three of these areas well tends to maximise the value of the business. Comparing the values generated from the

DuPont analysis for each of these three areas with industry benchmarks, we can begin to zero in on the areas needing attention. Once these areas have been identified, appropriate subsystem measures can be used to fine-tune the identification of the problem.

The DuPont Equation

ROE = Asset Turnover X Net Profit Margin X Leverage
[Asset Management] [Expense Management] [Debt Management]

Where:

Asset Turnover = Gross sales/ Average Total Asset Value
Net Profit Margin = Accrual Net Income/ Gross Sales
Leverage = [1/Equity/Total Asset Value]

Let's examine each of the three components of ROE. The first is asset turnover. Asset turnover measures the speed or rate at which the system can produce sales equal to the asset value used to generate them. Asset turnover is industry specific. For lengthy, biological production processes which cannot be speeded up (like line speeds on a assembly line), asset turnover is usually low. However, there are several things within management control which affect asset turnover.

The most common limiting factor on farms today is under-employment of existing resources. *Assets already purchased and in place* are often ineffectively used to generate sales. Asset turnover for a well run, farrow-to-finish, owned (not contracted) farm will be in the 0.8 to 0.9 range or above. If your values are much lower than this, the subsystem variables to assist you in diagnosing the problem include: wean-to-service interval, breeding herd mortality, non productive sow days, pre-weaning mortality, nursery death loss, average daily gain, pigs weaned per litter, days in the nursery, market weight, parity distribution, farrowing rate, finishing death loss and litters/female/year.

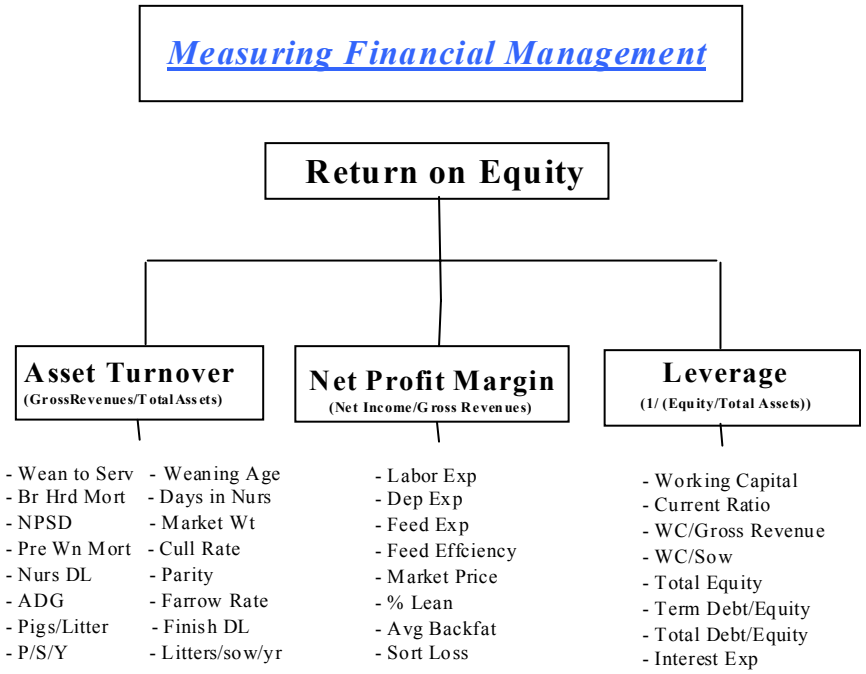
Second component of the DuPont equation is net profit margin. Instead of examining the level of profits we look at accrual net income standardised (divided by) by gross sales. Why standardise profits to gross sales? We can answer with another question. If a business makes a million dollars in profits this year is that good performance? If your thinking like an economist you answered, "It depends!" If the business made a million dollars profit on five billion in sales we would consider that poor performance indeed. Hence, we standardise to sales to examine profit efficiency rather than the level of profits.

The key for most farms here is expense control. Expenses overtime will tend to get out of control. This is almost universal and it applies to household finances as well as farm finances. Good long-term average net profit margins (as defined in the DuPont equation) for owned farrow-to-finish operations are 6-9%. The key subsystem indicators of expense control are feed expense/unit of gain, feed efficiency, labour expense, interest expense, genetic expense, utilities expense and depreciation expense. In addition, on the income side, market price, percent lean and average backfat are key subsystem determinants of net profit margin.

Lastly, managing leverage is critical to maximising the value of your business. It seems strange to some but the more equity you have, the lower ROE will be for a given level of net income produced. If you are leveraged and profitable, ROE will increase. On the other hand, if you do a poor job of asset and expense management, ROE decreases regardless of your level of leverage.

We are not recommending opening the floodgates of debt as a means to raise ROE, however, many profitable producers are under-leveraged. Their profits betray the fact that they are actually destroying their future ability to produce earnings by failure to reinvest in the operation. A cardinal tenet of economics is that scarce resources in a capitalist economy are allocated to their most productive use. If you are a profitable producer of pork, you should consider whether you have chosen a level of debt that is less than optimal. If so, you should weigh the use of additional debt to leverage your business into a larger and more profitable position. If you are an unprofitable producer, the opposite is the case.

Key factors and subsystem efficiency measures used in determining the optimal use of leverage are: working capital, current ratio, working capital/gross revenue, working capital/sow, total equity, term debt/equity, total debt/equity, and the use of leasing and contracting instead of owning assets. Values of the leverage measure above 2.5 must be accompanied by consistent, high profits with price risk protection or the farm can be imperilled by a working capital crisis.



Financial management using a simple construct such as the DuPont equation gives managers the ability to comprehensively assess the long-term production and financial performance of their operation. It rewards those who have taken the time and trouble to keep accurate production and financial records with a source of information to make wise decisions about their future.

BREAK-OUT SESSIONS

MANAGING GROWTH RATE VARIATION IN ALL-IN:ALL-OUT PRODUCTION

Or **This Little Piggy Went to Market….**

John Deen
University of Minnesota

The problem is simple to explain: We have designed systems with little flexibility and yet we face wide variation in pig-flow and pig performance. It is the age-old problem of putting a square peg in a round hole. Some pigs grow too fast, other pigs grow too slow, and some just do not make it and die or need to be euthanised.

With the square peg – round hole illustration, there are three simple choices:

- The first choice is to make the round hole bigger. This is analogous to increasing the capacity of the system to handle variation. This also means slack space when productivity is low.
- The second choice is to reshape the square peg. This means that the variation in pig productivity is reshaped by compromising pigflow and, in reality, it is the resultant poor performance that needs to be controlled.
- The last choice is to use a big sledge and throw away the parts that chip off. This is analogous to ignoring the problem and then compromising the quality of the process by overcrowding or shipping poor pigs.

Figure 1 shows the distribution of lightweight pigs in a large production system in Southern Minnesota. They occur as the system is either incapable of controlling growth, or its control is in conflict with other aims of the system.

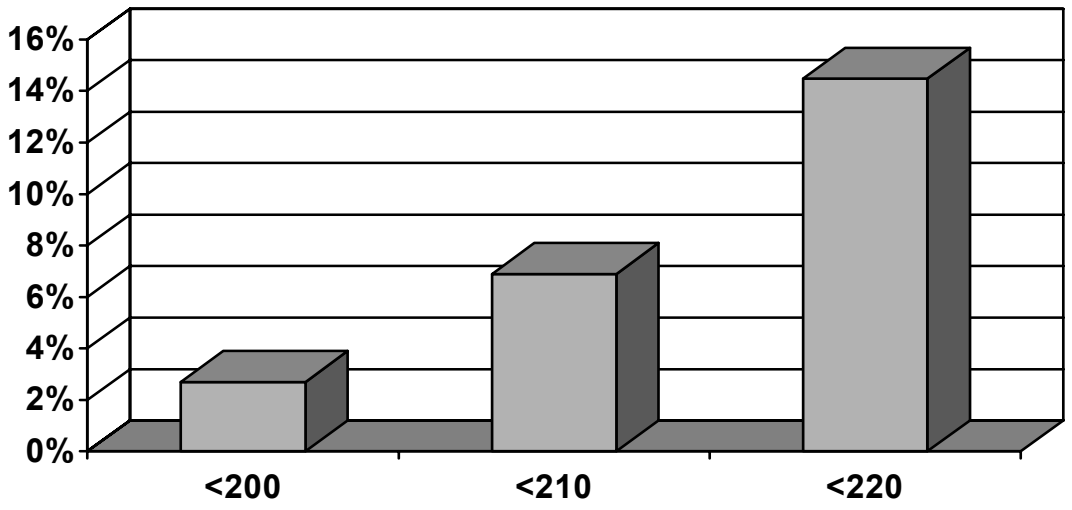


Figure 1. Proportion of lightweight pigs.

The conflicts are numerous in managing a variation in growth rates. We have the conflicts of the aims of:

- Fixed capacity vs. variable production
- Fixed capacity vs. variable specifications
- Cost control vs. quality
- Quality vs. variable requirements
- Maximisation of productivity vs. stability

Such conflicts are common across manufacturing industries. Quality management is the most common approach and a quote from Edward Deming says it best:

> *Improvement of the process increases uniformity of the product, reduces rework in mistakes, reduces waste of manpower, machine time and materials, and thus improves output with less effort. Other benefits of improved quality are lower costs, happier people on the job, and more jobs, through a better competitive position of the company.*

Genichi Taguchi's approach is to create a loss function for deviations from the aim of production. This is an equation for calculating the quality loss of a product. The further the product is from its target state, the greater the loss will be. Figure 2 illustrates one such loss function.

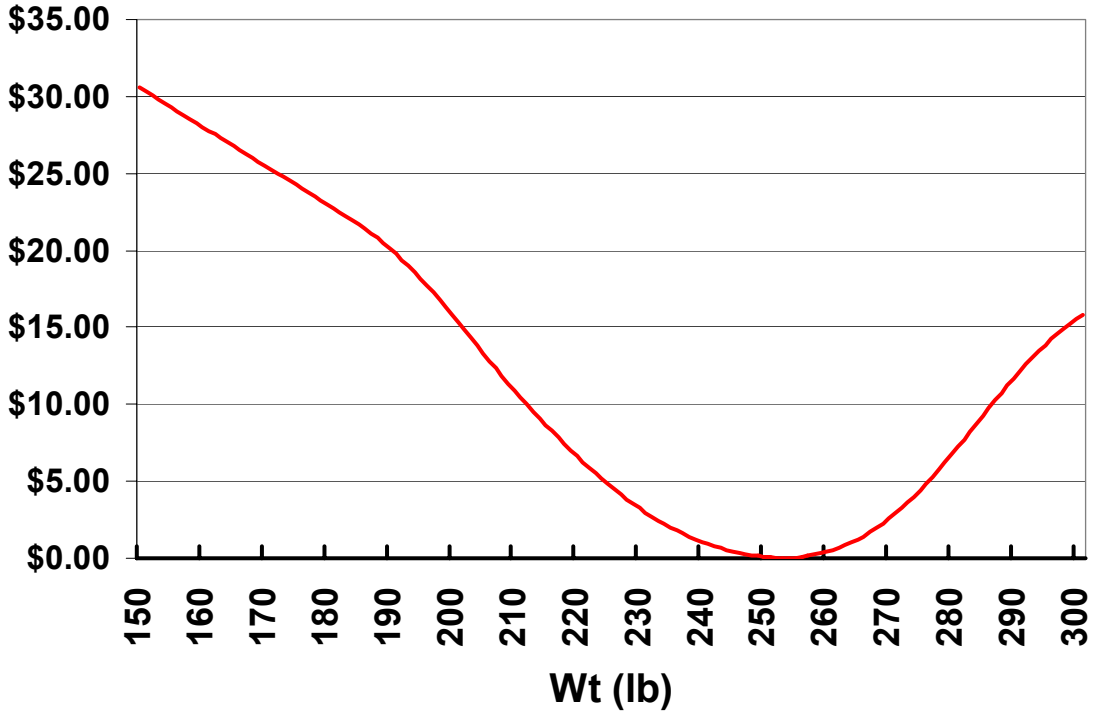


Figure 2. Loss function on marketed pig weights.

The approach that I take for growth variation on most farms is to emphasise the slow-growing pigs. Fast-growing pigs can be sorted out, but slow-growing pigs are difficult to handle in all-in:all-out systems. In this approach I emphasise two aspects at each stage of production. The first is variable weight at entry and the second is variable growth rates. At each stage we have criteria for what is a light pig at entry and at exit. For instance, the common criteria for nurseries is a minimum of 8 lbs. at entry and 30 lbs. at exit.

The big question that we have is whether a light pig performs differently than the other pigs. If so, can we compensate for that poorer growth? In this workshop we will go through some measurement methods and results. Figure 3 shows the results of the comparison of two entry treatments where the differences are real and the treatment effects are also real. Amoxicillin was given in the water and the Ceftiofur was administered by injection at entry. The effect was greater in small pigs and easily justified the treatment. There are many such interventions.

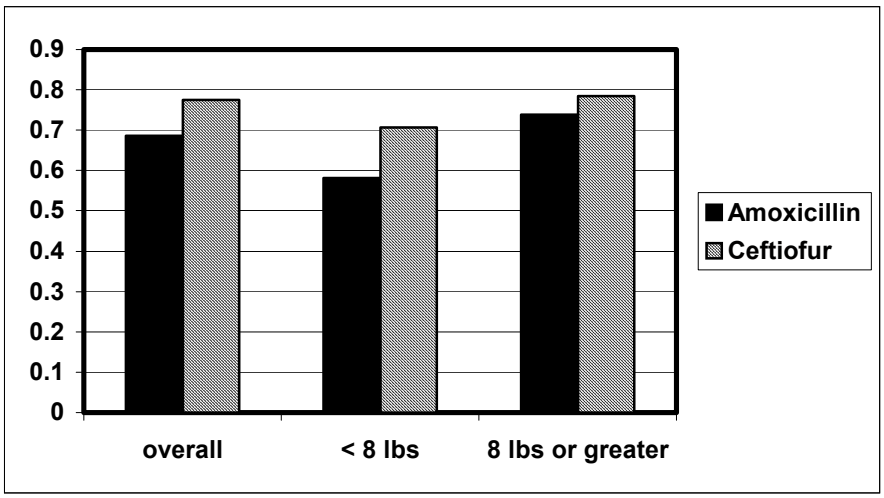


Figure 3. Treatment effects on ADG vs differing entry weights

A few general observations can be made from historic analyses:

- The relationships are farm and/or system specific. The range is large and averages are misleading.
- The relationship between entry weight and growth rate is stronger at younger ages. We need to sort and treat in the farrowing house and nursery. Controlling the growth process is the main aim in g/f.
- Bacterial disease control should emphasise small pigs at entry. Viral disease control does not improve with this emphasis
- We need to measure mortality rates vs. entry weight
- We should look at variable growth as attrition from potential output. Dying or becoming a runt is hard to differentiate by cause and we can often lump them together.

