Use of biotechnology and feed additives

R. A. Easter, H. H. Stein and N. L. Trottier

Department of Animal Sciences, University of Illinois, 1301 W. Gregory Dr., Urbana, Illinois

Introduction

Nitrogen in swine wastes derives principally from undigested feed residues, urinary losses due to inefficient metabolism and the deamination of excess dietary amino acids, and obligatory losses, e.g., hair, dermal cells and endogenous proteins of alimentary tract origin. Aside from fixed obligatory losses, the sources of unnecessary nitrogen excretion are in large part due to the following: digestive inadequacy, consumption of amino acids in excess of requirements and inefficient assimilation of amino acids into body protein. These problems are not newly identified, but evolving technologies make their solution more feasible than in the past.

Fundamentally, two strategies are available to reduce nitrogen output. The first requires modification of the animal through either classical genetic selection procedures or by newer methods (biotechnology) of molecular genetics. The second approach concerns the use of dietary additives to improve the efficiency of protein digestion, amino acid utilization and growth rate. Much preliminary work is being done (McLaren et al., 1990) to map the porcine genome in an effort to identify the genetic base for economically important traits. The successful application of gene manipulation technologies to the problem of nitrogen pollution remains to be realized. Thus, this paper will focus on dietary additives in these categories: amino acids, repartitioning agents, antimicrobials, enzymes and probiotics.

Amino acids

It is understood that nonruminant animals have dietary requirements for 10 essential amino acids and, in addition, a dietary need for a quantity of additional nitrogen that can be employed metabolically to synthesize nonessential amino acids. Unfortunately, no combination of natural feed ingredients provides the exact amounts of each of the necessary nutrients with no excesses. Nitrogen arising metabolically from the consumption of excess amino acids contributes significantly to the daily output. Table 1 provides a perspective on the magnitude of this problem. Shown in the left-hand columns of the table is the makeup and percentage composition of a "typical" corn-soybean meal-based diet for finishing pigs. Note the column headed 14% C.P. (crude protein) diet. All essential amino acids are present in excess of the requirement. In some instances, cf., leucine and arginine, the excess is more than twice the dietary requirement. This represents excess nitrogen consumption that, ultimately, is excreted.

Recent advances, especially in fermentation technology, have made industrial production of several amino acids economically practical. These amino acids can be employed in formulation to reduce excess dietary nitrogen. This is well illustrated by comparing the column labeled 14% C.P. with the column labeled 11% C.P. + Lys, Thr, Trp (11% crude protein plus lysine, threonine and tryptophan). Reducing the total dietary protein and correction of specific amino acid deficiencies results in an average 20% reduction of amino acid excesses.

Table 1. Comparison of the amino acid excesses in a normal and a low-protein, amino acid supplemented diet for finishing swine.[a]

Ingredient composition of diet		Amino acid composition	Percent of requirement	
Ingredient	Percent in diet	Amino acid	14% C.P. diet	11% C.P. + Lys, Trp, Thr
Corn	82.12	Lysine	115	117
Soybean meal, 48%	15.74	Threonine	140	110
Dicalcium phosphate	.73	Tryptophan	155	118
Calcium carbonate	.86	Isoleucine	160	122
Antibiotic	.10	Met + Cys	153	130
Vitamins	.10	Histidine	230	187
Trace-mineral salt	.35	Leucine	297	257
Total	100.00	Valine	189	149
		Arginine	879	645

[a]Calculations based on NRC, 1988.

Diets formulated in a similar manner to either 16% C.P. or 12% C.P. were fed to growing pigs housed in metabolic cages and nitrogen excretion was measured (Kerr, 1987). The results are shown in table 2. First, note that total daily nitrogen intake was reduced by from 25.10 g to 18.81 g when the 12% C.P. amino acid-supplemented diet was fed. Fecal nitrogen was unaltered. However, there was more than a 50% reduction in the output of urinary nitrogen. It is troublesome that daily nitrogen retention by pigs fed the 11% C.P. + Lys, Trp, Thr diet was not equal to those fed the 16% C.P. diet. A subsequent growth experiment (Kerr, 1987) conducted from 10 to 90 kg live weight indicated that lean muscle component growth was not reduced when pigs were fed the low-protein, amino acid-supplemented diet but the liver and other organs were, in fact, smaller. It is likely that this factor accounts in significant part for the differences in nitrogen retention.

