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September 21-23, 1998
Bloomington, Minnesota

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59th Minnesota Nutrition Conference

Swine

8:30 Continental Breakfast - **Sponsored**
A.M. Moderator - **Larry Dunn**
9:00 What's New in the 1998 NRC Nutrient Requirements of Swine - **Lee Johnston**
9:30 Experiences with the 1998 NRC Nutrient Requirements of Swine - **Ron Moser**
10:00 Refreshment Break - **Sponsored**
10:30 Dietary Formulations to Reduce N Output and Odor - **John Patience**
11:00 Dietary Formulations to Reduce H_2S and Trace Mineral Waste - **Jerry Shurson**
11:30 Speaker Panel: Questions & Answers

12:00 **Luncheon sponsored by Pfizer Animal Health**

Poultry

P.M. Moderator - **George Speers**
1:00 Betaine in Non-Ruminant Diets - **Janet Remus**
1:40 Recent Research on Amino Acid Digestibility of Feed Ingredients for Poultry - **Carl Parsons**
2:10 Refreshment Break - **Sponsored**
2:40 Metabolizable Energy and Digestible Amino Acid Requirements for Commercial Layers - **Craig Coon**
3:10 Ideal Protein for Turkeys - **Jeff Firman**
3:40 Adjourn

59TH MINNESOTA NUTRITION CONFERENCE & IPC TECHNICAL SYMPOSIUM SPEAKERS

Adwell, Jerry, is Director of Pork, Refinery, Feeds & Provisions with Hormel Foods Corporation. He earned B.S. and M.S. degrees from NW Missouri State University.

Akayezu, Jean Marie, is Innovation Development Manager with Cargill Animal Nutrition in dairy. A Ph.D. was earned at University of Minnesota and a D.V.M. at International School of Veterinary Medicine and Science, Dakar, Senegal.

Bimbo, Anthony, received a B.S. in Chemistry from Villanóva University. He is a private consultant with over 36 years of experience in the fishing industry. This experience covers technical, marketing and operations as well as marine oil refining and surimi manufacturing.

Coon, Craig, is a Professor, and currently holds the Arkansas Poultry Federation Endowed Research Chair position at the University of Arkansas. From Texas A&M University he earned his B.S., M.S. and Ph.D.

Hall, Mary Beth, is Assistant Professor of Dairy Cattle Nutrition with University of Florida, Gainesville. She received her B.S. and Ph.D. from Cornell University, M.S. at Virginia Tech.

Kuehn, Carla, is pursuing a Ph.D. in Ruminant Nutrition at the University of Minnesota and works in extension outreach programs pertaining to dairy cattle nutrition. Her B.S. and M.S. are from University of Minnesota.

Kung, Limin, is Associate Professor at University of Delaware. His responsibilities include dairy nutrition research, extension and teaching. He received a B.S. and M.S. from University of Hawaii, and his Ph.D. from Michigan State University.

Easter, Robert, earned his B.S. and M.S. at Texas A&M University, and Ph.D. from University of Illinois. He is Professor of Animal Science at University of Illinois.

Firman, Jeff, is Associate Professor at University of Missouri, working in poultry teaching, research and extension. His B.S. and M.S. are from University of Nebraska and his Ph.D. is from University of Maryland.

Hogberg, Maynard, is Chairperson and Professor, Department of Animal Science, at Michigan State University. From Iowa State University he earned a B.S. in Agricultural Education, M.S. in Animal Science, and Ph.D. in Animal Nutrition.

Hugoson, Gene, is Commissioner, Minnesota Department of Agriculture.

Humphrey III, Hubert H. "Skip", is Minnesota Attorney General.

James, Bob, is Professor of Dairy Management at Virginia Tech. He received a B.S. in Animal & Poultry Science from University of Delaware and M.S. and Ph.D. in Dairy Science at Virginia Tech.

Johnston, Lee, Associate Professor at the University of Minnesota West Central Experiment Station, Morris, MN, where he supervises the swine research unit. He earned a B.S. from Penn State, M.S. at Texas Tech and Ph.D. from Michigan State.

59TH MINNESOTA NUTRITION CONFERENCE & IPC TECHNICAL SYMPOSIUM SPEAKERS

Messerich, John, is Director of Specialty Fish Meal Products at International Proteins Corporation. He attended the University of Minnesota - Duluth, School of Business & Economics. Since 1992, John has been in charge of the development, promotion and sales of Specialty Marine Products.

Moser, Ron, is Director of Nutrition and Research at United Feeds. He received a B.S. from Oklahoma State University, an M.S. in Animal Science and a Ph.D. in Swine Nutrition from University of Nebraska.

Parsons, Carl, is Professor in the Department of Animal Sciences with University of Illinois at Urbana-Champaign. He received a B.S. from University of Maryland Eastern Shore, M.S. and Ph.D. from Virginia Polytech Inst. & State University.

Patience, John, is President and Chief Executive Officer of the Prairie Swine Center, Saskatoon, and Adjunct Professor at the University of Saskatchewan. John earned a B.S. and M.S. degree from the University of Guelph and a Ph.D. from Cornell University.

Remus, Janet, is Research and Development Manager for betaine applications in poultry for Finnfeeds. She received her B.S. degree from the University of Nebraska, and her M.S. and Ph.D. degrees from the University of Missouri, specializing in poultry nutrition.

Schaefer, Dan, is Professor of Animal Science at University of Wisconsin - Madison, where he earned his B.S. and M.S. He received his Ph.D. from University of Illinois. He conducts teaching and research in beef cattle production.

Shurson, Jerry, is Professor of Animal Science at the University of Minnesota. His duties involve teaching, research and extension in swine nutrition and management. He received a B.S. from University of Minnesota and M.S. and Ph.D. from Michigan State University.

Stern, Marshall, received his B.S. from Cornell University, M.S. and Ph.D. from University of Rhode Island. He is Professor in the Department of Animal Science at the University of Minnesota.

Strandberg, Paul, is Assistant to Minnesota Attorney General.

Veenhuizen, Mike, is owner of Livestock Engineering Solutions in Greenwood, Indiana. He holds engineering degrees from Purdue and Iowa State Universities. Mike's expertise is in design and evaluation of livestock facilities, agricultural waste systems, and ventilation systems.

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MANUFACTURE OF HIGH QUALITY FISH MEAL

John A. Messerich
Director of Specialty Fish Meal Products
International Proteins Corporation

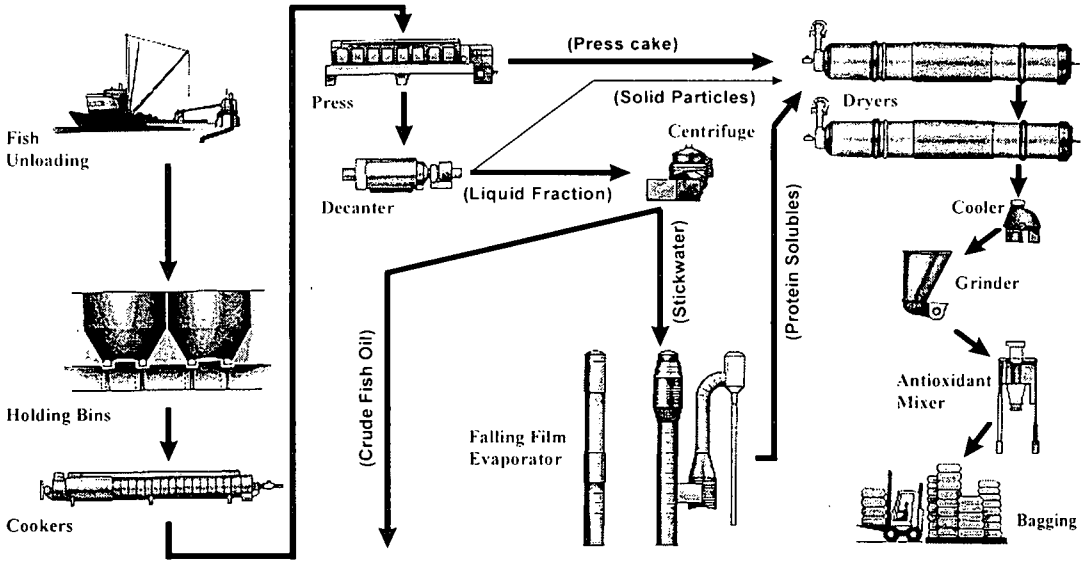
INTRODUCTION

Why use fish meal in your diet? In general, fish meal is recognized around the world as an excellent source of protein for practically all the essential amino acids. The fat content contains high amounts of omega 3 fatty acids which over the past few years scientists are recognizing as a disease preventative and reproduction enhancement. Fish meal also contains important vitamins and minerals all of which add to the overall nutritional package. However, fish meal is not just a commodity anymore. With the changing end use of fish meals away from poultry and into niche areas in the feed sector, it is important to be able to differentiate between different fish meal products and identify which products will result in the best value. This paper will review the actual production process in an attempt to give a better understanding on how quality can be affected during production and explain and define some of the quality parameters being used in the market place today.

II. PRODUCTION PROCESS

In a modern fish meal factory the entire production from pumping the fish from the boat to bagging or bulking the meal takes place in an enclosed system (figure 1). The process starts with segregation of the raw material by measuring for freshness using total volatile nitrogen and raw material temperature. After segregation, the fish enter the cooker and are heated to 95° C for about 30 minutes. This allows the protein to coagulate and frees the water and oil. The screw press then separates out all the fat possible, generally below 12% in the presscake, and this presscake is then introduced to the dryer. The remaining free liquid, called "press liquor", is run through a decanter to remove any solid particles before entering a centrifugation system which will separate the crude fish oil from the remaining stickwater. The stickwater has a dry matter content of approximately 5-8% which is mainly soluble protein. To retrieve this valuable protein, the stickwater is concentrated to 40-50% dry matter in an evaporator. The concentrated material, called "solubles", is added back onto the presscake for drying. The end result will be a whole fish meal, as opposed to presscake fish meal when the solubles are not added back. In a high quality production system, the meal will exit the dryer with 10-12% moisture content and then during the cooling process, which brings the meal down to approximately 30° C, the moisture level will end up at 8-9%. Keep in mind, it is the moisture which is protecting the protein from overheating during the entire process.

Figure 1 - Fish Meal Production Process



To produce high quality fish meal there are two main variables that must be controlled; raw material freshness and drying temperatures. It is important to note that it is the combination of these two factors which will yield the most digestible fish meal.

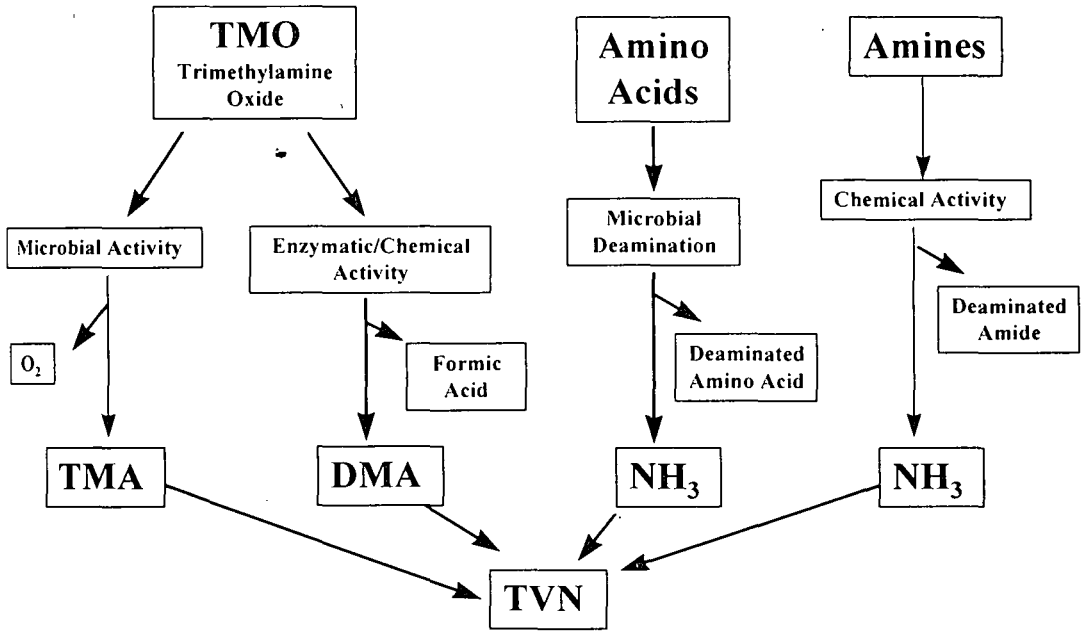
A. Raw Material Freshness

1. Type and Specie of Fish - In contrary to popular belief, the vast majority of fish meal production comes from whole industrial fish and not from offal. Industrial fish are those fish which are not used for human consumption due to size, bone content, or simply lack of appeal in the edible market. The fish resources being utilized are strictly controlled by the individual countries and their marine biologists recommendations through a variety of quota systems, restrictive fishing seasons, fishing permits, etc. The species of the fish will not indicate if the meal is of high quality. However, certain species of industrial fish are naturally more meaty and less bony yielding a meal with lower phosphorus levels and greater nutrient density. Although all fish fat is unsaturated, some are more so, tending them to be highly unstable and more susceptible to oxidation, rancidity and palatability problems. Feeding patterns and enzyme activity will also play a large role in raw material condition. For example, the Icelandic Capelin are caught in large schools during their annual migration to spawn. Prior to this migration, they build up their body fat to provide energy for the long journey and abstain from feeding during the migration. The Menhaden, which are caught mainly in the Gulf of Mexico, are filter feeders and caught while schooled for protection from predators. Since they are feeding when caught, there is a much higher level of enzyme activity in the gut.

2. Environment Prior to Processing - Even with today's modern refrigerated vessels, there is no replacement for mother nature. The water temperature where the fish are caught is still extremely important. This is due to economies of scale in the industrial fishing business. An industrial fishing vessel does not have the end product margin to sail out and catch only one net set. It takes many net sets to fill a vessel hold, and each time a new set is emptied in the hold, the temperature of the fish and the sea water put additional strain on the refrigeration units. Therefore to get the freshest raw material to the factory, it is a great advantage to start with very cold water.

3. Time from Catch to Processing - Even ice cold waters of the North Atlantic or Antarctic can not insure fresh raw material on arrival at the plant if the sailing time is too long. The rate at which a fish spoils is dependent on several factors; the species of fish, storage time and temperature. Fish deteriorate more rapidly at higher temperatures or if the gut is full at the time of catching, especially if broken up during handling. Therefore, most producers of quality meals will measure for total volatile nitrogen (TVN) and then sort their raw material prior to processing. TVN (figure 2), as a proportion of total nitrogen rises as fish spoil. Soon after fish are caught deterioration begins through self digestion, or autolysis due to the enzymes present within the fish itself and through microbial spoilage. A major part of the process of deterioration is the breakdown of proteins to simpler nitrogenous compounds of which some are volatile and it is the quantity of these volatile nitrogenous compounds which have been chosen to reflect freshness.

Figure 2 - Sources of TVN in Raw Fish



B. Temperature of the Drying Process

As mentioned above, it is necessary to have more than just fresh raw material to produce highly digestible fish meal. The equipment is also of great importance, especially the dryer. It is of course well known that overheating can destroy the availability of the amino acids. There are four basic types of dryers being used in the fish meal industry today. Older plants and those not attempting to produce a higher quality tend to be flame dryers.

Flame Dryers - are good for volume production, but lack any real type of control for moisture, time and therefore temperatures in the meal. They also tend to scorch the outer portion of the meal particles with the direct flaming action, denaturing that particular bit of protein. Surprisingly, the majority of fish meal plants in North America are still using flame dryers.

Steam Dryers - have either rotating discs or tubes inside and as the name suggests will heat the meal tumbling around these heating elements at about the boiling point (100° C), or slightly less. Steam dryers were originally invented to reduce the smell of producing meal on flame dryers. Soon after, it was also found that the lower drying temperature greatly increased the digestibility and today, despite their higher price, they are the most commonly used system worldwide.

Vacuum Steam Dryers - To reduce the heating effect further, a more sophisticated steam dryer was developed. The outer jacket was reinforced to allow the system to be put under pressure to lower the boiling point to about 75° C. This allows the meal to be dried at a temperature of about 70° C.

In-direct Hot Air Dryers - are basically a very sophisticated flame dryer without the flame coming in direct contact with meal. This is accomplished by a heat exchanger which super-heats the air prior to sending it into the drying chamber. This air is then re-circulated through a condenser removing the moisture it has picked up and sent back to the exchanger. The system uses very high heat for a short, well controlled period of time, resulting in the meal being dried at about 70° C the same as a vacuum steam dryer.

There are also numerous combinations as most producers find it economically advantageous to dry in multi-phase systems.

III. QUALITY PARAMETERS

As I am sure you have discovered, fish meal is far from a generic ingredient and there are literally dozens of different qualities available today and just as many ways to measure their differences. The value the market assigns to a fish meal is most often determined by different measures of raw material freshness and meal digestibility.

A. Measures for Raw Material Freshness

As mentioned earlier, total volatile nitrogen is commonly used to sort out the higher quality raw material at the production plant. It has also become common for some buyers to ask for TVN or ammonia, or ammonia less free nitrogen, and/or one or more biogenic amines in the meal. There is also a tendency now to measure the fat quality in the meal by testing ffa or anisidine levels for signs of deterioration of raw material quality. Although these tests are excellent for fish oil, buyers should be careful using these for the meal. The extraction process can significantly alter the results as well as the inherent variation in the ffa between fish species. TVN on the meal can also be misleading since the volatile nitrogenous gases can easily be burnt off during high heat drying. Amines are formed from the decarboxylation of amino acids and are non-volatile. Although biogenic amines offer buyers one of the more reliable ways to check the raw material freshness, there are still a couple of things to be wary of. Biogenic amines are concentrated mainly in the soluble portion of the fish meal. This means if you are receiving presscake meal instead of whole meal, the biogenic amine level may be low and indicate a fresher raw material was used than what was really the case. Also, the level of biogenic amines can vary greatly between species of fish. For example, histamine is a good indicator of the freshness of South Chilean Mackerel, but practically non-existent in North Atlantic Herring, even if the Herring was very stale. Therefore, if you are to use biogenic amines as a freshness measure, it is a good idea to test more than one biogenic amine, and the level of soluble protein. The follow tables (1 and 2) can help illustrate some of the parameters mentioned above to be wary of.

Table 1: CHEMICAL COMPOSITION OF FISH MEAL FROM MACKEREL AND PROCESSED AT LOW AND ELEVATED TEMPERATURES

	Raw Material Quality			
	High		Low	
TVN, mg/100g FISH	22		100	
Processing Temperature	Low	High	Low	High
FISH MEAL				
Dry Matter (DM). %	95.2	99.5	94.3	98.9
Protein. % of DM	81.5	81.0	83.0	81.8
Fat, % of DM	10.0	10.3	8.3	8.6
Ash, % of DM	10.0	10.3	9.9	10.1
Water Soluble Protein, g/16g N	23.9	21.9	38.4	35.7
TVN %	0.14	0.10	0.24	0.12
Biogenic amines, ppm in DM:				
Cadaverine	150	130	4500	3750
Histamine	120	140	4830	3570
Putrecine	180	120	790	690

Table 2: CHEMICAL COMPOSITION OF FISH MEAL MADE FROM HERRING OF DIFFERENT QUALITY UNDER LOW TEMPERATURE COMMERCIAL PROCESSING

	Raw Material Quality		
	High	Medium	Low
TVN, mg/100g FISH	22	62	142
FISH MEAL			
Dry Matter (DM). %	92.4	92.9	92.47
Protein. % of DM	79.2	79.3	75.2
Fat, % of DM	9.4	8.7	11.8
Ash, % of DM	13.1	13.0	13.2
Water Soluble Protein, g/16g N	16.5	18.1	21.6
TVN %	0.12	0.16	0.25
Biogenic amines, ppm in DM:			
Cadaverine	330	1000	1600
Histamine	<30	440	830
Putrecine	30	230	630
Tyramine	<30	400	800

B. Measures for Digestibility

Both chemical and biological digestibility methods are used to try and differentiate the value of today's fish meal products. The pepsin test, which is common for many proteins is not critical enough for fish meals, so even a lower quality fish meal will show a good result. Therefore the Torry University in Scotland developed a test which reduces the amount of pepsin and holds the temperature constant. In Denmark, the Danish Fish Meal Association developed a multi-enzyme digestibility test using 3 different enzymes, while in some countries the Carpenter available lysine test is still used. All of these methods have their drawbacks in consistently predicting digestibility. The Norwegian Herring Oil and Meal Research Institute claim to have been unable to find any satisfactory correlation between chemical criteria and biological value when using mink. Since digestibility studies are often difficult, time consuming and expensive to run, various biological tests using model animals have been developed with good correlation for everything from salmon to nursery pigs.

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Notes

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FISHMEAL AND OIL
A GLOBAL PERSPECTIVE

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INTRODUCTION

El Nino, omega-3 fatty acids, *trans* fatty acids, aquaculture, and soybean meal prices all have one thing in common, they are influencing the success or failure of the industrial sector of the commercial fishing industry. It isn't possible to weave all these issues together in the short period of time available today so this presentation will be broken down into 5 mini-presentations. These presentations will cover world fishery statistics to put the resource into perspective, fishmeal statistics, fish oil statistics, quality issues regarding fishmeal and oil and finally weaving them together into a look at the future. The dynamics of the industrial fishing sector have changed over the past few years. Fisheries have collapsed, major exporting countries have become importers, traditional markets have disappeared, prices have risen to all time highs and everything seems to depend on the emerging markets in Asia which are experiencing an economic crisis of their own.

STATISTICS

According to the latest available FAO data, between 1953 and 1996 the commercial world catch of fish and shellfish has grown at an overall rate of about 8.5% per year. Figure 1 shows the world's commercial fish landings over that period (U.S. Dept. of Commerce 1985-1997). Closer examination of the data, however, reveals that landings from the oceans have actually plateaued in recent years (growing at about 1.8% per year) while aquaculture production has been increasing. Data specific to aquaculture was not separated from fresh water landings until 1984 so in Figure 2 (FAO 1995; FAO 1996; FAO 1998) we have plotted the annual growth in aquaculture over the period 1984-1996 which is the latest data available. It shows aquaculture growing at a phenomenal annual rate of 23% which may not be logistically sustainable. Aquaculture statistics tend to drift back and forth and sometimes it is difficult to determine if aquatic plants have been included in the figures.

When we look at the geographical distribution of the catch for the last 12 years we find that the growth in Asian landings continues at an average rate of about 6% and that the drop in the former USSR landings have more than been compensated for by growth in landings from South America (14%) where the fish are primarily used to produce fishmeal and oil. North America, Europe, Africa and Oceania seem to be stable with very little growth. This is shown in Figure 3 (U.S. Dept. of Commerce 1985- 1997). Of course the So. American fishery is currently emerging from a devastating El Nino and is not expected to recover until late 1998 or mid 1999. Figure 4 shows a plot of the change in the sea surface temperature (SST) in the equatorial Pacific Ocean off the coast of Peru over the period 1991- 1998 (U.S. Dept. of Commerce 1991-1998). It clearly

shows the dramatic increase in temperature that is associated with El Nino. If you don't think a several °C change in sea surface temperature is significant, Figure 5 shows what has happened in Peru and Chile during these El Nino events (FAO Fishstat PC 1998).

World landings are also characterized by the intended end use of the fish caught. In Figure 6 we see that use for fishmeal and oil has ranged from 25 - 30% over that same 12 year period despite major fluctuations in some of the landings of individual species (U.S. Dept. of Commerce 1985-1997). This, of course, does not take into account the trimmings and offal that is also converted or potentially can be converted into fishmeal, oil or silage type products. A conservative estimate is that only about 50% of a fish is utilized in food products, the remaining 50% is head, tail, entrails, skin and scales which can be converted into fishmeal or other value added products. In fact these trimmings offer future possibilities for the production of fishmeal as more fish are used for edible purposes. The same holds true for shellfish waste. Assuming 50% of the fresh, frozen, canned and cured fish is waste, then about 30-40% of the total landings are discarded as waste or an average of 35 million metric tons per year (which potentially converts to 6 million metric tons of fishmeal per year). There are some logistical problems associated with the use of this raw material right now but these problems should be solved during the next 5 years. It has also been conservatively estimated by FAO that about 25 million tons of fish are thrown back into the sea by fishermen because the fish are not suitable for landing (Alverson, Freeberg, Pope and Murawski 1994). This is called by-catch or discards and will be the subject of national legislation around the world to ensure that these fish are utilized in some way. In most cases, the by-catch is never counted in statistics because it never reaches the docks. At the very least, these discards could be converted into fishmeal and would represent an additional 4 million metric tons of fishmeal per year.

There are about 12 species of fish used for the production of fishmeal and oil. Some of these are listed in Figure 7 along with the countries where these fish are landed (Bimbo and Pike 1996). These fish are generally classified as pelagics. They are small, oily, bony fish not generally suited for food use now but might someday be upgraded when markets are developed and the technology to manufacture food products from them improves. For the present, they are indirectly transformed into human food products through the conversion to animal proteins in the form of feeds for poultry, pigs, ruminants, fish and crustaceans. The state of the utilization of the industrial fish species in the world has been reported by the UN Food and Agriculture Organization (FAO). On the basis of a classification of moderately fished, fully fished and depleted stocks, none of the industrial fish species are considered depleted (FAO 1993). Industrial fishing is undertaken by conventional fishing vessels using conventional nets with government controlled mesh sizes. World wide nearly all of the industrial fish caught are subject to quotas. These are set by government bodies on the basis of scientific advice to ensure that the stocks are sustainable.. No significant impact of industrial fisheries on availability of food for other predator species has been reported by independent scientific investigation. The industrial fisheries in Europe, and North and South America are sustainable and ecologically sound. The fishmeal and oil industry believes it is necessary that industrial fisheries continue to be controlled and managed, based on scientific advice, by duly elected representatives of society in order to maintain this resource in a manner that is biologically, economically and socially sound. Fish are one source of protein available for human food either by direct consumption or indirectly through

the conversion of feeds to animal proteins. Figure 8 (Oil World Annual 1998) compares fish landings with oilseed production.

Fishmeal competes with other sources of protein on the world market and represents about 4% of the total availability of these proteins. Figure 9 (Oil World Annual 1998) compares fishmeal with these other sources of protein. Seven (7) regions produce about 90% of the world's fishmeal and these are shown in Figure 10 (Oil World Annual 1998). Peru and Chile produce 45-50% of the world's fishmeal. During the period January-September 1998 we expect fishmeal production in the major exporting countries to be about 40% of what it was during the same period in 1997. This is shown in Figure 11 (IFOMA personal communication 1998).

As with most commodities, countries either produce and export, or import and consume fishmeal depending upon whether the markets in their country can utilize the production. Figure 12 (Oil World Annual 1998) compares the major fishmeal exporting regions over the period 1988 - 1997. Scandinavia, Peru and Chile export over 80% of the world's fishmeal, and Peru and Chile account for over 65% of the total.

Five (5) regions account for about 80% of the fishmeal imports with Asia (50%) and the European Union (20%) as the major markets see Figure 13 (Oil World Annual 1998). China, Japan, Taiwan and more recently Indonesia and Thailand account for most of the Asian imports of fishmeal as shown in Figure 14 (Oil World Annual 1998). The consumption trend is moving away from livestock and towards aquaculture so concentrated fishmeal consumption will appear in countries or regions where aquaculture dominates. Aquaculture seems to be able to pay the higher prices and the fish:soy price ratio reflects this new trend in the market. It is interesting to note that the marked increase in the price ratio of fish and soy corresponds to the start of the 1997-98 El Nino, see Figure 15 (Oil World Annual 1998). On the other hand, the USA is primarily a poultry producer and there is a resistance to the use of fishmeal when the price ratio increases. This can be seen in Figure 16 (Oil World Annual 1998). The USA also uses fishmeal in the diets of early weaned pigs where it has been shown that high quality fishmeal produced from fresh raw material and gently processed will result in better growth for pigs weaned at 4 weeks of age (Gulbrandsen 1984).

Fish oil competes with other sources of animal fats and vegetable oils on the world market but only represents about 1% of the total availability of these products. On the other hand, fish oil represents about 12% of the specialty oil and fat group. This is shown in Figure 17 (Oil World Annual 1998). Five (5) regions produce about 80% of the world's fish oil and these are shown in Figure 18 (Oil World Annual 1998). Peru and Chile produce between 35 and 50% of the world's fish oil. It has been estimated that for January-December 1998 fish oil production will only be 68% of what it was during 1997 (IFOMA personal communication 1998).

Figure 19 (Oil World Annual 1998) compares the major fish oil exporting regions over the period 1988 - 1997. Scandinavia, Peru, Chile and the USA export over 80% of the world's fish oil.

Four (4) regions account for about 70% of the fish oil consumption with Asia (12%), the European Union (30%) and Norway (9%) as major markets, see Figure 20 (Oil World Annual 1998). It's interesting to note that Norway consumes almost as much as fish oil as the entire Asian continent. This is because of the growth in the Salmon industry there and the importance of fish oil in salmonid feeds. Asia, on the other hand produces non-carnivorous fish that don't require fish oil. There has also been a steady growth in consumption of fish oil in Mexico and Canada in recent years. Mexican consumption is for edible fats and oils while the Canadian consumption reflects the growth in aquaculture on both coasts.

Fish oil prices generally follow the world fats and oils market. Major European consumers of fats and oils use a food oil index to determine the purchasing price of fats and oils. The index is based on the major vegetable oils, 35% soya, 35% palm, 15% rapeseed, and 15% sunflower. Figure 21 (Oil World Annual 1998) compares historical fish oil prices to this food oil index. Fish oil, which normally holds up the bottom of the price group has now surpassed the food oil index, again, reflecting the El Nino situation. Fish oil consumption is also in transition, moving away from the traditional hydrogenation market where it competes with the other fats and oils and towards aquaculture. As in the case of fishmeal, aquaculture appears willing to pay these high prices for fish oil. Looking at the regional situation Figure 22 shows that there is no price resistance to fish oil in the USA, Canada and Mexico.

Fishmeal is used in the feeds of poultry, pigs, ruminants, fish, crustaceans, pets and fur bearing animals because it increases productivity and improves feed efficiency. Fish oil is a major source of energy and provides the essential omega-3 fatty acids that are required by many species. The omega-3 fatty acids also positively effect the immune system of animals, improve the fatty acid composition of eggs, and may have an effect on bone development. Some of these diseases cost the poultry industry several hundred million dollars in lost productivity per year.

Figure 23 (IFOMA personal communication 1998) compares the global consumption of fishmeal and oil by the end user estimated for 1997. Poultry is the major consumer of fishmeal even though usage has dropped recently. Aquaculture accounts for 28% of the fishmeal and 42% of the fish oil consumption. In Figure 24 (Bimbo and Pike 1996) we have broken out the aquaculture portion for 1994 to show the various species and how much meal and oil are being consumed. In Figure 25 (IFOMA personal communication 1998) we show the dramatic transition that is taking place in the consumption of fishmeal and oil projected out to 2010.

QUALITY CONSIDERATIONS

Fishmeal can be designated as any one of a number of types: standard, fair average quality (FAQ), prime, super-prime, vacuum dried, LT, LT94, special quality, select, steam dried and any number of other designations. Standard or FAQ fishmeal is produced as described above and represents about 65-70% of the total fishmeal available on the world market today. It is produced from fish that are relatively fresh but which are not characterized as far as quality parameters are concerned. Standard or FAQ fishmeal is used in poultry, growing pig and some aquaculture diets. Presscake meals (no stickwater concentrate added) are used in ruminant feeds since the level of by-pass protein is much higher than fishmeals with all the stickwater concentrate added back.

Special quality fishmeals are called prime, super-prime, LT, LT-94, SQ, Special A or B and other similar designations. Quality names do not make quality products, see Figure 26. These fishmeals are produced from very fresh fish which have been characterized by maximum raw material TVN and or histamine levels. The fish are then processed by methods that are designed to protect the digestibility of the proteins, the availability of the amino acids and the oxidative stability of the fat in the meal. These processing methods might include low temperature cooking, low temperature (60°- 80° C. max.) drying, and limitations on the quality of the stickwater concentrate that is added back to the fishmeal. In some cases, anti-oxidant is added before and after the dryer to control oxidation. By controlling the freshness of the raw material and the processing methods used to produce the fishmeal, a very high quality product that is suitable for early weaned pigs, pets and various fish and crustacean species is produced. Today, for example, over 60% of all the fishmeal used in fish feeds in Norway is LT meal. Special quality fish meal is used in the diets of early weaned pigs, pets and aquaculture species. The importance of the temperature at which the fishmeal is dried cannot be over stressed. Figure 27 (Pike, Andorsdottir, and Mundheim 1990) compares salmon growth and mink digestibility against the temperature used to dry the fishmeal.

FAQ or standard fishmeal is the commodity grade product available throughout the world. The composition of the fishmeal will vary according to the species of fish that has been processed. Figure 28 (Bimbo and Crowther 1992) compares several different types of FAQ or standard fishmeals on the market today. The special quality fishmeals also vary according to the species of fish being processed. What distinguishes the special quality products from the standard fishmeals is the level of guarantees for raw material freshness and other parameters in the fishmeal as well as methods for processing the fish. Fresh raw material and gentle processing are the keys to special quality fishmeal products. In general, a company offering special quality products will be willing to supply the analytical data that confirms that the product is special quality. Figure 29 (Barlow, and Bololanik 1996) compares some of these additional parameters. While some of the low ash fishmeals that have recently come on the market might also be considered as "special quality products", one should determine whether they are FAQ low ash or special quality low ash products.

Specifications for fishmeal should include the proximate analysis for protein, fat, moisture and ash. These should total about 100%. Dilute Pepsin digestibility (0.0002%) analyses will give you some indication of how the meal has been treated and whether it has deteriorated. LT meals have been characterized by a minimum of 90% true mink digestibility and LT94 indicates a 94% dilute pepsin digestibility. A total fat (Bligh and Dyer method) when compared with the ether extractable fat will tell you whether there is appreciable oxidation in the fishmeal. Tests for ffa and peroxide value in the extracted fat in the fishmeal have been used but until standard methods are developed these are of value only for internal evaluation. TVN and biogenic amine analyses will indicate the quality of the raw material that was used to produce the fishmeal but it is important to remember that different species of fish will produce different levels of individual biogenic amines as shown in Figure 30 (Pike and Hardy 1997) so an index of the 4 major ones is more indicative of the quality. The total of the 4 major biogenic amines; histamine, cadaverine, putrecine, and tyramine should be less than 2000 ppm and for anchovy type fishmeals the

histamine should be less than 1000 ppm. Other parameters to be considered are available lysine (the value should be at least 85% of the total lysine value) and in-vivo digestibility with mink or salmon (90% minimum). In-vivo digestibility data is difficult to obtain so we tend to rely on and continue to look for chemical parameters to determine fishmeal quality. The fishmeal must also be antioxidant treated to protect the fat from rancidity. The current antioxidant of choice throughout the industry is ethoxyquin. Some work is progressing on the possible use of "natural antioxidants" in some specialized markets but no data is available at the present time. Figure 31 (Pike, Andorsdottir, and Mundheim 1990) brings processing temperature, raw material freshness, mink digestibility and some chemical tests together for comparison.

Fish oils are highly un-saturated with iodine values (measures of unsaturation) as high as 220. Aside from the fact that the oil is a source of energy, the main reason for using fish oil in aquafeeds is that it is a source of omega-3 fatty acids and particularly the long chain EPA (C20:5) and DHA (C22:6) fatty acids. The level of these omega-3 fatty acids will vary depending upon the species of fish from which the oil was produced. Figure 32 (Bimbo 1998) provides a detailed composition of the fatty acids in many of the commercially available fish oils on the market today. Important quality parameters for fish oil should include moisture and impurities and measures for level of oxidation in the oil. The primary test used is the peroxide value determination but the anisidine number should also be measured and the Totox value calculated by the formula:

$$\text{Totox Value} = (2 \times \text{Peroxide Value}) + \text{Anisidine number}$$

A Danish company offered a novel description of these values using their LLH Principle. L stands for Low anisidine number which indicates that only minimal oxidation has occurred in the remote past. The second L stands for Low peroxide value which indicates that only minimal oxidation has occurred in the more recent past and the H stands for High oxidative resistance which predicts a long shelf life (Vinter 1995; Anonymous 1995). The presence of copper as low as 0.1 ppm can be harmful, temperature and light will harm the oil as will the presence of oxygen. The oxidation rate doubles for every 10° C. rise in temperature and the oxidation rate can be several thousand times faster in sunlight than in the dark. These are shown in Figure 33. Blanketing the oil with nitrogen will double the shelf life over the same oil stored at ambient temperature without a nitrogen blanket.

FUTURE CONSIDERATIONS

By the year 2010 the growth in aquaculture is projected to reach about 45 million metric tons although FAO predicts that it will reach 61 million metric tons. This is shown in Figure 34 (FAO Aquastat PC 1998). China is the major aquaculture producer with India a distant number 2, as shown in Figure 35 (FAO Aquastat PC 1998). By 2010, we expect aquaculture to be consuming about 75% of the world's fish oil and 43% of the world's fishmeal production, see Figure 36 (Barlow and Pike 1998). Fishmeal quality must continue to improve in order to supply the special quality products that are needed in this market. We can expect that as more of these special quality products enter the market, feed efficiency will improve and it will take less fishmeal to produce the required growth. There will also be improvements in logistics and animal husbandry in these areas. There will be a shift in the species that will be cultivated, this is shown in Figure 37 (Barlow and Pike 1998). The demand for high quality fish oil will continue to

increase causing the high price to remain and making vegetable oils more competitive in this market. This will result in the development of blended fats of suitable quality and providing the necessary levels of the essential omega-3 fatty acids. Fish oil prices don't appear to be coming down any time in the future, indicating it's move away from the commodity sector and into the specialty area where it's omega 3 fatty acids are considered essential.

SUMMARY

The demand for edible fish protein by a growing world population will require that aquaculture maintain at east a 25-30% annual growth. This assumes an average 13 kg/person annual consumption with the increase coming from the increased population. This is shown in Figure 38 (FAO Aquastat PC 1998; FAO Fishstat PC 1998). At the current rate of growth in the population and the static growth in the ocean fish catch, there could be a shortfall of as much as 45 million metric tons of edible fish protein which can only be supplied by aquaculture. Alternative sources of edible fish protein include by-catch and conversion of the pelagics to food use. While conversion of the pelagics to food use has been studied over the years and surimi, minces and other products developed, sufficient markets have not developed to fill this need. The production of fishmeal and oil indirectly supply edible protein and fat through the feeding of fish and other livestock and offer the means to sustain the growth in aquaculture over this period. But fishmeal and oil quality must continue to evolve to higher quality products that meet the needs of the new aquaculture species. There will be more emphasis on complete utilization of what we have available including trimmings, by-catch, and other seafood wastes. The only component of the fish that should be discarded is clean water, everything else must be utilized.

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FIGURE 1. WORLD COMMERCIAL FISH CATCH

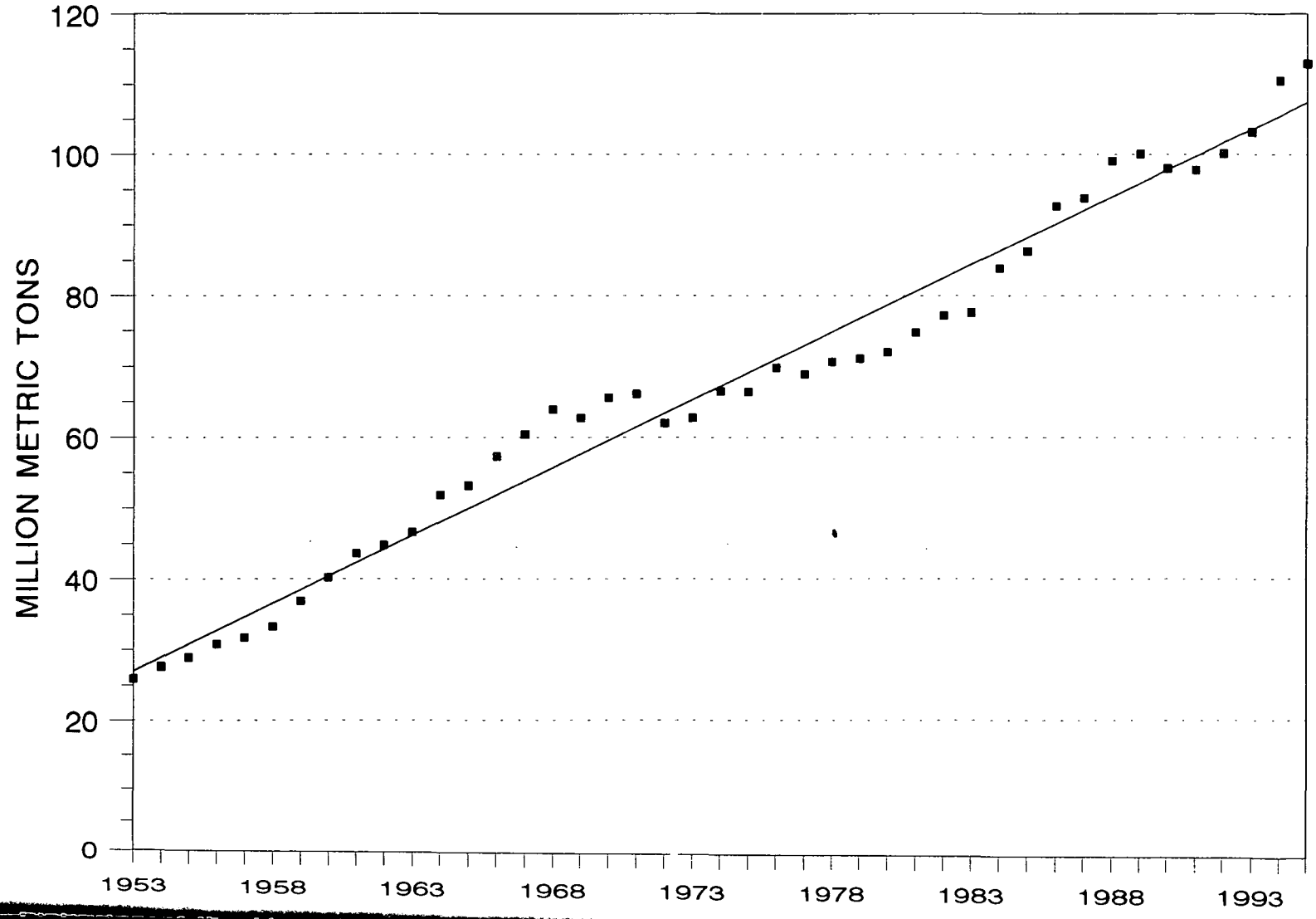
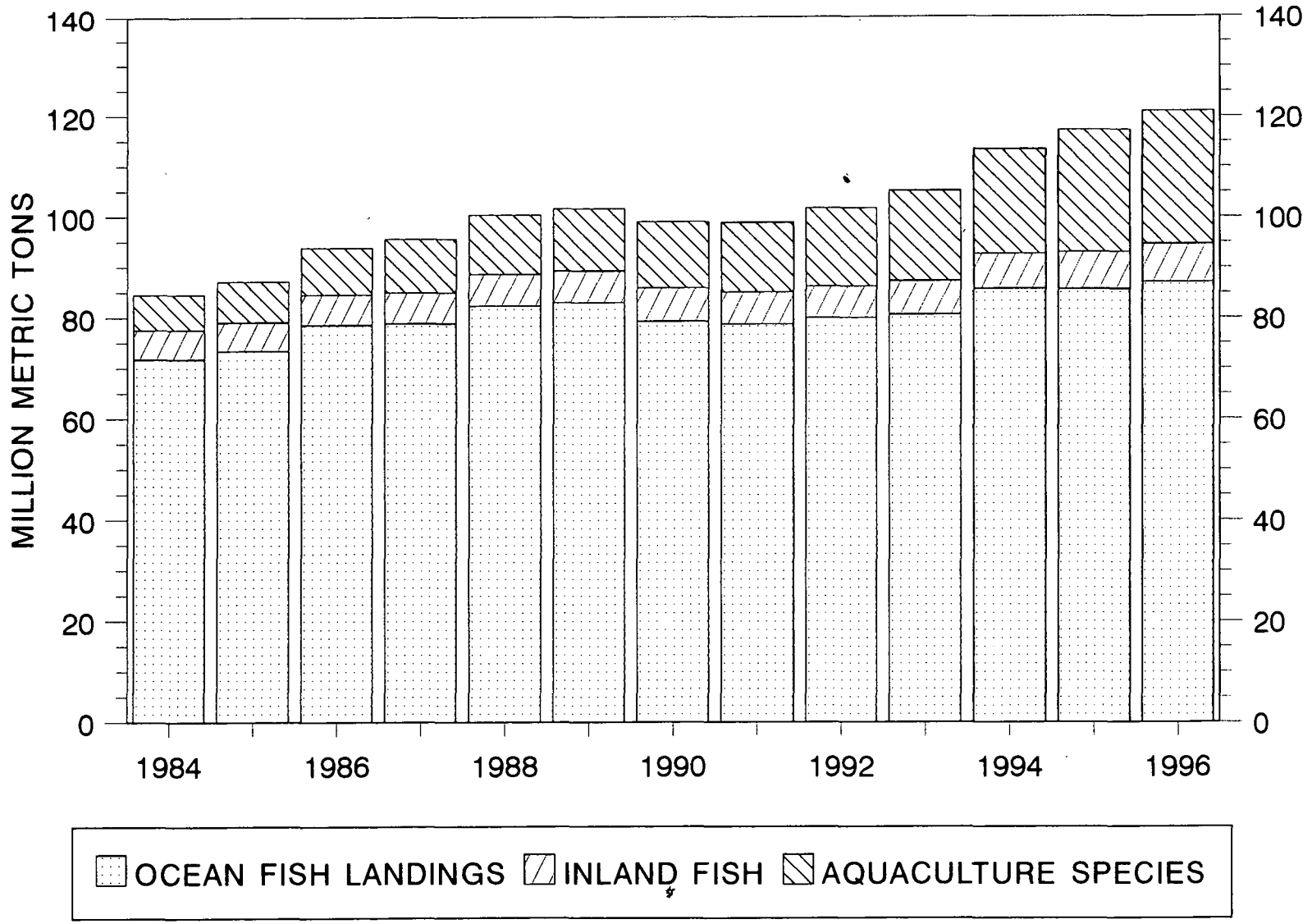


FIGURE 2. WORLD AQUACULTURE PRODUCTION

1953 1958 1963 1968 1973 1978 1983 1988 1993

Source: Fisheries of the United States 1996

FIGURE 2. WORLD AQUACULTURE PRODUCTION



Source: FAO Fisheries Circulars 815 and 886, FAO AquaStat PC 1998

FIGURE 3. WORLD CATCH OF FISH AND SHELLFISH

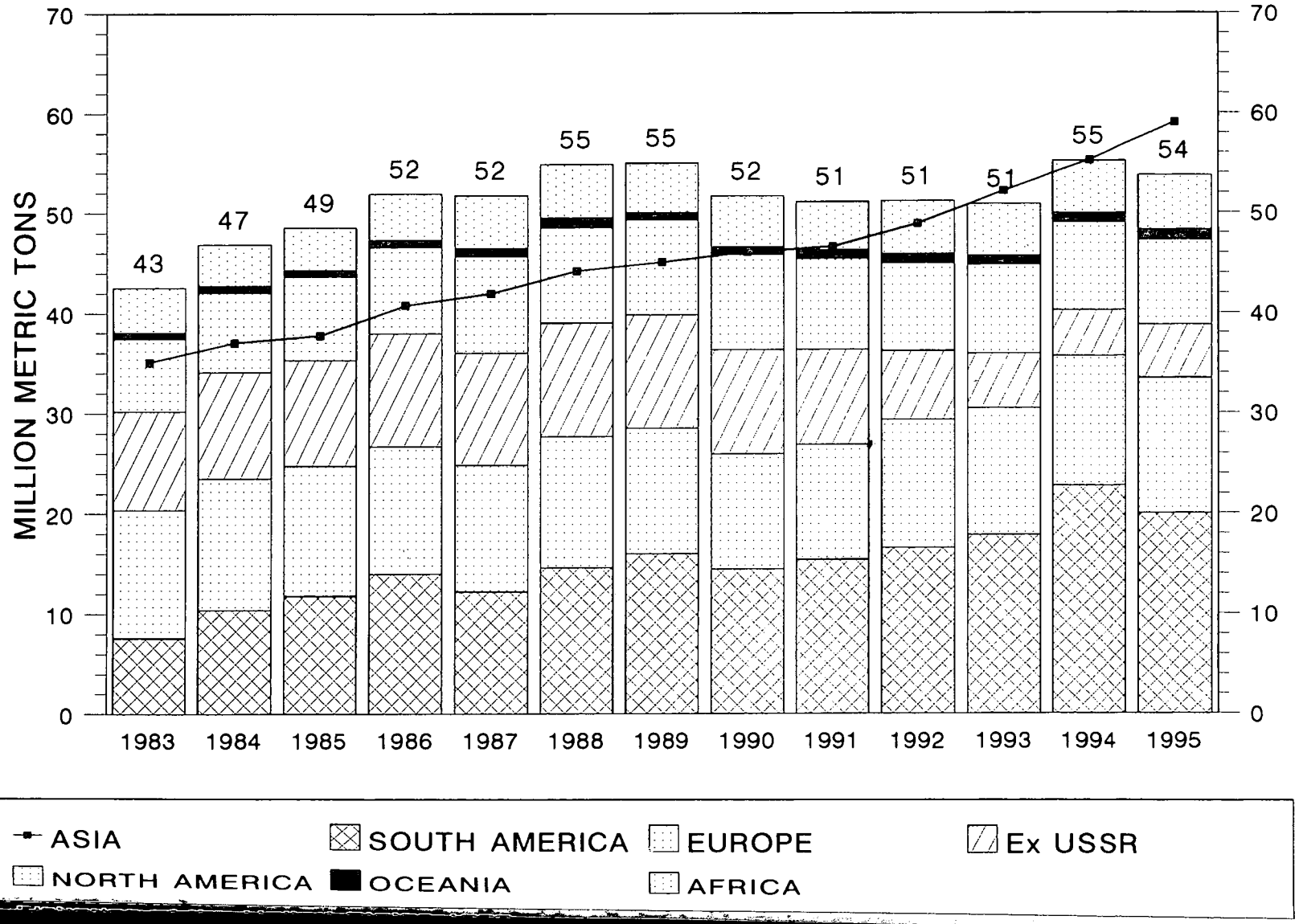
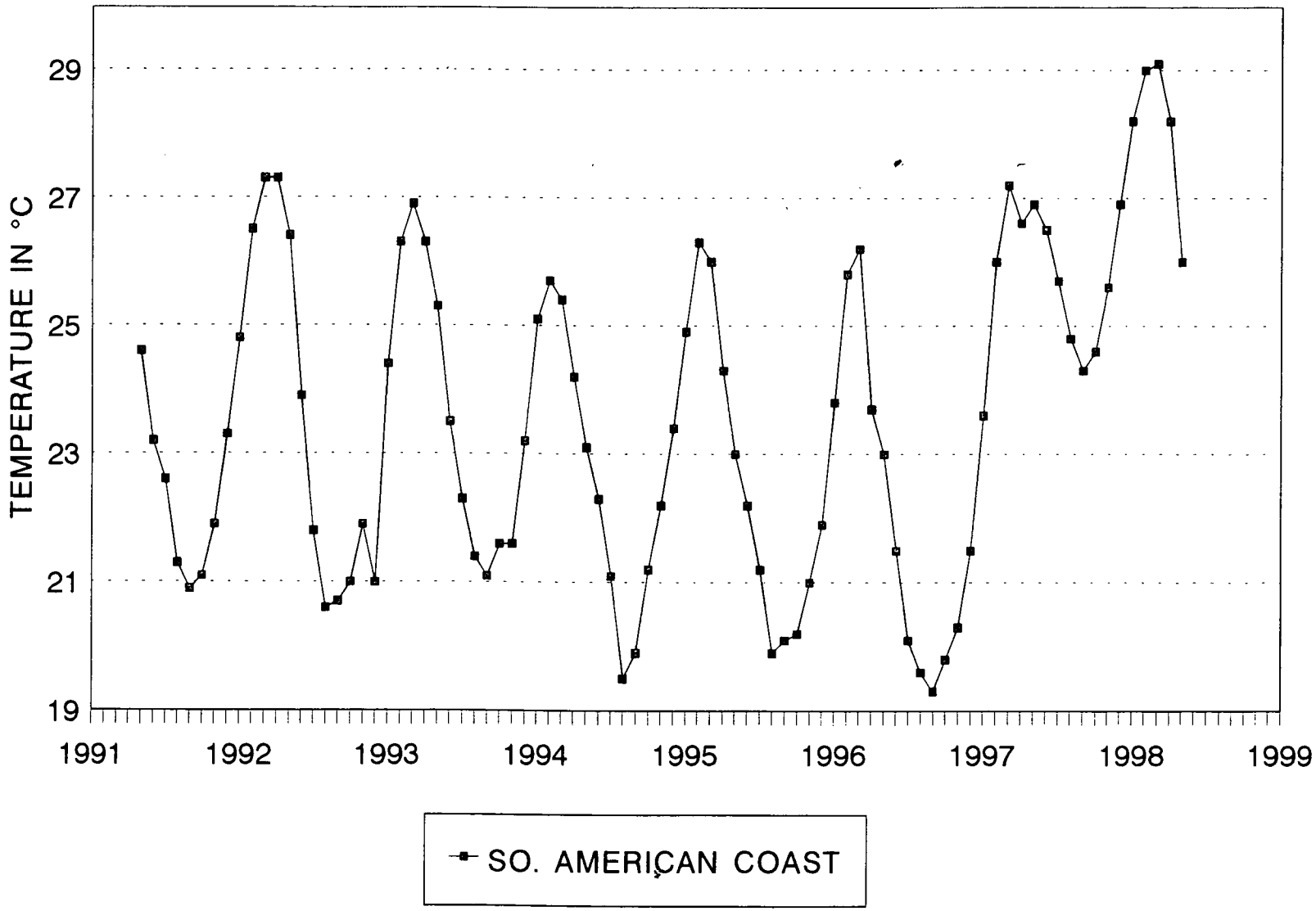


FIGURE 4. SEA SURFACE TEMPERATURES

NORTH AMERICA ■ OCEANIA AFRICA

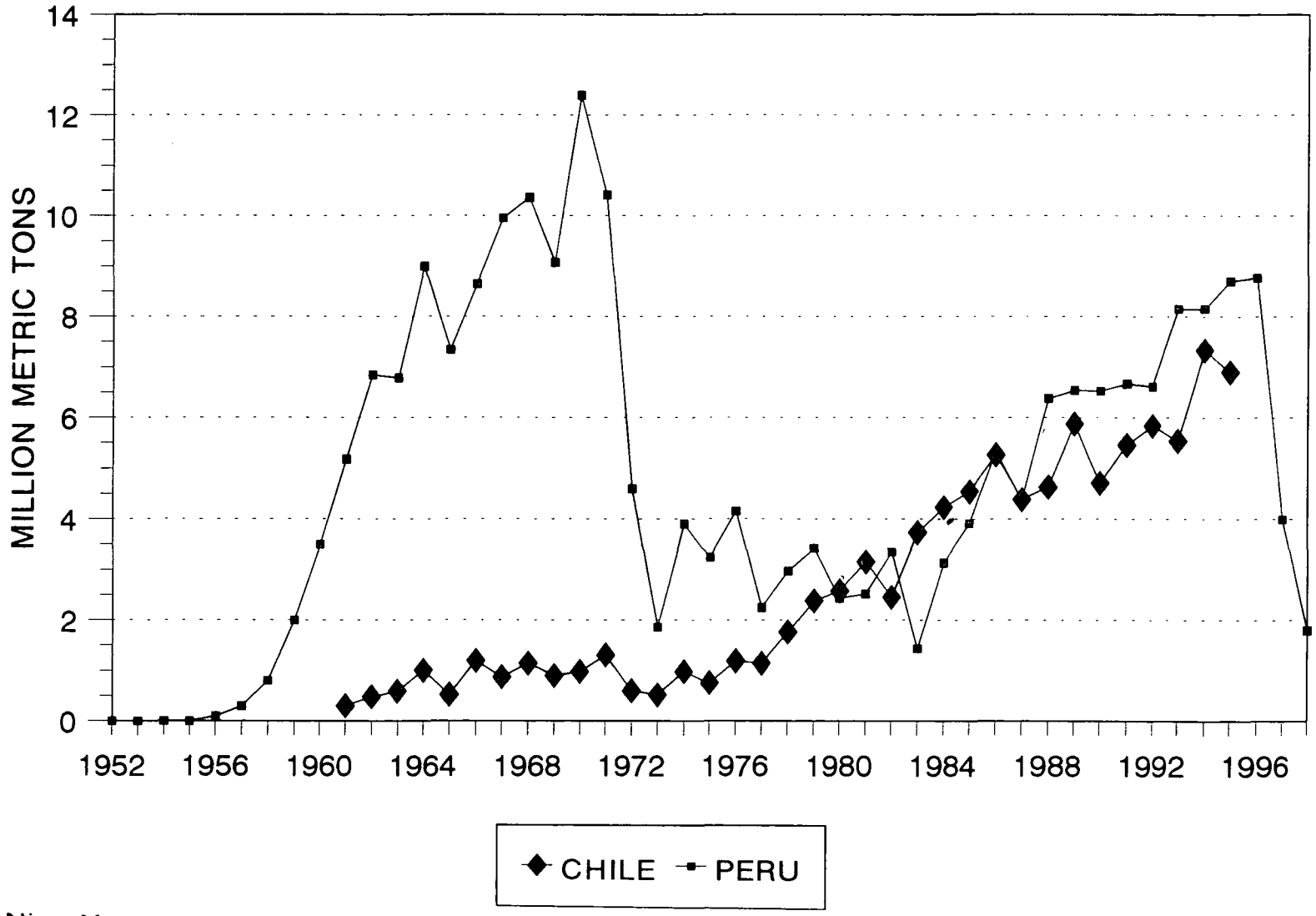
Source: Fisheries of the United States 1996

FIGURE 4. SEA SURFACE TEMPERATURES



Source: NOAA Climate Diagnostics Bulletins 1991-1998

FIGURE 5. PERU AND CHILE PELAGIC FISH CATCH



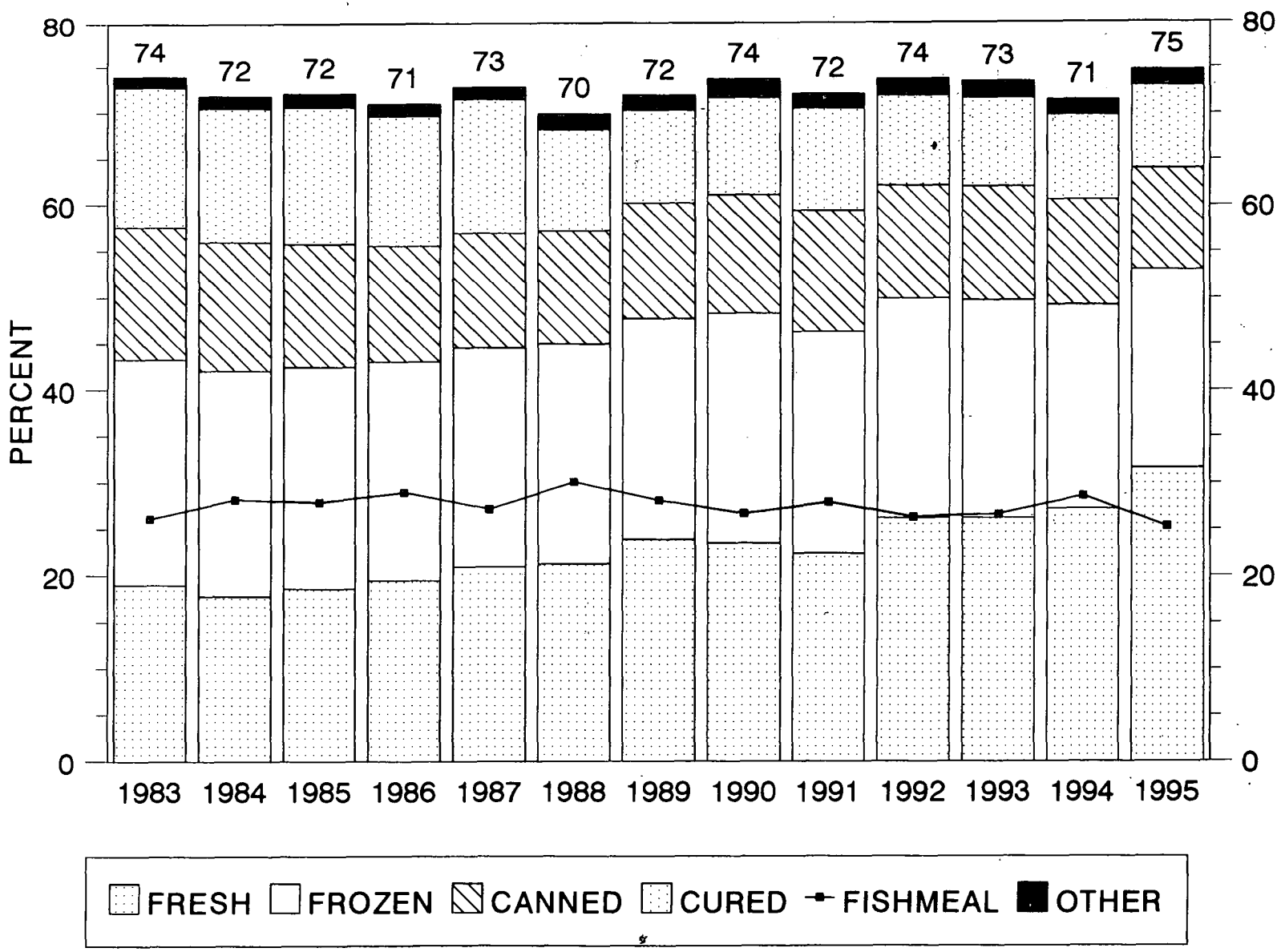
Major El Nino Years 1957-58, 72-73, 82-83, 86-87, 91-92, 97-98.

FIGURE 6. DISPOSITION OF WORLD CATCH BY USE

Major El Nino Years 1957-58, 72-73, 82-83, 86-87, 91-92, 97-98.

Source: FAO Fishstat PC 1998

FIGURE 6. DISPOSITION OF WORLD CATCH BY USE



Source: Fisheries of the United States 1996

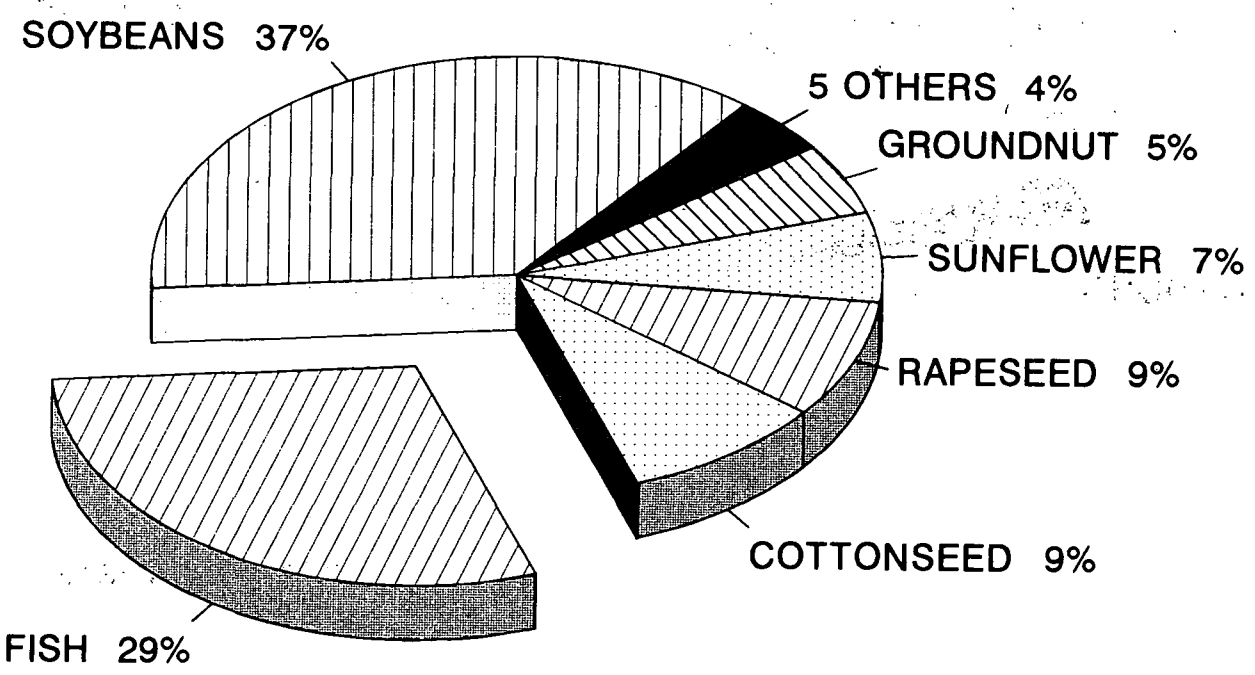
FIGURE 7. FISH CAUGHT FOR FISHMEAL AND OIL PRODUCTION

SPECIES	COUNTRY
Anchovy	Peru, Chile, So. Africa, Namibia
Jack Mackerel	Chile, Peru
Capelin	Norway, Iceland, Russian Fed.
Menhaden	USA
Pilchard/Sardine *	Peru, Chile, So. Africa, Namibia, Japan
Atlantic Horse Mackerel	Ireland, Norway, Denmark, Spain
Sandeel	Denmark, Norway, Færoe Is.
Norway Pout	Denmark, Norway, Færoe Is.
Sprat	Denmark, Russian Fed.
Blue Whiting	Norway, UK, Russian Fed., Ireland
Atlantic Herring *	Iceland, Norway, Denmark, UK, Færoe Islands, Sweden, Ireland

* Only trimmings can be processed to fishmeal and oil.

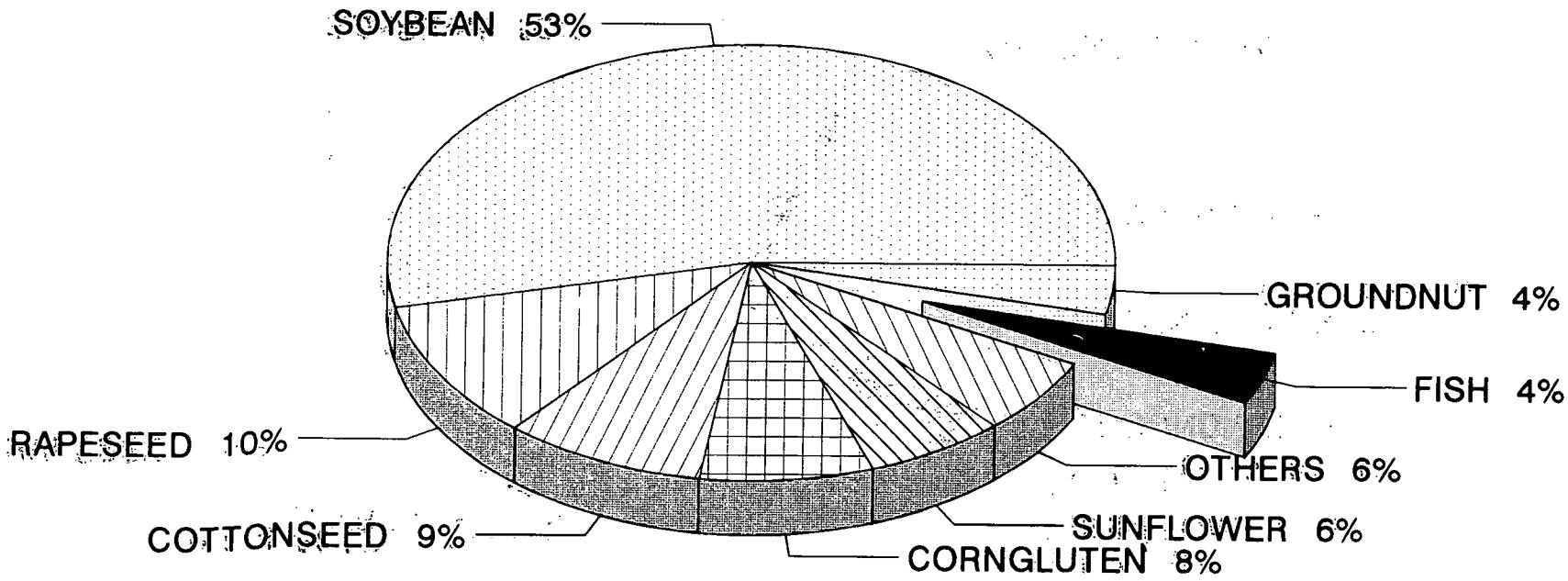
FIGURE 8. OILSEEDS VS FISH LANDINGS 1995-1999F

FIGURE 8. OILSEEDS VS FISH LANDINGS 1995-1999F



Others= Linseed, Copra, Castorseed, Sesame and Palmkernel
5 Year Average Harvest, Including Fish = 370.7 MMT
Source: Oil World Annual 1998 and Fisheries of the United States 1996

FIGURE 9. WORLD PROTEIN MEAL PRODUCTION 1994-1998F



Others = Sesame, Linseed, Copra, Palmkernel and Corngerm

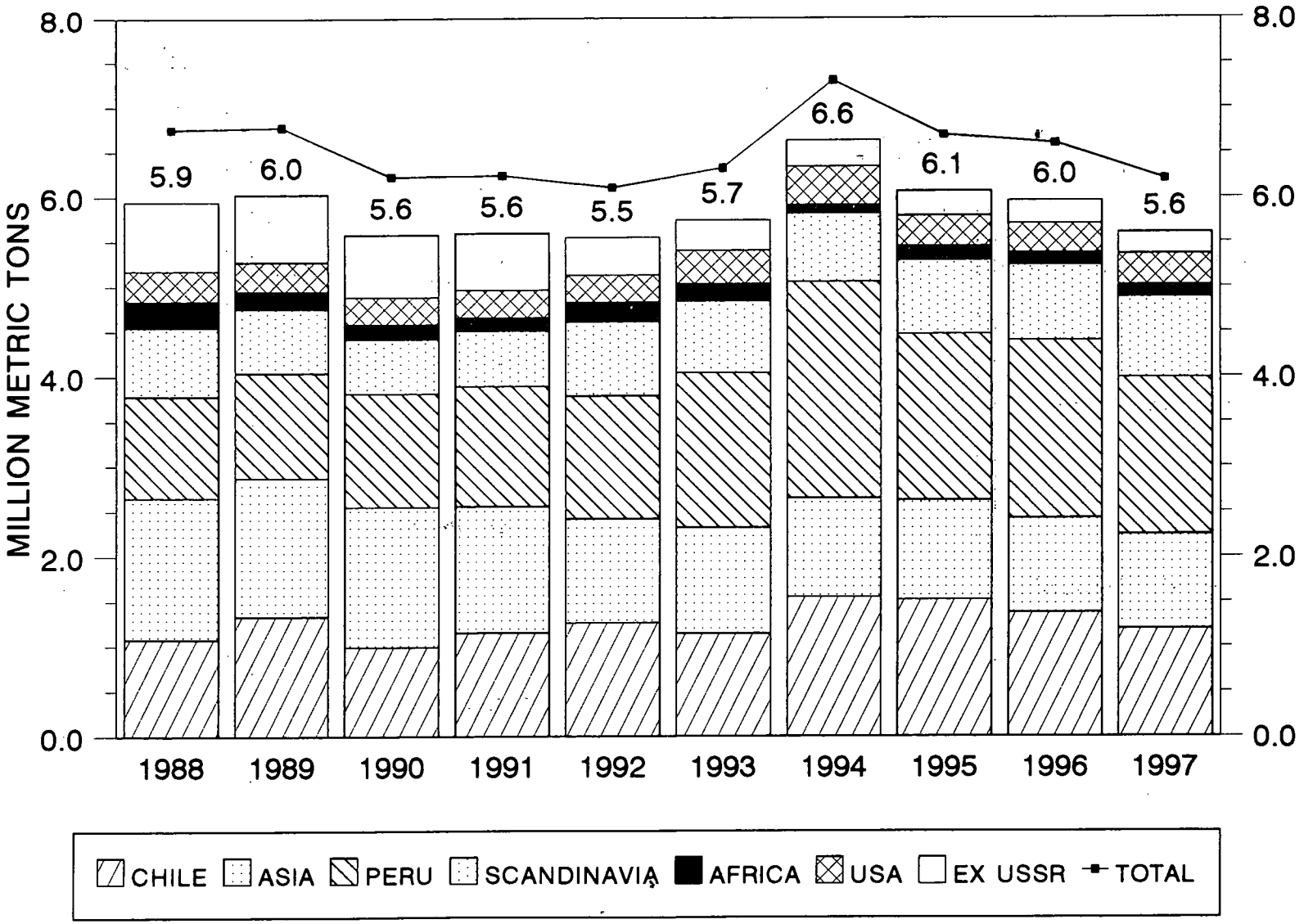
5-YEAR Average Production = 166.95 MMT

Source: Oil World Annual 1998

FIGURE 10. WORLD FISHMEAL PRODUCTION

Others = Sesame, Linseed, Copra, Palmkernel and Corngerm
5 YEAR Average Production = 166.95 MMT
Source: Oil World Annual 1998

FIGURE 10. WORLD FISHMEAL PRODUCTION

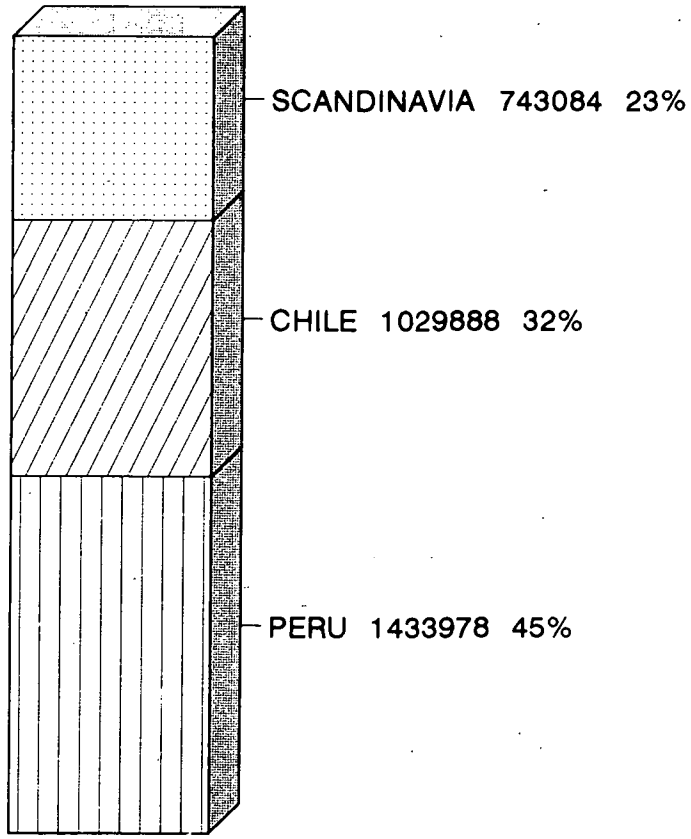


Scandinavia = Denmark, Sweden, Faeroe Is., Iceland and Norway.

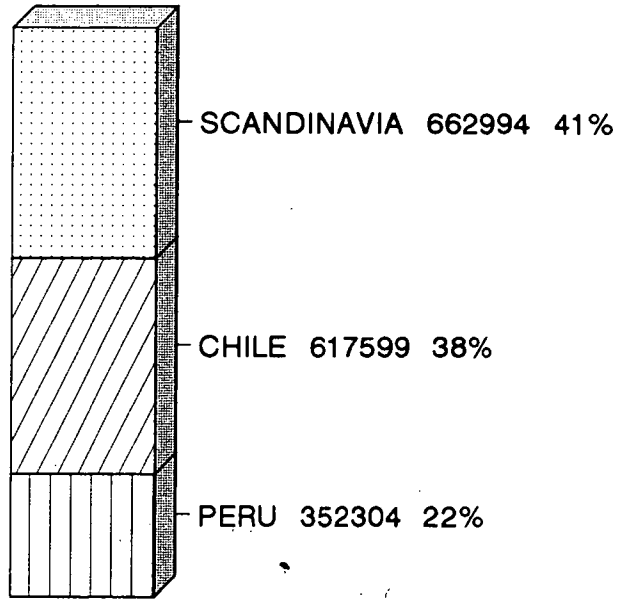
Source: Oil World Annual 1998

FIGURE 11. FISHMEAL PRODUCTION JANUARY - SEPTEMBER 1997 AND 1998

IN THE MAJOR EXPORTING COUNTRIES



1997



1998 est.