Quality production in this case is profitable and challenging. It is a change in mindset, but it does produce results.

GROW/FINISH VARIATION: COST AND CONTROL STRATEGIES

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Variation in growth rate for grower/finisher pigs causes increased fixed costs of production and makes all-in all-out production management difficult or impossible. We conducted an observational study on 9 cooperating commercial farms between 1998-2000. All pigs born over a 1-6 week period were weighed onto the study at 1-2 days of age, to ensure a minimum of 250 pigs per farm. The pigs were then weighed at weaning and approximately 7, 14, and 20 weeks of age. Due to biosecurity concerns and the number of farms involved, after the pigs were weaned, the farms were not visited on a weekly basis. Therefore, the exact age of the pigs at the 7, 14, and 20 week weighing, within a farm, varied by 14 days.

The strength of this project is that data were collected on a wide variety of farms with no management intervention from the researchers. Therefore, we believe the data collected is a valid representation of the typical production found in Ontario farms. The farms selected for the study were those owned by cooperating producers whose units were within a 1 2 hour drive of the University of Guelph. The farms included one multi-site unit where the nursery pigs moved to three different finisher barns, two, 2 site, single-source off-site nursery units with the finisher barn on the sow site, one farrow to feeder barn, four single site farrow to finish units with commercial production, one farrow to finish, multiplier unit, and the University of Guelph research herd. The disease status on these farms ranged from those without porcine reproductive and respiratory syndrome virus (PRRSV) or *Mycoplasma hyopneumonia* to those with these diseases and swine dysentery and *A. pleuropneumonia.* The weakness of this project is that it is an observational study and as such, although the pigs were weighed as individuals, the management decisions and the disease status of the units were farm-level factors. With only 9 farms, we were unable to apply statistical tests to many of the factors of interest.

The purpose of this project was to describe: (1) the production found on commercial swine units in Ontario, (2) variation in the production as measured by the coefficient of variation (CV), (3) impact of the size of the young pig on the weight and weight gain of the older pig, and (4) impact of specific management factors on the growth rate and variation in weight at the grower finisher level.

The weight of a young pig has a large influence of the weight of that pig later in life (Table 1) (P=0.0001 for all relationships mentioned). A pig that weighs an extra 0.5 kg at birth will weigh an extra 0.8 kg at weaning and 1.2 kg at 7 weeks of life. A pig that weighs an extra 1 kg at weaning will weigh an extra 0.3 kg at 7 weeks and an extra 0.9 kg at 20 weeks of age. A pig that weighs an extra 5 kg at 7 weeks of age will weigh an extra 1.5 kg at 14 weeks and an extra 2.0 kg at 20 weeks of age. A pig that weighs an extra 10 kg at 14 weeks will weigh an extra 11 kg at 20 weeks of age.

Table 1. Additional weight of pig (kg, parameter estimate) for every 1 kg increase in weight at a previous stage of life.

	Weight			
Factor	Weaning	7 week	14 week	20 week
Birth weight	1.7	2.3	NS	NS
Wean weight		0.3	NS	0.9
7 week weight			0.3	0.4
14 week weight				1.1

WATER

We conducted a field trial to determine the association between water intake and nursery pig average daily gain (ADG). A total of 1932 pigs were weighed at weaning and placed in nursery pens holding approximately 30 pigs each. The pens had Crystal Springs wet-dry feeders, however, the water was not connected to the feeders. The control pens had one water nipple attached to the back wall of the pen (over the slats). The treatment pens had the water nipple at the back of the pen and the water in the wet-dry feeders was functional.

The pigs given the extra water gained significantly better than the pigs without the extra water (Table 2). Pigs without the extra water spent time lining up at the water nipple. Large pigs guarded the water nipple and did not allow other pigs access to the water without a fight. The water consumed by the pigs did not differ by treatment. We might have expected that the control pigs without access to water would consume less water rather than more water. However, previous research suggests that pigs using wet-dry feeders will consume less water than pigs eating from dry feeders.

Table 2. Change in weight gain of pigs by change in water access.

Growth Parameter	Pigs with extra water	Pigs in control pens	P-value
Weaning weight	6.29	6.29	>0.05
Weight at 8 weeks of age	17.34	15.70	0.01
ADG from 3 - 8 weeks	0.315	0.273	0.01
Weight gain from 3-8 weeks	11.04	9.41	0.01
Water consumed /pig/day	1.37 litres	1.57 litres	>0.05

We observed the same relationships in the observational study (Table 3). Drinker, feeder and space per pig are completely confounded with one another and with disease status and management system. Therefore, the numbers can only provide an indication but not a cause and effect relationship between productivity and access to feed and water. The weight of pigs at 7 weeks of age was numerically higher in farms where there was plenty of water. This is evident in the comparison in waterers per pen and in the number of pigs per pen. If pigs have limited access to water, their feed consumption will be reduced. The growth rate increased in both the grower and finisher phase when there were two drinkers per pen. By providing an

extra waterer, the variation in pig weight (CV) was reduced by more than half (from 48 to 13 or from 45 to 20).

Pigs need plenty of access to feeder space to grow to their genetic potential. If there were sufficient feeder spaces for one space per 5 pigs, the pigs grew better than if there were more pigs per feeder space. Similarly, pigs that were over-crowded had lower average daily gains than pigs given plenty of room. The amount of space provided to the pigs in the grower barn did not change the average daily gain in the grower barn but it did alter the CV. Pigs provided with more space grew more evenly than pigs given restricted space. In the finisher barn, the pigs given more space had a numerically higher ADG and grew more evenly than the pigs that had less space.

Table 3. Average weight of pigs at 7 weeks of age for various management factors.

Factor		Factor Level		
Drinkers per pen		1 drinker	2 drinkers	3 drinkers
	Average weight	14.1	14.4	18.5
	ADG 7-14 wks	0.70 (48)	0.74 (13)	
	ADG 14-20 wks	0.71 (45)	0.80 (20)	
Pigs per drinker		10 pigs	11-15 pigs	more than 15
	Average weight	19.9	14.3	14.2
Pigs per feeder		less than 5 pigs	5 or more pigs	
	Average weight	19.9	14.3	
Pigs per m^2		< 0.74 m^2/pig	≥ 0.74 m^2 / pig	
	Average weight	16.7	14.2	
	ADG 7-14 wks	0.07 (48)	0.70 (18.5)	
	ADG 14-20 wks	0.72 (37)	0.88 (19)	

WEIGHT AND VARIATION IN WEIGHT BY AGE OF PIG

The standard deviation and the CV are both measures of how variable the pig weight is at each age. The CVs do not change very much as the pig ages (Table 4). The standard deviation tends to be 24% of the average of the birth weight of the pig. The standard deviation is also 24% of the average weight of the pig when the pigs are 20 weeks old. This tells us that if we add and subtract 24% of the average weight of the pig, either at birth or at 20 weeks, these ranges will include 66% of all of the pigs that were weighed. For example, 66% of the pigs weighed between 1.3 and 2.1 kg at birth. Also, 66% of the pigs weighed between 63.9 and 104.3 kg at 20 weeks of life. Similarly, 95% of the pigs weigh between the average plus or minus 48% of the average pig weight. Thus 95% of the pigs at 20 weeks of age weighed between 43.7 and 124.3 kg. Other researchers have suggested that the variation in pig weights increases as the pigs get older. However, from our study we conclude that the CV does not increase as the pig ages. This tells us that proportionally the variation does not increase.

The variation appears to grow because the difference between the weights of the newborn pigs is 0.85 kg, whereas the difference between the weights of the 20 week old pigs is 42 kilograms. Unfortunately, this is still within the biological realm of 25% of the average pig.

Table 4. Average weight and variation in weights at various ages of life.

Age	Average Weight	Standard deviation	Coefficient of Variation	Smallest 25%[1]	Largest 25%[2]
Birth (1-4 days)	1.7	0.4	24	<1.45	>2.0
Weaning (17-24 days)	5.8	1.5	26	<4.9	>7.18
7 weeks (49-55 days)	15.5	4.8	31	<12.3	>19.0
14 weeks (96-105 days)	48.3	9.4	19	<42.3	>54.5
20 weeks (133-152 days)	84.1	17.5	20	<71.4	>97.0

[1]This shows that 25% of the pigs weighed less than 68.1 kg at 20 weeks of age.
[2]This shows that 25% of the pigs weighed more than 96.0 kg at 20 weeks of age.

FARM DISEASE STATUS AND PIG FLOW

Farms with more diseases and those using a continuous flow production system had lower ADG and a higher coefficient of variation than farms with fewer diseases or those that used an all-in all-out production flow. The disease status does not necessarily indicate that the farm had an active infection or clinically sick pigs, it just shows that the farm was not free of certain diseases.

Farms that were positive for more diseases had lower average daily gain in the grower and the finisher barn than farms that were free of diseases. This shows that for certain diseases that are easy to keep out of a barn, such as *Actinobacillus pleuropneumoniae* (APP), swine dysentery, and mange, it would be worth while to eradicate these diseases to improve average daily gain.

Diseases also have a very large impact on variation in weight gain. This can be seen by the CV. The herds with few diseases have a low CV. This means that the pigs are very close in weight to the other pigs of the same age. In the farms with diseases, the pigs do not grow in a uniform manner. This is because some pigs become chronically ill and are not able to gain weight. Other pigs in the same farm will not show clinical signs of disease, perhaps they have very strong immune systems and are able to fight the infection. This causes a wide variation in size of pig at the very same age.

There is also an obvious benefit to all in / all out production. Even though the first farm in the table has both PRRS virus and Mycoplasma, the pigs grow rapidly and in a uniformly because the pigs are managed all in all out by site. This means that the pigs coming into the barn are not exposed to the viruses and bacteria in the barn or in the air that older pigs carry. There is also a benefit to running the barn all in all out by room. As you can see from the table, the ADG is higher and the CV is lower in farms that use all in all out by room than in the farms

that run the facility on a continuous flow basis. Small farms that have insufficient weekly production to manage the farm this way can be encouraged to batch farrow, every two to three weeks.

NUMBER OF TIMES A PIG IS MOVED IN THE GROWER / FINISHER BARN

The pigs represented in the data in Table 5 were weighed at 13 weeks, 22 weeks, and 25 weeks of age. Please note that the pigs that were moved only once in the finisher barn were weighed at an older age than the pigs that were not moved at all or the pigs that were moved two or more times. Also, although the pigs that were moved two or more times were slightly lighter at the initial weighing, they were also 4 days younger than the pigs that were not moved at all.

Previous research has indicated that moving a pig in the grower/finisher barn adds 5 days to the days to market. This herd was chosen for this report because the producer moved some pigs a number of times during the growing phase. This allowed us to compare a sufficiently large group in each of the three categories: no-move, one move and two or more move.

At 25 weeks of age, the pigs that were not moved were 24 kilograms heavier than the pigs that were moved once. If the pigs grew at 0.75 kilograms per day, then the pigs moved once would need an extra 32 days to reach market weight. The pigs that were not moved were 44 kilograms heavier than the pigs that were moved two or more times. These pigs would need an extra 59 days to reach market weight. These numbers exaggerate the impact of the move because typically it is the slower growing pigs that are moved. If a pig is put in a pen and grows very rapidly, the pig tends to be shipped without being moved. However, if a pig does not grow well, then when its pen-mates are shipped, it is re-grouped with other pigs that are not growing well. Producers would be wise to minimize the number of moves for growing/finishing pigs to give them the optimum conditions for growth.

Table 5. Weights of finisher pigs based on the number of moves the pigs experienced. (Note, this data all comes from only one farm).

	Number of times the pigs were moved		
	0	1	2 or more times
Weight at 13 weeks of age	46	42	40
Age in days (approximately 13 weeks)	95	98	91
Weight at 22 weeks of age	68	62	51
Age in days (approximately 22 weeks)	151	165	159
Weight at 25 weeks	106	82	62
Age in days (approximately 25 weeks)	173	179	173

TRACKING PIGS FROM BIRTH TO MARKET

Table 6 describes the average carcass characteristics for pigs that grew quickly (25th percentile), slowly (75th percentile) or had average growth (50th percentile). The fast growing pigs reached market at 158 days, the average pigs at 169 days of age, and the slow growing at 181 days of age. The index, dress weight, and percent lean yield did not differ between these groups. There were more barrows in the fastest growing group than gilts. Only 34% of the slowest growing pigs were barrows. The fastest growing pigs had a larger fat depth than the slowest growing pigs. The slowest growing pigs had the smallest lean depth.

The lean yield was reduced by 1.2% in barrows compared to gilts, and was reduced by 5.7% for every extra 0.1 increase in average daily gain. Faster growing pigs had a lower lean yield. Fat depth was higher by 2.5 in barrows compared to gilts and increased by 7.2 for every increase in 0.1 of average daily gain. These factors only explained 9% of the variation in fat depth and 12% of the variation in lean yield.

These results suggest that producers may wish to feed fast growing barrows differently to reduce the level of fat and increase the lean yield. It could be that these producers are feeding to the average pig in the grower barn rather than the fastest growing pig. Producers in Ontario are working hard to phase feed nursery pigs, to the extent that large nursery pigs are given a different feed than small nursery pigs of the same age. Similarly, it may benefit Ontario swine producers to feed grower /finisher pigs different rations according to their size at a given age.

Table 6. Average growth and carcass characteristics for fast, medium and slow growing pigs.

	Percentile (by age)		
Parameter	25th	50th	75th
Age at slaughter (days)	158	169	181
Index	109	108.8	109.1
Dress weight (kg)	89.2	87.2	87.2
Fat depth (mm)	19.6	17.3	16.7
Lean depth (mm)	19.2	19.2	18.3
Estimated percent lean yield (%)	54.4	55.9	56.4
Weight at birth (kg)	1.8	1.6	1.5
Average daily gain 14 weeks to market	0.86	0.83	0.71
Number of pigs in sample	292	436	292
Percentage Barrows (%)	55%	46%	34%

IMPLICATIONS

1. Pigs that are provided access to extra water sources grow better in the nursery
2. Pigs with adequate access to water will not spend time fighting over the water source

3. Water is a relatively inexpensive resource and should not be the limiting factor in growth rate or variation in growth rate
4. Growth rate is improved and variation is reduced when pigs have more access to feeder space and more space per pig
5. Weight variation remains consistent (CV of 24%) throughout the pig's life
6. Weight variation is increased in disease positive farms and in farms that use continuous flow production compared to disease free farms and all-in all-out production

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EMERGING TOOLS IN ARTIFICIAL INSEMINATION

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ABSTRACT

Artificial insemination (AI) is arguably the single most important tool in improving swine genetics. AI units select and house boars who meet their customers' needs, and collect and process semen of adequate quantity and quality for insemination. Swine producers must efficiently use semen and labour to maximise the number of females pregnant, and the number of piglets produced per litter. Both the AI units and the swine producers must drive their suppliers to undertake the research and development necessary to improve performance. For the AI units this means more semen, stored longer and producing more inseminations per ejaculate. For the producers it means a higher conception rate and larger litters year-round. Both the artificial insemination units and swine producers must prepare for the markets of the future, which could include the need for sexed semen, transgenic pigs, and a major international export market.