Recent work (Hansen et al., 1993) has further demonstrated the feasibility of using reduced-protein, amino acid supplemented diets in swine nutrition.

Table 2. Nitrogen (N) utilization by growing pigs fed low-protein, amino acid supplemented diets.

Item	Dietary treatment		
	16% C.P. corn-soybean meal	12% C.P. + Lys, Trp, Thr	12% C.P. corn-soybean meal
Daily N intake, g	25.10	18.81	17.70
Daily fecal N, g	4.61	4.35	4.04
Daily urinary N, g	6.49	2.67	5.17
Daily N retained, g	13.99	11.79	8.51

Adapted from Kerr, 1987.

Beta-Adrenergic agonists

Definition

Beta-adrenergic agonists have been shown to have pronounced effects on skeletal muscle accretion and adipose tissue, particularly in pigs. They have been termed "nutrient partitioning agents" since they are thought to bring about a "shift" in the flow of nutrients away from adipose tissue depots towards muscle (Dalrymple et al., 1983). They are also defined as exogenous phenethanolamines, a generic class of substituted catecholamines as their structure and pharmacological properties resemble the natural endogenous phenethanolamine epinephrine (Baker et al., 1984). These compounds are active orally and parenterally (Baker et al., 1984) and their ability to decrease fat retention and enhance muscle accretion provides an attractive method of altering body composition in the growing pig (Bracher-Jakob and Blum, 1990). Apart from their efficacy as growth promoter, β-adrenergic agonists may contribute to an important reduction of nitrogen excretion in swine waste.

Mode of action

Our interest in β-adrenergic agonists in pig production has centered on four major compounds, i.e., clenbuterol and cimaterol (American Cyanamid Company), ractopamine (Eli Lilly and Company) and L644,969 (Merck, Sharp and Dohme Research Laboratories) (Peters, 1990). Their structures are very much related to epinephrine, a hormone synthesized and secreted by the adrenal medulla under the control of the sympathetic nervous system. Factors such as anxiety, trauma, hypovolemia, hypotension, anoxia, extremes of temperature, hypoglycemia, and severe exercise cause a rapid secretion of epinephrine from the adrenal medulla (Landsberg and Young, 1985). There are two types of adrenergic receptors on cell membranes, the α-receptors and the β-receptors (Mersmann, 1987). Heart contractility, fat cell lipolysis and bronchodilation are stimulated through the interaction of the agonists with the β receptors, whereas gut sphincter and skin arterioles contraction and cerebrum function are under the α-adrenergic receptors control (Mersmann, 1987). Adrenergic receptors are also classified into subtypes, such as β_1 and β_2 for the β receptors and α_1 and α_2 for the α receptors (Mersmann, 1987).

Beta-adrenergic receptors are coupled to the adenylate cyclase system of the target cell membrane (Anderson, 1988). Hormone-receptor interaction activates the adenylate cyclase enzyme which catalyses the synthesis of cyclic-AMP. Cyclic-AMP in turn activates protein kinase enzyme responsible for intracellular proteins phosphorylation (Anderson, 1988). Hormone sensitive lipase enzyme is activated upon phosphorylation and thus increased lipolysis within the adipocytes follows (Anderson, 1988). This is thought to provide additional energy substrates for other metabolic functions, such as protein synthesis and(or) accretion. This mechanism may in part explain the decrease in fat deposition and increased lean growth, however, when clenbuterol and ractopamine were tested *in vitro* in porcine adipose tissue, despite the observation that initial ligand-receptor binding did occur with a high degree of specificity, neither compound stimulated lipolysis (Mersmann and MacNeil, 1992).