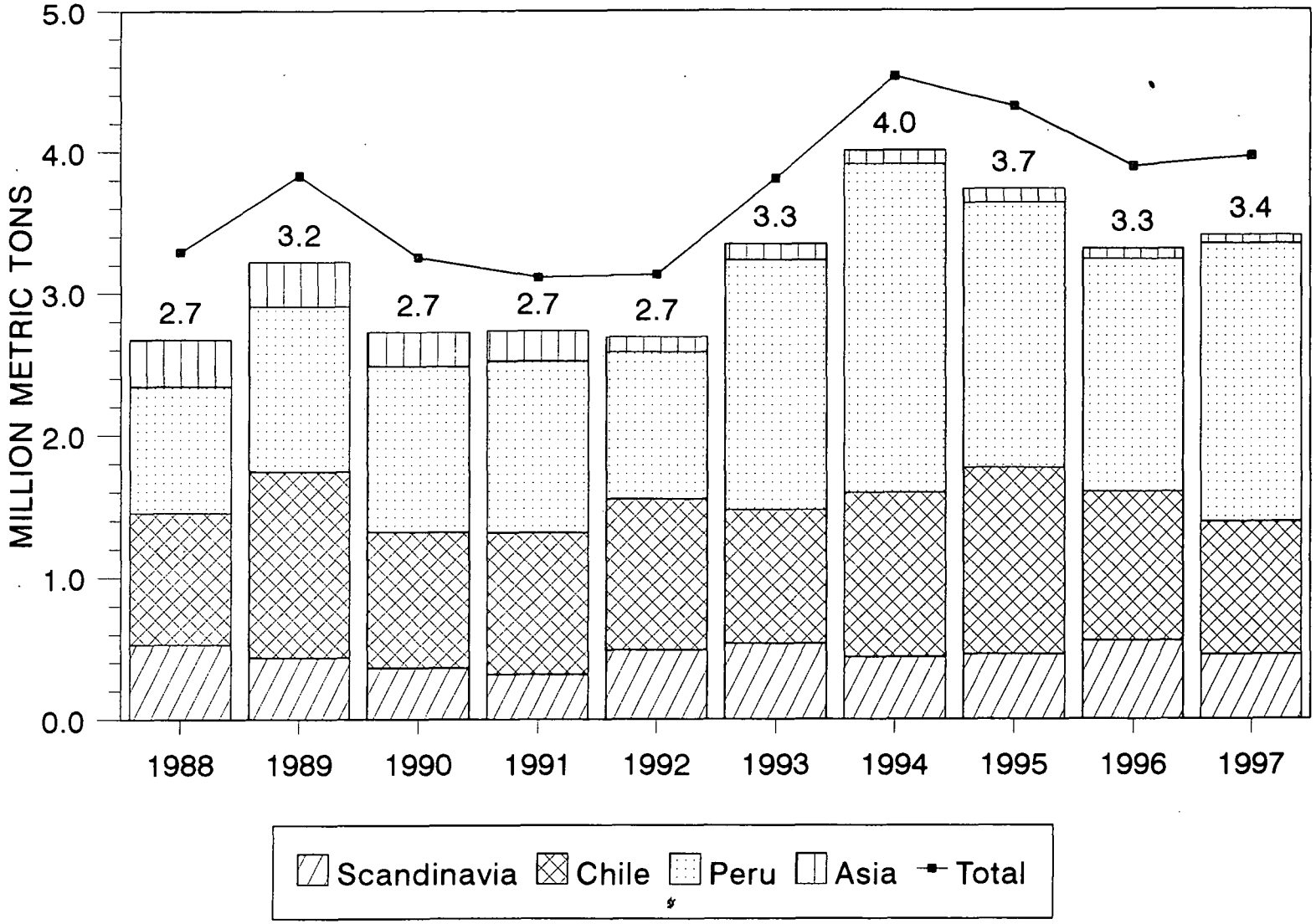
For the 9 months Jan-Sept 1997, production = 3.21 mmt

For the 9 months Jan-Sept 1998 est. production = 1.63 mmt

FIGURE 12. WORLD FISHMEAL EXPORTS

For the 9 months Jan-Sept 1997, production = 3.21 mmt
For the 9 months Jan-Sept 1998 est. production = 1.63 mmt
Source: IFOMA 1998, FEO 1998

FIGURE 12. WORLD FISHMEAL EXPORTS



Scandinavia = Denmark, Sweden, Faeroe Is., Iceland and Norway

Source: Oil World Annual 1998

FIGURE 11. = 13. MAJOR FISHMEAL IMPORTERS

Scandinavia =

Source: Oil World

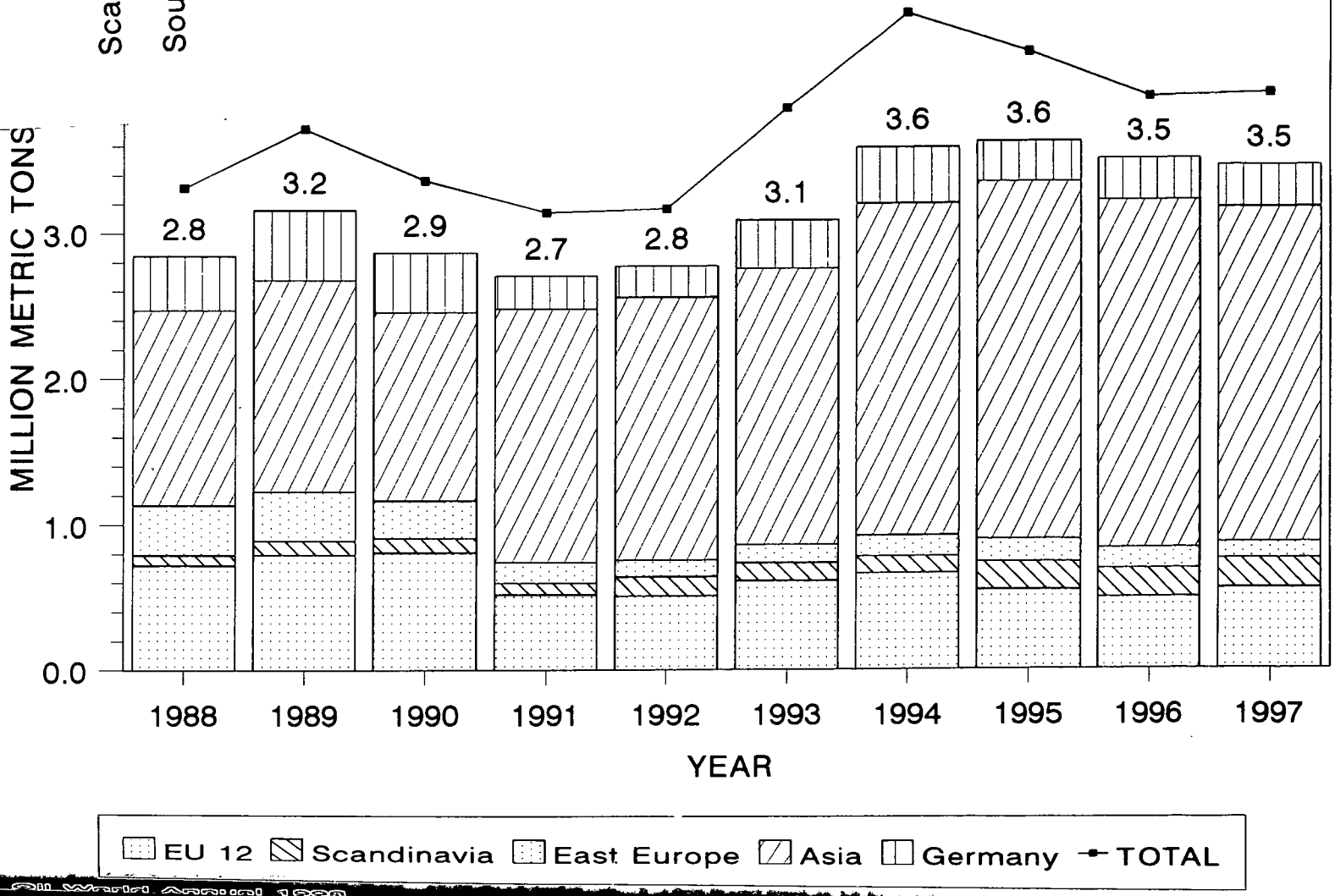
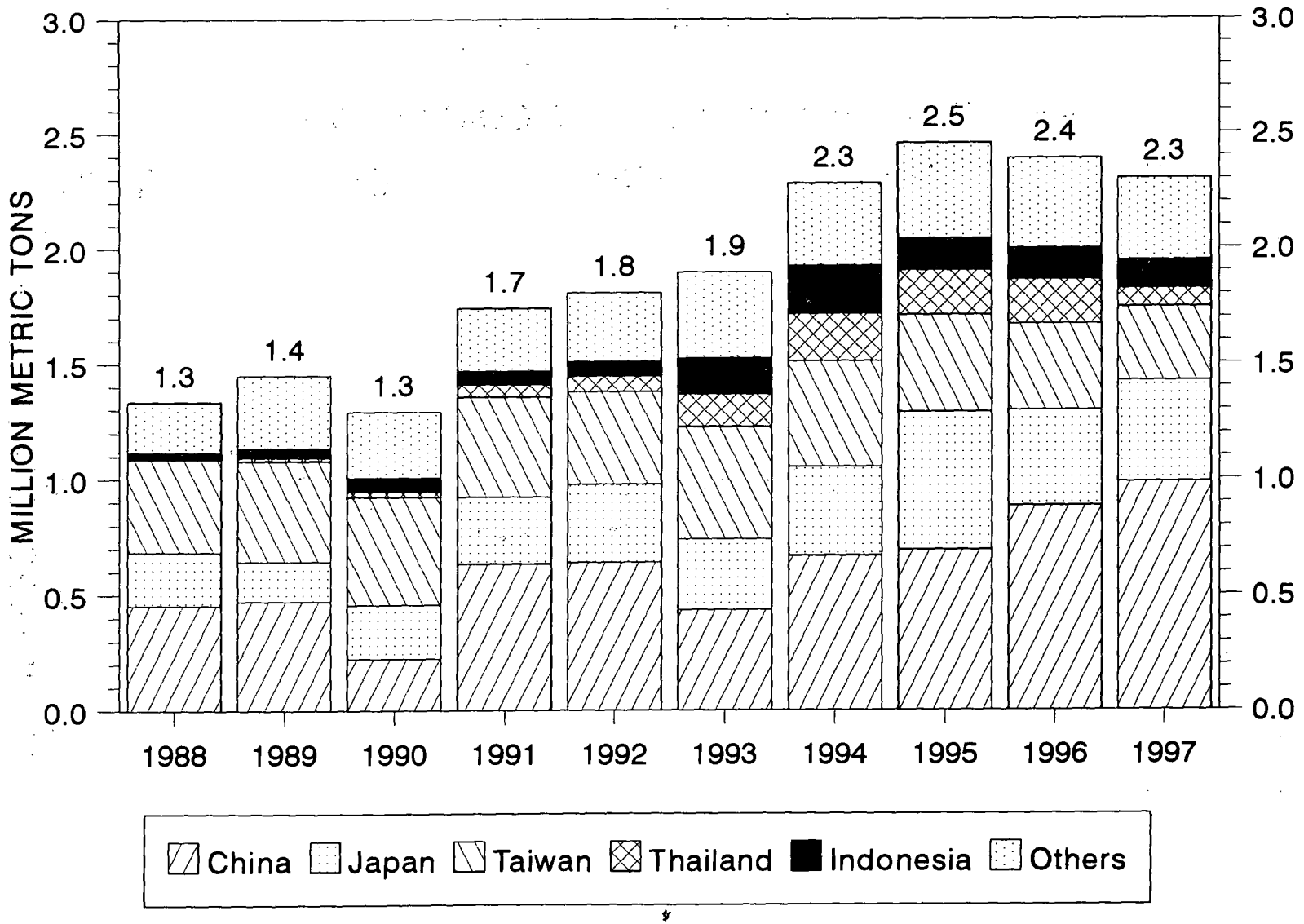


FIGURE 14. ASIAN FISHMEAL IMPORTS

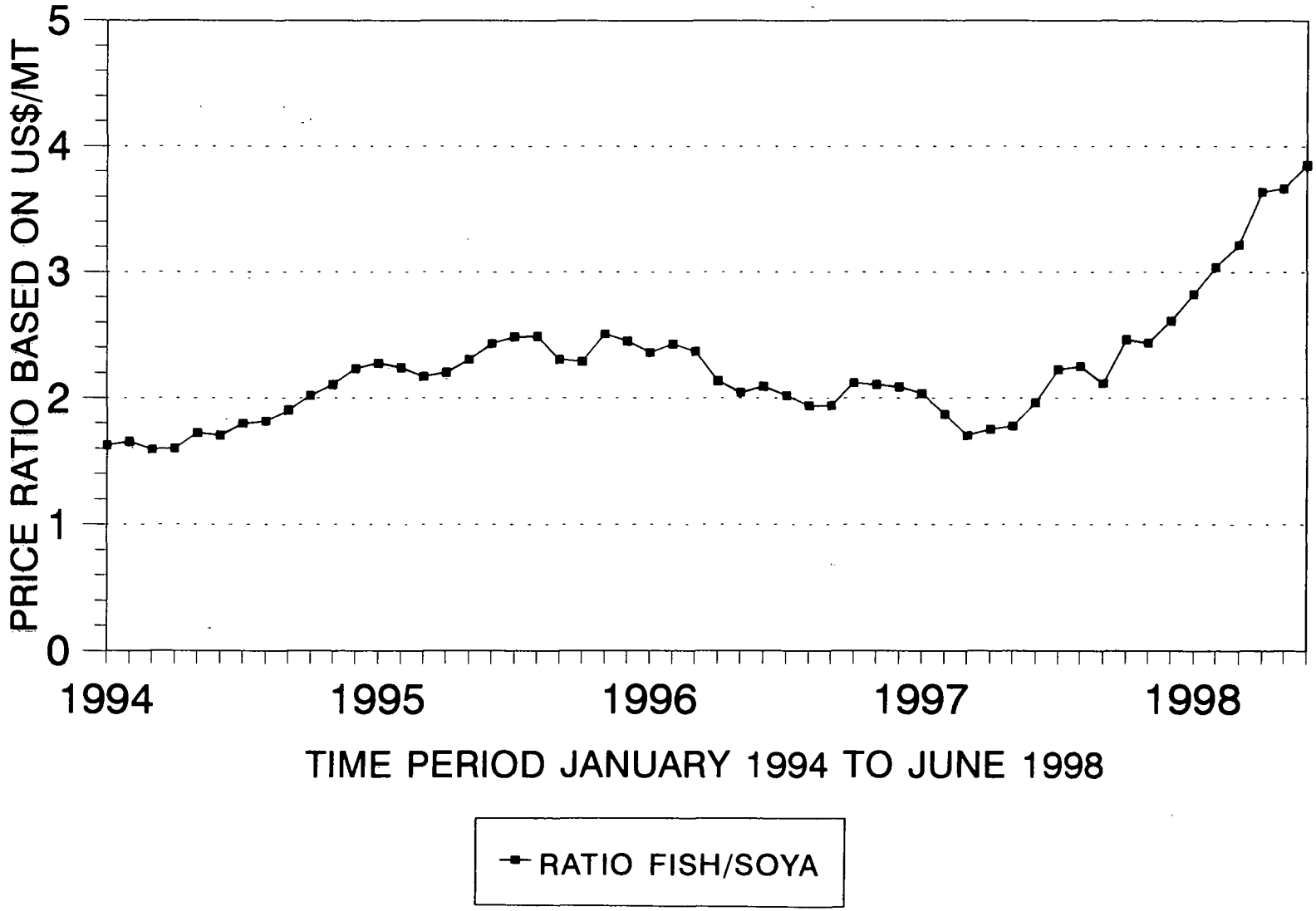
Source: Oil World Annual 1998

FIGURE 14. ASIAN FISHMEAL IMPORTS



Source: Oil World Annual 1998

FIGURE 15. FISH MEAL VS SOYBEAN MEAL PRICES

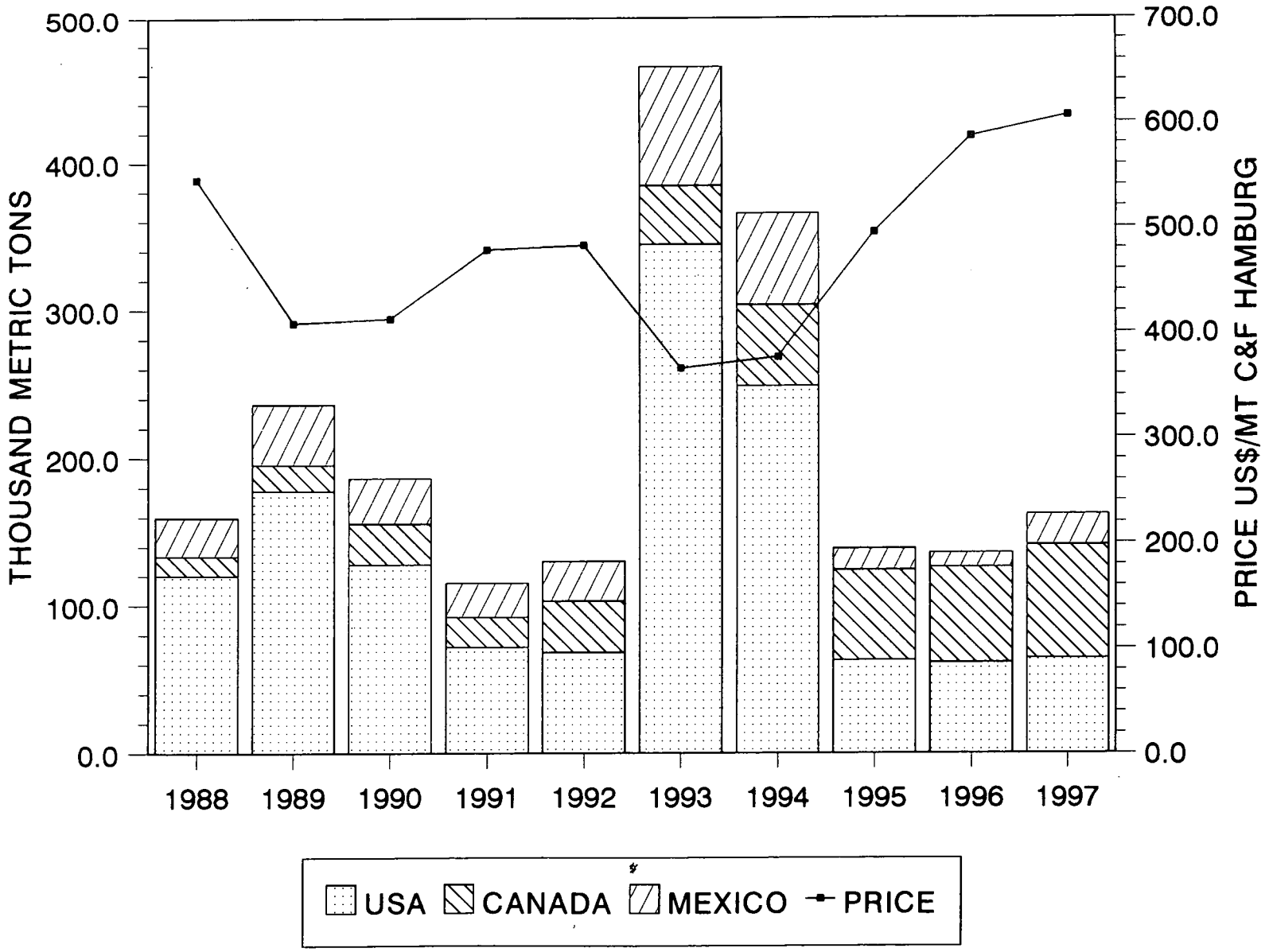


Soybean Meal Price 44-45% Protein Hamburg
Fishmeal Price C&F Hamburg (64/65% Protein)
Source: Oil World Annual 1998

FIGURE 16. USA, CANADA AND MEXICO FISHMEAL IMPORTS

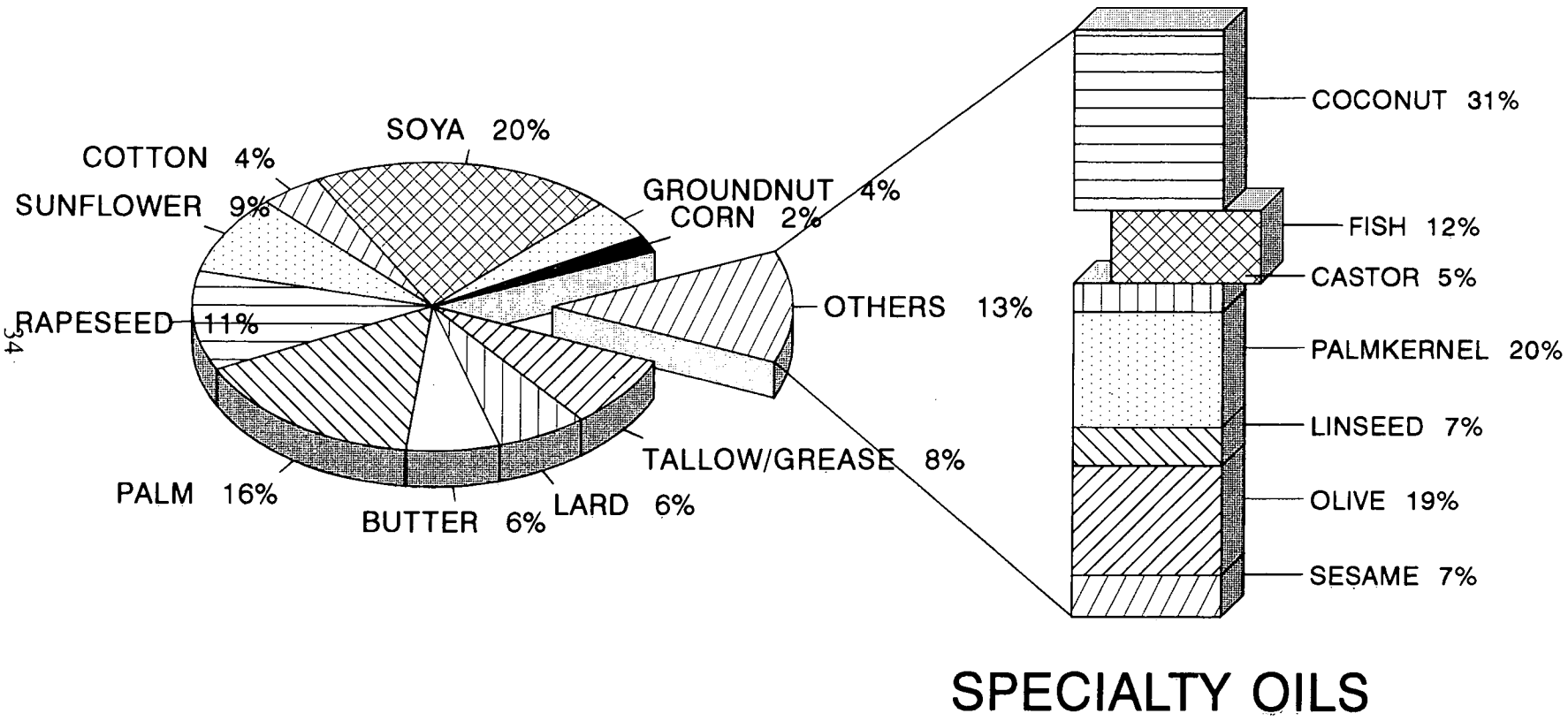
Soybean Meal Price 44-45% Protein Hamburg
Fishmeal Price C&F Hamburg (64/65% Protein)
Source: Oil World Annual 1998

FIGURE 16: USA, CANADA AND MEXICO FISHMEAL IMPORTS



Source: Oil World Annual 1998

FIGURE 17. WORLD PRODUCTION OF FATS AND OILS



5 YEAR AVERAGE PRODUCTION = 92 MILLION METRIC TONS

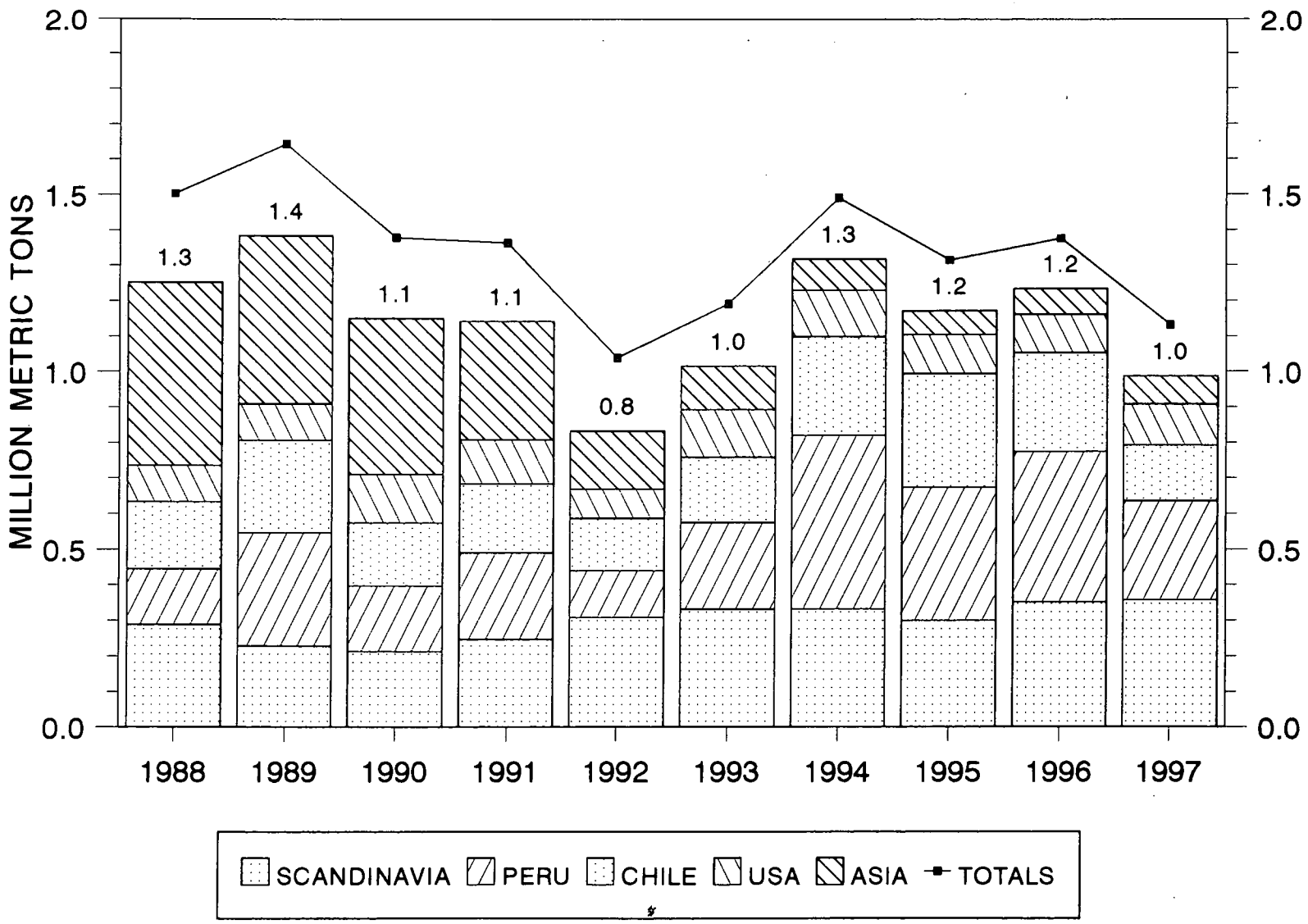
Source: Oil World Annual 1998

FIGURE 18. WORLD FISH OIL PRODUCTION

5 YEAR AVERAGE PRODUCTION = 92 MILLION METRIC TONS

Source: Oil World Annual 1998

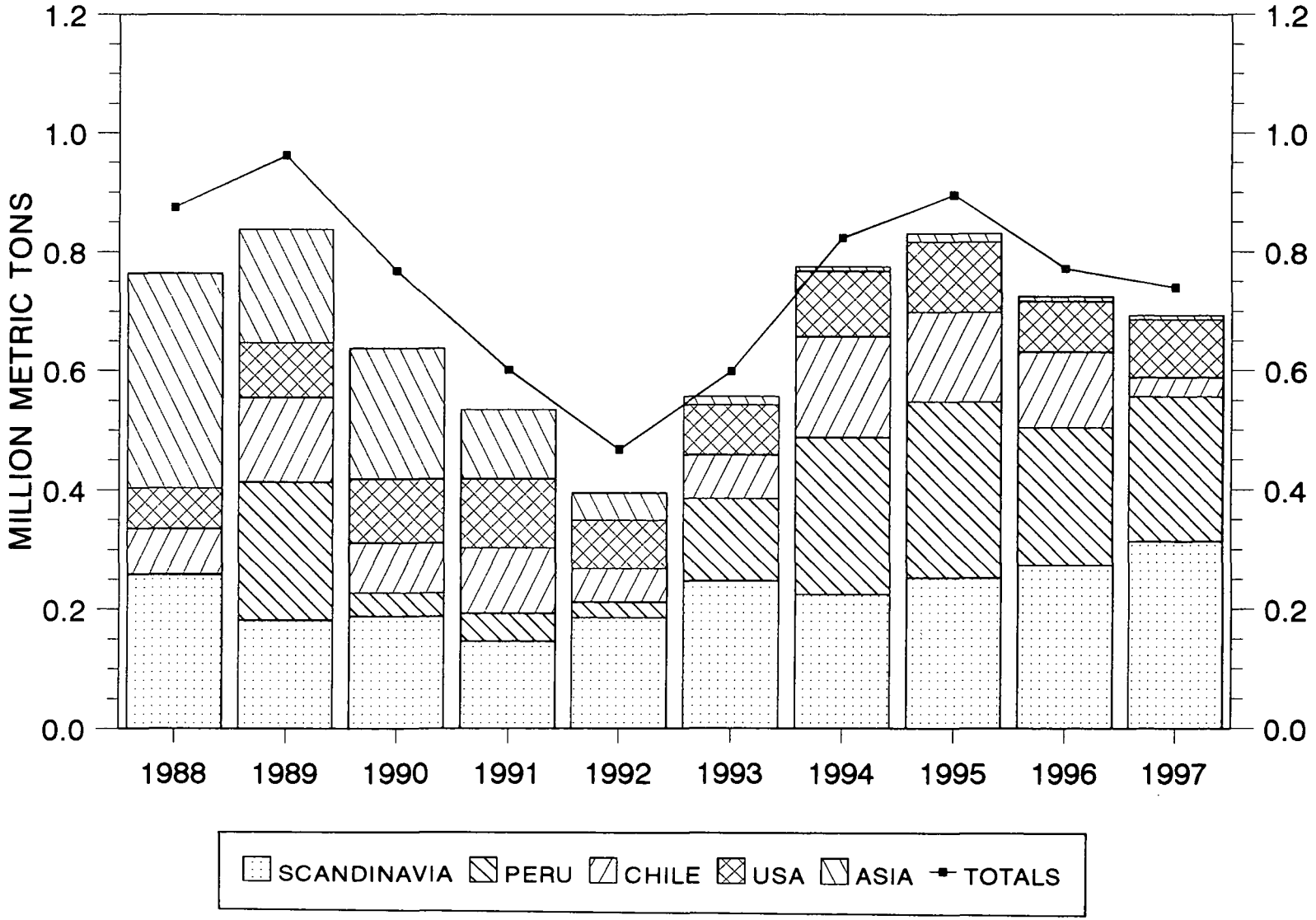
FIGURE 18. WORLD FISH OIL PRODUCTION



Scandinavia = Denmark, Sweden, Faeroe Is., Iceland and Norway.

Source: Oil World Annual 1998

FIGURE 19. WORLD FISH OIL EXPORTS



Scandinavia = Denmark, Sweden, Faeroe Is., Iceland and Norway.

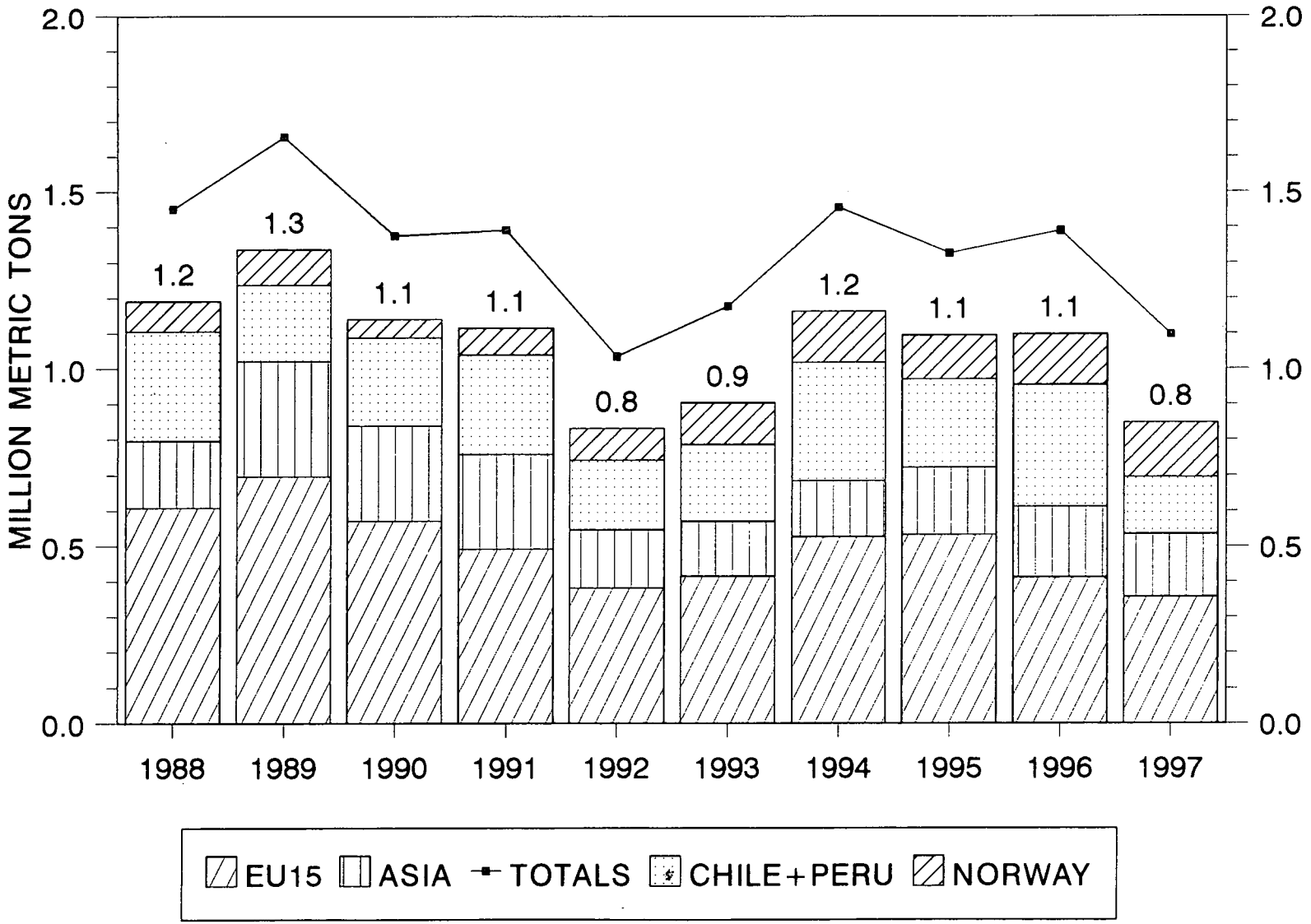
Source: Oil World Annual 1998

FIGURE 20. FISH OIL CONSUMERS

Scandinavia = Denmark, Sweden, Faeroe Is., Iceland and Norway.

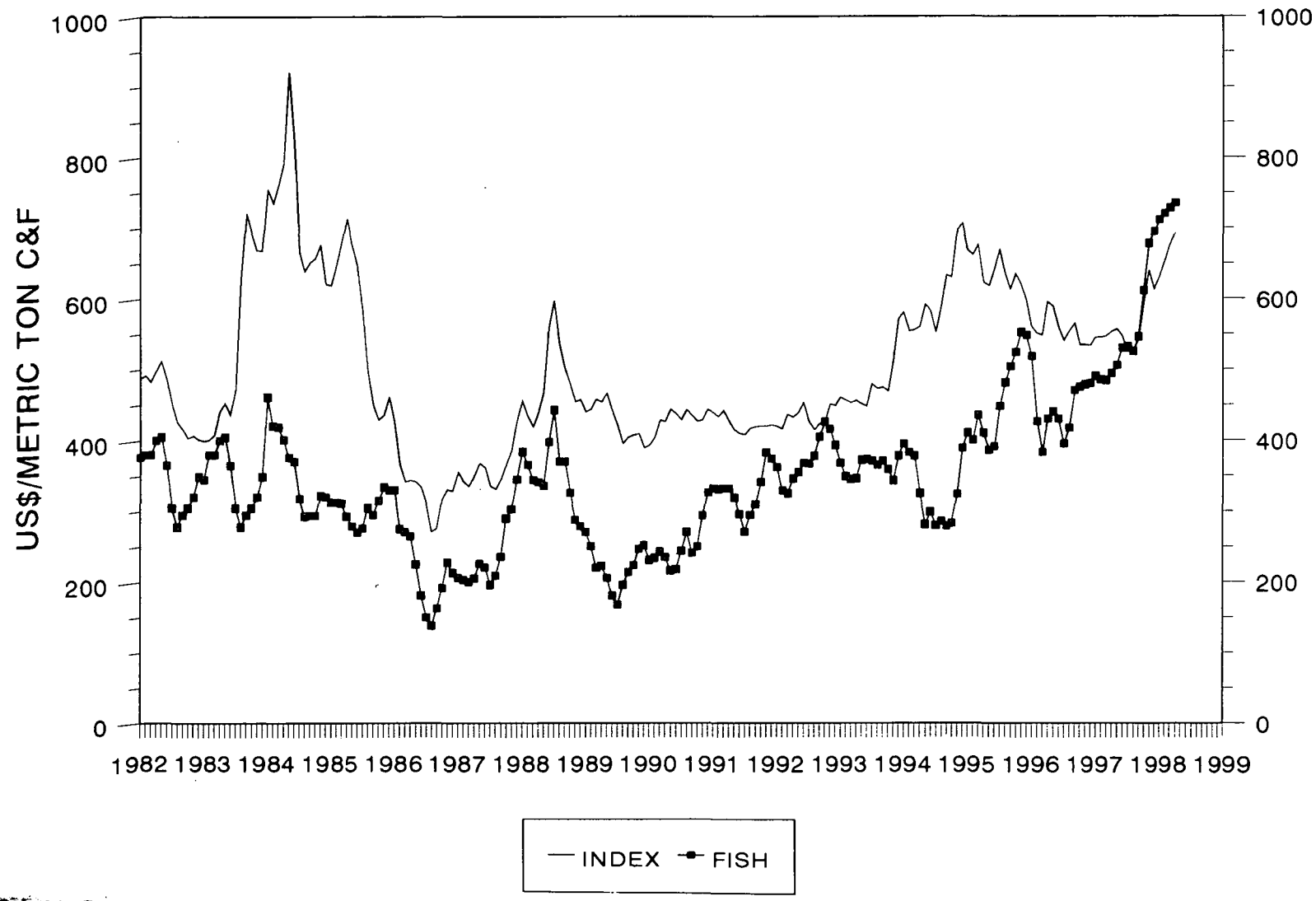
Source: Oil World Annual 1998

FIGURE 20. FISH OIL CONSUMERS



Source: Oil World Annual 1998

FIGURE 21. FISH OIL PRICES, ROTTERDAM



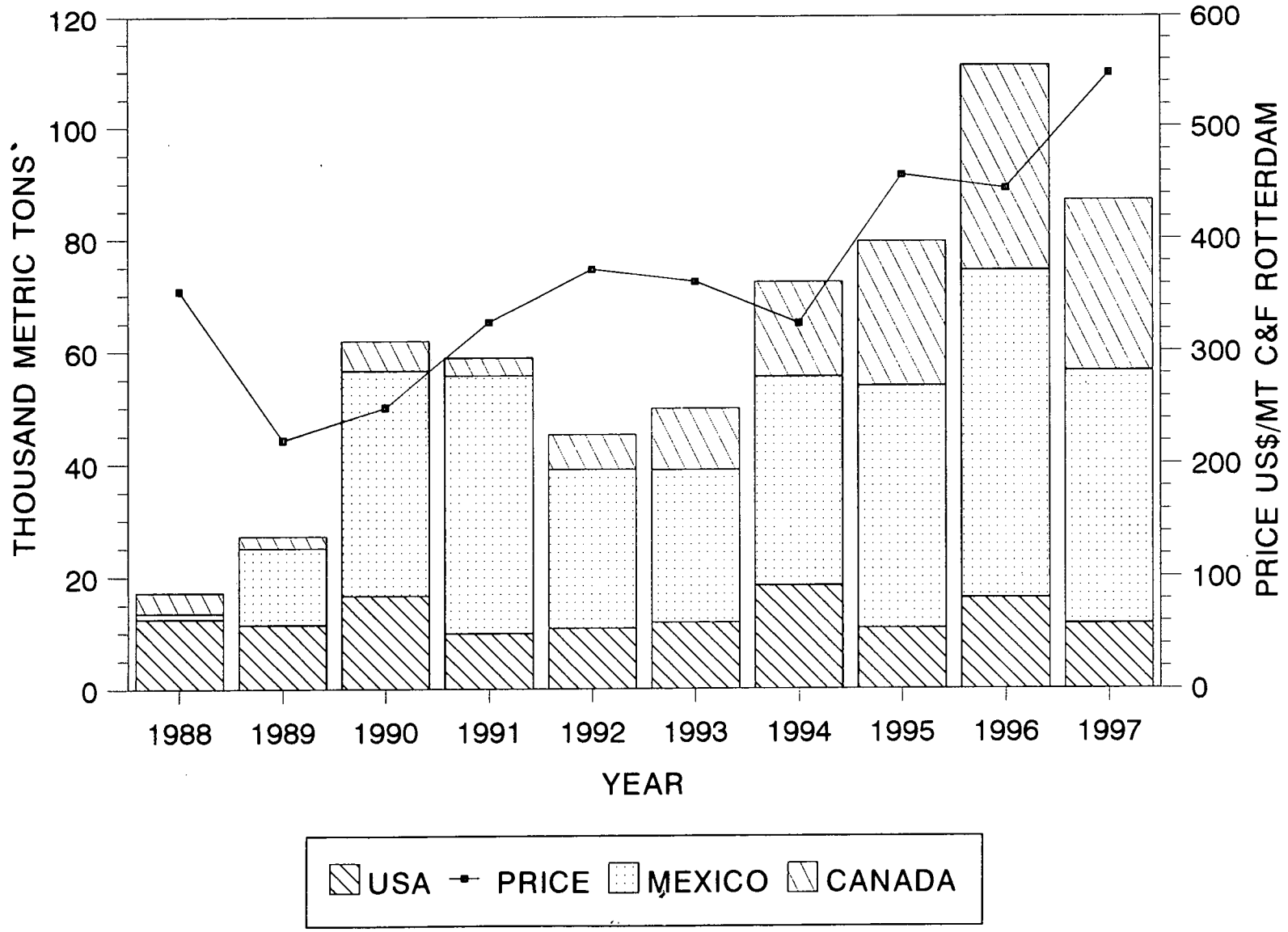
Index = 35% Soy + 35% Palm + 15% Rapeseed + 15% Sun

FIGURE 22. USA, CANADA AND MEXICO FISH OIL IMPORTS

Index = 35% Soy + 35% Palm + 15% Rapeseed + 15% Sun

Source: From Oil World Annual 1998

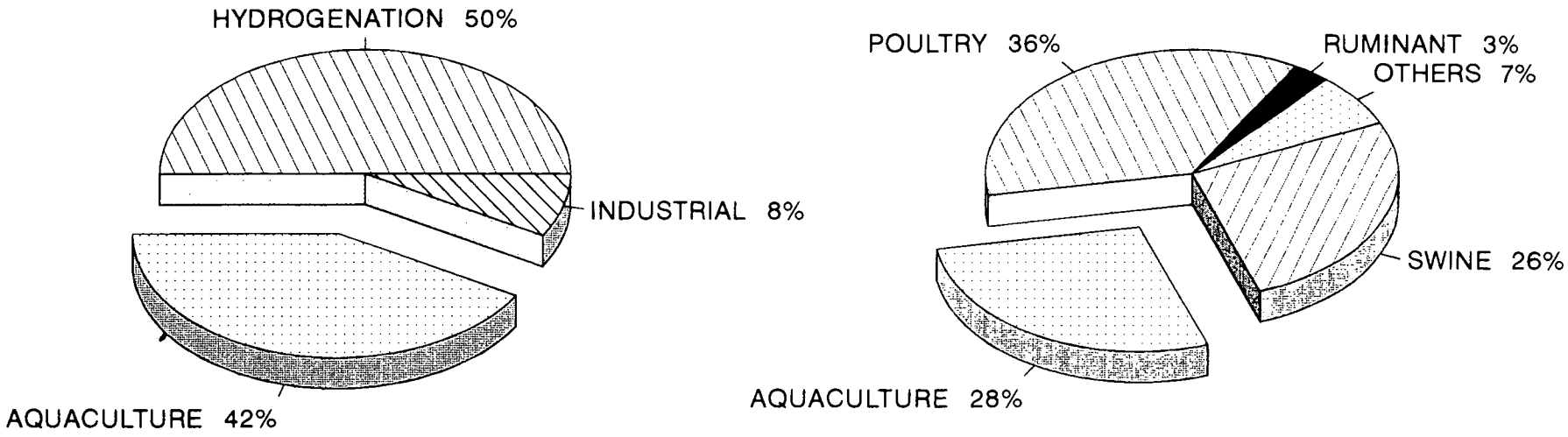
FIGURE 22. USA, CANADA AND MEXICO FISH OIL IMPORTS



Source: Oil World Annual 1998

FIGURE 23. WORLD CONSUMPTION OF FISHMEAL AND OIL

ESTIMATED FOR 1997



FISH OIL

FISHMEAL

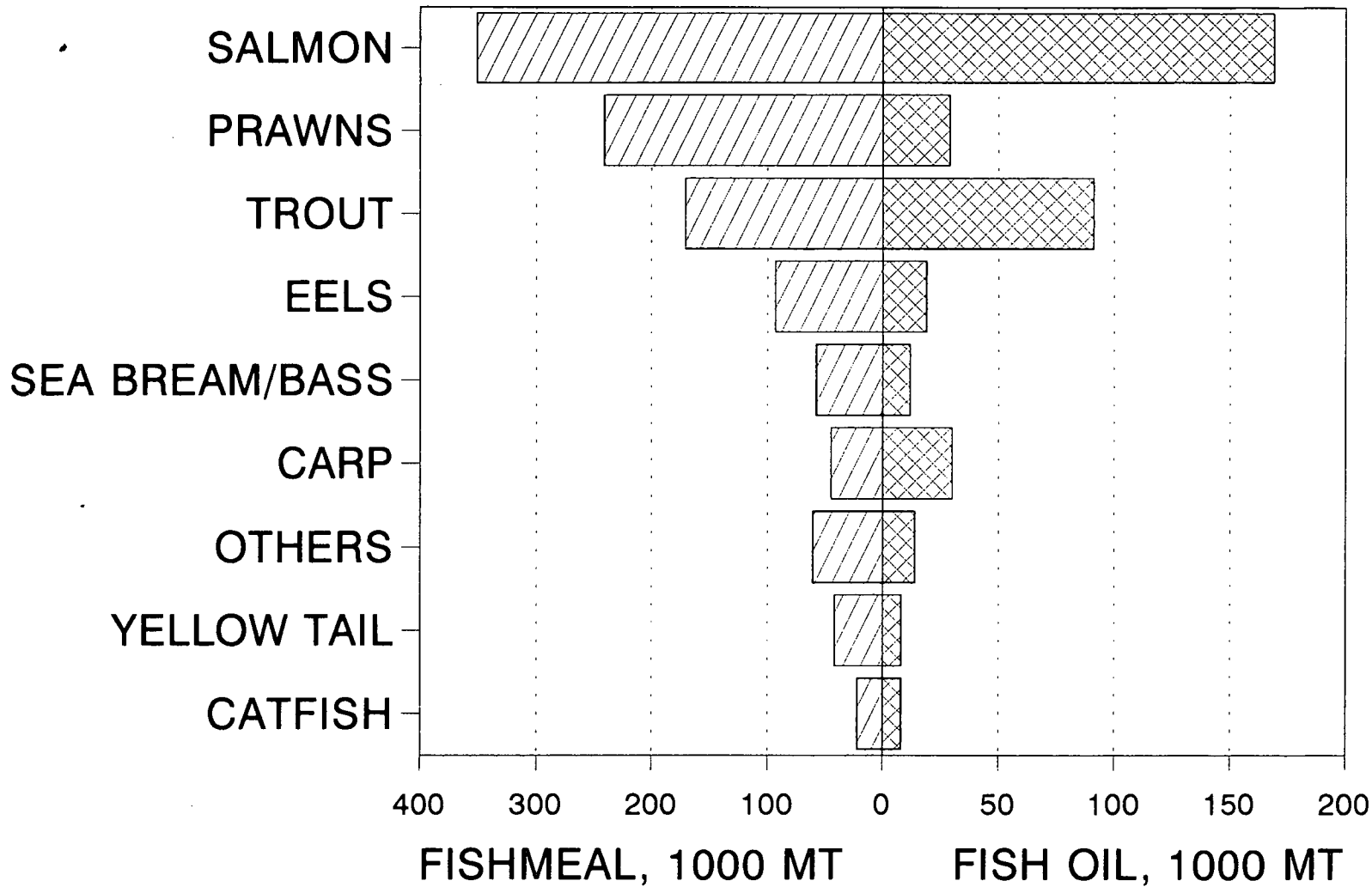
Based on 1.2 mmt of fish oil production

Based on 6.6 mmt of fishmeal production

FIGURE 24. 1994 WORLD CONSUMPTION OF FISHMEAL AND OIL IN AQUAFEEDS

Based on 1.2 mmt of fish oil production
Based on 6.6 mmt of fishmeal production
Source: IFOMA 1998

FIGURE 24. 1994 WORLD CONSUMPTION OF FISHMEAL AND OIL IN AQUAFEEDS



Total aquafeed consumption estimated at 3.57 mmt
Total fishmeal estimated at 1.09 mmt, fish oil 0.38 mmt
Source: Bimbo and Pike 1996

FIGURE 25. CHANGE IN FISHMEAL AND FISH OIL CONSUMPTION

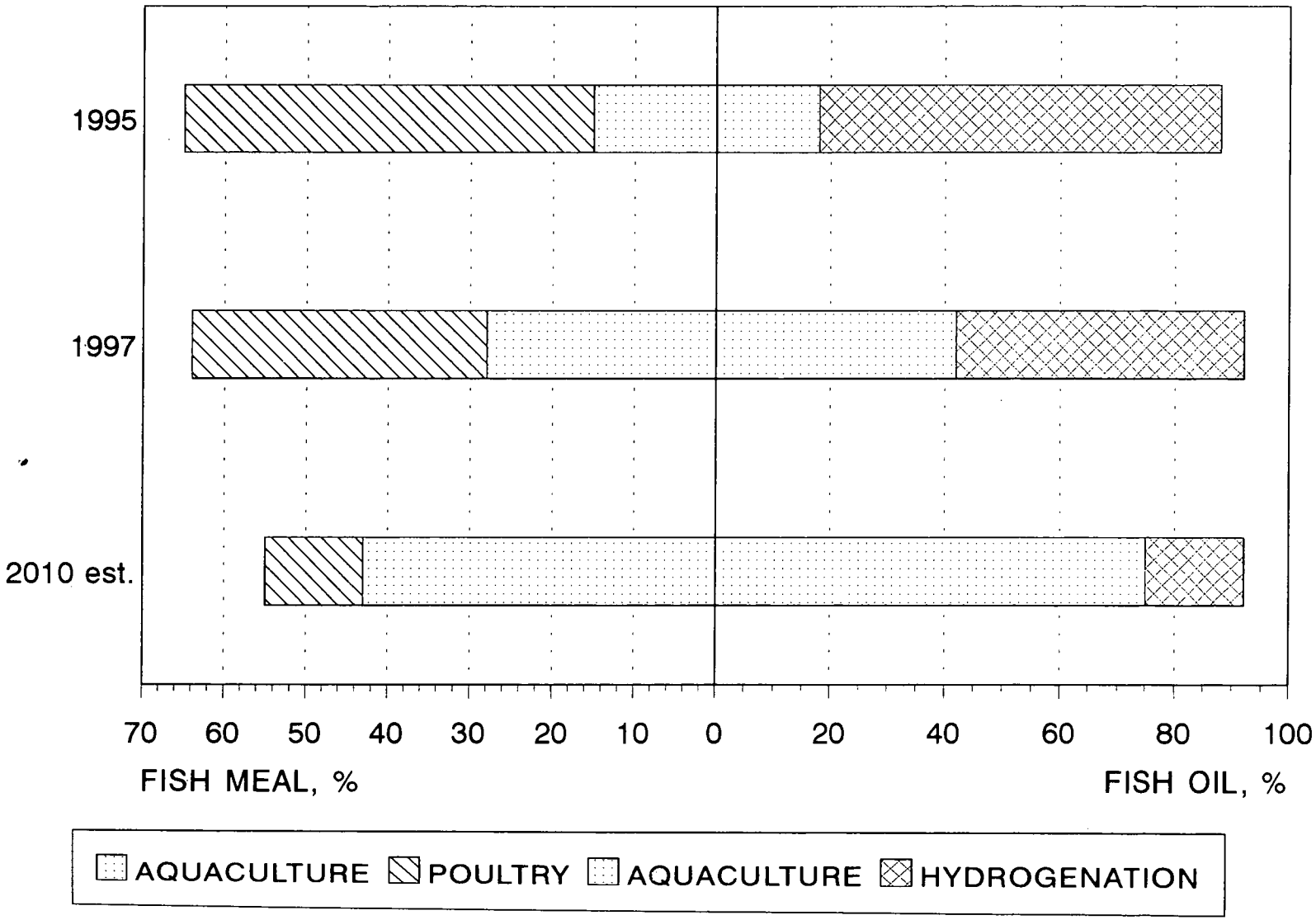


FIGURE 26. FISHMEAL DESIGNATIONS

PURCHASING AGENTS CAN BECOME CONFUSED

Source: IFOMA 1998

FIGURE 26. FISHMEAL DESIGNATIONS
PURCHASING AGENTS CAN BECOME CONFUSED

FAQ STANDARD (A,B) PRIME STEAM DRIED COMMERCIAL COMMODITY GRADE

SUPER-STANDARD STEAM DRIED PRIME

PRIME SELECT SPECIAL QUALITY PRIME

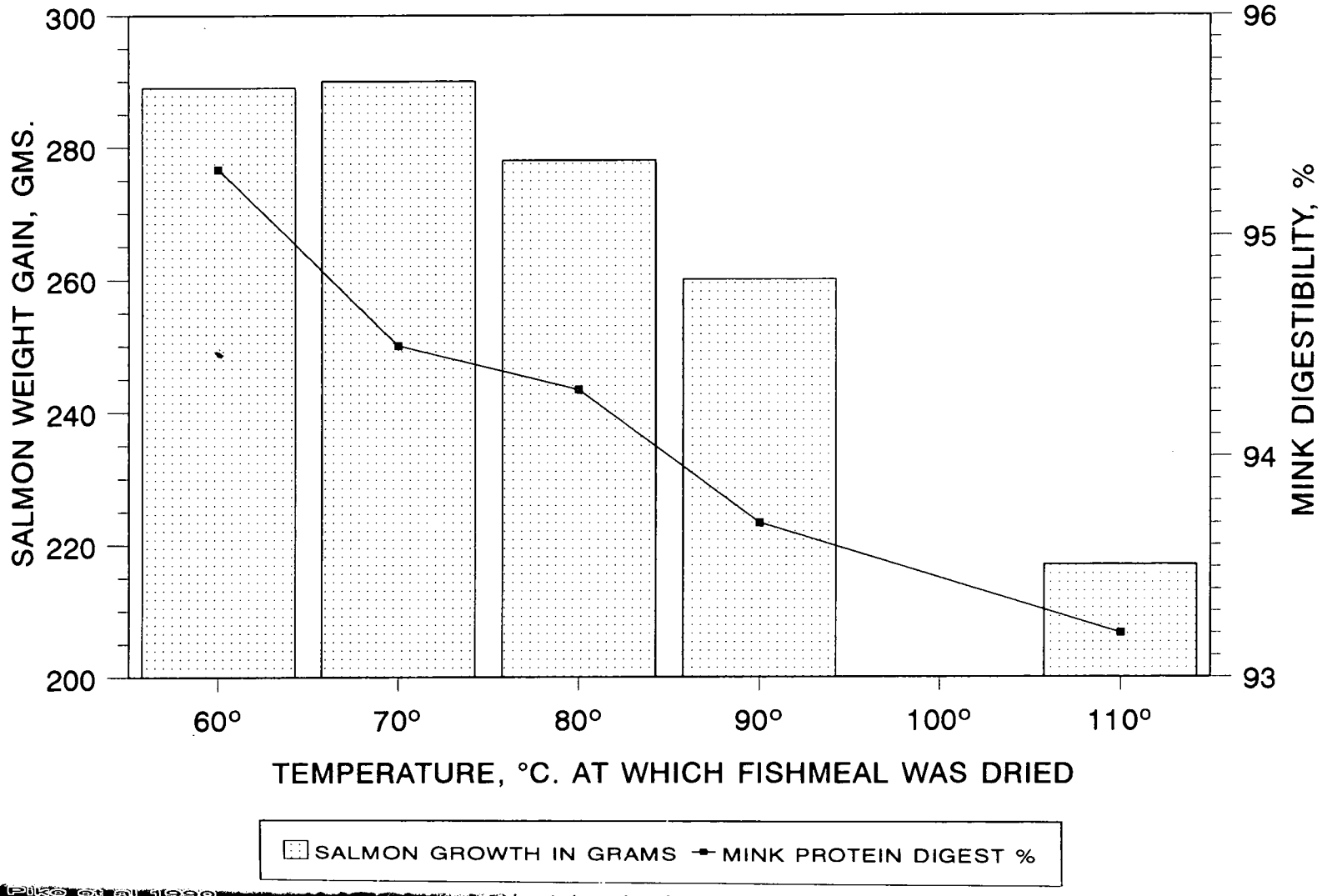
SUPER-PRIME SPECIAL SELECT SPECIAL QUALITY SPECIAL (A,B)
VACUUM DRIED STEAM DRIED LT LT94

OTHER MODIFIERS THAT CAN BE USED WITH THE ABOVE MEAL TYPES:

PRESSCAKE MEAL RUMINANT GRADE AQUACULTURE GRADE
LOW ASH PET FOOD NATURAL

FIGURE 27. GROWTH OF ATLANTIC SALMON

FED HERRING FISHMEAL PREPARED AT DIFFERENT TEMPERATURES



Source: Pike et al 1990

PROXIMATE	
Crude Protein	
Ether Extract	
Moisture	
Ash	
% OF CRUDE PROTEIN	
ENERGY	
Poultry, M.E.	
Pigs, D.E.	
Rumen D	
Ruminant	
Fish, M.E.	
AMINO	
Lysine	
Methionin	
Cystine	
Tryptopha	
Arginine	
Phenylalan	
Threonine	
MINERA	
Calcium, %	
Phosphoro	
Sodium, %	
Magnesium	

FIGURE 28. TYPICAL NUTRIENT COMPOSITION OF VARIOUS FISH MEAL TYPES.

	HERRING	WHITE FISH	ANCHOVY	MENHADEN
PROXIMATE ANALYSIS, %				
Crude Protein	71.9	64.5	66.4	62.2
Ether Fat	7.5	4.9	9.7	9.0
Moisture	8.4	10.0	8.6	8.4
Ash	10.1	20.0	15.4	18.4
PROTEIN CHARACTERISTICS, % OF CRUDE PROTEIN				
Rumen Degradable	48.8	53.3	48.5	50.5
Water Soluble	19.8	8.9	18.3	15.5
ENERGY CONTENT, MJ/KG				
Poultry, M.E.	13.7	11.6	13.5	12.8
Pigs, D.E.	18.1	15.6	16.9	16.5
Ruminants, M.E.	16.4	13.4	13.1	12.8
Fish, M.E.	17.0	16.5	16.5	16.0
AMINO ACIDS, % OF PROTEIN				
Lysine	7.73	6.90	7.75	7.56
Methionine	2.86	2.6	2.95	2.64
Cystine	0.97	0.93	0.94	0.79
Tryptophan	1.15	0.94	1.20	1.00
Arginine	5.84	6.37	5.82	5.73
Phenylalanine	3.91	3.29	4.21	3.81
Threonine	4.26	3.85	4.31	4.28
MINERALS				
Calcium, %	1.9	8.0	3.9	4.9
Phosphorous, %	1.5	4.8	2.6	3.0
Sodium, %	0.4	0.8	0.9	0.7
Magnesium, %	0.1	0.2	0.3	0.2

Source: Pike et al 1990

	HERRING	WHITE FISH	ANCHOVY	MENHADEN
Potassium, %	1.2	0.9	0.7	1.0
Iron, ppm	150	300	246	864.6
Copper, ppm	5.4	7.0	10.6	7.5
Zinc, ppm	120	100	111	97
Manganese, ppm	2.4	10.0	9.7	39.8
Selenium, ppm	2.8	1.5	1.4	1.8
VITAMINS, ppm				
Panthothenic Acid	30.6	15.0	9.3	8.8
Riboflavin	7.3	6.5	2.5	4.8
Niacin	126	50	95	55
Choline	4396	4396	4396	4396
B12	.25	.07	.18	.06
Biotin	.42	.08	.26	.26
ESSENTIAL FATTY ACIDS, % OF FATTY ACIDS				
C18:2n-6	2	1	1	1
C18:3n-3	1	1	1	1
C18:4n-3	2	2	2	2
C20:4n-6	1	na	1	1
C20:5n-3	6	12	16	12
C22:5n-3	1	2	2	3
C22:6N-3	13	19	14	9
TOTAL N-3 FATTY ACIDS	23	35	34	30

Source: Bimbo and Crowther 1992.

HADEN
1.0
64.6
7.5
97
39.8
1.8
8.8
4.8
55
4396
.06
.26
1
1
2
1
12
3
9
30

FIGURE 29. ADDITIONAL FISHMEAL QUALITY PARAMETERS

QUALITY PARAMETER	STANDARD FISHMEAL	SPECIAL FISHMEAL	PRIME FISHMEAL	SUPER PRIME FISHMEAL
RAW MATERIAL FRESHNESS	↔	↑	↑ ↑	↑ ↑ ↑
TVN IN FISHMEAL	↔	↓	↓ ↓	↓ ↓
FFA IN FISHMEAL	↔	↓	↓ ↓	↓ ↓
HISTAMINE IN FISHMEAL	↔	↓	↓ ↓	↓ ↓ ↓
CADAVERINE IN FISHMEAL	↔	↓	↓ ↓	↓ ↓ ↓
MINK DIGEST.				↑
PEPSIN DIGEST.	↔	↑	↑ ↑	↑ ↑
BIOTOX SCORE	↔	↓	↓ ↓	↓ ↓ ↓

SPECIAL QUALITY FISHMEAL QUALITY SPECIFICATIONS VARY BY SPECIES OF FISH PROCESSED AND SUPPLIER.

Source: Barlow and Bololanik 1996

FIGURE 30. COMPARISON OF BIOGENIC AMINES IN TWO DIFFERENT FISHMEALS

PRODUCED FROM RAW MATERIAL AT THREE DIFFERENT STAGES OF FRESHNESS.

	FRESH	MODERATELY FRESH	STALE
HERRING MEAL			
TVN IN RAW MATERIAL mgN/100g	22	62	143
CADAVERINE, ppm	330	1000	1600
PUTRESCINE, ppm	30	230	630
HISTAMINE, ppm	<30	440	830
TYRAMINE, ppm	<30	400	800
ANCHOVY MEAL			
TVN IN RAW MATERIAL mgN/100g	14	30	50
CADAVERINE	28	1850	4701
PURESCINE, ppm	51	803	1599
HISTAMINE, ppm	35	446	916
TYRAMINE, ppm	-	285	657

TVN is on the raw material. Biogenic Amines on the fishmeal

Source: Fiko and Hardy 1987 in press

FIGURE 31. FRESHNESS OF RAW MATERIAL AND PROCESSING TEMPERATURE EFFECTS ON MINK DIGESTIBILITY

TVN is on the raw material, Biogenic Amines on the fishmeal
Source: Pike and Hardy 1997 in press

FIGURE 31. FRESHNESS OF RAW MATERIAL AND PROCESSING TEMPERATURE EFFECTS ON MINK DIGESTIBILITY

FISH TVN, mgN/100 g FISH DRYING TEMP, ° C	22 60°	22 140°	100 60°	100 140°
DILUTE (0.0002%) PEPSIN DIGEST., %	96.5	83.6	97.9	97.1
WATER SOLUBLE PROTEIN (% Prot)	23.9	21.9	38.4	35.7
BIOGENIC AMINES, MG/KG				
CADAVERINE	150	130	4500	3750
HISTAMINE	120	140	4830	3570
PUTRESCINE	180	120	790	690
SPERMIDINE	50	-	80	110
MEAL AMMONIA NITROGEN, %	0.14	0.10	0.24	0.12
MINK DIGEST, % ±sd				
ADULTS	94.0±0.6	88.3±1.1	92.0±1.9	88.0±2.0
KITTENS	89.7±1.0	82.3±1.5	86.6±2.0	83.4±2.9

Source: Pike et al 1990

FIGURE 32. TYPICAL[1] FATTY ACIDS IN SOME COMMERCIALLY AVAILABLE MARINE OILS, AS % OF THE FATTY ACIDS.											
	ANCHOVY	JACK MACKEREL	MENHADEN	SARDINE/ PILCHARD	CAPELIN	HERRING	MACKEREL	NORWAY POUT	SAND EEL	SPRAT	TUNA
C14:0	9	8	9	8	7	7	8	5	7	-	3
C15:0	1	1	1	1					1		1
C16:0	17	18	19	18	10	17	14	12	13	17	22
C16:1	13	8	12	10	10	6	7	4	5	7	3
C17:0	1	1	1	1							1
C18:0	3	3	3	3	1	2	2	3	2	2	6
C18:1	10	16	11	13	14	14	13	10	7	16	21
C18:2	1	1	1	1	1	1	1	1	2	2	1
C18:3	1	1	1	1	1	2	1	1	1	2	1
C18:4	2	2	3	3	3	3	4	3	5		1
C20:1	1	2	1	4	17	15	12	13	12	10	1
C22:1	1	1		3	15	19	15	17	18	14	3
C20:5	22	13	14	16	8	6	7	9	11	6	6
C22:5	2	2	2	2		1	1	1	1	1	2
C22:6	9	15	8	9	6	6	8	14	11	9	22
OTHERS[2]	7	8	14	7	7	1	7	7	4	14	6

1 The Fatty Acid Composition of fish oil can vary by season, area of the catch, food that the fish are consuming, sexual maturity of the fish and age of the fish. This data reflects some general fatty acid profiles that should only be used to screen oils for possible use. In all cases, an updated fatty acid profile on the batch of oil to be used should be either supplied with the oil or performed by the researcher.

2 Other fatty acids: C16:2. C16:3, C16:4 and C20:4.

Source: Bimbo 1998

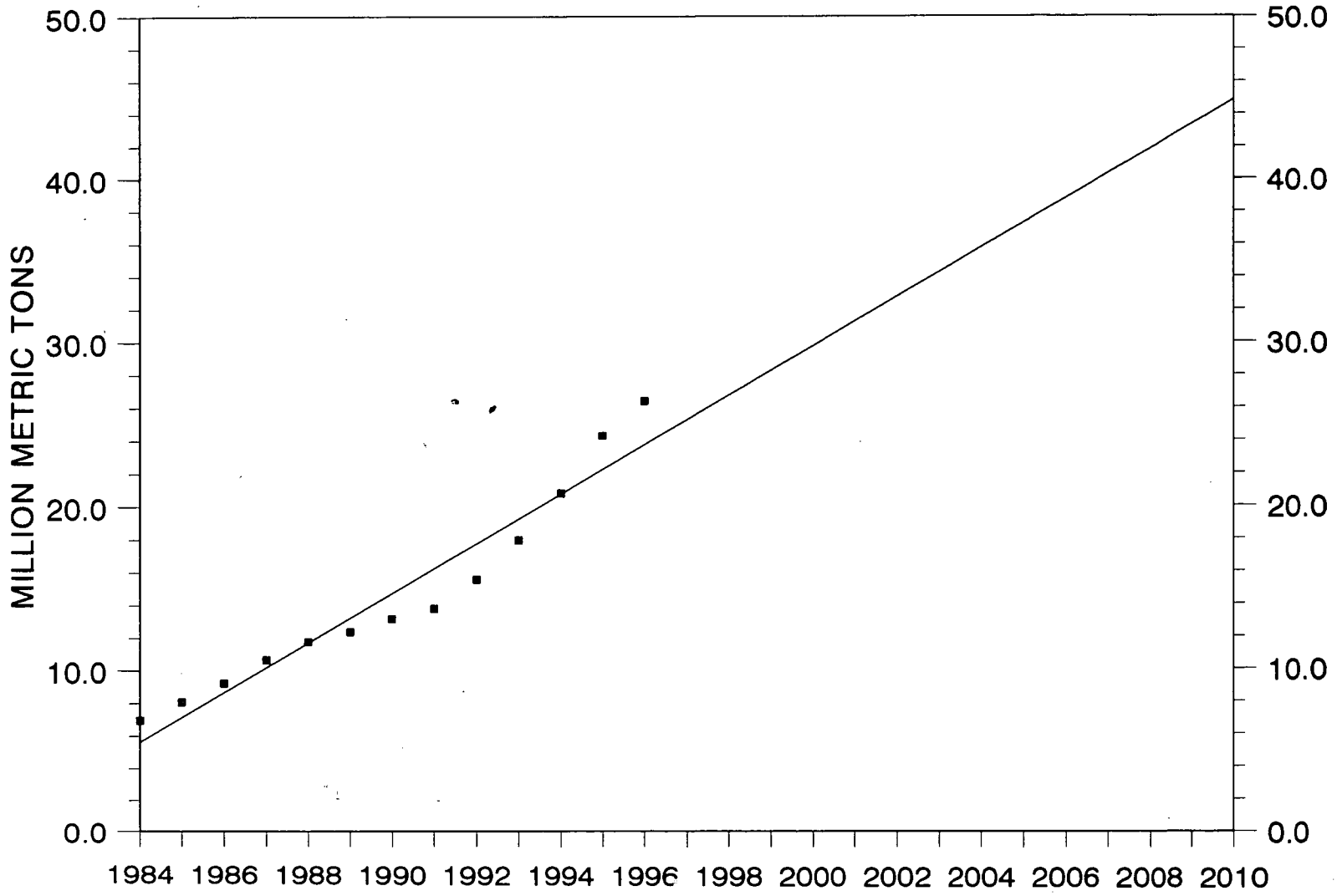
FIGURE 33. FISH OIL QUALITY CHARACTERISTICS

FIGURE 33: FISH OIL QUALITY CHARACTERISTICS

- FFA, COLOR, MOISTURE, IMPURITIES, IODINE VALUE
- TOCOPHEROL CONTENT
- OMEGA 3 FATTY ACID CONTENT
- ANISIDINE NUMBER (AN) L
- PEROXIDE VALUE (PV) L
- TOTOX VALUE = (2 X PV) + AN H
- COPPER
- HEAT LIGHT OXYGEN
- ANTI-OXIDANT TREATED

Source: Bimbo 1998

FIGURE 34. AQUACULTURE GROWTH THROUGH 2010 PREDICTED



IFOMA AND FAO ARE PREDICTING 61 MMT IN 2010

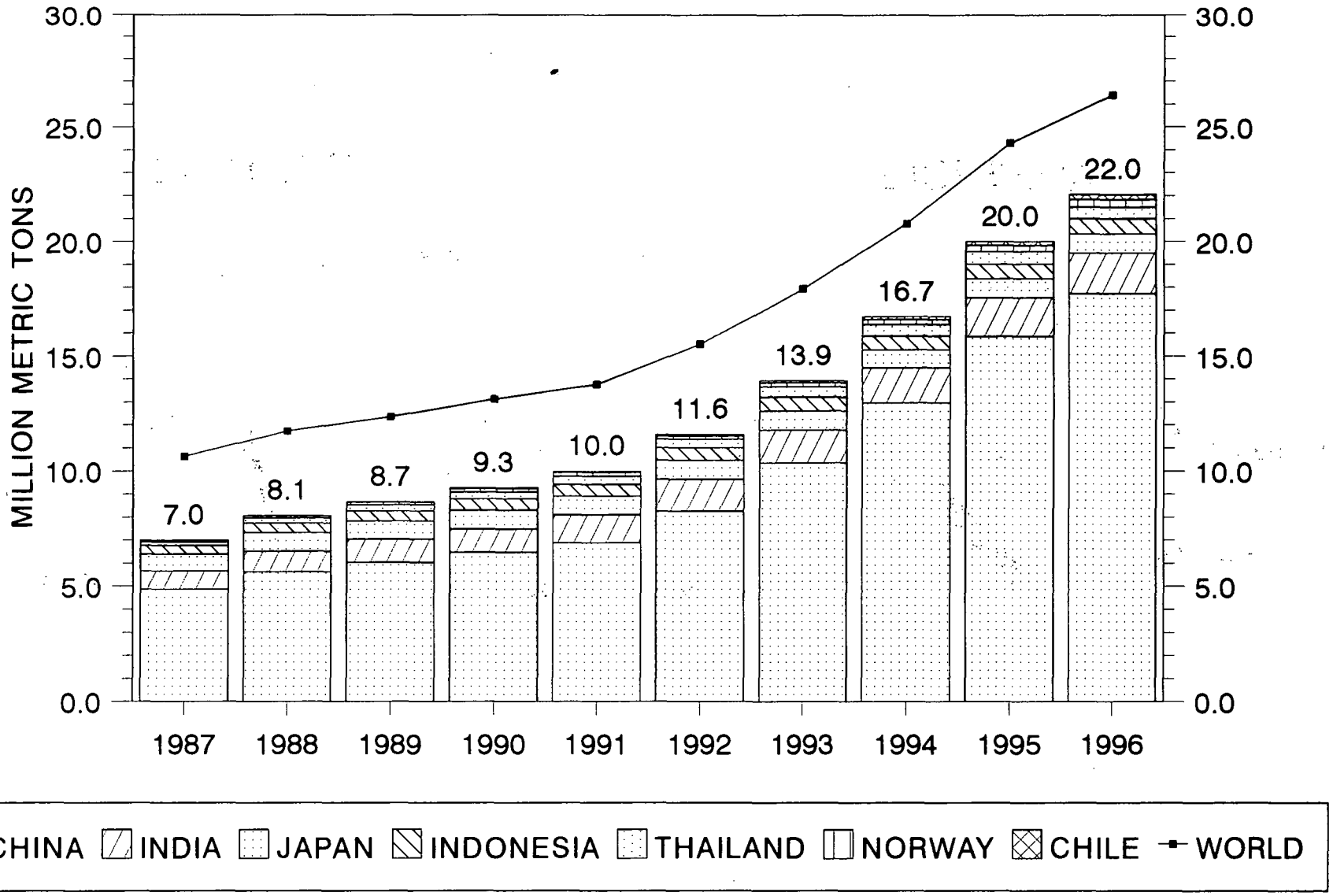
Source: FAO Aquaculture Statistics

FIGURE 35. MAJOR AQUACULTURE PRODUCING COUNTRIES

IFOMA AND FAO ARE PREDICTING 61 MMT IN 2010

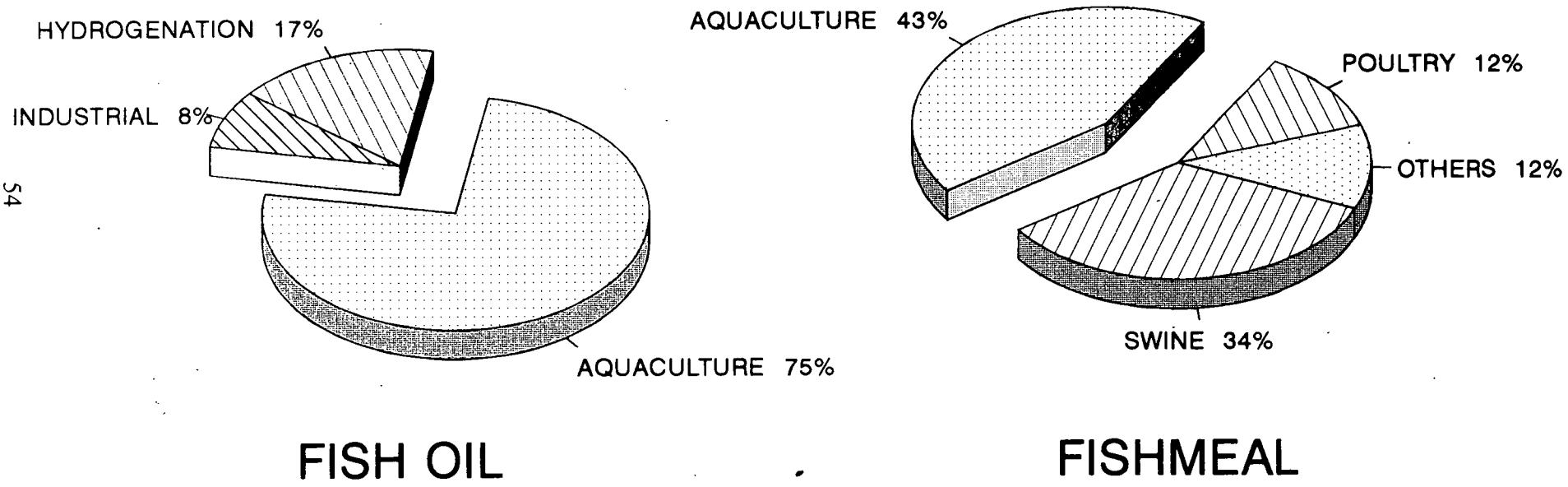
Source: FAO Aquacult PC stat 1998

FIGURE 35. MAJOR AQUACULTURE PRODUCING COUNTRIES



Source: FAO Aquacult PC stat 1998

FIGURE 36. WORLD CONSUMPTION OF FISHMEAL AND OIL
BY MARKET SEGMENT ESTIMATED FOR 2010



FISH OIL

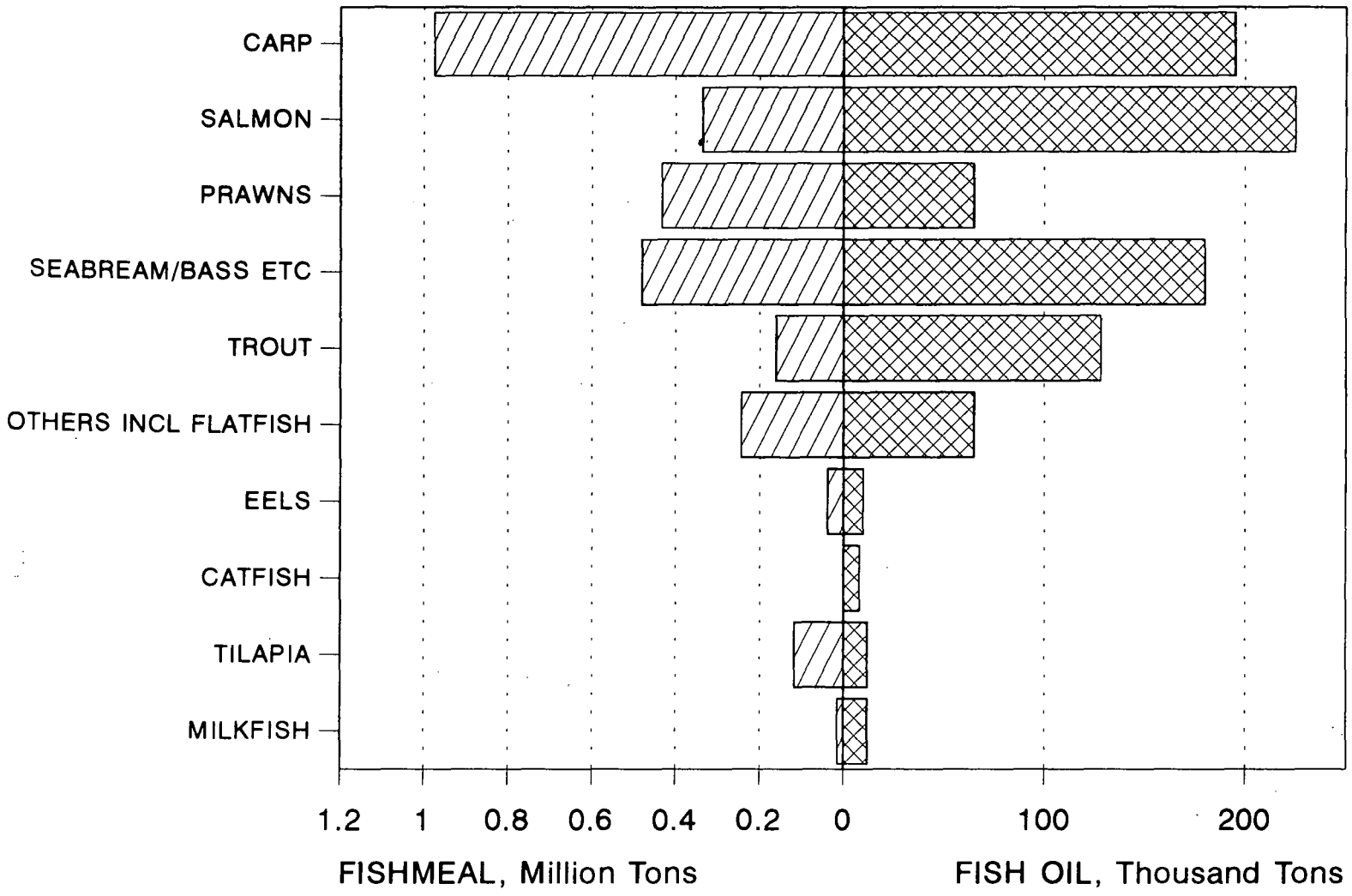
FISHMEAL

Based on 1.2 mmt of fish oil production
Based on 6.5 mmt of fishmeal production
Source: IFOMA 1997

FIGURE 37. PROJECTED 2010 WORLD CONSUMPTION OF FISHMEAL AND OIL IN AQUAFEEDS

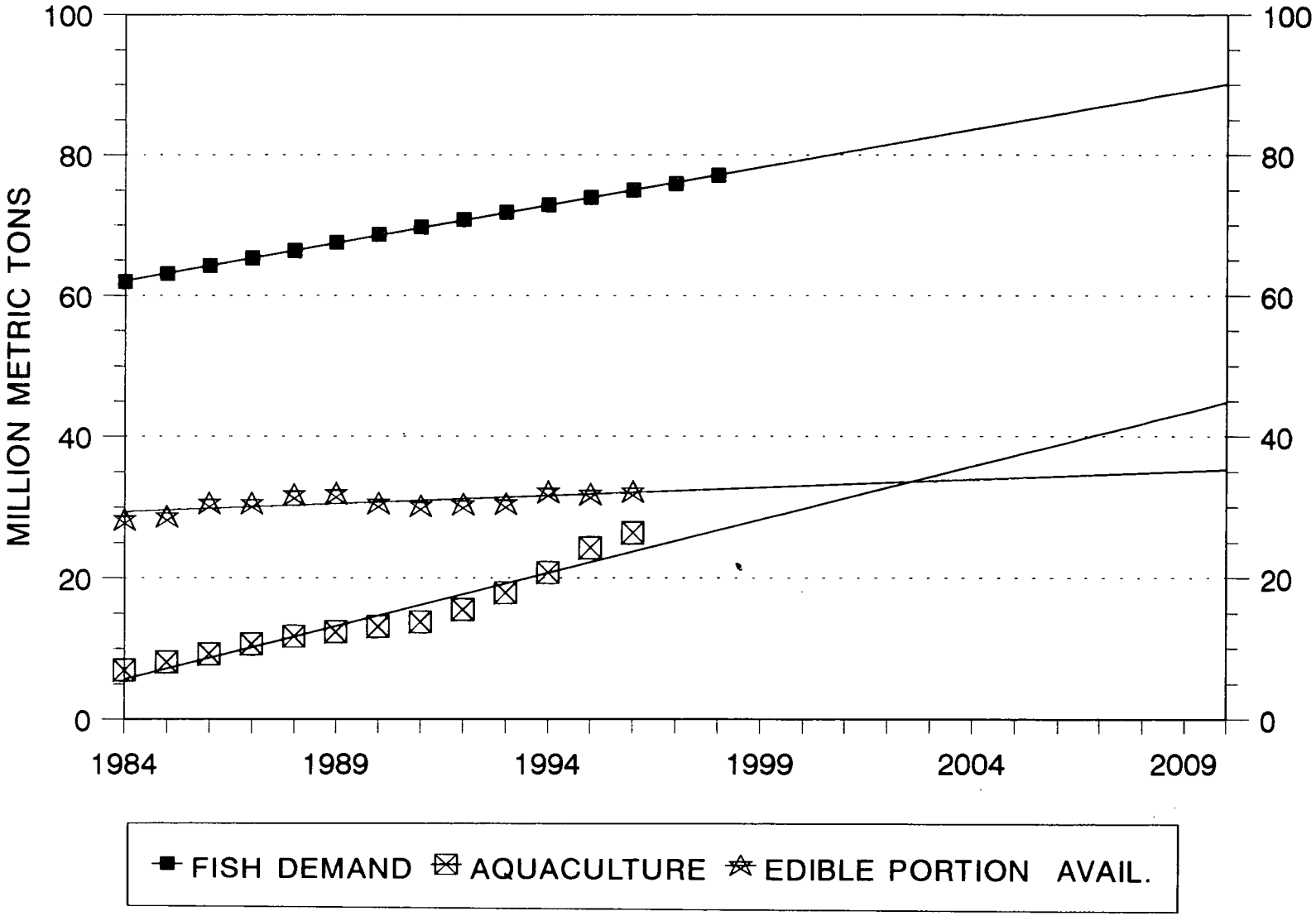
Based on 1.2 mmt of fish oil production
Based on 6.5 mmt of fishmeal production
Source: IFOMA 1998

FIGURE 37. PROJECTED 2010 WORLD CONSUMPTION OF FISHMEAL AND OIL IN AQUAFEEDS



Total Aquafeed consumption estimated at 48.5 mmt
Total fishmeal estimated at 2.796 mmt, fish oil 0.9 mmt
Source: IFOMA 1998

FIGURE 38. SUPPLY VS DEMAND FOR EDIBLE FISH PRODUCTS



DEMAND : Assume constant 13 kg/capita. (Fisheries of the US 1996)
AVAILABLE EDIBLE PORTION : (Assume total landings x .75 - aquaculture) x .50
Source: FAO Fisheries and Aquaculture Dept. 1998

UTILIZATION OF FISH MEAL BY LACTATING DAIRY CATTLE

Marshall D. Stern and Alex Bach
Department of Animal Science
University of Minnesota

DEMAND : Assume constant 15 kg/capita. (Fisheries of the US 1990)
AVAILABLE EDIBLE PORTION : (Assume total landings x .75 - aquaculture) x .50
Source: FAO Fishstat and Aquastat PC 1998

INTRODUCTION

Incorporation of protein sources that are resistant to microbial degradation in the rumen into diets fed to dairy cows can provide a practical means of increasing dietary protein flow to the small intestine. However, it is important not to depress microbial protein production in the rumen because this could counterbalance the increase in dietary protein flow to the small intestine, resulting in no increase in total protein flow. As milk production of dairy cows increases, the amino acid profile of the protein delivered to the small intestine and its absorption from the small intestine become more important. To maximize milk production, the total amount of degradable protein, the amino acid profile of protein leaving the rumen undegraded and amino acid absorption from the small intestine need to be considered.