INTRODUCTION

In North America in 1994, artificial insemination (AI) was used in 15% of all swine breedings. That number reached 50% in 1999 (Buhr, 1999) and AI is predicted to cover 80% of all breedings by 2005 (Burke, 2000). Over these same time periods, pork production systems continue to change, striving for greater production efficiencies and to meet the demands of consumers (for product and for the quality of production), niche markets, and legislators. The North American AI industry is in the challenging position of having to meet these rapidly changing demands during its own period of phenomenal growth. In addition, the "AI industry" has two parts: the AI units producing the semen, and the swine producers using the semen. Emerging tools for AI, then, are the implements, procedures and strategies that will start build on the best of today's foundations to produce the most, highest quality sperm and the most, highest quality pigs.

PRODUCING THE MOST, HIGHEST QUALITY SPERM

To produce and package the optimal number and quality of sperm, we have to look at both the boar and the processing of the semen.

The Boar

I. Genetics

A boar is typically selected for inclusion in an AI semen production unit based on his genetic potential to produce piglets of excellent growth and conformation, and perhaps to produce female offspring with good mothering traits. It is also becoming evident that he could be, and arguably should be, selected for his semen traits, although many relevant aspects of this are poorly understood. Certainly semen quality in diary bulls can be inherited (Mathevon, Buhr and Dekkers, 1998), and boars selected for 10-11 generations on large scrotal circumference produced more sperm than boars randomly selected for the same period (Huang and Johnson, 1996). These boars also had more efficient testes, producing more sperm per gram of testes than did the controls' testes, and the bottom line is that the boars produced between 4 to 14 billion more sperm per ejaculate when collected three times per week.

Seminal plasma (the fluid minus the sperm) is a large portion of a boar's ejaculate, and some of its components might affect fertility. Seminal plasma is rich in proteins, and some of these proteins might improve the conception rate in cattle (Thérien *et al.*, 1997; Sullivan, 1999). These proteins apparently differ from one male to the next. Inseminating a female with seminal plasma from some boars, but not from others, prior to inseminating with sperm improved the conception rate and litter size (Soede *et al.*, 1998; Waberski *et al.*, 2000).

Boars can also be responsible for transmitting undesirable genetic effects to their offspring. One genetic defect leads to small litters, and at least half of the daughters would also produce small litters were they bred (Makinen *et al.*, 1999). This defective gene has been identified and can be detected with DNA screening. Hunter and Greve (1996) suggested that sires can be responsible for intersex gilts (also called pseudoherrmaphrodites or hermaphrodites). These gilts have vulvas that tip upwards, and a variety of other, less obvious and less consistently present, physical and behavioural abnormalities that interfere with normal breeding and pregnancy. No gene in the sire has yet been positively identified as responsible for this trait, and so it can only be tracked back to sires through litter reports.

The swine industry can benefit by maintaining a proper perspective on these genetic aspects. First, genetic research can eventually identify beneficial genes, and the industry can select for them, moving into such technologies as marker-based selection. AI units can benefit the Canadian swine industry by using their data (litter reports, etc.) to identify, trace and eliminate pigs carrying deleterious genes. The new Canadian Association of Swine AI Units can discuss with representatives of the Canadian swine industry the pros, cons and costs of screening all boars entering an AI unit for genetic abnormalities. Such a regulation is in place in France, and Sweden is reportedly considering a similar recommendation (in Makinen *et al.*, 1999).

II. Nutrition

Nutrition probably affects semen production, although very little directed research has been done on swine. Diet alters the membranes of bull sperm (Buhr *et al.* 1993), and diets rich in linolenic acid improved the fertilising ability of rooster sperm either temporarily (Kelso *et al.*,

1997) or permanently (Blesbois *et al.*, 1997). A recent review (Wilson, 2000) noted that different genetic lines of boars probably have different dietary needs for optimal sperm production: for example, lysine's variable effect on libido may reflect the different genetic makeup of the boars studied. Proper mineral balance is critical for strong feet and legs in a breeding boar; vitamins, fibre and 'feeling full' may enhance sperm production by alleviating stress; mycotoxins are suspected to decrease sperm quality and fertilising ability (Wilson, 2000). All of these possible influences indicate a real need for some dedicated directed research into the impact of feed on sperm production.

III. Environment

The environment of the boar is made up of many parts, but certainly includes temperature, light and handling. There is no question that high temperatures damage sperm production (volume, sperm concentration and sperm quality) in animals like the pig that have a scrotum. When nearly 30 boars in an AI unit were evaluated over 2 years of tropical temperature ranges (minimal changes in daylength), the percent of motile sperm and the percent of normal sperm dropped from the cool to the hot season. Interestingly, there was a difference among breeds, with Landrace boars having more motile and more normal sperm in the hot season than Duroc or York boars (Huang *et al.*, 2000). Because the process of producing a sperm takes approximately 60 days in a boar, the effect of a heat episode (be it a heat wave or a fever), often is felt any time over the subsequent 6-8 weeks. The idea of air-conditioning an entire swine facility is probably not cost-effective. Since pigs cannot sweat, they naturally will wallow in cool wet places to help cool themselves when it is hot. Modern housing facilities cannot provide wallows, but some provide overhead showers (either pig-operated or management-controlled) to try to allow the pigs to compensate for hot days. These can be quite effective, but work best with good ventilation and must be evaluated in any one operation for its effect on the slipperiness of floors and the possibility of foot rot or similar health issues common to damp areas.

Pigs are sensitive to season, independent of the temperature. Day length is more important than light intensity (within reasonable limits), and is driven by the nature of the modern pig's ancestor, the European wild boar. Male piglets are slower to reach puberty in the spring than in the autumn, with the testes and certain other sex glands being more mature in 141-day old autumn pigs than the spring-reared pigs at the same age (Andersson *et al.*, 1998).

Housing and handling of boars is yet another area that is believed to affect sperm production, but there is little valid information available. Culling in AI units ought to be primarily for genetic reasons, and proper handling and housing can decrease the number of animals culled for injury or behavioural reasons. Boars in crates may have an increased frequency of leg problems compared to boars in pens, although boars in pens find it easier to masturbate which reduces sperm available for collection and sale. Bedding such as straw is also recommended, as it can reduce stress and improve comfort through reducing wetness, providing rooting material, and increasing the fibre in the diet. Straw bedding may or may not reduce leg problems, but must be obtained from a reliable supplier to protect biosecurity (Glossop, 2000). Many authorities recommend regular exercise, even if that is just running up and down alleys that are not wide enough for the boar to turn around. Optimal boar housing for sperm

production is not known, but increasing the comfort of the animal will reduce stress and improve the public perception of animal husbandry, both of which are beneficial to the swine industry.

IV. Health.

The health of the boars in an AI unit is of paramount importance in maintaining biosecurity in the swine herds served by the resident boars. In general, AI semen is far less of a health hazard than natural mating, as the boars are regularly health tested, the processed semen is treated to minimise bacterial contamination, and there can be no cross-contamination of uterine infection from one sow to another as is possible in natural mating when one boar serves multiple sows. However, there is also very clear documentation of semen from infected boars transmitting classical swine fever (deSmit *et al.*, 1999), Porcine Reproductive and Respiratory Syndrome Virus (PRRSV; Gradil *et al.*, 1996; Christopher-Hennings, 2000), and doubtless other viruses. A low percentage of the females inseminated with this semen developed the disease, but even one infected female is enough to infect and devastate a herd that was previously virus-free. Boars shedding the virus in their semen are frequently symptom-free, and thus the best way to decrease the transmission is to test boars with the highly sensitive new detection assays based on PCR technology. New and more effective vaccines are constantly being developed, and it is therefore possible to protect boars already in an AI unit. It is important to note that vasectomised boars can also be carriers of PRRSV, so producers must make sure to protect all the animals in their herds as well as insisting on the highest possible health standards from their semen providers.

Processing the Semen

I. The laboratory

A laboratory producing the highest quality semen starts with proper collection, carefully dilutes the semen with a solution ('extender') designed to maintain the sperm's fertility, and evaluates the quality of the semen before and after extension. In this way, the customer is provided with a product best able to maximise conception rates and litter size.

<u>Ia. Semen collection</u>

Semen is collected from a mature boar two or three times a week, using the gloved hand technique and having the boar mount a specially built 'dummy' sow. Proper collection procedures are outlined in several publications (e.g. Buhr, 1999). Briefly, the boar's prepuce is emptied of any retained fluid and the underline is cleaned with a disinfectant and then water, to reduce the chances of bacterial or other contamination. The disposable gloves are made of a non-spermicidal material and changed after cleaning the boar, between boars, and whenever they become soiled. It seems unlikely that an artificial vagina will be developed for boars in the near future, due to general satisfaction with current methods. Semen is collected into a container whose temperature is maintained at 35°C, to prevent the semen from experiencing a rapid temperature change. Boar sperm will easily suffer 'cold-shock' if abruptly chilled as

little as 3°C. Cold shock will kill or damage the vigour of sperm, and reduce the sperms' longevity (the length of time a sperm remains able to fertilise). Chilling injury can result from drafts in the collecting room, cold hands, an improperly warmed collection vessel, etc.

The sperm rich portion of the ejaculate is collected through sterile gauze to filter out gel particles. Gel particles in the semen will attract and bind the sperm and, if present in sufficient numbers, will reduce the fertilising ability of the semen by tying up the sperm. The person collecting the semen and/or handling the boar definitely influences the amount and quality of semen collected (Mathevon, Dekkers and Buhr, 1998). A good handler makes the animal comfortable, confident, and stimulated, and, by carefully noting the beginning and end of the sperm-rich portion of the ejaculate, collects all, and only, the sperm-rich fraction. The sperm-poor seminal plasma that precedes and follows the sperm rich fraction is currently collected separately and discarded, but may some day provide a value-added product for the AI industry. The seminal plasma of some boars will, when inseminated into some gilts and sows, enhance conception rates and litter size (Waberski *et al.*, 2000). When we understand what the important factor(s) is/are to stimulate the female response, certain boars may have their seminal plasma harvested for use as a fertility enhancement treatment.

Ib. Extender

The best extender is always a controversial topic, and commercial suppliers are always developing new products (e.g. Kuster and Althouse, 1999). There are usually approximately 3 billion (3×10^9) sperm in 70-100 ml of any extender plus antibiotics for one insemination dose, and most females are inseminated at least twice. Boar semen is currently extended in extenders described either as 'medium-term' or 'long-term', meaning that they will keep sperm viable for up to 3 days (72 hours) or up to 5 days (120 hours) from the day of collection, respectively. Most extenders recommend storage at approximately 16-18°C, and stored sperm should be gently remixed in the bottle every 24 hours. Carefully controlling the rate at which freshly-collected semen is cooled during processing can allow semen to be stored at a temperature not lower than 12°C (Althouse *et al.*, 1998). A producer needs to estimate when his females will be in heat, when the semen from the desired boars will be available, and ask the AI unit if they can supply semen that will meet those storage conditions. Everyone involved must recognize that the longer term extenders are more expensive, and boars are always different, so that some boars will produce semen that lasts quite differently when compared to semen from another boar in the identical extender.

A major problem for any comparison of any semen processing procedures is to get sufficient inseminations to adequately determine if the new treatment does indeed have an effect. This requires hundreds or thousands of inseminations, and so is frequently carried out at a commercial operation. A commercial unit needs adequate conception rates to remain economically viable, and so insemination is frequently done with 3 or more billion sperm in each of two or three inseminations. This is considerably more sperm than necessary to ensure maximal fertilisation, and so frequently an effect of a treatment is not seen because so many sperm used that their sheer numbers overwhelms any small but important difference among treatments (Tardif *et al.*, 1999).

Ic. Sperm dose

This brings up the interesting question of sperm dose - how many sperm are required to produce the most pregnancies with the most piglets. This is not an easy question to answer, as semen from different boars responds differently, and many other factors (timing of insemination, age of the female, etc) affects the success of the fertilisation. However, weaned sows inseminated with 1, 3 or 6 $x10^9$ sperm at a variety of times before ovulation had similar pregnancy rates, but there was a trend to bigger litters with more sperm (Steverink *et al*., 1997). Pubertal gilts induced to ovulate with PG600 had similar pregnancy rates and litter sizes with 3 and 0.3 x 10^9 sperm (Tardif *et al.*, 1999). All these results were obtained with 'normal' cervical inseminations, but progress in deep intrauterine inseminations may make inseminations with substantially fewer sperm economically viable. Prepubertal gilts induced with PG600 were surgically inseminated with 0.002 to 0.5 billion sperm placed directly into the oviduct. The lowest doses tended to reduce litter size and percentage of normal embryos, but did not affect conception rates (Krueger *et al.*, 1999). Producers are certainly not likely to widely embrace surgical insemination, but several commercial suppliers have designed and recently released a deep intrauterine insemination rod. This could permit insemination doses to contain fewer sperm while maintaining excellent conception rates and litter sizes, thus allowing more litters from the most popular boars. Such technology will also facilitate the use of sexed semen and frozen semen, and possibly embryo transfer.

II. Predicting fertility

Every semen processing lab assesses the freshly collected semen, measuring the concentration of sperm (usually by a spectrophotometer, Coulter Counter or haemocytometer), the volume of semen, and the percent of motile sperm by visual estimation of how many sperm are moving under a microscope. Many labs will at least occasionally evaluate sperm morphology, which involves microscopic examination and classification of the shape of at least 100 sperm from an ejaculate. If all freshly-collected ejaculates, regardless of apparent quality, are used for insemination, the fertility of the semen is related to the percent of motile sperm. This is particularly evident if the inseminations are done with a relatively low number of sperm. The conception rate in prepubertal induced gilts was correlated with visually-estimated motility when the gilts were inseminated with 0.3 x 10^9 sperm, but not when they were inseminated with 3 x 10^9 sperm (Tardif *et al.*, 1999). Much work has, however, confirmed that if the worst-quality ejaculates are eliminated from such a breeding trial, then the percent of motile sperm is only poorly correlated to fertility. In other words, in a group of medium-to-good quality ejaculates, a change in the visually evident motility does not necessarily lead to a change in fertility – and the same holds true for morphology. This means that the tools used to evaluate sperm quality do not relate to the single most important aspect of quality – the fertilising ability. Therefore there is considerable interest in developing a test that does predict fertility.