Other mechanisms may exist for stimulation of lipolysis in the pig given clenbuterol or ractopamine. In addition to increased lipolysis, β-adrenergic agonists inhibit long chain fatty acids synthesis and fatty acids esterification in triacylglycerol (Saggerson, 1985). However, while clenbuterol did not inhibit triacylglycerol biosynthetic pathway in porcine adipose tissue *in vitro* (Mersmann, 1987), ractopamine was shown to inhibit the rate of fatty acid synthesis (Merkel et al., 1987).

The effects of β-adrenergic agonists on muscle protein turnover are disputable (Reeds and Mersmann, 1991). Bocklen et al. (1986) have demonstrated the presence of β-receptors on pig skeletal muscle membrane. As opposed to their catabolic effect on adipose tissue, β-adrenergic agonists promote muscle protein anabolism, such as amino acid transport and protein synthesis (Inkster et al., 1989; Bergen et al., 1987; Nutting, 1982) and decrease protein degradation (MacRae et al., 1988; Bergen et al., 1987; Li and Jefferson, 1977). Although these effects have been demonstrated with ractopamine in the pig and with clenbuterol in other species (Wilson et al., 1987; Emery et al., 1984), some studies have found no change in muscle protein synthesis in animals fed β-adrenergic agonists (Johnson et al., 1987).

Effects on performance

Feeding β-adrenergic agonists generally reduces weight gain of the liver, kidneys, intestinal tract and skin (Reeds and Mersmann, 1991) while increasing muscle protein deposition. Their effects are similar but the magnitude may vary, depending on the dose and time of administration (Peters, 1990), the genetic background of the animal and the level of dietary protein (Mitchell et al., 1990). Beta-adrenergic agonists fed to pig during their finishing period increased the rate and improved the efficiency of protein deposition while decreasing the apparent efficiency of energy utilization (Mitchell et al., 1991). Table 3 illustrates the percentage improvement of performance with β-agonists treatment, as averaged over various literature values (Peters, 1990).

Table 3. Percentage improvement in growth performance following β-adrenergic agonist treatment in finishing pigs.

Measurements	Percent improvement
Live weight gain	+5
Feed intake	-3
Feed efficiency	+6
Dressing percentage	+1.5
Kidney fat	-15
Carcass lean	+7
Carcass fat	-25
Area of Longissimus dorsi	+8.5

(Adapted from Peters, 1990).

All these effects appear to be the result on an increase in efficiency of protein utilization coupled with an increase in energy repartitioning towards muscle rather than adipose tissues.

Quantitative nitrogen reduction

Although β-adrenergic agonists do not seem to improve nitrogen digestibility (De Schrijver et al., 1991), their effect on nitrogen utilization is clear, as seen in performance data. Also, plasma urea concentration is significantly lower in finishing pigs fed clenbuterol, evidencing its effect on nitrogen utilization and retention (De Schrijver et al., 1991). In general, research on β-adrenergic agonists has focused on growth promotion. Some studies provide nitrogen balance data which can provide quantitative estimates of reduced urinary nitrogen excretion in pigs fed β-adrenergic agonists. Table 4 shows the improvement in nitrogen deposition and retention when clenbuterol (van Weerden, 1987 and De Schrijver et al., 1991) and Ro 16-8714 (Bracher-Jakob and Blum, 1990) are fed to pigs from 60 to 100 kg body weight.

Based on the average improvement nitrogen retention value obtained from table 2, i.e., 3.1 g nitrogen retained per day, we can estimate a quantitative urinary nitrogen reduction in swine fed β-agonists during the finishing period of growth. Assuming a commercial unit finishing 5,000 pigs per year, with a β-agonist treatment period of 7 weeks, we can estimate an annual waste nitrogen reduction of approximately 760 kg.

Table 4. Improvement in daily nitrogen (N) deposition and retention following β-adrenergic agonists treatment in pigs from 60 to 100 kg body weight.