Fish meal (FM) can be an excellent protein supplement for high producing dairy cows because it is relatively low in rumen degradability compared with plant proteins and it is high in crude protein, essential amino acid content, and is highly digestible in the small intestine. However, ruminal degradation of FM protein can vary considerably, ranging from about 30 to 70% (Mehrez et al., 1980). This variation is influenced by several factors including species of fish used as the starting material, quality of the raw material, proportion of solubles added back, drying conditions, differences in nutrient content due to processing methods and potential use of additional processing steps such as use of formaldehyde (Kaufmann and Lupping, 1982; Goldhor and Regenstein, 1987). Because of the variation in ruminal degradability and oil content of FM, the effects of feeding FM to dairy cows have been inconsistent regarding ruminal fermentation and production responses. Therefore, it is critical to control the above factors to maintain a uniform high quality FM product to be included in diets fed to lactating dairy cattle.

RUMINAL METABOLISM OF FISH MEAL

Factors Affecting Microbial Degradation of Fish Meal Protein in the Rumen

Mehrez et al. (1980) studied the effect of various processing factors of FM, and found that the largest single factor influencing degradability was the length of time that fish were stored prior to processing. Storage for 3 days increased degradability of FM protein in the rumen by 14 percentage units. This increase was attributed to enzymatic and bacteriological changes that take place in fish postmortem, causing proteolysis of fish muscle which leads to a higher soluble protein in the FM and an increase in degradability. Heat used in the drying process of fish protein can induce formation of S-S cross-linking from –SH oxidation (Opstvedt et al., 1984).

Fish protein heated for 20 min at temperatures ranging from 50°C to 115°C showed a linear decrease in the content of –SH (sulfhydryl) groups and a concomitant increase in the content of S-S (disulfide) bonds. These changes can result in a decrease in the rate of ruminal proteolysis of fish protein due to the large number of disulfide bridges (Chen et al., 1987). The amino acid most affected during heating of fish protein is cysteine. Opstvedt et al. (1984) determined that heating at 115°C caused a loss in cysteine and cystine. At temperatures of 95°C or greater, protein and amino acid digestibility of fish protein in rainbow trout was reduced compared with raw fish protein.

Other processing factors affecting ruminal microbial degradation of FM protein are the amount of solubles added back to the product and the type of fish used to produce the FM. Yoon et al. (1996) showed that increasing the amount of solubles added back to FM from 2.1 to 30.5% of DM can increase degradability of FM protein from 27.4 to 56.4%. Of the various FM characteristics that were evaluated by Yoon et al. (1996) for 17 Menhaden FM samples from five processing plants, the amount of fish solubles added back to the dried FM was most closely related (r = .87) to changes in ruminal protein degradation. Using the in situ N disappearance data of Sticker et al. (1986), we calculated degradation of Maine herring (21.5%) and Mexican anchovy (19.4%) FM to be approximately 40% lower than Menhaden FM (34.1%).

Effects of Fish Meal on Ruminal Microbial Metabolism

Hoover et al. (1989) examined the effects of various forms of FM on microbial metabolism in continuous culture of rumen contents. Fish meals were: FM containing 34.4% free fatty acids, FM containing 34.4% free fatty acids with $CaCl_2$ added, FM containing 65.6% free fatty acids and defatted FM. With pH maintained at 6.2, the inclusion of any FM except the defatted FM greatly reduced the acetate:propionate ratio and microbial crude protein production and efficiency were impaired. Because these effects were not shown when the diet was prepared with defatted FM, the effects were probably due to the fatty acid content of FM. Protein degradation was also greater for the defatted FM diet than other FM diets. Ouellet et al. (1997) supplemented grass silage with isonitrogenous amounts of FM containing 3.1% lipids (% of DM) or fish protein hydrolysate (FPH) containing 1.2% lipids (% of DM). Fish hydrolysate is a protein source that resembles FM, but is more degradable in the rumen because the protein is partially hydrolyzed into peptides during the manufacturing process. They observed greater fiber digestion with FM than FPH supplementation with no change in total or individual VFA concentrations. Oullet et al. (1997) suggested that the slower rate of degradation of FM may have exerted a beneficial effect on fibrolytic activity in the rumen. Stritzler et al. (1998) found an increase in cell wall degradability with FM supplementation which was associated with a greater ATP concentration in the solid residue from rumen contents, whereas ATP in the liquid phase remained unchanged. This indicates that FM may exert its effects on the microbes intimately associated with fiber and not upon the whole microbial population. Fish meal supplementation may have increased the amount of branched chain amino acid degradation to branched chain VFA in the rumen, which are important growth factors for several fibrolytic bacteria.

Impact of Fish Meal on Microbial Protein Production

Reductions in microbial protein flow to the duodenum with FM supplementation have been observed in vivo with cattle (Rooke and Armstrong, 1987; Zerbini et al., 1988; Titgemeyer et al., 1989) and sheep (Hussein et al., 1989). In contrast, Dawson et al. (1988) noted an increase in total microbial crude protein flow to the duodenum when FM was added to an all silage diet fed to steers. Intake of amino acids was greater when cows were fed a soybean meal (SBM) diet compared with a FM diet, but total flows of amino acids to the duodenum were similar for both diets (Zerbini et al., 1988). Greater quantity of protein leaving the rumen undegraded in cows fed FM compared with SBM was counterbalanced by less microbial protein synthesis in the rumen. A similar response in total amino acid flow was detected by Hussein et al. (1989) in lambs fed SBM vs FM as the protein supplement.

INTESTINAL PROTEIN SUPPLY FROM FISH MEAL

Total and Individual Amino Acids Provided by Fish Meal

Fish meal has an excellent amino acid profile, close to that believed required for growth and milk production (Tamminga, 1982). Rooke and Armstrong (1987) found that as FM was added to diets fed to cattle, the quantity of amino acid-N increased and the amino acid composition of the duodenal digested changed such that the content of arginine increased and isoleucine decreased. Dawson et al. (1988) also observed an increase in flow of amino acids to the duodenum of steers with FM supplementation. Titgemeyer et al. (1989) evaluated SBM, corn gluten meal (CGM), blood meal (BM) or FM in supplying amino acids to steers. They showed that decreases in bacterial crude protein compared with a basal diet were greatest when FM was fed, followed by CGM, BM and SBM. Fish meal supplied more total amino acids to the duodenum than soybean meal. Blood meal and CGM supplied the greatest amount of total amino acids to the duodenum. The three resistant protein sources (FM, CGM, BM) were quite different in their inherent amounts of individual amino acids and subsequently those that escaped ruminal degradation. Blood meal supplementation led to the greatest amounts of lysine, histidine, arginine and valine, whereas CGM resulted in the greatest amounts of methionine, leucine and isoleucine supplied to the duodenum. Fish meal provided a well balanced amino acid profile as it ranked second in the greatest amounts of lysine, methionine, isoluecine and arginine supplied to the duodenum.

Calsamiglia et al. (1995) investigated the effects of diets containing eight protein sources on microbial metabolism and amino acid supply in continuous culture of rumen contents. Diets were formulated to provide adequate degradable protein to maximize microbial protein production so that differences in amino acid supply could be attributed to individual protein sources. Diets containing BM provided the largest amounts of essential amino acids and lysine, while FM provided the largest amounts of methionine and second largest amount of lysine in fermenter effluent (Table 1). This observation is important because lysine and methionine have been recognized as the two first limiting amino acids for milk production.

Keery et al. (1993) examined the effects of supplemental SBM, heated SBM, FM or a combination of FM, heated SBM and CGM on amino acid supply to the small intestine. Supplementation of diets fed to steers with FM, heated SBM or the combination of protein

sources increased flow of essential amino acids to the abomasum and increased absorption of essential amino acids from the small intestine. Christensen et al. (1993) formulated diets for lactating cows that provided 30 or 45% ruminal undegradable protein (RUP). A combination of meat meal, CGM, BM, hydrolyzed feather meal (HFM) and FM replaced SBM to attain the higher level of RUP in the diet. Passage of total N, nonammonia N and dietary N was greater with the high RUP diets. Lysine and valine flow to the duodenum increased, but passage of methionine and other essential amino acids was not altered when cows were fed the high RUP diet. From these studies, it seems logical to feed combinations of protein sources for supplying the individual amino acids required by ruminants in optimal proportions.

TABLE 1. Amino acid flow (g/d) from continuous culture fermenters fed diets containing various protein sources.

Amino acid	CTRL[a]	SBM	LSBM	CGM	BM	HFM	FM	MBM
Total	10.1^{d}	11.0^{d}	13.2^{c}	13.4^{c}	13.6^{c}	13.4^{c}	12.6^{c}	10.9^{d}
Essential[b]	4.7^{e}	5.2^{e}	6.2^{d}	6.1^{d}	6.9^{c}	6.1^{d}	6.0^{d}	5.1^{e}
Lysine	$.68^{fg}$	$.72^{f}$	$.82^{e}$	$.60^{g}$	1.05^{c}	$.72^{f}$	$.94^{d}$	$.72^{f}$
Methionine	$.13^{e}$	$.14^{e}$	$.17^{d}$	$.17^{d}$	$.17^{d}$	$.14^{e}$	$.20^{c}$	$.14^{e}$

[a]CTRL = urea and tryptone; SBM = soybean meal; LSBM = lignosulfonate-treated SBM; CGM = corn gluten meal; BM = blood meal; HFM = hydrolyzed feather meal; FM = fish meal; MBM = meat and bone meal.

[b]Includes Arg, His, Ile, Leu, Lys, Met, Phe, Thr, and Val.

[c,d,e,f,g]Means within the same row with different superscripts differ ($P < .05$).

Intestinal Digestion of Fish Meal Protein

One of the major concerns of using animal proteins in diets fed to lactating dairy cattle is their quality (consistency in processing) and ability to be digested post-ruminally in the small intestine. To evaluate the effects of different processing procedures on intestinal protein digestion of various animal proteins, Howie et al. (1996) obtained seven samples each of several animal byproducts. Estimates of intestinal digestion of ruminally undegraded crude protein, determined using the three-step procedure developed by Calsamiglia and Stern (1995), ranged from 40.9 to 70.1% ($\bar{x}$ = 56.0% ± 4.0), 59.2 to 75.2% ($\bar{x}$ = 65.3% ± 2.0), 72.0 to 90.3% ($\bar{x}$ = 79.6% ± 2.5), and 28.8 to 79.2% ($\bar{x}$ = 61.4% ± 6.8) for meat and bone meal, hydrolyzed feather meal, ring-dried blood meal, and batch-dried blood meal, respectively. Yoon et al. (1994) used 18 menhaden FM samples from various processing plants to evaluate the effects of processing on intestinal digestion of protein and noted values (Figure 1) ranging from 72.8 to 86.4% ($\bar{x}$ = 77.7 ± 3.5). Similar intestinal digestion of FM protein (83.2%) was determined by Piepinbrink and Schingoethe (1998). These results demonstrate that considerable variation exists in intestinal digestion of protein among and within different protein sources, and this variation can possibly be influenced by source of raw material, quality of raw material (storage time and temperature), and drying conditions, among other factors.

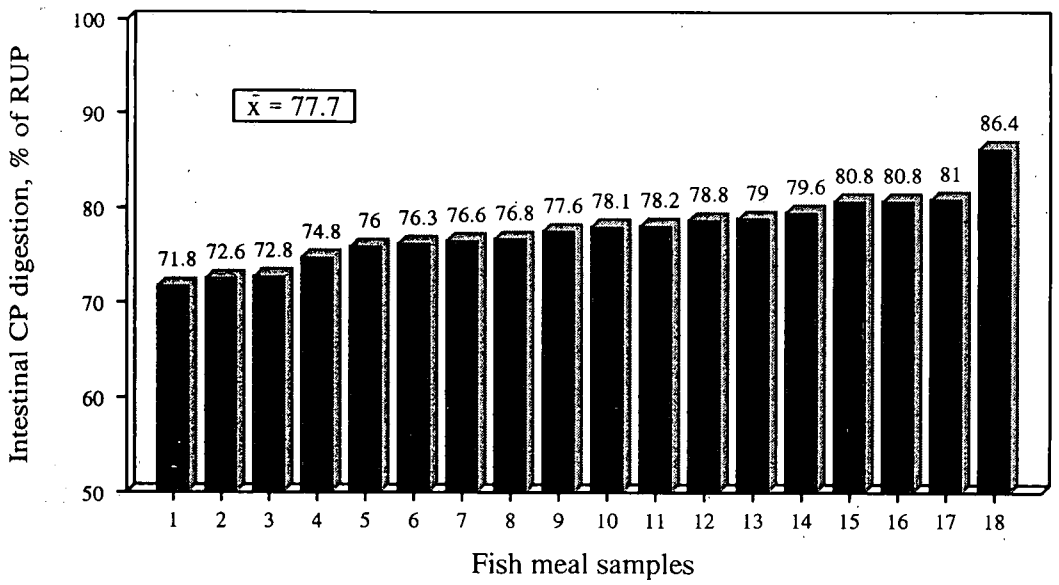


Figure 1. Intestinal crude protein (CP) digestion (percentage of ruminally undegraded protein [RUP]) for menhaden fish meal samples from five processing plants (Yoon et al., 1994).

EFFECTS OF FISH MEAL SUPPLEMENTATION ON MILK PRODUCTION BY DAIRY CATTLE

Milk Yield

Extensive research has been conducted to identify specific essential amino acids that may be limiting milk protein synthesis. Much of this research has focused on the manipulation of the quantities of essential amino acids delivered postruminally for digestion and absorption, and subsequent delivery to the mammary gland by feeding various amounts of RUP. However, milk responses to feeding different levels and sources of RUP have not been consistent. Various reasons have been attributed to the lack of response to RUP supplements; such as a decrease in bacterial protein synthesis in the rumen or low digestibility of the RUP fraction reaching the small intestine (Stern, et al., 1994). Also, the inconsistent results on milk production with RUP supplementation could be attributed to the RUP value used to formulate the diets. The RUP value can vary depending on the mathematical approach used for RUP determination and on the length of ruminal incubations included in the model (Bach et al., 1998).

Fish meal is a protein source that is high in RUP and has a consistently high intestinal digestion (Yoon et al., 1994). Responses in milk production with FM supplementation depend on the degradable intake protein, amino acid profile, fermentable energy and other characteristics of the basal diet. Therefore, it is not surprising that milk responses to FM supplementation have been inconsistent. Some researchers (Miller and Galwey, 1981; Erfle et al, 1983; Ørskov et al., 1987) have observed increases in milk yield when feeding FM, however others (Oldham et al., 1985; Sloan et al., 1988; Zerbini et al., 1988; Blauwiekel et al., 1990) have not observed such a

response. A total of 43 comparisons from 24 studies were used to summarize the effects of FM supplementation on milk production (Table 2). Results were expressed as a differential change from the control diet with SBM as the main protein source in the control diet in the majority of the studies. Numbers in bold indicate that changes were significant at $P < .05$. The average increase in milk yield was .8 kg/d with FM supplementation among the 24 studies. In 37 comparisons, there was a numerically positive response in milk yield, with a negative response in only 6 comparisons. However, only 5 changes were significant. The lack of response, or the negative response in some comparisons, could be explained by a decrease in ruminal microbial protein flux or lower ruminal digestion of OM due to inadequate supply of ruminal degradable protein.

Milk Protein

Several studies (Broderick et al., 1971; Whitelaw et al., 1986; Choung and Chamberlain, 1993) have shown that improving the amount and quality of amino acids reaching the small intestine can result in an increase in milk protein yield. Fish meal is high in the two most limiting amino acids, methionine and lysine and has the potential to increase yield of milk protein. Murphy and O'Mara (1993) reviewed the factors that affect milk protein concentration and concluded, that in general, with high forage diets (more than 50% of DM), FM supplementation increases milk protein concentration. Rulquin and Verité (1993) reported that supplementation of ruminally protected methionine and lysine resulted in the lowest milk protein increase when the supplemented diet contained FM, compared with diets containing either CGM, SBM, or groundnut meal. The low increase in milk protein yield when supplementing the FM diet with ruminally protected methionine and lysine was attributed to a relatively high supply of these amino acids from FM. However, several authors (Spain et al., 1990; Zerbini et al., 1988; Windschitl and Randall, 1990) reported no changes in milk protein content when including FM in dairy diets.

In general, supplementation of FM resulted in an average increase of 20 g/d in milk protein yield, (Table 2). Seven comparisons were different ($P < .05$) from the control, with 4 comparisons being negative. In contrast, the average change in milk protein content (%) when supplementing FM was -.01% units. The fact that FM increases milk yield but at the same time decreases the percentage of protein in milk, might be an indication that the high content of absorbable amino acids present in FM may affect the endocrine system inducing a homeorrhetic change, rather than improving the protein metabolism of the animal.

Milk fat

Fish meal has consistently decreased milk fat content in dairy cows (Blauwiekel and Kincaid, 1986; Zerbini et al., 1988; Blauwiekel et al., 1990; Spain et al., 1990). Mantysaari et al. (1989) reported a decrease in milk fat percentage after the 50th d of lactation associated with FM supplementation; however, no decrease in milk fat percentage was found during the first 50 d of lactation. Pennington and Davis (1975) did not observe a decrease in milk fat when fish oils were infused into the abomasum. There has also been different responses on milk fat yield depending on parity number. Several authors (Akayezu et al., 1997; Chilliard and Doreau 1997)

TABLE 2. Summary of effects of different amounts of fish meal on milk, protein and fat yield, and milk composition[a].

Reference	FM intake, kg/d	Milk yield, kg/d	Milk fat, g/d	Milk CP, g/d	Fat, %	Protein, %
Atwal and Erfle, 1992	1.3	**0.7**	**141.7**	9.6	**0.39**	-0.03
	1.3	**1.2**	**160.5**	**25.8**	**0.41**	-0.04
Akayezu et al., 1997	0.5	2.2	48.6	28.1	-0.06	-0.11
Baker et al., 1996	1.2	**2.6**	0	100	-0.3	-0.1
Blauwiekel et al., 1990	1.0	3.3	-152.9	101.4	**-0.98**	0.05
Bruce and Herlugon, 1990	2.2	2.7	-80.2		-0.63	
Bruckental et al., 1985	1.5	0.8	-120	40	**-0.36**	0.03
Burke al., 1997	0.7	-0.2	50	40	0.08	0.05
	0.6	0	30	-20	0.04	-0.09
Calsamiglia et al., 1992	0.7	1.1	-40.6	2.4	**-0.22**	**-0.09**
	0.7	0.3	-37.1	-22.2	-0.15	**-0.1**
Calsamiglia et al., 1995	1.0	-1.9	-190	**-40**	**-0.49**	0.12
Carroll et al., 1994	0.7	1.6	40	60	-0.1	0
Chiou et al., 1997	1.0	**-2.5**	-30	10	0.29	**0.5**
Cody et al., 1990	0.4	0.85	14.5	43.5	-0.06	0.11
	0.6	1.45	9.5	**82.5**	**-0.21**	**0.19**
Erfle et al., 1983	0.8	1.8	-75.8	49.1	-0.62	-0.05
	1.9	-1.6	-259.1	-48.1	-0.87	0.03
Garnsworthy, 1989	0.8	1.33	**-115**	18	-0.8	-0.07
	0.8	0.64	59	25	0.05	0.044
Mantysaari et al., 1989	1.1	**0.6**	**-81**	11	**-0.35**	0
Oldham et al., 1985	0.6	2.1	1	107	-0.26	0.1
	1.2	3.3	78	108	-0.02	0.08
	1.8	2.6	**145**	108	**0.27**	-0.04
Petit and Veira, 1991	1.0	0.7	80	70	0.18	0.13
Sloan et al., 1988	1.0	0.2	-40	10	**-0.33**	-0.02
Spain et al, 1990	0.3	1	10	**50**	**-0.23**	-0.05
	0.7	1.9	-10	10	**-0.25**	**-0.13**
	0.3	0.3	-90	**-60**	**-0.45**	**-0.3**
	0.7	0.8	-140	**-130**	**-0.65**	**-0.49**
	2.7	0.3	**-240**	**-40**	**-0.78**	**-0.16**
	1.4	0.9	-140	0	**-0.52**	**-0.19**
Spain et al., 1995	0.6	0.9	-47.1	30.6	-0.3	0
	1.0	0.2	-95	6.8	-0.4	0
	1.5	0.3	**-117.5**	-15.4	-0.5	-0.1
	1.2	0.2	**0**	0	-0.1	0
Succi et al., 1993	0.7	0.4	11.5	33.6	-0.01	0.08
Windschitl et al. 1991	0.3	1.1	27.6	-	-0.04	-
	0.6	2.1	-0.5	-	-0.22	-
	0.7	0.6	-221.6	-	-0.7	-
Windschitl, 1991	1.9	-1.9	**-240**	-30	**-0.47**	0.02
	1.8	-1.3	**-250**	-20	**-0.53**	0.04
Zerbini et al., 1988	2.1	0.4	**-90**	30	**-0.38**	0.07
			Statistics			
Average	1.0	0.8	-46.4	20.1	-0.28	-0.01
Standard deviation	0.6	1.3	107.4	51.0	0.35	0.15
Maximum	2.7	3.3	160.5	108.0	0.41	0.50
Minimum	0.3	-2.5	-259.1	-130.0	-0.98	-0.49

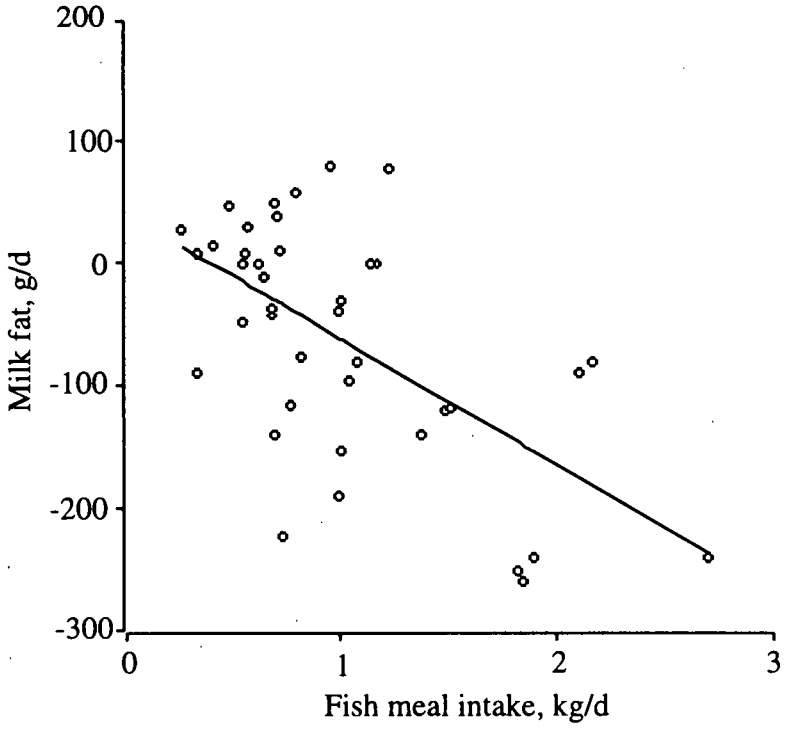
[a]Numbers in bold indicate significant differences ($P < .05$).

reported a greater decrease in milk fat content in primiparous cows than in multiparous cows when supplementing with FM or fish oils.

Opstvedt (1985) summarized the effects of fish oils on milk fat and found a linear relationship (r^2 = .56, $P < .01$) between fish oil intake and milk fat content. From this regression line it can be determined that feeding less than 38 g/d of fish lipids (equivalent to about .5 kg of FM) should not have detrimental effects on milk fat content (%). However, due to the usual increase in milk yield associated with feeding FM or fish oils it was concluded that feeding less than 100 g/d of fish lipids would not have significant effects on milk fat yield. From these observations it can be concluded that the maximum amount of FM to be fed should be limited by the amount of fish lipids that the animal would receive. The negative linear trend observed between the intake of fish oils and milk fat was also observed with FM by Spain et al. (1995). Consistent with observations by Opstvedt (1985) and Spain et al. (1995), regression analyses (Figure 2) on the data from the 24 studies cited in Table 2 show that there is a negative relationship between FM intake and milk fat content (r^2 = .20, $P < .05$) or milk fat yield (r^2 = .36, $P < .001$). Fish meal supplementation resulted in an average decrease in milk fat content (%) of .28 percentage units. A total of 35 comparisons, 81.4% of all observations, had a negative effect on milk fat content. However, the number of negative comparisons with fat milk yield (g/d) decreased to 25; 55.8% of all observations.

Milk fat depression has been associated with the fat content of FM, which is rich in long chain polyunsaturated fatty acids with 16 to 25% of the total fatty acids being polyunsaturated. There are three main reasons that may explain why the fat content of FM reduces milk fat percentage: 1) modification of ruminal fermentation, 2) inhibition of fatty acid uptake by the mammary gland, and 3) reduced activity of some of the enzymes that participate in the synthesis of milk fat in the mammary gland. Long chain unsaturated fatty acids have been reported to change the rumen microbial population (Storry et al., 1974) and consequently change acetate to propionate ratios which may affect milk fat percentages. Spain et al. (1990) suggested that long chain unsaturated fatty acids had a negative effect on ruminal degradation. Hoover et al. (1989) showed that the acetate to propionate ratio of ruminal fluid maintained in continuous culture fermenters decreased when feeding diets containing FM and the fermenter pH was maintained above 6.2, but it did not decrease when the FM was defatted. However the acetate to propionate ratio did not decrease when the fermenter pH was allowed to drop below 6.0, indicating that the negative effects of fat from FM on ruminal fermentation were reduced at low pH. Gordon and Small (1990) also suggested that the decrease in milk fat observed with FM supplementation could be due to a reduction in the ruminal acetate to propionate ratio. Perhaps, a greater production of propionate associated with FM diets could be responsible for decreasing milk fat synthesis by inducing an increase in plasma insulin concentrations. For example, Jenny et al. (1975) reported an increase in blood glucose concentrations associated with changes in ruminal VFA patterns. The negative effects of FM on milk fat depression associated with changes in ruminal fermentation have been minimized on some occasions by the inclusion of rumen buffers in the diet. For example, Vandersall et al. (1989) fed 1.4 kg of FM and reported an increase in milk fat percentage from 3.0 to 3.4% when buffers were included in the diet.

Calsamilgia et al. (1992) reported a decrease of .47% units in milk fat when comparing cows in early lactation receiving a combination of SBM and FM vs a diet containing only SBM as the



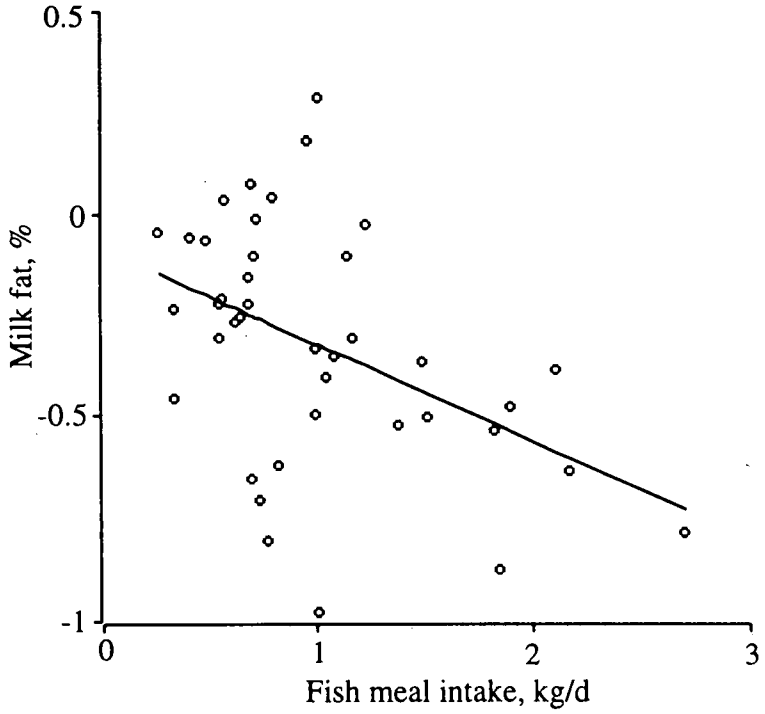


Figure 2. Relationship between fish meal intake and milk fat yield and milk fat content.

main supplemental protein. Cows that received the diet with FM ingested about 68 g/d of fish oils, and thus, a reduction in milk fat content (%) could have been expected. The control diet in this study had soybean oil added to account for the extra oil present in FM, and thus the reduction in milk fat content with the FM diet could not be attributed specifically to fat content of the diets, but to the type of oil included in the diet.

Spain et al. (1995) evaluated the effects of FM on milk fat yield of dairy cows and concluded that the negative effects of FM on milk fat yield were not due to changes in ruminal fermentation, but due to postruminal changes. Similarly, Calsamiglia et al. (1995) infused isonitrogenous amounts of FM in the rumen or duodenum and found that site of FM dosing had no effect on ruminal fermentation. Dosing with FM regardless of site, resulted in a reduction in milk fat content without a change in the ratio of ruminal acetate plus butyrate to propionate. They concluded that decreases in milk fat content associated with FM could be due to postruminal alterations of metabolism rather than ruminal effects. Several researchers (Mattos and Palmquist, 1974; Storry et al. 1974) have suggested that the uptake of long chain fatty acids by the mammary gland depressed the absorption of fatty acids by inhibiting the acetyl-CoA carboxylase or the lipoprotein lipase activities. Varman et al. (1968) suggested that polyunsaturated fatty acids of 20 or more carbon atoms has a direct effect on reducing the uptake of fatty acids from plasma by the mammary gland. Furthermore, several researchers (Yang and Williams, 1978; Iritani et al., 1980; Herzberg and Rogerson, 1988) suggested that PUFAs decrease the activity of several key lipogenic enzymes in nonruminants. Lacasse et al. (1998) attributed the decrease in milk fat mainly to a reduction in short chain fatty acids present in milk, which suggests that fish oils inhibited the *de novo* milk fat synthesis in the mammary gland. Long chain fatty acids are transformed into long chain acyl-Coenzyme A's within the mammary gland. Farrell et al. (1995) showed that long chain acyl-CoenzymeA's, longer than 14 carbons, were strong inhibitors of isocitrate dehydrogenase, which is the primary source of NADPH required for the *de novo* synthesis of fatty acids in the mammary gland. These authors also showed that the strongest inhibitor was the acyl-CoA of the stearic acid (C18:0) followed by the *trans* isomer of oleic acid (C18:1). Recently, Ahnadi et al. (1998) showed that the reduction in *de novo* milk fat synthesis induced by long chain unsaturated fatty acids was also due to a direct depression in the gene expression of the mammary lipogenic enzymes acetyl-CoA carboxylase and fatty acid synthase.

EFFECT OF FISH MEAL ON MILK FLAVOR

Feeding large amounts of FM has been associated, on some occasions, with off-flavors in milk. As mentioned previously, fish lipids contain relatively large amounts of highly unsaturated long chain fatty acids. Lacasse et al. (1998) reported that fish oils could affect milk fat composition. Milk fat content of trans-fatty acids and the content of long chain fatty acids increased with fish oil supplementation. Also the milk content of polyunsaturated fatty acids increased with fish oil supplementation. Fish meal has about 8 to 10% fat, with a high content of PUFAs, including the unique fatty acids eicosapentaenoic (C20:5n-3) and docohexaenoic (C22:6n-3). In general, unsaturated fatty acids are biohydrogenated in the rumen, however, fish lipids appear to be very resistant to ruminal biohydrogenation (Dawson et al., 1991; Ashes et al., 1992; Spain et al., 1995) and have the potential to create rare milk flavors. Lacasse et al. (1998) reported that feeding fish oils changed milk fat composition and that the peroxide index of milk increased.

Consequently a taste panel was able to detect unusual tastes in milk when feeding fish oils at 2% of DM. Also, fish lipids, which are rich in polyenoic fatty acids (Opstvedt, 1974), have a tendency to oxidize in FM. Therefore the type of fish used in processing of FM and the condition of the fish fat in the diet with respect to the degree of fatty acid oxidation could be important factors causing off-flavors. The use of antioxidants appears to minimize the appearance of off-flavors in milk (Pike et al., 1994).

EFFECT OF FISH MEAL ON FERTILITY

There is a number of nutritional factors that may affect the reproductive status of an animal. For example, high levels of ruminal ammonia, and thus, high plasma ammonia and urea concentrations, have been associated with infertility problems (Ferguson and Chalupa, 1989). Ferguson et al. (1990) suggested that plasma ammonia and urea concentrations may be reduced when feeding RUP sources, resulting in improved reproductive performance. There have been at least two possible mechanisms proposed by which FM and other RUP sources may improve reproductive performance: 1) improved energy balance by decreasing the amount of energy directed towards the metabolism of ammonia, and 2) lower protein degradation in the rumen, which would decrease ammonia, urea and other nitrogenous compounds that may be toxic to sperm, ova, or embryos (Staples et al., 1993).

Carroll et al. (1994) did not find significant differences in fertility when supplementing with FM. In contrast, Diskin et al. (1993) reported an increase in the conception rate from 58 to 76% when supplementing FM. Bruckental et al. (1989) and Armstrong et al. (1990) reported a 20 percentage unit increase in pregnancy rate when FM replaced SBM as the protein supplemented in the basal diet. However, in a study by Armstrong et al. (1990), plasma urea and ammonia concentrations increased with FM supplementation, thereby, the positive effects on fertility could not be explained by reduction in plasma urea concentrations. Perhaps the improved reproductive efficiency associated with feeding FM could be found in the fat fraction of FM. Fish meal lipids have a considerable amount of unique fatty acids eicosapentaenoic (C20:5n-3) and docohexaenoic (C22:6n-3). These PUFAs, have been shown to reduce the synthesis of $PGF_{2\alpha}$ by direct inhibition of the cyclooxygenase activity of the uterine wall (Smith and Marnett, 1991). A reduction in $PGF_{2\alpha}$ synthesis may be associated with slow regression of the corpus luteum, which may facilitate a greater pregnacy rate because the progesterone levels are maintained higher. This theory could be further supported by Oldick et al. (1997) who showed that dominant follicles from cows offered yellow grease (unsaturated fat) were larger and grew faster than those from cows offered tallow (saturated fat).

CONCLUSIONS

Fish meal has several characteristics that make it a desirable protein supplement for diets fed to lactating dairy cattle including high protein content, high undegradability in the rumen and its excellent amino acid profile. In addition to these characteristics, palatability, intestinal absorption of amino acids, cost per unit of intestinally absorbable dietary protein, availability and consistency of product, and impact on milk production (yield and composition) are key elements in deciding how and when to use fish meal in diet formulations for lactating dairy cattle.

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Notes

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EVALUATION OF FISH PROTEINS FOR NURSERY PIG DIETS

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INTRODUCTION

In a natural setting sows wean their pigs sometime after eight-weeks of age. Over the past four decades management and health considerations have encouraged ever-earlier weaning strategies. Provision of diets to economically replace sow milk for the newly weaned pig continues to challenge scientists. Not only is milk a rich source of nutrients, it also provides immune proteins and growth factors (Odle et al., 1996) that are as of yet not well understood.

Most alternatives to milk present the pig with complex carbohydrates, proteins and fats which it is ill prepared to digest when weaned precociously. These same dietary constituents are often used with great efficiency a few weeks later. Critical factors include the lack of adequate production of certain carbohydrases (Chapple et al., 1989a, 1989b) and proteases (Makkink et al, 1994) and a deficiency of hydrochloric acid output in the stomach (Cranwell, 1985). Clearly the rate and timing with which digestive capacity increases are influenced by genetic and environmental, i.e., dietary, factors (Buddington, 1994). The exploitation of opportunities via genetic manipulation remains to be realized. Selection of dietary ingredients matched to the pig's digestive capacity continues to be the most practical approach to supporting maximum post-weaning growth performance. This paper will focus on protein-rich ingredients.

PROTEIN SOURCES FOR THE NEWLY WEANED PIG

The introduction of multi-phase nursery feeding programs in the mid 1980's focused attention on the need to identify protein-rich feed ingredients suitable for weanling pig diets. Soy proteins were relatively inexpensive and, thus, attractive. But, soy proteins are typically large

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and possess complex levels of structural organization that increase the difficulty of digestion. Additionally, work done in the late 1970's (Barratt et al., 1978) had suggested that there were undesirable intestinal immune responses when soy proteins were fed to young animals. A large quantity of subsequent work has focused on improving the nutritional value of soy proteins through various processing methods, cf., Sohn et al. (1994) and Dréau et al. (1994).

Animal-derived alternatives to soy proteins have shown great promise. Clearly, milk products are well-utilized by the pig (Mahan, 1992). But, spray-dried porcine plasma (SDPP), first introduced in the late 1980's (Gatnau et al., 1989) has become a standard by which other proteins are evaluated, cf., Hansen et al. (1993). The early work with SDPP was summarized by the original investigators (Gatnau et al., 1993) in a review article. More recent work has addressed possible non-nutritional mechanisms that underlie the SDPP response (Ermer et al., 1994; Rodas et al., 1995).

The project described herein was undertake to determine the feeding value of high-quality fish products relative to SDPP.

EVALUATION OF FISH MEALS

Four different fish meals were used to evaluate their nutritional value in young pig diets. The specifications for the fish meals used in this study are listed in Table 1 and amino acid composition is shown in Table 2.

Table 1. Fish Meals (FM) Used in the Experiments

	FM1	FM2	FM3	FM4
Species	Manheden	Mackerel	Herring	Mackerel
Origin	U.S.A.	Chile	Denmark	Chile
Dry temperature	Unknown	85	70	70

Table 2. Amino Acid Composition of Fish Meals[1]

	FM1	FM2	FM3	FM4
Aspartic acid	6.24	6.62	6.50	6.71
Threonine	2.80	3.11	3.12	3.20
Serine	2.64	2.86	2.89	2.93
Glutamic acid	9.05	9.44	9.42	9.53
Proline	3.35	3.45	2.98	3.16
Glycine	5.12	5.00	4.37	4.49
Alanine	4.25	4.59	4.43	4.52
Cysteine	.34	.40	.44	.40
Valine	2.99	3.36	3.57	3.58
Methionine	1.87	2.03	2.08	2.09
Isoleucine	2.51	2.84	2.86	3.02
Leucine	4.64	5.16	5.29	5.41
Tyrosine	1.94	2.17	2.18	2.30
Phenylalanine	2.56	2.73	2.82	2.92
Histidine	1.49	2.94	1.64	3.25
Lysine	5.17	5.57	5.64	5.74
Arginine	4.08	4.31	4.04	4.28
Total	61.03	66.56	64.27	67.51

[1] "As is" basis

Experiment 1.

Eight piglets (Camborough-15 x line 326, Pig Improvement Company, Lexington, KY) were surgically prepared (Giesting and Easter, 1991) at 14 day-of-age with simple T-cannulas for use in measuring the apparent amino acid digestibility the fish meal products. The pigs were housed individually in raised-deck pens equipped with solid sidewalls and plastic-coated steel flooring. The pen size was 1.2 m x 1.2 m. Ventilation was provided by a mechanical system, waste was removed by an underfloor scraper system and lighting was automatically regulated to approximate the seasonal day length. Ambient temperature within the room was approximately 30 °C immediately after weaning and it was adjusted downward to approximately 22 °C by the end of the experiment.

The surgically modified pigs were weaned at d 21 of age and assigned randomly to four dietary treatments. Composition of the four diets is shown listed in Table 3. Each pig was assigned to a treatment sequence with treatments rotated weekly until all treatment diets had been fed to each available pig in a Latin Square design. Four pigs were allotted to one Latin Square making two replications. Each weekly period was divided into a five-day adjustment phase and a two-day collection phase. Collections were made for approximately 12 h on two consecutive days.

Table 3. Composition of Diets for Experiment 1[1]

Ingredients, %	FM1	FM2	FM3	FM4
FM1	16.00			
FM2		16.00		
FM3			16.00	
FM4				16.00
Lysine	.30	.23	.22	.18
Methionine	.10	.08	.08	.08
Cysteine	.10	.08	.08	.08
Tryptophan	.08	.06	.06	.08
Threonine	.20	.15	.14	.13
Isoleucine	.22	.17	.16	.14
Leucine	.05	0	0	0
Valine	.15	.10	.07	.06
Histidine	.05	0	.13	0
Phenylalanine	.08	.05	.04	.01
Tyrosine	.08	.05	.04	.01
Lactose	25.00	25.00	25.00	25.00
Starch	44.74	44.68	43.68	44.93
Glucose	7.00	7.00	7.00	7.00
Soybean oil	4.00	4.00	4.00	4.00
Solka fluc	1.00	1.00	1.00	1.00
Vitamin mixture	.20	.20	.20	.20
Trace mineral-salt	.35	.35	.35	.35
Limestone	0	.50	.65	.35
Di-calcium	0	0	.80	.10
Antibiotics	.05	.05	.05	.05
CrO_2	.25	.25	.25	.25

[1] "As is" basis

The apparent amino acid ileal digestibility values (Table 4) were consistently higher ($P <$ .05) for the herring and mackerel fish meal than menhaden fish meal. Specially, FM4 had higher ($P <$ .05) digestibility for the major essential amino acids, i.e. lysine, tryptophan, and threonine compared to other fish meals.

Table 4. Apparent Amino acids Digestibility Values of Fish Meals (1 to 4 wk post-weaning)

Amino acid	FM1	FM2	FM3	FM4
Aspartic acid	37.1 □4.46^{b}	33.7 □3.11^{b}	45.5 □3.40^{a}	33.0 □4.45^{b}
Threonine	48.6 □3.15^{b}	49.8 □2.33^{ab}	56.0 □3.28^{ab}	56.7 □3.29^{a}
Serine	30.6 □3.45^{b}	43.0 □3.21^{a}	44.6 □3.54^{a}	43.6 □4.93^{a}
Glutamic acid	51.8 □5.42^{b}	53.5 □6.32^{b}	63.3 □3.78^{a}	61.2 □3.39^{ab}
Proline	29.4 □4.54^{b}	30.4 □3.60^{b}	33.7 □2.94^{b}	47.0 □3.63^{a}
Glycine	36.9 □3.57^{b}	35.9 □4.11^{b}	37.4 □3.53^{b}	48.2 □4.90^{a}
Alanine	48.1 □4.75^{c}	55.7 □4.27^{b}	60.5 □3.10^{ab}	63.4 □2.53^{a}
Cysteine	47.3 □3.75^{bc}	43.9 □3.45^{c}	53.7 □3.92^{ab}	57.2 □3.66^{a}
Valine	57.7 □3.29^{c}	70.6 □2.57^{a}	63.4 □2.91^{bc}	64.5 □2.88^{b}
Methionine	71.5 □3.18^{c}	75.2 □2.40^{bc}	84.7 □1.71^{a}	76.7 □2.26^{b}
Isoleucine	60.8 □3.15^{ab}	55.4 □3.74^{b}	57.8 □3.13^{b}	65.0 □3.13^{a}
Leucine	55.6 □3.68^{b}	58.3 □3.78^{b}	64.5 □3.37^{a}	65.2 □3.26^{a}
Tyrosine	47.9 □4.19	50.0 □4.44	54.3 □4.57	54.9 □4.80
Phenylalanine	54.2 □3.83	57.1 □4.18	60.2 □3.81	60.8 □3.82
Histidine	55.2 □3.58^{c}	68.0 □2.36^{b}	74.0 □2.27^{a}	72.1 □1.94^{ab}
Lysine	67.0 □3.14^{b}	68.1 □3.41^{b}	75.0 □2.41^{a}	75.5 □2.17^{a}
Arginine	59.4 □3.32^{b}	65.3 □2.97^{ab}	71.5 □3.32^{a}	71.8 □3.13^{a}
Tryptophane	63.4 □2.94^{ab}	64.2 □2.21^{ab}	59.9 □3.56^{b}	68.3 □3.26^{a}
Average	51.4 □3.11^{b}	54.3 □2.93^{ab}	58.9 □2.88^{a}	60.3 □3.07^{a}

[a,b,c] Numbers with different superscripts in the same row were different significantly ($P <$ .05)

Experiment 2.

One hundred-twenty, three-week-old, pigs (Camborough-15 x line 326, Pig Improvement

Company, Lexington, KY) were used to evaluate growth performance of young pigs fed diets containing four different fish meals. The pen size was 1.2 m x 1.2 m. Other managements were the same as described in Experiment 1.

Six replicates pens having five pigs per pen-replicate were fed each diet. Diets and water were available ad libitum. Pigs were weaned at three weeks of age and assigned randomly to four dietary treatments. Diet composition data are shown in Table 5. Fishmeal was added (9.5 to 11.0%) as a protein source. Whey protein (20%) was added to each diet. Each amino acid was matched with requirements suggested by NRC (1988). Starch and soybean oil were used as energy sources. Diets were pelleted with as low of a temperature as possible (55 °C) to minimizing loss of digestibility due to heat treatment. Pigs were weighed individually and feed intake was recorded at weekly intervals during the four-week experimental period.

Table 5. Composition of Diets for Experiment 2[1]

Ingredients, %	FM1	FM2	FM3	FM4
FM1	11.00			
FM2		9.50		
FM3			9.50	
FM4				9.50
Starch	20.00	20.25	19.05	20.15
Soybean oil	1.75	2.50	3.00	2.50
Limestone	.35	.40	.65	.45
Di-calcium	.30	.75	1.20	0.80
Common Ingredients :				
Corn		35.00		
Soybean meal		10.00		
Whey protein		20.00		
Solka fluc		1.00		
Antibiotics		.05		
Trace mineral-salt		.35		
Vitamin mixture.		.20		

[1] "As is" basis

The results of this experiment are shown in table 6. In the second week post-weaning, pigs fed FM2 diet showed the highest ($P < .05$) average daily gain (ADG) and pigs fed FM4 diet had the highest ($P < .05$) gain/feed ratio. The growth of piglets was numerically greater by 7.7% for the pigs fed the mackerel and herring fish meals compared to menhaden fish meal during the whole experiment period even there was no significant difference ($P > .05$). The gain/feed ratio was consistently better for FM4 than any other treatment during the entire experiment period ($P < .05$).

Table 6. Supplementation Effects of Fish Meal (FM) on Growth Performances of Young Pigs (one to four wk post-weaning)

	FM1	FM2	FM3	FM4
4th week after the birth				
Ini. Wt (kg)	5.35□.03	5.38□.03	5.31□.03	5.33□.03
Final Wt (kg)	5.89□.08^{b}	6.16□.08^{a}	5.97□.08^{ab}	5.98□.08^{ab}
ADG (g)	78□10^{b}	111□10^{a}	95□10^{ab}	93□10^{ab}
ADFI (g)	140□12	148□12	135□12	133□12
Gain/feed	.55□.05^{b}	.77□.05^{a}	.67□.05^{ab}	.71□.05^{a}
5th week after the birth				
Ini. Wt (kg)	5.35□.03	5.38□.03	5.31□.03	5.33□.03
Final Wt (kg)	7.04□.18^{b}	7.64□.18^{a}	7.50□.18^{ab}	7.38□.18^{ab}
ADG (g)	121□13^{b}	161□13^{a}	156□13^{ab}	146□13^{ab}
ADFI (g)	204□13	223□13	222□13	202□13
Gain/feed	.59□.04^{b}	.73□.04^{a}	.70□.04^{ab}	.73□.04^{a}
6th week after the birth				
Ini. Wt (kg)	5.35□.03	5.38□.03	5.31□.03	5.33□.03
Final Wt (kg)	9.16□.28	9.69□.28	9.35□.28	9.52□.28
ADG (g)	181□13	205□13	192□13	199□13

ADFI (g)	309□16	322□16	308□16	310□16
Gain/feed	.58□.02	.64□.02	.62□.02	.64□.02
7th week after the birth				
Ini. Wt (kg)	5.35□.03	5.38□.03	5.31□.03	5.33□.03
Final Wt (kg)	12.26□.31	13.07□.31	12.35□.31	12.95□.31
ADG (g)	247□11	275□11	251□11	272□11
ADFI (g)	419□18	427□18	402□18	410□18
Gain/feed	.59□.02[b]	.65□.02[a]	.63□.02[ab]	.67□.02[a]

[a,b,c] Numbers with different superscripts in the same row were different significantly ($P < .05$)

Experiment 3.

One hundred-sixty, two-week-old, pigs (Camborough-15 x line 326, Pig Improvement Company, Lexington, KY) were used to estimate the relative bioavailability (RBV) of lysine from FM 4, which shown to have the highest quality among four fish meals, to spray dried porcine plasma protein. Housing, ventilation, room temperature, and other managements were the same as described previously.

A classical slope-ratio design (Sato et al., 1987) was employed in this experiment. Average daily gain vs. lysine intake was plotted to get regression equations. For the slope-ratio design, it is important that the protein level selected for the basal diet be in the *linear portion of the protein response curve.* As protein in the diet is increased, there is a corresponding increase in growth rate. As the protein, or more correctly amino acid, requirement is met, the rate of growth increase slows down or reaches plateau. To evaluate the capacity of an ingredient to provide protein in a diet, the initial diet has to be deficient and the incremental levels such that for each increase in protein concentration there will be a corresponding increase in growth. The basal protein level selected for this experiment is 15.9 % (1.11% lysine) which is clearly deficient for two-week-old pigs.

The pigs were weaned at two weeks of age and randomly allotted based on sex, weight and ancestry to one of the five dietary treatments. Eight replicates having four pigs per pen-replicate were fed each diet. Feed and water were offered ad libitum. Pig weights and feed intakes were measured on every third day. A single diet (Table 7) was fed for a total of fifteen days. This

was designed as a test to determine relative feeding value and was not an attempt to test the product in a multi-phase feeding program. Corn and soybean meal were used as the basal ingredients. All diets contained 50% corn, 6% dehulled soybean meal, 10% casein and 22% lactose. Cornstarch, a non-protein ingredient was replaced by plasma protein or FM4 (2.5% and 5%). Synthetic lysine, methionine, threonine and tryptophan were added as needed to equalize the dietary content of each of these nutrients. The use of supplemental amino acids can be questioned, but it is the investigators' view that supplementation with these amino acids would be practical in a normal commercial formulation. Each diet was pelleted.

Table 7. Composition of Diets for Experiment 3[1]

Ingredients, %	Control	FM2.5[2]	FM5[3]	PP2.5[4]	PP5[5]
Corn Starch	5.00	2.50	0	2.50	0
Plasma Protein	0	0	0	2.50	5.00
FM4	0	2.50	5.00	0	0
Soybean Oil	3.85	4.08	4.32	3.91	3.95
Lysine	0	.04	.07	0	0
Methionine	.10	.14	.17	.12	.15
Tryptophan	0	.02	.04	0	0
Threonine	0	.04	.08	0	0
Di-calcium	1.05	.70	.40	.85	.65
Limestone	.95	.93	.87	1.07	1.20
Common Ingredients :					
Corn			50.00		
SBM			6.00		
Lactose			22.00		
Casein			10.00		
Antibiotics			.50		
Vitamin mixture			.20		
Trace mineral-salt			.35		
Calculated analysis:					
Protein, %	15.95	17.70	19.44	17.92	19.89
Lysine, %	1.11	1.28	1.45	1.28	1.45
Met+Cys, %	.67	.77	.87	.77	.87
Tryptophan, %	.19	.23	.27	.23	.27
Threonine, %	.72	.84	.95	.84	.95
Ca, %	.73	.73	.73	.73	.73
P available, %	.36	.36	.36	.36	.36
P total, %	.47	.47	.47	.47	.47
ME kcal/kg	3570.80	3593.90	3616.90	3595.50	3618.90

[1] "As is" basis, [2] FM2.5=2.5% fish meal, [3] FM5= 5.0% fish meal, [4] PP2.5=2.5% porcine plasma protein, [5] PP5=5.0% porcine plasma protein

Most pigs lost weight during the first three days of the experiment regardless of dietary treatment. It was reasonable to question whether this initial three-day period should be included in the data summary. Equations explaining weight gain and ADG of pigs fed diet with FM 4 or porcine plasma were generated to obtain at slope ratios (Table 8 and Figure 1).

Table 8. Equations and Relative Bioavailability (RBV)[1] for Weight Gain and ADG of Fish Meal (FM) and Porcine Plasma (PP) Treatments

	Weight gain		ADG	
	Equation	RBV	Equation	RBV
Lysine intake, g/d				
FM 4	0.065 x FM + 1.59	115%	0.0054 x FM + 0.13	115%
PP	0.057 x PP + 1.59		0.0047 x PP + 0.13	
Dietary lysine level, %				
FM 4	0.0733 × FM + 1.7996	92.9%	0.0061 × FM + 0.1500	92.4%
PP	0.0789 × PP + 1.7996		0.0066 × PP + 0.1500	

[1] Relative bioavailability (RBV) = slope of FM 4 response / slope of PP response

Following this procedure, FM 4 was found to have 115% of RBV to plasma protein in weight gain and ADG based on the lysine intake during d 3 to d 15 post-weaning. Moreover there was no significant difference between the slope of FM 4 response line and the and plasma protein response line ($P > .05$). These data indicate that high-quality fish meal can be used effectively as a protein source in diets for weanling pigs.

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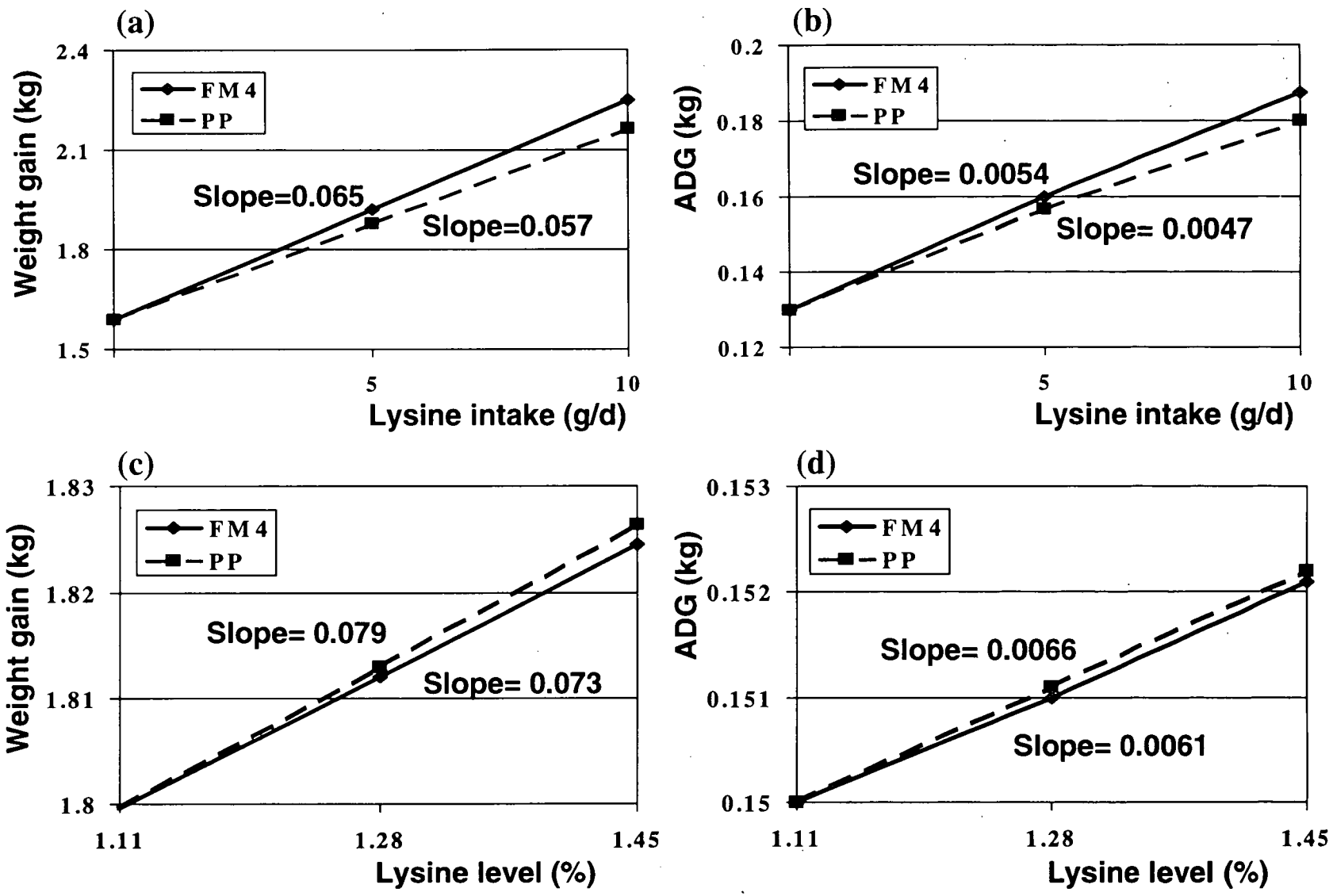

Figure 1. Changes in Weight Gain and Average Daily Gain of Pigs Fed Diets Containing Mackerel Fish Meal (FM4) or Porcine Plasma Protein (PP) as Lysine Intake or Lysine Level in Diets Increase

PRACTICAL APPLICATION OF FISH MEAL IN SWINE DIETS

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or Porcine Plasma Protein (PP) as Lysine Intake or Lysine Level in Diets Increase

INTRODUCTION

Fish meals are an excellent, high quality source of amino acids, and are particularly high in methionine relative to lysine. However, protein quality (amino acid digestibility) is highly influenced by the type of fish used, amount of decomposition before processing, and heat processing methods. Fish meals are also high in fat (approximately 10%) which gives them a digestible energy value higher than soybean meal, blood by-products, and dried whey, but less than dried skim milk. Because of their high bone content, fish meals also contribute significant amounts of calcium and phosphorus, and the bioavailability of phosphorus is very high (94%). However, as for most animal protein by-products, the concentration and digestibility of amino acids and other nutrients, as well as the cost of nutrients, can be highly variable among fish meal sources. Consequently, careful consideration must be used when selecting fish meal sources to find the best value for specific applications.

COMPARATIVE VALUE AND NUTRITIONAL CHARACTERISTICS OF HIGH QUALITY FISH MEAL

In North America, fish meal is used primarily in starter diets at levels of up to 10% of the diet. It is rarely used in grow-finish and sow diets due to its high cost relative to that of soybean meal. Furthermore, if more than 1% of the total dietary fat in grow-finish diets is derived from fish meal, a "fishy taint" may be observed in pork obtained from pigs fed high fish meal diets during this production phase.

High quality fish meal is widely used and is generally considered to be an essential ingredient in complex, high nutrient dense diets for early weaned pigs. High quality fish meal contributes several important characteristics to the diet including: improved diet palatability, good amino acid balance and digestibility (Table 1), specific long chain poly-unsaturated fatty acids, high digestible energy levels compared to other high protein sources (Table 1), and it allows the exclusion or partial exclusion of soybean meal from the diet to avoid the negative effects of allergic responses to soy protein in diets for early weaned pigs. Typically, fish meal is considered to be an economical replacement for dried skim milk in Phase I diets, as long as an equivalent amount of lactose contributed from dried skim milk is added to the diet to avoid reduced pig performance. Good quality fish meal is also cost and nutritionally competitive with spray dried blood meal in Phase II diets depending on price differentials between the two ingredients. However, spray-dried porcine plasma – the most expensive ingredient in starter diets – appears to be a difficult ingredient to replace in starter diets because of its beneficial immunological properties. Because of the many beneficial characteristics of high quality fish meal, it may be possible to minimize the level of spray dried

porcine plasma used and increase the amount of fish meal in the diet to reduce cost without compromising pig performance. Unfortunately, studies to test this possibility have not yet been conducted.

Table 1. Nutritional comparison of fish meals and other high protein starter diet ingredients

Ingredient	DE, kcal/kg	ME, kcal/kg	Lysine, %	Methionine, %	Threonine, %	Tryptophan, %	Phosphorus, %
IPC-790 fish meal[d]	UD[a]	UD[a]	5.44 **(76)**[b]	1.92 **(77)**[b]	2.83 **(57)**[b]	0.67 **(68)**[b]	2.08 (UD)[a,c]
Select Menhaden fish meal[d,e]	UD[a] 3770[e]	UD[a] 3360[e]	4.83 **(67)**[b] 4.81 (89)[b,e]	1.74 **(72)**[b] 1.77 (88)[b,e]	2.66 **(49)**[b] 2.64 (85)[b,e]	0.55 **(63)**[b] 0.66 (79)[b,e]	UD[a] 2.88 (94)[c,e]
Spray dried porcine plasma[e]	UD	UD	6.84 (87)[b]	0.75 (64)[b]	4.72 (82)[b]	1.36 (92)[b]	1.71 (UD)[a,c]
Spray dried blood meal[e]	3370	2945	7.45 (91)[b]	0.99 (85)[b]	3.78 (86)[b]	1.48 (88)[b]	0.30 (92)[c]
Dried skim milk[e]	3980	3715	2.86 (91)[b]	0.92 (92)[b]	1.62 (85)[b]	0.51 (90)[b]	1.00 (91)[c]
Spray dried whey[e]	3335	3190	0.90 (82)[b]	0.17 (84)[b]	0.72 (79)[b]	0.18 (78)[b]	0.72 (97)[c]
Soybean meal, 47.5[e]	3685	3380	3.02 (85)[b]	0.67 (86)[b]	1.85 (78)[b]	0.65 (81)[b]	0.69 (23)[c]
Soy protein concentrate[e]	4100	3500	4.20 (93)[b]	0.90 (91)[b]	2.80 (90)[b]	0.90 (89)[b]	0.81 (UD)[a,c]

[a] UD = undetermined.
[b] Values in parentheses are % apparent ileal digestibility.
[c] Values in parentheses are % P bioavailability.
[d] Bold values were determined at the University of Illinois.
[e] Values obtained from NRC (1998).

Digestible energy and ME values have not been specifically determined for IPC-790 fish meal. However, ME has been estimated to be approximately 3550 kcal/kg, which is higher than that of Select Menhaden fish meal (3360 kcal/kg ME) published in NRC (1998). The energy value of high quality fish meal meets or exceeds that of spray dried blood meal, spray dried whey, and soybean meal. This is important when formulating complex starter diets, which normally have limited "formulation space," to achieve the goal of maintaining high dietary energy density.

The level of total lysine, methionine, threonine, and tryptophan of IPC-790 and Select Menhaden fish meals, is higher than that found in dried skim milk, spray dried whey, and soybean meal. Lysine and methionine levels (but not threonine and tryptophan levels) of these fish meals also exceed those found in soy protein concentrate. However, because of the relatively high cost of soy protein concentrate relative to fish meal, fish meal is a much more cost competitive, high quality amino acid source in starter diets. High quality fish meal appears to be a much more digestible source of

methionine compared to spray dried porcine plasma. Conversely, spray dried porcine plasma is a more digestible source of lysine, threonine, and tryptophan compared to fish meal. The good amino acid balance found in fish meal gives it an advantage over spray dried porcine plasma due to its relatively high methionine:lysine ratio. Because of the significantly lower level of methionine in spray dried porcine plasma, supplementation of D, L methionine is required to provide adequate amino acid balance in complex diets for early weaned pigs. Like spray dried porcine plasma, spray dried blood meal is also lower in methionine relative to lysine, as well as having a lower isoleucine:lysine ratio. However, spray dried blood meal has higher digestibility of methionine, and higher levels and digestibility of lysine, threonine and tryptophan compared to fish meal. Unfortunately, the poorer amino acid balance found in blood meal compared to fish meal, limits its maximum inclusion rate in complex starter diets in order to be sure that isoleucine is not a limiting amino acid. Amino acid digestibility of blood meal can be highly variable among sources due to heat processing methods used. Blood products can cause major flowability problems, especially added to the diet in combination with dried milk products, due to their sticky, hygroscopic properties.

Fish meal also provides significant quantities of highly available (94%) phosphorus to the diet. This benefit is often overlooked when selecting various protein sources for starter diets. However, since phosphorus is the third most expensive nutrient provided in swine diets, and the increased need to minimize phosphorus excretion in the manure for environmental management purposes, fish meal is a superior source of available phosphorus compared to all other common amino acid sources used in starter diets.

Researchers Kim and Easter, at the University of Illinois compared apparent amino acid digestibility of IPC-790 fish meal to select Menhaden fish meal, and found the level and digestibility of lysine, methionine, threonine, and tryptophan to be higher for IPC-790 fish meal (Table 1). These researchers also showed that the apparent amino acid digestibility values obtained for select Menhaden fish meal are significantly lower than those listed in NRC (1998). Perhaps some of this discrepancy is due to differences in age of pigs used to establish these values. If older, less dietary sensitive pigs were used to determine NRC (1998) values, this would explain the higher apparent amino acid digestibility for Select Menhaden fish meal published in NRC (1998), compared to those obtained in the Illinois study utilizing weaned pigs. A similar research study conducted by Knabe at Texas A & M University also showed similar apparent digestibility advantages compared to Select Menhaden fish meal as observed in the University of Illinois study. Thus, it appears that IPC-790 fish meal has an advantage in total and digestible amino acid content compared to Select Menhaden fish meal for early weaned pigs, and the digestibility values listed in NRC (1998) appear to overestimate the apparent digestibility of amino acids in Select Menhaden fish meal.

ENERGY AND NITROGEN DIGESTIBILITY OF IPC-790 AND SELECT MENHADEN FISH MEAL IN DIETS FOR EARLY WEANED PIGS

As previously described, digestible and metabolizable energy values are poorly established for IPC-790, and discrepancies in amino acid digestibility values between NRC (1998) and University of Illinois results suggest that further evaluation of the energy and protein digestibility of starter diets containing fish meal is needed. We conducted a simple study with the primary objective of comparing energy and protein digestibility of complex, early weaned starter diets containing 0% fish meal, 10% IPC-790 fish meal, 10% Special Select fish meal, and 11.3% Special Select fish meal. The level of 11.3% Special Select fish meal was chosen to determine if the use of the differential in

apparent amino acid digestibility values between IPC-790 and Special Select fish meal, determined at the University of Illinois, provided the necessary accuracy when formulating practical starter diets containing fish meal.

A total of 20 crossbred pigs were weaned at 18 days of age, moved to individual collection cages, and fed a common Phase I starter diet for the first seven days postweaning. On day 8, pigs were weighed and randomly assigned to one of the four dietary treatments (five replications/treatment) for a seven-day adjustment, 3-day collection period. Pigs were fed an amount of their respective experimental diet equivalent to 2% of their body weight twice daily. Diet composition and calculated nutrient levels are shown in Table 2. All diets were fed in meal form. Feces and urine were collected during the 3-day collection period and weighed. Fecal samples were dried and subsamples of urine were used to determine gross energy and total nitrogen content. Gross energy and nitrogen content of feed samples for each diet were also determined, and used to determine energy and nitrogen digestibility.

Table 2. Composition (%) and calculated nutrient analysis of experimental diets				
Ingredient	**Control**	**10% IPC-790**	**10% Select Menhaden**	**11.3% Select Menhaden**
Corn	22.09	31.08	29.88	30.81
SBM, 48%	40.28	22.13	24.18	22.09
Dried whey	20.00	20.00	20.00	20.00
Lactose	10.00	10.00	10.00	10.00
Fish meal	0.00	10.00	10.00	11.30
Choice white grease	4.00	4.00	4.00	4.00
Dicalcium phosphate	1.75	1.13	0.65	0.51
Limestone	0.59	0.37	0.00	0.00
Salt	0.20	0.20	0.20	0.20
Vitamin premix	0.30	0.30	0.30	0.30
Choline chloride	0.12	0.12	0.12	0.12
Trace mineral premix	0.15	0.15	0.15	0.15
Zinc oxide	0.28	0.28	0.28	0.28
Mecadox-10	0.25	0.25	0.25	0.25
Total	**100.00**	**100.00**	**100.00**	**100.00**
Calculated nutrient analysis				
Crude protein, %	24.1	23.0	22.9	22.8
Crude fat, %	5.32	6.38	6.40	6.55
Crude fiber, %	1.92	1.61	1.64	1.60
Calcium, %	0.90	0.90	0.93	0.96
Phosphorus, %	0.80	0.80	0.80	0.80
ME, kcal/kg	3377	3439	3428	3432
Lysine, %	1.50	1.50	1.50	1.50
Met + cys, %	0.75	0.78	0.79	0.80
Threonine, %	1.02	0.99	1.01	1.01
Tryptophan, %	0.33	0.28	0.29	0.28

Due to the random allocation of dietary treatments to pigs, slightly lighter weight pigs were fed the 10% and 11.3% Select Menhaden fish meal diets. This resulted in a trend toward slightly lower feed and gross energy intake for the 10% Select Menhaden fish meal diet compared to an equivalent level of IPC-790 fish meal, and was less than the control diet (Table 3). However, when 11.3% Select Menhaden was added to the diet, gross energy intake tended to be similar to 10% IPC-790. Digestible energy was higher for the control diet compared to the 10% Select Menhaden fish meal diet, but was similar between the IPC-790 and 11.3% Select Menhaden diet. To account for the bias toward lower GE intake and lower fecal GE excretion of pigs fed the Select Menhaden fish meal diets, DE/GE x 100 was calculated and used as the dietary energy digestibility evaluation criterion. Pigs fed the 10% IPC-790 fish meal diet had equivalent DE/GE compared to pigs fed the 10% Select Menhaden fish meal diet, but pigs fed the 10% IPC-790 diet had lower DE/GE compared to the 11.3% Select Menhaden fish meal diet. These results suggest that IPC-790 and Select Menhaden fish meal have equivalent digestible energy values, and the use of 10% fish meal from either source maintains high dietary energy digestibility (90%) similar to complex starter diets without fish meal.