Several sophisticated sperm motility analysers are now available. These computer-assisted sperm analysers (CASA) machines can analyse many different aspects of sperm motility (how fast, how straight, how vigorous) and can even be set to analyse morphology. CASA machines are very expensive (normally over $50,000.00 Canadian), require a well-trained

technician, and require relatively expensive slides (but with these slides the machine can assess sperm concentration as well). When analysed in this way, some aspects of motility are related to both conception rate and litter size (Holt *et al.*, 1997). However, this analytical system is probably too expensive for most AI units. Other new tests are constantly being developed, found capable of differentiating among boars in the lab, but then do not succeed in predicting fertility (Tardif *et al.*, 1999; Holt *et al.*, 1997). Therefore AI labs continue to measure sperm quality by the best methods they have, but do so recognizing that there is little relationship of these measures to practical fertility. They therefore compensate by including more sperm than ought to be necessary in order to ensure that their customers have optimal conception rates and litter sizes, thereby sacrificing the number of doses produced. There will be a considerable market for the first inexpensive easy-to-operate semen quality analyser.

PRODUCING THE MOST, HIGHEST QUALITY PIGS

No artificial insemination programme (and no natural breeding programme, for that matter) is going to achieve maximum fertility if the females are not properly selected, handled and prepared, and if the semen is not properly handled and delivered into the female. New insights into these aspects are improving conception rates, litter sizes and piglet vigour.

The Gilt and Sow

Clearly there are differences between gilts and sows, most particularly with gilts being in heat a shorter time (Steverink *et al.*, 1999) and producing smaller litter (Peltoniemi *et al.*, 1999) than sows. However for optimal success in AI, gilts are not so different from sows and so all information here can be assumed to apply equally to both types of pigs – any differences will be clearly specified.

I. Selection and handling

Females entering the breeding herd can and should be selected for their estimated breeding value (EBV) for litter size. When sows whose EBVs for litter size were inseminated, their fertilisation rate days after breeding, and their percent of normal embryos, was related to their EBV and the number of piglets born (Steverink *et al.*, 1997).

Females, like males, experience seasonal changes in their fertility, due both to daylength and temperature. Gilts are up to 10 days older at puberty if they are growing through the spring and summer, so while the average age at first breeding is around 234 days, gilts reach puberty at 230 days of age between January-June, and at 237 days July-December (Peltoniemi *et al.*, 1999). Farrowing rates are lowest in August to September, although there is no difference in litter sizes in those sows that do farrow. The percentage of females coming back into heat after breeding is highest in August to November. This includes both those females presumed not to catch and coming back into heat around 21 days, and those that presumably got pregnant but lost the pregnancy, coming back into heat around 25-30 days (Peltoniemi *et al.*, 1999). The late return to estrus may be caused by high temperatures interfering with the

normal embryo-dam communication necessary to maintain an early pregnancy (Peltoniemi *et al.*, 2000).

Housing and feeding bred females, not surprisingly, affects their ability to hold a pregnancy. Newly bred sows housed in groups are more likely to come back into heat 25-37 days after breeding than are sows in stalls, probably because of the stress associated with establishing a social hierarchy (Peltoniemi *et al.*, 1999). This difference between group and stall penning is even more evident in the period of seasonal poor fertility. Interestingly, sows in stalls have more late abortions (55 – 107 days; Peltoniemi *et al.*, 1999) than group-penned sows, which may be related either to a lack of exercise or stress from behavioural frustrations. Straw bedding reduced the percentage of sows coming back into heat after breeding, and reduced the impact of season on fertility. Feeding roughage (hay or straw) similarly decreased the percentage of sows coming back into heat, suggesting that the effect of straw bedding may be either due to it serving as dietary roughage, or reducing stress by providing material in which the sows could root. (Peltoniemi *et al.*, 1999). Current recommendations are that sows should be full-fed through lactation until they are bred, and then intake should be restricted (Peltoniemi *et al.*, 2000). However, the restriction should not take the form of complete feed denial, as denying food to females for 48 hours after breeding slowed embryo development (Mburu *et al.*, 1998).

II. Insemination

Successful pregnancies depend upon vigorous sperm encountering recently-released eggs in the oviduct of the female. Behavioural heat precedes ovulation, being nature's way of increasing the chance that sperm will be present and waiting when the eggs are ovulated. For successful AI, or any controlled breeding system, the critical factors controlling successful conception and maximum litter size are the proper timing of insemination and the proper placement of semen in the tract.

<u>IIa. Timing of insemination</u>

Heat detection is critically important in the proper timing of AI. Heat detection is most successful if females are subjected to a back-pressure test in the presence of a boar once every 12 hours or more frequently; snout to snout contact with the boar is best, particularly for gilts. For sows, the weaning to estrus interval should be approximately 4 to 5 days (3.8 ± 0.6 days for 115 sows on one farm; 5.4 ± 3.5 days for over 12,000 sows on 55 farms, Steverink *et al.*, 1997, 1999). As this interval extends beyond 4 or 5 days, the actual heat period shortens, and conception rate and litter size decreases (Steverink *et al.*, 1999). The average length of estrus varies due to parity, season, weaning-to-estrus interval and farm management (Soede *et al.*, 2000), but can be thought to average 40 hours in gilts and 48 hours in sows, ranging from 12-88 hours (Steverink *et al.*, 1997).

The best conception rates and litter sizes are achieved when the female is inseminated anywhere from 24 hours before, to 4 hours after, ovulation (Waberski *et al.*, 1994), with ovulation occurring anywhere from 10-85 hours after the onset of estrus (Soede and Kemp, 1997) depending upon parity and farm. Ovulation can be assumed to occur approximately 2/3

of the way through the period of standing heat of the female, but that is not helpful because the length of estrus cannot be calculated until it is too late to successfully inseminate the female. However, sows within a farm have quite consistent estrus periods when the length of heat is calculated taking into account the days from weaning to estrus, so carefully kept records allow ovulation to be predicted with good results (Soede *et al.*, 2000).

Inseminating once in the 24 hours before ovulation with 3 x 10^9 sperm in a good extender within 48 hours of semen collection will fertilise 90% of all eggs released (Soede *et al.*, 2000). However, anything that reduces the number or quality of sperm in the oviduct, narrows that 24 hour window preceding ovulation. Therefore it is best to inseminate at least twice, 12 hours apart, in the period preceding the anticipated ovulation. Double inseminations on average improve farrowing rates (from 80.8 to 85.1% for sows and from 81.2 to 88.2 for gilts) and litter sizes (Steverink *et al.*, 1999). Inseminating as often as possible is not recommended, as inseminating late in estrus or just after the end of estrus can actually decrease the farrowing rate of gilts and second-parity sows, and decrease the number of total and live-born piglets in all pregnancies (Rozeboom *et al.*, 1997). In addition, the uterus in late estrus is less able to resist bacteria, and so late inseminations also increase the risk of uterine infections.

IIb. Insemination technique

What are the latest improvements in insemination techniques?

The use of seminal plasma is being explored from many different perspectives. Seminal plasma has been inseminated into females 12-24 hours prior to inseminating semen, and has also been used experimentally in place of an extender to dilute semen. Seminal plasma appears to stimulate a rapid response, presumably from the uterus, that speeds up ovulation in those females who regularly ovulate an extraordinarily long time after estrus (Waberski *et al.*, 2000). Ovulation after seminal plasma infusion in these sows then occurs much closer to the normal interval after the start of estrus. The effect is not consistent (Soede *et al.*, 1998) and may indicate a difference among boars in the exact nature of the stimulant they naturally produce in the semen. Certain boars stimulate, and others inhibit, embryonic growth from an early stage of development (Ramsoondar and Christopherson, 1998). Seminal plasma from some boars may have more of the component(s) that stimulate the uterus to protect the new embryos from the dam's immune system (Rozeboom *et al.*, 2000). Others have suggested that seminal plasma may contain compounds that stimulate uterine contractions, thus helping sperm to reach the oviduct (reviewed by Soede *et al.*, 1997). The lining of the oviduct prior to ovulation is deeply folded and produces viscous mucus (Mburu *et al.*, 1996) that readily traps and holds sperm in stasis for up to 24 hours awaiting the ovulated oocytes. These various studies all support the idea that seminal plasma has valuable components which might benefit establishment of pregnancy, but it is clear that both the components and their actions must be much better understood before commercial application is possible.

Injection of $PGF_{2\alpha}$ into the vulva tissue, or adding 5 mg into the extended semen just prior to insemination, may promote sperm transport to the oviduct and thereby enhance fertility (Pena *et al.*, 1998, 2000). Vulvar injection of $PGF_{2\alpha}$ increased average conception rate and litter size

(Pena *et al.*, 1998) and addition of $PGF_{2\alpha}$ to the inseminate improved the summer conception rate and annual litter size (Pena *et al.*, 2000). The authors suggested that $PGF_{2\alpha}$ might advance ovulation, but that it would be of little benefit in well-managed herds except perhaps in periods of seasonal infertility.

Backflow of semen during or shortly after insemination has long been a concern, but recent evidence suggests that some of the concern is misplaced (Steverink *et al.*, 1998). Semen backflow occurs within 5 minutes in 66% of all inseminations, and the volume lost in this time period contains the exact amount of sperm you would expect: if 70 ml of extended semen containing 3 x 109 sperm has been inseminated, and 5 ml flows back out in the first five minutes, there has been [5/70 x (3 x 109)] = 0.2 x 109 sperm lost. So if a large volume flows back out in the first 5 minutes, there is indeed cause for concern, but a small volume is not a concern. The female tract is very effective at moving sperm out of seminal plasma and up into the oviduct, and so backflow over the next 30 minutes, which happens in 98% of all inseminations, contains less and less sperm per ml fluid lost. In fact, Steverink *et al.* (1998) suggested that this backflow is one of the pig's natural mechanisms for removing the large volume of inseminate from the tract.

Many new devices are constantly being introduced. Some of them will be valuable to some operations, but not to others. There is no device that can completely substitute for good management, but many tools can improve many levels of management.

THE FUTURE

What will the future bring? Here's a list of a few insemination-related things that might be available to the swine industry within the next 10 years:

1. Sexed semen (Johnson and Welch, 1999). Producers will be able to purchase semen that will guarantee the sex of at least 85% of a litter.
2. Transgenic pigs (Niemann, 2000). These will be pigs that carry genes of commercial interest, which will most likely be pigs whose organs can be used for transplantation into humans with little or no risk of rejection.
3. The use of sperm to actually transfer genes of interest into eggs (Lavitrano *et al.*, 1997). This will facilitate the creation of transgenic pigs.
4. Low dose insemination. This has many ramifications, including more semen doses available from popular boars and less costly sexed or transgenic semen.
5. Embryo transfer (Day, 2000).
6. Frozen semen (Buhr, 1999; Ericksson and Rodriguez-Martinez, 2000). This will create an international export market for semen.

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MANAGING TODAY'S REPRODUCTIVE FEMALE

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INTRODUCTION

Successful breeding herd reproductive performance has become increasingly more difficult to manage during the past decade. Simultaneous advances have been made in pigs/sow/year, predominantly due to management, and in leanness (growth rate and carcass characteristic), predominantly due to genetics. Today, we are managing a more prolific, leaner, and larger mature sow than we did before 1990.

The substantial increase in production efficiency has not come with out some sacrifices. More and more operations are reporting cases of decreased sow longevity, anestrual problems, and inconsistency in overall conception or farrowing rates. Because a single infertile sow or gilt cannot influence overall reproduction to the extent that an infertile boar will, it's easier to overlook reproductive problems with the breeding herd until the problem is causing substantial economic loss. Management considerations in optimising female reproductive performance include genetics, nutrition, environment, health, stress and of course, breeding. However, reaching and maintaining reproductive performance targets extends beyond these factors to include: production scheduling, choice of a mating system, good record keeping, breeding barn design and skilled, proven personal. Presented here is comprehensive look at present management strategies for optimising breeding herd reproductive performance. Although each management factor listed here could in itself be addressed in much more detail, the following will briefly address a specific oversight in each area that should pertain to all swine farms.

MANAGEMENT CONSIDERATIONS FOR TODAY'S FEMALE

Genetics

There are numerous maternal lines used in the industry world-wide and although selection for prolificacy is common across all maternal line programs, selection pressure for changes in carcass lean and fat have been less consistent across maternal lines. In some maternal lines much progress has been made in decreasing fat and increasing muscle. For example, average backfat thickness in U.S. Yorkshires females decreased by about two tenths of an inch from 1991 to 1997 (Long, 1998). Several maternal lines used in the industry today are classified as "high-lean" (>.320 g per day fat-free lean, while other equally productive and useful maternal lines are slightly above "average" (270 to 320 g per day fat-free lean) in their genetic ability to deposit lean (Table 1).

Table 1. Variation in the physical maturation of gilts.

	Measurement		
	Wt, kg	Backfat, mm	ADG (kg) or Age (d)
NPPC Gilt Development Project-180 d (Long, 1999)			
▪ Line A	108.0	21.6	0.69
▪ Line B	106.1	23.6	0.72
▪ Line C	105.2	22.4	0.75
▪ Line D	112.5	24.9	0.74
▪ Line E	109.8	19.8	0.74
University of Minnesota-P1 Farrowing (H.Yang, 1998)			
▪ PIC Camborough 22™	165	15.8	329
NPPC Maternal Line Test-P1 Farrowing (Goodwin and Boyd, 1998)			
▪ Lowest Line	187	18.3	354
▪ Highest Line	215	25.4	370
Michigan State University-Puberty (Lyvers unpublished)	139	17.6	195

Lean growth curves are routinely used to plan nutrition programs for terminal market hogs, matching nutrients to lean and fat deposition potential. Growth curves have equal usefulness in rearing maternal line replacement females. Accurate estimations of lean and fat tissue accumulations several times during rearing provide targets at which nutritional programs can be aimed.

The genetic merit of the breeding stock that you choose in your operation should be documented and made available for you. Along with merit, the information provided should include some estimation of key behaviour characteristics that indirectly effect reproduction, which is commonly overlooked. Some examples of these behaviours include: (1) age at puberty for determining when to move gilts, induce estrus (PG600), and breed, (2) lactation feed intake under optimal conditions, (3) estrus length for gilts and sows in establishing insemination strategy, and (4) an estimate of female longevity. It is important to remember that farm-to-farm differences will exist and therefore validation of characteristics that indirectly affect reproductive performance will improve the management level of breeding females and the consistency of reproductive performance.

Gilt Development Programs

Research reports indicate that nutrition during the rearing (grow-finish phases) of the gilt may influence the length of her reproductive life. Feeding programs for gilts and sows should be

aimed at the female possessing a targeted amounts of body fat, bone, and lean at criticall points in time such as selection, first breeding or conception, parity one gestation, parity one farrowing, and parity one weaning. Maximum longevity is obtained by incorporating the best combination of nutritional regimes during the periods preceding each one of these events. The longevity of very lean genotypes may be improved by the provision of a moderate protein, high-energy diet during rearing and the longevity average lean genotypes may be improved by limiting energy intake during development. In the later case, energy restriction during rearing most consistently results in fewer feet and leg disorders. Disagreement among studies evaluating the effect of gilt body composition at first breeding on longevity suggests that controlled feeding and excellent management during acclimation and throughout parity-one gestation and lactation will lessen the effect of rearing practices on lifetime performance.