Study	N deposition (%)	N retention (%)	N retention (g)
De Schrijver et al., 1991	8.5	12.4	2.1
Bracher-Jacob and Blum, 1990	25.7	7.0	3.8
van Weerden, 1987	24.0	7.0	3.4
Average	19.4	8.8	3.1

Antibiotics and chemotherapeutics

Definition

Antibiotics and chemotherapeutics are medications added to swine feeds to improve performance. Antibiotics are produced by fermentation while chemotherapeutics are made by chemical synthesis. Most antibiotics and chemotherapeutics are added to a level of 40 to 50 ppm in piglet and grower diets; lower concentrations are used in finisher diets.

Mode of action

The mode of action of antibiotics and chemotherapeutics as growth promoters is not fully understood, however, it is generally accepted that the growth responses, in significant part, are due to effects on the intestinal microbiota (Visek, 1978). Studies have shown that antibiotic feeding results in reduced ammonia production by bacteria and less intestinal mass (Visek, 1978). Other proposed effects of antibiotic feeding include:

1. Suppression of subclinical infections.
2. Reduction of microbial production of growth-depressing toxins.
3. Reduced microbial destruction of essential nutrients increased vitamin or other growth factor synthesis.
4. Thinning of the intestinal tract resulting in enhanced efficiency of absorption and utilization of nutrients.

Effect on performance

The growth performance responses to antimicrobials have been shown in numerous experiments with the greatest effect observed in newly weaned pigs (Roof and Mahan, 1982, Stahley et al., 1980, Livingstone and Livingstone, 1968, Lillie et al., 1977).

Significant improvements are also seen in growing-finishing pigs although the improvement obtained in this period is smaller than in the starter period. In some experiments with growing-finishing pigs, there has been no improvement in performance (Kornagay et al., 1975). Zimmerman (cited by Parker, 1989) have summarized the studies on the value of antimicrobials in swine feeding (table 5).

Table 5. Percentage improvements from use of antibiotics.[a]

Period	Daily gain	Feed/gain
Starter	15.0	6.5
Grower-finisher	3.6	2.4

Adapted from Zimmerman, 1986 (cited by Parker, 1989).
[a] Data from 1978-1985.

Antibiotics and chemotherapeutics remain the most consistently effective feed additives for improving performance; the response has not diminished with continued use (Parker et al., 1989).

Quantitative nitrogen reduction

Based on the average increase in feed efficiency, the reduction in nitrogen excretion can be calculated from values shown in table 6.

Table 6. Effect of antimicrobial feeding on nitrogen excretion.

	6-25 kg	25-110 kg
Crude protein in diet, %	20	16
Feed conversion rate without antimicrobial	1.9	3.0
Feed conversion rate with antimicrobial	1.78[a]	2.93[b]
Crude protein intake without antimicrobial, kg	7.22[c]	40.8[d]
Crude protein intake with antimicrobial, kg	6.76[e]	39.85[f]
Crude protein intake/pig, kg	.46	.95

[a] 1.9 kg x .935
[b] 3.0 kg x .976
[c] 19 kg x 1.9 x 20%
[d] 85 kg x 3.0 x 16%
[e] 19 kg x 1.78 x 20%
[f] 85 kg x 2.93 x 16%

If it is assumed that the protein accretion in the pig is unaffected by feeding antimicrobials, one can calculate the reduction in nitrogen output simply due to improvements in feed conversion efficiency. Our calculations (Table 6) shown that protein consumption is reduced by .46 kg during the starter period and .95 kg during the growing-finishing period. From weaning to market the total value is 1.41 of protein or .23 kg of nitrogen per pig. In units producing 5,000 pigs per annum, the calculated reduction in feed nitrogen would be 1,150 kg weanling pigs as well as the growing-finishing pigs.

It has been suggested that the an effect of dietary antibiotics is to increase the digestibility of nitrogen and amino acids in the small intestine (Just, 1980, cited by Ellis et al., 1983). In only a few studies has the effect of antibiotic feeding on nitrogen digestibility been evaluated (Thacker et al., 1992, Ellis et al., 1983). In these experiments, a small increase in protein digestibility as well as in protein accretion has been observed. If this is a consistent effect, the overall reduction in the nitrogen excretion could be higher than the amount calculated.

Enzymes

Definition

These are industrially produced digestive enzymes intended to increase the digestibility of feedstuffs.