Pigs fed the 10% and 11.3% Select Menhaden diets had lower feed and nitrogen intake compared to the control and IPC-790 treatments. This was due to the use of slightly lighter weight pigs and lower feed intake provided to pigs on the Select Menhaden fish meal treatments. As a result, pigs fed the 10% and 11.3% Select Menhaden diets had lower fecal nitrogen excretion than the control and 10% IPC-790 treatment groups. Urine and total nitrogen excretion were significantly higher for pigs fed the control diet compared to pigs fed any of the fish meal diets. This suggests that apparent amino acid digestibility was higher in the fish meal supplemented diets. Pigs fed the 10% IPC-790 diet had higher % nitrogen retention than pigs fed the control diet, and numerically tended to have slightly higher nitrogen retention than the 10% Select Menhaden fish meal diet. Furthermore, formulating the 11.3% Select Menhaden fish meal diet using the differential in apparent amino acid digestibilities between Select Menhaden fish meal and IPC-790 (determined at the University of Illinois) resulted in identical nitrogen retention values between 11.3% Select Menhaden and IPC-790 fish meal diets. Based on these results, use of 10% fish meal from either source provides equivalent energy digestibility, and maintains high dietary energy digestibility compared to a complex, non-fish meal diet. Fish meal improved nitrogen digestibility compared to non-fish meal control diet, and numerically, IPC-790 may be slightly superior to Select Menhaden fish meal based on total nitrogen digestibility. This is consistent with results from apparent amino acid digestibility studies conducted at the University of Illinois and Texas A & M University. Finally, use of the differentials in amino acid digestibility between Select Menhaden and IPC-790 fish meal appears to be accurate and suggests that a complex starter diet containing 11.3% Select Menhaden fish meal provides equivalent nitrogen retention as obtained with feeding a diet containing 10% IPC-790 fish meal.

Table 3. Comparison of IPC-790 and Special Select Menhaden fish meal on energy digestibility, and nitrogen digestibility and retention in early weaned pigs					
Measure	**Control**	**IPC-790 10%**	**Select Menhaden 10%**	**Select Menhaden 11.3%**	**Standard Error**
Initial weight, kg	8.45	8.42	7.78	8.05	0.52
Energy					
Gross energy intake, kcal/pig/day	1301[a]	1225	1100[b]	1188	91
Fecal energy excretion, kcal/pig/day	116	121[a]	103	90[b]	14
Digestible energy, kcal/pig/day	1185[a]	1105	996[b]	1098	85
DE/GE	91.1	90.1[a]	90.4	92.5[b]	1.02
Nitrogen					
Nitrogen intake, g/pig/day	11.33[a]	11.36[a]	9.07[b]	9.16[b]	0.77
Fecal N excretion, g/pig/day	1.64[a]	1.54[a]	1.18[b]	1.08[b]	0.20
Urine N excretion, g/pig/day	2.17[c]	1.29[d]	1.25[d]	1.27[d]	0.21
Total N excreted, g/pig/day	3.81[c]	2.83[d]	2.42[d]	2.35[d]	0.20
N retained, g/pig/day	7.51	8.53[a]	6.65[b]	6.81	0.78
% N retention	65.03[c]	74.54[d]	73.00[d]	74.26[d]	3.00

[a,b] Least squares means within row with different superscripts are different P<.1.
[c,d] Least squares means within row with different superscripts are different P<.05.

SUMMARY

High quality fish meal has several advantages over other competing ingredients in complex, high nutrient density diets for early weaned pigs. These include increased diet palatability, good amino acid balance and digestibility, specific long chain poly-unsaturated fatty acids, high digestible energy levels compared to other high protein sources, and it allows the exclusion or partial exclusion of soybean meal from the diet to avoid the negative effects of allergic responses to soy protein in diets for early weaned pigs. Our evaluation of IPC-790 fish meal and Select Menhaden fish meal showed that these two sources of fish meal have equivalent digestible energy values, and adding 10% fish meal from either source maintains high dietary energy digestibility (90%) similar to complex starter diets without fish meal. Furthermore, our research results suggest that adding fish meal from either source improved nitrogen digestibility compared to non-fish meal control diet, and numerically, IPC-790 may be slightly superior to Select Menhaden fish meal based on total nitrogen digestibility. Finally, use of the differentials in amino acid digestibility between Select Menhaden and IPC-790 fish meal (determined at the University of Illinois) appear to be accurate and suggest that a complex starter diet containing 11.3% Select Menhaden fish meal provides equivalent nitrogen retention as obtained with feeding a diet containing 10% IPC-790 fish meal.

Notes

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FEED AND FORAGE EVALUATION -- THE NEW FRONTIER

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"Meanwhile, experimental inquiry has been increasingly active; the laws of animal nutrition are getting to be better understood, the theories have been put to the test of actual experience, and while their value to the farmer has been abundantly verified, weaknesses have been developed and ways in which improvements are wanted have become apparent. We are constantly working toward a clearer understanding of the principles of feeding and a more successful application of them to the practice of the farm. With the rest it has become evident that to meet the demands of both physiological chemistry and practical feeding, the chemist must devise more accurate methods of estimating the nutritive value of feeding stuffs." -- W. O Atwater, 1891.

A goal of feed evaluation is to find quantitative measures with which we can predict the nutrients available to support animal performance. Since the first attempts at setting feeding standards for cattle, the aim has been to replace the qualitative "eye of the master", with quantitative values for which recommendations can be developed. Current feed evaluation methods offer descriptors of nutrient content, and physical form, that in turn are used to predict available nutrients, as well as dietary effects, such as ruminal acidosis. Great strides have been made as our knowledge of vitamin, mineral, energy, and protein feeding of cattle has progressed, yet there are still many gaps in our knowledge. New evaluation measures must be closely linked to our understanding of the biology of the animal and microbes, because the analyses must make 'biological sense' for them to be most useful.

CHEMICAL ANALYSES

"In making an analysis of a plant or seed with reference to feed value it is both impossible and inadvisable to determine the amount of each compound present, so the chemist determines the following groups of compounds: Proteins, fats, fiber, nitrogen-free-extract, moisture and ash. He usually adds the crude fiber and nitrogen-free-extract together and calls it carbohydrates. This clas(s)ification is not altogether satisfactory and will probably be revised as our knowledge of nutrition and chemistry increases. However, for the present, these must suffice." -- W. H. Strowd, 1925.

Carbohydrates

Chemical analyses of feeds are only useful for ration formulation if they describe the feed in some nutritionally relevant way. Carbohydrates have offered us some challenges in this regard. For more than 100 years, the proximate and then the detergent systems of analysis have classified carbohydrates as fiber and non-fiber. The fiber carbohydrates include the relatively slower digesting carbohydrates: hemicellulose and cellulose (Figure 1). Crude fiber was originally used

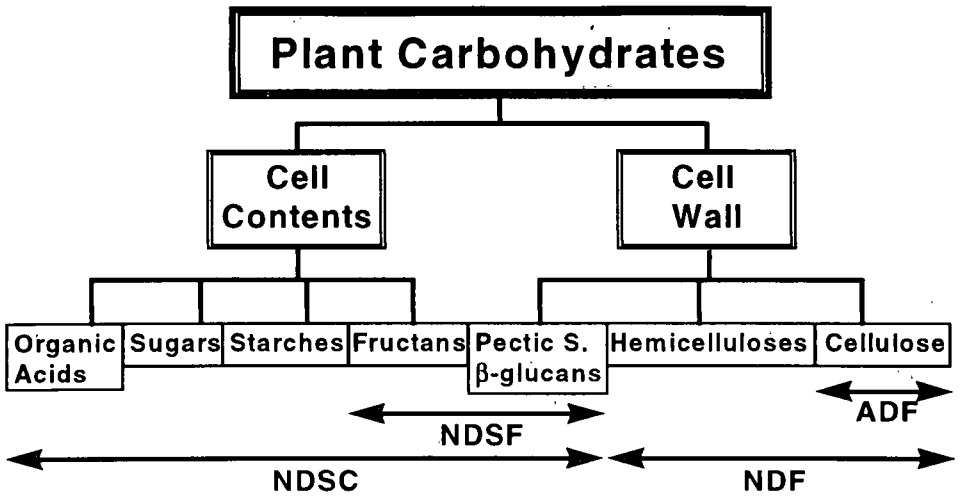


Figure 1. Plant carbohydrate fractions. ADF = acid detergent fiber, NDF = neutral detergent fiber, NDSC = neutral detergent-soluble carbohydrates, NDSF = neutral detergent-soluble fiber.

to describe the fiber fraction, but flaws in the method's ability to isolate fiber from more digestible carbohydrates lessened its usefulness as a nutritional entity (Van Soest, 1994). The detergent system offers improvement over crude fiber in ration formulation, but even this system does not describe uniform fractions. Among feedstuffs, all NDF or ADF are not created equal. Plants differ in the proportions of cellulose, hemicellulose, and lignin they contain, and in their rates and extents of digestion. For example, the NDF in citrus pulp digests at a rate of 25%/h with an extent of 80%, whereas the values for soy hulls are 4%/h and 95% (Hall *et al.*, 1998). One of the challenges we face is to develop reliable methods to estimate the differences in rates of digestion of these fractions that are applicable to the animal.

The carbohydrates not included in NDF are generally among the most digestible carbohydrates. The neutral detergent-soluble carbohydrates (NDSC) include organic acids, simple sugars, oligosaccharides, starch, fructans, pectic substances, (1→3)(1→4)-β-glucans, and other carbohydrates of appropriate solubility. The difficulty we have faced in working with these NDSC is that they have been represented as a single, calculated value that does not appreciate the nutritionally diverse nature of this pool (Figure 2). The NDSC vary in potential to support microbial growth, rates of digestion, microbial fermentation characteristics, and ability to be digested by mammalian enzymes. A lack of practical analytical methods to separate the NDSC has been the major stumbling block in partitioning these components for use in the field. Hoover and Miller (1995) have provided one of the most extensive sets of feed values for sugars and starch using a nonstructural carbohydrate method (Smith, 1969). A pending method (Hall *et al.*, submitted) partitions NDSC into organic acids, sugars, starch, and soluble fiber (carbohydrates indigestible by mammalian enzymes (Hall *et al.*, 1997)) (Figures 3a and 3b). Application of this partitioning should allow more accurate prediction of animal performance. But, it will likely raise additional questions on how variation in the soluble fiber and organic acid compositions affect animal performance.

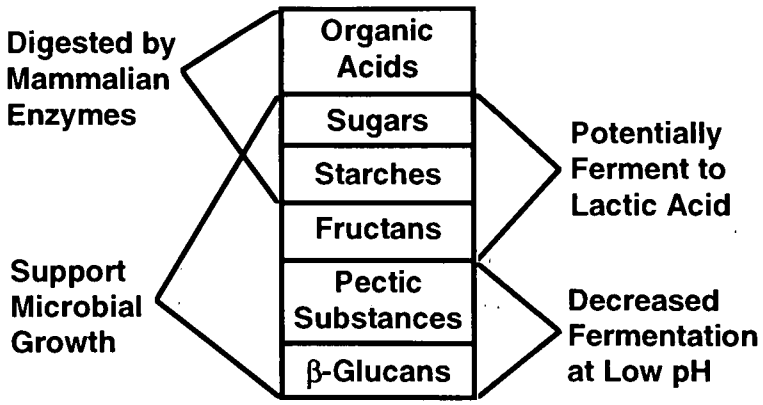
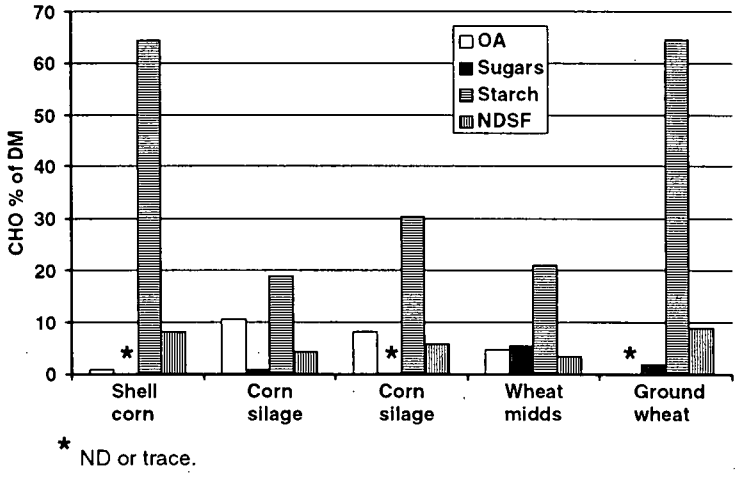


Figure 2. Nutritional characteristics of neutral detergent-soluble carbohydrates.



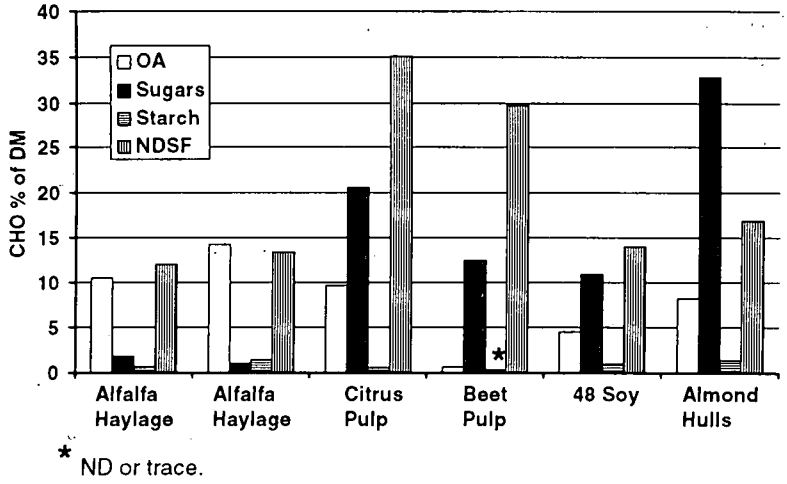


Figure 3 a and b. Neutral detergent-soluble carbohydrate composition of feedstuffs as determined with the proposed NDSC partitioning system (Hall et al., unpublished). OA = organic acids, sugars = mono- and oligo-saccharides, NDSF = neutral detergent-soluble fiber.

Protein

"Given the best kind and character of proteins, a cow does not need as high percent of protein in her ration as many of us have fed in the past, or may now be feeding."
-- M. H. Keeney, 1940 .

The advent of the rumen degradable (DIP) and undegradable (UIP) intake protein system (NRC, 1985) gave recognition that all crude protein sources are not utilized in the same fashion by the microbes or the animal. A problem has been that there are no "approved" analyses for UIP and DIP. Since the rumen degradability of protein is affected by the residence time of feeds in the rumen, static tabular values do not suffice. One analysis system partitions crude protein on the basis of true protein or non-protein nitrogen, and then by their solubility in buffer, neutral detergent and acid detergent (Licitra *et al.,* 1996). This partitioning is then used to relate the fractions to their digestion by the rumen microbes and animal using a nutritional model (Sniffen *et al.,* 1992). Closer attention is also being paid to the amino acid composition of feeds and what amino acids are available for the cow to absorb (Clark *et al.,* 1992; Schwab, 1995). Many questions surround the prediction of the composition of amino acids from feed and microbes that pass to the small intestine. The future holds further investigation into specific amino acids and how both feed and microbes can best meet the animal's requirements.

PHYSICAL FACTORS

Characterizing the effects of physical form on digestion and rumen function will be among our greatest challenges. There is likely to be as much variation in many feeds' physical form as there is in their chemical composition. Consider that physical form is affected by harvest method, grinding, extruding, rolling, ensiling, steam flaking, pelleting, mixing, and any other processing or handling to which the feed is subject. Physical form is associated with the effectiveness of fibrous feedstuffs in enhancing rumination and rumen motility. Systems such as the Penn State particle separator are available to evaluate particle size in feeds. This information plus a knowledge of the density, composition, and hydration of the sample can offer an assessment of "effective fiber", but there is no agreed upon system to utilize this information. It also appears that a feed's ability to encourage rumination varies with the particle size and characteristics of the other feeds with which it is fed (Mooney and Allen, 1997). An effective fiber system will be most useful if it takes into account the particle size of material actually consumed by the cow. This may require combined assessment of feed offered, feed refused, and possibly even of feces. Particle size in the feces can increase with decreasing "effective fiber". A system must take into account the sorting of finer or coarser material from the ration by the cow, as she is the final arbiter of what fiber is effective.

Physical forms of concentrates affect their digestion. For example, with corn, particle size, processing, hydration, intactness of the pericarp, intactness of the protein matrix surrounding the starch, etc. can affect its digestibility. The physical factors affect rates of ruminal digestion, as well as rates of passage which dictate where, and to what extent materials are digested. Current methods for estimating digestion in vitro or in vivo call for the grinding of feeds, which largely

eliminates the effects of physical form. Methods that evaluate the effects of physical form on digestion rates of feed components are needed.

DIGESTION

> *"It is a matter of every-day experience that only a part of the food eaten is actually used by the animal. It is, therefore, of importance in cattle feeding to have a knowledge, not only of the chemical composition of a given food, but of the amounts of the nutrients, which are capable of being assimilated. It is not so much what an animal eats, as that which it digests, that is actually turned to account." -- C. D. Woods, 1894.*

The digestibility of a feedstuff under various animal and ruminal conditions is what we strive to predict through the use of chemical compositions. New energy equations using a number of different feed composition measures rather than ADF alone offer improved prediction of the net energy in feeds (Weiss, 1993). However, animals do not use net energy, they utilize amino acids, organic acids, sugars, and fatty acids for different, specific purposes (Figure 4). Volatile fatty acid yield can be manipulated by the type of carbohydrate provided (Ariza-Nieto *et al.*, 1998) with possible effects on the yield and composition of milk. Ultimately, we need to be able to predict the supply of metabolizable nutrients the animals receive in order to predict performance.

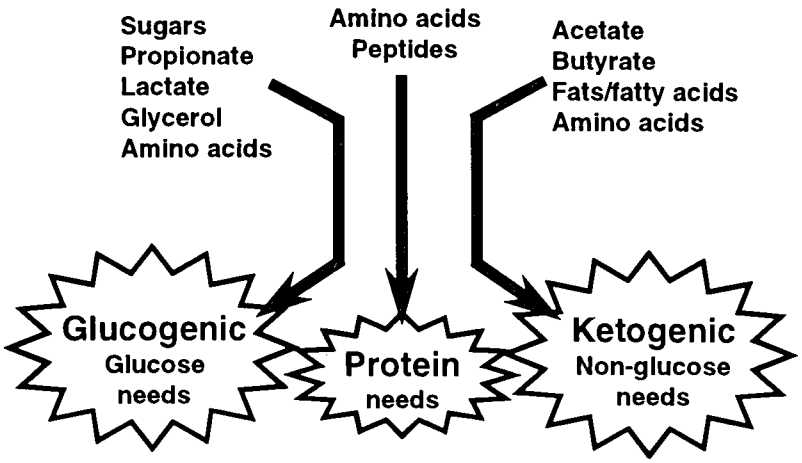


Figure 4. Specific uses of absorbed nutrients.

To determine the supply of metabolizable nutrients, the rate and location of digestion of the feed components must be known (Figures 5a and 5b). The digestion of a particular carbohydrate or protein in the rumen, small intestine, or hindgut determines whether the animal absorbs organic acids or glucose, or whether the microbial protein is available for digestion, or is excreted in the manure. Digestion of feed nitrogen in the rumen determines whether that nitrogen will reach the small intestine as amino acids or non-protein nitrogen from the feed or microbes. Current methods to determine rate of ruminal carbohydrate fermentation include in situ digestion in dacron bags in the rumen, and in vitro digestion with rumen microbes in the laboratory. The most

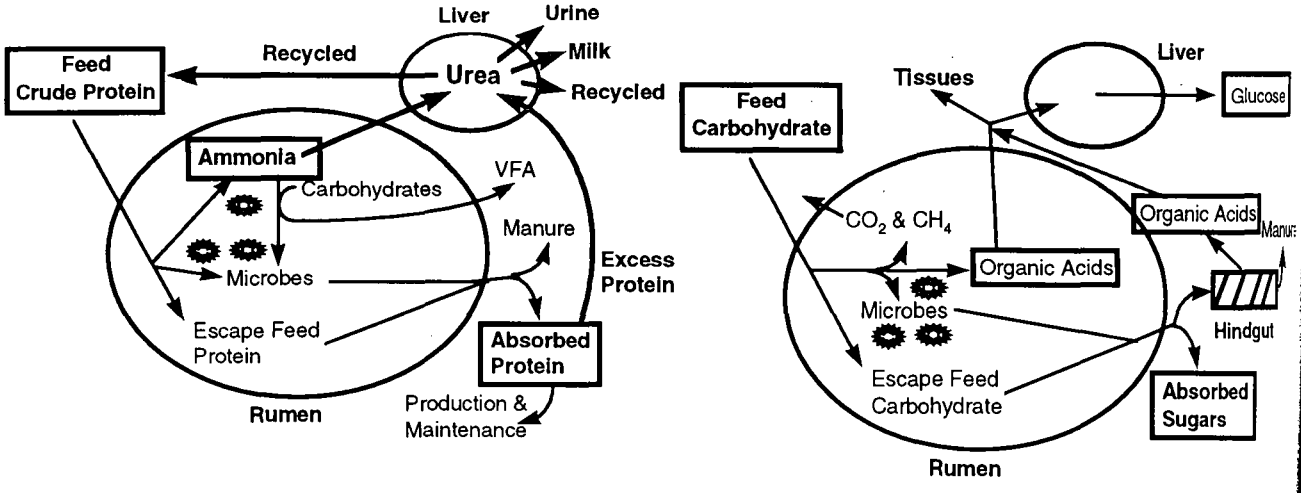


Figure 5. Digestive fates of crude protein and carbohydrates.

common methods measure fermentation of dry matter, organic matter, and NDF, but have been ill suited to assess the digestion of the NDSC or protein. A newer method that measures the gas produced during fermentation (assumed to be proportional to the amount of carbohydrate fermented) allows determination of the rate of NDSC fermentation (Pell and Schofield, 1993). A difficulty faced by any of these methods is that there appear to be cow effects on the fermentation results: the rumen inocula from different cows offer somewhat different results (Mertens *et al.*, 1997). This may be related to the variation among laboratories in which relative ranking of the feeds is the same, but absolute values for extent of fermentation differ (J.E. Moore, personal communication). Additionally, the positive and negative associative effects that feed components have when they are fed together may not be considered in these assays.

The other factor that is needed to make use of ruminal digestion rates, is ruminal passage rate. The passage rate sets the amount of time that the feed resides in the rumen and is subject to ruminal fermentation. The competition between rates of digestion and passage determines the extent to which feeds are fermented in the rumen, the amount of fermentation products that will be produced, and how much microbial and feedstuff material will pass to the small intestine. Rate of passage is affected by a number of factors, including animal body weight, dry matter intake, and composition of the ration. The methods for estimating rate of passage all have their deficiencies. They attempt to use an indigestible marker, such as a rare earth or chromium bound to fiber, or acid-insoluble ash for solids, and cobalt-EDTA for liquids, to determine passage rate out of the rumen. Methodology improvements are needed to improve predictions.

INTEGRATION

The future of feed evaluation involves integration. Nutritionists do this on an intuitive level, but more objective measures to combine with experience will serve the industry better in the long run.

Accurate assessments of feed composition, digestion and passage must be brought together to more accurately predict nutrient supply and animal performance. Various nutritional models (Sniffen *et al.,* 1992; Murphy *et al.,* 1986) permit us to evaluate rations on this integrated basis, but the current models sometimes raise as many questions as they answer. When, with the best information available, the outcome of a model does not accurately predict the performance of a group of cows, we know that the cows are not at fault. This is actually a strong point of using models: they readily point out areas in which we need to improve our information. Models are being used in the field, and also serve as excellent teaching and research tools for exploring the biology behind rations. Understanding that biology is of use to nutritionists whether they decide to make field use of a model or not.

CONCLUSION

The quest to improve feed evaluation has been a continuing pursuit as we learn more about animal requirements, and the factors that affect nutrient supply. The task ahead of us on the frontier of feed and forage evaluation entails development of new methods, and perhaps making better use of those currently available. Improved methods are needed for protein, carbohydrate, physical form, digestion, and ruminal passage assessments. These methods will be essential to moving ahead in ration formulation, because if we cannot measure them, we cannot objectively manipulate them in the ration. In the future, we will combine more chemical and biological feed evaluations to more accurately describe the components' nutritional relevance. The extent to which we take those evaluations will be limited by the laws of diminishing returns: they will be used to the point where the assays become burdensome, either analytically or financially, for what they offer in return. That will no doubt vary by farm and by nutritionist.

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CORN SILAGE HYBRIDS FOR DAIRY OR BEEF CATTLE

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INTRODUCTION

Corn hybrid selection for dairy or beef cattle is an important management decision for producers. Specific quality traits are available from various hybrids that affect dry matter (DM) or forage digestibility, protein quality, starch content and/or digestibility, or lipid content. Selecting a hybrid based on one or more of these traits depends upon the type of animal, the importance of the trait in the diet of the animal, and the overall economic gain from the hybrid.

HYBRID DIFFERENCES

Differences between hybrids exist. These differences may be evident in nutrient content, morphology, or yield of the whole plant matter. In addition, large variations in stover or whole plant tissue digestibility are apparent across hybrids. Digestibility of the stover or the whole plant may play a large role in determining the feeding value of the silage hybrids. However, it is difficult to make comparisons between hybrids using only hybrid characteristics or laboratory digestibility value information.

Hunt et al. (1992) attempted to relate morphological and chemical composition traits of six different corn hybrids with *in situ* digestibility (Table 1). Morphological differences existed among the hybrids. Hybrid B contained the largest amount of grain while hybrid E had the greatest amount of stover present. These morphological differences did not necessarily translate into differences in fiber values. For example, hybrid A and C were low in NDF and ADF and their ear and stover percentages were equal to E and F which were high in fiber content. Differences in grain yield across hybrids did not translate into differences in starch content. In addition, higher grain yields did not explain differences in whole plant digestibility as hybrids A and C tended to be the highest for their whole plant digestibility, but did not have the highest grain yield. However, stover digestibility of A and C was the highest of all hybrids.

In hybrid selection for dairy or beef cattle, it is important to consider many different factors when looking for a high quality feed. However, often the only information available on a hybrid is yield, chemical composition, or a laboratory digestibility value. This information may assist in hybrid selection, but it does not provide information on the true energy content of the silage or the true digestibility of the silage. Furthermore,

harvest management and methods also can affect how the silage is utilized by the animal. This paper summarizes recent animal performance data from some of the common corn silage hybrids available. Few data or studies are cited. This indicates a need for increased research efforts to define animal responses to corn hybrid alternatives.

Table 1. Composition of whole plant samples from divergent corn hybrids.

	Hybrid						
	A	B	C	D	E	F	SE
DM Yield (ton/acre)	11.3	10.8	12.1	11.0	11.0	11.0	0.6
Plant Composition							
% Grain	39.0^{ab}	44.0^{c}	38.8^{ab}	42.3^{bc}	37.0^{a}	39.0^{ab}	1.2
% Ear[1]	46.8^{a}	52.0^{b}	47.0^{a}	50.3^{ab}	45.9^{a}	47.3^{a}	1.6
% Stover[2]	53.2^{b}	48.0^{a}	53.0^{b}	49.7^{ab}	54.1^{b}	52.7^{ab}	1.6
DM	33.7	38.4	40.0	38.6	39.1	38.8	3.3
NDF	41.7^{a}	42.2^{ab}	43.7^{ab}	45.0^{bc}	47.5^{bc}	49.0^{c}	1.7
ADF	23.9^{a}	24.0^{a}	24.6^{a}	27.0^{b}	27.7^{bc}	28.3^{c}	0.9
Starch	26.7	31.6	28.7	27.4	24.1	24.3	2.6
Whole plant ISDMD[3], %	60.4^{bc}	59.1^{bc}	60.6^{c}	60.0^{bc}	57.2^{b}	53.7^{a}	1.1
Stover ISDMD, %	52.3^{c}	45.8^{ab}	51.5^{c}	47.4^{b}	47.7^{b}	44.0^{a}	1.0

[1]Ear = grain and cob.
[2]Stover = stalk, husk, and leaf.
[3]ISDMD = *In situ* dry matter digestibility (24 hr digestion).
[Abc]Means within the same row without common superscripts differ ($P \leq 0.05$).
Hunt et al., 1992.

HYBRIDS AVAILABLE

Brown midrib (BMR)

Brown midrib (BMR) corn hybrids contain less lignin in the stalks and leaves as compared to normal corn. Research in the 1970's showed that the fibrous portion of BMR corn is more digestible than normal corn hybrids. In dairy cattle, some studies showed that BMR silage increased dry matter intake (DMI), but not milk production (Stallings et al., 1982; Rook et al., 1977). However, Keith et al. (1979) found opposite results as cows consuming BMR corn silage produced more milk than those receiving normal corn silage with similar intakes. In beef cattle, Keith et al. (1981), found that feeding diets with BMR silage resulted in increased DMI and average daily gains (ADG).

Recent work was conducted to compare forage quality traits of a BMR hybrid to its isogenic normal counterpart (Table 2; Allen et al., 1997). Similar NDF concentrations were measured in the whole plant of each hybrid; but, less ADF and lignin were in the BMR hybrid. Therefore, the BMR hybrid had a higher *in vitro* true and NDF digestibility.

According to this study and previous work, yield reductions may result with the BMR hybrid.

Table 2. Comparison of forage quality traits of brown midrib (BMR) corn silage with its isogenic normal parent and its effect on dairy cattle performance.

Item	BMR	Normal	*P* <
Forage quality traits (Allen et al., 1997)			
DM, %	31.4	34.4	0.001
NDF, % DM	43.8	44.7	NS
ADF, % DM	22.6	24.0	0.001
Lignin, % DM	1.7	2.8	0.001
IVTD[1], % DM	78.0	73.8	0.001
IVDNDF[2], % DM	49.9	41.5	0.001
Crude protein, % DM	8.4	8.2	0.04
DM yield (T/ha)	16.0	18.3	0.001
Animal performance data (Oba and Allen, 1997)			
DMI, kg	25.5	23.5	0.001
Milk, kg	41.6	38.9	0.002
3.5% fat corrected milk, kg	40.9	38.4	0.001
Fat, %	3.43	3.46	NS
Protein, %	2.99	2.95	NS

[1] *In vitro* true digestibility.
[2] *In vitro* digestible NDF.

Brown midrib and the normal parent silage were included in diets of lactating dairy cattle at 44.6% of the diet DM and NDF was balanced at 31% of the diet DM (Table 2; Oba and Allen, 1997). Feeding BMR silage resulted in greater DMI, milk yield, and 3.5% fat-corrected milk. In a more recent follow-up lactation study, Oba and Allen (1998) compared the BMR hybrid to its isogenic normal counterpart at two concentrations of dietary NDF (29 or 38%, DM basis). Dry matter intake and milk production were increased in cattle fed the BMR hybrid at both dietary NDF concentrations. Milk fat percent was depressed at the 29% NDF concentration with the BMR hybrid and milk protein was not affected. Mean rumen pH was lowered with the BMR hybrid; this likely resulted in more rumen fermentation and more energy going toward milk production. The benefit of enhancing NDF digestibility of the diet with the BMR hybrid was greater in a high NDF diet.

Waxy

Waxy hybrids are characterized by changes in starch morphology. Starch in the kernel endosperm consists of two types of polymers: amylose and amylopectin. Amylose is a linear polymer of α-1,4 linked glucose units. The structure of amylopectin is similar, but with α-1,6 branch points every 20 to 25 glucose units along the linear α-1,4 glucose chain. Most corn hybrids contain approximately 75% amylopectin and 25% amylose; however, waxy hybrids are nearly all amylopectin, thereby making the starch softer and possibly more digestible. No published research evaluating waxy corn silage in ruminant diets was found.

High Lysine

High lysine corn contains genes from the opaque-2 and floury-2 mutant varieties. In conventional corn, approximately 50% of the protein is zein protein which is deficient in lysine. However, when these mutant genes are introduced into conventional corn, the synthesis of zein protein is reduced and the proportion of other proteins high in lysine (albumin, globulin, and glutelin) are increased. Normal dent corn grain contains approximately .25% lysine, and in high lysine corn grain, lysine content can range from .30 to .55% (Hawton et al., 1996).

A recent trial evaluated the use of high lysine hybrids as grain or silage in dairy cattle diets (Table 3). Lactating cows receiving 46% of their dietary DM as high lysine corn silage consumed 2.2 more kg DM and produced milk with higher lactose content. However, milk yield was not affected by feeding either the regular or high lysine corn as silage or grain. Dietary NDF content averaged 31.7% for the regular corn silage diet and 29.0% for the high lysine diet. This difference may have accounted for the increased DMI in cows fed the regular corn silage diet. Type of silage affected diet DM and starch digestibility as these values were higher for cows on the high lysine silage treatment. However, DM digestibility was higher for cows consuming the regular corn grain as compared to the high lysine grain. Rumen NH_3 levels were lower in cows consuming either the high lysine grain or silage.

In ruminant animals, the benefits to using high lysine corn have been due to its increased starch digestibility rather than the increased lysine content. Dado and Briggs (1996) found that the *in situ* starch digestibility in high lysine grain after a 6 hr incubation averaged 55.8% compared to 39.1% for a normal dent hybrid.

Because of its potential for increased grain digestibility, Ladely et al. (1995) fed finishing steers diets containing either control or high lysine corn grain. Steers fed high lysine corn tended ($P = 0.11$) to consume less DM (8.57 vs. 8.98 kg/d), gained similarly (1.69 vs. 1.68 kg/d), and had a 6% more efficient gain to feed ratio (0.199 vs. 0.189; $P < 0.10$) compared to steers fed control corn over the initial 102 days of treatment. Cattle on the high lysine diet continued to remain more efficient in their gain to feed ratio through 184 days of treatment (0.175 vs. 0.158; $P < 0.10$). Total tract starch digestion was higher in steers fed the high lysine corn diet (96.5 vs. 91.9%; $P < 0.10$).

Table 3. Effect of regular (reg) corn silage (CS) or grain (CG) and high lysine (HL) corn silage or grain fed to lactating dairy cattle.

	Reg CS		HL CS		*P*		
Item	Reg CG	HL CG	Reg CG	HL CG	CS	CG	CS x CG
DMI, kg/d	23.7	22.7	25.5	25.2	0.02	NS	NS
Milk, kg/d	26.6	26.8	27.2	27.0	NS	NS	NS
Milk fat, %	4.03	4.00	4.02	3.91	NS	NS	NS
Milk protein, %	3.34	3.37	3.39	3.33	NS	NS	0.04
Milk lactose, %	4.71	4.72	4.75	4.79	0.02	NS	NS
DM digestibility, %	67.5	58.8	71.2	66.9	0.05	0.03	NS
NDF digestibility, %	51.1	34.2	50.2	49.6	NS	NS	NS
Starch digestibility, %	87.1	83.7	89.0	91.7	0.04	NS	NS
Rumen NH_3, mg/dl	14.2	9.9	9.9	7.8	0.04	0.04	NS

Beek and Dado, 1998a and 1998b.

High Oil

High oil hybrids on the market contain a higher amount of oil relative to normal corn. The common variety used today is produced by using a breeding method known as "topcross". Topcross™ (DuPont Optimum Quality Grains, Des Moines, IA) grain is produced from a blend of seeds with 90 to 92% male sterile hybrid "grain parent" seed and 8 to 10% high oil "pollinator" seed. High oil kernels typically have a larger germ (embryo) compared to normal corn where the higher percentage of oil (approximately 8 to 10% vs. 3 to 5%; Hawton et al., 1996) is contained.

When combinations of high oil corn silage and grain were compared to combinations of normal corn silage and grain, no effect of silage was found for DMI or milk yield (Drackley et al., 1996; LaCount et al., 1995). However, LaCount found high oil corn silage decreased milk crude protein content by 0.06 percentage units. Drackley found high oil corn grain increased ($P < 0.05$) milk production by 1 kg and decreased milk crude protein content by 0.03 percentage units. In addition, LaCount found that feeding high oil corn grain in the diet resulted in cows consuming 1.9 kg more ($P < 0.02$) DM between week 4 and 14 of lactation, and 2.2 kg more ($P = 0.001$) DM between week 4 and 43 of lactation. From week 4 to 17 of lactation, cows consuming high oil corn grain produced 1.5 kg more ($P = 0.06$) milk. Dhiman et al. (1996) compared diets with high oil corn silage and high oil high moisture ear corn to normal dent silage and normal high moisture ear corn. *No effect was found for DMI, milk production, or milk composition.*

Changes in the composition of the fatty acid profile in milk may be found with the high oil diets (LaCount et al., 1995). Fatty acids of C15:0, C16:0, C16:1, and C17:0 decreased and C18:0 and C18:1 increased with the addition of high oil silage or grain in the diet. Concentration of short and medium chain fatty acids (C4:0 to C14:0) were not affected by either high oil grain or silage.

In beef cattle, no recent high oil corn silage work was found. However, there have been studies reported using the high oil corn grain (Andrae et al., 1998a; Andrae et al., 1998b). Three diets were fed with 82% of the dietary DM as normal or high oil corn grain, or 74% of the dietary DM as high oil corn grain being isocaloric to the diet with 82% normal corn grain. Total lipid content for the normal and high oil corn were 4.9 and 7.0% DM, respectively. Steers consuming the normal corn consumed more DM than those receiving either high oil corn diet. Corn hybrid had no effect on ADG, feed to gain efficiency, or carcass characteristics. Marbling scores were higher ($P < 0.05$) in steers consuming the high oil corn diets compared to the normal corn. Steers on the 82% high oil corn diet were more likely to reach US Choice grade compared to steers on the normal corn or isocaloric high oil corn diet. Feeding high oil corn tended ($P = 0.07$) to decrease carcass saturated fatty acids and increase ($P = 0.06$) C18:2, C20:4, and total polyunsaturated fatty acids.

High grain

Increasing the grain content of the plant should increase the total energy content of the silage because the kernel contains more energy than the fibrous stover. However, if the starch is unavailable for digestion in the rumen or post ruminally, no advantage to high grain hybrids will be realized.

A survey of corn silage from Minnesota dairy farms revealed corn grown in a growing season yielding high levels of grain and starch, did not correspond to increased *in vitro* digestible DM of the whole plant compared to corn from a growing season with less grain and starch (Table 4). Data from this study also showed that higher NDF and ADF concentrations in the 1993 growing season did not correspond to decreased *in vitro* DM or NDF digestibility. Data by Coors (1996) and Allen et al. (1991) also have shown that grain yield in the corn plant is not related to forage quality characteristics.

Table 4. Means and ranges of plant and nutritional composition of corn silage collected from the 1993 and 1994 growing season.

Item	1993 Mean	1993 Range	1994 Mean	1994 Range	$P <$
Plant composition					
Visible grain[1], % as fed silage	18.7	1.4 - 34.0	26.2	5.6 - 45.9	0.001
Stover[2], % as fed silage	81.3	66.0 - 98.6	73.8	54.1 - 94.4	0.001
Nutrient composition					
DM, %	39.9	22.8 - 52.1	40.1	24.9 - 53.6	NS
NDF, % DM	45.7	34.6 - 58.2	40.6	28.0 - 53.5	0.001
ADF, % DM	24.3	17.6 - 33.0	21.7	11.5 - 30.6	0.001
Lignin, % NDF	2.9	.4 - 7.0	4.3	2.3 - 7.0	0.001
Starch, % DM	26.6	10.4 - 36.8	33.2	23.3 - 52.6	0.001
IVDDM[3], % DM	77.4	69.8 - 84.4	75.2	68.1 - 86.0	0.05
IVDNDF[4], % DM	45.0	31.5 - 55.8	46.1	28.7 - 63.6	NS

[1] Visible grain is all corn grain in the sample that was removed.
[2] Stover is the portion of the sample that remained after the visible grain was removed.
[3] *In vitro* digestible DM.
[4] *In vitro* digestible NDF.
Kuehn et al., 1996.

Two hybrids (Pioneer 3377 and 3389) with high amounts of grain were compared in a beef feeding study (Hunt et al., 1993; Table 5). Grain concentration of the plant did not affect the NDF or ADF of the plant as both NDF and ADF were higher in the hybrid containing slightly more grain. In addition, *in vitro* digestible DM was not higher in the hybrid with more grain. In growing steers, DMI was higher for steers consuming the diet containing silage of higher grain and fiber content. However, ADG was not improved which resulted in a less efficient feed to gain ratio and feed costs / kg gain. With this change in efficiency and pricing the corn silage at $21.82/ton, the 3377 hybrid was valued at $316 more per acre.

Table 5. Plant and chemical composition and animal performance data of two grain hybrids used as silage.

Item	Hybrid 3377	Hybrid 3389	*P* <
Plant composition, % DM			
Grain	41.0	44.0	NS
Cob	7.8	8.0	NS
Stalk, leaf, husk	51.2	48.0	NS
Chemical composition, % DM			
NDF	42.7	48.1	0.01
ADF	26.3	30.0	0.01
IVDDM[1]	71.8	67.1	0.01
IVDNDF[2]	73.6	70.5	0.01
Growth performance trial			
DMI, kg/d	7.31	7.55	0.10
ADG, kg/d (0 to 84d)	1.08	1.01	0.05
Feed:gain	6.75	7.49	0.01
Feed $ / kg gain	0.59	0.63	-----

[1] *In vitro* digestible DM.
[2] *In vitro* digestible NDF.
Hunt et al., 1993.

Leafy

Leafy hybrids on the market have been selected for their leaf content. Because leaf material is more digestible than stalk material, in theory, these hybrids should offer a more digestible whole plant material. Kuehn et al. (1998a and 1998b) compared a leafy hybrid (TMF 95), a high grain hybrid (DeKalb 442), and a generic blend (Dahlco No. 2). Plant morphology and whole plant chemical composition are in Table 6.

Table 6. Plant morphology and chemical composition of a high grain, leafy, and blend corn hybrid.

Item	Hybrid			$P <$
	High Grain	Leafy	Blend	
Morphology	- - - - - - - - %, DM basis - - - - - - - -			
Grain	43.7	41.0	46.2	----
Cob	7.9	8.9	11.0	----
Leaf	11.9	13.0	10.1	----
Stalk, sheath, and tassel	29.5	30.4	24.7	----
Husk, shank, and silk	7.0	6.7	8.0	----
Chemical composition				
NDF	43.6	45.6	45.1	NS
ADF	23.6	24.3	24.4	NS
Crude protein	7.0[ab]	6.9[b]	7.3[a]	0.05
IVDDM[1]	66.8[b]	69.2[a]	66.7[b]	0.05
IVDNDF[2]	34.6	38.0	34.4	NS

[1] *In vitro* digestible DM.
[2] *In vitro* digestible NDF.
Kuehn et al., Unpublished

Although no statistical comparisons could be made on the morphology of the hybrids, the most grain, cob, and husk material was found in the generic blend corn. The leafy hybrid yielded the most leaf and stalk material. No differences were found in the NDF, ADF, or *in vitro* digestible NDF content across the three hybrids. Slight differences were found in crude protein and the leafy hybrid yielded the greatest amount of *in vitro* digestible DM material.

Three groups of dairy cattle in early lactation (3 to 154 days) were fed diets containing one of the silages at 40% of the diet DM. Animal performance data are in Table 7. Dry matter intake, milk production, milk fat, and milk protein concentration did not differ across dietary treatments. In addition, digestibility of DM and NDF did not differ across the three diets. Cows consuming the high grain corn silage diet gained more body weight throughout the trial, but this was only significant in multiparous cows.

Table 7. Performance and digestibility data for cows consuming diets containing corn silage from high grain, leafy, or blend hybrids.

	Hybrid			
Item	High Grain	Leafy	Blend	*P* <
DMI, kg/d	22.3	22.4	21.8	NS
Milk, kg/d	35.1	35.2	36.3	NS
Milk fat, %	3.91	3.93	3.97	NS
Milk CP, %	3.18	3.16	3.15	NS
DM Digestibility, %	55.9	56.4	53.9	NS
NDF Digestibility, %	26.4	28.8	24.2	NS

Kuehn et al.,1998a and 1998b.

Bal et al., (1998; Table 8) found a slight advantage feeding a grain hybrid compared to a leafy hybrid in DMI and total tract DM and NDF digestibility. No difference was found in milk yield or milk protein percent. However, cows consuming the leafy hybrid produced milk with a higher milk fat percent and had a higher total tract starch digestibility than cows fed a high grain corn silage.

Table 8. Effect of corn hybrids selected for leafiness or grain content fed as corn silage on performance and digestibility.

Item	Leafy	High Grain	*P* <
DMI, kg/d	26.8	27.7	0.10
Milk yield, kg/d	40.3	40.5	NS
Milk fat, %	3.57	3.50	0.10
Milk protein, %	3.39	3.39	NS
DM digestibility, %	58.8	60.8	0.01
NDF digestibility, %	27.4	31.2	0.01
Starch digestibility, %	94.3	92.3	0.01

Bal et al., 1998.

A recent study evaluated effects of hybrid or corn silage proportion in diets of yearling cattle (DiCostanzo et al., unpublished). Cattle were fed either a grain (Cargill 3677) or leafy (TMF 108) hybrid at either 12%. 24%, or 36% of the diet DM. Effect of hybrid was independent of corn silage proportion (Table 9). Hybrid type did not affect ($P > .05$) ADG, DMI, or DM required/kg gain. In contrast, and as expected, increasing corn silage to 36% of the dietary DM, regardless of hybrid type, reduced rate of gain. Dry matter required/kg gain was lowest for steers fed 12%, intermediate for those fed 24%, and highest for those fed 36% corn silage. The ratio of carcass to live weight (dressing percentage), and ribeye area of cattle fed the leafy silage tended ($P < .07$) to be smaller than those of cattle fed the grain hybrid silage.

Carcass weight was highest for cattle fed 12% corn silage for 126 days, or those fed 36% corn silage for 142 days. This resulted from fast rates of gain of steers fed 12% corn silage, or extended feeding period of those fed 36% corn silage. Dressing percentage and ribeye area decreased with feeding increasing corn silage proportion. Carcasses of steers fed 12% corn silage had higher dressing percentage and larger ribeye areas than those steers fed 24% or 36% corn silage.

Table 9.. Performance data of steers fed either a grain or leafy hybrid, and silages fed at increasing amounts of the diet DM.

	Hybrid		Corn silage, % diet DM			
Item	Grain	Leafy	12	24	36	MSE[a]
No. pens	8	8	6	4	6	
Animal performance data						
Initial body weight, kg[b]	411	411	410	409	413	10.7
Final body weight, kg[b]	627	624	630	612	635	221.7
ADG, kg	1.65	1.66	1.74[c]	1.67[c]	1.56[d]	0.01
Days on feed	---	----	126	126	142	
DM intake, kg/d	11.2	11.1	11.2	11.2	11.2	0.20
Corn silage, % DM	----	---	12.6	23.4	34.3	
Feed / kg gain	6.80	6.72	6.41[c]	6.71[d]	7.16[e]	0.01
Carcass evaluation data						
Hot carcass weight, kg	381	375	385[c]	365[d]	384[c]	182.2
Carcass weight, % of live	60.6	59.8	61.1[c]	59.7[d]	59.8[d]	0.68
Ribeye area, cm^2	89.4[c]	85.6[d]	91.3[c]	86.1[d]	85.5[d]	1.13
Fat depth, cm	1.17	1.19	1.14	1.17	1.24	0.01
KPH[f], %	2.27	2.26	2.33	2.18	2.29	0.01
Marbling score[g]	4.97	5.22	5.10	5.04	5.13	0.05
Yield grade	2.63	2.69	2.61	2.56	2.80	0.05

[a]Mean square error.
[b]Obtained after withholding feed and water for 16 hours.
[c,d,e] Means with different superscripts differ ($P < 0.05$).
[f]Kidney, pelvic, heart fat depot.
[g]4 = slight, 5 = small, 6= modest.

Leafy hybrid corn silage (TMF106) in yearling beef steers has been studied by DiCostanzo et al. (1997; Table 10). Diets consisted of increasing proportions of leafy corn silage, 12%, 24%, 36%, or 48% of the diet DM, with the remainder being corn grain. Although steer gains were not ($P > .05$) affected, DMI increased linearly ($P < .07$) with corn silage proportion; therefore, DM required per kg gain increased linearly ($P < .05$) with corn silage proportion. Carcass weight increased linearly ($P < .05$), while ribeye area and proportion of kidney, pelvic and heart fat depot decreased linearly ($P < .05$) with increasing corn silage proportion.

Table 10. Means for daily gain, dry matter intake and carcass traits of steers fed increasing amounts of leafy corn silage.

	Diet[a]				
Item	CS12	CS24	CS36	CS48	SE
No. pens	2	2	2	2	
Initial BW, kg[b]	395	390	390	394	
Final BW, kg[c]	586	578	623	612	
ADG, kg	1.49	1.47	1.43	1.34	0.07
Days on feed	128	128	163	163	
DM intake, kg/d					
Corn	7.99	7.16	6.17	5.18	
Corn silage	1.24	2.39	3.60	4.94	
Supplement	0.83	0.83	0.84	0.84	
Total[d]	10.06	10.39	10.61	10.96	0.23
Feed / kg gain[e], kg DM	6.74	7.08	7.46	8.18	0.22
Carcass traits					
Hot weight[e], kg	363	358	386	380	4.7
Ribeye[e], cm^2	83.6	83.9	81.0	81.0	0.65
Fat depth, cm	1.37	1.37	1.22	1.27	0.08
KPH[ef], %	2.34	2.38	2.21	1.94	0.10

[a] Corn silage fed at 12% (CS12), 24% (CS24), 36% (CS36), or 48% (CS48) of diet DM in corn grain diets.
[b] Measured after withholding feed and water for 18 hours.
[c] Calculated from carcass weight divided by .62.
[d] Linear effect ($P < .07$).
[e] Linear effect ($P < .05$).
[f] Kidney, pelvic, heart fat depot.

Conclusion

- While differences in corn silage hybrids are evident from the standpoint of morphology, nutrients, and *in vitro* digestibility, animal performance differences are more difficult to measure. In addition, inherent traits of these silages may be neutralized by environmental and management factors. Management factors such as whole plant maturity, kernel moisture, kernel size, silage particle size, and associative feed effects further influence animal response.

- The impact of high digestion rates (BMR and leafy hybrids), high oil, lysine or grain content on animal performance is tempered by a single agronomic trait—corn silage yield per acre. Thus, if choosing a specialty hybrid results in unchanged or positive animal performance, corn silage yield per acre may offset this response.

- The most important consideration in selecting a corn hybrid for use in animal diets is its overall economic gain to the dairy or beef enterprise. For a particular hybrid, it is important to consider its potential contribution to the diet whether this is increased oil, increased grain digestibility, or increased forage digestibility and what the cost (seed, agronomic practices, disease susceptibility, yield) and return relationship is.

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Notes

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A REVIEW ON SILAGE ADDITIVES AND ENZYMES

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INTRODUCTION

Fermentation in the silo can be a very uncontrolled process leading to less than optimal preservation of nutrients. Silage additives have been used to improve the ensiling process (better energy and DM recovery) with subsequent improvements in animal performance.

In order to understand how silage additives can help, one must first understand the ensiling process. Silage fermentation can be divided into 4 phases. The first phase is characterized by the presence of oxygen after forage is chopped and packed in the silo. Plant respiration continues for several hours (and perhaps days if silage is poorly packed) and plant enzymes (e.g., proteases) are active until oxygen is used up. During this phase, excess oxygen can lead to unwanted protein breakdown and excessive heating and growth of yeasts and molds that are undesirable. Oxygen can be eliminated by quick packing, even distribution of forage in the storage structure, chopping to a correct length and ensiling at recommended dry matters (DM) for specific storage structures. Oxygen must be eliminated before optimal fermentation can take place.

Under anaerobic conditions (lack of oxygen) the second phase of silage fermentation is dominated by microbial activity. Fermentation is controlled primarily by: a) type of micro- organisms that dominate the fermentation, b) available substrate (waster soluble carbohydrates) for microbial growth, and c) moisture content of the crop. During this phase, lactic acid producing bacteria (LAB) should utilize water soluble carbohydrates to produce lactic acid; the primary acid responsible for decreasing the pH in silage. Undesirable fermentations from microorganisms such as Enterobacteria and Clostridia can dominate if the pH does not drop rapidly. Where weather permits, wilting forage above 30-35% DM prior to ensiling can eliminate clostridia.

Lack of oxygen prevents the growth of yeast and molds and low pH prevents the growth of most bacteria during the third phase of fermentation. Silage can be kept for prolonged periods of time if these conditions prevail. The last, and fourth, stage of silage fermentation is during feed out and exposure to air. Good silage will remain stable and not change in composition or heat during the third and fourth stages of fermentation. Airtight silos and removal of sufficient silage during feed-out can prevent aerobic spoilage. Some good silage management practices are listed in Table 1.

The end products of silage fermentation are often monitored to assess silage quality and the composition of "normal silages" is presented in Table 2. Many commercial laboratories now offer analytical services for silage end products. Readers should be aware that numerous factors may affect silage composition.

Table 1. Some good silage management practices.

Silage Practice	Reasoning
Harvest crop at correct maturity and DM ♦ Corn silage: 1/2 to 2/3 milk line; 35% DM ♦ Alfalfa: < 1/10 bloom; bunk or bag silo - 35 to 45% DM, conventional upright 35 to 50% DM, oxygen limiting silo - 45 to 60% DM ♦ Grasses: boot; bunk or bag silo - 35 to 45% DM ♦ Small grains: boot to dough; 30 to 40% DM	• Optimizes nutritive value (protein, fiber, energy, etc.) • In some cases optimizes DM content • Ensures good packing, elimination of excess oxygen • Minimizes seepage losses • Prevents clostridial (butyric acid) fermentation
Chop material to correct length: about 3/8 to 1/2 inch	• Promotes good packing and elimination of oxygen • Promotes cud chewing by cow
Harvest, fill, and seal quickly	• Quick elimination of oxygen reduces DM losses from respiration and prevents growth of undesirable aerobic organisms • Sealing minimizes exposure to air • Pack to proper density to eliminate air
Wilt and chop during dry weather	• Prevents extensive DM losses from rained on forage • Promotes rapid drying
Check that all equipment is in good working order	• Sharpen knives • Be sure that silos are free from leaks • In upright silos, a good distributor helps to distribute and pack silage
Allow silage to ferment for at least 14 to 21 days	• Properly ensiled silage will minimize production losses during silage changeover

Table 2. Amounts of common fermentation end products in various silages.

Item	Alfalfa Silage, 30 - 35% DM	Alfalfa Silage, 45 - 55% DM	Grass Silage, 25 - 35% DM	Corn Silage, 35 - 40% DM	HM Corn,* 75% DM
PH	4.3 - 4.5	4.7 - 5.0	4.3 - 4.7	3.7 - 4.2	4.0 - 4.5
Lactic acid, %	7 - 8	2 - 4	6 - 10	4 - 7	0.5 - 2.0
Acetic acid, %	2 - 3	0.5 - 2.0	1 - 3	1 - 3	< 0.5
Propionic acid, %	< 0.5	< 0.1	< 0.1	< 0.1	< 0.1
Butyric acid, %	< 0.5	0	<0.5	0	0
Ethanol, %	0.5 - 1.0	0.5	0.5 - 1.0	1 - 3	0.2 - 2.0
Ammonia-N, % of CP	10 - 15	< 12	8 - 12	5 - 7	< 10

*High moisture.

SILAGE ADDITIVES

Silage fermentation is a dynamic process that is affected by variety of factors. Research on silage and silage additives has been conducted for many years. This review will focus on silage additives commonly used in North America. Readers are encouraged to further their knowledge on silage additives by reviewing the extensive body of journal articles on this subject. In addition, several excellent in-depth reviews are available on this subject (Bolsen, 1995; Muck and Kung, 1997; Kung and Muck, 1997).

Silage additives have been classified into various categories that generally include 1) stimulants of fermentation (microbial inoculants, enzymes, fermentable substrates), 2) inhibitors of fermentation (acids, other preservatives), and 3) nutrient additives (ammonia and urea).

In order for a silage additive to be useful it must increase DM (nutrient) recovery, improve animal performance (milk [quantity and/or composition], gain, body condition, reproduction), or 3) decrease heating and molding during storage and feed out. Changes in fermentation end products without quantifiable improvements in one or more of these categories is questionable.

STIMULANTS OF FERMENTATION

MICROBIAL INOCULATION. Organisms. Silage fermentation is highly dependent on the type of microorganisms that can dominate the process. Natural populations of lactic acid bacteria (LAB) on plant material are often low in number and heterofermentative (produce end products other than lactic acid). As shown in Table 3 homolactic fermentation is more desirable than other types of

fermentations because it results in a theoretical recovery of 100% for DM and 99% for energy in contrast to lower recoveries of DM and energy from other fermentations (note that certain types of heterolactic fermentation are also efficient). Thus, the concept of adding a microbial inoculant to silage was to add fast growing homofermentative lactic acid bacteria (^{ho}LAB) in order dominate the fermentation resulting in a higher quality silage.

Table 3. Predominant fermentation pathways in silage.

Type of fermentation	End-products	Theoretical DM recovery, %	Theoretical Energy recovery, %
homolactic (glucose)	lactic acid	100	99
heterolactic (glucose)	lactic acid, ethanol, CO_2	76	98
heterolactic (fructose)	lactic acid, acetate, mannitol, CO_2	95	99
yeast (glucose)	ethanol, CO_2	51	99
clostridia (glucose and lactate)	Butyric acid, CO_2	49	82

Some of the more common ^{ho}LAB used in silage inoculants include: *Lactobacillus plantarum, L. acidophilus, Pediococcus acidilactici, P. pentacaceus, and Enterococcus faecium.* Microbial inoculants contain one or more of these bacteria which have been selected for their ability to dominate the fermentation. The rationale for multiple organisms comes from potential synergistic actions. For example, growth rate is faster in *Streptococcus* > *Pediococcus* > *Lactobacillus*. Some *Pediococcus* strains are more tolerant of high DM conditions than are *Lactobacillus* and have a wider range of optimal temperature and pH for growth (they grow better in cool conditions found in late Fall and early Spring).

MICROBIAL INOCULATION. Fermentation and animal responses. Alfalfa, grass and small cereal grain crops have responded well to microbial inoculation. The fermentation of high moisture corn has also been improved with microbial inoculation. However, microbial inoculation has been less effective on corn silage. For example, I found 14 published (peer reviewed) studies in North America where corn silage was treated with a microbial inoculant, improvements in animal performance where found in only 3 instances and only minor changes in fermentation where found. However, Bolsen et al. (1992) reported that in 19 studies conducted at Kansas State University, with corn silage, inoculated silages had 1.3 percentage unit higher DM recovery, supported 1.8% more efficient gains, and produced 3.6 lb more gain per ton of crop ensiled with beef cattle. Similar results were found with treated sorghum silages. In certain instances, significant animal responses have been observed with inoculation although there was little effect on traditional end-products of fermentation (Gordon, 1989; Kung et al., 1993). These data would suggest that there may be unidentified components in inoculated silages that are responsible for improved animal performance.

When compared to untreated silages, silages treated with adequate numbers of a viable ^{ho}LAB should be lower in pH, acetic acid, butyric acid and ammonia-N but higher in lactic acid content. In a

review of the literature between 1990-95, Muck and Kung (1997) reported that microbial inoculation lowered pH, improved the lactic:acetic ratio, and lowered ammonia nitrogen content in more than 60% of studies. Dry matter recovery was improved by more than 35% and bunk life improved in about 30% of the studies. Dry matter digestibility was also improved in about one third of the cases. Microbial inoculation usually has little or no effect on the fiber content of silages because most lactic acid bacteria contain little or no ability to degrade plant cell walls. Decreases in fiber content may be due to partial acid hydrolysis of hemicellulose. Some data suggests that certain microbial inoculants can increase fiber digestion (Rice et al., 1990). Bunk life or aerobic stability has not been consistently improved by inoculation and in some instance inoculation has made aerobic stability worse. This is probably due to a lower acetic acid content.

Relative to animal responses Kung and Muck (1997) reported positive responses to microbial inoculants on intake, gain, and milk production (Table 4). The average response in milk production was a +3.1 lb per day in studies where milk production was statistically improved.

Table 4. A summary of animal responses to microbial inoculants between 1990 and 1995.

Type of Study	Intake	Gain	Milk Production
Number of Studies	67	15	36
Studies with Positive Responses	28%	53%	47%

(Kung and Muck[26])

Although literature summaries are encouraging, caution should be used when interpreting such data because all inoculants are not equal and the conditions (e.g. rate of application, inoculant viability, species of bacteria, crop, moisture levels) varied markedly among the studies. As many have pointed out in the past, products with organisms with the same name are not necessarily the same organism and may not have the same effectiveness (Dennis, 1992). For example, Rooke and Kafilzadeh (1994) reported that various strains of ^{ho}LAB improved silage fermentation but animal performance was improved by only 1 strain of organism. An impressive number of animal experiments has been conducted using a single silage inoculant containing *Lactobacillus plantarum* MTD1. A summary of 14 lactation studies (Moran and Owen, 1994) conducted in University and government research institutes in North America and Europe using MTD1 is shown in Table 5. Statistical analyses revealed that DM intake was numerically increased by 4.8% and that milk production was significantly increased by 4.6%. Improvements in milk yield were obtained with a variety of crops (grass, corn, alfalfa) across a wide spectrum of DM contents (15 to 46% DM). Body weight gain also tended to be better in cows fed silage treated with MTD1. Similarly, 19 comparisons among untreated silages and silages treated with MTD1 were summarized by Moran and Owen (1995) for beef cattle. Across all studies and types of forage, cattle fed inoculated silage ate 7.5% more DM and gained 11.1% more weight.

Table 5. The effect of feeding silage inoculated with MTD1 from 14 studies on silage DM intake and milk yield from lactating cows.

	Silage DM intake (lb/d) CONTROL	Silage DM intake (lb/d) MTD1	Milk yield (lb/d) CONTROL	Milk yield (lb/d) MTD1
Average	23.1	24.2	57.2	59.8
Difference		+ 4.8%		+ 4.6%

(Moran and Owen, 1995)

Unfortunately, there is no good way to predict the effectiveness of microbial inoculants. A model developed by Pitt (1990) suggested that inoculants would be most effective on alfalfa during cool conditions of first, third and fourth cuttings. However, there are numerous products that have little or no research to support claims of improved fermentation or animal performance. Another factor which complicates the evaluating process is that the majority of bacterial inoculants are repackaged for distribution under private label and numbers of bacteria may be low and/or other additives (e.g., enzymes, fermentation extracts, minerals) are included in the formulations.

MICROBIAL INOCULATION. Inoculation rate, use, and storage. The organism(s) from microbial inoculants must be present in sufficient numbers to effectively dominate the fermentation. Thus the most commonly recommended inoculation rate supplies 100,000 (or 1×10^5) organisms per gm of wet forage. There is little evidence that suggests that doubling or tripling this amount (e.g. 200-300,000 cfu) is beneficial. Additions of 1,000,000 cfu per gm of wet forage are probably not cost effective in North America.

Most microbial inoculants are available in powder or granular form. Inoculants applied in the dry form are often mixed with calcium carbonate (limestone), dried skim milk, sucrose or other carriers. These products can be applied by hand or by solid metering devices as per manufacturer's recommendations. Inoculants to be applied in the liquid form come as dried powders and are mixed with water just prior to use. (Use of chlorinated water may be detrimental to the inoculant.) Application can be with a simple watering can by weighing the incoming forage load and adjusting application based on the average unloading time. A better method is to use a metered liquid sprayer to evenly disperse the inoculant on the forage. Unused liquids should be discarded after a period of 24 to 48 h because bacterial numbers begin to decline.

Microbial inoculants can be applied to the forage at a variety of locations. However, application to forage at the chopper is highly recommended in order to maximize the time that microorganisms have in contact with fermentable substrates. Inoculants can also be applied at the blower of an upright silo or sprinkled over the forage mass between loads in a bunk silo. Proper distribution cannot be overlooked and is important for the inoculant to be effective. Throwing a can of dry inoculant in a wagon load of forage and hoping for even distribution is not an acceptable practice!

Theoretically, when inoculants are applied in the dry or liquid form to forage wilted to about 30 to 50% DM, efficacy of the same product should be equal, but there is little published data to support this contention. However, when moisture limits microbial activity (> 50% DM), inoculants

applied in a liquid may be more advantageous since bacteria are added with their own moisture to help speed up fermentation.

Storage is an important aspect of a high quality inoculant that contains live microorganisms. Inoculants should be kept in cool dry areas away from direct sunlight. Moisture, oxygen and sunlight will decrease stability of inoculants. Opened bags of inoculants should be used as soon as possible.

MICROBIAL INOCULATION. Miscellaneous organisms. Several microorganisms that are not ^{ho}LAB have been used as silage inoculants specifically for the purpose of improving aerobic stability. For example, the *Propionibacteria* are able to convert lactic acid and glucose to acetic and propionic acids that are more antifungal than lactic acid. Florez-Galaraza et al. (1985) reported that addition of *P. shermanii* prevented the growth of molds and markedly reduced the initial population of yeast in high moisture corn where the final pH was greater than 4.5. Dawson (1994) reported similar findings in high moisture corn. Weinberg et al. (1995)saw little benefit from adding *Propionibacteria* to pearl millet and corn silage (final pH < 4.0) but reported improvements in the aerobic stability of wheat silage when the decline in pH was slow. Similarly, in 3 studies using laboratory silos, we (Kung et al., unpublished data) did not observed beneficial effects of *Propionibacteria* in corn silage (final pH 3.6 to 3.8). However, Bolsen et al. (1996) reported more propionic acid, lower yeasts and molds, and greater aerobic stability in corn silage (pH of 3.6) treated with *Propionibacteria*. Some concerns relative to the use of *Propionibacteria* that have not been adequately addressed are the loss of DM (from CO_2 production) and the fact that *Propionibacteria* have proteolytic activity. In general *Propionibacteria* have been effective in situations where the decline in pH is slow and (or) when the final pH of silage has been relatively high (> 4.2 to 4.5).

Recently, *Lactobacillus buchneri,* a heterolactic bacteria capable of producing lactic and acetic acid, has been included as an inoculant for improving the aerobic stability of silages. Muck (1996) reported that corn silage treated with *L. buchneri* TY16 had greater acetic acid content and was more stable when exposed to air than untreated corn silage. In Europe, Driehuis et al. (1996) reported that increasing doses of *L. buchneri* from 10^3 to 10^6 cfu/g in laboratory silos decreased the lactic acid content but increase the acetic acid content in corn silage. Aerobic stability was markedly enhanced and improved with increasing inoculation rate. More positive data on non-homolactic acid fermenting is needed before their use becomes widespread.

ENZYME ADDITIVES. General description. Enzymes are proteins that assist in metabolic processes. A variety of enzymes, particularly those that digest plant fiber and starch have used as silages additives (Table 6). To date, we can find no evidence that would promote the use of protease enzymes as silage additives since they would most likely increase the concentration of rumen degradable protein in silage (an undesirable result). Silage additives may contain single enzyme complexes, combinations of enzyme complexes and combinations of enzyme complexes and LAB. Plant fiber-digesting enzymes (cellulases and hemicellulases) are the most widely used enzyme additives and will be the focus of the remainder of this discussion.

There are two primary reasons for adding fiber-digesting enzymes to silage. First these enzymes could partially digest the plant cell walls (cellulose and hemicellulose) yielding soluble sugars which could be fermented by LAB to lower the silage pH. This would stimulate silage fermentation and improve fermentation quality by increasing the rate and extent of decline in pH, increasing the concentration of lactic acid, improving the lactic acid:acetic acid ratio (which is indicative of greater efficiency of fermentation), and hence reduce DM losses. A faster decline in pH would also limit degradation and deamination of forage proteins and reduce ammonia production. Second, partial digestion of the plant cell wall may improve the rate and/or extent of digestibility. In order for the first event to take place the rate of cellulose hydrolysis must coincide with early growth

of lactic acid bacteria. For an improvement in digestibility, a change in the association of cell wall components must occur. (Amylase enzymes may provide substrates for LAB by partially digesting starch but would not degrade fiber.)

Table 6. Enzymes used as silage additives.

Enzyme complex	Target substrate	End-products
Cellulase	Cellulose	Glucose, maltose, limit dextrins
Hemicellulase (xylanase)	Hemicellulose	Xylose, xylans, arabinose
Amylase	Starch	Glucose, maltose

ENZYME ADDITIVES. Effects on silage fermentation and animal production. Fiber-digesting enzymes have been most effective in reducing the fiber content of grass and alfalfa crops ensiled in the 60 to 70% moisture range (Muck and Kung, 1997) the effect being greatest in grasses. Improvements in silage fermentation and decreases in fiber content appear more pronounced in immature grasses than mature grasses where hydrolysis of the cell wall would be more difficult due to increased lignification. Enzymes have improved fermentation by stimulating acid production, lowering pH, and lowering ammonia N. Results of enzymes on DM or fiber digestion have been more negative than positive. A possible reason for this is that fiber-degrading enzymes predigest the readily digestible fiber leaving a slower and less degradable fraction.

In a summary of animal responses between 1990-95, Kung and Muck (1997) found that positive responses in intake, gain and milk production were less for silages treated with enzymes (Table 7) than with microbial inoculants.

Table 7. A summary of animal responses to enzyme-treatment between 1990 and 1995.

Type of Study	Intake	Gain	Milk Production
Number of studies	29	10	12
Studies with positive responses	28%	40%	33%

(Kung and Muck[26])

There are many variables that may affect the efficacy of fiber-degrading enzymes. Just as bacterial inoculants require certain conditions for growth, enzymes require certain conditions for maximum activity. Most cellulase enzymes require a pH of 4.5 and temperature of 50°C for optimal

activity. Surface area, binding sites, moisture level and plant proteases may also inhibit enzyme activity. We also do not know the optimum mixture of enzymes that will improve silage fermentation. For example, 'cellulase' enzymes are a complex of various endo- and exo-beta-glucanases, cellobiohydrolase, and cellobiase. Complete breakdown of insoluble cellulose to glucose requires synergistic action between the enzymes. Furthermore, there is no universally accepted method for measuring enzyme activity. In the case of cellulases, activity is often expressed as the ability of the enzyme preparation to degrade filter paper cellulose under defined conditions that are not equivalent to conditions that are present in the silo. In many silage additives the quantity of enzymes is so small that one must question whether these enzymes have any positive effect on fermentation and animal performance and there is little published evidence that support additive effects from many of these products.

ENZYME ADDITIVES. Enzymes as feed additives. Recently, there has been increased research into treating diets for ruminants with plant cell-wall degrading enzymes just prior to feeding and an excellent review on this topic was recently published by Treacher and Hunt (1996). Silage fermentation is not affected but this method of treatment can improve the nutritive value of silage and thus a brief discussion is warranted. This approach offers exciting possibilities for using enzymes to improve nutrient digestion, utilization, and animal productivity and at the same time reduce animal fecal material and pollution. Spraying enzymes onto forages just before feeding provides increased management flexibility for feeding and also bypasses any negative interactions that the ensiling process may have on silage enzyme performance. When enzymes are sprayed onto silage before feeding, binding with substrates may help to protect these exogenous enzymes from ruminal degradation. Treating forages with enzymes in this manner may improve digestibility via a number of different mechanisms that including, direct hydrolysis, improvements in palatability, changes in gut viscosity, and changes in the site of digestion.

Spraying enzymes on the silage has increased the release of residual sugars and rate of NDF digestion. A mixture of fiber degrading enzymes sprayed onto the forage portion of a total mixed ration resulted in cows consuming 4 lb more DM per day and producing 2.8 lb more milk per day (stokes and Zheng, 1995). Maine researchers reported that dry matter intake increased by 10.7% and milk yield by 14.7% in one study (Stokes, 1992). However, Zheng and Stokes (1997) reported that the growth of Holstein heifers was not improved by application of fiber-degrading enzymes to the silage of a total mixed ration immediately before feeding. Sanchez et al. (1996) reported marked improvements in milk production when an alfalfa hay, alfalfa silage, and cottonseed mix was sprayed with a moderate but not with a lower or higher amount of fiber degrading enzymes. Positive responses to treating the forage portion (primarily corn silage) of a TMR with enzymes in 3 consecutive years have also been observed (Kung et al. 1997, unpublished data).

MOLASSES. Molasses has been used as a fermentation stimulant for many years and recently there has been a renewed interest in its use. Molasses is a by-product of the sugar-cane and sugar-beet industries and contains 79% soluble carbohydrates; 45 to 50%, of which sucrose is the main component. Molasses provides a relatively cheap source of fermentable carbohydrate for lactic acid bacteria and has been applied at a rate of 40-80 lb per ton of fresh forage.

Molasses in numerous silage experiments has been proven to be an effective silage additive in terms of promoting lactic fermentation, reducing silage pH, discouraging a clostridial fermentation and proteolysis, and generally decreasing organic matter losses. It is of particular benefit when applied to forage crops low in fermentable carbohydrates for lactobacilli. Recently, Keady (1996) reviewed the published literature on molasses as silage additives and concluded that molasses treatment improved silage preservation, but did not significantly alter the silage digestibility or animal performance although silage DM intake was improved.

INHIBITORS OF FERMENTATION

PROPIONIC ACID. Of the short-chain fatty acids, propionic acid has the greatest antimycotic activity. It is effective in reducing yeast and molds which are responsible for aerobic deterioration in silages. The antimycotic effect of propionic acid is enhanced as pH declines, making it an ideal candidate for improving the aerobic stability of corn silage where pH is low. In the past, aerobic stability was improved when large amounts of propionic acid (1 to 2% of the DM) were added to silage, but the high percentage of acid often restricted fermentation in these cases. The application rate of propionic acid additives has varied depending on moisture content of the forage, length of storage[13] and formulation with other preservatives. For example, for high moisture corn with a moisture content of 20% the application rate should be 0.1 and 0.5% for storage of 1 and 6 months, respectively, while it should be increased to 0.8 and 1.1% for 30% moisture of silage for the corresponding lengths of storage. Application rates of 1.5 to 2.0% for haylage and 2.0 to 2.5% for haylage with less than 30% of DM have been suggested. For corn silage, propionic acid at usage rates of 0.2 to 0.5% have been shown to be effective (Beck, 1975). Many current products that are added to forages at ensiling for the purpose of improving aerobic stability contain several ingredients including benzoic acid, sorbic acid, and citric acid; however, propionic acid usually constitutes the greatest percentage of the active ingredients. Recommended application rates of these products are relatively low (2-4 lb/ton of fresh forage). Such low application rates usually do not affect silage fermentation but reduce the numbers of spoilage yeasts and improve aerobic stability (Table 8). In addition, several products have been designed to be added to silages or TMR just prior to feeding to prevent heating and spoiling in the feed bunk. However, research from our lab and others suggests that controlling yeasts at the time of ensiling is more efficient than trying to control their numbers and metabolism in the feed bunk.

Table 8. Effect of a propionic acid-based additive on the number of yeasts and hours of aerobic stability of corn silage.

Treatment*, application rate	Yeast in silage, Number per gram	Aerobic stability, ** hours
Control	257,000	65
Product A, 2 lb/ton	27,000	120
Product A, 4 lb/ton	2,800	>160

*Product A contained buffered propionic acid (primary active ingredient) and other active ingredients.
**Hours before the temperature of the silage rose more than 2^0C.
Kung et al. 1998. (University of Delaware).

Propionic acid is difficult to handle because it is corrosive. Thus, the acid salts, e.g., calcium, sodium and ammonium propionate have been used in some commercial products. The efficacy of propionic acid and its salts is closely related to their solubility in water. The stronger the bond is between the acid-base, the less soluble the product is and thereby less effective in inhibiting fungi. Among these salts, ammonium propionate is most soluble in water (90%), followed by sodium propionate (25%) and calcium propionate (5%).

NUTRIENT ADDITIVES

AMMONIA and UREA. General description and effects. Anhydrous ammonia or water- or molasses-ammonia mixes have been used as silage additives. Ammonia additions have resulted in a) addition of an economical source of crude protein (Huber et al., 1979); b) prolonged bunk life during feeding (aerobic stability, Britt and Huber, 1975); c) less molding and heating during ensiling; and d) decreased protein degradation in the silo (Johnson et al., 1982). Urea has been added to corn silage as an economical source of crude protein. However, a beneficial effect of urea on improved bunk life and decrease in proteolysis has not been totally substantiated. Whenever ammonia or urea is added to the diet, special attention should be made to ensure that degradable and undegradable protein requirements are balance for the target ruminant animal.

Ammonia has been used to treat corn silage, small cereal grain silage and high moisture corn with varying degrees of success. Although some have used ammonia on alfalfa silage, this practice is not recommended (Kung et al., 1989). Addition of anhydrous ammonia or water-ammonia mixes initially buffers the plant material. For example, corn forage may have a pH of 5.9 but treated corn forage will have a pH of about 8.5 to 9.0. When fermentation in the silo is complete, corn silage treated with anhydrous ammonia usually is .1-.2 units higher in pH, contains .5-1.5% (DMB) more lactic acid, .5-1.5% more acetic acid, and less residual water soluble carbohydrates. Forages treated with ammonia have also been shown to be higher in insoluble N and true protein (Buchanan-Smith, 1982) primarily because ammonia reduces plant proteolysis. Although fermentation is generally stimulated by ammonia, the ensiling processes is prolonged because of ammonia buffering effect resulting in greater total acid production and inconsistent effects on DM recovery. Bolsen et al. (1992) reported that use of anhydrous ammonia had adverse effects on DM recovery, particularly in high moisture sorghum silage.

AMMONIA and UREA. Application to forage. Ammonia can be added at the chopper, blower, bagger or bunk. Mixed ammonia solutions are bulkier than anhydrous ammonia but retention of ammonia is usually greater. In addition, molasses (to improve palatability and fermentation) and minerals can be added in these solutions. Some ammonia will be lost (between 10 and 30%) and losses will be greater if ammonia is not applied properly and if forage becomes too dry. Ammonia should be applied to the forage before it contacts the blower to minimize losses. Ammonia should be added at the end nearest the cutter in a chopper with an auger system. If no auger is used, ammonia can be added behind the cutter prior to entering the blower. Ammonia can also be spiked into bunks between loads and it will disperse into the mass. Application of anhydrous ammonia should be at approximately 6 to 7 lb of N per 700 lb of forage DM (Table 9). This will increase crude protein from about 8 to 12.5% on a dry matter basis. Excess ammonia (12-15 lb per ton) may result in poor fermentation (because of a prolonged buffering effect) and animal performance. Using the Cold-flo method is the simplest way to add ammonia to silage. Gaseous ammonia is super cooled in a converter box and about 80-85% becomes liquid.