Sow Mortality

It is not uncommon to see typical herd mortality rates of between 5 and 10 percent or even greater in many swine operations. It appears that reproductive failure accounts for approximately 10 % of sow death in these operations (Geiger *et al.*, 1999), however, it is likely that a substantially greater number of females are culled due to a perceptive reproductive failure versus actually dieing. Fallouts due to reproductive failure or trauma are apparently difficult to control as numerous factors have been associated with both sow mortality and culling rates. Many of these factors are indirectly related to the areas discussed throughout this text, however, it is generally considered that that underlining determinant in most farms that have above average mortality and culling rates due to reproductive failure is largely related to failure in basic animal husbandry skills and observatory skills in the care of animals. We are obviously dealing with a much different animal today as well as different housing conditions in the US and Canada. Both of these changes should be considered in the management of animal movement, nutrition, health monitoring and treatment, and productively targets for effectively controlling economic losses from sow mortality and excessive non-genetic culling.

Nutrition

Perhaps the most influential nutritional affect on reproduction is the relationships between lactation feed intake and return-to-estrus interval (Reviewed by Einarsson and Rojkittikhun, 1993). Failure to recognize this relationship will result in increase non-productive sow days and inefficient pig flow through gestation and breeding. Increasing feeding frequency, avoiding excessive energy intake during gestation, high farrowing room temperatures and water restrictions are key management factors to consider when attempting to optimize lactation feed intakes.

Increase Feeding Frequency

When producers switch from feeding two times per day to three times per day, most experience a 10 to 15 percent increase in sow feed intake. There are some farms in North Carolina that actually feed four or more times per day in the summer. The main thing to remember is that when you increase the frequency of feeding, you must decrease the amount

that you feed each time. For example, if you are feeding 2.7 kg twice a day (5.4 kg total), then when you increase to three times per day, you may want to feed around 2.7 kg at the first feeding and 1.8 kg at each subsequent feeding (6.4 kg total).

The reason this strategy works is related to the normal increase in body temperature that occurs after a sow consumes a meal. Theoretically, there won't be as big an increase in a sow's body temperature after she eats 2 kg (as after she eats 2.7 kg) because there will be less feed to be digested. Consequently, this could be very important for sows whose body temperatures already may be in the upper end of the thermo-neutral range due to high temperatures in their environment.

Keep Feed Fresh

Sows tend to be picky eaters compared to most animals. In warm conditions, feed is more likely to spoil, especially if it contains high levels of fat. Increasing the feeding frequency in conjunction with feeding slightly smaller meals is an excellent way to keep feed fresh.

Try Wet Feeding

Wet feeding is a common practice to increase feed intake in many finishing operations and can be implemented during lactation. Success with this strategy may vary greatly among operations, but it has been reported to boost sow feed intake by as much as 15 percent. One drawback is that wet feed does not stay fresh in the trough for very long and molds will also accumulate without regular cleaning. It may be beneficial to acclimate females to this change of diet during late gestation.

Add Fat to the Diet

As a result of poor feed intake, many sows are not able to meet the metabolic demands of lactation and may fall into a severe negative energy balance. This factor probably accounts for most of the reproductive disorders during periods of elevated temperatures. One way to ensure that sows are consuming enough energy, even though they are eating a smaller quantity of feed, is to add fat to the lactation diet. Supplemental fat (7 to 10 percent animal or vegetable fat) will increase the dietary metabolic energy content of the feed.

There are two important considerations in adopting this practice. First, a diet containing high amounts of fat will become rancid more rapidly than a traditional diet with only 1 to 2 percent fat. Sows will not eat rancid feed. Therefore, feeding smaller quantities more often and smelling feed leftover in the sow feeder at each feeding to check for spoilage should be a standard practice. Second, because sows are consuming less feed, dietary levels of essential vitamins and minerals also need to be boosted to compensate for less feed consumed on a daily basis.

Give Water Constantly

High ambient temperatures will increase water requirements. Increased water consumption coupled with increased urinary water loss is one mechanism by which pigs lose body heat. An increase in ambient temperature from 12°-15° C to 30°-35° C will cause pigs to drink more than 50 percent more water. Nursing sows need to consume 30 to 40 litres of water every day, and gestating sows need 11 to 19 litres. One rule-of-thumb to follow is a water-to-feed ratio of 5:1. Fresh, constant water is also critical during breeding and gestation. The watering system should deliver a minimum of 1.0 litres per minute and ideally 2.0 litres per minute. Sows will quickly become frustrated if the flow rate is low, and this will reduce their appetite for dry feed. Water temperature and quality are also important. During periods of high temperatures, pigs will consume almost double the quantity of cool water (10º C) as warm water (27º C).

Reducing Embryo Mortality

Prenatal mortality may be as high as 40 percent in sows. The majority of this embryo loss occurs during the first two to three weeks following breeding. Factors associated with embryo loss include stage of pregnancy, disease, age of dam, genetic factors, nutrition, external environment, intrauterine environment, and stress—including heat stress. During the first 30 days following breeding, it is imperative that the following recommendations be put into effect to avoid increased embryo mortality:

1. avoid late estrual inseminations,
2. minimise unnecessary stress by mixing females only at weaning,
3. refrain from or even stop moving females in gestation to different locations, and
4. don't raise or lower feeding levels within the first 30 days after breeding with expectations of improving reproductive performance. Provide a good, level plane of nutrition during and after breeding. The strategies also should be used through the year.

Late Insemination

Following breeding, several processes occur to optimally prepare the uterus for implantation. A postbreeding inflammatory response occurs in the uterus of the pig to remove nonfertilizing spermatozoa and bacteria. In addition, during early to mid-estrus, uterine contractions help to physically remove the products of this inflammation.

The first step in limiting embryo loss is to avoid late inseminations. The simplest way to prevent late estrual inseminations is to ignore the "target" number of inseminations and breed females totally on the basis of a strong, standing heat response. Another way to reduce mistimed inseminations is to determine the average estrous length in your weaned sows, gilts, and repeat breeders and based on these averages, shorten the last insemination interval. For example, if you normally service sows AM day 1, AM day 2, AM day 3, change your schedule to AM day 1, AM/PM day 2. Thorough heat-checking before performing subsequent inseminations will help prevent poorly timed, late artificial inseminations, which may interfere with uterine preparation for implantation.

Mixing Females

Once fertilisation occurs in the oviducts, pig embryos descend into the uterus very 24-48 after ovulation. However, implantation does not occur until day 13 and full attachment not until day 28. During this time, the pig is highly susceptible to stress factors, such as movement and temperature. If females are to be mixed, this should be performed on the day of weaning to prevent unnecessary stress on the female. Any unnecessary stress following breeding can result in embryo detachment and loss.

Moving Females

After breeding and around day 30 of pregnancy, females may be moved to a different location; however, mixing sows and gilts at any time during or following breeding greatly increases the chances of subsequent embryo mortality. Temperature changes also are likely to increase embryo mortality, and during early pregnancy females should be protected from heat or cold in order to avoid unnecessary stress. Make sure that cooling and heating systems are routinely maintained and functional. You should have a backup system in place (i.e., hoses and spray nozzles) in case of equipment failures.

Nutrition

Sows and gilts should be provided enough feed following breeding to keep them on an even plane at maintenance levels or slightly above for thin females. The pre-mating nutritional status appears to be a greater determinant of embryo numbers and survival than post-mating ration in gilts. Using this strategy requires "flushing" them with an extra 1 to 2 pounds of feed during the estrus cycle before mating. This can be attempted for sows as well, though most postweaned sows voluntarily restrict their own feed intake. Keep in mind that high feed intake during the 30 days following breeding may have a negative impact on swine embryos, especially in pregnant gilts.

Because gestating sows are limit fed there are no extra measures to take in feeding during periods of heat stress. Just ensure the female is consuming feed daily (hopefully around 4 to 5 pounds, depending on diet formulation). Appropriate action to boost appetite may be required, similar to the procedures used during lactation.

Environment

Physical and social environment have been shown to influence reproduction. Management strategies that can reduced stress and allow for some social interaction with other animals will enhance the well being of animals and consequently, reproductive performance. Importantly, stress prior to, during, and following breeding can result in higher incidences of embryo mortality. One of the most common mistakes in management is a failure to recognise that during breeding and gestation, females are also susceptible to heat stress when temperatures reach and exceed 27 –29°C for short or extended periods of time (Flowers, 1997). Heat stress has its most detrimental effect on reproductive performance during two critical stages of the gestation period, the first 30 days and the last 30 days. Increasing ventilation rates, installing

cooling systems such as drip cooling, geothermal cooling or evaporative cooling systems are popular methods in alleviating heat related suppression of lactation feed intake.

Health

Identifying ways to reducing operational costs is generally considered a good managerial characteristic. However, the price for overlooking the complexity of herd health and its reproductive success can be high. During recent times, porcine reproductive and respiratory virus (PRRS) has been responsible for causing considerable amounts of reproductive failure on countless numbers of swine operations. Although there is still considerable controversy with regard to managing this disease, most would agree that management practices such as all-in-all out production, lengthy quarantine and testing, restricting people traffic, in-house gilt development, maintaining a closed herd, and vaccination (to a lesser extent) can all help reduce the impact of this and other reproductive syndromes.

Mycotoxins are also a common cause for reproductive failure in some herds, Aflatoxins and Zearalenone are most notable for causing reproductive problems which may include: estrogenic females, pseudopregnancy, embryonic death, and reduced piglet gain. Routine testing of feed samples and maintaining proper storage conditions for cereal grains are essential preventative measures for reducing the risks of mycotoxin problems. Although there numerous other health factors that can reduce reproductive performance (such as Lactation Failure (MMA) and Uterine Endometritis), today's female probably is not much different that females of the past with regard to the effect disease has or in controlling it. The only difference today compared to the past is that herds are often much larger and a simple depopulation is much less likely to solve the problem. Producers must be able to recognise and communicate potential health problems to their veterinarian or other professionals. Veterinarians are useful resources in evaluating breeding herd records, determining vaccination programming, periodic farm review, and training farm labour (injections, material handling, observations).

Production Scheduling

Season of the year, disease, environment, age, and genetic composition influence the number of females showing estrus and conceiving at a particular time. The number of replacement gilts needed to complete a farrowing group must be estimated in advance. As many as three replacement gilts may need to be selected during periods of stress for each farrowing crate to be filled. Keeping more gilts in the pool at any one time will increase the chance of obtaining more than enough pregnant females for a predetermined schedule. However, space in the gilt pool is often allotted based on the average annual need. Increasing the number of available gilts without simultaneously increasing space allowance most likely will result in additional stress on the gilts through crowding, which may ultimately increase the incidence of anestrus.

Potential Therapeutic Intervention

Historically, gonadotropins and progestens have been used with limited success to improve reproductive performance in swine. Nevertheless, application of these hormones in specific

swine management areas has helped reduce the reproductive lag associated with heat stress and negative energy balances during lactation. Hormonal strategies using PG600® (400 I.U. PMSG + 200 I. U. hCG), Regumate® (progesterone), and Lutalyse® (prostaglandin) may help counteract poor reproductive responses in limited cases. PG600® can be injected at weaning to stimulate follicular growth, speed return-to-estrus intervals, and reduce the incidence of anestrus. Some producers treat only problem groups of sows, such as those with low feed consumption during lactation or low parity, to improve the efficiency of this technology. However, cost is a major consideration, and this approach may show benefits only in herds where extended wean-to-estrus lengths (more than 10 days) or high frequencies of anestrus occur. PG600® is most commonly used to stimulate puberty in 175+ day-old pre-pubertal gilts. This is generally very effective and may also be useful during periods of high ambient temperatures to stimulate a first estrus in incoming gilts where cyclicity is suppressed. Lastly, prostaglandins, which are commonly used to induce parturition, are believed to speed uterine recovery when injected post-farrowing. However, prostaglandin used alone has not reduced the incidence of anestrus or extended wean-to-estrus interval (WEI).

Extended WEIs and anestrus following weaning in parity 1 sows are probably the most noticeable effect of poor lactational feed intake, short lactation lengths, and heat stress on reproduction. The combination of heat stress, parturition, lactation, and poor feed intake contribute to poor reproduction in all sows; however, P1 females also have a metabolic demand for growth. One strategy to minimise these impacts on overall herd reproduction is to adjust female replacement schedules to avoid large numbers of P1 farrowings during July and August. It may also be possible to treat this subpopulation of females with hormonal therapy during lactation and at the time of weaning to stimulate the reproductive system. A single injection of PG600® at the time of weaning has been effective in reducing WEI in sows. However, a recent field report suggests that a vulvular injection of 1/2 cc. of Estrumate (not currently labeled for swine use) within 24 hours after farrowing in conjunction with PG600® at weaning may be even more effective at reducing WEI and the incidence of anestrus than the use of either of these components alone.

Continual feeding of Regumate® (for 14 days) suppresses follicular growth and estrus until withdrawn. Regumate® usage appears to be useful in estrus synchronization of cycling females (especially gilts) and may be a useful strategy to improve reproductive performance after a short lactation in sows (feed the hormone throughout lactation and withdraw at weaning). In this situation, Regumate® is fed for 14 days and followed by an injection of prostaglandin on the morning of Day 15. But cost and the delivery system are major limitations of this regimen, especially if sows are not consuming feed during periods of heat stress. NOTE: Regumate® and Estrumate® are currently not approved for swine use and is produced in an oil-base form that is difficult to handle.

BREEDING STRATEGIES FOR TODAY'S FEMALE

The three direct areas of female management in the breeding process are heat detection, quality of insemination, and frequency and timing of inseminations. One of the most

common mistakes in managing these processes is in assuming that this is required to perform these tasks are easily learned. Dr. Billy Flowers conducted an evaluation of six different technicians' skills, as measured by experience, in 1995 (Flowers, 1995). The results from this evaluation showed that herd reproductive performance (as measured by the number of piglets produced from 230 matings) can vary significantly between breeding technicians, regardless of experience. Regardless of how many times a person has either supervised or performed a natural service or artificial insemination, some technicians will not succeed in producing a consistently high number of offspring from these matings. Therefore, careful supervising and evaluation of breeding barn personal, even the experienced technicians, is a must. Obviously, apples must be compared to apples, and therefore each individual technician should have equal opportunities in number of matings at similar times and under similar conditions to be fairly evaluated. Not everyone, regardless of their personality, experience and knowledge, will succeed in this area of reproductive management of females.