Mode of action

Digestive enzymes degrade feedstuffs, however, in many circumstances the pig's natural enzyme levels are too low or the requisite enzymes are missing. This is especially true in the newly weaned pigs (Chapple, 1989) where the lack of digestive enzymes is well established. This makes it possible that exogenous dietary enzymes could improve digestibility, particularly of nitrogen-rich proteins.

Effects on performance

In the chicken, pentosanase and β-glucanase have been shown to improve the digestibility of pentosans and β-glucans in barley (Bedford et al., 1992). Both β-glucans and pentosans are solubilized during digestion resulting in a viscous intestinal fluid that interferes with digestion (Thacker et al., 1992). It has also been suggested that the negative effect of β-glucans and pentosans in barley and rye results from the polysaccarides encapsulating the endosperm cells. Since they are inert to pancreatic enzyme attack, they prevent physical interaction between the gastrointestinal enzymes and their intended substrates. (Bedford et al., 1992).

Supplementation of a barley- or rye-based diet with β-glucanase and pentosanase respectively, would be expected to increase the digestibility of the nutrients in the diet and the overall performance. Bedford et al. (1992) found that adding β-glucanase to a barley-based diet for newly weaned pigs significantly improved performance and increased protein digestibility. In contrast, Graham et al. (1986) found that β-glucanase supplementation to a barley-based grower diet did not significantly affect the digestibility. Similar findings have been reported by Thacker et al. (1992).

Experiments to date with feed enzymes have not given consistently positive results. Consequently, we have elected not to calculate, at this stage of development, an estimate of the reduction in the nitrogen excretion made possible by their use.

Probiotics

Definition

A probiotic is a live microbial feed supplement. In concept, it should benefit the host animal by improving its gastrointestinal microbial profile (Fuller, 1989). Most of probiotics on the market contain lactobacilli and(or) streptococci and a few contain bifidobacteria (Fuller, 1989).

Mode of action

Several hypothesis have been developed to explain the mode of action of the probiotics. These are reviewed in detail by Vanbelle et al. (1990) and are not treated here.

Effect on performance

Several independent evaluations of probiotics have been conducted during recent years. Pollmann (1986) (cited by Lyons, 1988) summarized different experiments with probiotics for both starter pigs and growing-finishing pigs (Table 6 and 8).

Table 7. Summary of research conducted with starter pigs fed probiotics.

Culture	No. of studies	No. of pigs	Item	% Improvement over control
Lactobacillus fermentation product	4	960	Gain	8.4
			Feed/gain	4.8
Mixed lactobacillus	7	1052	Gain	2.5
			Feed/gain	6.8
Pure lactobacillus	2	227	Gain	8.6

(Adapted from Pollmann, 1986., cited by Lyons, 1988.)

Table 8. Summary of research conducted with growing and finishing pigs fed microbial cultures.

Culture	No. of studies	No. of pigs	Item	% response over control
Mixed lactobacillus	5	568	Gain	8.7
			Feed/gain	1.6
Streptococcus faecium	3	825	Gain	-1.8
			Feed/gain	-0.7

(Adapted from Pollmann, 1986, cited by Lyons, 1988.)

It is difficult to argue from the data in tables 7 and 8 that there has been an improvement in performance by feeding growing/finishing pigs probiotics. However, there is some evidence of benefit in starter pigs. The response of starter pigs to probiotics seems to be variable. Some (Danielsen et al., 1989, and Pollmann et al., 1980b) have seen no response while others (Collington et al., 1990, Lessard and Brisson, 1987 and Pollmann et al., 1980a) have reported significant improvements.

Quantitative nitrogen reduction

If the improvement in performance shown in table 7 is always obtained by feeding probiotics to starter pigs, then reduction in nitrogen excretion, based on improved feed efficiency, would be about 368 kg per year for a 5,000 pig unit.

Other additives

Other additives may have an influence on nitrogen excretion in swine waste. However, most of these products have not been thoroughly evaluated and their proposed effects are not well-established. Additives in this category include urease inhibitors and clays with cation exchange characteristics.