Table 9. Addition of ammonia and urea to corn silage.

	Anhydrous Ammonia	Ammonia-molasses mixes	Urea
Nitrogen, %	82	20-23[a]	46
CP equivalent, %	515	125[a]	282
Application, lb/ton of 35% DM forage[c]	7	± 25[a]	10-12[b]

[a]Varies based on specific product.

[b]Do not add urea to forage over 45% DM.

[c]Application rate should vary depending on forage DM. Higher amounts should be applied to drier forage. In all cases, the desired application rate is 5-6 lb of N per 700 lb of forage DM. i.e. 5-6 lb/ton at 35% DM; 4.3 to 5.1 lb/ton at 30% DM; 5.7-6.9 lb/ton at 40% DM.

Anhydrous ammonia should not be added to corn forage if the DM content is above 40-42% because fermentation is restricted in drier material and binding of ammonia will be less; thus normal fermentation may be disrupted. In instances where forage DM is above 40-42%, water-ammonia mixes or molasses-ammonia mixes should be used. Application for molasses-ammonia mixes should be as recommended by the manufacturer.

Ammonia is a hazardous gas and should be handled with care. Eye protection should be worn when making connections to pressurized tanks. Water should be available at all times. Ammonia is also corrosive to zinc, copper and brass. Therefore storage of ammonia-treated forage in zinc coated steel silos is not recommended.

Problems with hyper-irritability (bovine bonkers syndrome) in cattle fed ammoniated forages has not been observed in cattle fed ammoniated corn forages. Addition of ammonia to corn silage has no effect on nitrate levels in corn silage (Li et al., 1992)

CONCLUSIONS

Silage additives can be useful tools to improve silage quality and animal performance, however, they are not replacements for good management practices. Care should be taken when choosing a silage additive. Users should ask for proof of claims that are usually in the form of published scientific articles that have undergone peer review.

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Notes

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FEEDING PROGRAMS FOR THE SPECIALIZED HEIFER AND CALF RAISER

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Specialization is a key word describing the dairy industry. Herd size has increased, while number of herds has dropped rapidly in some parts of the country. One of the more popular changes observed has been the growth in the number of farms growing dairy heifer replacements as their primary source of income. In January of 1996, a heifer management conference was conducted under the auspices of the Northeast Regional Agricultural Engineering Service (NRAES) in Harrisburg, PA. After the conference several "growers" and university faculty with interests in dairy heifer management met to begin the process of establishing a Professional Dairy Heifer Growers Association (PDHGA). Their first conference was held in Atlanta in 1997 followed by Reno in 1998 with a third meeting scheduled for Minneapolis in March of 1999. From a humble beginning of 6 growers in Harrisburg to over 200 in Reno last year, this association is on course for continued growth.

What has lead to the development of the heifer grower industry? First, the dairy heifer enterprise has suffered from poor management as indicated by average ages of first calving exceeding 26 months with body weights less than desired on the majority of dairies in the U.S. Progressive, management-oriented entrepreneurs saw the opportunity to meet a need in the dairy industry and make a profit.

If heifer growers are to establish a successful enterprise they must add value to the heifer for the owner. Custom reared - Holstein heifers should calve at less than 24 months of age weighing near 1250 lb. after calving, a body condition score of 3.5 and be free of disease. Clients of these growers should accept no less. Financial success for both parties is achieved when these goals are met at low cost. Published estimates of rearing costs range from a low of $550 per heifer to $1,325 (Bolton, 1992; Miller and Amos, 1986; Randle et al., 1998). Typical rearing costs are shown in Table 1. Although total costs differ across different regions on the U.S. the relative proportions within each category remain similar.

Table 1. Typical Breakdown of Heifer Expenses from Birth to Calving. (Cady and Smith, 1996).

Item	Cost ($)	% of Total
Feed	678	54.6
Labor	156	12.6
Vet & Medicine	46	3.7
Breeding, bedding, supplies	71	5.7
Interest on investment (10.5%)	107	8.7
Initial value of heifer	100	8.0
Death loss (12.5%)	44	3.5
Ownership cost - buildings, equipment, taxes...	39	3.2
Total	1,241	100

Note that feed comprises over 54% of this budget with estimates as high as 70% of the total costs in some budgets. Therefore, profitable heifer rearing enterprises must concentrate on economical feeding programs. Labor is the second highest category and comprises 10 to 20% of total rearing costs in most estimates.

The purpose of this presentation is not to provide a "how to" description of heifer feeding programs because available feed resources and facilities vary so much across the U.S. This presentation will focus on a discussion of decision-making areas with considerable importance to the financial success of the heifer-feeding program. Managing the feeding program of the heifer enterprise is not unlike that of any other decision made on the farm. Good heifer managers maximize benefits, control expenses and manage risk well. The owner is most concerned with receiving the benefit of a well-grown heifer. The grower is interested in achieving this benefit at the lowest cost.

FOCUS AREAS FOR CALF FEEDING PROGRAM MANAGEMENT.

The primary goal during the pre-weaning period is to minimize mortality and encourage early weaning. Mortality represents the costs of the lost animals and the investment in rearing expenses up to the point where the animal died. These costs must be born by surviving heifers. Factors with considerable influence on profit during this phase are success of colostrum absorption, selection of liquid feeds, age at weaning and transition management.

Colostrum absorption - Since the calf obtains no immunity from the dam in utero, it must be obtained by absorption of immunoglobulins from colostrum. Fowler et al. (1998) found higher mortality and scouring in calves with serum Ig values less than 15 mg/ml. Results from the National Dairy Heifer Evaluation Project (1993) suggested 10 mg/ml as the lower limit. Primary factors influencing passive immunity transfer are age at first colostrum feeding, calving environment, and amount and quality of colostrum fed. None of these factors involve a high degree of technology, but each is very important to assuring passive transfer of immunity.

Timing of colostrum feeding is important for two reasons. First, the cells lining the intestine of the newborn are able to absorb whole proteins without digesting them. This ability declines rapidly after birth due to a change or maturation of these cells and to the development of digestive enzymes, which degrade these immune proteins. Under nearly ideal conditions the intestinal cells fail to absorb colostrum immunoglobulins (Ig) beyond 24 hours of age. The second reason for cessation of absorption of Ig may be

related to colonization of the intestinal tract by bacteria. Extent and rate of intestinal colonization is heavily dependent on the environment. Research at Virginia Tech (James et al., 1981) showed that large populations of intestinal bacteria early in life were associated with lower Ig absorption. Depression of Ig absorption may be due alteration of the absorptive surface from excessive microbial growth. Calves born in dirty, poorly ventilated box stalls are likely to experience more rapid colonization of the intestinal tract and decreased Ig absorption. In such cases, Ig absorption may be greatly diminished by 2 - 3 hours of life and near zero by 6 hours. The ideal situation is for the cow to give birth in a clean, well-drained grassy pasture. The best advice is to feed colostrum as soon as possible, but definitely within 6 hours of birth.

Only first milking colostrum should be used to feed the newborn calf, as it is highest in Ig content. Immunoglobulin content of colostrum increases with lactation number of the dam up to the 4th or 5th lactation after which there is no further improvement. Supplies of frozen colostrum should be maintained for use when fresh colostrum is not available. Thawing in warm, not hot water or less aggressive means of microwaving minimizes potential damage to the structure of Ig's. Recent research by Quigley et al (1998) suggests that freezing does not impair the ability of colostrum to provide adequate levels of protection for the neonate.

In most cases, colostrum substitutes won't confer the level of protection that maternal colostrum does. First, maternal colostrum provides IgG's to pathogens unique to the dam's environment. Second, absorption of maternal colostrum IgG's is usually better, although promising results have been observed in some bovine serum derived Ig supplements (Arthington et al., 1998).

Unfortunately colostrum management is beyond the control of many calf growers as they commonly receive calves during the first week, after Ig absorption has already ceased. Recognizing the importance of colostrum management to their success, many growers measure serum Ig levels prior to entry into the calf growing facility.

Choice of Liquid Feeds - The calf grower is faced with a challenging, but very important decision in selecting which feeds for the pre-weaned calf. The goal is to achieve adequate gains (.5 to 1.5 lb.) at the lowest possible cost and mortality. Choices are whole milk, waste milk, surplus colostrum or milk replacer. Whole milk provides the least risk but at the greatest expense. At prevailing milk prices ($15/cwt.) and 6 wk weaning, each calf would consume $63 worth of milk. Most calves in the U.S. are fed milk replacers owing to the advantage of lower cost (NAHMS, 1993). Quality varies widely as does price ($.65 to $.90/lb). Assuming the highest cost milk replacer is fed, a calf weaned at 6 weeks of age would consume $57 worth of replacer. This represents a feed cost savings of $6/calf. It is difficult to determine quality by examining the tag attached to the bag of replacer. Protein source and level, energy content and medication can classify milk replacers. Replacers should contain 18 to 22% CP on a powder basis. Recommended sources of protein include: dried whey protein concentrate, dried skim milk, casein, dried whey, dried whey product, soy protein isolate, protein modified soy flour and soy protein concentrate. Savings in ingredient costs are obtained by substituting plant proteins for milk proteins. Owing to their high cost, skim milk and casein are uncommon ingredients of replacers. Avoid replacers containing soy flour, meat solubles, fish protein concentrate and wheat flour due to poor digestibility. Fat from animal sources should comprise 10 to 20% of milk replacers. During cold weather the higher fat content is preferred to aid in maintaining body temperature. Higher fat replacers are not necessary during warm weather and may delay consumption of dry feeds and weaning. A tremendous opportunity exists for reducing liquid feed costs by feeding unsalable waste milk. It has no value to the

dairy and can be a source of high quality nutrients. However, the risk lies in the microbial and viral load found in waste milk. Researchers in California (Selim and Cullor, 1997) found significant levels of Strep, Staph, Enterobacter, E. coli and occasionally viruses such as BVD in samples of waste milk. In addition to the initial levels of bacteria found in waste milk, inadequate refrigeration prior to feeding can result in explosive growth of bacteria to unhealthy levels for the young calf. Antibiotic residues can also be a concern in milk obtained from the first two milkings after treatment. Growers must ask if the risks of higher microbial loads and antibiotic residues offset the savings from feeding waste milk? Another source of nutrients for the milk-fed calf is from the use of outdated whole, 2%, skim, and buttermilk recovered as it is returned to the milk processing plant. If the product is handled in clean equipment, microbial loads are low and product quality high. One grower of 2,000 calves in the south has used this as the primary liquid for several years.

Even greater opportunities for savings arise from early weaning programs. Most surveys of dairy producers have shown that average at weaning is 8 weeks (NAHMS, 1993), with many producers not weaning calves until 10 to 12 weeks of age. Prolonged milk feeding offers the benefit of enhanced gains. However, controlled studies have shown that these benefits are short-lived with most early-weaned calves catching up by 4 months of age. The down side of prolonged milk feeding is the higher cost of milk-based solids and greater labor required. Early weaning programs can result in 25 to 50% savings in feed costs. Early weaning is encouraged by offering water during the first week of life and palatable calf starter grain with the following nutrient specifications (NRC, 1989)

Nutrient	Amount Recommended
Crude protein (% of DM)	18.0
Fat (% of DM)	3.0
TDN (% of DM)	80
Metabolizable Energy (Mcal/lb. of DM	1.41
Calcium (% of DM)	.60
Phosphorus (% of DM)	.40
Vitamin A (IU/lb.)	1,000
Vitamin D (IU/lb.)	140
Vitamin E (IU/lb.)	11

FOCUS AREAS FOR HEIFER FEEDING MANAGEMENT

The goal for the post-weaning phase is to rear heifers sufficiently to enable breeding at 12 to 14 months of age and calve by 22 to 24 months of age. Studies of existing DHI records (Keown and Everette, 1986; Bethard, 1998) have shown optimal production and lifetime profit (Gill and Allaire, 1976) of Holsteins calving at these ages weighing 1200 to 1300 lb. after calving. Assuming a 100-lb. birth weight this requires modest average daily gains of approximately 1.8 lb. Such growth rates are readily achieved with average quality forages, byproducts and concentrates.

Control of feed cost is achieved through early calving and low ingredient cost. Van Amburgh (Feedstuffs, 1998) demonstrated the influence of age at calving on return to feeding using the Cornell Cattle System program in Holstein heifers calving at 21, 24 or 27 months as shown in the Table below. This simulation shows conclusively the benefits of early calving. However, it is not without risks. Research in Denmark and the U.S. summarized by Akers and Sejrsen (1996) has shown evidence of impairment of mammary development in prepubertal heifers gaining in excess of 2.0 lb./ day during the prepubertal period. Heinrichs (1998) found that pre-pubertal heifers gaining in excess of 2.2 lb. per day produced less milk during the first lactation than those gaining 1.5 lb. per day. Van Amburgh made a similar observation, but attributed depressed production to lower body weight of heifers raised at an accelerated rate during the prepubertal period. The research on the influence of prepubertal weight gain on mammary development is inconclusive. A review of literature by VandeHarr (1997) attributes a possible impairment of mammary development to narrow protein - to - energy ratios of prepubertal heifer diets. He implies that increasing protein in the diet of rapidly reared heifers may reduce these risks. This area of nutrition offers promise as Heinrichs and Lammer (1998) observed improved gains, wither height and feed efficiency in 440 lb. heifers fed diets with levels of crude protein above NRC recommendations.

Table 2. Predicted profitability of calving heifers at three ages, 21, 24 and 27 months, net return, to feeding represents the difference in value of the combinations of feeds used to predict growth and differences in overhead costs.

Age at 1st calving (months)	21	24	27
Start weight (lb.)	180	180	180
ADG weaning to breeding ,lb./day	2.2	1.7	1.4
Weight at confirmed pregnancy	800	800	800
Overall ADG, lb./day	2.1	1.87	1.67
Pre-calving weight, lb.	1,373	1,385	1,393
Days on feed	562	663	745
Feed costs/head, $	504	539	604
Total costs/head, $	1,043	1,134	1,260
Feed costs/lb. of gain	0.42	0.44	0.48
Total cost/lb. of gain	0.72	0.79	0.87
Net return to feeding, $/head	124	53	-74

Assumes weight loss at calving is approximately 130 - 140 lb., which represents a post calving body weight of 1,230 to 1, 250 lbs. ADG includes the weight of pregnancy and includes an average gain of 1.5 lb./day for fetal and uterine tissue development during the last trimester of pregnancy.

Several other concerns arise with the heifer reared to gain in excess of 2.0 lb. per day. Van Amburgh et al. (1998) and Bethard et al. (1997) observed that heifers fed for rapid gains during the pre-pubertal period had higher body condition scores than those fed for more moderate gains throughout the rearing period. After calving, body weight losses were greater. Possibly, enhanced protein nutrition of the rapidly reared heifer will alleviate this problem.

Considerable research has been conducted on the influence of rumen undegradable protein sources on heifer performance. Several studies conducted at Va. Tech with 400 to 800 lb. Holstein heifers showed improved feed efficiency when supplemental sources of rumen undegradable protein were included in the diet. However, in most cases the improvement in feed efficiency was not enough to offset added ingredient costs. Van Amburgh et al. (1998) failed to observe an economical response to rumen undegradable protein supplementation in heifers raised at three rates of daily gain from 1.3 to 2.2 lb.

A unanimous finding in rapidly reared heifers relates to the importance of reproductive management. If conception is delayed, considerable problems have been encountered in achieving pregnancy in younger, larger heifers.

The agreement for 1st calving by 24 months is almost unanimous. In most cases, many Holsteins and Jersey heifers are able to calve by 22 months. However, as herd average ages at first calving decline below 22 months for Holsteins, problems with dystocia and premature culling increase thereby increasing risks in all but the best managed heifer-rearing programs.
Rapid rates of gain (> 2.0 lb. / day) have involved feeding of higher quality forages and additional concentrate ingredients. A budget (Radcliff et al, 1998) to feed 300 lb. heifers at a high rate of gain estimated feed costs at over $1.00/day using considerable quantities of grain and high quality forage. This was justified by reduction in length of the rearing period.

However, another method of reducing rearing costs preferred by many growers is to utilized ingredients providing nutrients at the lowest possible costs. This strategy requires the grower to "think outside the box" when it comes to selecting ration components. Rations presented are based upon those used by several large growers in Colorado and Texas and rations used in heifer feeding trials at Virginia Tech.

Table 3. Example rations for growing a 500-lb. heifer at an average daily gain of 1.8 lb./day.

Ingredient	Lb.- DM	CP	RUP[1]	TDN	ME	NDF	$/day
Ration I	13.22	11.2%	45.4%	67%	1.0 Mcal/lb.	46%	.443
Gr. Wheat Straw -3.2 lb., Wet Brewers Grain - 6.4 lb., Carrots – 4 lb., Wet beet pulp – 4.0, Corn Screenings – 2.4 lb., Alfalfa Silage - 8 lb. - Included Rumensin							
Ration II	12.85	17.24%	29.35%	.76	1.18	35.91	$.635
Cotton Gin Trash – 1.6 lb., Rolled Corn – 2.8 lb., Distillers grains – 1 lb., Whole cottonseed - .8 lb., Alfalfa hay – 2.2 lb., Wheat Midds – 3.6 lb., Cottonseed meal - .8 lb., Sorghum Silage – 2.8 lb., Waste dairy products – 4.0 lb.							
Ration III	13.58	12.00	33.9	71	1.11	41.3	$.63
Corn silage – 15 lb., Soybean meal – 1.0 lb., Gr. Shelled corn – 3.5 lb., Orchardgrass hay – 5.0 lb.							

All rations fed as total mixed rations for ad libitum intake with prevailing feed prices as of August 1998.

Each ration was evaluated using the CPM program to determine expected gains based on metabolizable energy (ME) and metabolizable protein (MP). Although ration I was formulated for 1.8 lb. of gain, according to the grower, the CPM model indicated that ME supplied by the ration should provide for only 1.52 lb. of gain per day. In spite of the low CP level, the model predicted sufficient MP for 2.58 lb. of gain per day. This ration relied heavily on byproducts from vegetable processing, wet brewer grains and low cost alfalfa silage which was of insufficient quality for lactating dairy cattle or export to other regions of the U.S. as hay. Ration II used an exceptional array of byproduct feeds. Once again, alfalfa was of lower quality as was the whole cottonseed. Outdated dairy products (ice cream, cottage cheese, yogurt,.....) were also used as available in this ration. In comparison to ration I, this ration contained an abundance of protein of a very degradable nature. Sufficient ME and MP were present to support gains in excess of 2.2 lb. per day, which support observations on the feed lot of rapid gains, and heavy body condition. Ration III represents the traditional ration fed to dairy heifers in Virginia. MP and ME were present in sufficient amounts to support daily gains in excess of 2.0 lb. These rations demonstrate the ability of heifers to grow at rates, which support early calving at recommended body sizes at very low ration costs. The greatest limitation involved in successful use of byproduct feeds are personal prejudices and preconceived ideas of what will be successful. Once it has been determined that byproducts contain no harmful substances and that product quality is predictable, many byproducts are economical ingredients for heifer rations.

In some areas of the country, the greatest nutritional asset is the availability of abundant, low cost land suitable for pastures for dairy heifers. One example of successful pasture systems in U.S. lies in Missouri. A pasture-based growing system was described by Randle et al (1998) with daily feed costs of $.56/day. The first heifer

growers association – Sho Mo Heifer Growers is an active group with many utilizing pasture-based systems. The greatest challenges of pasture systems lies in the establishment of pastures which enable maximal grazing throughout the season and provisions for supplementation when pasture nutrients are not available. Examples of systems are described by Chester-Jones (1996).

Heifer feeding management to assure success. Housing, environment and health care strongly influence growth responses of heifers to feeding programs. Work at Va. Tech over the past 15 years in the counter sloped heifer barn system has demonstrated that heifers exhibit a 12 to 25% higher feed efficiency than indicated by NRC (Quigley, 1985). This is attributed to decreased exercise of animals raised in these systems. In addition, we found that heifers exiting these confinement systems to pasture or conventional housing systems with more exercise area commonly lose 10 to 15% of their body weight during the first 45 days. Increasing ration energy density and gradually increasing the exercise area during this time minimizes loss in body weight.

Ventilation, air quality and mud during cold weather dramatically influences nutritional efficiency of feeding systems. Wet; muddy hair coats result in a greater need for energy to maintain body heat.

Bunk management should provide fresh feed in a clean location. Although heifers are not as sensitive as lactating cows, the practice of piling several days of silage or TMR in front of heifers leads to depressed performance and risk of digestive upsets.

TMR's offer the opportunity to utilize many feed ingredients, which might be less palatable if fed separately or provide a means to limit intake of exceptionally palatable ingredients, which might be eaten too rapidly if fed alone.

Coccidia control and deworming programs are essential to a successful feeding program. There are few heifers, which don't face the risk of infection with coccidia. Inclusion of coccidiostats adds pennies to ration costs with substantial benefits. Deworming programs are of less importance to confinement-reared heifers, but are vital to success of pasture-based systems. The reason being that pasture is essential to the completion of the life cycle of most intestinal parasites. Strategic deworming programs involving treatment during the beginning of the pasture grazing system and again 3 to 6 weeks later are recommended.

Probably one of the most important components of the heifer-feeding program is the use of an accurate set of scales to weigh heifers on a routine basis. For the lactating herd, the DHI program has provided a valuable decision making tool for herd management. Similarly, heifer weights are essential to successful heifer growing systems. Scales should be electronic with facilities to enable weighing animals easily with minimal stress to the animal or grower. Such management information is necessary if the grower is to respond in a timely manner to the environmental and health related factors which might impair heifer growth or lead to overfattening. There is no better example of the use of routine body weight monitoring than the management system of the New Zealand Grazing Company that contract raises over 30,000 heifers annually (Wickham, 1997) All heifers are weighed monthly by a technician using electronic scales. Prior to leaving the farm on weigh day the grower receives a report, as does the owner of the heifers. This has enabled the New Zealand Grazing Company to guarantee performance of heifers and build a business from less than 5,000 heifers raised annually in 1988 to nearly 30,000 by 1994.

Feeding programs for heifers first must achieve the ultimate goal of providing an animal capable of expressing her genetic potential at a reasonable age. Current research indicates that this is somewhere between 22 and 24 months of age and a body weight of1250 lb. after calving for Holsteins. Future research may yield ways in which age at calving may be reduced without significant risk to mammary development. At the present time average ages of first calving below 22 months cannot be recommended. The second requirement for success involves aggressively seeking out low cost ingredients, which will enable attainment of growth goals. Profitable heifer growing operations will thrive in locations adjacent to sources of byproducts or low cost pasture which will enable economical feeding programs. The third requirement for success involves monitoring body weights of the growing heifers. Facilities must be incorporated into heifer management system, which enable weighing and measuring animals. Finally, this I data must be recorded in a system, which provides the operator with information to evaluate the effectiveness of feeding and herd health, programs.

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USE OF DISTILLERS' GRAINS AND CO-PRODUCTS IN RUMINANTS DIETS

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The fermentation of grains to produce alcohol yields whole spent stillage from which wet distillers' grains (WDG) and thin stillage are obtained by screening and pressing or centrifugation. Usually, WDG are dried to yield dried distillers'grains (DDG), or dried distillers' grains with solubles (DDGS) if solubles in the thin stillage are added back to the grains at drying. The solubles in the thin stillage may also be partially or totally dried to make condensed distillers' solubles (CDS) or dried distillers' solubles (DDS), respectively. Of these co-products, DDG and DDGS are the most commonly used, probably because of ease of handling, storage, and shipping. However, the high cost of drying has led people to investigate the possibility of feeding wet distillers' byproducts to ruminants.

NUTRIENT COMPOSITION

The chemical composition of distillers' grains co-products from various grains is shown in Table 1. These products are generally characterized by higher protein, fat, NDF and ash, and lower starch contents compared with the source grain. Distillers' dried grains and DDGS contain moderate levels of protein, and high levels of fat and fiber, which makes them attractive for use in ruminant diets. However, like many other byproduct feeds, the nutrient content in distillers' byproducts can be highly variable.

A recent survey conducted at the University of Minnesota (Harty et al., 1998) showed substantial variation in DDGS composition both within and across ethanol production facilities (Table 2). The survey involved a total of 95 samples from eight different production facilities located in Minnesota (5), South Dakota (2), and Nebraska (1). One sample was collected from each production facility on the first and third Tuesday of each month, over a 6-month period. The survey showed large variations for all nutrient values across production facilities ($P < 0.01$) (Table 2). Chase (1991) reported similar variations for CP, NDF and ether extract. Within production facility, DM, ether extract, ash, soluble protein, rumen degradable protein (RDP), rumen undegradable protein (RUP), and intestinal availability of protein (IACP) showed the largest variations, whereas CP, NDF, and ADF contents were considerably less variable than other nutrients. Factors influencing the composition of distillers' byproducts include the type of grain used, drying method, amount of solubles added, and fractionation of particle size.

Although corn is the major grain used in alcohol production, wheat, barley, rye, and sorghum (milo) may also be used. Lee et al. (1991) studied the composition of DDG and DDGS from corn, wheat, and mixtures of the two grains and found that DDG or DDGS from corn contained lower protein, lower fiber, but higher fat contents than the same co-products from wheat (Table 1). As corn decreased and wheat increased in the mixture, protein and fiber increased, whereas

fat content decreased. Similarly, Canadian Prairie spring wheat contained more protein and more fiber, but less fat than durum wheat (Table 1). Similar observations were made by Dong et al. (1987) on corn, white wheat, and red wheat DDGS (Table 1). When grain mixtures are used for alcohol production, the name of the grain contributing the larger proportion in the mixture is usually given to the byproduct; i.e. corn DDG or DDGS may contain grains other than corn.

Drying method is a primary factor in determining the overall quality of distillers' grains (Rasco et al., 1989). In their experiment, Rasco et al. (1989) found that protein and NDF contents were the most affected by drying method. The effect of drying method on protein content was attributed to the loss of fine particles during drying. The heat applied during drying renders some of the protein in distillers' grains insoluble in the neutral detergent solution, giving the appearance of higher NDF content in the dried product.

Compared with distillers' grains, the protein content in distillers' solubles is lower whereas the ash content is much higher (Lee et al., 1991; Belyea, 1994). Belyea (1994) also indicated that the composition of distillers' solubles show large variations. Therefore, the protein and ash contents of DDGS will vary depending upon the amount of solubles added. This will also affect protein solubility and degradability in the rumen.

A subtle yet significant source of variation in the composition of distillers' grains is the fractionation of particle size that may be caused by handling. Wu and Stringfellow (1986) conducted a particle size fractionation experiment on corn DDG and DDGS and showed protein and NDF are the components that are mostly affected. They used sieves with openings ranging from 177 to 841 μm (80 to 25 mesh screens). The DDG and DDGS tested were obtained from a commercial distillery and contained 26% CP and 58% NDF for DDG, and 29.5% CP and 40.5% NDF for DDGS. With DDG, the fraction going through the 500 μm (35 mesh) screen represented 36% of the total sample and contained 38% CP and 43% NDF, whereas the fractions retained on bigger screens contained from 16 to 25% CP and from 58 to 71% NDF. Fractionation was done on a 100-lb sample. In the case of DDGS, using a 1-lb sample, WU and Stringfellow (1986) found that the fraction going through the 500 μm represented 65% of the sample and contained 35% CP and about 30% NDF. The fractions retained on bigger screens contained 17 to 20% CP and 58 to 62% NDF. Additionally, reports indicate ash is a primary component of stillage solubles, whereas most of the lipid in distillers' grains products is associated with the insoluble solids (Rasco et al., 1989; Lee et al., 1991). These findings suggest handling that causes particle separation will result in considerable variation in DDG or DDGS composition. Harty et al. (1998) found that fine particles (< 1 mm) represented 58% of the sample weight on average across 8 ethanol production facilities; values ranged from as little as 19% to as much as 94%.

Table 1. Chemical composition of co-products of alcohol production from various grains.

Source grain	Co-product[8]	DM	Starch	Crude protein	Ether extract	NDF	Ash
				% of DM			
Barley[1]	DDG	87.5	...	28.7	...	56.3	...
Barley[1]	WDG	35.5	...	26.9	...	38.0	...
Corn[2]	DDGS	90.3	...	31.6	8.9	25.0	4.1
Corn[3]	DS	42.1	...	18.7	13.9	...	10.6
Corn[4]	DDG	...	1.3	32.9	17.6	...	2.5
Corn[4]	DDGS	...	1.6	28.7	17.6	...	5.2
Corn[5]	WDG	27.9	6.2	28.1	15.4	44.3	3.1
Corn[5]	TS	4.4	25.1	19.0	9.2	13.3	6.7
70% corn: 30% wheat[1]	DDG	...	1.3	38.0	12.4		3.2
70% corn: 30% wheat[1]	DDGS	...	1.1	33.5	12.1		5.3
Sorghum[6]	WDG	23.5	10.2	31.6	11.3	45.4	2.5
Sorghum[6]	DDGS	91.4	7.4	31.4	11.8	51.1	1.8
Sorghum, bronze[7]	DDGS	90.4	...	26.6	8.1	...	4.9
Sorghum, yellow[7]	DDGS	88.9	...	25.6	8.0	...	4.2
Wheat, Durum[1]	DDG	...	0.5	48.7	6.2		3.2
Wheat, Durum[1]	DDGS	...	0.5	42.7	5.6		5.3
Wheat, red[2]	DDGS	94.3	...	34.4	3.4	25.9	5.1
Wheat, Spring[1]	DDG	...	1.4	45.2	4.7		3.7
Wheat, Spring[1]	DDGS	...	1.5	41.9	3.9		5.9
Wheat, white[2]	DDGS	92.0	...	40.4	3.2	29.2	5.4
70% wheat:30% corn[1]	DDG	...	2.1	40.2	9.0		3.8
70% wheat:30% corn [1]	DDGS	...	1.8	35.9	9.9		4.9

Source: [1] Weiss et al., 1989; [2] Dong et al., 1987; [3] Belyea, 1994; [4] Lee et al., 1991; [5] Ham et al., 1994; [6] Lodge et al., 1997; [7] Hancock, 1995;

[8] DDG = distillers' dried grains, DDGS = distillers' dried grains with solubles, DS = distillers solubles, WDG = wet distillers' grains, TS = thin stillage.

Table 2. Nutrient composition of distillers' dried grains with solubles from different ethanol production facilities[1].

	Processing Facility								Across plant variation		
Item[2]	A	B	C	D	E	F	G	H	Mean	CV	P
Dry matter, %	91.2	93.4	92.4	94.4	91.9	93.3	92.6	92.5	92.7	1.1	< 0.01
NDF, % of DM	44.1	48.2	47.2	49.6	55.1	50.6	47.3	47.9	48.8	6.6	< 0.01
ADF, % of DM	14.4	16.3	16.3	14.8	16.6	16.9	14.3	14.1	15.5	8.1	0.04
EE, % of DM	11.8	10.0	11.2	8.8	9.4	12.4	10.1	10.6	10.5	11.6	< 0.01
Ash, % of DM	4.6	4.4	3.9	5.2	3.2	4.4	4.8	4.0	4.3	14.3	< 0.01
CP, % of DM	29.4	27.7	28.8	29.9	30.9	31.3	30.3	32.3	30.1	5.0	< 0.01
SP, % of CP	11.6	8.7	9.4	9.6	6.0	12.6	10.7	9.4	9.8	19.5	< 0.01
ADIP, % of CP	4.9	10.5	10.7	8.1	7.3	11.6	5.8	5.4	8.0	33.8	< 0.01
RDP, % of CP	52.0	42.5	47.5	52.2	37.3	51.3	45.8	44.1	46.6	11.2	< 0.01
RUP, % of CP	47.9	57.5	52.5	47.8	62.6	48.7	54.2	55.8	53.4	9.8	< 0.01
IAP, % of RUP	81.9	73.8	73.8	77.8	77.8	75.9	79.3	78.7	77.3	3.5	< 0.01
IAP, % of CP	39.1	42.5	38.8	37.1	48.7	36.6	42.9	43.9	41.3	9.9	< 0.01
PS1, % of sample	17.4	1.8	6.2	10.0	14.6	16.9	10.6	5.2	10.3	54.6	< 0.01
PS2, % of sample	50.7	12.5	22.0	18.1	36.9	33.4	41.6	36.2	31.4	30.0	< 0.01
Fines, % of sample	31.9	85.7	71.8	71.9	48.5	49.7	47.8	58.5	58.2	20.6	< 0.01

[1] Means are least squares means.

[2] DM = dry matter, NDF = neutral detergent fiber, ADF = acid detergent fiber, EE = ether extract, CP = crude protein, SP = soluble protein (in borate phosphate buffer), ADIP = acid detergent insoluble CP (ADIN x 6.25), RDP = rumen degradable protein, RUP = rumen undegradable protein, IAP = intestinally available protein, PS1 = fraction having a particle size greater than 2 mm, PS2 = fraction having a particle size less than 2 mm but greater than 1 mm, fines = fraction having a particle size less than 1 mm.

PROTEIN QUALITY OF DISTILLERS' GRAINS

Distillers grains are a good source of protein and other nutrients in ruminant diets. Distillers' dried grains and DDGS contain a significant amounts of both rumen degradable (RDP) and rumen undegradable protein (RUP), and post-ruminal digestibility of the RUP is generally high (Ingalls, 1994; Stern et al., 1995; O'Mara et al., 1997).

Typical RUP values for corn DDG and DDGS are 54 and 47% of the CP (NRC, 1989), although large variations can be found in the literature (Nakamura et al., 1994; Grings et al., 1992; Powers et al., 1995). Nakamura et al. (1994) reported RUP values ranging from 16 to 80% for DDG. In a recent survey, researchers (Harty et al., 1998) at the University of Minnesota found RUP for DDGS averaged 53% of the CP (n = 95) (Table 2), but ranged from 40 to 68%. Similar values have been reported by Stern et al. (1995). Factors affecting RUP content of DDG and DDGS include type of grain used, drying method (temperature and time), amount of solubles added, the laboratory technique used. In the survey conducted at the University of Minnesota (Harty et al., 1998), soluble CP was found to account for about 36% of the variation in RUP (Table 3).

Good quality RUP must be digestible and available for absorption in the small intestine. In the case of distillers' grains, Nakamura et al. (1994) obtained in vivo estimates of true N digestibility averaging 98% for DDG. In addition, Stern et al. (1995) reported in vitro estimates of intestinal digestibility of RUP ranging from 72 to 85% (n = 5; average = 81%) for DDG. More recently, Harty et al. (1998) tested 95 samples of DDGS and obtained in vitro estimates of intestinal digestibility of RUP that averaged 77%, and ranged from 71 to about 94%. Using the mobile bag technique, Ingalls (1994), and O'Mara et al. (1997) showed ileal disappearance of individual amino acids in the RUP (residual protein after rumen incubation) is quite high, ranging from 82 to 97% for barley DDGS, and from 76 to 84% for corn DDG, respectively. However, protein digestibility or total amino acid digestibility may mask digestibility problems for individual amino acids. In the study by O'Mara et al. (1997), estimates of intestinal digestibility were about 85% for total amino acids, but only 75% for lysine. Reduced efficiency of protein utilization has been reported when animals were fed distillers' grains (Klopfenstein, 1991; Cromwell et al., 1993), presumably because the protein in distillers' grains had been heat damaged and, thus, was poorly utilized (Dong et al., 1987; Klopfenstein, 1991; Chaudhry and Webster, 1993; Cromwell et al., 1993; Nakamura et al., 1994b), or because of a lysine deficiency (Dong et al., 1987; Cromwell et al., 1993; Armentano, 1994).

Table 3 shows the amino acid profile of various distillers' co-products. Corn protein is deficient in lysine, and so are corn products such as distillers' grains. Dong et al. (1987) reported that the amino acid profile of distillers' grains is similar to that of the source grain. As a result, differences in amino acid composition of distillers' grains reflects differences between amino acid composition of the source grains.

During the process of alcohol production, the grain is cooked to gelatinize starch before enzymatic degradation and yeast fermentation. Additionally, heat is used to dry the wet distillers' grains to produce DDG or DDGS. Heating of feeds can reduce protein degradation by

Table 3. Amino acid composition of distillers' grains from various grains and of corn distillers solubles.

	Distillers' byproduct					
Amino acid	Corn DDGS[1]	Bronze sorghum DDGS[2]	Yellow sorghum DDGS[2]	Corn distillers' solubles[3]	Barley DDG (% of DM)[4]	Barley WDG (% of DM)[4]
	% as fed					
Arginine	1.06	0.97	0.91	0.84	1.81	1.81
Histidine	0.72	0.57	0.55	0.58	0.33	0.22
Isoleucine	1.00	0.99	0.95	0.77	0.82	0.72
Leucine	3.33	2.55	2.39	1.31	2.10	1.88
Lysine	0.70	0.60	0.55	1.18	0.39	0.61
Methionine	0.51	0.46	0.42	0.27	0.29	0.25
Phenylalanine	1.45	2.02	1.83	0.68	1.15	1.01
Threonine	1.03	0.87	0.79	0.87	0.99	0.80
Tryptophan	0.19	0.22	0.21	0.18	. . .	. . .
Valine	1.35	1.25	1.24	1.02	1.10	0.93

[1] Cromwell et al., 1993 (n = 9).
[2] Hancock, 1995. Phenylalanine values include tyrosine.
[3] Belyea, 1994 (n = 6).
[4] Weiss et al., 1989.

ruminal microbes and increase efficiency of protein utilization by ruminants. However, excessive heating can actually render some of the protein totally unavailable to the animal (NRC, 1985; Stern et al., 1994), and decrease efficiency of protein utilization. Therefore, the potential for heat damage of protein in distillers' grains exists (Klopfenstein, 1991; Nakamura et al., 1994b). However, the point at which the negative effects of heating outweigh the beneficial effects has not been established (Van Soest, 1989; Merchen, 1994).

COLOR AND ADIN AS INDICATORS OF PROTEIN QUALITY OF DISTILLERS GRAINS

There has been much interest in using acid detergent insoluble N and color darkness as indicators of heat damage in distillers grains, presumably because ADIN represents indigestible N, and darkness suggests excessive heating. Van Soest (1989) indicated that the general belief in the indigestibility of ADIN is based on the early work of Yu and Thomas (1976) and Goering et al. (1973) on heat-damaged forages. However, since then, there has been evidence that ADIN in non-forage feeds behaves differently than ADIN in forages, as a large portion of ADIN (up to 58%) in non-forage feeds is digestible (Britton et al., 1986; Weiss et al., 1989, Van Soest, 1989; Van Soest and Mason, 1991). While the relationship between ADIN and N digestibility was found to be strong in forages (Yu and Thomas, 1976), it has not been consistent in non-forage feeds such as distillers' grains. Some studies showed a strong negative relationship between ADIN and N digestibility (Van Soest, 1989; Van Soest and Mason, 1991; Waters et al., 1992; Nakamura et al., 1994a), while others found ADIN was a poor indicator of protein unavailability

(Britton et al., 1986; Weiss et al., 1989; Nakamura et al., 1994a). One possible explanation for these apparently contradictory findings may be that the relationship between ADIN and protein digestibility is not constant across ADIN values. Evidence of this can be found in the studies by Nakamura et al. (1994a). In one study, ADIN content in protein sources ranged from 11.5 to 59.5% of N, and a strong negative correlation (r^2 = .66) was found between ADIN and apparent N digestibility. However, in another study, ADIN contents in protein supplements ranged from 7.8 to 27.9% of N, and the correlation between ADIN and apparent N digestibility was poor (r^2 = .24).

In a recent study by Harty et al. (1998), 98 samples were evaluated for the relationship between ADIN and intestinal availability of protein determined in vitro. The ADIN ranged from .78 to 35% of N. Over the entire range of the data, the correlation between ADIN and intestinal availability of protein (IACP) or intestinal availability of RUP (IARUP) was poor (r = -.24 and -.42, respectively). The best correlation between ADIN and IARUP (r = -0.87) was obtained when only ADIN values greater than 13% of the N (n = 17) were used. And even within this range, ADIN was very poorly correlated with IACP (r = -0.17). Cromwell et al. (1993) found a strong negative correlation between ADIN and nutritional quality of DDGS for pigs. In their study, ADIN ranged from 8.8 to 36.9. Van Soest (1989) indicated that normal feeds contain a N fraction that is unavailable, ranging from 3 to 15%. He suggested ADIN values within this range may not be high enough for negative effects.

The data on the relationship between color and protein quality of distillers' grain is very limited. Cromwell et al. (1993) used a special apparatus to measure the variation in color of DDGS. For each sample, three color scores were obtained: L (lightness, changing from black to white), chromaticity a (redness), and chromaticity b (yellowness). For lightness, the smaller the score, the darker the sample appears. For redness and yellowness, the higher the score, the more red or yellow the sample appears. Lightness in this study ranged from 53.3 (lightest) to 28.9 (darkest), and was correlated to ADIN (r = -.79), with ADIN increasing as samples got darker. A similar evaluation was done in the study by Harty et al. (1998). In their study, Harty et al. (1998) observed L scores ranging from 39.8 (darkest) to 59.1 (lightest), but observed poor correlation between lightness and IAPRUP (r = 0.32), or IACP (r = .17). This is in apparent contradiction to the findings by Cromwell et al. (1993). However, when the analysis was restricted to samples with ADIN > 13% of N, then lightness was strongly correlated to both ADIN (r = -0.80) and IARUP (r = -0.80). These findings suggest that if a sample of distillers' grains is dark in color, it may be a good idea to have the sample tested for ADIN. However, color by itself is not a good indicator of protein damage in distillers' products.

FEEDING DISTILLERS GRAINS BYPRODUCTS TO RUMINANTS

During the past 10 years, much of the research on feeding distillers' byproducts to beef cattle was conducted at the University of Nebraska (Larson et al., 1993; Ham et al., 1994; Nakamura et al., 1994, Lodge et al., 1997a; Lodge et al., 1997a).

The work by Larson et al. (1993) and Ham et al. (1994) was summarized by Klopfenstein and Stock (1993) and by Klopfenstein (1996). These studies show corn wet distillers' byproducts

(WDB; a combination of WDG and thin stillage) or corn DDGS have greater energy value for growth than dry rolled corn (1.28 to 1.69 times greater), and can also be effectively used as a source of protein in growing and finishing diets. Daily gain and efficiency of feed conversion of finishing calves or yearling steers fed distillers' co-products were consistently improved over those of animals fed dry rolled corn (Klopfenstein, 1996). These findings were in agreement with some earlier work (Firkins et al., 1985). In addition to greater energy content of corn distillers grains due to a higher fat, and, in the case of WDB, ethanol contents, maintaining good rumen health was identified as a major factor contributing to improved performance when corn distillers' co-products were fed in partial replacement of dry rolled corn. The beneficial effect on rumen health was attributed to the large reduction in starch intake and increased intake of highly digestible fiber when distillers' co-products were fed, thus possibly preventing subacute acidosis. In these studies, animals fed WDB also performed better than those fed DDGS. However, handling and storage difficulties associated with the high moisture content (68.6%, on average) of WDB limits its use.

More recently, the work of Lodge et al. (1997a) showed sorghum WDG and WDB had energy values similar to those of dry rolled corn, whereas sorghum DDGS had lower energy value than corn. Compared to corn WDG, sorghum WDG had lower apparent organic matter, true N and apparent N digestibility, but similar NDF digestibility.

Ham et al. (1994) found WDB and DDGS were better utilized as sources of protein than urea by growing calves. They also concluded that drying distillers' grains to produce DDGS did not adversely affect protein quality, as ADIN content (5.9, 13.9, and 14.8% of total N in test diets) had no effect on daily gains or efficiency of protein utilization. However, subsequent work by Nakamura et al. (1994) showed reduced protein efficiency by 34% when ADIN in DDG increased from 11.3% to 23.8% of total N, although true N digestibility was decreased by only 7%. Klopfenstein (1991) indicated that this type of heat damage due to excessive heating probably does not occur routinely.

Research on feeding distillers' grains to dairy cattle has been reviewed by Chase (1991) and, more recently, by Linn and Chase (1996). There is little information available on feeding wet distillers grains to dairy cattle. The reviews indicate dried distillers grains are a good source of RUP. Performance results in response to feeding distillers' grains, although variable, show DDG and DDGS can support similar or greater milk yields than soybean meal. However, less than optimum performance can result if an excessive quantity of distillers' grains (> 26% in the diet DM) is fed, possibly due to a shortage in RDP, low lysine intake, and/or limited protein availability due to heat damage. Distillers' grains can replace some of the forage fiber to maintain milk fat test, but have little ability to stimulate chewing. Recent work suggest distillers grains can be effectively used in dairy cattle diets if supplemented with lysine (Armentano, 1994; Nichols et al., 1998).

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Notes

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REQUIREMENTS FOR ENVIRONMENTALLY SOUND AND PROGRESSIVE LIVESTOCK PRODUCTION IN MINNESOTA[1]

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Thank you for giving me the opportunity to talk to this distinguished group of feed professionals. It's a real honor for me as one who considers Feedstuffs his bible on all aspects of farm policy.

The main lesson I've gotten from Feedstuffs and other farm publications and in my contact with farmers and others from around the country is that the topic I've been assigned is not only the hottest rural issue over the last decade, but the most rapidly changing.

Some would say that the two segments of my topic are mutually exclusive. There is great conflict found, not only in Minnesota, but seemingly everywhere concentrated livestock operations are found, between those "progressive" farmers who see expansion as the only path to survival in today's farm economy and those who see unlimited expansion as the greatest threat to everything that makes rural areas what they are and what they're perceived to have been.

The pressures from environmentalists, neighbors and government at all levels upon large-scale livestock production are greatly exacerbated by the current economy. Beef prices have been below break-even for much of the past few years prompting exhaustive study and agitation. Pork prices have been in the $30/cwt. range for almost all of the past year, and, in the face of increasing production, Feedstuffs forecasts hog prices at or below current levels for the foreseeable future. Likewise, Minnesota dairy producers have been exiting the industry at the rate of three every day and only recently have prices temporarily edged upwards.

Farmers aren't the only ones facing economic difficulty under these circumstances. The saga of Premium Standard Farms' glorious rise and subsequent fall is of interest to anyone connected with the livestock industry. IBP has canceled shifts in some slaughter plants and ConAgra is rumored to be shopping its Monfort division due to low profitability.

These harsh economic factors have put even more of an edge on an already acrimonious debate. Over the past year we have seen significant action at state and local levels and serious talk about comprehensive action from the federal government.

At a state level, the legislature mandated preparation of a generic environmental impact statement (GEIS). Minn. Laws 1998, ch. 366, sec. 86, subd. 2. In my address today, I will use

[1] The opinions expressed in this article are those of the author and should not be construed as the position of the Minnesota Attorney General's Office.

the subject matter of this study to frame what I deem to be the "environment" with which we must be concerned in the livestock debate. In terms of the law, "environment" doesn't mean just air, water and soil; it means, as well, all the effects of livestock production, socially and economically. You too, in your decisions regarding production, must look at the same factors in a changing regulatory landscape.

In terms of the traditional environment, air, water and land, livestock production in Minnesota faces extensive and increasing regulation.[2]

At the federal level, large scale confinement animal feeding operations (CAFOs) have been regulated by the Environmental Protection Agency which requires National Pollutant Discharge Limitation System permits for those feedlots over 1000 animal units.[3] For the most part this has been enforced by state regulators, in our case the Minnesota Pollution Control Agency. Until recently, the MPCA has not required that many such permits be obtained. That is changing for two reasons. First, the EPA has "clarified' the law's requirements and started requiring its state enforcement arms to more actively require NPDES permits. Second, the 1998 Legislature, in Minn. Laws, 1998, ch. 401, sec. 43, commanded that any feedlot with a capacity over 1000 animal units must obtain a general NPDES permit and any over 2000 animal units must obtain an individual NPDES permit.[4] Additional permit requirements and options were to be phased in for future years [5].

Despite the failure of the legislature to pass the proposed temporary moratorium on feedlots over 750 animal units,[6] the 1998 Legislature was extremely busy on the feedlot front. A wide variety of measures were enacted in Minn. Laws 1998, ch. 401. Money was appropriated for county enforcement efforts, NPDES permit processing, feedlot pollution prevention and alternative swine production research. A start was made on more stringent regulation of manure application

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[2] In this discussion, I will refer primarily to Minnesota law since I understand most of the audience is from this state. It is worthwhile to note, however, that the trend of increasing scrutiny is not confined to Minnesota but stretches across the nation.

[3] I will not be discussing specific requirements of the various regulators for several reasons. First, those of you in the industry know the law. I don't. Second, the requirements are in a state of transition with specific and extensive changes being proposed at all levels. Finally, litigation at various levels will have major effects upon, in particular, local regulatory authority.

[4] Again at the federal level, the decision by the 2d Circuit U.S. Court of Appeals potentially greatly extended the reach of EPA authority in the case of Concerned Area Residents for the Environment ("CARE") v. Southview Farms, 34 F.3d 114 (2d Cir. 1994). That case involving neighbors opposed to a dairy farm's operation broadened the definition of a point source (the operative term to invoke CAFO regulation) to include application of manure in such a way that it reached a water course.

[5] Also at a federal level, Congress is looking at imposing tougher uniform standards throughout the United States. It is unlikely that there will be any meaningful action soon.

[6] The House of Representatives approved, along party lines, a moratorium on operations over 750 animal units, but the Senate declined to follow.

with immediate certification required of manure testing labs and subsequent reports and provisions for licensing of manure applicators. Obviously, this addresses an area of importance since it has been estimated that due to lack of knowledge about nutrient content and poor guesses on application rates, manure can well be overapplied by a factor of ten.

Manure storage was also the object of attention. Open air lagoons were banned for at least two years and engineer or state agency approval of manure storage structures was required as a permit condition.

Local regulation of feedlots was also addressed. Counties were explicitly granted the right to impose regulations on feedlots stricter than the state requirements. The more controversial subject of township regulation was addressed indirectly. All local units of government with feedlot ordinances were to provide copies to the Minnesota Department of Agriculture prior to August 1 of this year.[7] Currently, under the recent decision of the Minnesota Court of Appeals in Canadian Connection v. New Prairie Township, 581 N.W.2d 391 (Minn. Ct. Of Appeals 1998), townships have extensive feedlot regulatory authority pursuant to their zoning powers, and the standard ordinance which has been widely circulated by the town clerk involved in the Canadian Connection case was upheld for the most part. Canadian Connection has asked the Minnesota Supreme Court to review the decision, but as of this writing, it is not known whether the Supreme Court will hear the matter.

The MPCA rules relating to feedlots (Minn. Rules, Part 7020) have been in the process of amendment now for several years. The legislature has provided that no new rules will take effect until the legislature's had a chance to look at them. The direction taken by the MPCA will have a major impact on the requirements for expansion of hog production in Minnesota.

Beyond normal permit requirements, Minn. Stat. ch. 116D (1996) (the Minnesota Environmental Policy Act) and the rules of the Environmental Quality Board mandate environmental review for certain large facilities. An environmental assessment worksheet (EAW) must be prepared when a total confinement operation is expanded or constructed, increasing capacity by 2,000 animal units or more. Minn. Rules Part 4410.4300, subp. 29. Certain smaller operations also face this requirement. If the potential for environmental effects is significant, a more comprehensive (and expensive) environmental impact statement (EIS) will be required.

The regulations involving the permitting and siting of feedlots are obviously complex and growing more complex by the day. A summary of this sort cannot hope to accurately and comprehensively guide a producer through all the necessary hoops. The MPCA feedlot unit is certainly the best first stop since they will provide a large packet of information and can knowledgeably discuss the process, including likely timelines, with an applicant. However, it is vital that local authorities at the township as well as the county level be consulted. Their opposition will make a project a lot more difficult and expensive than it might otherwise be.

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[7] To my knowledge, no report has been issued as of the date this article was prepared.

It is in connection with the last point that the more philosophical part of this presentation begins. By combining the terms "environmentally sound" and "progressive," the title of this presentation brings up the schism that has grown between the new breed of livestock producers and just about everybody else. Those who have been in the vanguard of modern livestock production have at times been accused of proceeding with a certain arrogance. They have put up facilities without talking to the neighbors or consulting with the locals. They have paid for it. When confronted with fears about pollution, they have not taken the time to explain the measures taken to prevent the problems. When odor is discussed, no action is taken.

It is true that pigs have always smelled. It is true that many of the dirtiest operations are the smallest. It is true that many opponents of large operations have other motives. Traditional pork producers see their prices diving and use the environmental laws to attack the new style producers. Other rural residents fear the effect of the new agriculture on the future of main street as their population shrinks and input sales drop. It may also be that some jealousy is involved.

Whatever the motives of critics, many producers have been less than progressive in their dealings with their opposition. While gobbling up all the technology they can, they have neglected the human side of the equation. I have often somewhat jokingly suggested that the feedlot controversy would go away if we simply enacted one requirement. Each pig farm must come with a pig farmer. While I have gotten scores of calls from farmers complaining about feedlots going in across the road where the owners live miles away, I have gotten very few complaints when the feedlot is connected to a farmstead. By working with neighbors of a facility before construction begins, opposition may often be nipped in the bud, and a little time and relatively little money taken to mitigate potential effects will pay off big down the road by avoiding delay and litigation costs. Good neighborhood relations will also ease future fears of sabotage which have been expressed by several large producers.

The economic environment is, perhaps, the major concern of many with livestock expansion. The new operations take a lot less labor than traditional methods and labor by owners is replaced by employee labor. While feedlot wages may be relatively high for rural areas, the overall effect is a loss of jobs and, eventually, rural population. Further, major producers can obtain inputs cheaper away from local communities and studies have confirmed that per unit of production larger operations spend less locally. The combination of loss of population and loss of main street business is especially frightening since as population goes, schools go, and the road downhill for affected communities.

The feed industry is in a rather ambiguous position. Many of you are the driving forces behind expansion as a result of your need to sell feed. Other independent feed suppliers are facing a loss of customers as independent producers exit the industry and their replacements produce their own feed from their own mills. Whatever the case, all of you are in an uncomfortable position.

Everybody in the industry is threatened by current market conditions. Even while prices remain at below break-even for the vast majority of producers, whatever their size, expansion continues unabated. Feedstuffs forecasts a major increase in production over the next two years and prices that will accordingly dip into the $20/cwt. range. In the past, the hog cycle was the textbook

example of supply and demand. When prices fell, farmers sold their sows and used the buildings for some other purpose. Eventually, demand would catch up with supply; prices would rise, and farmers would get back into the hog business.

The current prognosis seems to indicate that the laws of supply and demand are being broken. Prices plummet and production increases. The hog cycle is no more. While multi-purpose barns could sit empty or be converted to other uses, expensive single-purpose structures cannot. A producer loses less money by keeping the barns full, and, in any event, it is unlikely that the producer's lender would let such a thing happen.

What will happen to the economic environment of livestock production? An analogy to the office market of the 1980s might prove enlightening. Office towers sprouted like weeds in the early '80s and vacancy rates soared. The builders could not cash flow, but after one or two bankruptcies or foreclosures, the towers reached a price that would cash flow and rents could be affordable. The market settled.

If current trends continue, the pork industry might do likewise. The capital burden unsustainable by current producers might be lessened through debt settlement or resale and the big guys in financial straits might be bought out by the truly big guys with deep pockets. Premium Standard's buyout by Continental Grain might prove to be a model for the industry's future.

While Minnesota's corporate farm law (Minn. Stat. § 500.24 (1996)) prevents the direct purchase of Minnesota farmland by most large corporations (depending on their corporate structure, some like Murphy Farms, may be exceptions),[8] packers and other major corporations have achieved a degree of control over production that will greatly affect the economic landscape of the livestock industry. All in the industry need to know the additional regulation that this entails. Minnesota has laws regulating contracting ranging from the Wholesale Produce Dealers Act (Minn. Stat. ch. 27 (1996)), to the contract regulation law and accompanying rules (Minn. Stat. §§17.90 et seq.). These provisions are, in effect, consumer protection laws aimed at equalizing the power of the parties to the contracts.

USDA is likewise looking carefully at the economic environment of livestock production. The concentration of the beef packers is being examined by Packers and Stockyards Administration as well as by the antitrust division of the Department of Justice. Preferences in procurement contracts between beef feeders are the subject of, thus far unsuccessful, action by the P and S A. Secretary Glickman is considering any number of options to make markets more open to producers in the beef and pork industry as a result of many studies commissioned by USDA, including the Advisory Committee on Concentration in Agriculture, upon which I served.

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[8] The poultry industry has long been exempt from the corporate farm law since it was already corporately controlled when the current version of the law was passed in 1973. It is still subject to the Wholesale Produce Dealers law and the contract regulatory system.

I have concentrated primarily on hog production in this presentation because it is the subject of the most controversy in Minnesota today. Poultry has already gone totally along the concentration route but is still the subject of complaints on traditional environmental matters. Dairy, with three Minnesota producers leaving the business every day, is the subject of feverish expansion of those remaining in the business, with their expansion often financed by the large milk coops, as a result of their need to keep plants operating at capacity. These operations are increasingly controversial and will likely be the next object of attention by environmental activists.[9]

On the beef production front, the consolidation of the feeding operations into other parts of the country has made them almost invisible in the Minnesota feedlot controversies. Nationally, however, the concentration of beef production at all levels above the cow/calf and stocker levels, has been the impetus for almost all of the federal activity on the concentration front.

"Progressivity," as it has been traditionally thought of, is under ever increasing scrutiny for its effects on all aspects of the rural environment. The current flurry of activity in the regulatory environment is not a mere blip on the economic radar screen. Scrutiny, and in all likelihood, regulatory activity will grow at all levels of government. The GEIS process is an important process to help the industry and its regulators focus on the issues that need action and the issues that do not. The GEIS process is a matter of grave importance to all concerned with Minnesota's livestock industry. It is up to those whose livelihood depends on livestock to take an active part in the GEIS process and in the aftermath of legislative and regulatory activity.

It is further vital that our livestock industry look beyond technical proficiency and dollars and cents efficiency in its definition of "progressive". For the industry to grow and thrive, it must reach an accommodation with its neighbors and consumers to prevent ongoing warfare to the detriment of all. Our attention must be directed at all aspects of the environment in which this industry operates. We must take whatever measures are needed to protect our physical environment, but our task is not done when we have done our best on that front.

I can assure you that for those of us who believe that Minnesota needs a strong and sustainable livestock industry, the next few years will be very interesting. I would also note, however, that an ancient oriental curse is to the effect, "May you live in interesting times."

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[9] Along with environmental concerns, especially in areas with growing population, cooperatives' treatment of these operations has raised concerns over favoritism, especially in the higher prices they receive due to volume premiums. While Minnesota lost a federal court challenge to its prohibition of non-cost justified volume premiums, other states, such as Wisconsin, have successfully imposed some sort of limitations on these pricing policies.

REVITALIZATION OF A LIVESTOCK INDUSTRY - MICHIGAN'S STORY

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Every individual, organization or industry will face at least one crisis during their existence. How will they respond during this time of crisis? Will they turn and walk away or will the leadership rise and take charge of the situation? How an individual or industry responds will have a marked impact on the future of that individual or industry.

WHY IT HAPPENED

During the mid-1980's, Michigan's livestock industry was facing several challenges that could have a major impact on the future of animal agriculture in the state. Consolidation of animal agriculture had already taken place with the poultry industry in the state. Michigan's dairy and swine industries were frantically trying to determine what size and structure of industry was needed to be competitive in the years ahead. In addition, Michigan's livestock industry was being accused of polluting the water and air, thus being looked upon as an environmental liability. At the time the automobile industry, Michigan's largest industry, was in the middle of a depression which had severely eroded income to the State of Michigan. State government and universities were dramatically cutting back.

Michigan State University was having its share of problems also. For many decades, Michigan's animal agriculture had enjoyed an extremely close relationship with Michigan State University to the point that the industry relied on the research results and extension efforts to remain competitive. Budget cuts had eroded the operating budgets, faculty and staff. As operating funds became almost non-existent, resourceful faculty sought grants for their research and extension programs. Granting agencies and reviewers replaced the livestock industry as the clientele of the faculty, thus creating a major disconnect between the faculty and the livestock industry in the state. Research faculty had quit communicating with the livestock industry and no longer directed their efforts on problems faced by the Michigan livestock producer. A major disconnect also existed between the extension agents in the field and extension specialists in the departments. Extension agents generally did not have the depth of expertise to address those issues of highest importance to the progressive producer nor did they have the time to acquire this expertise as their job responsibilities were quite broad and general. The stature of agriculture on the campus of Michigan State University had eroded away from its once position of leadership within the university community.

HOW IT HAPPENED

When the animal industries came asking for assistance and help to solve the environmental issues and give direction for restructuring the livestock industry in the state to make it more competitive, the faculty and staff of the university were not in a position to respond. Budget

reductions had long eliminated the needed expertise and operating funds necessary to resolve the issues at hand. A Committee on Animal Agriculture, representing the leadership of the various animal agriculture commodity organizations, was formed to address the problems associated with manure management issues. This committee gave the challenge of defining generally acceptable manure management practices for the State's Right to Farm legislation to Michigan State University. This was viewed as being the most scientific and unbiased source of information to develop these guidelines. At the same time, the External Advisory Committee to the Department of Animal Science was determined to strengthen animal agriculture and help the university get the funds to do so. The environmental and restructuring issues were a defining moment of crisis. These issues became the galvanizing event that would bring the various livestock commodity groups together to work for a common cause. Before the initiative was finalized, all of agriculture would be united together with a common objective. The leaders of the livestock industry saw the necessity of getting further resources to Michigan State University so many of the important issues could be studied and solutions found. With encouragement from the Michigan Legislature, strengthening animal agriculture quickly became an economic development opportunity to diversify the State's economy so it would not be as dependent upon the auto industry. A Steering Committee consisting of Jack Laurie, President of Michigan Farm Bureau, Tom Reed, CEO of Michigan Livestock Exchange, Elwood Kirkpatrick, President of Michigan Milk Producers Association and Frank Merriman, President of Michigan Association of Agricultural Organizations and Cooperatives was formed and began to work diligently. An advisory committee was also established with representatives from all livestock commodity organizations, marketing organizations and the Michigan Department of Agriculture. These Steering and Advisory Committees were important in defining the plan and then selling it to the legislature as well as the university administration.

Developing the plan was a critical step in the process. There had to be acceptance and buy-in by both the livestock industries as well as the faculty and extension agents at Michigan State University. The first step was to identify the problems facing animal agriculture in Michigan that prevented the various animal industries from being competitive. Faculty developed a white paper for each species listing the economic potential and feasibility along with the constraints and opportunities that existed for that commodity. These white papers were then presented to the Steering Committee as well as to the appropriate commodity organizations for discussion, review and revision. Once the white paper on each commodity group was revised and agreed upon, the next step was to inventory the faculty expertise and physical facilities to see what changes were necessary to meet the objectives set forth in the white papers. Needed changes in physical facilities, organizational structure, expertise among the faculty and operating funds were identified. Faculty in the Department of Agricultural Economics developed a paper outlining the economic benefits to Michigan through additional jobs and income generated in the state. The plan was approved by the Steering Committee.

Several objectives of the Animal Initiative were identified. These were as follows.

1. Modernize animal industry facilities at Michigan State University.
2. Attract top faculty to Michigan State University.
3. Expand programmatic support for animal agriculture.
4. Revitalize research programs toward Michigan's needs.

5. Strengthen Extension's impact on animal agriculture.
6. Strengthen the teaching of tomorrows animal agriculture leaders.
7. Expand agriculture's contribution to Michigan's economy.

These objectives and the plan on how to resolve the important issues lead to an initiative of $70 million for new and/or remodeled facilities and an additional $4.2 million for programmatic support for new faculty positions, extension field agent positions, support staff and operating dollars. Through the efforts of everyone involved, the funds for the facilities were approved in 1992 and the programmatic support funds approved in 1994 by the Michigan Legislature.

RESULTS

In addition to the funding of the facilities and programmatic support, an initiative needs to be evaluated on the changes and impacts. Many changes that have come about because of the animal initiative and more are anticipated in the future. One of the first changes was a total restructuring of field staff into an Area of Expertise(AoE) concept. There was a need to restructure the Extension field staff so that they could narrow their area of expertise and be able to answer questions of a more complex nature. A paper by Leholm, et.al.[1] describes the changes and outcomes of this restructuring. Currently, fourteen dairy AoE agents, seven beef/sheep AoE agents and five swine AoE agents blanket the state. These agents spend all of their programming time associated with their respective species. Individual species AoE Teams have formed consisting of AoE agents and campus-based faculty to share expertise and work on priority problems together. This has had a significant impact on reconnecting our Extension field staff and campus-based faculty. Specific commodity advisory committee have been formed with external clientele. These advisory committees meet with faculty and extension AoE agents to work together to establish the applied research and extension priorities for each commodity area. The dairy team has expanded on this to include local partnering groups for each of the fourteen dairy AoE agents regions. Each of these local partnering groups has representation on the statewide MI-MSU Dairy Industry Committee. This has been an important time to reconnect the campus-based faculty with the livestock industry.

An Animal Industry Coalition has been formed within the university to provide programmatic leadership for the applied research and extension efforts. This coalition consists of the Director of the Agricultural Experiment Station, the Director of Michigan State University Extension, two Regional Extension Directors and five Department Chairs associated with animal agriculture(Animal Science, Agricultural Economics, Food Science and Human Nutrition, Agricultural Engineering and Large Animal Clinical Sciences). The Coalition functions primarily to allocate funds for research and extension projects each year. An added benefit is make sure that the organizational structure of the university allows for the various Teams to function efficiently. By meeting together, many of the past problems of different goals and agendas that existed between campus and the field no longer exist. Improved communications among the Coalition has solved these problems.

Communications between the university and the industry have also improved greatly. AoE Teams of Beef, Dairy, Swine, Sheep and Horse publish quarterly newsletters to their respective

industries. These newsletters contain the latest research results and solutions for many industry problems. This reconnectiveness of the faculty with the industry has also helped to reduce the time line for technology transfer. Communication has also been important to the Michigan Legislature. When the funding started, an brief two page newsletter was published and sent to the industry as well as the legislature keeping everyone up on the latest outcomes and accomplishments. This has helped maintain interest and enthusiasm as well as keeping those people informed to the positive impacts that have been created.

Another important involvement has been the inclusion of an industry representative on each search committee for faculty as well as AoE agent positions. Industry representatives serve several important roles on these search committees. They have helped sort out candidates who can and want to communicate with the industry, their presence on the committee also serves notice to the candidates that the industry is interested in the position and they can serve as an important liaison to the industry once the new agent or faculty member come onboard.

Several key Alliances have been formed to bring the major components of the industries together to collectively move the industries ahead. Alliances have been formed within the pork, beef and sheep industries. Common threads among these alliances is that they consist of the commodity group, state government(Department of Agriculture), Farm Bureau, Marketing organization, meat packer, retailer, Agri-business Association, Corn Growers Association, Soybean Growers Association and Michigan State University. These alliances have helped the entire industry to look at the bigger picture and to work collectively toward improving the overall efficiency. Each member has certain expertise that is needed. Michigan State University is looked upon to conduct the research and educational needs as defined by the alliances. This is truly a team effort. No longer do we have the various groups working independently and often in different and somtimes conflicting directions.

PRINCIPLES OF INITIATIVES

Several principles have surfaced during the Animal Initiative in Michigan that are important if these initiatives are to be successful. If an initiative is to start there needs to be recognition by agricultural leaders of an identifiable crisis as well as opportunities that exist if the crisis can be addressed. This is usually initiated by a small group of visionary leaders who see the problem and the opportunities that exist if the problem can be resolved. This group of visionary leaders are important in building recognition of the crisis and opportunity within a larger group. In most initiatives or movements there is a galvanizing event that can be identified. These galvanizing events serve as a focal point for action by members of this larger body. Next there needs to be the building of an initiative. It is important at this time that the ownership of the initiative is in the hands of the industry and not the university. In our situation, we developed a series of white papers for each species that we used with the industry to look at the constraints as well as the opportunities for that commodity. This helped greatly to gain industry support and leadership for the initiative.

After the industry has recognized the initiative the next step is to gain acceptance and support within the university. This is the point where issues such as university priorities, academic

freedom, and internal "turf" protection must be addressed. It is especially important that the university recognize that society, or some part of society, expects or needs something from the university. Likewise, there needs to be the willingness on the part of the university, government and industry to establish collaborative relationships. Once these processes are in place, a real initiative is in place.

The legislative process is the next step. Agricultural leadership, not the university, must carry this effort and develop the relationship with the legislature. Part of this relationship is to recognize the outputs/benefits of the initiative and what can be the expectations. Will it improve the economic , environmental or societal situation? Why is this initiative important to society? Unity among the agriculture community is essential at this point as the tendency is for various groups to splinter and push their own priorities. Agriculture is not blessed with a large constituency that can afford lack of unity. If agriculture can not unite behind a common program or initiative the legislative process will be very difficult.

Once the funding objective is reached, the tendency for everyone is to relax and feel that the job is completed. Everyone forgets about the promises made or the problems to resolve. This may be the most important time for developing accountability and to insure that those programs that were deemed important do indeed happen. Now is the time for faculty and staff to shoulder the burden and get to work. Buy-in early on by faculty is important so this part of the process is not missed. It is also just as important to keep the clientele and legislature informed on the progress that is being made. Newsletters and legislative staff tours are important activities that make sure that people can chart the impact of this initiative. Accountability is becoming an ever important ingredient in our ability to maintain our integrity. Demonstrating that we can and do what we say we will do will go a long way to sustaining our programs.

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Notes

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EFFECTS OF ENVIRONMENTAL LAWS AND REGULATIONS ON CURRENT AND FUTURE FOOD PRODUCTION SYSTEMS

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It's difficult to imagine an issue surrounded by more controversy than the current concern for environmental controls and regulations in Agriculture. Across society, both urban and rural, this subject has been a lightning rod for emotional discussion and heated debate.

To be sure, this is a very complex issue and while all phases of agriculture have been challenged with the prospect of ever increasing environmental regulations, animal agriculture and in particular, pork production, has been the focus. Given the sweeping changes that have occurred in the production of hogs over the last few years, it's not surprising that many societal and economic concerns have been interwoven with concerns about the environment. Many of us remember with affection, the lifestyle associated with the diversified farming operations of forty years ago. It's sometimes very difficult not to label our regret at the passing of that era as environmental concerns.

Clearly, all facets of agriculture must be concerned about and committed to protecting the environment. The records suggest that America's farmers and in particular, the nation's pork producers, have been excellent environmental stewards and indeed proactive. As an example, the Environmental Protection Agency's Carol Browner has praised the National Pork Producers Council for implementing the NPPC Environmental Dialogue with the E.P.A. This initiative has been viewed as very constructive and is testimony to the seriousness and commitment with which pork producers have addressed this issue.

Discussion recently about a proposed feedlot moratorium in Minnesota has heightened awareness and created even more polarization on the issue of livestock production and environmental regulations. There is growing concern about the potential for ground water contamination through runoff or leaks in manure storage facilities. These concerns are often based on information that is inaccurate or incomplete.

Though not widely known by the general public, today's pork producers have developed effective programs and strategies designed to protect our nations' environment and water resources. The discharge standard for concentrated hog feeding operations is zero and all manure must be completely contained. Later, when manure is applied to land as a fertilizer, the application must ensure that no surface or ground water contamination occurs. It's interesting to note that this is a much tighter

standard than those imposed on municipalities in their handling of municipal and industrial waste.

The manure from hog production is a natural fertilizer which saves billions of cubic feet of natural gas that would otherwise be used to manufacture fertilizers. Swine production, in fact, all livestock production combined, does not produce enough manure to meet the needs of crops and forages currently grown in the United States. At present, crop farmers throughout the U.S. apply significantly more nitrogen from manufactured fertilizer than the nitrogen resulting from all livestock manure sources combined. In other words, there is plenty of opportunity to use manure as a valuable by-product.

Concerns about odor have surfaced as one of the major rationales for new environmental regulations. Several technologies are currently under development which offer real potential in terms of their ability to help minimize odor levels. In the meantime, pork producers have taken a proactive position by implementing two new initiatives. The On-farm Odor/Environment Assistance Program provides trained technicians to conduct audits of pork production operations and make recommendations for odor and environmental management. The Odor Solutions Initiative is another pork producer funded program designed to identify and determine the efficacy of potential technological solutions for odor reduction currently under development. In terms of the current status of odor problems, it's interesting to note that in Minnesota, studies show that the vast majority of complaints about hog odors come from facilities that are greater than three years old.

In Minnesota, pork production is truly a multi-billion dollar industry and offers significant economic benefits to our state. In 1996, the value of the state's hog production at the farm level amounted to 1.2 billion dollars and processing of hogs totaled 2.9 billion dollars. In 1992, revenue generated from pork sales to other states and export markets, amounted to 1.5% of out-of-state sales for all Minnesota industries. Minnesota currently has approximately 18,000 full-time pork related jobs. Of these, only 6,600 are directly related to livestock production. Minnesota farmers currently export 70% of their corn, a commodity needed to feed hogs. Every unit trainload of corn exported out of the state translates into lost jobs and economic pressure on main street businesses.

The focus of much of the discussion surrounding the need for new environmental laws and regulations has been the new growth in animal agriculture. Ironically, most of the industry's environmental challenges have been with older, smaller facilities. Facilities constructed in the last two to three years have an excellent record of appropriate handling of manure and control of odors. As a result, more restrictive environmental laws and regulations, if not fashioned carefully, will likely restrict the construction of new, environmentally responsible facilities while perpetuating older facilities that are

more prone to problems. At the very least, more restrictive environmental laws and regulations have the potential to adversely affect an industry that contributes a great deal to our economy and affects many people directly and indirectly. In view of increasing demand for high quality fresh pork and processed pork items throughout the world, it's reasonable to suspect that the magnitude of this economic restriction will only increase over time. Most importantly, environmental laws and regulations have to be well thought out in terms of their impact on the ability of animal agriculture to function within a given infrastructure. If laws become so restrictive, that participants view moving to other more friendly sites in the U.S. or other countries as their only option, we all lose as a result. Once gone, it will be hard to entice these enterprises to return. In the case of the Midwest where we have the most abundant and reasonably priced feedstuffs, along with a system which allows for the effective use of manure, it would be a tragedy to allow legislation to force livestock production elsewhere.

Minnesota currently has extremely strict environmental regulations as do many other states actively involved in the production of livestock. In those cases, where a few operators have created problems with odors or water contamination, the laws should be effectively enforced. In the meantime, we would do well as a society to work toward understanding and appreciating the tremendous contribution animal agriculture makes to our economy and to make a commitment to working more closely to resolve these issues that affect us all.

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Impact of Regulatory Compliance on Production Costs for Livestock Producers

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INTRODUCTION

Changes in today's livestock industry and social and environmental pressures have become a vital part of the decisions and management practices on modern livestock farms. It is recognized that air and water quality considerations are a part of modern livestock production. In recent years, the livestock industry has been a target for environmental concern and public criticism. While the majority of livestock producers employ sound environmental practices, the image of livestock feeding is affected by negative news reports. In recent years, a better understanding of how livestock production might impact the environment has increased. Public interest and concern about the impact livestock production has on the environment and quality of life has also increased. Environmental concerns and public interest are demanding decision makers in many areas to enact ordinances and legislation to more closely regulate the livestock industry.

ENVIRONMENTAL IMPACT POTENTIAL

Surface and ground water is highly valued for aquatic life, water supply, and recreation. Concerns about the potential impact of the handling, storage, and land application of livestock manure and wastewater on water quality have brought about new legislation, regulations, and guidelines.

When manure nutrients are applied to crops, they reduce the need for application of commercial fertilizer. However, if more manure nutrients are applied than the crop can use or when soil or weather conditions are not suitable, pollution problems may result. Livestock production facilities have become more concentrated and intensified with more animals produced in one location.

Management of a confined feeding operation requires attention to manure production, storage capacity, available land for manure application, and nutrient management and utilization.

Undoubtedly, odor control and its impact on outdoor air quality is also an important design and management issue. Odors originating from livestock production facilities can be a source of irritation between producers and rural and suburban neighbors. The nuisance caused by odor is a function of individual perception. It is difficult to agree on what is an acceptable odor intensity or acceptable odor frequency resulting from

production. Odor perception and tolerance varies from person to person. The goal of the livestock producer should be to concentrate on those techniques that minimize odor and maximize manure management efficiency.

Factors directly affecting environmental impact potential are:

- Site Selection -- Where are buildings and manure handling located in relation to surface and ground water sources, neighbors, prevailing winds, and air drainage?
- Design -- Proper design of building ventilation, sanitation, and manure collection, handling, and utilization system is critical.
- Management -- Day-to-day operation and management of the housing system and manure handling, storage, and treatment facilities and land application strategies directly affect environmental impact.
- Community Relations -- How a livestock production facility and business is viewed by neighbors and the local community?

ENVIRONMENTAL CONTROL STRATEGIES

Site Selection

Site selection cannot be over emphasized when considering a new or modified facility or manure handling/storage/treatment plan. Proper site selection allows flexibility when implementing design and management options.

Several factors must be considered when selecting a livestock facility site to comply with regulations and minimize environmental impact. None of these factors is controlling in itself. These factors are:

- Isolation of the facility site
- Ground and surface water sources
- Direction and distance to water sources
- Geological features of the production site
- Minimum separation distances and other site conditions required by law
- Local sensitivity to odor perception
- Direction of and distance to neighbors
- Prevailing wind direction
- Geographic features that influence land application and air movement
- Visual and aesthetic perception of building and manure handling structures

The direction and distance to neighbors and communities must be considered in relation to prevailing wind directions. Production size and intensity and prevailing summer wind direction affect required separation distances from neighbors. Several states and localities are establishing separation distances based on production capacity. Detection of odors from swine facilities varies with local conditions. Local conditions will dictate the appropriate separation distances to maintain. Check local regulations and zoning restrictions.