The use of AI can allow for a higher degree of quality control than natural service, specifically, semen quality and genetic improvements. AI users however, are totally responsible for fertile semen that is deposited into the uterus, which is unlike natural service where the boar controls these occurrences. Accurately timing multiple inseminations can be difficult and, is the fundamental in the success of AI. Missed timed inseminations leads to lower fertility and many of the problems associated with farrowing rate and litter size can be attributed to poorly timed and performed inseminations. Rozeboom *et al.*, (1997) showed that when the last of multiple inseminations is performed during late estrus, lowered farrowing rates and litter size will occur. A common mistake in many operations is a failure to ensure that female are actually in standing heat while performing what is considered to be the last AI. Direct female-to-male contact (at least nose-to-nose) at every heat check and breeding is a key components in effectively using multiple inseminations. Even though insemination frequency improves reproductive performance, breeding the sow when she's not longer in estrus does not. Become familiar of herd estrual behavior, implement an AI schedule and do not assume that it's correct for each female!

Counteracting the Negative effects of Reduced Lactation Lengths

Significant improvements in wean-pig diets, disease eradication strategies, and sow performance have simultaneously driven producers to gradually decrease average lactation lengths throughout the past decades. Many producers in the U.S. now wean sows between 18 and 21 days after farrowing, which is in striking contrast to the more traditional 42 day and 28 day lactation lengths in the 70s and 80s. Perhaps no other management decision can impact sow performance, facility utilisation and pig flow in a swine operation as much as lactation length. And even though there appears to be clear health and performance benefits for pigs following a short lactation length (12-14 d) there is at this point, physiological limitations to reducing lactation lengths much below 17 days while still achieving constancy in reproductive performance, return-to-estrus intervals, farrowing rate and subsequent litter size.

Early weaning (12-14 days vs. 18-24 days) has clear advantages to piglet health and growth performance. However, losses in reproductive performance may quickly negate these benefits and farm profitability could suffer as a result since realised benefits on sow performance are

much considerably less today when compared to large decreases in lactation lengths (i.e. from 5-6 weeks to 3 weeks) that producers implemented during the 70s and 80s. In herds that experience difficulty in maintaining consistent levels of sow performance after making the transition from a conventional to early weaning strategy, consider the following guidelines for managing the early weaned female:

1. Conduct a thorough retrospective analysis of your production records, identify the lowest lactation length tolerable on your specific operation and try not to deviate from it at weaning.
2. When weaning, reduce the range of lactation lengths so that most sows fall within a lactation length that is compatible with satisfactory reproductive performance for your operation (i.e. 14-16 days vs. 12-18 days).
3. Focus on maximising feed intake during lactation and reducing heat stress.
4. Identify sub-populations of females such as Parity 1 females or females with poor lactation feed intakes and provide extra lactation time or therapeutic intervention.
5. Carefully weigh the benefits of early weaning with the cost of reduced sow performance before converting from a traditional weaning system or construction of a new facility.

CONCLUSIONS

Today's female is considerably leaner, later maturing and larger, and more productive per farrowing. The most common mistakes in managing breeding females generally occurs when one fails to recognise that management changes must how accompany the physical and physiological changes of the female itself. Genetics, nutrition, health, environmental factors and to a lessor degree, breeding strategies, all have major influences on the reproductive dynamics, behaviours and reproductive performance of the breeding herd. The reason that very few farms consistently reach and maintain a high level of reproductive performance is because management fails to understand how changes in these management areas described here can impact reproductive process even though we are dealing with much different beast today than in the past.

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LUNCH BUCKET APPROACH TO ON-FARM FEEDING OF GROWER-FINISHER PIGS

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INTRODUCTION

Given the strong relationship between feeding management and profitability in the growing-finishing (G/F) barn, it is critical to pay close attention to the various aspects of developing effective feeding programs for G/F pigs. In this workshop the main aspects are discussed and illustrated with some examples.

The format of the paper and workshop follows the approach that should be used when reviewing the nutritional program used in the G/F phase for a swine producer or production system. A Swine Nutrition Audit program, developed in 1998 at Kansas State University, has been quite popular with producers. In a Swine Nutrition Audit, producers submit their close-out records, carcass information from the slaughter house, diet formulations, and ingredient prices. A farm visit is conducted to review other aspects of the nutritional program and prioritise the areas with the biggest opportunities for increased profit.

The key areas that need to be reviewed to determine the effectiveness of the feeding program for G/F pigs are as follows:

Record analysis
Diet formulation
Ingredient procurement
Feed processing
Feed delivery
Application in the barn
Simplification

KEY AREAS FOR REVIEW

I. Record Analysis

As most producers have moved to all-in, all-out systems, the quality of close-out records has improved immensely However, the importance of accurate records can not be overstated. Accurate data is essential for proper decision making for direction of the G/F nutrition program and to assess whether the program in place is being followed. The records that we use include close-out data, carcass information, and feed delivery records.

We use the records to make an assessment of normal production numbers, such as average daily gain (ADG), feed to gain (F/G) and feed cost per kg of gain. We try to adjust the numbers to a common base when comparing different producers. For example, feed efficiency is adjusted for in weight and out weight, the energy level in the diet, and the diet form using baseline targets, such as those presented in Table 1. These values should be used as upper limits for the feed efficiency targets. If your performance is not better than these values, diet formulation, feeder adjustment, particle size, or other issues need to be reviewed.

The ADG values must be taken in context of the available space in the system. A big question that must be answered is whether improved ADG would yield more profit for the system. In essence, are pigs able to achieve the optimal market weight with the available finishing space? The carcass grade and yield sheets from the packer also help in this assessment. However, market weights must be interpreted with caution. Some producers sell their pigs below optimal weights even though the finishing capacity is available to further increase shipping weights. The question of available space may change with season of the year and may drive your diet formulations to be different for some seasons versus others. For example, because ADG is reduced during the summer, the value of higher energy diets to drive ADG and technologies, such as Paylean (not [yet] allowed in Canada) increase during the summer months.

Table 1. Feed efficiency targets for G/F pigs consuming corn-soybean meal based diets.

		Meal diets		Pelleted diets	
Entry wt, kg	Market wt, kg	0% fat	5% fat	0% fat	5% fat
18	110	2.92	2.63	2.74	2.47
18	115	2.97	2.67	2.79	2.51
18	120	3.02	2.72	2.84	2.55
23	110	2.97	2.67	2.79	2.51
23	115	3.02	2.72	2.84	2.55
23	120	3.07	2.76	2.89	2.60
28	110	3.02	2.72	2.84	2.55
28	115	3.07	2.76	2.89	2.60
28	120	3.12	2.81	2.93	2.64

From the packer kill sheets, we also try to assess carcass leanness. This data may be needed in the review of diet formulations if other data is not available.

The other records that are used is feed delivery information. Our main goal in reviewing the total tons of each diet delivered to each group of G/F pigs is to determine whether the feed budget is being followed or if particular diets are being over or underfed.

II. Diet Formulation

In reviewing diet formulas, numerous issues must be considered. Given the cost of protein (lysine and other essential amino acids), energy and phosphorus in pig diets, careful consideration must be given to feed formulation. It is usually appropriate to consult a qualified nutritionist when developing specific feeding programs for individual pig units. The keys to diet formulation for finishing pigs are as follows:

a. Determine the appropriate lysine to energy ratios in the various diets, which will allow you to set the target dietary levels for lysine and other amino acids.
b. Determine the appropriate energy level in the diet- appropriate energy levels may vary whether the goal is to meet nutrient needs at as low of cost as possible (e.g. minimise feed cost per kg of [lean] gain) or to maximise return over feed cost (e.g. maximise profit per pig place in the barn).
c. Carefully review any "extra" feed additives that increase cost.
d. Consider environmental impact of formulations and make sure that meat quality is not reduced by the feeding program.

II.a. Set targets for dietary lysine to energy ratios

The lysine to energy ratio should vary with pig type, management conditions, economic conditions and production objectives. Once target lysine to energy ratio are established, target levels for other amino acids and phosphorus can be estimated easily as well. Various approaches, that differ in complexity, may be used to set target lysine to energy ratios:

1. Conduct full-scale nutrition experiments where pigs are fed different diets and the animal response is closely monitored. This requires a major commitment and accurate data collection. If experiments are not conducted correctly, results can be misleading and efforts are wasted. This approach is valid for very few large operations with units dedicated to experimentation. Producer groups with common genetics and production systems should consider joining together to build research barns to conduct appropriate large-scale trials under field conditions.

2. Establish lean tissue growth and feed intake curves, based on weighing and scanning with real-time ultrasound of representative groups of pigs at regular intervals. This approach is quite critical when multiple phase feeding programs are considered, i.e. to establish the optimum diet composition for the various stages of growth. It requires expertise in taking and interpreting real time ultrasound measurements, and deriving lean tissue growth curves and feed intake curves. For establishing lean tissue (and fat tissue) growth curves, a group of 40 representative pigs (per sex) should be weighed and scanned every 3 weeks, to obtain at least 5 and preferably 6 data points covering the entire body weight range in the G/F barn. Feed intake curves may be established directly, or indirectly based on estimated dietary energy requirements for lean tissue growth, fat tissue growth and maintenance. Feed intake curves may be established directly based on observations from the same number of animals as required for establishing lean tissue growth curves (using software like PorkMa$ter: a com-

puterized performance monitoring system for grower-finisher pigs) or based on total feed usage for the entire G/F pig unit.

3. Standardized or practical version of approach 2. Derive average lean tissue growth rates over the entire G/F period and use some standard lean tissue growth curve shapes to estimate farm-specific lean tissue growth curves. This approach is used by NRC (1998) and may be combined with estimates of feed intake (see approach 2) to derive estimates of optimum energy to lysine ratios.

In Canada, for the calculation of average fat-free lean gains for groups of G/F pigs the following information is required:

1. average body weight (kg) when pigs enter the growing-finishing barn,
2. average hot carcass weight (kg),
3. average lean content (%) in the carcass (unfortunately this is now given as a percentage of cold carcass sides, rather than the hot carcass; see assumption 2 below), and
4. the average number of days required to grow pigs from initial to final body weight.

Two assumptions are required:

1. The lean content in pigs at the initial body weight. This value is unlikely to vary much between pig genotypes at body weights between 15 and 30 kg. It may be predicted from body weight:

$$\text{lean content (kg)} = 0.441 \times \text{live body weight (kg)} - 1.751.$$

2. The difference in weight between the weight of the hot carcass and cold carcass sides. This represents the weight of the head, feet, kidney, leaf fat and some drip losses that may occur. Based on the results of the Ontario Pork Carcass Appraisal project (Courtesy Dr. John Gibson, U of Guelph; data from more than 1700 pigs) the weight of the cold carcass sides can be predicted using the following equation:

$$\text{weight of cold carcass sides (kg)} = 2.400 + 0.867 \times \text{hot carcass weight (kg)}.$$

For example, in a G/F pig unit, pigs are entered at 26 kg body weight, pigs require, on average, 110 days to reach market weight, have an average hot carcass weight of 86 kg and a lean yield of 60.5%. In this example, the amount of lean in the pigs body at initial body weight is 9.715 kg (0.441 x 26 - 1.751). The weight of the cold carcass sides is 76.962 kg (2.400 + 0.867 x 86). The amount of lean in the carcass is 46.562 kg (76.962 x 60.5/100). The lean gain is 335 g/d ([46.562 - 9.715] / 110 = 0.335 kg/d x 1000).

To be consistent with NRC (1998), this average lean gain needs to be converted to average fat-free lean gain. Since lean gain, according to the Canadian conditions contains about 10% fat, average lean gain should be multiplied by .90.

Based on average lean tissue growth rates, optimum levels of lysine and other amino acids may be derived from NRC (1998), (e.g. Table 2).

Table 2. Effects of body weight, fat-free lean gain and feed intake on true ileal digestible lysine (Lys) and threonine (Thr) and available phosphorus (av. P) requirements when fed a diet containing 3400 kcal/kg DE and according to NRC (1998). If diet energy density differs the target nutrient levels may be changed proportional to diet energy density.

	Feed intake 90% of NRC			**Feed intake 80% of NRC**		
Fat-free lean gain (g/d)	Lys (%)	Thr (%)	Av. P (%)	Lys (%)	Thr (%)	Av. P (%)
			30 kg body weight			
400	1.09	.68	.24	1.07	.68	.24
350	.96	.61	.24	.94	.60	.24
300	.83	.53	.24	.81	.52	.24
			75 kg body weight			
400	.81	.52	.17	.87	.56	.17
350	.71	.46	.17	.76	.49	.17
300	.62	.40	.17	.66	.43	.17

Nutritionists at Kansas State University use all three approaches depending on the information available from the particular producer. If the producer is not a member of a production group with research barns (approach 1) and serial ultrasound curves are not available (approach 2), they use a short-cut approach that they have developed to determine the appropriate diet lysine to energy ratio from the NPPC fat free lean index information that U.S. producers receive on their kill sheet. The concept uses a standardized approach to determine protein accretion from the fat free lean index, as published by Schinckel and de Lange (1996). Fat accretion curves were developed from data developed at the Prairie Swine Center (Lorschy *et al.*, 1997) and from data that we developed in the field. Their data allowed for the conversion of backfat to percent body fat. Data that we developed in field allowed calculation of a linear regression of increases in backfat as body weight changes. Thus, we could determine fat accretion on a daily basis. Using the protein and fat accretion curves, energy intake can be estimated. The influence of changing growth rate and fat-free lean index was modeled. Growth rate did not have a major impact on the predicted optimum diet lysine to energy calorie ratio. Thus, we obtained estimates of the target diet lysine to energy ratio based on fat free lean index alone.

There are two main problems with approaches 2 and 3. First, you rely on estimates of the amount of dietary lysine required for each incremental unit of protein accreted. Research in this area is not always in agreement. For example, NRC relies on an estimate that for each gram of protein accretion, 0.12 g of true digestible lysine is required. The two numbers that go into this calculation are the lysine content of body protein and the efficiency of utilisation of true digestible lysine for protein accretion. Research in commercial G/F barns indicated that the value from NRC (0.12 g of lysine per gram of protein accretion) will overestimate the lysine requirement and that the value may be closer to 0.11 g. The second problem with approaches 2 and 3 is getting a good estimate of energy intake. Recent equations published by Noblet *et al.* (1999) appear to match feed intake measurements in the field more appropriately than equations published in NRC (1998).

II.b. Establish optimum energy density

Another important concept in feed formulation is the concept of optimum diet nutrient density. Two aspects should be considered: the cost of nutrients and the relationship between diet nutrient density and daily nutrient intake. Rather than evaluating diets based on cost per ton of feed, it is important to consider the diet nutrient density at which the cost per unit of nutrients (energy balanced with other nutrients against energy) is the lowest. This can be evaluated by formulating diets that differ in nutrient density, e.g. increase or decrease the target diet nutrient content all in the same proportions, and calculate the cost per unit of energy at each of the diet nutrient densities. The diet with the lowest cost per unit of nutrients will generally results in the lowest cost per kg of body weight gain.