Urease inhibitors

Release of ammonia via hydrolysis of endogenous urea in the intestinal tract is thought to be important in the nitrogen metabolism of animals (Varel et al., 1987). Certain extracts from yucca plants have been shown to inhibit urea hydrolysis. Kjeldsen (1992) found no difference in air ammonia concentration by including an urease inhibitor to growing-finishing diets. However, in the same study, a significant improvement in feed conversion was obtained. If the feed efficiency is consistently improved by certain urease inhibitors and protein retention remains unchanged, this product may be useful in reducing total-farm nitrogen output.

Clinoptilolite

Clinoptilolite and several other clay minerals are claimed to bind ammonia in the gastrointestinal tract of the pigs and thereby promote the overall performance of the pig (Varel et al., 1987). Although few experiments have demonstrated this effect (Varel et al., 1987, Halama, 1989), further investigations are needed in order to examine the effectiveness of clinoptilolite as a product to decrease the nitrogen excretion in swine waste.

References

Anderson, D. B., 1988. Effect of phenethanolamines on growth and carcass composition of meat animals. National Feed Ingredient Association Proceedings.

Baker, P. K., Dalrymple, R. H., Ingle, D. L. & Ricks, C. A., 1984. Use of a β-adrenergic agonist to alter muscle and fat deposition in lambs. Journal of Animal Science. 59:1256-1261.

Bedford, M. R., Patience, J. F., Classen, H. L. & Inborr, J., 1992. The effect of dietary enzyme supplementation of rye- and barley-based diets on digestion and subsequent performance in weanling pigs. Canadian Journal of Animal Science. 72:97-105.

Bergen, W. G., Johnson, S. E., Skjaerlund, R. A., Merkel, R. A. & Anderson, D. B., 1987. The effect of ractopamine on skeletal muscle metabolism in pigs. Federation Proceedings. 46:1021.

Bocklen, E., Flad, S., Muller, E., & von Faber, H., 1986. Comparative determination of beta-adrenergic receptors in muscle, heart and backfat of Pietrain and Large White pigs. Animal Production. 43:335.

Bracher-Jacob, A. & Blum, J. W., 1990. Effects of a β-adrenergic agonist on growth performance, body composition and nutrient retention in finishing pigs fed normal or low amounts of protein. Animal Production. 51:601-611.

Chapple, R. P., Cuaron, J. A. & Easter, R. A., 1989. Effect of glucocorticoids and limiting nursing on the carbohydrate digestive capacity and growth rate of piglets. Journal of Animal Science. 67:2956-2973.

Collington, G. K., Parker, D. S. & Armstrong, D. G., 1990. The influence of inclusion of either an antibiotic or a probiotic in the diet on the development of digestive enzyme activity in the pig. British Journal of Nutrition. 64:59-70.

Dalrymple, R. H., Ricks, C. A., Baker, P. K., Pensack, J. M., Gingher, P. E. & D. L. Ingle., 1983. Use of the β-agonist clenbuterol to alter carcass composition in poultry. Federation Proceedings. 42:668 (Abstract).

Danielsen, V., Vestergard, E. and Jensen, B., 1989. Malkesyreproducerende bacterier i smagrisefoder. Statens Husdyrbrugsforsog, Meddelelse 752. 4 pp.

De Schrijver, R., Fremaut, D. & Van Den Broeck, M., 1991. Effects of short-term feeding of clenbuterol on nitrogen retention, performance and meat quality in finishing pigs. Journal of Agricultural Science. 116:105-109.

Ellis, M., Davies, M., Brigs, P. A. & Armstrong, D. G., 1983. A note on the influence of Avoparcin on apparent digestibility and nitrogen retention in growing pigs. Animal Production. 36:151-153.

Emery, P. W., Rothwell, N. J., Stock, M. J. & Winter, P. D., 1984. Chronic effects of β_2-adrenergic agonists on body composition and protein synthesis in the rat. Bioscience Report. 4:83.

Fuller, R., 1989. Probiotics in man and animals. Journal of Applied Bacteriology. 66:365-378.