Design

Design features and details must be selected and evaluated based on their impact on water quality (surface and ground water) and odor production. Manure storage and treatment structures are required to meet more comprehensive design, construction, and operation standards. Recently, modern production sites require more attention to many factors in the planning and construction phases. These include:

- -- Thorough site investigations
- -- New concrete design standards and specifications
- -- New earthen basin (storage and lagoon) liner standards and specifications
- -- Regular site inspections during construction
- -- Additional site inspections and testing
- -- Additional reporting requirements

The increasing cost of higher degrees of odor control must be balanced with the local requirements for odor control. A concentrated manure storage will require different design features to reduce the impact of high odor release than a dilute treatment lagoon design. Design features that improve the visual perception of the production buildings, manure storage, or treatment lagoon are valuable for all system designs.

Building and Manure Collection

The management of manure handling systems and building layout will affect both water quality and odor generation. Questions that need to be addressed are:

- -- Should manure be handled as a liquid or a solid?
- -- Should storage be provided in the building or outside?
- -- How often should manure be removed from a building or an outside lot?

Principles to consider in selecting the collection system are:

- -- Manure handling equipment (solid or liquid)
- -- Distance to application fields
- -- Odor release potential from in-building manure or outside storage structures.
- -- Flush systems reduce odors inside a building but increase the volume of waste water to be handled and land applied.
- -- Dust control strategies. Reducing dust levels within a building will lower odor problems.
- -- Frequency of manure removal.

Storage Structures

Storage structures must be constructed to provide a water-tight seal. Concern about water-tight construction has increased the attention to construction standards for concrete storage tanks and the liner specifications for earthen structures. Continued

attention to construction standards and specifications have increased the potential cost to producers as much as 10% to 25% over typical construction costs.

Concern about odorous compounds from concentrated manure storages require more attention to site selection and design. Storage design and management practices that limit odor drift and promote turbulent mixing, dilution, and dissipation of odors are desirable. Except when there is reasonable site isolation, manure storage structures should be screened or a cover considered to reduce odor release and exposure. Several different floating covers are being evaluated for odor reduction and durability.

Odor release during agitation and emptying of a storage represents another challenge. It must be recognized that agitation and emptying a manure storage is an event that will likely create some odor release. Adequate manure storage capacity is need to provide management flexibility for scheduling appropriate field spreading to avoid high risk odor and spreading conditions. Plan agitation and emptying to take advantage of weather conditions such as windy conditions and increasing air temperatures to improve mixing and dilution of odors. When agitating the storage, locate the agitation pump discharge below the water surface to reduce the release of hydrogen sulfide related odors. Agitation pump discharge above the surface has resulted in five times greater release of hydrogen sulfide compared to below surface discharge (Patni and Clark, 1990).

Land Application of Manure

The nutrients generated from a livestock production facility are typically land applied and used as a fertilizer to meet part of a crop nutrient management plan. Land application of manure is an efficient utilization alternative because of nutrient benefits derived by crops from the manure. Manure nutrients help to maintain soil fertility. Experience also indicates that manure can also improve soil tilth, increase water holding capacity, improve aeration, and promote beneficial soil organisms.

There are two principle objectives in land applying manure: 1) ensuring effective utilization of manure nutrients by crops and 2) minimizing water pollution potential. The proper management of nutrients from manure, along with previous crops and commercial fertilizers, means better water quality and resource utilization. More nutrients are used by the crops, therefore less tends to leach through the soil or runoff into lakes and streams.

Concern about nutrient movement into groundwater and surface water (lakes and streams) has prompted a discussion about setting manure nutrient application rates based on nutrient loading, either nitrogen or phosphorus. These discussions will impact the amount of land required, allowed application rates, and type of equipment needed to handle manure in the future to meet potential new application standards. Current discussions among regulators, scientists, and industry representatives pertaining to nutrient application, soil fertility, and environmental preservation may affect the required land base needed by a producer.

The potential impact that nutrients can have on water quality and the environment depends on the potential for nutrients to move from agricultural production acres into groundwater and surface water. Effective management of manure nutrients can reduce the potential for them to leach through the soil or runoff into lakes or streams.

ENVIRONMENTAL CONCERNS

A 1996 survey of 16 states conducted by Purdue University briefly summarized current land application regulations or guidelines. The sixteen states surveyed include Arkansas, Florida, Iowa, Illinois, Indiana, Kansas, Michigan, Minnesota, Missouri, North Carolina, North Dakota, Nebraska, Ohio, Pennsylvania, Texas, and Wisconsin. The results of this survey indicated that ten states require manure nutrient application rates be based on nitrogen as a limiting nutrient. Five of the states responded that manure nutrient applications are established in a manure management plan based on agronomic rates for the crops grown. The survey results did not define how agronomic rates were determined. One state reported that there are no specific requirements, but that the State Dept of Agriculture and NRCS recommend rates based on phosphorus.

Current environmental concerns about surface water quality have suggested that future manure application guidelines should be based on a phosphorus application rate. Several factors need to be considered when establishing practical application guidelines. Some of these factors include effective nutrient management and conservation, land use and land area requirements, handling and transportation needs, and sensitivity and potential for nutrient pollution.

Current Issues

It is clear that producers applying crop nutrients as manure must consider both crop needs and the potential for environmental degradation. An effective manure nutrient management plan should include the following components.

- -- Determine what nutrients are already available in the soil
- -- Determine the nutrient needs of the crop
- -- Make the best use of manure
- -- Consider contribution from other nutrient sources
- -- Make best use of commercial fertilizer
- -- Keep soil conservation and water quality in mind
- -- Evaluate yield and performance and make adjustments.

Factors Controlling Application Rate

Manure application rates are based on several factors which include:

-- existing soil fertility levels (soil tests)
-- previous crop
-- manure nutrient content (manure tests)
-- crop nutrient need and expected yield response
-- soil type
-- sensitivity to nutrient movement from the site
-- slope
-- field moisture capacity

The factors that are most often used to determine the amount of manure that should be applied to crop land are existing soil fertility levels, manure nutrient content, and crop nutrient needs. The other factors must be evaluated to help establish application rates that will minimize leaching or runoff from the site.

Along with applying the correct amount of nutrients, the method of application is important. Injection or incorporation of manure by primary tillage as soon as possible after application minimizes the potential for direct runoff. Manure should not be applied to the surface of wet, sloping or frozen fields if a normally anticipated rainfall would cause overland flow from the point of application. Liquid manure should not be applied at rates that cause surface runoff or direct entry of manure into subsurface drainage systems.

Best Management Practices

Loss of nutrients from farm fields and livestock production operations can be substantially reduced by using nutrient management systems tailored to the enterprise and to the soil, topographic, and climatic conditions. Several different management practices can be implemented to reduce the impact of nutrient losses from the farm. Some of the effective nutrient management practices include:

-- **Set realistic yield goals.** Crop yield goals influence crop nutrient needs. Use actual crop yield records on specific fields. Adjust yield goals for a 5%-10% yield increase. Do not fertilize for an unattainable yield goal.

-- **Use soil test data.** Regularly conduct soil tests to identify the existing soil fertility levels. Use the soil tests with previous crop data, manure application rates, and other fertilizer applications to determine appropriate crop nutrient application rates.

-- **Conduct manure nutrient tests.** Regularly test manure to determine the actual nutrient content. Balance manure nutrient applications with crop nutrient needs.

-- **Calibrate application equipment.** Develop a calibration chart for all application equipment to effectively apply the manure nutrients required by the crop.

-- **Use a crop rotation.** A balanced crop rotation can better utilize the available manure nutrients over several cropping years reducing the potential for build-up.

-- **Use buffer zones to protect environmentally sensitive areas.** Conservation buffer strips maintained in permanent vegetation can intercept sediment and nutrients before they enter the surface water sources. Properly installed and maintained buffer strips can remove 50 percent or more of nutrients from runoff and slow erosion and remove sediment from runoff waters.

Conservation and management practices that reduce runoff can reduce the amount of nutrients leaving the farm and entering the surface waters.

COMMUNITY RELATIONS

Community relations is perhaps the most important and least technical part of a manure management and odor control plan. Community relations is an integral part of a farm business management plan. One step to achieving a positive relationship with the community is to operate in a responsible manner. Comply with all regulations and where possible, exceed environmental standards and guidelines.

In addition to responsible facility and manure management practices, emphasizing the positive actions and benefits of livestock production in the community and improving the communities understanding of the livestock industry can improve community relations. There are several actions that can be included in an effective environmental and community relations plans.

1. Location and visibility.
   a) Consider distance from:
      -- Roads
      -- Neighbors
      -- Public areas (parks, lakes, streams, schools, churches)
   b) Consider prevailing wind patterns and topography.
   c) Consider fences and trees to disperse and mix odors and emissions
   d) Develop a landscape and facility management plan. Use landscaping features to project a positive image of your production enterprise.
   e) Consider the use of:
      -- Screens
      -- Hills
      -- Berms

-- Colors that enhance the visual perception
-- Low noise equipment
-- Dust control techniques
-- Shrubs, flowers
-- Decorative fences

2. Comply with all regulations.
   a) Meet all regulation and reporting requirements
   b) Review regulations and compliance regularly
   c) Maintain required setback distances

3. Practice a "good neighbor" policy.
   a) Demonstrate commitment to community and the environment
   b) Develop a manure management and operation plan that maximizes nutrient utilization, protects the environment, and considers neighborhood activities.
   c) Support the local community with your business
   d) Support local events such as local charities, school programs, community celebrations, and scholarship programs.

4. Communicate
   a) Conduct neighbor tours to demonstrate good production practices and inform neighbors about your business.
   b) Conduct tours for officials and regulatory staff
   c) Inform neighbors about manure management and application plans, include times and possible application areas. Identify time and locations that should be avoided (neighbor gatherings, celebrations, special events).
   d) Encourage neighbors to contact you with concerns before taking other actions.
   e) Take responsibility for management practices. If accidents occur, respond quickly to correct the situation.
   f) Recognize good neighbor and community relations are important to the success of the community and your business.

5. Continuing education and certification
   a) Take advantage of available resources to inform yourself.
   b) Consult professionals for both technical and community relations advice.
   c) Take advantage of certification and training programs through land grant universities and industry associations to demonstrate a proactive approach to environmental management.

A crucial aspect of an environmental management plan as part of a community relations plan is good management. This includes both the proper operation of the manure handling system and the neatness and cleanliness of the total facility. A well-kept, neat

facility will receive less negative reaction to the same level of odor than a debris-laden, weed-covered facility. The maintenance of good community relations with neighbors is essential.

ODOR/ENVIRONMENT ASSESSMENT

An important step toward successful development and management of production systems is to conduct an assessment. An objective evaluation of the overall production site, production buildings and lots, manure storage and treatment, and land application and utilization must be conducted.

Livestock producers are being challenged to evaluate the practices on the farm that impact the environment to prevent water pollution and odor problems. Management of manure and waste water is an important part of a total farm management plan because it can positively or negatively impact air, water, land and environmental resources. Successful management is the key to maximizing an important resource and minimizing negative effects on the environment. The following are some common sense practices for successful environmental management on the farm.

- Maintain building and production areas by keeping grassed areas mowed and trimmed. Implement routine maintenance plans that include building repair, painting, and clean-up. Remove used equipment and debris from around the buildings.

- Develop and implement a routine building sanitation program. Routinely clean and maintain ventilation fans and inlets, flooring, wall surfaces, and feeding system. Reducing dust and manure build-up can improve indoor and outdoor air quality.

- Keep access roads in good repair. Maintain stone drives or paved areas by replenishing stone, grading, and weed removal and control.

- Grade away from buildings to promote surface water drainage freely away. Keep drainage areas and diversion ditches well seeded, graded, and free of soil erosion.

- Install a manure storage depth gage. Routinely observe and record manure storage depths to plan storage management and land application schedules.

- Maintain an emergency freeboard and storm storage volume in all open-top manure storage and treatment lagoons. Provide a one to two foot freeboard and emergency storm (25-yr, 24-hr) volume (typically 4-6 inches) above the required storage volume. Pump storage when the freeboard and storm volumes begin to fill up.

- Enough storage capacity provides flexibility in scheduling land application. Evaluate on-farm management systems and determine land availability when sizing

manure storage. Provide a storage length of 180 to 360 days, a minimum 120 days storage is often required.

- Provide separation distances between manure storage and streams and drainage ditches. Check state and local requirements. Provide secondary containment with beams or dikes in high risk areas.

- Check and maintain inside and outside berms of earthen storage or treatment lagoons. Look for rodent burrows, tree roots, erosion, or seepage that can weaken the berm.

- Divert all surface runoff, roof runoff, drainage water, and other uncontaminated water sources away from open lots and out of manure storage and treatment lagoons to reduce manure and wastewater volume and conserve storage capacity. Some treatment lagoon designs include runoff collection to maintain proper dilution volumes.

- Collect all wastewater generated on the farm such as lot runoff, excess drinking water, clean-up water, and other contaminated water. Do not allow any wastewater generated on the farm to be discharged directly to a drainage ditch, field, stream, or other surface water source.

- Develop a nutrient management plan. Effective nutrient use protects the environment and provides an economic return to the land owner. Use soil test results, manure analysis results, and crop rotation and yield goals to determine manure application rates in gallons/acre or tons/acre.

- Plan land application to minimize leaching, surface runoff, and odors.
  -- determine application rates based on crop nutrient needs, soil moisture capacity, and weather conditions
  -- inject or immediately incorporate manure to conserve nutrients and reduce odors
  -- provide a grassed buffer strip between manure application fields and streams and drainage ditches

- Develop an emergency response/action plan. Think about and practice what to do in case of an emergency. Have a written plan. Inform and educate everyone who works around the farm how to respond to an emergency.

- Maintain dead animal collection and disposal areas.
  -- Provide a solid, well drained base for rendering pick-up locations and composting sites.
  -- Control surface drainage to prevent leaching and runoff from dead animal collection and disposal areas.
  -- Screen collection points and compost areas from public view.

- Implement an odor control strategy that includes:
  - -- good neighbor, community, and public relations
  - -- site selection, isolation, and separation. Provide visual barriers around buildings and manure storage/treatment
  - -- up-to-date facility designs--ventilation; manure collection, storage, and treatment; land application.

Conducting an on-farm assessment provides several beneficial functions. An objective look at the production enterprise can impartially evaluate and identify production and management practices that can impact air and water quality around the farm. The person conducting the assessment can also consider the effectiveness of management practices for environmental conservation on your farm with other livestock producers.

In addition to regular self-assessment evaluations, the on-farm odor/environment assessment allows the producer to comprehensively evaluate their production system and business. Regular review and evaluation and proper management of buildings, manure handling, and production practices can help assure that your farm is environmental sound.

SUMMARY

Environmental compliance requirements will vary at different locations. A systematic approach to site selection and evaluation is the initial step in planning a new or expanded production unit.

In most cases, proper management of production facilities will complement an environmental management and operation plan. Management decisions that include consideration of good odor control and manure handling and utilization practices provide the most immediate and least costly alternative for good environmental management. Site selection, design of the manure handling and disposal system, management of lagoons and storages, selection of equipment and conditions for land application of manure, and proper management are essential.

Good community relations or "neighborliness" can go a long way to reducing the adverse reaction or affect of exposure to odors in the community. Being pro-active in demonstrating the value of livestock production operations and its people to the local community is essential. Be sure that a positive perception is maintained. What the neighbors see affects their attitude and perception about livestock production enterprises. Use visual screens, such as trees or buildings, to screen manure storages and other areas that remind people of odors and may suggest water quality impacts. A good community relations effort on the part of the farm manager may be one of the best control measures available.

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WHAT'S NEW IN THE 1998 NRC NUTRIENT REQUIREMENTS OF SWINE

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The National Research Council's Committee on Animal Nutrition is charged with establishing nutrient requirements for a variety of animal species. In April of this year, the Subcommittee on Swine Nutrition released the Tenth Revised Edition of the *Nutrient Requirements of Swine*. This document provides a basis for formulation of practical swine diets in the U.S. and many other countries. The intent of this paper is to chronicle the most significant changes in the 1998 *Nutrient Requirements of Swine* compared with the Ninth Edition released in 1988. Therefore, it is assumed that the reader has a thorough understanding of the contents of the ninth edition. A complete discussion of the basis for the nutrient requirements will not be attempted.

MODELS FOR PREDICTING ENERGY AND AMINO ACID REQUIREMENTS

The most exciting, noteworthy, and discussed feature of the Tenth Edition is the inclusion of computer models for predicting energy and essential amino acid requirements of gestating sows, lactating sows, and growing-finishing pigs weighing greater than 20 kg. These models move the *Nutrient Requirements of Swine* to a new level of sophistication and enhance the document's utility further into the future. Use of prediction models allows the user to define the genetic and environmental conditions under which the pigs will be raised. These computer models use various inputs (discussed below) to predict energy and essential amino acid requirements for pigs. The user must take responsibility for accuracy of the inputs and must decide if these inputs represent current levels of pig performance, target performance levels or maximal genetic potential of the pigs being fed. The model calculates dietary lysine needs then applies an ideal amino acid ratio to lysine for determination of other amino acid levels. Amino acid requirements can be expressed on a total, apparent ileal digestible or true ileal digestible basis. Requirements for minerals and vitamins are determined empirically through extensive review of scientific literature just like all nutrient requirements were determined in the 1988 version. The requirements for all nutrients can be expressed on a concentration or daily intake basis.

The internal calculations used by the model to predict nutrient requirements are presented entirely in Appendix 1 of the NRC publication. By publishing the assumptions and calculations used by the committee, the model becomes less of a "black box". Even though the model is fairly transparent, the user cannot manipulate the model aside from altering input information. If a user disagrees with a certain calculation or assumption, he or she cannot change the model's method of calculation to his or her liking. Validation of the models was achieved using 5 experiments for growing-finishing pigs, and 6 experiments for lactating sows. In most cases, the models slightly underestimated the lysine requirements. No evaluation of the gestating sow model was conducted due to the

lack of reported experiments with enough detail to allow comparison of predicted and measured lysine requirements. Now that the models are in the public domain, more extensive validation will likely occur and is needed in the next few years.

GESTATING SOWS

The gestating sow model requires the following inputs: dietary energy density (DE or ME basis), sow weight at breeding, and expected total number of pigs born in the next litter. In addition, the user must enter daily energy intake or desired gestation weight gain of the sow. If environmental temperature is included, the model will adjust expected feed intake to account for differences in ambient temperature. Outputs include maternal gain in body weight, lean and fat; expected intake of feed and energy; and energy density of the diet in addition to requirements for essential amino acids, minerals and vitamins.

When compared to the 1988 version of NRC, essential amino acid requirements are increased by 12 to 60% in the new version. Daily metabolizable energy requirements are essentially unchanged in the 1998 version compared to 1988. The manganese and vitamin E requirements from the 1988 version are doubled to 20 ppm and 44 IU/kg of diet, respectively, in the 1998 version. The folacin requirement was increased from .3 ppm in 1988 to 1.3 ppm in 1998.

LACTATING SOWS

Users of the lactating sow model must input dietary energy density (DE or ME basis), sow weight after farrowing, length of lactation, number of pigs nursed, and daily weight gain of individual pigs. Either daily energy intake or expected lactational weight change of the sow must also be entered. As in the gestation model, including environmental temperature will adjust expected feed intake and nutrient density of the diet. Environmental temperature has no direct impact on sow performance expectations or daily requirements for any nutrient except energy. Outputs of the model include: changes in sow body composition, milk production, predicted feed intake, as well as requirements for essential amino acids, minerals, and vitamins on a concentration and a daily basis.

Daily metabolizable energy requirements are increased slightly (2%) compared with the 1988 version. Essential amino acid requirements are increased 20 to 100% compared with amino acid requirements listed in the 1988 version. A large portion of this increase can be attributed to the improvement in lactational performance of sows over the last decade. Increases in the manganese, vitamin E, and folacin requirements for the lactating sow are identical to increases for gestating sows.

BREEDING BOARS

A new addition to the tenth edition of the *Nutrient Requirements of Swine* is a separate table listing the nutrient requirements of sexually active boars. While these requirements are based on very limited data, a separate listing indicates that the NRC Committee

believes requirements for some nutrients for breeding boars may differ from that of reproducing females. Essential amino acid requirements for boars are about 10% higher than similar requirements listed for gestating sows in the new edition of NRC. However, mineral and vitamin requirements are identical to those listed for gestating sows. Limited data prohibited modeling of nutrient requirements for the boar so all nutrient requirements were determined empirically.

NURSERY PIGS (3 - 20 kg)

Similar to the breeding boar, nutrient requirements for the weaned pig were determined empirically. The NRC Committee concluded there was insufficient data reported in the scientific literature to generate a reliable computer model for prediction of nutrient requirements of this class of pigs. Energy requirements and estimated voluntary feed intake were increased slightly for these young pigs compared to the 1988 version. In contrast, essential amino acid requirements increased 7 to 60% in the 1998 version compared with the previous edition. The range of increase for lysine requirements was 7% for the lightest category of pig (3-5 kg) up to 21% for the heaviest category of nursery pig (10-20 kg).

Sodium requirements listed in the tenth edition are 150 to 250% of levels listed in the 1988 version. Similarly, chloride requirements increased between 180 and 300%. Vitamin requirements for nursery pigs remain unchanged in the 1998 version compared with the last edition.

GROWING – FINISHING PIGS (20 - 120 kg)

Energy and essential amino acid requirements are predicted based on the following inputs: dietary energy density (DE or ME basis), body weight and sex of the pig, and fat-free lean gain. The fat-free lean gain input is an average over a user-defined weight range. Associated with this average lean gain is a default lean growth curve that allows prediction of lean gain and the associated nutrient requirements at any given weight within the specified body weight range. The user can alter the lean growth curve to suit his or her production situation. Daily energy intake, floor space allowance, and environmental temperature are optional inputs. Floor space allowance and environmental temperature are used to adjust voluntary feed intake and the dietary concentration of nutrients. Outputs include: carcass lean gain, whole body protein and fat gain, expected feed intake, average daily gain, efficiency of weight gain, and energy and amino acid requirements on a concentration and a daily basis.

Essential amino acid requirements on a concentration basis increased 10 to 50% for pigs weighing 20 to 80 kg compared with the last edition of the *Nutrient Requirements of Swine*. For pigs weighing 80 to 120 kg, amino acid requirements are essentially unchanged from the 1988 version. Nutrient requirements for pigs weighing greater than 120 kg are not included in the tenth edition because the committee was not confident of the limited published data for these heavier weight pigs. There are no changes in the

mineral or vitamin requirements of growing-finishing pigs in the 1998 compared with the 1988 version.

FEED COMPOSITION TABLES

Feed composition tables in the tenth edition are a compilation of nutrient analyses published in other sources. There are 79 ingredients in the 1998 feed composition tables compared with 56 in the ninth edition. Nutrient analysis of some ingredients found in the 1988 version may have changed for the 1998 version. These apparent discrepancies reflect changes in cultivars, processing techniques, and(or) improved analytical procedures.

Feed composition tables in the tenth edition have been expanded significantly compared to the previous edition. Concentrations of net energy, neutral detergent fiber, acid detergent fiber and bioavailable phosphorus for most ingredients have been added to the 1998 version while crude fiber concentrations were removed from the feed composition tables. Removal of crude fiber may present some challenges to feed manufacturers that must meet tag guarantees for crude fiber in feed products. Both apparent and true ileal digestibility of amino acids in feedstuffs are also reported. Linear regression equations that allow prediction of lysine, tryptophan, threonine, methionine, and methionine+cystine concentrations from crude protein content of an ingredient are provided. In addition, the correlation between crude protein content and amino acid concentration in the feedstuff is reported for each equation.

A more thorough characterization of fats and oils is provided in a separate table. This table includes concentration of selected fatty acids, unsaturated to saturated fatty acid ratio, and energy content on a digestible, metabolizable and net energy basis. Inconsistencies in the energy concentration of saturated and unsaturated fats present in the ninth edition have been corrected in the new version.

SUMMARY

The Tenth Edition of the *Nutrient Requirements of Swine* represents another step forward in the continuing process of fine tuning the nutrition of pigs. Incorporation of computer models to predict nutrient requirements provides nutritionists the potential to more clearly define dietary needs that are sensitive to biological, financial and environmental issues. No doubt, future versions of this publication will include more extensive models that have been more extensively validated.

HOW TO ORDER THE 1998 NRC PUBLICATION

Nutrient Requirements of Swine, Tenth Edition
Price: $40 plus $4 shipping and handling

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2101 Constitution Avenue, NW
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Notes

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EXPERIENCES WITH THE 1998 NRC NUTRIENT REQUIREMENTS OF SWINE

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The National Research Council's Subcommittee on Swine Nutrition has released its publication, Tenth Revised Edition of the *Nutrient Requirements of Swine*, in April 1998. This new NRC, 1998 is long overdue because much knowledge has surfaced since the last publication 10 years ago. The committee is to be commended for its painstaking review of the literature and the thorough reporting of its findings. The inclusion of mathematical equations to predict energy and amino acid requirements for various production phases is innovative and will serve as a spring-board for future models.

The 1988 version of *Nutrient Requirements of Swine* was referenced by nutritionists around the world. It has served as the standard by which minimum nutrient requirements for swine are compared. However, much research in swine nutrition has been reported since its publication, leaving the 1988 version inadequate and in great need of updating. The NRC, 1998 contains many revisions of nutrient requirements and some additional information in critical areas such as water and non-nutritive feed additives.

Even with the commendable effort of the subcommittee, it can be expected that this latest publication will come under much scrutiny. Some nutritionists will be critical of the interpretation of the research used and may wish to cite research reports omitted from the publication. Feed industry nutritionists will again have to consider that this publication reports minimum standards without any safety allowances when formulating diets.

As a professional nutritionist actively working in the feed industry, I have been asked to review the changes in the NRC, 1998 and share some of my experiences. Since its release in April, there has not been enough time to thoroughly test the model in all areas. In fact, a group of pigs placed on test and fed according to the energy and amino acid requirements as estimated by the growth model would, at the time of this writing, just now be marketed. Even so, I will attempt to fulfill this purpose by accomplishing the following objectives:

1) Discuss fundamental principles applied and revisions included in the NRC, 1998 that will be readily accepted by the swine feed industry,

2) Discuss some concerns that maybe expressed by the swine feed industry, and

3) Present a case study that determines nutrient (lysine) requirements and expected performance of a growing pig from the growth model, then compare those results with actual performance measurements. In this section, I will emphasis some of the pitfalls in determining nutrients requirements using the NRC, 1998.

PRINCIPLES AND REVISIONS READILY APPLIED

Feed industry nutritionists are quick to agree with the committee's fundamental principle that "quantitative nutrient requirements are not the same for all pigs". The 1988 version assumed all pigs had the same nutrient requirements. The NRC, 1998 not only recognizes this principle, but provides mathematical modeling methods for determining situation (farm) - specific estimates of nutrient requirements.

Equations for predicting digestible energy (DE), metabolizable energy (ME) and net energy (NE) are an important addition to the NRC, 1998. But, also useful is energy requirements expressed on a DE and ME basis, so as to accommodate the various formulation applications in the feed industry. Nutritionist with access to a variety of feed ingredients will depend heavily on the establishment of energy requirements using the NE system. However, if ingredients are limited to corn and soybean meal, ME will remain an adequate expression of energy requirements.

Of the many factors affecting energy requirements, the growth model considers two that are extremely important, space allowance and temperature. High stocking density and high ambient temperature will restrict energy intake in commercial production.

Ideal ratios of essential amino acids to lysine is a fundamental principle that will be accepted by the feed industry. The models provide the important feature of blending amino acids patterns. In the growth model, the amino acid pattern for lean tissue growth is predominant early, while the amino acid pattern for maintenance becomes more influential later in the pig's growth curve.

Expressing amino acid requirements on a true ileal digestible basis, apparent ileal digestible basis, and total basis are needed addition to NRC, 1998. These will provide flexibility in various formulations applications. The use of true ileal digestible values is vital when a variety of feed ingredients are used. Total amino acid values will be used to express amino acid requirements when corn and soybean meal are predominant in swine diets.

Several nutrient requirements have been increased in the NRC, 1998 as compared to the previous version. Lysine requirements for growing pigs, sodium chloride requirements for young pigs, and the manganese, vitamin E and folic acid requirements for sows have all been increased. These revisions will be supported by the feed industry.

Although the research is somewhat limited, the addition of a section on the nutrient requirements of boars is a start toward further refining the nutrient needs of this often forgotten animal. The expanded chapter on non-nutritive feed additives, and the new chapters on water and nutrient excretion provide excellent and timely information on these important areas for swine nutritionists to consider.

SELECTED AREAS OF CONCERN

In an attempt to address some of the concerns of the feed industry regarding the NRC, 1998, I will focus on the growing pig. Regarding these concerns, I have more questions than answers. I will reference the subcommittee's five principles used in the development of the models (chapter 3). There should be general agreement with these principles. However, inherent in each principle are pitfalls, some readily expressed by the committee.

For the most part, the committee has accomplished its desire to develop a model that is easy to use (principle #1). But, there is a concern that it may be too easy and could be misinterpreted by users with limited knowledge. Without knowledge of the principles described in the text, the use of the model can lead to erroneous recommendations.

The committee's desire to develop a growth model with continued relevance (principle #2) is a laudable goal. It is difficult to predict how changes in genetics and production systems will affect nutrient requirements. However, feed industry nutritionists must formulate diets in two production phases not adequately addressed in the NRC, 1998.

The committee does not estimate nutrient requirements for the growing pig beyond 120 kg (264 lb.). For many years, pork packers have offered carcass price incentives to producers who can market lean pigs at weights heavier than 264 lb.. The committee clearly states that the published research in this area is limited. However, the committee has often been forced to estimate nutrient requirements based on limited, and sometimes no research. Could the model have been expanded along "logical patterns of variations" in protein accretion rate and energy intake for an additional 40 lb. of body weight with stated warnings regarding the limited research in this area?

Earlier this decade, producers began adopting medicated early weaning (MEW) and segregated early weaning (SEW) concepts to improve health status of growing pigs. Because of these systems, nutritionists have faced the challenge of formulating diets for weaning pigs weighing less than 10 lb.. NRC, 1998 recommends nutrient requirements for pigs weighing 3 to 5 kg (6.6 to 11 lb.). Unfortunately, the committee was able to cite only one data base for determining the lysine requirement for this very young pig. Only two additional reports can be referenced for the lysine requirement of the 10-lb pig. Because of the weaning systems employed by most academic research stations, the body of data for determining lysine requirements for the young pig, begins at a 13-lb body weight. In figure 2-1, the committee shows its best estimate for the lysine requirement (total lysine basis) for the very young pig.

In addition, SEW systems have improved health of the pigs with one true indicator being improved feed intakes. How much of the research cited in NRC, 1998 was conducted on young pigs in systems where the health status is marginal? How has this improved health status of SEW pigs impacted their nutrient requirements? Several groups are actively conducting research in this area. There was no attempt by the committee to assess differences in nutrient requirements (if any) of high health and immune-challenged pigs.

Finally, there is concern regarding the default equation for DE intake (National Research Council, 1986). The equation was recently modified based on empirical data to represent greater feed intakes during the early growth period and decreased intakes during late finishing. Even so, the equation overestimates actual intakes of pigs in commercial production. Granted there is opportunity to override the default and enter DE intakes determined from actual feed intakes from farm-specific situations. But, without actual intakes, there may be tendency for the uninformed user to accept the default intakes as typical of commercial production which in turn affects the models ability to predict amino acid requirements.

In addition, the default floor space allowance greatly exceeds amounts typically provided in commercial settings. Entering a realistic floor space allowance reduces estimated feed intakes some, but the model still overestimates feed intake.

CASE STUDY

The following is a case study to determine lysine requirements and expected performance of growing pigs from the growth model. I will attempt to follow a logical pattern of testing the model in an applied setting with the estimates compared to actual feed intakes.

For this case study, I will use records from 3000 barrows collected since March 1, 1998. Genotype of all barrows was the same. Pigs were housed in confinement buildings typical of a commercial production facility. Starting and ending weights averaged 36 and 270 lb., respectively. The growing period was130 days. Average daily gain was 1.79 lb., average daily feed was 4.81 lb., and feed/gain was 2.69. The yield was 75.8%, which resulted in a hot carcass weight of 205 lb. Fat-free lean was determined to be 49.8%. According the equations in NRC, 1998 Appendix 2, carcass fat-free lean gain/day was calculated to be 318 grams/day which describes a pig with a medium-high lean growth rate.

Lysine specifications for each phase of growth (a given weight range) were determined by using the following average weight in each phase: 60, 120, 160, 200, and 240 lb. First, actual feed intakes were determined at each weight (Table 1). Then, the growth model was used to determine the lysine requirement for each phase assuming default DE intake and the default growth curve. Notice that the expected feed intake is substantially higher than actual. Expected daily gains are unrealistically high. Are the lysine requirements reported an accurate estimate of the lysine needs of these growing barrows?

TABLE 1		BODY WEIGHTS OF BARROWS, LB.			
	60	120	160	200	240
FARM SITUATION					
Actual daily feed intakes, lb	3.20	4.40	5.00	5.80	6.00
DEFAULT					
Exp. daily feed intake, lb	3.35	5.26	6.11	6.72	7.11
Exp. daily gain, lb	1.71	2.30	2.47	2.51	2.45
Exp. feed/gain	1.96	2.29	2.47	2.68	2.90
Lysine, total, %	1.04	0.79	0.69	0.61	0.55
DEFAULT @ 7 sq.ft/pig					
Exp. daily feed intake, lb	3.24	4.95	5.79	6.33	6.74
Exp. daily gain, lb	1.67	2.20	2.36	2.39	2.30
Exp. feed/gain	1.94	2.25	2.45	2.66	2.94
Lysine, total, %	1.07	0.84	0.73	0.65	0.58
FARM @ 7 sq.ft/pig					
Actual daily feed intake, lb	3.20	4.40	5.00	5.80	6.00
Exp. daily gain, lb	1.67	1.95	2.06	2.16	2.04
Exp. feed/gain	1.91	2.25	2.46	2.69	2.94
Lysine, total, %	1.07	0.90	0.82	0.70	0.64

Next, I reduced the space allowance from the default value of 10.76 sq.ft./pig to a more commercially applicable value of 7.0 sq.ft/pig. This lowered expected daily feed intake, but the model continues to overestimate feed intakes when compared to actual. Daily gain was reduced commensurate with intake, but remain unrealistically high. Feed/gain was similar to previous. Lysine requirements increased slightly.

Next, I entered DE intakes calculated from on-farm intakes and the energy density of feed provided at each growth phase. I had first assumed that I would not have to maintain the space allowance restriction since I was using on-farm intakes that should account for this restriction. Then I determined that the expected performance and lysine requirement was further reduced when the lowered space allowance was considered. Apparently, the actual (lower) energy intakes and the reduced space allowance together contributed to lower expected feed intakes as compared to results from the previous run of the model and much lower compared to the run assuming the default energy intake equation.

Daily gain was reduced, especially at heavier weights, but remain higher than actually observed. Feed/gain remained similar to previous. Lysine requirement increased slightly.

In this case study, the model seems to overestimate actual daily gain. This is puzzling because actual feed intakes were assumed, lower space allowance was imposed, ambient temperature was not a factor and lysine levels suggested by the model was similar to those fed at the farm. Does the model assume a higher efficiency of converting lysine to lean gain than what was actually occurring on the farm? Or is the actual growth curve different than the default growth curve?

The NRC 1998 offers the opportunity for the user to provide a lean growth curve that is different from the default curve (Appendix 3). It is well-documented that growth patterns of pigs are not the same. Our initial attempts at developing a lean growth curve on a specific genotype from a data base (that includes serial ultrasound scans) has not yielded reliable results. Reasons for the discrepancies are currently being investigated.

SUMMARY

Without question, the NRC, 1998 is greatly improved over the previous version. With time, nutritionists will have increased opportunity to test and validate the published requirements. The mathematical equations provide an established base for future refinements and improvements. As knowledge is rapidly increasing, the feed industry may not have the luxury of waiting 10 years for the next version of *Nutrient Requirements of Swine.*

NUTRITIONAL STRATEGIES TO ADDRESS ENVIRONMENTAL ISSUES RELATED TO PORK PRODUCTION: NITROGEN EXCRETION AND WATER CONSERVATION

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INTRODUCTION

The pork industry used to lament that it couldn't attract sufficient attention among consumers and legislators. As we approach the new millenium, the pork industry now laments that it is attracting too much – and inappropriate – attention! While the long term prospects for pork production in North America remain strong, it is clear that increasing attention must be directed towards environmental issues, as environmental sustainability is essential to our success. Therefore, the environmental initiatives of your industry leaders, such as the NPPC, should be applauded for being pro-active, internally directed and responsible.

While legislation, monitoring and self-regulation are going to be central to the industry's future, there are other implications for pork producers (Hacker and Du, 1993). One of these is a re-orientation of feeding programs to include environmental issues as well as the previous emphasis on production efficiency, product quality and consumer safety. Thus, feeding programs will need to address the excretion of nitrogen, phosphorus, potassium, sulphur, trace minerals and heavy metals in the slurry. Nitrogen and phosphorus, and in some cases sulphur and certain trace minerals, can be used as plant nutrients when applied to the land as slurry; in this instance, the issue revolves around application procedures to maximize benefit to the soil and eliminate run-off or leaching into water resources.

ODOUR

Odour is clearly the number one environmental issue surrounding the pig industry, at least from the perspective of the general public. Because odour is a highly subjective topic, it is a very difficult one for science to address. In addition, attempts to quantify odour in a manner that objectively reflects a human perspective have proven elusive, although great progress has been achieved in recent years.

There are some 160 identifiable compounds in pig slurry which can contribute to odour (O'Neill and Phillips, 1992). They can be subdivided into 6 categories: carboxylic acids, alcohols, phenolic compounds, mercaptans and sulfides (Zhu et al., 1996). It is not clear at this time what role nutrition might play in reducing odour emissions from pig barns. Certain dietary components, such as sulphur and nitrogen, are closely associated with many of the odour producing compounds. Furthermore, diet composition might affect the availability of substrates for fermentation processes which subsequently lead to the development or suppression of odours. Hobbs et al. (1996) demonstrated that reducing dietary protein concentration reduced several of the odour producing compounds. One can speculate that modifying gut pH, or the use of agents which modify gut bacterial populations, could prove to be helpful in reducing odours.

NITROGEN

One of the primary objectives of the pig industry currently is to maximize the rate of nitrogen retention within the pig carcass, as this will directly result in maximizing daily protein deposition. From an environmental perspective, the focus is on minimizing nitrogen excretion. Maximizing nitrogen retention and minimizing nitrogen excretion are not mutually exclusive objectives by any means, but they present different challenges and require consideration of different aspects of nitrogen metabolism. More than anything else, satisfying the two objectives concurrently means that nutritionists must achieve the highest possible degree of precision in order to meet the pig's metabolic requirements while avoiding excessive supply.

The utilization of dietary nitrogen is variable, but typically falls within the range of 30 to 55% (NRC, 1998). Thus, some 45 to 70% of the nitrogen in the diet will appear in the slurry. Part of the challenge is to maximize nitrogen retention in the carcass, since by extension this would reduce the quantity of nitrogen appearing in the slurry. Metabolically, this is more difficult to achieve than it seems, since excretory nitrogen is derived from two quite different pools – the diet and endogenous secretions.

The problem is best illustrated by referring to Figure 2. In a high quality diet, 95% of dietary nitrogen is absorbed by the small intestine, so digestibility would not be a large problem. Endogenous secretions, on the other hand, represent a much greater challenge, since they are less digestible (75% versus 95%) and since the total quantity of endogenous nitrogen released into the small intestine can vary widely. The utilization of absorbed nitrogen for protein synthesis is only moderately efficient, with some 30% of absorbed nitrogen lost. Of course, this proportion can vary widely depending on many factors, including the amino acid balance of the diet. Let us look at each of these components, and develop strategies to address each in turn.

Nitrogen utilization

Various models of nitrogen utilization in the pig have been developed. Fundamentally, nitrogen is employed in six fundamental processes: digestion and absorption, maintenance of skin and hair, protein turnover, gut maintenance and secretions, amino acid catabolism and protein synthesis (Moughan, 1994).

Digestion and absorption

More will be said about digestion and absorption later, but suffice at this time to say that numerous factors, both extrinsic and intrinsic, can influence the extent of digestion and absorption; in particular, bacteria play a much larger role than many people appreciate; some estimates suggest that as much as 80% of the nitrogen appearing in the faeces is associated with bacteria. In a highly digestible diet, 90 to 95% of ingested nitrogen is absorbed (Figure 3); approximately 5 to 6% of the absorbed nitrogen may exist as ammonia and will therefore be eliminated in the urine. The faeces will contain somewhat more than 5 to 10% of the ingested nitrogen, the extra arising from endogenous sources (Huisman et al., 1993; Figure 2). The extent of nitrogen digestibility is independent of sex or strain of pig, but is influenced by age, disease and many factors associated with diet composition.

Skin and hair replacement

A very small proportion of total nitrogen flow is involved in the integument. It has been estimated at well under 1% of the total and therefore it is of little relevance in the current discussion.

Protein turnover

On a daily basis, about 5% of total body protein is turned over (Moughan, 1994). Since the body consists of about 16% protein, a 50 kg pig will turn over about 400 g of protein daily. Obviously, protein turnover is not a perfectly efficient process, so that a portion of this protein – estimated by Moughan

(1989) at 4% - will be inevitably lost. The rate of turnover is related to protein deposition rate, and is influenced by health status.

Gut maintenance and secretions

Gut function, including motility, digestion and absorption, result in loss of gut tissue and the secretion of enzymes and other proteinaceous compounds, into the body of the intestinal tract. This material is exposed to the same digestive processes which breakdown the feed material, and therefore is itself degraded and to a large extent, absorbed. The absorption of endogenous secretions has been estimated at about 75 (Huisman et al., 1993). Many factors will influence the level of endogenous secretions, including dry matter intake, dietary fibre content and the presence of various anti-nutritional factors. One of the topics of great interest in swine nutrition at the present time is methods of accurately measuring endogenous secretions. It is an important subject, as it influences not only our ability to measure true amino acid availability, but also our understanding of nitrogen metabolism.

Amino acid catabolism

Amino acids are broken down as a consequence of normal cell metabolism, or if absorbed amino acids have been altered, such as by exposure to heat and moisture, rendering them unavailable for protein synthesis. The breakdown of amino acids may occur if energy is limiting and the carbon skeleton of amino acids is required as an energy source. In addition, dietary amino acids are required as essential precursors of glutathione, nitric oxide, polyamines, purine and pyrimidine nucleotides and certain amino acids (Wu, 1998). There is very little information of the quantity of amino acids broken down in the pig.

Models of nitrogen metabolism

Considering all of the above components of nitrogen flux, Moughan (1994) has developed a model, the output of which is presented in Figure 3. In this example, even with a pig of reasonable protein deposition rate and receiving a well balanced diet, only 28% of total dietary nitrogen is retained. It is quite valuable to study this model, or others like it, as it provides insight into where nitrogen losses occur, and thus helps us to focus our attention on the important variables.

A somewhat different approach is presented in Figure 2. Huisman et al. (1993) has tracked dietary nitrogen as at flows from the stomach through the digestive tracts and into one of the three ultimate fates – voided in the urine, excreted in the faeces or retained as body protein.

The Huisman et al. model is interesting, as it focuses attention on the nitrogen of endogenous origin. As mentioned previously, 90 to 95% of nitrogen in a high quality diet will be absorbed, while only 75% of endogenous nitrogen is absorbed. If nitrogen of endogenous origin represents 50 to 60% or more of the quantity of nitrogen in the diet, and if it is utilized with less efficiency, then we must focus more attention on this pool if we are going to truly minimize overall nitrogen excretion.

Nitrogen digestibility

Based on the data of de Lange et al., 1990, Huisman et al. (1992) and Makkink and Heinz (1991), many common feedstuffs, including barley, peas and soybean meal, will result in true N digestibility greater than 90%. This being true, one can reasonably conclude that reducing nitrogen excretion through improved nitrogen digestibility (true) will provide only marginal benefits. For example, increasing the true nitrogen digestibility of barley from 90 to 95% would decrease nitrogen excretion by less than 1%. Thus, the use of various techniques to improve nitrogen digestibility and thus reduce nitrogen losses will provide little benefit when these ingredient are employed.

However, there are many exceptions. For example, the true nitrogen digestibility of by-product feedstuffs can be much lower than 90%, so that improving nitrogen digestibility would prove beneficial.

Examples of ingredients with lower true nitrogen digestibility include canola meal and heat processed by-products.

It is also well known that certain chemical components present in common feedstuffs can reduce nitrogen digestibility; these include non starch polysaccarides and various anti-nutritional factors (eg. protease inhibitors). However, it is possible to minimize their impact by applying certain specific processing techniques; for example, well controlled heat treatments should benefit the pig consuming diets containing protease inhibitors, and dehulling is an effective way to reduce dietary fibre content.

Endogenous secretions

The role of endogenous secretions cannot be underestimated in any discussion of nitrogen excretion. Apparent ileal digestibilities are vastly superior to faecal digestibility when it comes to formulating diets, but true ileal digestibilities are even better. There is no doubt that true ileal digestibility will become the standard in the future, once methodological issues have been addressed. In the interim, it is important to recognize that apparent digestibilities differ, in some cases substantially, from true (Table 1).

Endogenous secretions represents a formidable challenge in terms of reducing nitrogen excretion into the slurry. In part, this is due to the apparently lower digestibility of endogenous nitrogen secretions, and in part, because the quantity of such secretions, and thus their contribution to the total nitrogen load, varies significantly. For example, Schulze et al. (1993) reported that endogenous secretions represented from 53% to 92% of total daily nitrogen supply when comparing soybean meal, fish meal, skim milk powder and soybean protein isolate.

Amino acid utilization

The efficiency with which dietary amino acids will be converted into protein, and thus retained in the carcass, will depend on many factors. First, the amino acids present in excess of that required for a given rate of protein deposition will be catabolized in some fashion; thus will reduce the apparent efficiency of incorporation of dietary amino acids into carcass protein. This has nothing to do with the efficiency of the process of protein synthesis, but rather the relationship between supply and utilization. The rate of protein synthesis in the pig will depend on many obvious factors, such as genotype, the thermal environment, health status, gender and the presence of stressors.

A less obvious factor, or at least one which is less understood, is energy supply. Protein synthesis is a process which requires energy. Insufficiency of energy intake, which often occurs during the weanling and growing phases, and which may be a factor even in the finishing phase in some instances, will place an upper limit on protein synthesis, and thus reduce nitrogen retention. For this reason, to maximize the utilization of dietary protein for anabolic processes, diets must be formulated to ensure adequacy of energy, as well as amino acid, supply.

There appears to be an intrinsic minimum lipid:protein ratio which cannot be exceeded. This ratio is influenced presumably by genotype and gender, and must be acknowledged in any feeding program. Simply stated, as protein deposition increases, lipid deposition must increase proportionately; alternatively, insufficiency of energy available to support this minimum rate of lipid deposition will limit protein deposition rate, resulting directly or indirectly in reduced nitrogen retention.

Any practice which increases the rate of protein synthesis has the potential, at least, of reducing the rate of nitrogen excretion. Thus, improved control of the barn environment, leading to less thermal stress and less social stress, should result in better and more predictable feed intake. This, in turn should lead to improved and more predictable levels of nitrogen retention.

The use of growth promotants which stimulate lean accretion rates will generally improve nitrogen retention. This, of course, depends on maintaining an appropriate relationship between nutrient supply and nutrient demand for catabolism.

Ingredient variability

Another issue with regards to nitrogen retention and utilization is ingredient variability. For example, Fairbairn (1997) reported that nitrogen retention measured within 20 barley samples varied from 35% to 45%. However, this study did not determine if the differences in nitrogen retention represented differences in true nitrogen digestibility or in the level of endogenous secretions.

Formulation practices to reduce nitrogen excretion

Once one understands the nature of nitrogen excretion, and the factors which influence it, it becomes a much easier task to formulate diets with the objective of reducing the nitrogen content of the slurry. It is intuitively clear that maximizing nitrogen retention at the lowest possible cost and minimizing nitrogen losses in the slurry are not mutually exclusive and in fact are, in most instances, goals which encourage similar feeding practices. Following are some possible ways to reduce nitrogen excretion; the practicality of each will depend on individual circumstances.

Phase feeding

Phase feeding is already practiced to a large extent in North America, so any progress which can be expected will relate more to the application of the concept than to its introduction. However, its impact should not be underestimated. For example, Henry and Dourmad (1993) reported that the use of a two-phase feeding program during growout will reduce nitrogen excretion by 10 to 20%.

Avoiding over-formulation

Although easier said than done, avoiding excess protein in the diet is one way to reduce nitrogen excretion. Even in well balanced diets, 5 to 10% of the nitrogen in the diet is present in excess of requirement. Over-formulation is often employed as a means to maximize the performance of all pigs in a group, including those with poor appetites, or others with very high protein deposition rates. In reality, this practice is costly and reflects more a lack of information on actual nutrient requirements than a need to provide a large "safety factor." For examples, Lorschy et al. (1998) recently reported that within a group of pigs, those expressing higher than average protein deposition rates also consume more feed, such that only modest increases in nutrient concentration in the diet are required to satisfy these high performing animals. Avoiding excessive protein content in the diet is an example of where production efficiency and environmental management follow a common path.

Low protein diets

Another way to minimize nitrogen excretion is to formulate diets to the same overall levels of essential amino acid, but use more synthetic amino acids and less intact protein. The net result is a more balanced overall protein with fewer excess amino acids present in the diet. One approach is to establish within the feed formulation program a lower limit for the ratio of lysine:crude protein. As illustrated in Table 2, increasing the lysine:crude protein ratio from 4.9 to 5.7 would reduce nitrogen excretion by about 22%; however, the increased feed cost would normally be prohibitive. Increasing the lysine:crude protein ratio from 4.9 to 5.2 would reduce nitrogen excretion by 11% with a much more modest impact on feed cost.

It has proven difficult to achieve equivalent performance in pigs when using low protein diets supplemented with synthetic amino acids. For example, Kerr and Easter (1995) observed that performance and nitrogen retention declined when crude protein was reduced from 16% to 12%; supplementation of the low protein diet to achieve equivalent performance and nitrogen retention resulted in equivalent nitrogen excretion as well, thus defeating the original objective.

Ingredient selection
As described above, certain ingredients are more digestible than others, such that the simple choice of ingredients can reduce nitrogen excretion in the slurry. However, some of the less digestible ingredients may also be highly economical; eliminating them from the diet would therefore increase overall production costs.

Manage barn environment
Maintaining an optimum physical and social environment for the pig will result in more consistent and predictable feed intake; this, in turn, will make it much easier to formulate diets which maximize nitrogen utilization. Factors which reduce feed intake, particularly on an irregular or unpredictable basis, make it difficult if not impossible to adjust diet composition to ensure adequate but not excessive amino acid levels.

Indirect means
While direct focus on the pig and its use of nitrogen is important, other opportunities to reduce overall nitrogen excretion must be considered. For example, increasing sow herd productivity means that more pigs are produced per sow, resulting in a lower allocation of breeding herd nitrogen excretion to each market hog. Jongloed (1991) has estimated that sows retain less than 20% of dietary nitrogen. The impact of the breeding herd on overall nitrogen excretion is therefore important.

Reducing feed wastage is also important. While properly managed feeders waste, on average, about 3.5% of total feed (Gonyou and Lou, 1998), improper adjustment, disrepair and poor design can lead to wastage which is double or triple these levels. The consequence of feed wastage must not be underestimated, since all of the feed nitrogen in wasted feed appears in the slurry.

Other considerations
The nitrogen content of slurry, in and of itself, is not a bad thing. It really only becomes an environmental issue when other things happen: nitrogen is released into the atmosphere as ammonia, or nitrogen, often as nitrate, leaches into ground or surface water and this leads to water pollution. Slurry management, to minimize ammonia release and to prevent leeching into water, can and should be an objective of the pig industry. The appropriate application of slurry onto the land is not only desirable as a fertilizer and soil texture modifier, but any such nitrogen applied to the land reduces the need for nitrogen fertilizers. This, in turn, helps to conserve fossil fuels, which are consumed in large quantities in commercial fertilizer production.

WATER

Water represents more than 50% of total body weight (Table 3), yet until recently has received little attention by either researchers or legislators. Water is inexpensive to obtain and is generally considered to be a reasonably abundant resource in most pig producing regions. Until recently, most people believed that, provided animals receive a continuous supply of water, generally via nipple drinkers, requirements would be met with little or no human intervention (Fraser et al., 1990).

While water is abundant, resources are not limitless. Increasingly, water supplied to pig farms is obtained from the same ultimate source as human drinking water or water for irrigation, so conflicts over access are becoming more common. The cost of water is rising, not only in its supply, but also in its removal. Lemay (personal communication) recently calculated that wasted drinking water, occurring with the use of nipple drinkers, increases the cost of production by about CAD $0.61 per pig, due solely to increased slurry hauling charges. Thus, water conservation measures make both economic and political sense to pork producers.

There is appropriate concern regarding the restriction of water intake on nutrient intake and utilization. There is little research on the topic, but that which is available suggests that water intake is not as critical as many people surmise. For example, Mroz et al. (1996) reported that varying the water:feed ratio from 2:1 to 4:1 in gestating sows had no impact on apparent digestibility of dry matter, organic matter, ash, nitrogen, calcium or phosphorus. However, it more than doubled daily urinary output, from 2.9 to 6.5 L/d. The Dutch government recommends a water:feed ratio of 2.5:1, 2.25:1 and 2.0:1 for growing pigs from 25 to 40, 45 to 70 and above 70 kg, respectively (Central Veevoederbureau, 1993). These standards are low by some current recommendations. however, they are supported by various studies, such as that reported by Cai and Zimmerman (1992) who found no effect of reducing the water:feed ratio to 1.5:1.

A typical water balance for a growing pig appears in Table 4. It illustrates that even with modest water consumption, urinary output is equal to more than half of total drinking water consumed. Diet modification is certain to alter free choice water consumption. For example, reduction in water intake has been associated with lower protein (Pfeiffer et al., 1995) and mineral levels in the diet.

CONCLUSION

At the beginning of this decade, pig nutritionists in North America paid almost no attention to such issues as slurry composition or quantity. As we leave this decade, the situation could not be more different. Nitrogen retention is now almost as important in terms of its impact on slurry composition as it is in carcass composition and lean tissue gain.

Further developments can be expected in our ability to modify slurry nutrient content at the lowest possible cost. Intuitively, maximizing nitrogen retention at the lowest possible cost, and minimizing nitrogen excretion into the manure, should not be competing objectives.

Finally, the authors hope that nutrient management is considered in terms of the total agronomic cycle, including crops, as manure application to the land is a technology that transcends modern agriculture and provides benefits beyond that of simple nitrogen and phosphorus supply. However, the view of slurry as "waste" which is becoming all too common today, must be erased and replaced by a philosophy of managing nutrient cycles in ways which minimize environmental disturbances and maximizes the efficiency of the food production system – animal and plant.

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Table 1. Apparent and true nitrogen digestibility in 7 week old piglets

	Skim Milk Powder	Soybean Meal	Fish Meal
Apparent ileal N digestibility, %	84.4	76.5	73.0
Endogenous N less, mg/d	768	1422	1558
True ileal N digestibility, %	92.7	90.6	89.3

Source: Makkink, 1993.

Table 2. Impact of increasing lysine:protein ratio on diet cost and relative nitrogen excretion

	1	2	3	4
Ingredients				
Wheat	47.11	56.67	-	-
Barley	20.98	16.41	69.72	74.68
Canola meal	15.00	15.00	11.98	3.90
Soybean meal	14.10	8.82	12.28	15.22
Canola oil	-	-	2.90	2.70
l-Lysine HCl	0.06	0.21	0.19	0.24
l-Threonine	-	0.07	0.07	0.11
dl-Methionine	-	-	0.02	0.07
l-Tryptophan	-	-	-	-
Other	2.75	2.82	2.88	3.08
Nutrients				
D.E., Kcal/kg	3,250	3,250	3,250	3,250
Cr. protein, %	21.0	19.5	18.0	17.0
dLysine:DE	2.5	2.5	2.5	2.5
tLysine:CP	4.9	5.2	5.7	5.9
dEB, mEq/kg	180	145	175	170
Cost, USD/ton	99.64	103.15	109.98	117.24
Nitrogen excretion	100	89	78	71

Table 3. Body composition of pigs during the growout phase of production

	45 kg		75 kg		120 kg	
	Barrows	**Gilts**	**Barrows**	**Gilts**	**Barrows**	**Gilts**
Body weight, kg	44.0	44.8	75.1	75.8	121.5	119.5
Empty body weight, kg	40.5	40.8	71.2	70.7	115.4	113.5
Ave. daily gain, g	930	881	1,094	999	1,019	1,032
Protein deposition rate, g/d	139	130	156	153	146	143
Feed conversion	0.681	0.644	0.409	0.429	0.311	0.375
Body composition						
- Nitrogen, %	2.6	2.6	2.7	2.7	2.6	2.6
- Water, %	65.1	64.5	50.0	46.6	52.4	51.0
- Ash, %	3.6	3.2	3.5	4.4	3.4	2.9

Adapted from Lorschy et al., 1998.

Table 4. Typical water balance in the growing pig

Intake	**mL**	**Output**	**mL**
Drinking water[a]	5,625	Body accretion[d]	510
Food water[b]	275	Faeces[e]	1,485
Water of oxidation[c]	560	Lungs[f]	700
		Skin[g]	420
		Urine[h]	3,345
TOTAL	**6,460**	**TOTAL**	**6,460**

Assumptions: 75 kg pig growing at the rate of 1,050 g/d, protein deposition rate of 155 g/d and eating 2,500 g/d of a reasonably well balanced commercial diet. All calculations rounded to nearest 5 g. Actual results may vary widely from this example, due to environmental, nutritional, health and genetic factors.

[a] Assuming ad libitum water intake equal to 2.25 times feed intake. Actual intake under commercial conditions may vary, depending on air temperature, feed composition, etc.

[b] Assuming feed contains 89% dry matter.

[c] Assumed to be 7.43 mL/kg BW (Gill, 1989).

[d] Assumed to be 48.3% of body weight (Lorschy et al., 1998)

[e] Assumed the digestibility of the dry matter of the diet to be 80%, and the faeces to contain 30% dry matter

[f] Estimated at 0.01 mL/kg BW/day (Gill, 1989)

[g] Estimated at 13.2 mL/m^2/hr (Gill, 1989)

[h] To maintain water balance

PIG BARN
NUTRIENT FLOW CHART

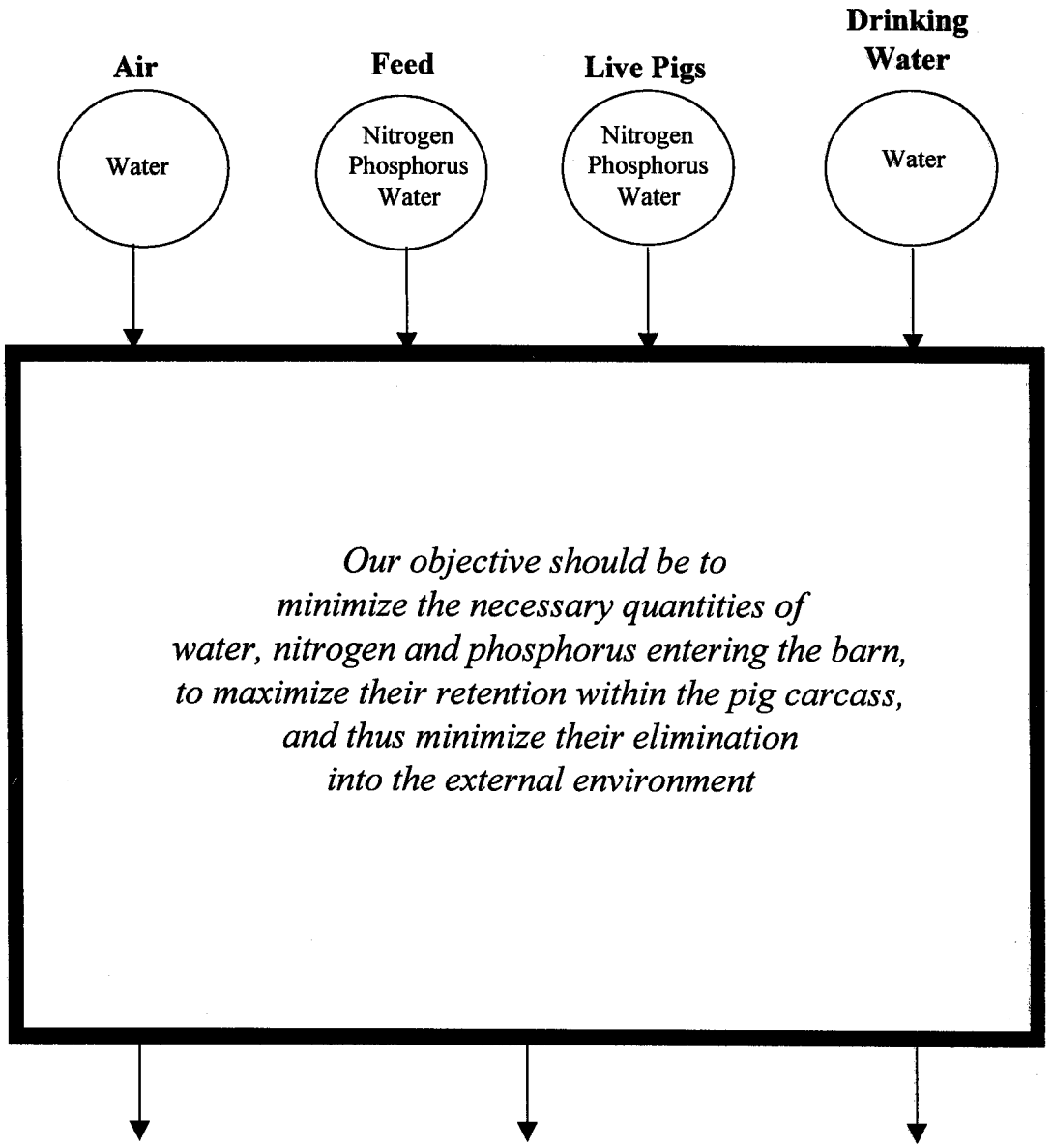
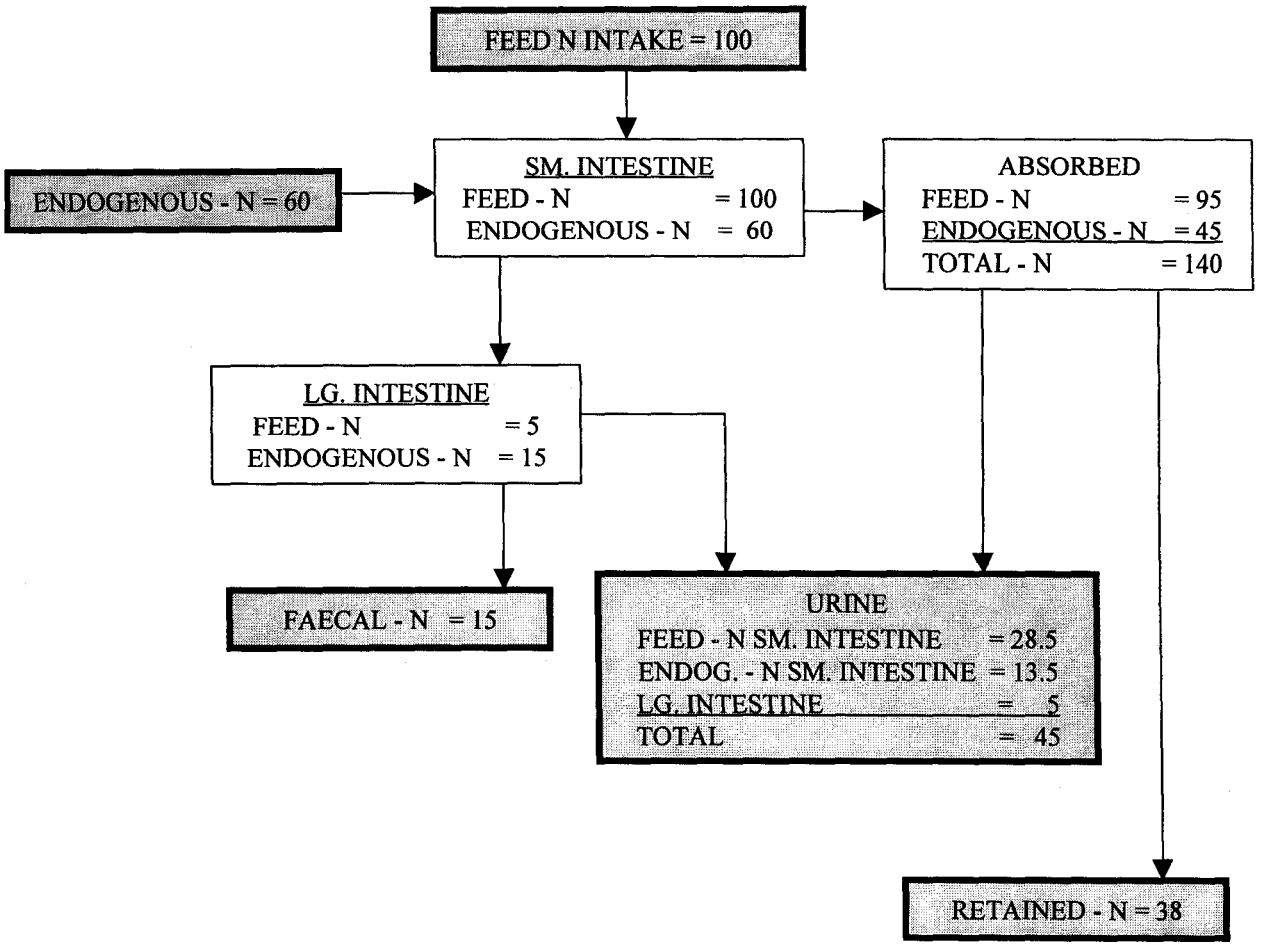


Figure 1

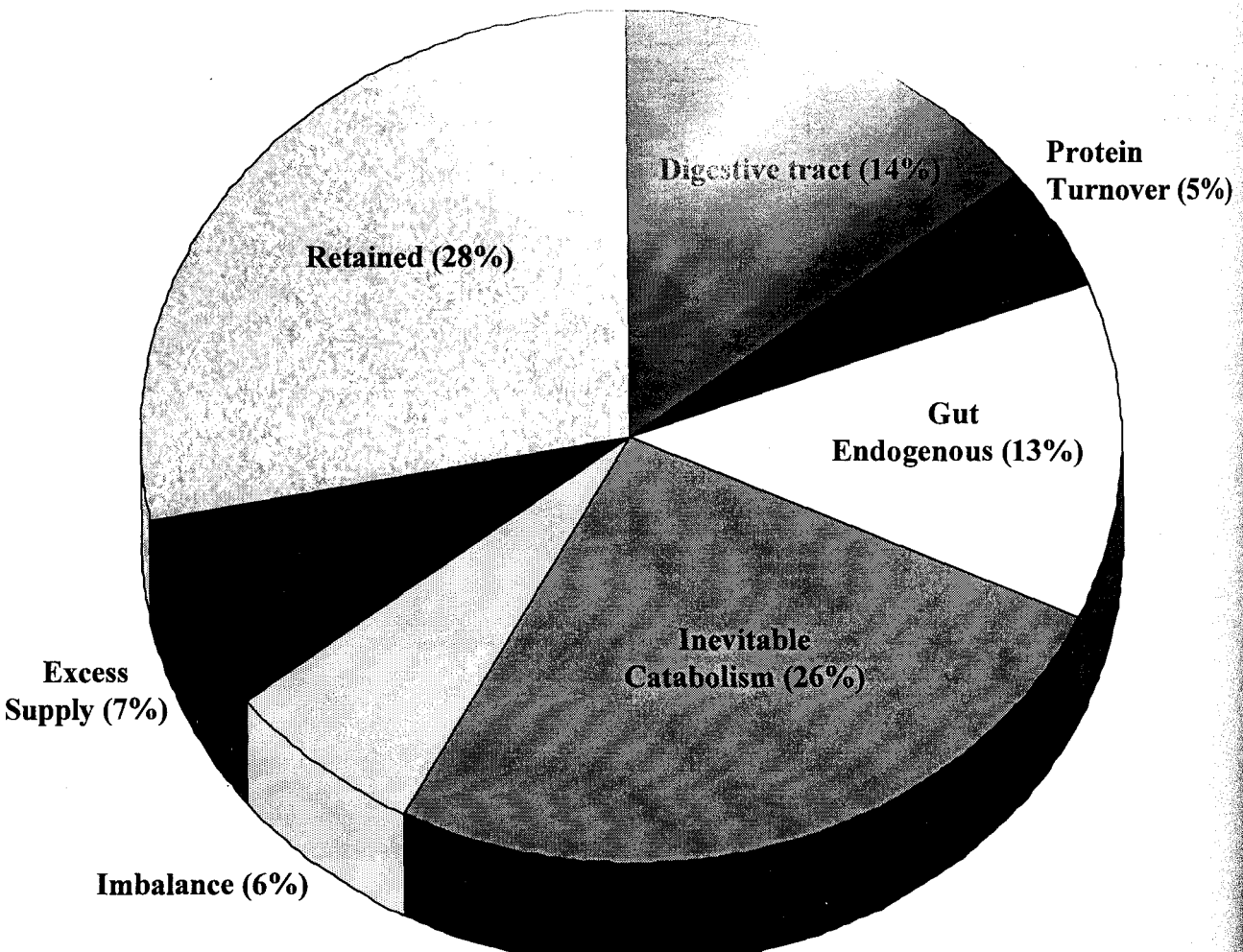
NITROGEN FLOW IN THE PIG



Source: Huisman et al., 1993. Assumes 95% true ileal digestibility of feed N, 80% apparent ileal digestibility of feed N, 75% true digestibility of endogenous N. Therefore, for every 100 g of nitrogen consumed in the feed, 95 g will be absorbed and 5 g will flow through into the large intestine. Endogenous N secretion will be 60 g, of which 45 g (75%) is absorbed and 15 g will enter the large intestine. Thus, in this example, the large intestine receives a total of 20 g N for every 100 g of dietary N (e.g.. 80% apparent digestibility of feed N). Also, for every 100 g dietary N, 140 g is absorbed from the small intestine. Of this absorbed N, about 30% represents obligatory losses which occur during resynthesis of protein. Urine also contains the N which is absorbed from the large intestine. In this example, N retention is equal to 38% of dietary N intake.

Figure 2

NITROGEN FLOW IN THE GROWING PIG



Source: Moughan, 1994). Predicted utilization of dietary nitrogen by a 50 kg pig (P_d = 130 g/d) consuming 2.6 kg/d of a diet containing 3,170 kcal DE/kg, 0.92% total lysine and 17.8% crude protein.

Figure 3

NUTRITIONAL MANIPULATION OF SWINE DIETS TO REDUCE HYDROGEN SULFIDE EMISSIONS

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INTRODUCTION

Hydrogen sulfide gas is one of hundreds of known odor producing compounds emitted from livestock facilities. The smell of hydrogen sulfide is best described as a "rotten egg" smell. Hydrogen sulfide gas is heavier than air and tends to be in highest concentrations at the surface of manure storage containments. However, unlike other gases produced in livestock operations, it can be deadly if high concentrations (over 100,000 ppb) are present. Generally, this only occurs when anaerobic deep pits beneath swine confinement buildings are agitated during manure removal and adequate ventilation is not provided. Low levels of hydrogen sulfide can cause headaches, dizziness, nausea, or insomnia. Because of these potential adverse health effects, it has become the latest environmental component being studied and monitored near swine facilities in 23 states including Minnesota.

The Minnesota Department of Health considers a level of less than 50 ppb hydrogen sulfide of ambient air exposure in one hour to be safe for humans to breathe. This level is not an established standard yet in Minnesota, but is considered a maximum safe value for monitoring purposes. However, OSHA has established a level of 10,000 ppb hydrogen sulfide exposure per eight-hour day to be the maximum tolerable level in the work place for worker safety.

Currently, MPCA is monitoring hydrogen sulfide levels on livestock farms. Hydrogen sulfide levels on most farms fall below the 50 ppb maximum, but some farms occasionally have a brief increase in emissions before dropping back to less than 50 ppb. Furthermore, we do not understand why hydrogen sulfide is a problem on some farms and not on others. The concern over hydrogen sulfide emissions from confinement swine operations has made it more difficult for producers to obtain building permits because permits cannot be issued if there is knowledge that a state environmental standard is going to be violated.

The purpose of this paper is to review our current understanding of hydrogen sulfide production and odor, as well as the influence of diet formulation and feeding programs for reducing hydrogen sulfide gas in swine facilities.

SULFUR NUTRITION AND METABOLISM IN THE PIG

Sulfur is an essential element for the pig, and the sulfur requirement appears to be adequately met by providing adequate levels of the sulfur containing amino acids methionine, cystine, and cysteine, and

the water soluble viatmins biotin and thiamin. Certain mucopolysaccharides, including chondroitin sulfate and the mucoitin sulfates, heparin, glutathione, taurine, and coenzyme A are also important sulfur containing metabolic compounds. Because proteins are present in every cell of the body, and S-containing amino acids are components of almost all proteins (usually 0.6 to 0.8% of the protein), sulfur is widely distributed throughout the body and is found in every cell to make up about 0.15% of body weight. Sulfur functions mainly through its presence in organic metabolites. Inorganic sulfate from exogenous dietary sources and from endogenous release from S-containing amino acids is used in synthesizing the chondroitin matrix of cartilage, in biosynthesis of taurine, heparin, cystine, and other organic constituents of the animal body (Baker, 1977).

Inorganic sulfur is considered to be essential for animals for normal maintenance or productive functions. Furthermore, because intestinal absorption of inorganic sulfur compounds is low, sulfur toxicity is not a practical problem. Absorption of inorganic sulfate from the gastrointestinal tract is inefficient. Active transport of SO^{2-}_4 takes place from the upper small intestine. Both inorganic and organic forms of sulfur are used for sulfation of cartilage mucopolysaccharides. Organic forms of S are absorbed readily relative to all sulfur compounds. Inorganic sulfur is excreted via feces and urine. Unabsorbed sulfur is likely reduced in the lower GI tract and excreted as sulfate. Urinary sulfur is present mainly as inorganic SO^{2-}_4, but also as a component of thiosulfate, taurine, cystine, and other organic compounds. Because the bulk of body sulfur is present in amino acids, it is not surprising that urinary S excretion tends to parallel urinary N excretion. High protein diets are associated with large amounts of urinary sulfur and nitrogen.

Banwart and Bremner (1975b) were able to detect only one (dimethyl sulfide) of six sulfur containing gases in fresh swine manure using gas chromatography methodologies. Reduction of inorganic sulfate to sulfide occurs to a limited extent in nonruminants (Kline et al., 1971). Therefore, it appears that most of the production of hydrogen sulfide and other volatile sulfur containing gases occurs as a result of microbial fermentation during manure storage.

PRODUCTION OF GASES AND ODOR IN STORED MANURE

Once urine and feces enter an anaerobic pit, numerous chemical transformations occur. For example, urea is hydrolyzed to ammonia and CO_2, and sulfate is reduced to hydrogen sulfide. Plant fiber and protein are also anaerobically degraded to low molecular weight compounds during anaerobic digestion. Over 150 volatile odorous compounds have been identified in swine manure, and most are presumed to be products of anaerobic microbial degradation of waste (Spoelstra, 1980). Of these 150 volatile compounds, the following compounds are considered to be the main components responsible for offensive odors in swine waste (Spoelstra, 1980).

Air Components	Waste Components
ethanoic acid	ethanoic acid
propanoic acid	propanoic acid
butanoic acid	butanoic acid
	2-methyl propanoic acid
	pentanoic acid
	2-methylbutanoic acid
	3-methylbutanoic acid
	2-methylpentanoic acid
phenol	phenol
	3-methylphenol
4-methylphenol	4-methylphenol
4-ethylphenol	4-ethylphenol
	benzoic acid
indole	
skatole	skatole
	phenylacetic acid
diethyldisulfide*	
propanethiol*	
butanethiol*	
dipropyldisulfide*	
2-methylthiophene*	
propylprop-1-enyldisulfide*	
2,4 dimethylthiophene*	
2-methylfuran	

* ***Indicates sulfur containing compounds.***

Notice that approximately 50% of the compounds considered to be primary contributors to swine odors in air of confinement swine facilities contain sulfur. The reason that some compounds are undetectable in air but are found in swine waste is because of chemical reactions between these compounds and the atmosphere. The reduced sulfur compounds are very reactive in air.

In addition to the sulfur compounds listed above, other sulfur containing compounds are also present in air and waste of swine facilities. During manure storage, sulfate is reduced to hydrogen sulfide (Riviere, 1974). The following are additional sulfur containing compounds that have been detected in air and pig manure:

Air Components	Waste Components
carbonyl sulfide	
hydrogen sulfide	hydrogen sulfide
methanethiol	methanethiol
dimethylsulfide	dimethylsulfide
	diethylsulfide
dimethyldisulfide	dimethyldisulfide
dimethyltrisulfide	dimethyltrisulfide
	ethanethiol
diethyldisulfide	diethyldisulfide
propanethiol	propanethiol
butanethiol	butanethiol
dipropyldisulfide	
2-methylthiophene	
propylprop-1-enyldisulfide	
2,4-dimethylthiophene	
2-methylfuran	

Most of these compounds are present only in trace amounts (Banwart and Bremner, 1975a). Hydrogen sulfide and methyl mercaptan are most frequently reported as constituents of pig waste and are quantitatively the most important S-containing volatile constituents (Spoelstra, 1980). In ventilation air, only traces of these compounds have been reported (Schaefer et al, 1974; Avery et al, 1975). This is probably due to oxidation of mercaptans to the less volatile disulfides by air (Kadota and Ishida, 1972) and possibly by adsorption. Hydrogen sulfide is likely to originate mainly from microbial reduction of sulfate. Urine contains about 1100 mg/l of sulfur, mainly as sulfate, which originates from animal metabolism (Loehr, 1974). Sulfate reducing organisms have been found to be present in pig wastes in amounts up to 10^3-10^4 per ml (Riviere et al., 1974). Sulfate reducing bacteria have been shown to produce trace amounts of carbon disulfide, carbonyl sulfide, and methyl, ethyl and propyl mercaptans (Hatchikan et al., 1976). In addition, hydrogen sulfide can be produced by microbial degradation of cysteine and cystine (Freney, 1967; Riviere et al, 1974). Carbon disulfide and diethyl sulfide have been reported as products from cysteine. Methionine is decomposed mainly to methyl mercaptan and dimethyl sulfide (Freney, 1967; Kadota and Ishnada, 1972). Most of the other identified S-containing volatiles seem to be derived from more seldomly occurring amino acids like substituted cysteine, which occur in plants (Meister, 1965; Freney, 1967).