However, when the value of throughput in the pig unit is considered, there is value to increasing the nutrient density to levels that are higher than those in diets that yields the lowest cost per unit of energy. This is because an increase in diet nutrient density will increase the daily nutrient intake, and as a result growth rate will increase. This is particular applicable to young pigs, up to about 60 kg body weight. It may also apply to finishing pigs that are managed under practical conditions, e.g. that are crowded or that are under mild heat stress.

In these considerations, the producer's production goal must be established. The question to ask is whether the goal is minimise production costs per kg of gain or the maximise profit over feed cost. Because of the importance of energy intake in driving average daily gain and market weight, high energy diets can often increase margin over feed cost and, thus, net profit, while not being the lowest in feed cost per kg of gain.

The following example illustrates the impact of adding extra energy to the diet (as dietary fat in this example) in field conditions on feed cost per kg of gain and return over feed cost.

Value of energy density example.

The data used in this example is from an experiment conducted in a commercial research facility using 480 pigs to determine the influence of fat additions to the G/F diet on pig performance and carcass composition. The four dietary treatments were based on increasing added dietary fat (0, 2, 4, or 6%). Diets were corn-soybean meal based and fed in three phases. Within each phase, identical lysine to energy ratios were maintained among the experimental diets. The lysine to energy ratio was decreased in each subsequent phase and as pigs became heavier.

A brief summary of the response to fat is shown in Table 3. The influence of added fat on pig performance is listed as the percentage improvement over the control diet. The influence of added fat on ADG was greater (1.5% for every 1% fat) and more consistent during phase 1 than during subsequent phases. Overall, addition of each 1% fat resulted in approximately a 1% increase in ADG. The negative influence of added fat on ADFI became greater as the trial progressed with approximately a 1% reduction in ADFI for every 1% added fat. The most consistent response to dietary fat was the improvement in F/G. Every 1% addition of fat

resulted in approximately 2% improvement in F/G. Not only was the F/G response to added fat consistent among the three phases, within each phase, increasing added fat from none to 2, 4, or 6% resulted in a 4, 8, and 12% improvement in F/G.

Table 3. Percentage response in pig performance to each 1% increment of added dietary fat.

Item	ADG	ADFI	F/G
Phase 1 (36 to 59 kg)	1.50%	-0.80%	-2.00%
Phase 2 (59 to 95 kg)	0.80%	-1.10%	-1.60%
Phase 3 (95 to 120 kg)	0.60%	-1.30%	-1.90%
Overall (36 to 120 kg)	0.83%	-1.10%	-1.84%

To further examine the value of fat for an individual production system, we will consider a series of six G/F diets, phase fed from 27 to 110 kg (Tables 4 and 5). In Table 4, the average prices from a 5-year price series from 1994 through 1998 were used to determine the economics of adding fat to each individual phase. Because fat price can vary considerably depending on the method of purchase and handling, we also present a similar analysis in Table 5 with an extra $.02/lb added to the fat price. This $0.02 handling charge allows us to evaluate the sensitivity of the economic scenario to a small change in fat price. Using the prices without the handling charge (Table 4), feed cost per pig decreases slightly in the first three diets (27 to 74 kg) as fat is added to the diet. From 74 to 120 kg, feed cost per pig increases slightly, such that for the overall period, there was no difference in feed cost for pigs fed corn-soybean meal based diets with or without 6% added fat. However, because of the extra weight gain, adding fat to the diet increased return over feed cost for every dietary phase. The return ranged from an extra $1.23 when adding fat to the diet for pigs weighing 27 to 45 kg to $0.02 for pigs weighing 99 to 120 kg. This is because the response in ADG was greatest in the early phases compared to the later phases. The other cost that must be considered is the potential negative effect on carcass premiums. Recent research from Kansas State University suggests that if a decrease in carcass premium is discernible when fat is added to the diet under field conditions, it is only because of the fat added during the last dietary phase from approximately 99 kg to market weight.

The data in Table 5 demonstrates the impact of a small change in fat price on the economic scenario. By adding $0.02/lb to the price of fat, adding fat to the diet will no longer reduce feed cost during any phase. Feed cost per pig is increased by $0.05 to $0.22/phase or $0.63 per pig if added for every G/F phase. Thus, if space was not limited, adding fat to the diet would increase production cost. However, because of the increased weight gain with added fat; it is still economical at the higher price in systems that are limited in space. In this scenario, adding fat to the diet would increase margin over feed cost for every diet from 27 to 99 kg. The only phase that would realise a net loss by adding fat to the diet is the last phase from 99 to 120 kg. The improvement in daily gain during this last phase is not great enough to overcome the increased feed cost.

This example demonstrates that economic analysis of a dietary program should not focus on feed cost per pound of gain alone. More inclusive measurements of profitability need to be

included. Margin over feed cost is a relatively easy value to calculate and provides a more complete picture of the impact of a dietary change on profitability. Similar cases can be presented where slightly higher lysine levels or feed additives, such as Paylean, will increase feed cost per pound of gain, but still be more profitable because of higher margin over feed cost.

II.c. Feed additives

The cost of additives (antibiotics, extreme fortification with vitamins and minerals, etc) in G/F pigs diets can be substantial. The value of these additives should be questioned at regular intervals, considering solid scientific evidence demonstrating their value, health problems and environmental management. Some technologies, such as synthetic lysine and phytase, can decrease nutrient excretion and lower feed cost. Conversely, other additives in the G/F area, such as antibiotics, often must pay for themselves through reduced death loss or decreased variation, which is much more difficult to quantify. Feed additive (antibiotics, etc) use on commercial farms is often much higher than specified in diets and can consume a big chunk of profit for our commercial producers compared to many integrated systems. A typical problem that can occur is that the producer experiences a problem in the G/F barn and adds a particular antibiotic, which quickly becomes a routine procedure for all subsequent groups instead of being removed from the diet after the problem is under control.

II.d. Consider Environmental issues

In regions where the negative impacts of pigs on the environment is a concern, diets may be modified to reduce the excretion of nitrogen (reduce diet protein levels by replacing protein sources with synthetic amino acids), phosphorus (include phytase, the enzyme that enhances phosphorus availability in feed ingredients of plant origin), or odourous compounds (feed additives that may influence microbial fermentation in the pig).

III. Ingredient Procurement

In choosing the proper pig feed ingredients various aspects should be considered, including available nutrient content, variability, effect on diet palatability, effect on carcass and meat quality, contamination with compounds such as mycotoxins, storage and handling, availability and cost.

In terms of nutrients, the content of available amino acids, energy and phosphorus should be considered. Tables are available that provided average contents of true ileal digestible amino acids, digestible energy and available phosphorus for the most common pig feed ingredients. Routine sampling of ingredients (at harvest time) for content of dry matter (water content should be considered before any other nutrient), protein (can be used to estimate amino acid content) and fiber (NDF, neutral detergent fiber) is recommended. Depending on the ingredient additional analyses may be conducted, such as fat (high oil corn, full-fat soybeans), ash, calcium and phosphorus (meat meals, mineral sources), mycotoxins (corn and wheat samples).

Table 4. Example of economic decision on adding fat to the G/F diet by phase of production [a]

Weight		Feed Budget, lb/pig		Feed cost, $/pig			Feed cost, $/lb of gain		Extra gain from fat		Value of fat
Initial	Final	With fat	No fat	With fat	No fat	Diff.	With fat	No fat	lb/pig	$/pig	$/pig
27	45	34.5	39.0	$6.30	$6.34	$.04	$0.161	$0.163	3.99	$1.19	$1.23
45	60	34.5	39.0	$6.05	$6.07	$.02	$0.178	$0.179	2.73	$0.77	$0.79
60	74	34.5	39.0	$5.69	$5.70	$.01	$0.184	$0.184	1.89	$0.51	$0.52
74	87	34.5	39.0	$5.45	$5.44	($.01)	$0.195	$0.194	1.21	$0.32	$0.31
87	99	34.5	39.0	$5.27	$5.25	($.02)	$0.203	$0.202	0.7	$0.18	$0.16
99	120	68.0	77.1	$10.11	$10.07	($.04)	$0.215	$0.214	0.24	$0.06	$0.02
				$38.87	$38.87	$0.00	$0.190	$0.190	10.8	$3.03	$3.03

[a]Average 5-year prices from southern Minnesota were $2.51/bu corn, $207/ton SBM, $0.158/lb fat, and $0.46/lb market hog price.

Table 5. Example of economic decision on adding fat to G/F diet by phase of production with $0.02 handling charge on fat [a].

Weight		Feed Budget, lb/pig		Feed cost, $/pig			Feed cost, $/lb of gain		Extra gain from fat		Value of fat
Initial	Final	With fat	No fat	With fat	No fat	Diff.	With fat	No fat	lb/pig	$/pig	$/pig
27	45	34.5	39.0	$6.39	$6.34	($.05)	$0.164	$0.163	3.99	$1.19	$1.14
45	60	34.5	39.0	$6.14	$6.07	($.07)	$0.181	$0.179	2.73	$0.77	$0.70
60	74	34.5	39.0	$5.79	$5.70	($.09)	$0.187	$0.184	1.89	$0.51	$0.42
74	87	34.5	39.0	$5.54	$5.44	($.10)	$0.198	$0.194	1.21	$0.32	$0.22
87	99	34.5	39.0	$5.36	$5.25	($.11)	$0.206	$0.202	0.7	$0.18	$0.07
99	120	68.0	77.1	$10.29	$10.07	($.22)	$0.219	$0.214	0.24	$0.06	($0.16)
				$39.50	$38.87	($.63)	$0.193	$0.190	10.8	$3.03	$2.40

[a]Average 5-year prices from southern Minnesota were $2.51/bu corn, $207/ton SBM, $0.178/lb fat ($0.158/lb plus $0.02 handling charge), and $0.46/lb market hog price.

Based on ingredient specific effects the inclusion level of some ingredients may be limited, such effects on diet palatability (canola meal), carcass quality (full fat soybeans).

To assess the actual value of pig feed ingredients, least cost – or best cost – feed formulation systems should be used. These systems provide information on the actual financial value versus the actual cost based on the costs of other ingredients.

Optimal purchasing of ingredients is essential to control the cost of the G/F feeding program. Reviewing ingredient costs with individual producers yields different ingredients that need work. Understanding of budgets and diet formulas help put the different ingredients in perspective relative to cost. A mental model that can be used to prioritize efforts in managing feeding programs to increase return is depicted in Figure 1. This two dimensional graph can help improve understanding of where opportunities for cost savings exist. The percentage of feed cost contributed by various ingredients is depicted along the horizontal axis. The opportunity margin is depicted along the vertical axis. The opportunity margin is defined as the average percentage of each component cost that may be available for increasing net profit. The opportunity margin is derived from either reducing ingredient cost or changing usage of that ingredient to reduce feed cost or increase revenue. Therefore, the area of each box represents the opportunity for profit by reducing the cost of a particular ingredient.

As expected, corn and soybean meal comprises the largest percentage of feed cost. However, the opportunity from lowering corn or soybean meal price is usually small such as $0.10 per bushel of corn or $10 per ton of soybean meal. However, because of the large area of opportunity with corn, soybean meal, and fat, usage of these ingredients drives a large share of a nutritionist's focus on lysine and energy requirements in swine diet formulation. Obviously, other energy and protein sources can be substituted for corn and soybean meal in this graph depending on local prices and manufacturing situations. The next area that usually results in a large opportunity is feed manufacturing. The impact of feed manufacturing and delivery will be further detailed in a subsequent section. The next three opportunity areas are pelleted diets (starter diets fed to pigs weighing less than 7 kg), vitamin premixes, and to a lesser extent the specialty nursery diet ingredients of whey, fish meal, or blood meal. There is little centrally reported pricing for these ingredients, thus, fairly large differences in pricing exist in the market place. Secondly, the composition and quality of these ingredients varies greatly, leading to difficulties in making accurate price comparisons. Thirdly, usage has an impact on the opportunity cost. For example since the pelleted diets are usually much more expensive than the average diet cost, small unneeded increases in usage lead to large increases in cost without improvements in net return. Feed medications are also in this category, however, pricing is usually fairly consistent and the opportunity lies in medication selection and amount used. An ingredient that we have found a fairly large opportunity is salt. Two factors are responsible. The first is the grade of salt fed. Sometimes the design of the feed mill cannot handle a feed-grade salt and a free-flowing food grade must be utilized. The second is that since salt is such a low cost ingredient per kg, transportation costs has a large impact on opportunity. The final significant area of opportunity is the phosphorus source. Most of the opportunity for this component results from efficient transportation or purchasing and quantity discounts.

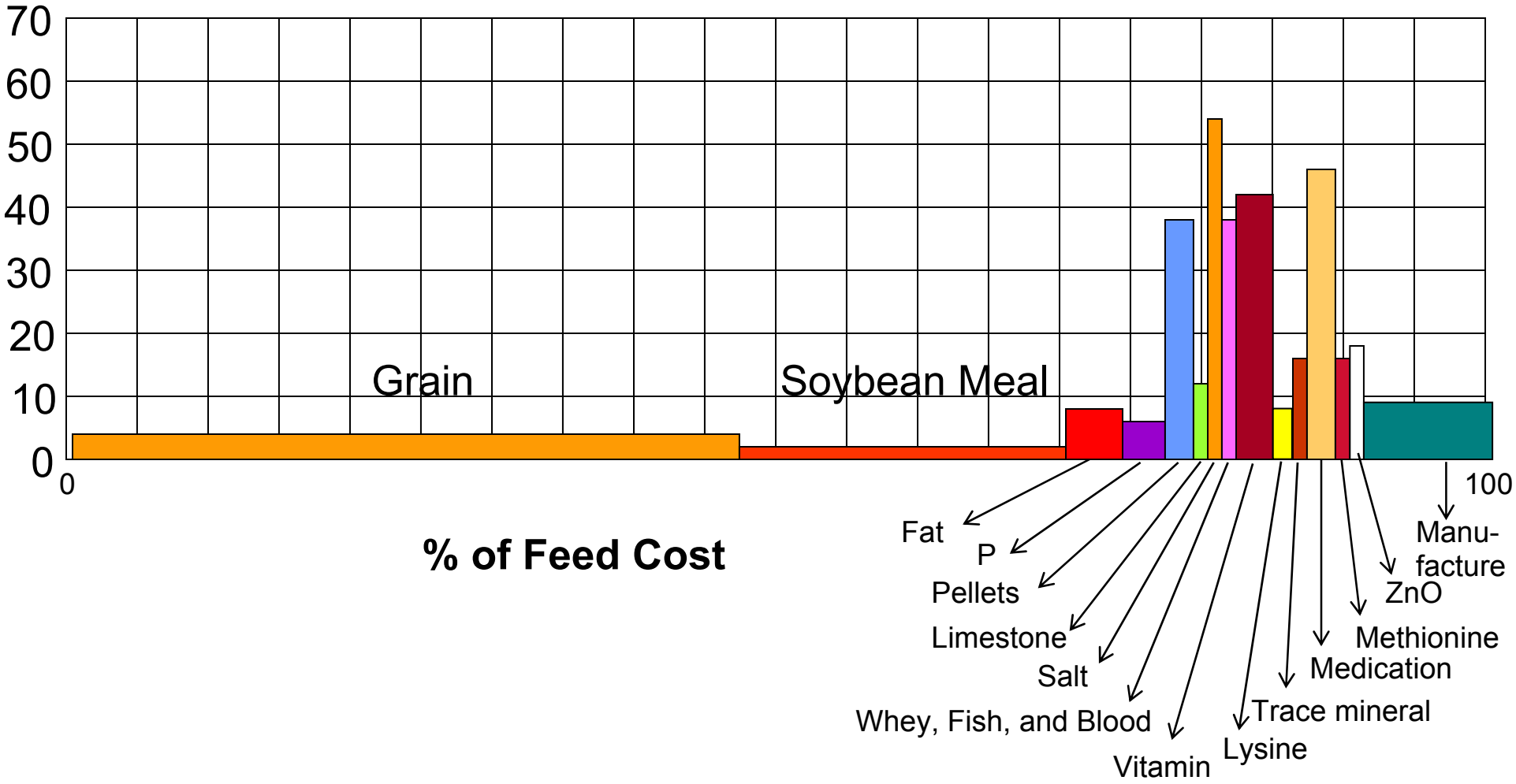


Figure 1. Opportunity margin for various parts of the feeding program.