Graham, H., Hesselmann, K., Jonsson, E. & Aman, P., 1986. Influence ob β-glucanase supplementation on digestion of a barley-based diet in the pigs gastrointestinal tract. Nutrition Reports International. 34:1089-1097.

Halama, A. K., 1989. Mineralische futtersusatstoffe als ballasttrager. Allgemeine Muhlenmarkt, Wien, Ausgabe April:105-107.

Hansen, J. A., Knabe, D. A. & Burgoon, K. G., 1993. Amino acid supplementation of low-protein sorghum-soybean meal diets for 20- to 50-kilogram swine. Journal of Animal Science. 71:442-451.

Inkster, J. E., Hovell, F. D. DeB, Kyle, D. J., Brown, D. S. & Lobley, G. E., 1989. The effect of clenbuterol on basal protein turnover and endogenous nitrogen loss of sheep. British Journal of Nutrition. 62:285.

Kerr, B. J., 1987. Considerations in the use of crystalline amino acids in swine diets. Ph.D. Thesis, University of Illinois.

Kjeldsen, N., 1992. Micro-Aid til slagtesvin. Den Rullende Afprovning, Landsudvalget for svin, Danske slagterier, Meddelelse Nr. 216. Denmark. 4 pp.

Kornagay, E. T., Thomas, H. R. & Kramer, C. Y., 1975. Effect on subsequent feedlot performance of rotating or withdrawing dietary antibiotics from swine growing and finishing rations. Journal of Animal Science. 41:1555-1562.

Landsberg, L. & Young, J. B., 1985. Catecholamines and the adrenal medulla. In: Williams: Textbook of endocrinology. W. B. Saunders Company, Philadelphia, PA, p. 891-965.

Lessard, M. & Brisson, G. J., 1987. Effect of a lactobacillus fermentation product on growth, immune response and fecal enzyme activity in weaned pig. Canadian Journal of Animal Science. 67:509-516.

Li, J. B. & Jefferson, L. S., 1977. Effect of isoproterenol on amino acid levels and protein turnover in skeletal muscle. American Journal of Physiology. 232:E243.

Lillie, R. J., Frobish, L. T., Steele, N. C. & Graber, G., 1977. Effect of dietary copper and tylosin and subsequent withdrawal on growth, hematology and tissue residues of growing-finishing pigs. Journal of Animal Science. 45:100-107.

Livingstone, R. M & Livingstone, D. M. S., 1968. Copper sulphate and antibiotics as feed additives for early weaned pigs. Journal of Agriculture Science. 71:419-424.

Lyons, T. P., 1988. Probiotics: An alternative to antibiotics. The Bovine Practitioner. 23:64-69.

MacRae, J. C., Skene, P. A., Connel, A., Buchan, V. & Lobley, G. E., 1988. The action of the β-adrenergic agonist clenbuterol on protein and energy metabolism in fattening wether lambs. British Journal of Nutrition. 59:457.

McLaren, D. G., Fernando, R. L., Lewin, H. A. & Schook, L. B., 1990. Integrated strategies and methodologies for the genetic improvement of animals. Journal of Dairy Science. 73:2647-2656.

Merkel, R. A., Dickerson, P. S., Johnson, S. E., Burkett, R. L., Burnett, R. J., Schroeder, A. L., Bergen, W. G. & Anderson, D. B., 1987. The effect of ractopamine on lipid metabolism in pigs. Federal Proceedings. 46:1177 (Abstract).

Mersmann, H. J., 1987. Acute metabolic effects of adrenergic agonists in swine. American Journal of Physiology. 252:E85.

Mersmann, H. J., 1987. Primer on Beta-adrenergic agonists and their effect on the biology of swine. Proceedings of the University of Illinois, Pork Industry Conference, p. 19-31.

Mersmann, H. J. & MacNeil, M. D., 1985. Relationship of plasma lipid concentrations to fat deposition in pigs. Journal of Animal Science. 61:122-128.