CHEMISTRY OF HYDROGEN SULFIDE PRODUCTION AND OTHER VOLATILE SULFUR COMPOUNDS DURING MANURE STORAGE

Sulfur is found in a variety of chemical forms and is interconverted between forms depending on chemical conditions in manure storage systems. Figure 1 shows interconversions that occur in the sulfur cycle (Sawyer and McCarty, 1978).

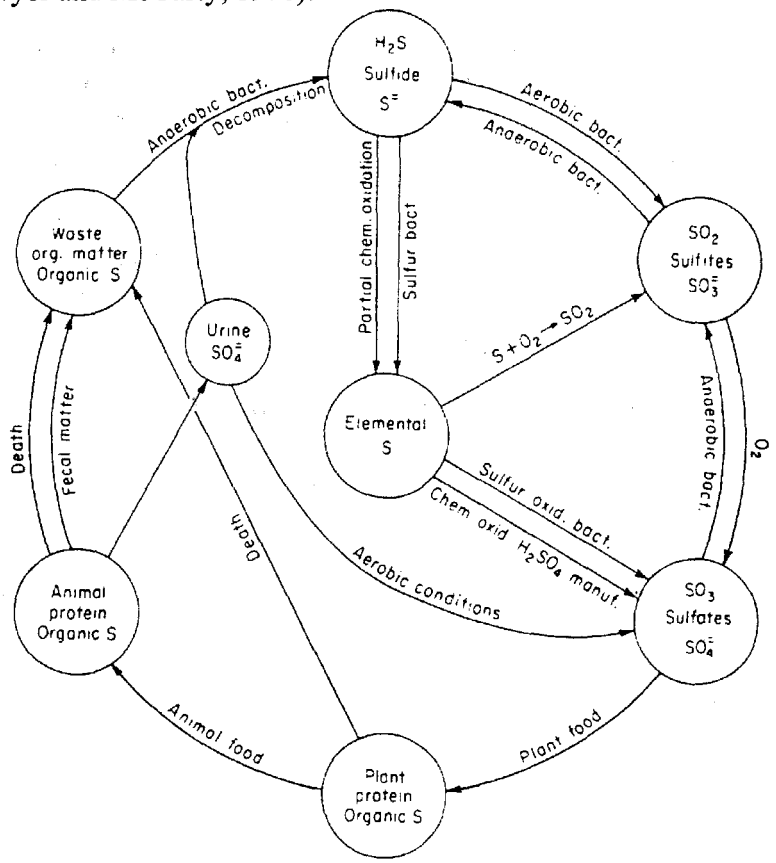


Figure 1. The sulfur cycle

Sulfates are indirectly responsible for odor and corrosion of waste handling systems resulting from reduction of sulfates to hydrogen sulfide under anaerobic conditions (Sawyer and McCarty, 1978).

$$SO^{2-} + \text{organic matter} \xrightarrow[\text{bacteria}]{\text{anaerobic}} S^{2-} + H_2O + CO_2$$

$$S^{2-} + 2H^{+} \longrightarrow H_2S$$

Sulfates serve as a source of electron acceptors for biochemical reactions produced by anaerobic bacteria in the absence of dissolved oxygen and nitrate. Sulfate ions are reduced to sulfide ions, which establish an equilibrium with hydrogen ions to form hydrogen sulfide based on its primary ionization constant. Thus, depending on pH of the slurry, the chemical form of sulfur compounds can be very different. When pH of slurry is 8 or more (basic), most reduced sulfur exists in solution as HS^- and S^{2-} ions, and the amount of free H_2S is so small that odor problems do not occur. At a pH below 8, equilibrium shifts rapidly toward formation of un-ionized H_2S and is about 80% complete at pH 7. Under these conditions, the partial pressure of hydrogen sulfide becomes great enough to cause significant odor problems whenever sulfate reduction produces significant quantities of sulfide ion. Figure 2 shows the relationship of pH on hydrogen sulfide equilibrium.

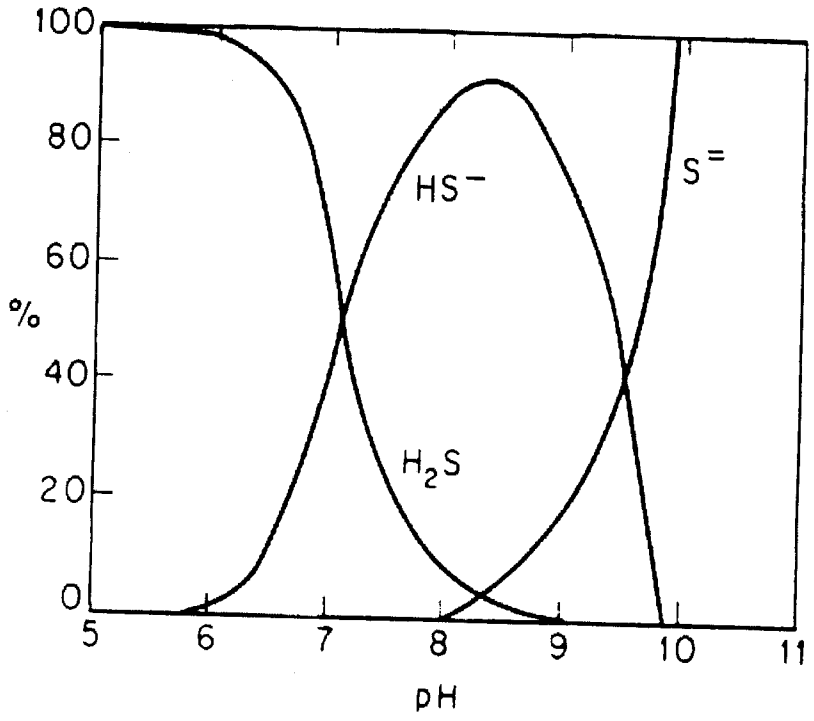
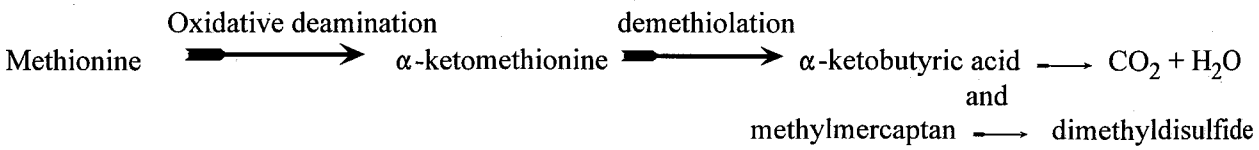


Figure 2. Effect of pH on hydrogen sulfide-sulfide equilibrium (10^{-3} molar solution, 32 mg H_2S/l)

Hydrogen sulfide production in swine confinement finishing units has been shown to be highly correlated with average outside air temperature, ratio of pit area to building volume, air exchange rate for the building and daily dietary sulfur intake (Avery et al., 1975). Anaerobic fermentation is essential for production of hydrogen sulfide gas, as well as most other volatile sulfur gases, except dimethyl sulfide which can be produced under aerobic fermentation (Banwart and Bremner, 1975b). Methyl mercaptan and hydrogen sulfide have been shown to be the predominant (80%) volatile S gases produced under simulated anaerobic fermentation conditions (Banwart and Bremner, 1975b). However, during a 30-day incubation period, only 0.03% of total S present in swine manure was volatilized to sulfur gases (Banwart and Bremner, 1975b).

The major proportion of sulfur in the diet is provided by the sulfur containing amino acids methionine, cystine, and cysteine. Hydrogen sulfide, methyl mercaptan, dimethyl sulfide, and dimethyl disulfide are produced by microbial decomposition of methionine and other sulfur compounds present in manure (Freney, 1967; Kadota and Ishida, 1972). For example, DL-methionine is decomposed by bacteria using the following pathway (Kadota and Ishida, 1972):



Carbon disulfide is produced by microbial decomposition of cystine and cysteine in manure (Banwart and Bremner, 1975b). However, it is not known how carbonyl sulfide is produced because there is no evidence in the literature that suggests that this compound is produced by microbial decomposition of sulfur compounds.

PROBLEMS ASSOCIATED WITH MEASURING SULFUR COMPOUNDS IN SWINE MANURE

Reduced sulfur compounds are very reactive in air (Spoelstra, 1980). Therefore, there is rapid interconversion of various sulfur forms. In addition, hydrogen sulfide is one of the two most volatile sulfur containing compounds, making it difficult to measure accurately. Most analytical methodologies for measuring sulfur, sulfate, and sulfide compounds have been developed for soil tests. There are two standard methods that have been used to measure sulfates in waste water: gravimetric and turbidimetric procedures (Sawyer and McCarty, 1978). The gravimetric method is considered to be the most accurate method (Sawyer and McCarty, 1978) and the method that we have used in our research. However, comparing the fecal and urine sulfur and sulfate excretion values obtained in our studies, it is a concern that levels of total fecal and urine sulfur excretion expressed as mg/pig/day are lower than absolute values for fecal and urine sulfate excretion (Table 6 and 7). Therefore, we question the accuracy and application of current standard analytical methods for sulfate measurements in swine feces and urine.

Sulfides have typically been measured using colorimetric or volumetric methods. Both methods have significant limitations resulting in determining the sulfide content by difference after separating inorganic from organic sulfur, and elemental sulfur from sulfate to determine percentage of sulfide. We are currently experimenting with a new technique using a sulfide electrode manufactured by Cole-Parmer in an attempt to be able to quickly, simply, accurately and economically measure sulfide ions

in aqueous solutions rather than using laborious, expensive, and questionable chemical analysis procedures to separate various sulfur forms in feces and urine. Hopefully, this technique will provide more rapid, precise measurements of sulfide concentrations in manure samples than current chemical analysis methodologies.

Correlation of Hydrogen Sulfide with Odor and Feed and Water Sources on Commercial Swine Farms

We recently completed a study (Jacobson et al., 1998, unpublished) to determine if sulfur in swine feed and drinking water on commercial swine farms could be correlated with hydrogen sulfide emmissions from manure storage systems. Six commercial swine farms representing three different manure storage types (earthen basin, outdoor pit or tank, and indoor deep pit), which were part of an ongoing odor monitoring project, were used in this study. Three farms were located in southwestern Minnesota and the other three farms were located in central Minnesota. Each pair of farms with common manure storage types were compared. Air samples were collected at the surface of the manure storage unit and analyzed for odor threshold using an olfactometer, and a hydrogen sulfide was measured using a Jerome™ meter or sensidyne indicator tubes. Similar odor levels were obtained for each pair of the three manure storage types compared. However, one farm within each manure storage type had a much higher concentration of hydrogen sulfide than the other paired site. To determine if sulfur content of water and feed samples were related to odor and hydrogen sulfide levels on these farms, samples of feed and water were collected and analyzed for total sulfur content. Estimated sulfur consumption and excretion were calculated and weighted based upon number of pigs in various phases of production and their expected consumption and manure excretion levels.

Hydrogen sulfide levels for all six farms during spring, summer, and fall seasons are shown in Figure 3. Note that each pair of farms had either a high or low level of hydrogen sulfide gas within manure storage type. The fall season had the highest hydrogen sulfide levels among the three seasons for air sampled directly above the manure storage surface. No single manure storage type seems to have higher hydrogen sulfide levels than another. These two observations are consistent with those observed with a larger, ongoing odor monitoring project being conducted at the University of Minnesota.

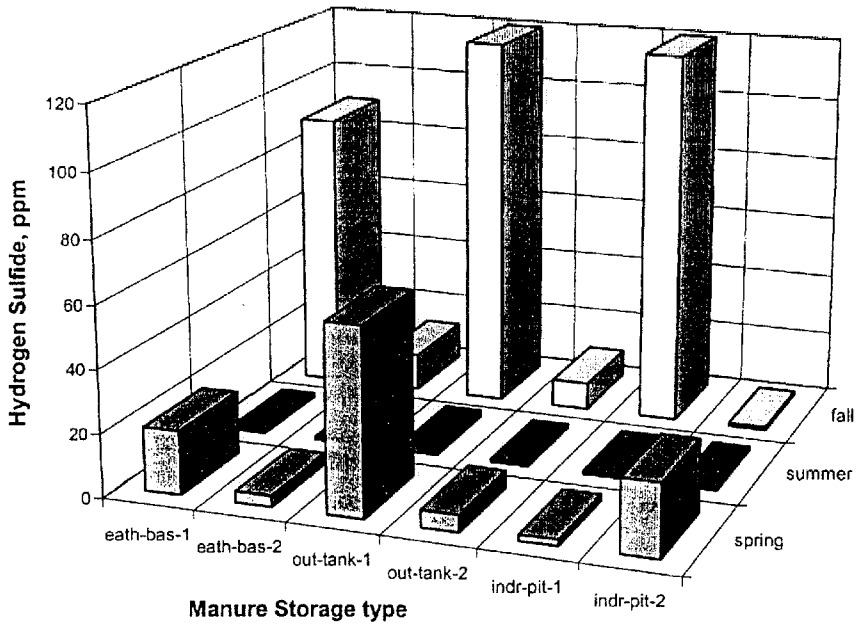


Figure 3. H_2S concentrations, for air collected directly above the manure surface, for the three paired manure storage units

Variation in odor threshold level for these three paired manure storage units during spring, summer, and fall are shown in Figure 4. There were only small differences in odor levels between paired farms, and odor levels were much higher during spring (April and May) compared to those measured during summer and fall. Odor levels are generally higher in spring because increasing temperatures

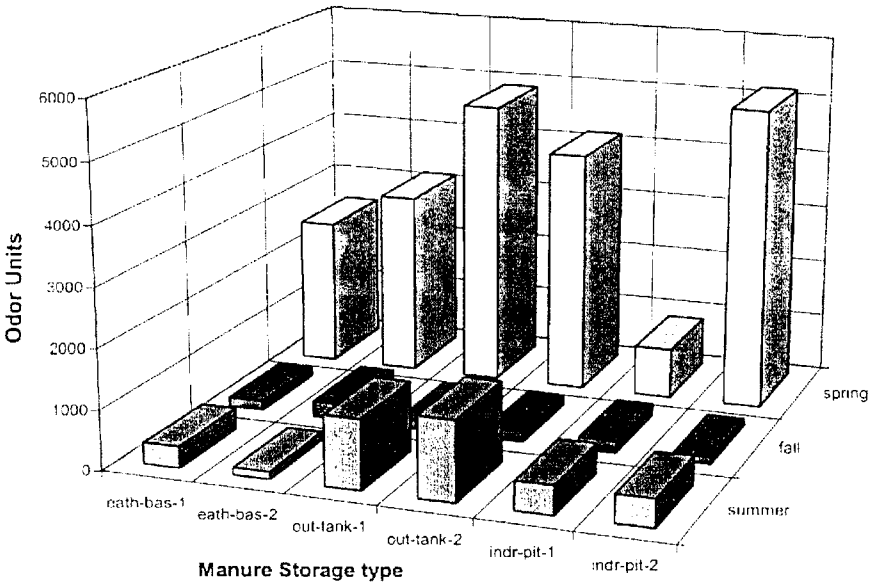


Figure 4. Odor levels, for air collected directly above the manure surface, for the three paired manure storage units.

accelerate microbial activity for decomposing "poorly fermented" organic compounds that have accumulated during colder months, and subsequently produces large quantities of odorous gases. These data, along with those obtained from a larger U of M odor monitoring study, suggest that there does not appear to be a particular manure storage system that consistently produces high odor levels. Furthermore, correlation between odor levels and hydrogen sulfide levels is poor as shown in Figure 5 and Table 1. Thus, these preliminary data suggest that if high sulfate drinking water and high dietary levels of sulfur are found in on-farm production conditions, hydrogen sulfide levels may be increased on some farms compared to farms with low sulfur feed and water.

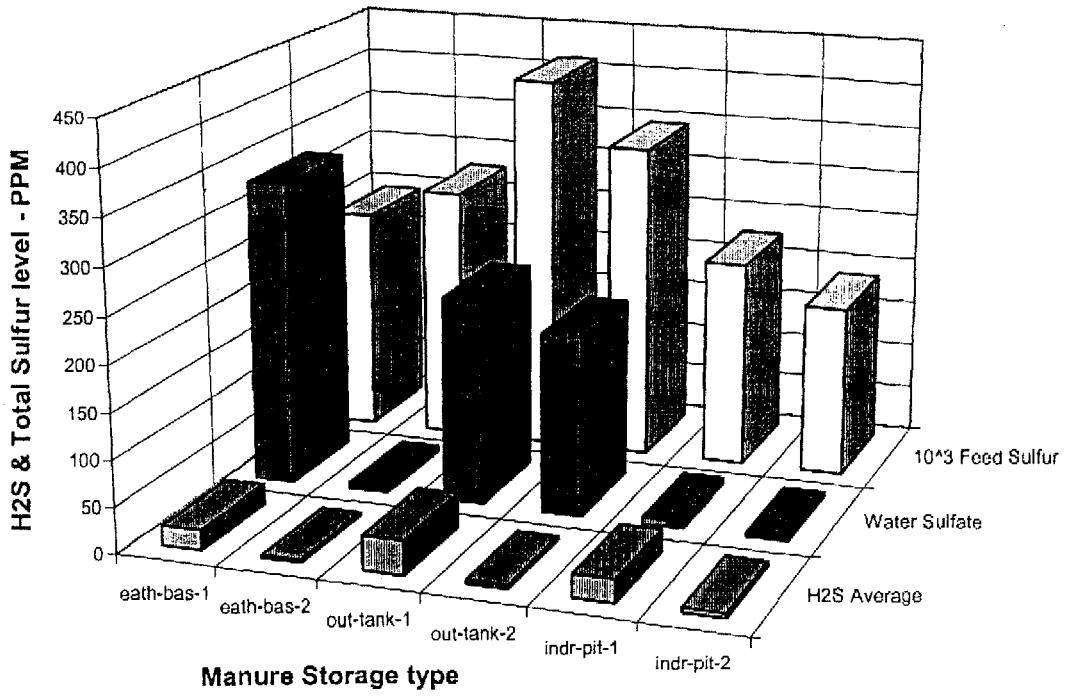


Figure 5. Average H_2S levels, total sulfur in water and feed concentrations for the three paired manure storage units

Table 1. Comparison of manure storage type, average hydrogen sulfide level, and total sulfur in water and feed fed to swine on commercial swine farms in Minnesota

Farm	Average Hydrogen Sulfide Level, ppm	Water Sulfur, ppm	Feed Sulfur x 10^3, ppm
Earthen basin 1	22	331	244
Earthen basin 2	3	6	278
Outdoor tank 1	37	223	412
Outdoor tank 2	4	195	344
Indoor pit 1	25	4	225
Indoor pit 2	5	7	186

DIETARY SOURCES AND LEVELS OF SULFUR

Sulfur content of common swine feed ingredients ranges from 0.02% in dried bakery product to 1.59% in low lactose dried whey (NRC, 1998). However, since most sulfur values published in NRC (1998) were determined several years ago, and many are based on only a few observations, we chose to analyze all ingredients used in complex starter diets for total sulfur content and compare these values with those published in NRC (1988 and 1998). The results of this comparison are shown in Table 2. We used a LECO procedure to determine sulfur values of each ingredient shown in the analyzed column. Note that our analyzed values for sulfur were very similar to NRC (1988, 1998) values except for a much lower sulfur value for spray dried whey (edible grade) and a somewhat higher value for spray dried blood meal. The discrepancy for dried whey is likely due to potential differences in nutrient levels of various sources and grades coupled with natural analytical variability. The discrepancy for spray dried blood meal is likely due to variability in product quality among sources. NRC does not list sulfur values for spray dried porcine plasma, IPC 790 fish meal, tricalcium phosphate, D,L methionine, or copper sulfate. Therefore, sulfur values were either calculated based on sulfur amino acid content listed on ingredient specification sheets for spray dried porcine plasma; or in the case of IPC 790 fish meal and tricalcium phosphate, taken directly from product specification sheets; or calculated using the chemical formula (copper sulfate) assuming 100% purity. Note that calculated and product specification values did not match our analyzed values very closely except for tricalcium phosphate. These results suggest that NRC sulfur values are accurate and can be used for most commonly used ingredients in starter diets. However, analysis of spray dried plasma, spray dried blood meal, fish meal, and spray dried whey should be conducted to establish reliable values of sulfur content when selecting ingredient sources to minimize sulfur content of starter diets.

Table 2. Comparison of sulfur content of common starter diet ingredients between NRC (1988), NRC (1998), and actual analyzed values used in U of M nutrition experiments			
Ingredient	**% S (NRC, 1988)**	**% S (NRC, 1998)**	**% S Analyzed**
Corn, yellow dent	0.11	0.13	0.11
Dried whey, edible	**1.04**	**0.72**	**0.21**
Soybean meal, 44%	0.42	0.43	0.39
Lactose	0.00	--	0.01
Oat groats	0.20	0.20	0.19
Spray dried porcine plasma	**0.75***	--	**1.05**
IPC 790 fish meal	**0.45****	--	**0.93**
Skim milk, dried	0.32	0.32	0.38
Choice white grease	0.00	--	0.00
Spray dried blood meal	**0.34**	**0.47**	**0.51**
Dicalcium phosphate	0.80	0.80	0.84
Tricalcium phosphate	0.00**		0.02
Limestone	0.00	0.04	0.02
Salt	0.00	0.00	0.00
Mecadox-10	--	--	0.05
U of M vitamin premix	0.00**	--	0.20
D, L methionine	**21.49****	--	**8.46**
High sulfur TM premix	6.20*	--	8.21
Low sulfur TM premix	0.00*	--	0.05
L-lysine HCl	0.00**	--	0.00
Choline chloride	0.00*	--	0.05
Copper sulfate	**12.84***	--	**9.39**
Zinc oxide	0.00*	--	0.03

* Values were calculated.
** Values were obtained from supplier specification sheets.

Relative Contribution of Feed Ingredients to the Total Sulfur Content of Phase I, Phase II and Phase III Diets

We formulated experimental high and low sulfur Phase I, II, and III diets using book values from NRC (1988) and obtained remaining sulfur values from product specification sheets if not provided in NRC (1988). Using published values shown in Table 2, we calculated that our high sulfur,

conventional diet should contain 0.45% sulfur and our modified low sulfur diet should contain 0.24% sulfur. In other words, by adjusting inclusion rates of some ingredients that contribute major amounts of sulfur, we theoretically should achieve a 47% reduction in sulfur content while satisfying all other required nutrient levels. However, due to the wide disparity between NRC (1988) and our analyzed sulfur values for dried whey and IPC 790 fish meal, the actual reduction of total sulfur in our low sulfur Phase I diet was only 13%. This points out the importance of analyzing each ingredient for sulfur content before formulating low sulfur diets.

As shown in Table 3, the primary sulfur contributors in the high sulfur Phase I diet were:

1 Spray dried plasma (20.5%)
2 Fish meal (15.3%)
3 Spray dried whey (13.7%)
4 Soybean meal (13.0%)
5 Corn (9.8%)
6 Oat groats (6.2%)
7 Skim milk (6.2%)

These ingredients collectively account for nearly 85% of total sulfur in this diet formulation. Dicalcium phosphate, D,L methionine, TM premix and copper sulfate contribute the remaining 15% of sulfur to the diet. By eliminating dried whey from the formulation, replacing dicalcium phosphate with tricalcium phosphate, and copper sulfate with zinc oxide, and using a no sulfate TM premix, small improvements were achieved in reducing total diet sulfur content.

A 39% reduction in total sulfur content of the low sulfur Phase II diet was achieved by minimizing the use of high sulfur ingredients, and replacing them with lower sulfur alternatives (Table 4). However, only a 19% reduction in total sulfur was achieved for the low sulfur Phase III diet compared to the high sulfur Phase III diet due to the use of fewer ingredients and less flexibility for diet manipulation (Table 5).

Table 3. Diet composition and percentage contribution of each ingredient to the total sulfur content of a high and low sulfur Phase I starter diet

Ingredient	High Sulfur Diet, %	% of Total Dietary S	Low Sulfur Diet, %	% of Total Dietary S
Corn, yellow dent	27.334	9.8	28.990	12.2
Dried whey, edible	20.000	13.7	0.000	0.0
Soybean meal, 44%	10.250	13.0	12.250	17.9
Lactose	10.000	0.3	21.500	0.8
Oat groats	10.000	6.2	10.000	7.3
Spray dried porcine plasma	6.000	20.5	6.000	24.0
IPC 790 fish meal	5.000	15.3	5.000	17.9
Skim milk, dried	5.000	6.2	10.000	14.5
Choice white grease	3.000	0.0	2.250	0.0
Spray dried blood meal	0.000	0.0	0.000	0.0
Dicalcium phosphate	1.400	3.9	0.000	0.0
Tricalcium phosphate	0.000	0.0	1.900	0.0
Limestone	0.650	0.0	0.150	0.0
Salt	0.000	0.0	0.000	0.0
Mecadox-10	0.400	0.0	0.400	0.0
U of M vitamin premix	0.300	0.3	0.300	0.4
D, L methionine	0.150	4.2	0.160	5.3
High sulfur TM premix	0.150	3.9	0.000	0.0
Low sulfur TM premix	0.000	0.0	0.056	0.0
L-lysine HCl	0.150	0.0	0.150	0.0
Choline chloride	0.116	0.0	0.116	0.0
Copper sulfate	0.100	2.9	0.000	0.0
Zinc oxide	0.000	0.0	0.278	0.0
Nutrient level				
Calculated sulfur, %	0.45	100.00	0.24	100.00
Analyzed sulfur, %	0.32	100.00	0.28	100.00

Effect of Diet Manipulation on Sulfur Excretion, Growth Performance, Odor, and Hydrogen Sulfide Emissions

After an extensive literature review, we were unable to find any published studies related to diet manipulation on sulfur retention and excretion, growth performance, or odor and hydrogen sulfide emissions. Therefore, we conducted a series of trials with the following objectives:

1. Quantify the amount of sulfur consumed, retained, and excreted from pigs weaned at 18 days of age when fed either a typical or low sulfur Phase I, Phase II, and Phase III diet sequence.
2. Quantify the amount of elemental sulfur, sulfate, and sulfide consumed in feed and excreted in feces and urine when feeding a typical and low sulfur Phase I, Phase II and Phase III diet.
3. Determine the effect of feeding a typical and low sulfur diet on energy and nitrogen retention during Phase I, Phase II, and Phase III.
4. Determine the effects of feeding low sulfur diets on pig performance.
5. Determine the effects of feeding low sulfur diets on odor, hydrogen sulfide and other gas levels in confinement nursery rooms.

Procedures for Experiment I

A three-phase nursery diet feeding sequence of "typical," high sulfur diets and modified, low sulfur diets shown in Tables 4 and 5 was used. These diets provided equivalent concentrations of nutrients except sulfur. Based on our initial calculations using NRC (1988) sulfur values for feed ingredients, our modified, low sulfur diet should have reduced total sulfur consumption by 30 %. The greatest percentage of this reduction in sulfur consumption should have been obtained in Phase I (53.5%) and Phase II (55%), followed by only a modest reduction in sulfur consumption during Phase III (12.5%). Therefore, we hypothesized that if sulfur digestibility/bioavailability is similar between "typical," high sulfur diets and modified, low sulfur diets, and if sulfur values of feed ingredients published in NRC (1988) were accurate, these dietary modifications would reduce sulfur excretion by 30%.

A total of 20 PIC barrows (10 pigs/treatment) were weaned at 18 days of age at the St. Paul Swine Research unit. Pigs were weighed, blocked by weight and litter, and assigned within block to one of two dietary treatment sequences. Pigs were placed in individual stainless steel collection cages and were fed either the high sulfur or low sulfur Phase I diet for seven days. Pigs were fed an amount of feed from their respective experimental diet, equivalent to 2% of their initial body weight twice daily. Total fecal and urine excretion was collected for three days (day 5 to 7) and stored for later laboratory analysis.

On day 8, pigs fed the high sulfur Phase I diet were weighed and switched to the high sulfur Phase II diet for a 14-day feeding period. Similarly, pigs fed the low sulfur Phase I diet were weighed and switched to the low sulfur Phase II diet. Pigs were again fed an amount of experimental diet equivalent to 2% of their body weight on day 8 for one week, and urine and feces were collected from day 12 to 14. This same procedure was used for each of the five weekly collection periods for pigs fed both experimental diets in all phases.

Table 4. Diet composition and nutrient values of high sulfur and low sulfur Phase I and Phase II experimental diets

Ingredient	Phase I High Sulfur Diet, %	Phase II High Sulfur Diet, %	Phase I Low Sulfur Diet, %	Phase II Low Sulfur Diet, %
Corn, yellow dent	27.334	49.484	28.990	48.350
Dried whey, edible	20.000	20.000	-------	-------
Soybean meal, 44%	10.250	17.000	12.250	23.500
Lactose	10.000	-------	21.500	14.000
Oat groats	10.000	-------	10.000	-------
Spray dried porcine plasma	6.000	-------	6.000	-------
IPC 790 fish meal	5.000	5.000	5.000	5.000
Skim milk, dried	5.000	-------	10.000	-------
Choice white grease	3.000	3.000	2.250	2.800
Spray dried blood meal	-------	2.500	-------	2.500
Dicalcium phosphate	1.400	1.250	-------	-------
Tricalcium phosphate	-------	-------	1.900	1.950
Limestone	0.650	0.550	0.150	0.100
Salt	-------	-------	-------	0.400
Mecadox-10	0.400	0.400	0.400	0.400
U of M vitamin premix	0.300	0.300	0.300	0.300
D, L methionine	0.150	-------	0.160	-------
High sulfur TM premix	0.150	0.150	-------	-------
Low sulfur TM premix	-------	-------	0.056	0.156
L-lysine HCl	0.150	0.150	0.150	0.150
Choline chloride	0.116	0.116	0.116	0.116
Copper sulfate	0.100	0.100	-------	-------
Zinc oxide	-------	-------	0.278	0.278
Nutrient Level				
Crude protein, %				
Lysine, %				
Methionine + cystine, %				
Calculated Sulfur, %	0.45	0.40	0.24	0.18
Analyzed Sulfur, %	0.32	0.31	0.28	0.19

Table 5. Diet Composition and Nutrient Values of High Sulfur and Low Sulfur Phase III Diets		
Ingredient	**Phase III High Sulfur Diet, %**	**Phase III Low Sulfur Diet, %**
Corn, yellow dent	57.834	58.100
Soybean meal, 44%	34.000	34.000
Choice white grease	4.000	4.000
Dicalcium phosphate	1.700	-------
Tricalcium phosphate	-------	1.750
Limestone	0.850	0.350
Salt	0.400	0.400
Mecadox-10	0.400	0.400
U of M vitamin premix	0.300	0.300
High sulfur TM premix	0.150	-------
Low sulfur TM premix	-------	0.056
L-lysine HCl	0.150	0.150
Choline chloride	0.116	0.116
Copper sulfate	0.100	-------
Zinc oxide	-------	0.278
Nutrient Levels		
Crude protein, %		
Lysine, %		
Methionine + cystine, %		
Calculated Sulfur, %	0.24	0.21
Analyzed Sulfur, %	0.26	0.21

Feed samples of each diet, as well as fecal and urine samples from each collection period, were analyzed for nitrogen, sulfur, sulfate, sulfide content. Gross energy was determined for only feed and feces. Sulfur content of feed and feces was determined using a Total Sulfur Analyzer manufactured by LECO Corporation, St. Joseph, MI. Sulfur content of urine was determined using Inductively Coupled Plasma Atomic Emission Spectrophotometry (Perkin-Elmer, Norwalk, CT). Sulfate was analyzed using a Gravimetric method with ignition of residue, which is a standard method for evaluation of sulfate in water and wastewater. We devoted considerable effort toward finding acceptable methods for measuring sulfide in feed, feces and urine. Although we developed a colorimetric assay for sulfide determination in urine, it could not be successfully applied toward measuring sulfide in feces because it is difficult to determine color change in cloudy, high organic matter solutions. Thus, precision of this measurement was poor and sulfide data were not included in this study.

Results from Experiment 1

As expected, feeding the low sulfur diets tended to reduce total sulfur consumption during Phase I, and did reduce sulfur consumption during Phase II, Phase III and overall average sulfur consumption for the entire 5-week experiment (Table 6). The reason for lack of a significant reduction of total sulfur intake during Phase I was a result of using ingredient values for sulfur from NRC (1988) instead of actual analyzed values of sulfur from ingredients used in the formulation. Surprisingly, total fecal sulfur excretion of pigs fed the low sulfur diet was higher compared to pigs fed the high sulfur diet in each phase and for the overall 5-week feeding period, while total urinary sulfur excretion and total sulfur excretion (fecal + urine) were reduced in all feeding phases by feeding the low sulfur diet sequence (Table 6). Although the reason for higher fecal sulfur excretion for pigs fed the low sulfur diet is unclear, the net effect of feeding the low sulfur diet was a 30% reduction in total fecal excretion. Another interesting, but difficult to explain, finding was reduction in total sulfur retention for pigs fed the low sulfur Phase II and Phase III.

Since sulfate appears to be the predominant chemical form of sulfur excreted in swine manure, we wanted to measure effect of dietary sulfur level on sulfate excretion. As expected, Table 7 shows that sulfate intake was less for pigs fed the low sulfur diet compared to pigs fed the high sulfur diet. However, amount of fecal and urine sulfate excretion was greater than total amount of fecal and urine sulfate excretion shown in Table 6, which is theoretically impossible. This result confirms the difficulty and challenge of accurately quantifying various sulfur compounds in feces and urine. Although fecal sulfate excretion tended to be higher for pigs fed the low sulfur diet, increased variability in sulfate values due to the analytical procedure used prevented these apparent differences from being significantly different. Amount of sulfate excreted in urine was dramatically higher than in feces, and was higher for pigs fed the high sulfur diet compared to pigs receiveing low sulfur intake in Phase II, Phase III, and for the average of the 5-week experiement (Table 7). Net sulfate retention was negative for pigs fed both high and low sulfur diets in all phases of the experimental period. This means that more sulfate was excreted in feces and urine than the total sulfate consumed by the pig, suggesting significant conversion of various chemical forms of non-sulfate, sulfur forms consumed by the pig into primarily the sulfate form for excretion. Pigs fed the high sulfur diet had higher loss of sulfate (less retention) than pigs fed the low sulfur diet during Phase III. This finding suggests that excess sulfur consumed by pigs is primarily converted to sulfate for excretion. Pigs fed the low sulfur diet had less sulfate intake and excretion resulting in less sulfate loss.

Table 6. Effects of feeding a 3-phase, high sulfur diet sequence compared to a 3-phase, low sulfur diet sequence on total sulfur intake, fecal sulfur excretion, urinary sulfur excretion, and sulfur retention

Measure	High Sulfur	Low Sulfur	Standard Error	Significance
Sulfur intake, mg/pig/day				
Week 1 (Phase I)	541	469	38	NS
Weeks 2 & 3 (Phase II)	650	404	38	P < .0003
Weeks 4 & 5 (Phase III)	948	732	57	P < .015
Weeks 1-5 (Average)	747	548	45	P < .006
Fecal S excretion, mg/pig/day				
Week 1 (Phase I)	77	111	9	P < .01
Weeks 2 &3 (Phase II)	87	115	10	P < .06
Weeks 3 & 4 (Phase III)	158	193	16	P = .15
Weeks 1-5 (Average)	114	145	10	P < .05
Urine S excretion, mg/pig/day				
Week 1 (Phase I)	137	42	15	P < .0005
Weeks 2 & 3 (Phase II)	110	30	7	P < .0001
Weeks 4 & 5 (Phase III)	212	53	16	P < .0001
Weeks 1-5 (Average)	156	42	10	P < .0001
Sulfur excretion (Fecal S + Urine S), mg/pig/day				
Week 1 (Phase I)	214	153	17	P < .02
Weeks 2 & 3 (Phase II)	197	145	13	P < .01
Weeks 4 & 5 (Phase III)	371	245	27	P < .005
Weeks 1-5 (Average)	270	187	17	P < .003
Sulfur retention (S intake - Fecal S - Urine S), mg/pig/day				
Week 1 (Phase I)	327	315	33	NS
Weeks 2 & 3 (Phase II)	453	258	30	P < .0002
Weeks 4 & 5 (Phase III)	577	486	33	P < .065
Weeks 1-5 (Average)	477	361	30	P < .01

Table 7. Effects of feeding a 3-phase, high sulfur diet sequence compared to a 3-phase, low sulfur diet sequence on total sulfate intake, fecal sulfate excretion, urinary sulfate excretion, and sulfate retention

Measure	High Sulfur	Low Sulfur	Standard Error	Significance
Sulfate intake, mg/pig/day				
Week 1 (Phase I)	384	275	25	P < .007
Weeks 2 & 3 (Phase II)	469	315	28	P < .001
Weeks 4 & 5 (Phase III)	889	576	50	P < .0003
Weeks 1-5 (Average)	620	411	36	P < .0007
Fecal sulfate excretion, mg/pig/day				
Week 1 (Phase I)	99	124	13	NS
Weeks 2 &3 (Phase II)	119	253	84	NS
Weeks 3 & 4 (Phase III)	211	225	34	NS
Weeks 1-5 (Average)	152	216	41	NS
Urine sulfate excretion, mg/pig/day				
Week 1 (Phase I)	374	300	60	NS
Weeks 2 & 3 (Phase II)	686	419	112	P =.11
Weeks 4 & 5 (Phase III)	1537	620	123	P < .0001
Weeks 1-5 (Average)	964	476	81	P < .0005
Sulfate excretion (Fecal + Urine), mg/pig/day				
Week 1 (Phase I)	473	423	62	NS
Weeks 2 & 3 (Phase II)	804	673	133	NS
Weeks 4 & 5 (Phase III)	1748	845	142	P < .0003
Weeks 1-5 (Average)	1116	692	93	P < .005
Sulfate retention (Intake - Fecal - Urine), mg/pig/day				
Week 1 (Phase I)	-89	-149	57	NS
Weeks 2 & 3 (Phase II)	-335	-357	129	NS
Weeks 4 & 5 (Phase III)	-859	-269	104	P < .0008
Weeks 1-5 (Average)	-496	-280	73	P < .05

Our goal in formulating low sulfur diets was to reduce sulfur excretion without reducing energy and nitrogen digestibility, retention and pig performance. Tables 8, 9, and 10 show results of feeding the low sulfur diet on energy digestibility, nitrogen retention and excretion, and growth performance, respectively. There were no differences in digestible energy and nitrogen retention between pigs fed

either high or low sulfur diets. Therefore, a reduction in sulfur and sulfate excretion can be achieved without negatively affecting energy or nitrogen digestibility and retention (Tables 8 and 9, respectively). These results are consistent with the growth performance comparison shown in Table 10, showing similar gain, feed intake and feed conversion by feeding either the high or low sulfur diet sequence.

Table 8. Effects of feeding a 3-phase, high sulfur diet sequence compared to a 3-phase, low sulfur diet sequence on gross energy intake, fecal gross energy excretion, and digestible energy

Measure	High Sulfur	Low Sulfur	Standard Error	Significance
Gross energy intake, kcal/pig/day				
Week 1 (Phase I)	691	664	52	NS
Weeks 2 & 3 (Phase II)	851	869	60	NS
Weeks 4 & 5 (Phase III)	1456	1422	96	NS
Weeks 1-5 (Average)	1061	1049	71	NS
Gross fecal energy, kcal/pig/day				
Week 1 (Phase I)	49	52	4.2	NS
Weeks 2 &3 (Phase II)	58	77	4.3	$P < .01$
Weeks 3 & 4 (Phase III)	115	139	12.2	NS
Weeks 1-5 (Average)	79	99	6.4	$P < .08$
Digestible energy (GE intake - Fecal GE), kcal/pig/day				
Week 1 (Phase I)	642	612	48	NS
Weeks 2 & 3 (Phase II)	793	792	57	NS
Weeks 4 & 5 (Phase III)	1340	1284	87	NS
Weeks 1-5 (Average)	982	953	66	NS

Table 9. Effects of Feeding a 3-Phase, High Sulfur Diet Sequence Compared to a 3-Phase, Low Sulfur Diet Sequence on Total Nitrogen Intake, Fecal Nitrogen Excretion, Urinary Nitrogen Excretion, and Nitrogen Retention

Measure	High Sulfur	Low Sulfur	Standard Error	Significance
Nitrogen intake, g/pig/day				
Week 1 (Phase I)	5.54	5.44	0.42	NS
Weeks 2 & 3 (Phase II)	6.93	6.84	0.48	NS
Weeks 4 & 5 (Phase III)	11.18	11.26	0.75	NS
Weeks 1-5 (Average)	8.35	8.33	0.56	NS
Fecal N excreted, g/pig/day				
Week 1 (Phase I)	0.53	0.63	0.06	NS
Weeks 2 &3 (Phase II)	0.62	0.85	0.06	$P < .03$
Weeks 3 & 4 (Phase III)	1.16	1.36	0.12	NS
Weeks 1-5 (Average)	0.82	1.01	0.08	$P < .10$
Urine N excreted, g/pig/day				
Week 1 (Phase I)	0.68	0.58	0.09	NS
Weeks 2 & 3 (Phase II)	0.82	0.93	0.08	NS
Weeks 4 & 5 (Phase III)	2.50	2.35	0.26	NS
Weeks 1-5 (Average)	1.46	1.43	0.13	NS
Nitrogen retained (N intake - Fecal N - Urine N), g/pig/day				
Week 1 (Phase I)	4.33	4.22	0.37	NS
Weeks 2 & 3 (Phase II)	5.49	5.07	0.40	NS
Weeks 4 & 5 (Phase III)	7.53	7.55	0.47	NS
Weeks 1-5 (Average)	6.07	5.89	0.40	NS

Table 10. Effects of feeding a 3-phase, high sulfur diet sequence compared to a 3-phase, low sulfur diet sequence on average daily gain, average daily feed intake, and gain/feed during a 5-week feeding period

Measure	High Sulfur	Low Sulfur	Standard Error	Significance
ADG, g/d				
Week 1 (Phase I)	273	229	20	NS
Weeks 2 & 3 (Phase II)	391	332	23	NS
Weeks 4 & 5 (Phase III)	536	568	17	NS
Weeks 1-5 (Average)	422	406	20	NS
ADFI, g/d				
Week 1 (Phase I)	274	246	9	NS
Weeks 2 &3 (Phase II)	505	530	30	NS
Weeks 3 & 4 (Phase III)	911	955	48	NS
Weeks 1-5 (Average)	621	644	28	NS
G/F				
Week 1 (Phase I)	0.995	0.932	0.049	NS
Weeks 2 & 3 (Phase II)	0.758	0.622	0.035	$P < .07$
Weeks 4 & 5 (Phase III)	0.592	0.598	0.023	NS
Weeks 1-5 (Average)	0.683	0.636	0.021	$P = .12$

Procedures for Experiment 2

A second experiment was conducted to determine if reduction in sulfur excretion from feeding low sulfur diet in the first experiment results in reduced hydrogen sulfide gas and odor as well as supporting growth performance of pigs equivalent to pigs fed the typical high sulfur diet. The same experimental diet sequence and formulations used in experiment 1 were used in this experiment. A total of 128 pigs with average initial body weight of 6.97 kg, and average of 20 days of age were weaned in two groups (64 pigs/group) and randomly allocated to one of four environmental rooms. A total of four replications per dietary treatment sequence was used. A total of 16 pigs were housed in raised deck nursery pens in each of four environmental rooms. Each room was randomly assigned to one of the two experimental diets. Pigs were weighed, and feed consumption was determined weekly to calculate average daily gain, average daily feed intake and gain/feed for a 5-week feeding period. Odor, hydrogen sulfide, and ammonia measurements were recorded weekly to determine the effect of diet on odors and gases.

Results from Experiment 2

Growth performance was not different between pigs fed either the high or low sulfur diet sequences (Table 10). Thus, reducing total sulfur content of the diet has no detrimental effects on pig performance as long as requirements for all other nutrients are met.

Figures 6-9 show the effect of feeding high and low sulfur diet sequences on odor detection, hydrogen sulfide level, and ammonia level during the 5-week feeding period. Odor levels were low but tended to increase linearly during the 5-week feeding period (Figure 6). Odor levels tended to be higher in rooms where pigs were fed high sulfur diets during week 3-5, which is likely due to increased microbial fermentation of manure due to increased manure volume. Hydrogen sulfide levels tended to be similar between dietary treatments during weeks 1 and 2, but tended to be higher for rooms where pigs were fed the high sulfur diet sequence during weeks 3-5 (Figure 7). Ammonia level tended to increase linearly each week (Figure 8), but was not affected by feeding a low sulfur diet (Figure 9). These results show that dietary sulfur level is a significant contributor to odor and hydrogen sulfide levels in confinement nursery facilities.

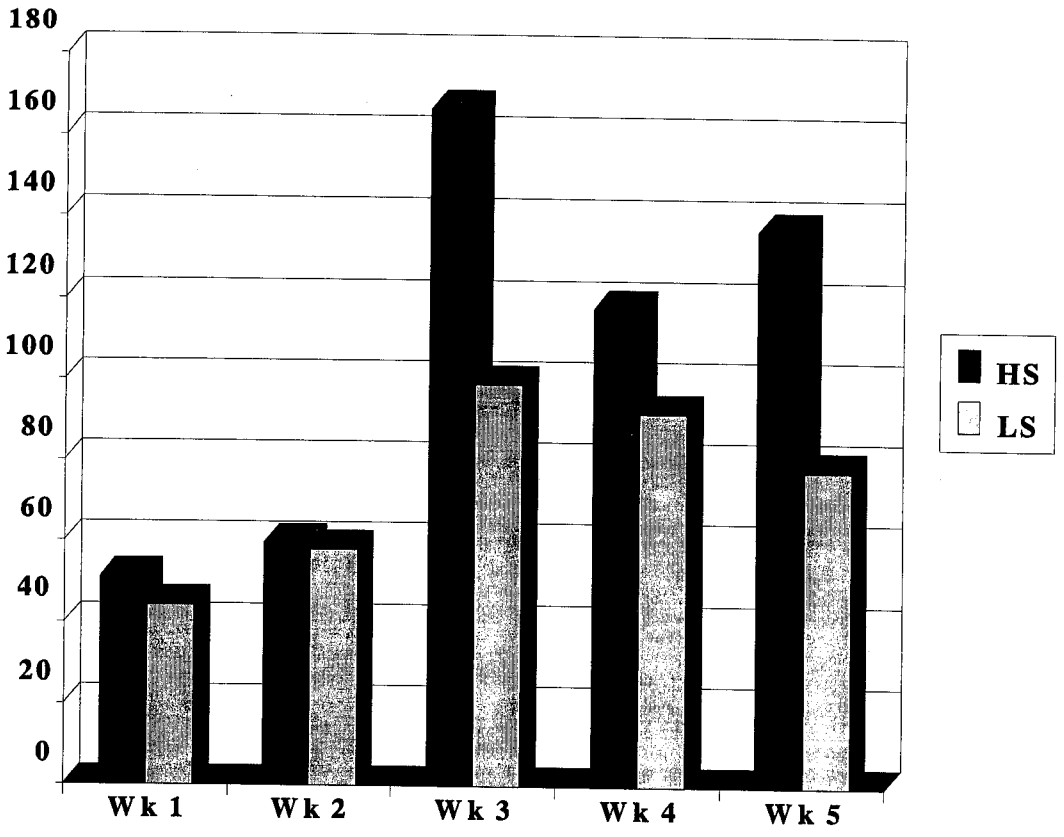


Figure 6. Weekly odor detection threshold for high sulfur (HS) and low sulfur (LS) treatments

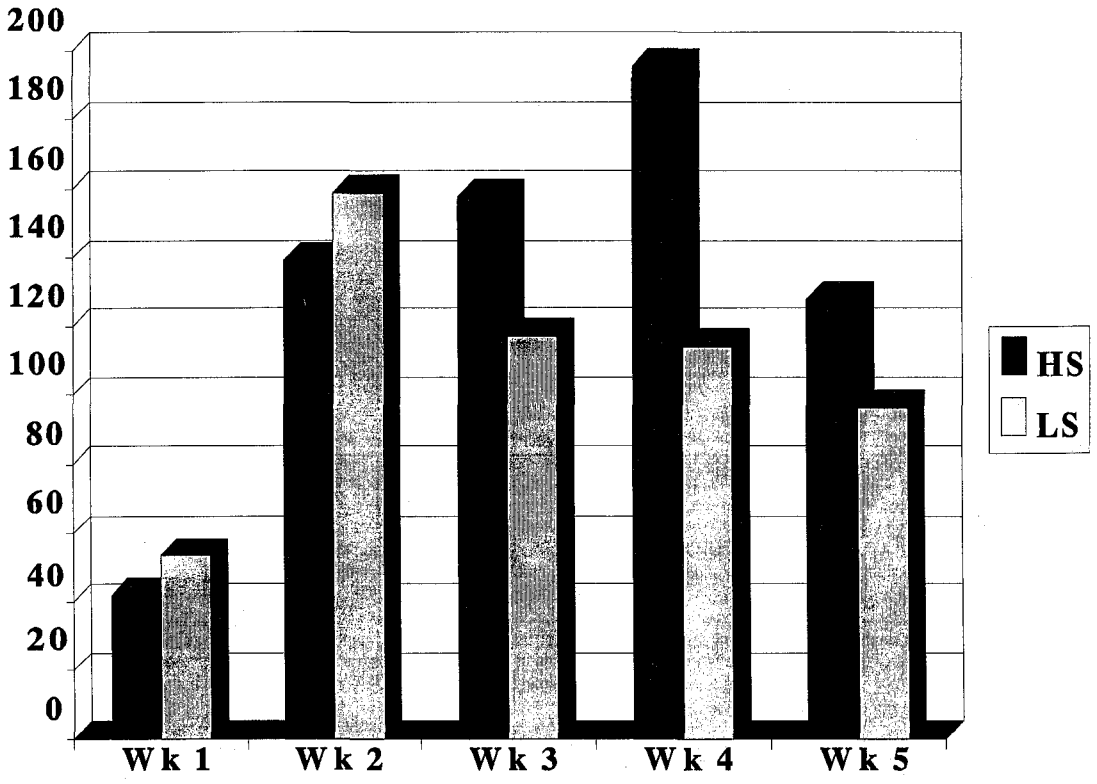


Figure 7. Weekly hydrogen sulfide levels for high sulfur (HS) and low sulfur (LS) treatments

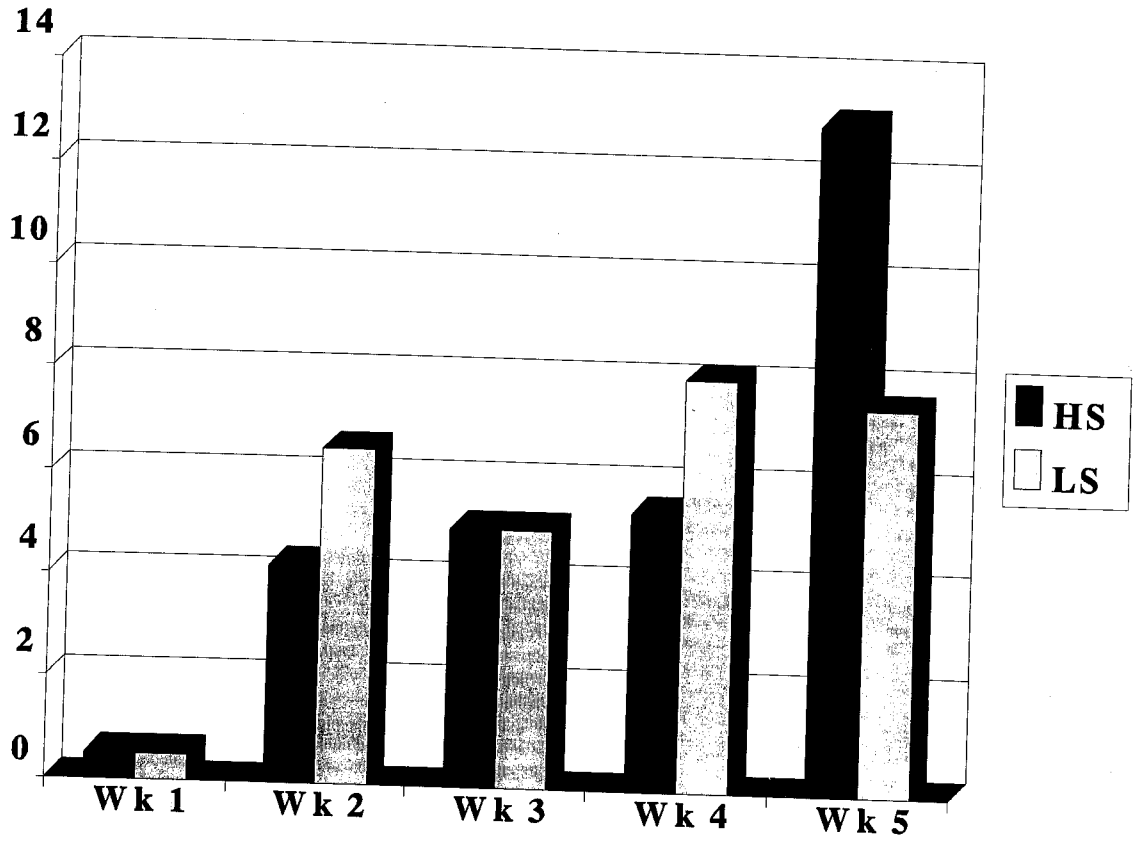


Figure 8. **Comparison of weekly ammonia level between high sulfur (HS) and low sulfur (LS) treatments**

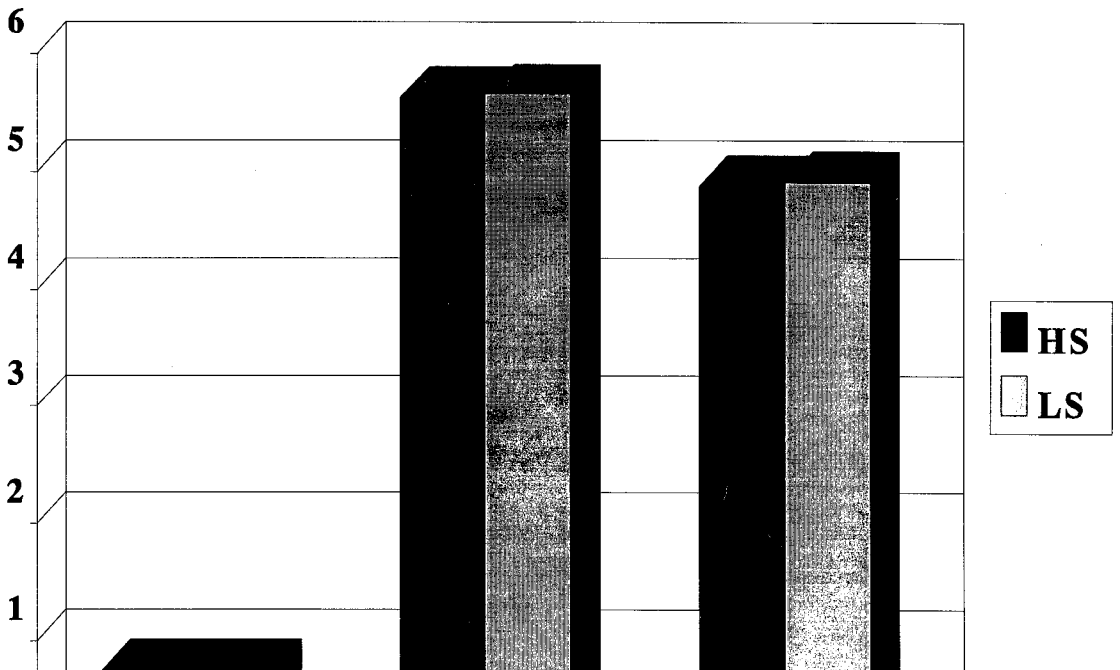


Figure 9. Initial, average, and increase in ammonia level between high sulfur (HS) and low sulfur (LS) treatments

SUMMARY

There are numerous odor compounds produced during manure decompostion in various manure storage systems. Several of these compounds contain sulfur. Hydrogen sulfide is a specific sulfur containing gas that contributes to total odor emitted from swine confinement facilities, and is currently being monitored by regulatory agencies on many commercial swine farms in Minnesota and 23 other states. Our studies show that level of hydrogen sulfide gas emitted from manure storage structures is not well correlated with odor levels from these same sources. Sulfate levels in drinking water and feed appear to be significant contributors to hydrogen sulfide levels on commercial swine farms, but other poorly identified factors are also involved in the level of hydrogen sulfide produced.

Sulfur is a required nutrient by the pig, and this requirement is met by providing adequate levels of organic sulfur in the form of the sulfur containing amino acids (methionine, cystine, cysteine). Little is known about interconversion of various sulfur compounds during digestion, absorption, and excretion other than the predominant form of sulfur excreted in feces and urine is sulfate. Depending on pH of the slurry in manure storage structures, level of hydrogen sulfide gas may be low (pH greater than 8) or high (pH less than 8). Sulfates excreted in urine and feces are easiliy converted to hydrogen sulfide under anaerobic microbial fermentation processes in the manure storage structure.

Our studies have shown that by carefully selecting low sulfur feed ingredients and using them to formulate nutritionally adequate, low sulfur starter diets, total sulfur and sulfate excretion can be reduced by approximately 30%, without compromising energy and nitrogen digestibility or pig performance. Furthermore, our studies show that reduction in total sulfur consumption and excretion will lead to a reduction in hydrogen sulfide gas and odor, but not affect ammonia levels in nursery facilities.

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BETAINE IN NONRUMINANT DIETS

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Betaine is a naturally occurring substance found in wide variety of species. Its roles in living systems are as an osmolyte to aid in maintenance of cellular water balance and as a methyl group donor. Unlike some plant and invertebrate species, vertebrates have a limited ability to produce betaine within the body. However, this limitation on production within the body has not affected the response to dietary betaine.

BETAINE AS AN OSMOLYTE

An osmolyte is a substance that affects the movement of water, is taken up by the cell quickly, does not have any adverse impact on the cell and protects cellular macromolecules from inactivation. There are many substances capable of affecting water movement, however the vast majority are used by the cell for other purposes. Betaine, on the other hand, is used only as an osmolyte by the majority of the tissues in the body. An exception to this rule is the liver; this tissue can use betaine as a methyl group donor and as an osmolyte.

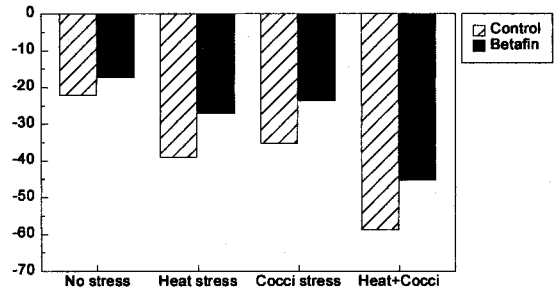
To understand why betaine's osmolyte role is important physiologically, it must first be understood that water content of the cell is a key factor in determining what physiological state the cell is in. The goal of osmotic regulation is to keep the cell volume as constant as possible (Haussinger, 1996). However, change in cell volume can cause a change in cell activity. A slightly swollen state is characteristic of an anabolic state or growth mode of the cell. In contrast, a slightly dehydrated state indicates a catabolic state or "degrading/break-down" mode. Electrolytes and osmolytes like betaine are not the only factors that influence cell hydration. Hormones can as well. Insulin's most famous role is in lowering blood glucose level and stimulating cellular uptake. However this hormone also induces cellular swelling (Haussinger, 1996). It is by increasing water level of the cell that insulin stimulates cellular growth activity. In contrast, glucagon alters glucose uptake patterns and activity of peripheral cells by slightly dehydrating them as well as stimulating production of glucose in the liver. Although some changes in cell water level are normal, large changes are stressful and potentially harmful to the cell's long term survival. This means that cell must find efficient ways of coping with these problems when they arise. Betaine is particularly useful to cells when they are in danger of dehydration (beyond "normal" parameters).

Hyperosmotic stress causes dehydration of cells. Cells have no direct way to hold or control water movement, so water can move according to the concentration gradient prevailing at that time. An example is shown in Figure 1.

piglet ileum had similar levels of potassium as tissue held at iso-osmotic conditions (Tiihonen, personal communication). However, piglet ileum exposed to hyperosmotic conditions in the absence of betaine had increased potassium levels. Since accumulation of betaine involves less energy expenditure than electrolyte accumulation, the cell is left in a more efficient state energetically. In addition, betaine has no harmful interactions with enzymes, unlike electrolytes.

Betaine has also been shown to improve body water retention. Using cycling heat stress and/or coccidia-challenge as stressors, broilers given betaine had higher levels of water retention than non-treated birds (Mooney *et al.*, 1998) (Figure 4).

Figure 4. Water retention of broilers exposed to heat stress and coccidiosis challenge



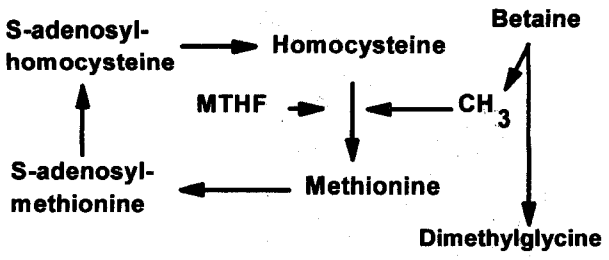
Water retention was calculated by using water consumption, urine production and evaporative cooling. The more positive the value, the better the rate of water retention. Since betaine was able to improve water retention of birds exposed to heat stress and/or coccidia challenge, these birds may be better able to cope with stress more efficiently.

Therefore, betaine, the osmolyte, can influence water balance in cells, tissues and ultimately, the whole animal. The key is in the amount of betaine given. Research using lesion scores as an indicator of osmotic benefit has shown that about 500 g betaine/ton is needed to be able to see a response. Since the gastrointestinal system, liver and kidney have first exposure to betaine, to see much "spill over" of betaine from these tissues, at least 750 g betaine/ton must be supplied in the diet.

BETAINE AND THE TRANSMETHYLATION CYCLE

Betaine has three methyl groups on its structure. The first of these groups is donated to homocysteine in its enzyme-induced conversion to methionine in the Transmethylation Cycle (Figure 5) of the liver. The other two methyl groups are donated to the one carbon pool that methylates substances like folic acid. Incidentally, the alternative or "back-up" step for conversion of homocysteine to methionine uses activated folic acid (methyltetrahydrofolate, MTHF) and vitamin B12 as cofactors. The presence of two separate enzyme systems for the same reaction indicates how important this step is to metabolism. In chickens, Saunderson and

Figure 5. Betaine in Transmethylation Pathway

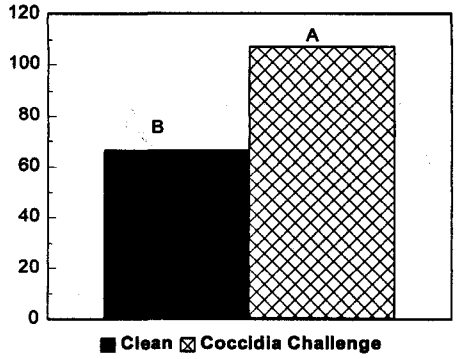


MacKinley (1990) noted that the folate based system is less active than the betaine utilizing system, thus the folate step could be considered a safety measure in case of low availability of betaine.

Research in the last six years has shown that about 15 to 20% of the methionine level or about 10% of TSAA can be spared in practical trial conditions using U.S. or European type diets. Practically speaking, the amount of methionine that can be spared in any given broiler diet is affected by three factors: bird stress level, dietary cystine level and amount of methionine needed to support nonmethylation functions.

Floor pen research has indicated that the FCR response to betaine supplementation in a basal low methionine diet is affected by the level of stress. This suggests that there is a change in activity of the transmethylation cycle. Since S-adenosylmethionine (S-AM) is used in a variety of reactions, including tissue repair and upregulation of the immune system, it would be logical that a stress could have this sort of impact. To test this concept, Tiihonen and coworkers (1997) analyzed liver S-AM content seven days after inoculation with a mixture of coccidia (Figure 7). It was found that birds challenged with coccidia had more S-AM in their livers at 21 days than did nonchallenged broilers.

Figure 7. S-adenosylmethionine in the liver of broilers without or without coccida challenge

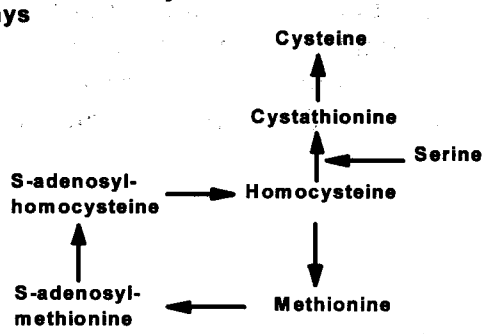


A, B =Means without a common letter differ significantly (P<0.05)
Units = nmol/g wet tissue

But why does stress affect betaine activity? By increasing the body's demand for S-AM, stress also increases the level of homocysteine available to be methylated back to methionine by betaine.

Homocysteine has several fates in the body. It can be methylated to methionine, converted to cysteine or be excreted on a limited basis. Practically speaking, conversion to cysteine has a direct impact on betaine activity since it affects the amount of homocysteine available to be methylated. For methionine to be converted to cysteine, it must first go through the methylation cycle to homocysteine (Figure 8). Then homocysteine is combined with serine, which eventually leads to the formation of cysteine.

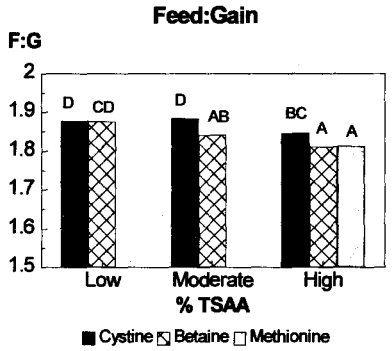
Figure 8. Transmethylation and Transsulfuration Pathways



The amount of cysteine which must be made from methionine via homocysteine is dependent how much cystine the diet contains. If the diet is low in cystine or poorly digestible, then the amount that must be made from methionine is increased. The reverse is also true, if dietary cystine levels are high or highly digestible, then synthesis from methionine is decreased. Since homocysteine is permanently lost from the Transmethylation pathway when cysteine is formed, diets low in dietary cystine affect betaine activity by decreasing availability of homocysteine for methylation. Research by Emmert and coworkers (1996) shows that cysteine increases the

activity of betaine-homocysteine methyltransferase. The implication of this work is that dietary cystine can decrease cysteine synthesis in the liver which would subsequently increase homocysteine availability and ultimately, the activity of betaine in methylation. To test this, broilers were fed diets containing varying levels of cystine as a percentage of total sulfur amino acids in the presence and absence of betaine. Methionine was held constant in each phase at levels adequate to support nonmethylation functions of this amino acid. In addition, stress level was low in this trial. Built-up litter was used, but no coccidia challenge was present. The results of Figure 9 show that the FCR response to betaine supplementation increased as dietary cystine level increased. Use of cystine to meet the total sulfur amino acid requirement (listed as high on figure 9) did improve feed:gain compared to the basal diet (listed as low) but did not match the results of the "typical" methionine diet (shown in gray, methionine used to meet total sulfur amino acid requirements in each phase). However, supplementation of betaine to the moderate and high TSAA diets (cystine used to increase TSAA instead of methionine) resulted in feed:gain values similar to that of the "typical" methionine diet.

Figure 9. Feed:Gain of 6-week-old broilers fed diets varying in cystine level with or without betaine addition



Betaine addition = 665, 600, 500g/ton/phase
A, B, C, D: columns without a common letter differ significantly (P<0.05)

The work of Mudd and coworkers (1975; 1980) indicates that amount of methionine needed in the Transmethylation Cycle far exceeds what the dietary consumption is. From an evolutionary standpoint, the methyl based conversion of homocysteine back to methionine increases the efficiency of methionine use in this pathway, thus lowering the dietary demand from what it could be without this conservation step. However, the methylation of homocysteine does not completely offset the need for methionine in the diet. Many poultry diets contain too low a native methionine level to support nonmethyl functions (i.e. lean tissue accretion); hence some methionine supplementation may be needed even in the presence of betaine.

CHOLINE AND BETAINE RELATIONSHIP

Since choline must be converted to betaine before use in methylation, choline is clearly not 100% bioefficient in methylation. In addition, choline is used in phospholipids and

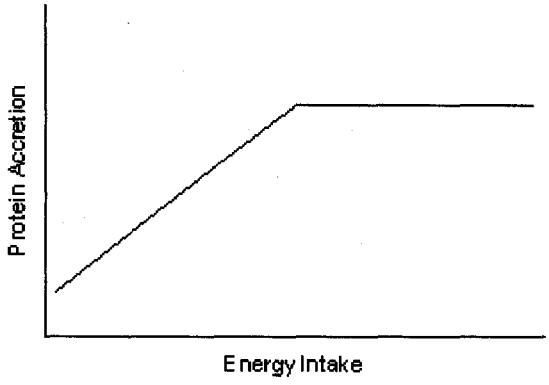
acetylcholine, functions in which betaine does not participate. The reverse is true as well – choline cannot act as an osmolyte in cells. Work by Tiihonen (personal communication) noted that the majority of choline is already bound as phospholipids when it emerges from the gastrointestinal tract of the broiler. Since only free (nonbound) choline can be converted to betaine, the low level of free choline limits the amount of betaine that can eventually be formed. In addition, the conversion from choline to betaine varies in efficiency across species. Estimates based on previously published literature indicate a range in efficiency between 50 and 60%. Unfortunately, much of the research examining this activity of choline has used traditional type chickens. Work by Tiihonen (personal communication) shows that efficiency of choline conversion to betaine is about 55% in the Ross broiler. Since the rate of betaine formation from choline in the Ross broiler fell in the range predicted by previously published work, it seems that genetic selection for growth rate has not altered this aspect of the broiler.

BETAINE IN SWINE DIETS

Betaine can be used as a methyl source in swine diets. Choline is not considered essential in many swine diets, yet it can be added in commercial conditions. Sparing choline with betaine is one way of improving methyl efficiency in swine. Some studies have examined use of betaine to spare methionine, certainly the potential is there for this application. But the most exciting area has been in studying the relationship between betaine and energy in grower/finisher swine diets.

Results from the trials conducted in research institutes suggest that the effect of betaine is to increase the energy value of the diet. Thus, the response to betaine supplementation in terms of carcass parameters (backfat thickness and lean percentage) will depend on whether the pigs are below or have reached their genetic capacity for protein accretion (Figure 10). Pigs that are still in the linear portion of the curve will respond to an increased energy value of the diet with an increased protein deposition. The net result is a bigger loin eye area and less backfat. Conversely, pigs that have reached their genetic ceiling will not respond to an increased availability of energy/nutrients with increased protein deposition; therefore, the extra energy available will be used to deposit more fat (hence thicker backfat).

Figure 10. Relationship between energy intake and rate of protein deposition



To test the concept that betaine supplementation increases the energy/nutrient value of the diet, two types of studies have been used. The first method compares the performance of pigs given

diets either *ad libitum* or on a restricted basis, while the second way is to formulate diets differing in energy content and observe response to betaine addition. Trials using both of these methods are discussed below.

The first trial examined the effect of betaine addition (1 kg/ton) on the performance of growing-finishing gilts and barrows fed either on a restricted or an *ad libitum* basis (Casarin *et al.*, 1997). During the growing phase (days 70 to 126), barrows and gilts receiving diets supplemented with betaine exhibited better feed conversions than their control counterparts, the magnitude of the improvement being greater for the pigs fed on a restricted basis (Table 1).

Table 1. Interactive effects of betaine and feed intake level on growth performance of growing-finishing pigs

Criterion	Barrows				Gilts			
	Ad libitum		80% of Ad libitum		Ad libitum		80% of Ad libitum	
	Control	Betaine (1kg/t)	Control	Betaine (1kg/t)	Control	Betaine (1kg/t)	Control	Betaine (1kg/t)
Growing								
ADG, kg/d	0.886^{a}	0.888^{a}	0.751^{b}	0.759^{b}	0.805^{a}	0.798^{a}	0.691^{c}	0.762^{b}
ADFI, kg/d	2.138^{a}	2.113^{a}	1.598^{c}	1.552^{c}	1.995^{b}	1.854^{b}	1.532^{c}	1.559^{c}
Feed:gain	2.413^{d}	2.379^{c}	2.127^{b}	2.044^{a}	2.478^{d}	2.323^{c}	2.217^{b}	2.045^{a}
Finishing								
ADG, kg/d	1.038^{a}	1.023^{a}	0.904^{b}	0.936^{b}	0.888^{b}	0.813^{b}	0.797^{c}	0.917^{b}
ADFI, kg/d	2.960^{a}	2.898^{a}	2.162^{d}	2.156^{d}	2.673^{b}	2.368^{c}	2.082^{d}	2.140^{d}
Feed:gain	2.851^{c}	2.832^{c}	2.391^{a}	2.303^{a}	3.006^{d}	2.912^{d}	2.612^{b}	2.330^{a}
Overall								
ADG, kg/d	0.932^{a}	0.929^{a}	0.798^{b}	0.813^{b}	0.830^{b}	0.803^{b}	0.724^{c}	0.809^{b}
ADFI, kg/d	2.385^{a}	2.349^{a}	1.767^{d}	1.733^{d}	2.198^{b}	2.008^{c}	1.678^{d}	1.733^{d}
Feed:gain	2.559^{d}	2.528^{d}	2.214^{b}	2.131^{a}	2.648^{d}	2.500^{d}	2.317^{c}	2.142^{a}

^{a,b,c,d} Means within a row with different superscripts are significantly different ($P < 0.05$)

As expected, gilts fed on an *ad libitum* basis consumed less feed than the barrows did and had a greater response to betaine. These results indicate that betaine supplementation during the growing period is beneficial. During the finishing phase (days 126 to 150), the trends were similar than for the growing period but the differences between control and betaine fed groups were not significant, the exception being for gilts fed on a restricted basis. Overall, feed conversion was improved by betaine supplementation in both barrows and gilts fed on a restricted basis. Pigs fed betaine had less backfat at all levels of intake: 23% improvement for pigs fed ad libitum and 28% for the feed restricted pigs (Table 2).

Table 2. Interactive effects of betaine and feed intake level on carcass parameters of growing-finishing pigs

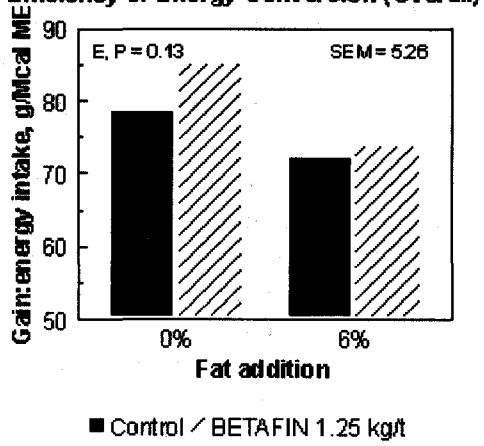
Criterion	Barrows				Gilts			
	Ad libitum		80% of Ad libitum		Ad libitum		80% of Ad libitum	
	Control	Betaine (1kg/t)	Control	Betaine (1kg/t)	Control	Betaine (1kg/t)	Control	Betaine (1kg/t)
Dressing %	83.4[a]	82.7[a]	80.7[b]	80.1[b]	83.0[a]	82.7[a]	80.7[b]	80.2[b]
Backfat, mm	14.2[d]	11.2[c]	12.0[c]	10.5[b]	13.0[d]	9.7[a]	13.0[d]	7.5[a]
Lean meat, %	51.0[d]	50.6[d]	52.2[c]	52.3[c]	51.7[d]	54.4[b]	53.0[b]	55.1[a]

[a,b,c,d] Means within a row with different superscripts are significantly different ($P < 0.05$)

The effect of betaine supplementation on percent lean was more pronounced in gilts than barrows. The results of this experiment suggest that betaine supplementation would be most effective in improving rate of gain under conditions where feed intake is below the pig's potential.

The next trial studied the interactive effects of betaine, energy level and protein level (Matthews *et al.*, 1997) but the focus here will be on the interrelationships between betaine (0 or 1.25 kg/t) and energy level (0 or 6% added fat) so only the treatment groups receiving diets adequate in crude protein (and amino acids) will be taken into consideration. To be able to compare results obtained with diets differing in their energetic density, the energetic efficiency (g growth/Mcal ME intake) was calculated for all treatments (Figure 10).

Figure 10. Interactive effects of betaine and energy on the efficiency of energy conversion of finishing gilts



Overall, the gilts receiving the diet supplemented with betaine were 8.2% more efficient than their control counterparts. For pigs receiving the diets containing high levels of fat, the magnitude of improvement caused by betaine supplementation was only 2.3% over their control counterparts. It is also relevant to compare the effect of the addition of either betaine or fat, gilts receiving the diet supplemented with betaine were 15% more efficient than gilts eating the high fat diet. These data again support the idea that betaine supplementation is more beneficial at lower levels of energy intake but also suggest that betaine supplementation may be used as an alternative to high fat addition.

The major benefit of using betaine in swine operations is with the "energy boosting" effect of betaine. In the case of growing and finishing pigs with submaximal energy intake, as is frequently the case under commercial conditions, betaine addition can result in improvements in feed efficiency in the range of 5 to 8%. If energy intake is sufficient to support maximal lean growth, such as is the case when high fat levels (4-7%) are included in the diet, the utilization of betaine results in cost savings by allowing for the removal of part of that fat without affecting the performance of the pigs.

BETAINE IN POULTRY DIETS

Betaine is used both as a methyl donor and osmolyte in broiler diets. Typical betaine additions (100% basis) range from 0.05 to 0.08% of the diet for broilers. Benefits on lesion scores have been noted at 0.05%, however osmolyte activity increases as dosage of betaine increases. Commonly, methionine and choline are spared as a result of betaine usage, although degree of sparing does vary.