IV. Feed Processing

The main areas of concern in the feed processing area are feed manufacturing cost, particle size of the grain, and diet form (pellet or meal) being fed.

Feed Manufacturing Costs

On-farm feed manufacturing costs from a study of 17 Kansas Swine farms conducted by the Grain Science and Agricultural Economics Departments at K-State are listed in Table 6 (Herrman *et al.*, 1997). First, note the large range in costs of $11.85 per ton between the highest cost farm and lowest cost farm. This represents $4.38 difference per pig. Secondly, observe that the difference in feed manufacturing costs from 1 standard deviation (SD) above to 1 SD below the average is $2.59 per pig. The impact of the differences in feed manufacturing costs is examined in the last two columns. The first column is based on the assumption of a farm with average feed manufacturing costs having the same profitability as the 10-year average profitability from the Iowa State swine records summary. Note that if it is assumed that the farm has the lowest feed manufacturing cost, profit will increase by 10.4%. Conversely, farms with the highest cost will have 17.6% lower profit than farms with average feed manufacturing costs. An alternative scenario using a profit of $5 per pig for the category with average feed manufacturing cost is examined in the last column. As profit margins decrease, the importance of lower manufacturing costs becomes magnified.

Table 6. Feed Manufacturing Costs from 17 Kansas Swine Farms in U.S. Dollars[1] .

Category	$/Ton	$/Pig Marketed	$/cwt Live	Average Profit Change Impact	Low Profit Change Impact
Highest	$ 15.49	$ 5.73	$ 2.29	-17.6%	-55.0%
Plus 1 SD	$ 11.56	$ 4.28	$ 1.71	-8.3%	-25.9%
Average	$ 8.06	$ 2.98	$ 1.19	0.0%	0.0%
Minus 1 SD	$ 4.56	$ 1.69	$ 0.67	8.3%	25.9%
Lowest	$ 3.64	$ 1.35	$ 0.54	10.4%	32.7%

[1]Feed manufacturing ($/ton) costs reported by Herrman *et al.*, 1997. The $/pig marketed assumes that 335 kg of feed is required to produce 1 market pig. The $/cwt assumes an average live market weight of 114 kg. The profit change scenarios were calculated using the average profit per pig for the 1985-96 10 year Iowa State University Swine records.

Particle Size

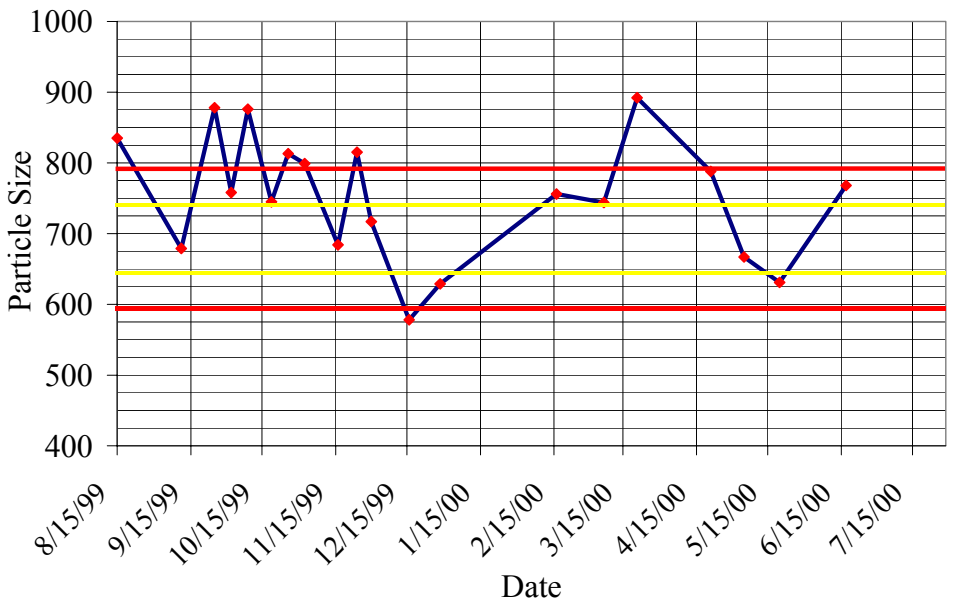
Another opportunity area for improving net return is grain particle size reduction. A summary of research from Kansas State (KSU Swine Nutrition Guide) indicates that for every 100 micron decrease in average particle size, feed efficiency improves by 1.2%. This results in approximately a $0.40 to $0.50 improvement in feed cost per pig for every 100 micron reduction in average particle size. The research is clear that reducing particle size improves energy utilisation and feed efficiency. However, implementation of the proper particle size is a problem in many feeding programs. Without continual monitoring, particle size is difficult to maintain in the optimum range of 600 to 800 microns. Listed in figure 2 are the particle

size analysis results for 9 months from one production system. Based on these analyses this production system incurred approximately $50,000 in lost opportunity because of particle size in excess of 750 microns.

Diet form

Producers often have questions on the value of pellets versus meal for G/F pigs. Literature indicated that pelleting the diet will improve ADG from 3 to 8% and feed efficiency from 5 to 8% in the G/F phase in pigs fed corn and soybean meal-based diets. If byproducts such as wheat shorts are used, these effects are slightly larger. Pelleting allows a greater range of ingredients to be used in the diet. The biggest problem with pellets in the field is pellet quality. In experiments of Stark *et al.* (1994), feed efficiency tended to decrease as the amount of pellet fines was increased in the diet until pigs fed diets with high concentrations of fines (between 20 and 40%) were no more efficient than pigs fed the meal control. In a similar experiment, Amornthewaphat *et al.* (1999) reported a linear decrease in efficiency of growth of G/F pigs as pellet fines was increased from none (7% greater gain/feed than the meal control) to 50% (2% greater gain/feed compared to the meal control). The problem with fines is that pigs sort the pellets from the fines and fines build in the feed trough and feed wastage is increased. The buildup of fines is less for wet/dry feeders than for dry feeders. Thus, the decision on whether to pellet diets is complicated by the ability to properly adjust feeders. The advantage in ADG and feed efficiency to pellets is clear, as long as pellet quality does not cause a feeder adjustment problem.

Figure 2. Particle Size Monitoring



V. Feed Delivery

The main areas to review under feed delivery are feed budgets and the impact of trucking costs on profit. Feed budgets are essential to minimise overfeeding or underfeeding of particular diets. Feed budgets can be altered for individual production units to match the mixer or truck size to make the delivery process more efficient. If multiple phase diet programs are used, feeding by feed budget is more accurate than feeding by time or by trying to estimate weights for dietary changes. Kansas State University has a simple feed budget program that can be used to estimate amount of feed required for various weight ranges. It adjusts the budget based upon feed efficiency and weight ranges from past closeouts. An example of the amount of feed required for various weight ranges is shown in Table 7. This table can be used to determine feed requirements for a dietary phase. For example, if the feed efficiency from 20 to 110 kg is 2.80 and the diet weight range is from 20 to 45 kg, the quantity of feed required per pig is 54.6 kg (10.0 + 10.4 + 10.9 + 11.4 + 11.9).

Table 7. Quantity of feed (kg) needed for each 5-kg increment at various F/G values.

Weight, kg		Feed efficiency from 20 to 110 kg				
Initial	Final	2.40	2.60	2.80	3.0	3.2
20	25	8.6	9.3	10.0	10.7	11.4
25	30	9.0	9.7	10.4	11.2	11.9
30	35	9.4	10.1	10.9	11.7	12.5
35	40	9.8	10.6	11.4	12.2	13.0
40	45	10.2	11.0	11.9	12.7	13.6
45	50	10.6	11.5	12.3	13.2	14.1
50	55	11.0	11.9	12.8	13.7	14.6
55	60	11.4	12.4	13.3	14.2	15.2
60	65	11.8	12.8	13.8	14.7	15.7
65	70	12.2	13.2	14.2	15.2	16.3
70	75	12.7	13.7	14.7	15.7	16.8
75	80	13.1	14.1	15.2	16.2	17.4
80	85	13.5	14.6	15.7	16.8	17.9
85	90	13.9	15.0	16.1	17.3	18.5
90	95	14.3	15.4	16.6	17.8	19.0
95	100	14.7	15.9	17.1	18.3	19.5
100	105	15.1	16.3	17.6	18.8	20.1
110	115	15.5	16.8	18.0	19.3	20.6
115	120	15.9	17.2	18.5	19.8	21.2
120	125	16.3	17.7	19.0	20.3	21.7
125	130	16.7	18.1	19.5	20.8	22.3

Delivery Costs

The impact of truck size on delivery cost is depicted in Table 8. This data is based on costs reported by Baumel (1997). The delivery cost per mile increases linearly as the truck size

increases from 6 to 24 tons. However, the cost per ton-mile (cost per mile/truck size) decreases in a curvilinear fashion. Based on these data the cost per ton-mile is decreased by 43% when comparing a truck size of 12 to 24 tons. While the advantage is going to depend greatly on the distance of feed transport, for a 15 mile delivery this translates into a $0.62 per ton and $0.23 per pig decrease in feed cost for when using the 24 ton compared to the 12 ton trucks. These figures also illustrate that the savings in transportation costs are significant when utilising on-farm produced grains and feed manufacturing.

Table 8. Influence of feed truck size on delivery costs.

	Capacity of truck, tons			
Delivery cost	6	12	18	24
Cost/mile, $	$ 1.07	$ 1.14	$ 1.18	$ 1.29
Cost/ton/mile, $/ton	$ 0.178	$ 0.095	$ 0.066	$ 0.054
Cost for 1000 head, $[a]	$2,136	$1,140	$792	$648
Cost per pig, $ [a]	$ 2.14	$ 1.14	$ 0.79	$ 0.65

[a]Assumes a delivery 20 miles from the feed mill (40 miles round trip).

VI. Application In The Barn

The nutrition program is not complete when the feed is delivered to the feed bin. Application in the barn centres on three areas, feeder adjustment, bin management, and pig monitoring.

Feeder adjustment

Feed wastage from poor feeder adjustment is a problem in most G/F barns. Improvements in feed efficiency from the reduction in feed wastage directly reduce cost per kg of gain and per pig. For example, feed cost is lowered over $1.00 per pig in the finisher and $0.40 per pig in the nursery by reducing feed efficiency by 0.1. Feed efficiency improvements of 0.1 to 0.2 (ex. 3.0 to 2.9 or 2.8) have been accomplished frequently in the field by improving feeder adjustments. Many times the improper adjustment is the result of difficulty that management has communicating to personnel adjusting the feeders as to what proper adjustment should look like. Posting laminated pictures in every room of every G/F and nursery facility has been an effective tool to communicate proper feeder adjustment. The pictures serve as constant motivational reminders to help reduce feed wastage.

Bin management

The goal in bin management is to always have high quality feed available for every pig in the barn. As part of this, you do not want to decrease the quality of the feed delivered from the feed mill by moisture buildup or bridging of feed in the bins. The other aspect is to not run bins empty for extended periods of time, such that pigs are without feed. Consistent availability of feed is a key for reducing ulcer and ileitis problems in the G/F barn.

Pig monitoring

Visual monitoring of pigs for normal growth, comfort (absence of vices such as tail biting, etc.), and freedom of disease needs to be conducted on a daily basis. Problems or mistakes in the nutrition program are often found first by the critical eye of an excellent stockperson in the barn. The nutritionist and feed manufacturer relies on the person in the barn to communicate concerns or problems as quickly and thoroughly as possible to determine the cause and remedy the situation.

VII. Simplification

As production systems have grown in size and a higher proportion of the labour in the feed mill and G/F barns has little practical agricultural background, steps must be taken to reduce the complexity of the feeding program to reduce errors. Any decision to add additional ingredients to the diet must include an understanding of the ability of the feed mill to handle the extra ingredient and consistently add it to the diet at the desired level. Any decision to add additional diets to the feeding program must consider the potential impact on reducing the efficiency of the feed mill and increasing cost of milling and delivery. Decisions on trace mineral and vitamin levels in each diet often must be made considering the limitation in the feed mill concerning the number of premixes that can be stocked and rotated in a reasonable timetable. Increasing the number of premixes in the mill also increases the potential that the wrong premix will be used.

In order to simplify the nutritional program, consider limiting the number of ingredients and number of diets as much as possible. For example, the same diets could be used for barrows and gilts, but different feed budgets can be used to accomplish the goal of split-sex feeding. If you are working with numerous feed mills, reduce the frequency of changes in diet formulation. Many mistakes that occur in the field can be traced to mistakes in entering diets into the computer in the feed mill or in errors in diet formulation. Reducing dietary changes and having a system to review diet formulas after changes have been made can reduce problems.

CONCLUSIONS

The most economical feeding programs are much more than a set of diet formulations based on a set of nutrient levels. Determining the correct amino acid and energy levels are a very important part of a nutrition program. However, other factors, such as ingredient procurement, feed processing, budgeting, delivery, and feeder adjustment are just as important in determining the success of the nutrition program. The various areas of the nutrition program are not independent of each other and must be considered in unison. For example, the ingredient purchaser must interact and communicate with the nutritionist as to which ingredients are available. Nutritionists must communicate the feeding value of the ingredient to the purchaser so the purchaser can base decisions of different ingredients on a similar nutritional value. Farm management must communicate a common message on the importance of feed management in the barn. The nutritionist and feed mill manager must work together to

simplify the nutrition program and prevent problems from occurring. Finally, the person in the G/F barn must communicate potential concerns or problems to the nutritionist and feed mill personnel. The various aspects reviewed in this paper help provide tools to review all aspects of the nutrition program.

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