Mitchell, A. D., Solomon, M. B. & Steele, N. C., 1990. Response of low and high protein select lines of pigs to the feeding of the beta-adrenergic agonist ractopamine. Journal of Animal Science. 68:3226-3232.

Mitchell, A. D., Solomon, M. B. & Steele, N. C., 1991. Influence of level of dietary protein or energy on effects of ractopamine in finishing swine. Journal of Animal Science. 69:4487-4495.

Nutting, D. F., 1982. Anabolic effects of catecholamines in diaphragm muscle from hypophysectomized rats. Endocrinology. 110:307.

NRC, 1988. Nutrient Requirements of Swine (9th ed.). National Academy Press, Washington, DC.

Parker, G., Cromwell, G., Hays, V. & Mikean, J., 1989. Feed additives for swine. Pork Industry Handbook. PIH-31. Cooperative extension service, University of Illinois at Urbana-Champaign. 4 pp.

Peters, A. R., 1990. β-Agonists and pig production. Pig news and information. 11:519-522.

Pollmann, D. S., Danielson, D. M. & Peo, E. R. Jr., 1980a. Effects of microbial feed additives on performance of starter and growing-finishing pigs. Journal of Animal Science. 51:577-581.

Pollmann, D. S., Danielson, D. M. & Peo, E. R. Jr., 1980b. Effects of lactobillus acidophilus on starter pigs fed a diet supplemented with lactose. Journal of Animal Science. 51:638-644.

Reeds, P. J. & Mersmann, H. J., 1991. Protein and energy requirements of animals treated with β-adrenergic agonists: A discussion. Journal of Animal Science. 19:1532-1550.

Roof, M. D. & Mahan, D. C., 1982. Effects of carbadox and various dietary copper levels for weanling swine. Journal of Animal Science. 55:1109-1117.

Saggerson, E. D., 1985. Hormonal regulation of biosynthetic activities in white adipose tissue. In: A Cryer and R.L.R. Van. (Ed.) New Perspectives in Adipose Tissue: Structure, Function and development. Butterworths, London, p. 87.

Stahley, T. S., Cromwell, G. L. & Monegue, H. J., 1980. Effects of dietary inclusion of copper and (or) antibiotics on the performance of weanling pigs. Journal of Animal Science. 51:1347-1351.

Thacker, P. A., Campbell, G. L. & Grootwassink, W. D., 1992. Effect of Salinomycin and enzyme supplementation on nutrient digestibility and the performance of pigs fed barley- or rye-based diets. Canadian Journal of Animal Science. 72:117-125.

Vanbelle, M., Tellor, E & Focant, M., 1990. Probiotics in animal nutrition: a review. Archives of Animal Nutrition. 40:543-567.

van Weerden, E, J., 1987. Effects of clenbuterol on N deposition and carcass composition in castrated male pigs. In: J. P. Hanrahan: Beta-agonists and their effects on animal growth and carcass quality. Elsevier Applied Science, New York, NY, p. 152-162.

Varel, V. H., Robinson, I. M. & Pond, W. G., 1987. Effect of dietary copper sulfate, Avreo SP 250, or clinoptilolite on ureolytic bacteria found in the pig large intestine. Applied and Environmental Microbiology. 53:2009-2012.

Visek, W. J., 1978. The mode of growth promoting by antibiotics. Journal of Animal Science. 46:1447-1469.

Wilson, M. A., Forsberg, N. E., Zhong, C., Dalrymple, R. H. & Ricks, C. A., 1987. Protein synthesis and degradation in sheep skeletal muscle: Effects of maturity and of dietary and medium cimaterol. Journal of Animal Science. 65:251 (Abstract).

Nitrogen flow in pig production and environmental consequences

Proceedings of the First International Symposium on Nitrogen Flow in Pig Production and Environmental Consequences, Wageningen (Doorwerth), The Netherlands, 8 - 11 June 1993
(EAAP Publication No. 69, 1993)

M.W.A. Verstegen, L.A. den Hartog, G.J.M. van Kempen and J.H.M. Metz (Editors)

Pudoc Scientific Publishers
Wageningen 1993