In turkeys, an energy model, similar to that noted in pigs, is being studied. A tom trial was performed which examined use of betaine over the top of existing metabolizable energy levels and then started to spare energy after 6 weeks of age (Field trial 1997-1998) and continuing to approximately 22 weeks of age. No change in choline or methionine levels were made to the diets. Addition of 0.1% betaine 'over the top' boosted performance of the poults (Table 3).

Table 3. Effect of adding betaine over the top of existing diet.

Treatment	4 weeks		6 weeks	
	lbs	FCR	lbs	FCR
Control	1.86	1.63	3.83	1.81
Betaine	1.98	1.58	4.03	1.77

During the 6-9 week phase, metabolizable energy levels were reduced by 3% and supplemented with betaine (0.1%). During this period, toms supplemented with betaine had better performance than the birds fed the typical high energy diet (Table 4).

Table 4. Cumulative effect of betaine in a diet reduced in metabolizable energy by 3% vs. typical diet

Treatment	9 weeks*	
	lbs	FCR
Control	9.03	1.92
Betaine	9.39	1.90

*6-9 week diet was spared in ME

After 9 weeks of age, metabolizable energy level was reduced by 6% and 0.1% betaine was added (Table5).

Table 5. Reduction of metabolizable energy by 6% with betaine addition in diets fed after 9 weeks of age vs. typical diet

Treatment	12 weeks		15 weeks		18 weeks		22 weeks	
	lbs	FCR	lbs	FCR	lbs	FCR	lbs	FCR
Control	16.13	2.13	23.12	2.46	28.51	2.94	37.50	3.17
Betaine	16.47	2.14	23.63	2.46	28.07	3.07	37.22	3.33

Performance up to and including 15 weeks of age was similar between control and betaine supplemented toms, however subsequent performance to 22 weeks did not show the same result. This change in response after 15 weeks of age suggests that either the level of betaine addition was too low or that too much energy was spared in these phases. Carcass measurements suggested that betaine supplemented birds had a higher breast yield than controls (Table 6).

Table 6. Effect of betaine on breast yield in heavy toms.

Treatment	Breast
	(% of carcass weight)
Control	32.67
Betaine	33.92

This trial indicates that energy and betaine may share a similar relationship to that noted in swine. In addition, the effect on breast yield is consistent with work done in broilers.

Work by Ferket and coworkers (1993) indicates that betaine can be used instead of choline when the essential requirement of 1300 ppm total choline is met in starter poult diets. Essential requirement refers to choline used for phospholipids and acetylcholine. This means that betaine can be used to spare choline in turkey diets as well as an osmolyte.

WHY IS THERE AN ENERGY – BETAINE RELATIONSHIP?

This is an area of ongoing research. A possible examination is the effect that betaine has on energy expenditure related to water volume regulation of cells. Ion pumps are expensive; to get one molecule of potassium into the cell, 2 units of ATP are consumed. Hence usage of betaine

could result in immediate energy savings for this maintenance activity. Evidence in boars indicates that betaine decreases maintenance energy expenditure (Campbell, personal communication).

SUMMARY

The dual functions of betaine in the body allow it to be used a variety of ways, depending on what is the desired response is. Use of betaine as an osmolyte helps protect cells against water loss, but it also can be used to adjust caloric efficiency of pigs and turkeys. As a methyl donor, betaine promotes regeneration of methionine in the liver, which allows optimized dietary addition of this amino acid in broiler diets. In addition, betaine can be used to spare choline added for methyl purposes in animal diets. Overall, the activities of betaine in the body make it a valuable tool in animal diets.

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RECENT RESEARCH ON AMINO ACID DIGESTIBILITY OF FEED INGREDIENTS FOR POULTRY

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INTRODUCTION

Research during the last 5 years has revealed that the nutritional value and formulation of poultry feeds can be improved by considering amino acid digestibility of feed ingredients. This paper will first discuss improved formulation of poultry feeds by use of AA digestibility. The second part of the paper will focus on AA digestibility of new feed ingredients for improving the nutritional value of poultry feeds. New plant breeding and molecular biology/gene transfer methods are resulting in production of many new genetically modified grains and oilseed meals. This is a very exciting area and offers great future opportunities for poultry producers.

USE OF AMINO ACID DIGESTIBILITY IN FEED FORMULATION

The digestibility of amino acids (AA) varies greatly among feed ingredients and sometimes among different samples or batches of the same ingredient. For example, the digestibility of AA in soybean meal is greater than most other types of oilseed meals (NRC, 1994). The variability in AA digestibility among different animal protein meals and samples of the same meal can be very large. The results in Table 1 are from a recently completed study in my lab where we evaluated 32 different meat and bone meal samples produced in different commercial rendering processing systems and at different processing temperatures in attempt to determine the sources of variation in AA digestibility among meat and bone meals. The digestibilities of Lys and particularly Cys and PER values varied tremendously among three selected low-quality and high-quality meals from the 32 evaluated. The processing system and temperature were found to be important factors, with higher AA digestibilities in processing systems that used lower processing temperatures. It was interesting to find that very high-quality meat and bone meals can be produced with good processing conditions (Lys digestibility coefficients of 90% or higher).

Table 1. Variation in protein quality among samples of meat and bone meal (MBM)

MBM sample	Processing temperature (°C)	Digestibility coefficient (%)[1] Lysine	Cystine	Protein efficiency ratio (PER)[2]
Low quality 1	152	78	20	1.52
Low quality 2	152	71	31	1.32
Low quality 3	149	71	23	.97
High quality 1	110	92	71	2.68
High quality 2	110	91	59	2.37
High quality 3	129	90	71	2.26

[1]Determined in cecectomized roosters.
[2]PER = chick weight gain per unit of protein intake determined in chicks fed 10% protein diets containing a MBM as the only source of protein from 8 to 18 days of age.
Wang and Parsons (1998a).

Recently, we have conducted further work with meat and bone meal to assess the effects of pressure processing on AA digestibility. The reason for evaluating pressure processing is due to concerns of bovine spongiform encephalopathy (BSE). The feeding of BSE-infected MBM to ruminants may cause BSE. It is suspected that the consumption of meat from BSE-infected cattle may, in turn, cause Creutzfeldt-Jakob Disease (CJD) in humans. Consequently, extreme restrictions have been placed on the feeding of MBM in the United Kingdom and the feeding of MBM containing ruminant tissue to ruminants has been banned in the U.S. BSE and CJD are caused by heat-stable prion proteins that can be at least partially inactivated by pressure cooking. The European Union requires that MBM be processed at 3 atmospheres (30 gauge psi) for 20 minutes at 133° C (271° F) to reduce the risk of BSE and CJD. Future requirements/regulations for MBM processing are unknown. It is possible that MBM may have to be pressure processed in the U.S. in the future.

Processing conventionally-rendered MBM at 15, 30, 45 or 60 psi for 20 min. influenced AA digestibility (Table 2). Pressures of 15 and 30 psi produced moderate depressions in digestibility of most AA, including Thr, Lys and Met. The reductions in digestibility of Cys were greater than those for the other AA. Increasing the pressure to 60 psi produced large decreases in AA digestibility for all AA, with by far greatest reduction occurring for Cys. The large reduction in digestibility at 60 psi was due both to destruction of AA and decreased digestibility of AA that were not destroyed.

Table 2. Effect of pressure processing on amino acid digestibility coefficients (%) for meat and bone meal[1]

Gauge pressure (psi)[2]	Thr	Lys	Met	Cys
0	80[a]	75[a]	79[a]	65[a]
15	74[b]	65[b]	74[b]	46[b]
30	73[b]	64[b]	75[b]	44[b]
45	71[b]	60[b]	73[b]	44[b]
60	58[c]	45[c]	58[c]	14[c]

[a-c]Means within a column with no common superscript differ ($P < .05$).
[1]Shirley and Parsons, unpublished data.
[2]Meat and bone meals processed for 20 min. at the specified pressure.

Due to differences in AA digestibilities among ingredients, formulation of poultry feeds on a digestible AA basis should be superior to formulation on a total AA concentration basis. However, the poultry industry has generally been slow to change from total AA formulation to digestible AA formulation. This has occurred for two primary reasons. First, there has not been a good data base of amino acid digestibility values. Second, there have been little or no data on digestible AA requirements. The development of the precision-fed cecectomized rooster assay (Parsons, 1986) has resulted in a large increase in digestible amino acid data and also provided a means of obtaining ingredient digestibility data within a reasonable amount of time and at a reasonable cost.

A number of recent studies (e.g. Fernandez *et al.*, 1995; Rostagno *et al.*, 1995) have shown definite benefits to formulating diets on a digestible AA basis versus a total AA basis. The results of a study from my lab for low and high-quality meat and bone meals are shown in Table 3. Inclusion of 10 or 20% of either low or high-quality meat and bone meal into a corn-soybean meal diet on a total AA basis resulted in depressed chick weight gain and/or feed efficiency. When diets were formulated on a digestible AA basis, 10% low-quality or 10 or 20% high-quality meal had little or no negative effect on performance. These results clearly illustrate the superiority of formulating diets on a digestible or available AA basis. A negative effect was observed from 20% low-quality meat and bone meal even on an available AA basis. Further experiments showed that the latter negative effect was not associated with AA and was due to some other unknown characteristic of the meal. Similar types of responses were observed in a recent study on rendered spent hen meal (Table 4). Inclusion of 15% of three spent hen meals in a corn-soybean meal diet on a total AA basis depressed chick performance. Formulation of the SHM diets on a digestible AA basis yielded improved performance such that growth and feed efficiency of chicks fed 2 of the 3 SHM were not significantly different ($P < .05$) from those of chicks fed the corn-soybean meal diet.

Table 3. Dietary formulation with low-quality (LQ) and high-quality (HQ) meat and bone meals (MBM) on a total versus an available amino acid (AA) basis[1]

Dietary treatment	Formulation method	Weight gain (g)	Gain:feed ratio
Corn-SBM diet		326	.690
10% LQ MBM	Total AA	313	.644
20% LQ MBM	Total AA	288	.595
10% HQ MBM	Total AA	322	.656
20% HQ MBM	Total AA	310	.653
10% LQ MBM	Available AA	323	.669
20% LQ MBM	Available AA	304	.641
10% HQ MBM	Available AA	335	.688
20% HQ MBM	Available AA	332	.682
Pooled SEM		3	.004

[1]All diets contained 20% CP and were fed to chicks from 8 to 22 days of age. Lysine and sulfur amino acid digestibility coefficients (%) for the LQ and HQ MBM were 71 and 62 and 92 and 82, respectively (Wang and Parsons, 1998b).

Table 4. Growth performance of chicks fed a corn-soybean meal diet or diets containing 15% spent hen meal (SHM) formulated on a total or digestible amino acid (AA) basis[1]

Dietary treatment	SHM	Formulation method	Weight gain	Feed intake	Gain:feed
	(%)		(g)	(g)	(g:g)
1.	0		325^{a}	501^{b}	0.648^{a}
2.	SHM A	Total AA	287^{d}	531^{a}	0.541^{d}
3.	SHM B	Total AA	292^{d}	528^{ab}	0.552^{d}
4.	SHM C	Total AA	300^{cd}	517^{ab}	0.579^{c}
5.	SHM A	Digestible AA	310^{bc}	511^{ab}	0.606^{b}
6.	SHM B	Digestible AA	328^{a}	517^{ab}	0.633^{a}
7.	SHM C	Digestible AA	318^{ab}	502^{ab}	0.634^{a}
	Pooled SEM		5	10	0.006

[a-d]Means within a column with no common superscript differ significantly ($P < 0.05$).
[1]Means of four groups of five male chicks from 8 to 20 days posthatching; average initial weight was 93 g (Douglas and Parsons, unpublished data).

AMINO ACID DIGESTIBILITY OF NEW INGREDIENTS FOR POULTRY FEEDS

Recent advances in plant breeding/genetic engineering are resulting in many new genetically modified feed ingredients that have increased nutritional value for poultry feeds. Several

examples of these new ingredients are discussed below.

High-oil corn. Han and Parsons (1987) first showed that high-oil corn has increased nutritional value for poultry compared to conventional corn. Several studies in the last decade have confirmed the nutritional superiority of high-oil corn. Subsequently, high-oil corn has become the fastest growing new ingredient in the field of poultry nutrition. The increased nutritional value of high-oil corn is mainly considered to be due to increased ME content. However, recent work in my lab indicates that the digestibility of AA in high-oil corn is at least equal to conventional corn (Table 5) and may be higher than conventional corn.

Table 5. Composition (%), TME_n (kcal/g DM) and amino acid digestibility coefficients (%) of conventional corn (CC) and three high-oil corns (HOC1-3).

Component	CC	HOC1	HOC2	HOC3
Oil	3.8	5.2	6.0	8.6
Protein	9.0	8.9	9.5	8.9
Lys digest.[1]	79.3	78.6	92.8	87.8
Met digest.[1]	83.0	85.6	92.1	89.3
Cys digest.[1]	65.2	71.2	85.4	81.5
Thr digest.[1]	67.4	65.8	79.8	81.0
Arg digest.[1]	79.3	81.2	95.4	94.1
Val digest.[1]	85.8	88.3	100.8	100.7
Ile digest.[1]	84.2	86.4	100.0	98.7
Mean AA digest.	79.9	80.3	91.4	90.4
TME_n	3.880	4.024	4.038	4.140

[1]Amino acid digestibility and TME_n determined using the precision-fed cecectomized rooster assay; 9 roosters per corn sample (Parsons et al., 1998).

Nutri-Dense Corn. A new corn developed by Exseed Genetics has substantially increased levels of AA compared to conventional corn (Table 6). The digestibility of AA in the Nutri-Dense corn was found to be similar to a conventional corn sample. When the AA concentration is multiplied by the digestibility coefficient, it is apparent that the Nutri-Dense corn contains much higher levels of digestible AA than the conventional corn.

Table 6. Total and digestible amino acid levels (%) in conventional and Nutri-Dense corns[1]

	Conventional Corn			Nutri-Dense Corn		
Amino acid	Total	Dig. coef.	Dig. level	Total	Dig. coef.	Dig. level
Thr	.27	89	.24	.36	89	.32
Val	.39	86	.34	.54	88	.48
Ile	.29	90	.26	.39	90	.35
Leu	.91	96	.87	1.26	95	1.20
Phe	.37	90	.33	.51	90	.46
Lys	.26	90	.23	.36	90	.32
Arg	.35	88	.31	.54	90	.49
Met	.16	87	.14	.21	87	.18
Cys	.19	73	.14	.23	77	.18

[1]Amino acid digestibility determined using the precision-fed cecectomized rooster assay; 9 roosters per sample (Parsons, unpublished). Nutri-Dense corn obtained from Ex-seed Genetics, Decatur, IL.

Reduced trypsin-inhibitor and lectin-free soybeans. Two of the major antinutritional factors in soybeans are trypsin inhibitors and lectins. New varieties of soybeans have been developed at the University of Illinois that have no Kunitz trypsin inhibitor and no lectins. Although all of the Kunitz trypsin inhibitor has been genetically deleted, the Bowman-Birk trypsin/chymotrypsin inhibitor remains. The nutritional value of these new soybeans has been evaluated in several growth trials where chicks were fed 23% CP dextrose-soybean diets in which conventional, Kunitz-free or lectin-free raw fullfat soybeans provided the only source of dietary protein. Commercial dehulled SBM was included as a positive control. Additional experiments evaluated the amino acid digestibility of the different soybeans. The results of the chick and AA digestibility trials showed that the Kunitz-free and lectin-free soybeans have increased nutritional value compared to conventional soybeans, with the Kunitz-free being greater than the lectin-free soybeans. Thus, the trypsin-inhibitors are a greater antinutritional factor than the lectins. The lower nutritional value of Kunitz-free soybeans compared to commercial dehulled SBM is probably mainly due to the Bowman-Birk trypsin/chymotrypsin inhibitors that are still present.

High-lysine soybeans. Dupont Agricultural Products has developed a new transgenic soybean that has 50% more lysine than conventional soybeans (4.4 vs 3.0%). Levels of other AA in the two soybean meals were similar. The results of a precision-fed cecectomized rooster assay (Parsons and Araba, unpublished) indicated that the digestibility of the AA, including lysine, in the new high-lysine soybeans was the same as that in conventional soybeans when they were adequately heat processed by autoclaving for 5 minutes.

Table 7. Effect of heat processing on total amino acids (%) and digestibility of amino acids (%) in conventional and high-lysine soybean meals (SBM)[1]

	Conventional SBM		High-lysine SBM	
Amino acid	Total	Digest	Total	Digest
Lys	2.98	89	4.40	90
Met	.67	79	.65	78
Cys	.70	79	.69	82
Thr	1.72	80	1.78	84
Val	2.26	90	2.10	89
Arg	3.33	92	3.30	88

[1]Soybean meals obtained from Dupont Agricultural Products, Des Moines, IA. The raw soybean meals were autoclaved at 121° C for 5 minutes (Parsons and Araba, unpublished).

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Ideal Amino Acid Profile and Metabolizable Energy Requirements for Layers

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Introduction

The dietary requirements for ME and amino acids for layers should be based on specific environmental conditions, maintenance needs and product output. The maintenance energy requirement for layers is very dependent on environmental temperatures and body size and has a tremendous effect on total daily feed intake. The daily amino acid requirements for layers are primarily affected by egg mass output with a small percentage of daily needs used for maintenance. A factorial approach for determining the metabolizable energy and amino acid requirements should provide useful nutrition information for feeding both current and future layer strains. The genetic potential of the commercial layer is continuously changing to meet the market needs of the poultry industry. Genetic lines are being developed to support both the liquid egg and shell egg markets with large differences in egg mass output and feed efficiency. Prediction models for ME intake are of importance since dietary concentration of other nutrients depends on ME intake in laying hens. The accuracy of energy partition models relies on the estimation of maintenance (ME_m), and energy efficiency utilization (EU) for production. Significant coefficient variations for estimating ME_m and EU have been reported mainly because of the variations in methodology (1).

The objectives of this report are 1.) To present several experiments designed to determine the ME_m, and EU for egg production, 2.) To determine if the performance of layers fed corn-soy-meat and bone meal 14% protein diets supplemented with synthetic amino acids can be equivalent to layers fed 16 and 18% corn-soy-meat and bone meal diets and 3.) To determine the ideal amino acid profile and the daily intake of digestible amino acids needed for optimum performance of commercial layers.

Metabolizable Energy Studies

Experiment (EXP) 1: A total of 50 laying hens, 46 wk of age were individually caged at 19.7 C and fed *ad libitum*. Hens were intramuscularly injected with 10 mg TAM/kg body weight at days 1, 4, 7, and 10. Body weight (W, kg) and feed intake (FI) was recorded every 3rd day during the 9-wk experiment. Egg production (EP) was

recorded daily. Zero EP was reached one week after the 1rst TAM administration. The ME intake (MEI, kcal/h/d) was regressed against the $W^{0.75}$ and weight change (ΔW, g/d) using the data collected during the zero EP period for each hen to estimate ME_m and energy required for unit weight gain. These estimated values were then used to calculate the EU for production after the hen rejuvenated lay. Thus the ME_m and EU for production were estimated independently for each individual.

EXP 2: A total of 120 individually caged laying hens, 62 wk of age, were assigned into 6 rooms of 20 each (7.5, 15.2, 21.4, 25.8, 32.4, 36.5 C). Same technique as in EXP 1 was used is this experiment to determine ME_m as affected by temperature (T, °C) and EU for production.

EXP 3: A total of 90 laying hens, 84 wk of age, were assigned into 9 groups with 10 hens each. One group (10 hens) was sacrificed at beginning of the experiment for body composition analysis. The remaining groups were provided daily FI of 30, 40, 50, 60, 70, 80, 90 g/h, and *ad libitum* for 16 days, and sacrificed at the end of the trial and analyzed for body composition. Eggs laid during the experiment were weighed and analyzed for egg composition. The MEI was regressed against body energy change (BEC), and energy produced from egg mass (EME).

EXP 4: From the estimates obtained in EXP 1-3, two ME intake (MEI, kcal/d) prediction models were developed: $MEI=W^{0.75}(209.4-6.5873T+0.0905T^2)+5\Delta W + EM*EEC/0.63$ (Equation 1); $MEI=W^{0.75}(143.7 -1.612T) + 5\Delta W + EM*EEC/0.63$ (Equation 2), where EM = egg mass (g/h d), EEC = egg energy concentration (kcal/g EM). The two models were tested against the models in the literature (2-5) using following EXP data.

A total of 480 individually caged hens, 26 wk age, were assigned into a 4 x 4 (temperature x strain: 10.0, 18.3, 26.7, 35.0C; A, B, C, D) factorial arrangement. Four diets were formulated for each temperature based on the FI during a 2-wk acclimation period, and provided to hens *ad libitum* for 3 periods of 4 wk each. Individual performance (FI, W, and EM) was measured.

Results and Discussion

EXP 1: The estimated average daily ME_m was 117.3 ± 2.0 kcal/$W^{0.75}$. The EU for egg production was 60.4 ± 1.78% (Table 1).

EXP 2: The EU for production was estimated to be 112.8, 81.4, 61.4, 66.7, 63.0 and 69.8% at 7.5, 15.2, 21.4, 25.8, 32.4, 36.5 C, respectively (Table 2). The relationship of ME_m and T was well described by the equation:

ME_m (kcal/$BW^{0.75}$) = $0.0905T^2$ - 6.5873T + 209.4 (R^2 = 0.9805, P<0.005, MSR=28.4) during the non-laying period. ME_m determined during non-laying period appeared to be over-estimates of ME_m during laying period as evidenced by the over-estimated EU for production at the cold Ts (7.5 and 15.2C). By assuming a constant EUEP of 63% for the laying period across all temperatures the relationship of ME_m and T was well described by a linear regression line: ME_m (kcal/$BW^{0.75}$) = 143.7 - 1.612T (R2=0.78). Figure 1 illustrates the differences in ME_m predicted by the two equations for the six temperatures.

EXP 3: Three regression equations were derived from the data: MEI = 161.6 + 1.026BEC + 1.4623 EME (R^2=91.51) (equation 1); MEI = 120.1$W^{0.75}$ + 0.968 BEC + 1.397 EME (R2=0.9905) (equation 2); and using data from hens with negative weight change: MEI = 123.5$W^{0.75}$ + 0.985BEC + 1.348EME (R2=0.989) (equation 3). The data showed that body energy was used at an equivalent value compared to dietary energy. EUEP was 0.684, 0.716, 0.725 from equations 1-3, and ME_m was 120 and 123 kcal/kg $W^{0.75}$ from equations 1 and 2, respectively at 19.7 C.

EXP 4: Equation 2 produced the closest predictions to the actual ME intake. The NRC (2) equation produced the second best predictions among the models, but appeared to overestimate the intake at cold Ts. The empirical model (5) produced the most unreliable predictions (Table 3).

Amino Acid Requirement Studies

Layer Strains and Management. In Experiment 1, three hundred and sixty DeKalb-XL layers, forty-six weeks of age, were randomly allocated into cages (10 in. x 18 in.) with 3 hens per cage. The hens were divided into 15 groups with 8 replicates per group. Each replicate consisted of 3 hens in each of the cages. The layers were provided a 16 hour light and 8 hour dark photoperiod. The layers were housed at a constant 70 degree F temperature and provided water and feed *ad libitum*. The layers were fed the experimental diets for 16 weeks or four 28-day periods.

In Experiment 2, Fourteen hundred Hy-line W-36 hens (33 weeks of age) were randomly divided into 40 treatments with each treatment consisting of 7 groups of 5 hens each. Each group of hens was fed in stack cages (49.9 cm deep and 48.9 cm wide) and provided with a 16-hr light: 8-hr dark photoperiod with the environmental temperature maintained at 70 degrees F. The experimental diets were fed to the layers for a 16-week period or for 4 complete 28-day periods.

Eleven hundred and sixty Hy-line W-36 hens (35 weeks of age) were randomly assorted into 29 treatments in Experiment 3 with each treatment consisting of 10 groups. Each group of hens were housed in commercial stack cages (49.9 cm deep and 48.9 cm wide) with 4 layers per cage. The layers were provided with a 16-hr light: 8-hr dark photoperiod with the environmental temperature maintained at 70 degrees F. Experimental test amino acid diets were fed to the layers for a 12-week period or for 3 complete 28-day periods.

Eleven hundred and twenty Dekalb Delta layers, 38 weeks of age, were randomly assorted into 28 treatments in Experiment 4 with each treatment consisting of 10 groups. Each group of hens were housed in commercial stack cages (49.9 cm deep and 48.9 cm wide) with 4 layers per cage. The layers were provided with a 16 hour light: 8 hour dark photoperiod with the environmental temperature maintained at 70 degrees F. The 28 test diets were fed to the layers for a 12 week period or for 3 complete 28-day periods.

Six hundred and forty Hyline-W36 commercial layers, sixty weeks of age, were randomly assorted into 16 treatments in Experiment 5 with each treatment consisting of ten groups. Each group of hens was provided with a 16:8 light-dark photoperiod with the environmental temperature maintained at 70 degrees F. The 16 diets were fed to the layers for a 12-week period or for 3 complete 28-day periods.

Three hundred and thirty six DeKalb XL commercial layers, 29 ad 35 weeks of age, were randomly assorted into 21 treatments in Experiment 6. Each treatment consisted of feeding four groups of hens with four hens in each group. The hens were housed in commercial stack cages (49.9 cm deep and 48.9 cm wide) and provided experimental feed and water free choice for a six week period. Eleven treatments consisted of 29-week old layers at the beginning of the 6-week feeding experiment and ten treatments consisted of 35-week old layers at the initiation of the experiment. The 29-week old layers were provided a 15 hour light: 9 hour dark photoperiod for the first week of the six week study and 15 minutes light was added per week until 16 hours light was reached during the 5^{th} week of the experiment. The 35-week-old layers were provided 16 hours light: 8-hour dark period each day during the six-week experiment.

In Experiment 7, eight hundred and fifty layers (36 weeks of age), consisting of four commercial strains, were randomly assorted into 25 treatment with each treatment consisting of 8 groups. Each group of hens were housed in same stack cages as previously described in Experiment 2 and 3 and also provided same lighting and environmental temperature. Experimental protein and amino acid diets were fed the layers for a 16-week period or

for four complete 28-day periods. Each strain of commercial layer was fed each of the five experimental diets. Two additional groups of one commercial strain were fed the five experimental diets for the sixteen-week period. The additional layers of the one strain were utilized in a two-week nitrogen balance study that was conducted at the completion of the sixteen-week period.

Diets. The diets used for Experiment 1 were corn-soy diets containing 14%, 16%, 18%, and 19.5% protein. Combinations of essential and non-essential amino acids were added to both the 14% and 16% protein diets to determine which amino acids need to be supplemented to equal the performance of layers fed 18% protein diets. The diets used in Experiment 2 and 3 were corn-soy-meat and bone meal diets that have been previously reported (6). The 14% basal diets in both Experiment 2 and 3 were supplemented with crystalline methionine, lysine, arginine, threonine, tryptophan, isoleucine, and valine to equal the 18% protein total amino acid level (Experiment 2) or digestible amino acid level (Experiment 3). Layer responses to increments of methionine, lysine, tryptophan, arginine, threonine, valine, and isoleucine were evaluated by adding four levels of each test amino acid to the basal which provided 5 levels of each test amino acid. In Experiment 3, methionine and tryptophan test diets were not evaluated as in Experiment 2. The diets used in Experiment 4 consisted of two different types. A 25 %CP summit diet was formulated that consisted of corn, soybean meal, sesame meal, corn gluten meal, canal, and meat and bone meal which contained .931 % digestible lysine. The summit diet was then diluted with a dilution diet consisting of starch, glucose monohydrate, cellulose: sand, vitamins, and minerals. A range of experimental lysine levels (.3 to .93 digestible lysine) was provided by diluting the summit diet thus keeping the same protein and amino acid profile for all treatments. Another group of diets was formulated for 14, 15, and 16% protein levels using corn, sesame meal, corn gluten meal, canola, and meat and bone meal with digestible methionine, arginine, tryptophan, valine, threonine, and isoleucine kept constant by adding synthetic amino acids. Three traditional diets containing corn, soybean meal, and meat and bone meal were formulated to provide 16 %protein with and without additional lysine and an 18 % diet. Diets used in Experiment 5 consisted of three 14 % protein basal diets and an 18 % protein control diet consisting of corn-soy-meat. A 14% protein tryptophan deficient basal diet consisting of corn, meat and bone meal, corn gluten meal, and canola meal was used to provide five experimental tryptophan levels ranging from .09 to .155% digestible tryptophan. A 14% protein methionine and TSAA deficient basal was formulated consisting of corn-soy-meat. The two sulfur amino acid basal diets were the same except the TSAA deficient basal contained

no added dietary cystine and the methionione deficient basal contained .5% digestible cystine by adding .147% crystalline cystine. Four additional levels of methionine were added to each of the two sulfur amino acid basals to provide 10 diets ranging from .209% digestible methionine/.415% digestible TSAA to .478% digestible methionine/.684% digestible TSAA. The high cystine basal provided the same range of methionine levels with the TSAA ranging from .562 % digestible TSAA to .831 % digestible TSAA. Experiment 6 consisted of using a corn-soy 8% protein basal diet supplemented with both essential and nonessential amino acids to provide amino acids above NRC (1994) recommended levels except for methionine and cystine. Experimental diets were formulated to first evaluate methionine requirements by adding dietary cystine to the diets and then using this information to determine the cystine requirements by feeding the same basal without cystine with the determined methionine requirement levels. Experiment 7 diets were corn-soy-meat diets that were formulated to provide 14, 16, and 18% protein. The treatments consisted of feeding a 18% diet with additional methionine , 16% protein with methionine, 16% protein with methionine and lysine, 14% protein with methionine, lysine, tryptophan, and arginine, and 14% protein with methionine, lysine, tryptophan, arginine, isoleucine, and valine. The diets were formulated to provide the digestible amino acids determined to be required in Experiment 2 and 3.

Data Collection. Eggs were collected daily during the 6, 12, or 16-week studies to determine hen-day egg production. Egg weights were determined weekly on one-days eggs from each replicate. Egg mass was determined by multiplying egg production times egg weight and dividing by 100. Hen bodyweights were determined at the beginning of the experiment and after the experiment was completed for all experiments except Experiment 6 which was a six-week study. The body weights were determined every two weeks for Experiment 6. The data was expressed as g body weight change for the experiment. Feed consumption was determined by weighing back the feed after each 28-day period for the 12 and 16-week experiments and after every two weeks for Experiment 6. Egg composition (% albumen, % yolk, % shell and membrane) was determined on eggs between the 5th and 6th week and again between the 11th and 12th week for the 12-week experiments. The egg composition was determined on the 16th week for the 16 -week experiments. The amino acid digestibility of the diets were determined by the method of Sibbald by assaying the amino acids in diets and excreta samples collected from force feeding studies with adult Leghorn cockerels. In Experiment 7, a complete nitrogen balance study was conducted with 10 individual hens fed each of the five test diets. All eggs laid during the two-week study were saved for nitrogen analysis. The

change in carcass nitrogen was determined by sacrificing 10 hens of same strain fed the same five experimental diets for beginning nitrogen values and then sacrificing all fifty layers following the two week balance study. Celite was added at a level of 0.8% to each of the five test diets as an acid insoluble ash marker. The last two days of fourteen-day balance study were used to collect excreta samples for nitrogen analysis. The carcasses were defeathered and homogenized prior to nitrogen analysis.

Results and Discussion

Experiment 1. The feeding of 14% protein diets produced equal layer performance compared to the hens consuming the 16% and 18% protein diets. The highest egg production and egg mass was from the hens fed the 14% CP diets with supplemental levels of methionine, lysine, tryptophan, isoleucine, and valine and the hens fed the 16% diet supplemented with methionine, lysine, and non-essential amino acids. The poorest egg production was for the hens fed the 14% protein diet without added amino acids other than methionine.

An interesting observation occurred for some groups of hens fed the diets with additional NEAA. Hens fed the 16% CP basal with added lysine and NEAA and the 14% CP basal with added lysine, tryptophan and NEAA consumed the most feed during the 16 week trial. The NEAA may not add value to the diets deficient in other amino acids or in 16% protein diets that may have plenty of non-essential amino acid nitrogen and the extra nitrogen may require the hen to consume additional dietary energy to convert the nitrogen to uric acid for elimination. The birds fed the 14% CP diets with added NEAA were very efficient but did not produce the maximum egg mass for the low protein treatments. There were no significant differences in body weight gain, however, the 14% CP diet with no additional amino acids other than methionine and the diet with only additional methionine and lysine had the lowest weight gain. The percent yolk for the eggs from the experimental hens was the highest for hens fed the 14% CP diet with added methionine, lysine, tryptophan, isoleucine, valine, threonine, arginine, and NEAA. The layers fed the 14% CP with all of the added amino acids were also the most efficient layers (1.93 g feed/g egg mass) in the experiment. The highest % albumen of 57.0 in the egg was from hens fed a 19 % CP control diet. The albumen % in eggs from hens fed a diet with 14% CP with added methionine, lysine, tryptophan, isoleucine, valine, and NEAA was 56.8% and was not significantly different to the % albumen from the eggs for the hens fed the 19 % CP diets.

Experiment 2. Layers fed 14% protein diets with various combinations of added amino acids produced equal egg number, egg weights, egg mass, feed efficiency, and body weight gain compared to hens fed 16% and 18% diets. The addition of four levels of methionine to the 14% protein basal diets significantly increased percent egg production, egg weight, egg mass, and feed efficiency. The highest concentration of dietary methionine and TSAA produced 50 g daily egg mass and a feed efficiency (g feed/g egg mass) of 1.93 with daily intakes of 354 digestible methionine and 551 mg digestible TSAA. Layer diets containing 16% and 18% protein contained .338% digestible methionine and .571% digestible TSAA and .336% digestible methionine and .595% digestible TSAA respectively. The highest intake of digestible methionine and TSAA indicated a requirement of 7.04 mg methionine and 10.96 mg TSAA/g egg mass output. Cao et al. (7) reported a requirement of 350 mg digestible methionine and 245 mg digestible cystine (595 mg TSAA) per day for hens producing 54 g egg mass and maintaining their body weight. The digestible methionine and TSAA per g egg output was 6.48 and 11.02, respectively. The methionine and TSAA requirement data in Experiment 2 closely correlated with the report of Cao et al. (7).

The daily digestible requirement of lysine (P =. 07), arginine (P =. 01), valine (P =. 09), and threonine (P =. 12) for maximum egg mass production was 705 mg digestible lysine or 14.07 mg/g egg mass output, 1070 mg digestible arginine or 20.97 mg/g egg mass output, 731 mg digestible valine or 14.19 mg/g egg mass output, and 560 mg digestible threonine or 11.1 mg/g egg mass.

The addition of dietary isoleucine produced a significant response for egg weight (P =. 02) and body weight gain (P =. 02). The requirement for isoleucine for maximum egg weight and a positive weight gain was 603 mg digestible isoleucine/day or 12.07 mg/g egg mass output. Valine was the only amino acid other than isoleucine that produced a significant response for body weight gain (P=. 03). Valine also produced a significant increase in % albumen of eggs.

The addition of dietary tryptophan to the 14% protein basal did not produce a significant response in layer performance. The baseline daily intake of digestible tryptophan was 122 mg/day or 2.46 mg/g egg mass output.

Experiment 3. The daily requirements for all essential amino acids were determined to be less than observed in Experiment 2 even though the hens produced slightly more egg mass. The performance and efficiency of amino acid utilization was improved because the overall amount of crystalline amino acids added to the 14%

diets were less than in Experiment 2. The digestible amino acids of the 14% test diets were made equal to the digestible amino acids of the 18% protein diets instead of being made equal to the total amino acids.

The digestible lysine requirement for maximum egg mass (P=. 10) was 636 mg day or 12.27 mg/g egg mass output. The digestible valine requirement for maximum egg mass (P=. 01) was 646 mg/day or 12.32 mg/g egg mass output. Valine produced a very significant response (P=. 001) for weight gain similar to Experiment 2. The daily requirement for digestible isoleucine for maximum egg mass (P=. 06) was 555 mg or 10.72 mg/g egg mass output. The response of body weight gain (P=. 05) to isoleucine was second only to valine. The two branch chain amino acids consistently had the most significant impact on layer body weight gain in both Experiments 2 and 3.

Dietary valine was the only amino acid to increase the % albumen in eggs. The increase in % albumen caused by dietary valine occurred in Experiment 2 and 3 and was the only amino acid to cause this response. In Experiment 3 there was no increase in egg mass production with increases in daily intakes of threonine or arginine.

The highest egg mass production from hens fed 14% protein diets was 52.45 g/day compared to 51.94 g/day and 52.69 g/day for layers fed the 16% protein and 18.5% protein diet respectively. The research indicates the performance of layers fed 14% corn-soy-meat diets can be equivalent to layers fed 16 and 18% protein diets if the low protein diets are supplemented with adequate methionine, lysine, tryptophan, valine, and isoleucine.

Experiment 4. The digestible lysine was determined by the traditional method utilizing three protein levels with balanced amino acid levels and also by using the Summit: Dilution approach. The performance of the hens fed the Summit: Dilution diets indicated the layers needed 676 mg lysine /day or 11.82 mg/g egg mass. The optimum diet contained 18.68 %CP and .694 digestible lysine. The layers fed the traditional 14 % CP with all amino acids supplemented indicated a need of 742 mg /day, whereas hens fed the 15 and 16 % CP diets required 662 mg/day and 651 mg/day, respectively. The average lysine requirement for all treatments was 683 mg/day or 12.23 mg/g egg mass.

Experiment 5. The optimum performance of the layers was obtained on 143 mg/day of digestible tryptophan. The digestible tryptophan determined in experiment 2 was only 122 mg/ day. The hens were consuming corn, sesame meal, canola, and meat and bone meal diets instead of corn-soy-meat diets but both

experiments were conducted with digestible tryptophan values. The hens were 62 weeks of age in experiment 5 whereas in earlier experiments the layers were less than 62 weeks of age. The layers fed the low cystine basal required only 283 mg methionine/day or 496 mg TSAA mg/day. The hens performed very well on the 283 mg/day of methionine thus producing 51 g egg mass with a feed efficiency of 2.04 which was equal to hens fed the 18% control diet. The hens fed test methionine levels from diets with the high cystine basal tended to produce less egg mass with equivalent methionine levels compared to the low cystine basal, however the highest egg mass output of 51.3 g/day occurred for the hens fed the highest methionine level with the high cystine basal. The research with the low cystine basal diet indicates the layer cystine requirement may be no more than 213 mg/day.

Experiment 6. The methionine and cystine requirement of layers was determined in a two-part experiment. The layers were fed a basal containing .42 digestible cystine or a basal containing .15 digestible cystine. Layers fed the high cystine basal required 352 mg/day of methionine to produce 54 g egg mass. The cystine requirement was determined to be 244 mg /day for hens producing 54 g egg mass day. The higher requirements for methionine and cystine compared to data from experiment 5 can be partially related to the 4 g additional egg mass produced per day in experiment 6. If you convert the 213 mg/day from experiment 4 to requirements per g egg mass the hens would require 4.2 mg cystine/g egg mass whereas hens in experiment 6 required 4.5 mg cystine/g egg mass. The amino acid requirements for all six experiments and the average of the experiments are reported in Table 4.

Experiment 7. The performance of four commercial strains of layers fed the five experimental diets is reported in Table 5. The layers fed the 18% protein diets, 16%protein diets with and without added lysine, and 14% protein diets with added arginine, tryptophan, valine, and isoleucine produced the same egg mass, hen day egg production, egg weights, body weight gain, feed efficiency, and egg composition during a sixteen week feeding study. All diets were formulated with additional methionine. Layers fed the 14% protein diets supplemented with lysine, arginine, and tryptophan produced significantly less egg mass, lost the most weight, and had the poorest feed efficiency compared to the other groups. The nitrogen balance study conducted at the end of the feeding trial shows the potential improvement in nitrogen retention of feeding the lower protein diets that are supplemented with optimum levels of amino acids (Table 6). Layers fed the 14% protein diets supplemented with methionine, lysine, tryptophan, arginine, isoleucine, and valine retained approximately 46% dietary nitrogen whereas layers fed 18% protein diets retained only 38.9% nitrogen. The feeding of 14% protein diets consisting of corn-soy-meat provides a

deficient daily intake of isoleucine and valine. The costs of adding the branch chain amino acids to low protein diets for feeding commercial layers would be too expensive at the present time.

Summary

Experiments were conducted to investigate the energy maintenance requirement (ME_m) as affected by temperature (T in °C), and utilization efficiency for egg synthesis (EUEP) using either a new technique with hens treated with Tamoxifen (TAM) or restriction feeding technique (RFT). The estimated ME_m was 117.3 ± 2.0 kcal/kg $W^{0.75}$, and the EUEP was 60.4 ± 2.0% using TAM at 19.7 C. Using TAM technique in another experiment at temperatures of 7.5, 15.2, 21.4, 25.8, 32.4, 36.5 C, the relationship of ME_m and T was well described by: ME_m (kcal/$BW^{0.75}$) = $0.0905T^2$ - 6.5873T + 209.4 for a non-laying period, and = 143.7 - 1.612T for a laying period when assuming a constant 63% EUEP. The ME_m determined during the non-laying period appeared to overestimate ME_m during the laying period for hens housed at 7.5 and 15.2 C. The data indicates that dietary energy not retained during egg formation may be used to maintain body temperature for layers housed in cold temperatures. Using RFT, EUEP was 0.684, 0.716, and ME_m 120 and 123 kcal/kg $W^{0.75}$ from two regression equations. From the coefficients determined using TAM, two ME intake prediction models were developed, and tested against other models in the literature. Model 2 [$MEI=W^{0.75}$ (143.7 -1.612T) + 5ΔW + EM*EEC/0.63, where MEI = energy intake (kcal/h), W = BW (kg), ΔW = BW change (g/h/d), EM = egg mass (g/h d), EEC = egg energy concentration (kcal/g EM)] produced the nearest predictions among the models tested.

The main objective of the layer feeding trials was to determine if the performance of layers fed low protein diets supplemented with essential or non-essential amino acids could be equal to layers fed 18% CP diets supplemented with methionine. Five thousand eight hundred and sixty six layers consisting of four different strains were fed experimental diets from eight to sixteen weeks in seven different experiments. The experimental diets were isocaloric containing 2900 kcal ME/kg and digestible amino acids were determined for the test diets. The response of each test amino acid was evaluated separately in two of the seven experiments by adding four supplemental levels to 14% protein diets. The 14% CP diets, except for the test amino acid, were supplemented with all essential amino acids providing amino acid levels contained in 18% CP control diets. Isoleucine and valine added to 14% CP diets significantly increased body weight gain and also had a larger effect on percent albumen and yolk than other amino acids. The addition of tryptophan to the low protein corn-soy-meat diets had no effect on

layer performance. Non-essential amino acids added to the 14% CP diet did not improve performance and actually tended to increase feed consumption and decrease feed efficiency. The egg composition and performance of layers fed corn-soy-meat 14% CP diets with added methionine, lysine, isoleucine, and valine was equal to layers fed 18% CP control diets. The research showed that four different commercial layer strains fed 14% protein diets with added synthetic amino acids to provide an ideal protein performed equal to layers fed higher protein diets. Nitrogen loss in excreta was 15 percent less for layers fed 14% protein diets supplemented with amino acids compared to layers fed 18% protein diets. The ideal amino acid profile determined from the research at the University of Minnesota is shown in Table 7. The amino acid profile is related to lysine requirements for both the NRC (1994) suggested requirements and the average values obtained from the MN series of layer amino acid experiments. The MN layer arginine and methionine ratios to lysine are higher whereas the TSAA, isoleucine, tryptophan, and valine are slightly lower than the NRC ratios.

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Table 1. Estimated ME_m (a), energy required for unit weight change (c and c') using two regression models[1] and the estimated EU for production (EUEP) in EXP 1.

	Model 1			Model 2		EUEP
	a	c	Adjusted R^2	c'	Adjusted $R^{2\prime}$	(%)
n	46	46	46	46	46	38
Mean	117.3	3.764	0.977	3.742	0.768	60.45
SE	2.03	0.101	0.003	0.098	0.023	1.776

[1]Model 1: $MEI = aW^{0.75} + cWC$, where WC = weight change (g/d). Model 2: MEI = a' + c'WC (without forcing the line through the origin).

Table 2. Production parameters, and calculated coefficients in EXP 2.

T (°C)	7.5	15.2	21.4	25.8	32.4	36.5
n	18	14	19	14	14	9
EM (g/h/d)	48.15	48.08	48.48	52.29	49.57	31.85
Egg GE (kcal/gEM)	1.65	1.61	1.64	1.66	1.65	1.60
BW (kg)	1.64	1.73	1.66	1.91	1.63	1.53
W change (g/h/d)	-0.19	-1.71	0.91	-0.06	-4.76	-4.05
FI (g/h/d)[1]	108.1	94.3	103.0	97.3	83.8	59.3
EU for production (%)	112.8	81.4	61.4	66.7	63.0	69.8
ME_m (kcal/$W^{0.75}$/d)	167.2	124.2	114.5	97.8	94.6	86.9
ME_m Corrected[2]	134.2	108.5	118.9	92.4	98.2	83.1

[1]Feed contained 2954 kcal/kg. AMEn.

[2]Maintenance corrected values were calculated by assuming a 63% EU for production and 5 kcal increase or decrease in energy requirement per g weight gain or loss.

Table 3. Actual ME intake (MEI; kcal/d) and predicted ME intake (kcal/d) using prediction models in EXP4.

Temp	Strain	MEI	Model 1	Model 2	Emmans 1974	NRC 1994	Pesti 1992	Peguri and Coon
10		324	361	324	357	338	364	354
18.3		297	319	311	333	322	333	342
26.7		282	290	294	305	301	301	324
35		223	219	215	214	219	328	227
	B	277	288	278	290	286	338	296
	CV	296	314	302	326	313	335	341
	DD	291	305	293	309	302	293	321
	HW	264	284	273	287	282	362	292

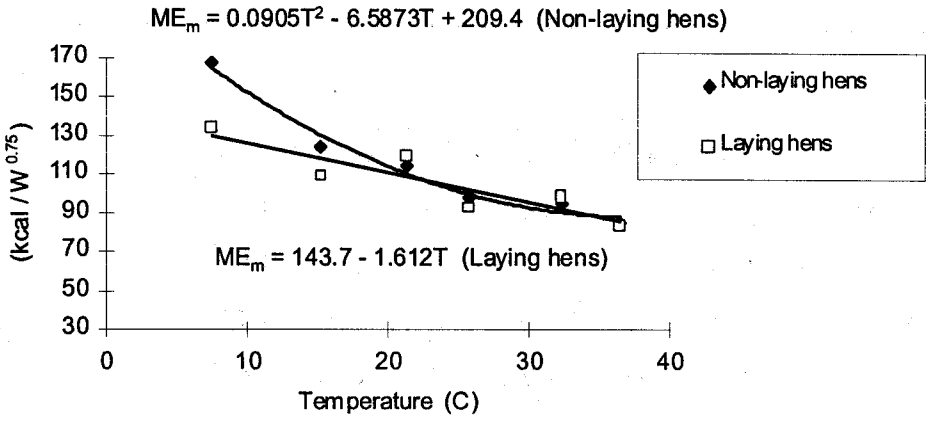

Figure 1. The effect of temperature on energy maintenance requirement.

Table 4. Daily Requirements of Digestible Amino Acids for Commercial White Layers.

Amino Acid	NRC		Exp. 2		Exp. 3		Exp. 4		Exp. 5		Exp. 6		Ave	
	Total[1] (mg/d)	Digestible[2] (mg/d)					(mg/d)		(mg/g Egg Mass)[3]					
Methionine	300	258	354	7.04	------	------	------	------	283	5.57	350[5]	6.48	329	6.36
TSAA	580	499	551	11.02	------	------	------	------	496	9.76	595[5]	11.00	547	10.59
Lysine	690	593	705	14.07	636	12.27	683[4]	12.23	------	------	------	------	675	13.17
Arginine	700	602	968	19.52	791	15.29	------	------	------	------	------	------	880	17.41
Isoleucine	650	559	603	12.07	555	10.72	------	------	------	------	------	------	579	11.4
Threonine	470	404	560	11.1	430	8.43	------	------	------	------	------	------	495	9.77
Tryptophan	160	138	122	2.46	------	------	------	------	143	2.89	------	------	132	2.68
Valine	700	602	731	14.19	646	12.32	------	------	------	------	------	------	689	13.26

[1]Based on 100 grams of feed intake per day.
[2]NRC Amino acid digestibility based on total X 86%.
[3] Amino acid requirements are based on egg mass production (includes shell). Divide mg amino acid/g EggMass value by .911 to convert daily requirements to egg content production.
[4] Average Lysine requirements based on feeding 14, 15, and 16% CP corn-soy basal diets plus an experiment using a Summit Diet:Dilution system (U.K.).
[5]Cao et al., 1995.

Table 5. Layer performance of four commercial strains fed experimental amino acid diets.

Diets	HDEP	EW	EM	FCHD	FE	ΔBWT	%ALB	%YLK
1. 18%CP	81.4[a]	62[a]	50.4[a]	94.5[a]	1.90[a]	51.1[a]	59.5[a]	27.8[ab]
2. 16%CP	80.5[a]	61.3[a]	49.4[a]	94[a]	1.91[a]	-1.5[b]	58.9[ab]	28.8[a]
3. 16%CP+Lys	82.9[a]	61.6[a]	51[a]	96.6[a]	1.88[a]	2.8[ab]	59.6[a]	27.4[b]
4. 14%+Lys+Trp	76.8[b]	60.1[b]	46.2[b]	95.4[a]	2.07[b]	-62.5[c]	58.5[b]	28.1[ab]
5. Diet 4+Ile+Val	80.2[a]	61.3[a]	49.2[a]	96.3[a]	1.96[a]	2.0[ab]	59.5[a]	28[ab]
Mean	80.3	61.3	49.2	95.4	1.94	-1.64	59.2	28.03
S.D.	6.86	2.43	4.91	10.8	.224	109.6	2.71	3.16
S.E.	.54	.19	.39	.86	.018	8.67	.158	.183
Crit. LSD value,.05	3.05	.81	1.91	NA	.104	50.5	.89	1.12
P value	.003	.0002	.0001	.82	.002	.0009	.06	.14

Table 6. Layer fourteen-day nitrogen balance study.

Diets	N Intake (G)	Egg N (G)	ΔCarc. N (G)	N Loss (G)	%N RET.
1. 18CP	38.14[a]	14.57[a]	.205[a]	23.37[a]	38.89[b]
2. 16CP	34.33[b]	13.60[ab]	-.216[a]	19.86[bc]	42.37[ab]
3. 16CP+Lys	34.40[b]	14.18[a]	.019[a]	20.20[b]	41.48[b]
4. 14CP+Trp+Arg	30.25[c]	12.43[b]	-.652[a]	18.33[bc]	39.56[b]
5. Diet 4+Ile+Val	30.74[c]	13.73[a]	.59[a]	17.17[c]	45.94[a]
mean	33.54	13.70	-.01	19.87	41.57
S.D.	4.29	1.47	1.55	3.57	5.16
S.E.	.62	.21	.22	.53	.76
Crit.LSD value,.05	2.94	1.19	N.A.	2.69	4.26
P value	.0001	.011	.53	.0007	.022

Table 7. Ideal amino acid profile for layers

Amino Acid	NRC (1994)	MN (1998)
Lysine	1.00	1.00
Methionine	.434	.487
TSAA	.84	.81
Arginine	1.01	1.30
Isoleucine	.942	.857
Threonine	.681	.730
Tryptophan	.231	.196
Valine	1.014	1.021

Ideal Protein in Turkeys

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Introduction

Protein/amino acids (AA) is one of the major cost components of the diets of turkeys. It is also one of the components of the diet that affect performance in a practical sense. Considering the major importance of feed to the turkey industry, there is relatively speaking, little research on the feeding of turkeys. This has led to wide variation in feeding programs. Feeding of ideal proteins is an attempt to feed as close to the actual requirement as is feasible given the available data at the time. Precise feeding of nutrients has the potential to reduce feed costs, improve efficiency and reduce pollution.

Background

The data on protein and amino acid requirements of turkeys have been recently reviewed (Firman, 1994). Briefly, there is really very little data on the requirements for turkeys. The general amino acid data found in the NRC go back to the early 70's with research from Warnick and Anderson (1973). This data was collected in bronze turkeys with what we would consider non-standard diets during the starter period only. Much of the later numbers have been extrapolated from this starter period. Based on these early data, it appeared that lysine and sulfur amino acids are most limiting in commercial type diets. Dr. Potter, at VPI, performed a number of studies using deletion methods to determine that threonine, valine and isoleucine were next limiting in corn-soybean meal diets. We have also used a low protein diet and found the same amino acids are limiting based on an addition method. When one looks at digestible numbers for turkeys there is even less data available as would be expected. We have done a good deal of work with cecectomized turkeys to calculate digestibilities of a variety of feedstuffs (Firman, 1992; Firman and Remus, 1993; 1994) and have some data on starter turkey diets, but really there is little to go on at this point in time. Given the paucity of data, I believe one must take a close look at how we can best utilize what is currently available and where we need to go in the future to make some progress.

Over the years a number of us have argued about what are the correct protein/AA requirements, how low can we go on protein, which AA are limiting, whether or not there is an energy relationship, whether poults can handle fat, what is the proper way to determine digestible AA, etc. For the most part, I believe these arguments are mute. If our overall goal is to optimize the production process for maximal economic return, we need to look carefully at the data that is available to us currently and determine how best to utilize this data.

TABLE 1

Percent Digestibility of Common Feedstuffs in Turkeys

Feedstuff	Arginine	Serine	Histidine	Isoleucine	Leucine	Lysine	Methionine	Cystine	Phenylalanine	Tyrosine
Alfalfa	75.7	56.7	69.0	65.6	71.1	69.3	62.9	59.4	69.8	55.3
Barley, steam rolled	89.8	77.5	85.5	69.7	71.6	66.8	67.2	79.2	82.6	78.8
Blood meal	90.0	90.9	91.6	79.8	89.7	92.0	92.0	84.8	89.7	89.9
Corn gluten meal	94.9	94.5	94.0	94.6	97.2	88.1	96.4	88.1	96.6	96.9
Corn gluten feed w/bran	85.1	71.0	79.0	71.2	84.1	72.4	83.3	70.6	79.3	80.7
Corn grain #1	87.9	94.0	84.3	88.6	93.6	70.1	86.5	84.8	92.5	86.7
Corn grain # 2	96.0	84.0	87.0	81.0	93.0	82.0	92.0	83.0	94.0	90.0
Fish meal, Menhaden	93.1	90.4	91.6	92.0	93.0	94.5	93.4	84.2	92.1	93.3
Meat and bone meal	89.1	86.7	86.9	85.8	87.0	85.8	85.7	80.8	85.4	85.7
Oats	95.2	96.9	90.6	92.1	93.8	86.3	84.5	95.2	95.3	97.7
Poultry by-product meal	91.2	85.0	83.4	86.6	87.3	89.3	89.3	78.1	86.8	85.5
Ruminant by-product meal	82.0	78.0	84.0	78.0	82.0	81.0	81.0	68.0	81.0	78.0
Feather meal	89.5	89.3	74.4	86.8	85.0	76.2	80.3	86.8	85.8	85.9
Sorghum, grain (milo)	67.2	85.5	80.5	79.1	88.4	52.4	75.6	82.1	94.7	86.0
Soybean meal 48%	96.0	85.0	91.0	81.0	89.0	93.0	87.0	79.0	92.0	93.0
Wheat bran	93.5	90.3	98.4	86.2	88.2	91.3	88.9	89.6	89.4	89.7
Wheat middlings	96.4	97.5	99.8	93.7	94.7	96.5	93.8	99.7	96.2	93.2
Wheat, soft white	94.1	95.7	94.0	92.2	94.8	88.0	86.6	87.7	97.3	96.9
Wheat shorts	96.1	95.4	95.7	90.4	93.1	89.4	89.6	90.4	94.9	99.6

TABLE 1 (continued)

TABLE 1 (continued)

Feedstuff	Threonine	Tryptophan	Valine	Aspartic	Glutamic	Proline	Alanine	Average
Alfalfa	51.8	83.4	67.2	72.1	55.8	81.2	55.3	67.1
Barley, steam rolled	71.4	99.2	74.1	79.6	83.2	90.3	64.4	78.3
Blood meal	90.3	94.1	87.7	89.1	86.7	86.2	89.9	89.3
Corn gluten meal	91.1	88.8	93.0	92.7	96.5	94.6	95.9	93.3
Corn gluten feed w/bran	61.6	61.7	76.9	73.4	83.4	79.5	82.0	76.1
Corn grain #1	87.2	68.1	85.3	82.2	93.3	98.1	89.8	85.9
Corn grain #2	66.0	79.0	76.0	79.0	91.0	86.0	73.0	84.2
Fish meal, Menhaden	91.8	95.7	90.6	91.0	92.1	88.2	88.6	91.2
Meat and bone meal	82.6	88.9	85.8	81.7	81.9	83.5	85.4	84.8
Oats	96.4	94.5	93.8	90.7	93.8	96.1	84.4	92.8
Poultry by-product meal	87.3	94.8	85.2	82.0	87.5	85.1	87.0	86.5
Ruminant by-product meal	75.0	85.0	80.0	–	80.0	81.0	81.0	80.0
Feather meal	84.9	87.4	85.3	74.0	82.4	88.5	80.0	83.3
Sorghum, grain (milo)	90.2	98.5	70.5	75.1	89.5	93.5	87.9	81.0
Soybean meal 48%	83.0	94.0	78.0	87.0	85.0	82.0	73.0	86.4
Wheat bran	93.2	93.4	91.0	86.1	90.8	91.6	84.0	90.3
Wheat middlings	98.2	94.8	94.3	95.2	96.0	97.7	89.3	96.0
Wheat, soft white	90.4	94.6	90.4	87.9	95.3	94.2	84.5	92.0
Wheat shorts	93.1	92.2	92.2	88.1	90.5	99.5	83.5	92.5

Current State of Nutrition

With the lack of data on requirements for turkeys, it would appear that most nutritionists have formulated on the quite logical assumption that if we feed a great deal of a given nutrient we will avoid deficiency symptoms and maximize growth rate. There is very little data on what happens when we reduce nutrient input other than it has the potential to reduce growth rate. When we look at least cost diet formulation, for the most part it is done with very little data on what happens to total production cost when we make changes such as reducing protein. Thus what we see many companies do is to overfeed nutrients. This is safe and effective in terms of bird response, but also results in high costs and excess excretion of nutrients. Ultimately what we will need to do is collect data and use computer models to help elucidate the true least cost modes of turkey production.

Ideal Protein/Precision Feeding

Precision feeding may be defined as an attempt to feed as close to the exact requirement as possible on those nutrients that are expensive or that may have other detrimental effects when fed in excess. While data for all of the requirements does not exist, the program at Missouri has been attempting to fill this void in the area of amino acids. The long term benefits include the potential for lower feed costs, increased efficiency and reduced excretion of waste products. The potential downside is that we may have slight reductions in growth rate as we feed closer to the true requirements.

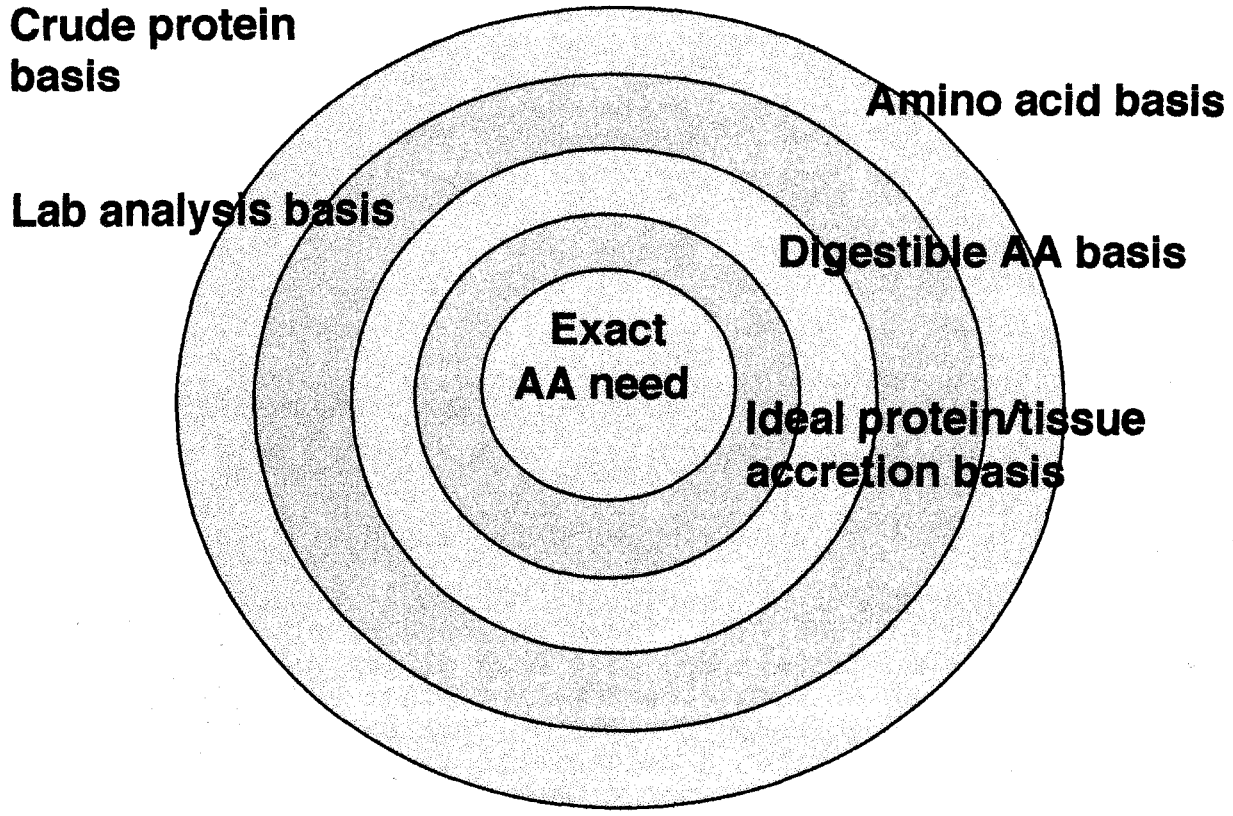
Precision feeding in relation to protein nutrition of turkeys has led our research program to research several areas. The first of these is the issue of digestible amino acid content of feedstuffs commonly used for turkeys. As noted earlier we have published several manuscripts related to this topic.

Our second step down the path of ideal protein was to begin to determine the digestible amino acid requirements of turkeys in the starter period. This has proved difficult due to the lack of a crystalline AA diet or a diet low enough in protein that titrations of the AA could occur while achieving similar performance to that of a standard high protein diet. This led to the formulation of a low protein diet based on an estimate of the ideal protein. We have a good bit of experience with these types of diets and are as low as 16% intact crude protein (CP) + AA while still achieving similar growth to a 28% CP diet. We are continuing to investigate this at the various stages of growth with studies in toms to market weight determining digestible lysine and sulfur AA.

What are the potential benefits of ideal proteins? I believe it will be difficult to improve growth rate over the current system in place for most companies. In theory we can use any ingredient within some non-AA constraints such as high phosphorus levels. We should get more accurate pricing of ingredients since price will more closely relate to the usable amino acid content of the feedstuff. This should also result in decreased feed costs and in reduced nitrogen excretion. Below is a diagram (Figure 1) that

shows the targets for our current research and future endeavors.

Figure 1. Research Targets



Ultimately we will collect sufficient data to feed the exact AA needs of the turkey. However until that time we need to continue to make progress in terms of incremental steps toward the goal. We have used the same basic set of requirements for many years with few changes. The NRC requirements are listed below for the starter period (probably most accurate period):

Table 2. NRC requirements for the starter period

Amino acid	% of diet
Protein	28.00
Lysine	1.60
Meth + Cys	1.05
Arginine	1.60
Histidine	0.58
Isoleucine	1.10
Leucine	1.90
Phe + Tyr	1.80
Threonine	1.00
Tryptophan	0.26
Valine	1.20
Gly + Ser	1.00
Total AA Req	13.09

Based on these numbers we need to feed a little over 13% crude protein (CP) + some nitrogen to build the indispensable AA that do not need to be provided in the diet, but that must be provided as a nitrogen source. Certainly we don't need 15% CP to build these other AA. Our research has indicated that we can go down to about 16% CP + AA with similar performance as a 28% diet. It may be lower than that level in actuality, but formulation using practical components becomes quite difficult and expensive at a much higher level than this. Based on costs of dietary AA, it is cheaper to overfeed protein and make sure we get all the AA requirements met, than to feed closer to the exact requirements, especially when we probably don't have the best data. Our friends in the pig industry have taken a mechanistic approach to AA nutrition that is incorporated into a useful equation shown below:

$$\frac{\text{gms protein deposited for period} \times \text{\% AA composition}}{\text{efficiency of deposition} \times \text{AA digestibility}} = \text{gms AA period}$$

Looking at protein/AA from this standpoint is why I believe we have been discussing apples and oranges. If we continue to do work based on gross feed values we will continue to have difficulty making sense of the data. In other words, if we have company X feeding strictly corn-soy and company Y feeding a complex diet, we can have a 10% difference in what the turkey actually can use from the feed. It's not surprising that we see differences in terms of response to the various diets we feed. Let's take a look at where our research has led us in the past few years at Missouri.

Formulation on a Digestible AA Basis

Several years ago I made the decision that we needed a more defined set of requirements that could be used to take into account for all the different things that affect how much of an AA the turkey will use. Some of these include dietary energy content, sex, strain, temperature, management, etc. Two goals came to mind:

the first of these was to formulate more accurately for our current bird and second to find a more rapid method of updating requirements. Our first step on this path was to determine the digestibility of a number of feedstuffs in cecectomized turkeys. These data have been presented previously. In summary it appears that there are few differences in digestibility in relation to age or sex, there are notable differences between the cecectomized rooster and the cecectomized turkey models and finally that additions of high levels of fat may affect digestibility of some feeds. Our values currently in use are shown in Table 1. Based on this information we have moved towards digestible formulation and attempting to determine the digestible requirements in the starting period and the ideal protein. Before we get into those data, lets take a look at the value of digestible formulation.

Given that the complete data set for formulation is not available, is there any point worrying about this until the data set is complete? I believe some benefits can be found with only an input in time. Table 3 shows some data collected on several other trials over the past few years where one group of birds had diets formulated with digestible AA basis (toms) versus total AA basis (hens). These diets used a wide variety of by-product meals going to what would be considered high levels, with similar amino acid requirements used within each study and between diets. As can be seen from the data, formulation with digestible AA resulted in similar response to the control diet even with very high levels of by-products added, while differences were noted when the diets were formulated on a total AA basis.

Table 3: Digestible formulation versus non-digestible

% Soybean meal	Hen gain	Tom gain
30% BP	1.61a	1.80a
20% BP	1.74b	1.77a
10% BP	1.82c	1.77a
control	1.86c	1.84a

Weight gain of hens (total AA) and toms (digestible AA) during the starter period BP = by-product addition

Thus it appears that there is some benefit to digestible formulation even without the benefit of digestible requirements. On the surface the benefits to digestible formulation appear obvious. If one has the exact amino acid need of the turkey, in theory at least, any feedstuffs could be used as long as the amino acid requirements could be met with the combination used. While there would still be some constraints on certain feedstuffs due to other potential problems, amino acids should not be one of them, enhancing the ability to use by-products in rations. Since we would know the exact requirements for each amino acid, we should be able to reduce the overfeeding of protein and utilize lower protein diets. This could lead to reduced nitrogen excretion and less potential waste product produced. If we fed less excess

nitrogen, there would also be less energy used by the bird for nitrogen excretion, thus improving feed efficiency. This is difficult to show experimentally, but is probably a real effect. Overall, this has the potential to reduce feed costs for the industry. The down side of this is that we must tediously collect a substantial amount of data to see all of the benefits.

Since there may be some benefits to digestible formulation without benefit of requirements lets look at how one can use the computer to formulate on a digestible basis. The first step if one wishes to formulate with digestible AA is to set up or modify your formulation database. Basically one can add new ingredients (ie.digest-corn) or add new nutrients to your current ingredients (ie. digest-lysine). The numbers can be found based on our digestibility values (Table 1) or your own data X the % AA in each feedstuff. This is the digestible AA content of each feedstuff. Obviously this will take several hours of work to do. Setting up new ingredients with new standard AA values is probably the easiest to keep track of, but lacks the benefit of comparison to total AA content.

Once this is complete, the second step is to put in some numbers for digestible requirements. While this appears to be the most critical aspect, it probably is less important than the feedstuffs. Obviously having the correct requirement is valuable, but consistency across formulation may be more valuable. Thus said, one can estimate the requirement in several ways. The easiest is to just reduce the requirement by 15% as a general guideline. While this is better than nothing it doesn't give a very good estimate. The better approach is to take a formulation that has worked well for you and is relatively straightforward (ingredients that tend to have low variability) and back calculate the requirement from this. This can be done by typing in the ingredient profile into the computer that uses the digestible database and letting the computer do the calculations for you. Given the newly calculated requirements, you can now proceed to formulate with a variety of ingredients.

What can you do to tweak the system? If we could spend several hundred thousand dollars and several years of effort, we could have the needed data. Short of this, regular analysis of your feedstuffs for total AA content is valuable. A baseline data set needs to be done for each ingredient and supplier so that changes from harvests or time of the year can be noted. Having digestibility assays run using turkeys will also be beneficial after you have a data set developed. Ultimately we will need to determine the digestible AA requirements of the turkey on a daily basis to gain the most efficiency from the nutritional system.

Digestible Requirements and Ideal Protein

We are currently working on the digestible amino acid requirements of turkeys at Missouri. This has been one of the major focuses of my research for the past five years or so. Several pieces of information need to be in place before one can actually run an experiment on the digestible requirements. The first of these was the data on digestible AA which has been mentioned previously. The second bit of information is a low

protein diet that can be used to titrate the AA on a digestible basis. To the best of my knowledge, Potter at VPI had the lowest protein diet that supported maximal growth at 22% CP + AA. We have used a similar diet with good results, but needed something with even lower protein for our titrations. This led us to formulate a very low protein starter diet (as low as 16% intact protein + AA) with corn and soybean meal that would support maximal growth. To get a diet at this level, we also were led into the ideal protein area and now have an estimate of the ideal protein (Table 4).

Table 4: Estimated ideal protein ratio for starting turkeys expressed as a percentage of the lysine requirement (Chick and pig ratio for comparison)

Amino Acid	Turkey	Chick	Pig
Lysine	100	100	100
SAA	59	72	60
Threonine	55	67	65
Valine	61	77	68
Arginine	<71*	105	--
Histidine	36*	31	32
Isoleucine	60	67	60
Leucine	124*	100	111
Phe+Tyr	105*	105	95
Tryptophan	16*	16	18

* Currently under investigation

Once this data had been collected we could then go on to determine requirements for essential AA on a digestible basis. As one might expect, lysine was the first AA studied. Based on a number of experiments, 1.32% lysine appears to support maximal growth (Table 5) and 1.34% supports maximum efficiency. We have also worked on the sulfur AA requirement with .78% of the diet supporting maximal growth (Table 6). Tables 7-10 show data on several other AA. While these numbers appear low, keep in mind that this is on a digestible basis, with the other amino acids balanced based on our ideal protein ratio. This also does not take into account any safety factor and is only at one energy level (~3200 kcal/kg). We are currently looking at different energy levels to see how these will affect requirements.

Table 5: Digestible lysine requirement of hens during the starter period

Lysine level (%)	Gain(g)
1.26	267
1.29	269
1.32	293
1.35	288
1.38	280
1.41	289

Table 6: Digestible methionine-cystine requirement of hens during the starter period

Methionine+cystine level	Weight gain
.59	222
.62	261
.65	305
.68	318
.71	303
.74	333
.77	347
.80	355
.83	350

Table 7: Digestible threonine requirement of hens during the starter period

Threonine level (%)	Gain(g)
.60	275
.64	321
.68	352
.72	334
.76	332
.80	362
.84	342

Table 8: Digestible valine requirement of hens during the starter period

Valine level	Weight gain
.72	210
.79	289
.86	326
.93	325
1.07	329
1.14	337
1.21	339

Table 9: Digestible arginine requirement of hens during the starter period

Arginine level	Weight gain
.95	299
1.05	311
1.15	311
1.25	343
1.35	309
1.45	343
1.55	338
1.65	310

Weight gain of hens fed different levels of digestible SAA

Table 10: Digestible isoleucine requirement of hens fed low energy diets during the starter period

Isoleucine level (%)	Gain(g)
.66	312
.72	328
.79	334
.85	327
.92	333
.98	343
1.05	335
1.11	359

Let's take a moment and look at what ideal protein is, what it can be used for and what it probably shouldn't be used for. Although you can probably think of your own definition, the ideal protein is the theoretically exact balance of amino acids that meet the animals needs. There should be no excess, no deficiency and as little of the AA should be used for energy as possible. Nitrogen excretion would be minimized in this situation and all dispensable AA should be provided in another form (ie. not indispensable AA). The concept is that all of the AA can be related to lysine (by choice) and that if the lysine needs of the animal increase due to genetics, etc. then the AA pattern remains the same relative to the lysine requirement. The ratio probably changes slightly throughout the growth cycle of the animal as it moves to periods of feather growth versus breast meat accretion for example. The ideal ratio is useful from several standpoints. It allows for determination of digestible AA requirements which can then be easily modified through the changes in the requirement for lysine. This allows for rapid research response to improving genetics and the new AA requirements that go with this. It has allowed us to formulate very low protein diets for determination of AA requirements. It forces us to move to digestible formulation

which I believe is useful in terms of more accurately meeting the turkeys needs, reduction of overfeeding and correcting the value of feedstuffs based on their utilization capability for the animal. Pricing of ingredients based on the actual usable nutrient content may be the most useful portion of the switch to digestible requirements and formulation. All of this sounds very good, but there are also some inherent difficulties when we try to use the ideal values for practical formulation.

Use of the ideal protein has taken some criticism based on the lack of practicality in formulations. This has probably occurred for several reasons. First is that one has to be set up for digestible formulation or the ratio has little meaning since the data are collected using digestible values. Second, the numbers should just be used as minimum requirement values for each AA as it will not work to try to meet the exact requirements. Meeting the exact requirements means going very low on protein and adding back substantial amounts of crystalline AA (extremely expensive). Thus the ideal ratio is probably most useful in determination of digestible requirements. In practical formulations, we will only need requirements for 3-4 amino acids given the current cheap protein prices. As long as protein sources remain inexpensive, it will be cheaper to overfeed some amino acids than to meet the exact requirements.

Protein/energy Relationship

Another area of concern with digestible formulation and ideal protein is the relationship to energy. Our real concern with determination of digestible requirements is to relate the data to lysine requirements so that as we change dietary lysine levels we can adjust all of the other AA without data collection per se. To this end we have looked at lysine/energy ratios at several different energy levels. Based on our initial research we had found a lysine requirement of 1.34% at an energy level of 3175 kcal/kg. Given this we would predict a relationship of .43% lysine per mcal/kg at other energy levels. In other experiments using a low energy diet (2550 kcal/kg) with lysine titrations we have found a similar relationship with .44% lysine per mcal/kg at these low energy levels. We have not been able to determine if this relationship exists at higher energy levels due to variability in the turkey model and what may be changes in digestible lysine content of the diet due to the high fat levels being fed.

Summary

In summary, I believe that we have sufficient data to start formulation of turkey diets on a digestible basis and to use the ideal protein ratio as a starting point to determine digestible requirements. While some would have us wait for the data set to be complete, there are sufficient benefits with an incomplete data set to proceed. More data will be presented as we continue to collect new information on the digestible requirements for the turkey. The final tables (Tables 11 and 12) are the lowest levels we have fed in trials to market weight and our current estimate of the amino acid

TABLE 11. Lowest tested levels of DIGESTIBLE AMINO ACIDS in Nicholas Toms 0-18 wks*

	WEEKS					
	0-3	3-6	6-9	9-12	12-15	15-18
Lysine	1.40	1.32	1.15	.91	.78	.78
Met + Lys	.84	.78	.69	.60	.51	.51
Thr	.77	.72	.63	.55	.50	.50
Val	1.05	.99	.86	.75	.69	.69
Arg	1.66	1.56	1.33	1.14	1.03	1.03
His	.62	.58	.51	.44	.41	.40
Iso	.96	.90	.78	.66	.60	.59
Leu	1.85	1.76	1.57	1.40	1.30	1.30
Phe + Tyr	1.84	1.74	1.50	1.30	1.18	1.17
Trp	.28	.26	.21	.18	.16	.15

*NOTES: These diets were formulated with constraints on lys, sulfur AA and thr. Other amino acids were checked but were deemed adequate. These levels are probably higher than needed and many amino acids will always be high in a least cost formulation, but should be checked due to changes from cost or ingredient.

TABLE 12. Estimated DIGESTIBLE REQUIREMENTS **for the Essential Amino Acids in the Turkey

	Weeks					
	0-3	3-6	6-9	9-12	12-15	15-18
Lysine**	1.36	1.28	1.11	.85	.68	.55
Meth + Cys	.80	.76	.66	.53	.47	.40
Threonine	.75	.72	.62	.50	.45	.40
Valine	1.03	.97	.84	.65	.52	.42
Arginine	1.43	1.34	1.17	.89	.71	.58
Histidine	.49	.46	.40	.31	.25	.20
Isoleucine	.94	.88	.77	.59	.47	.38
Leucine	1.69	1.59	1.38	1.05	.84	.68
Phe + Tyr	1.43	1.34	1.17	.89	.71	.58
Trp	.22	.20	.18	.14	.11	.09

**No safety factor included. Estimate based on typical energy levels used. We are currently researching lysine levels and plan methionine in the next year. Please test levels or discuss with me before making any dramatic changes in your feeding program. Most of these AA will be much higher in a least cost formulation.

requirements to market weight of turkeys. Needless to say one should use extreme caution when reducing nutrient inputs to avoid any disasters.

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