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Nutritional impact on manure management

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Introduction

The desire of the consumer for inexpensive, lean, high quality meat has encouraged the development of larger production units without corresponding increases in land area for manure application and space for odor dispersion. These production units capture economies of scale by spreading fixed costs over a large number of animals. However, there may not be economies of scale for manure management because of increased manure transportation costs associated with dispersing larger amounts of manure from one location to another. The estimated global livestock population of 3.9 billion animals produces about half a billion tons of manure. Manure nutrient excretion is influenced primarily by the nutrient content of the diet. The elements nitrogen and phosphorus have become two of the primary nutrients of major concern when trying to manipulate production systems to decrease the excretion of nutrients and obtain environmental stewardship. The objective of this paper is to present nutritional management strategies as tools for decreasing the environmental threat of land application of manure.

Nature of mineral losses in livestock production

On average, 60 to 80% of ingested nitrogen and phosphorus is excreted in pig manure as shown in **Table 1**. The main sources of nitrogen in manure are fecal nitrogen and urinary nitrogen. Sources contributing to fecal nitrogen are undigested feed nitrogen, microbial nitrogen, and endogenous nitrogen. Factors increasing fecal nitrogen output include usage of low digestible feedstuffs, presence of antinutritive factors such as various fiber sources, trypsin and chymotrypsin inhibitors, lectins, phenolic compounds, and tannins. Absorbed amino acids that cannot be used for protein deposition are broken down, and nitrogen in the form of urea is excreted in the urine. Urinary nitrogen is excreted mainly as urea in cattle, sheep, and pigs and as uric acid in poultry. Other nitrogen containing compounds excreted in urine include allantoin, hippuric acid, and creatinine. Endogenous nitrogen losses are derived from the gastrointestinal tract and comprise protein, peptides, amino acids, and other nitrogen-containing substances from saliva, bile, pancreatic, gastric and intestinal secretions, plasma, and sloughed epithelial cells.

Feces and urine of livestock usually get mixed after excretion. Due to microbial activity in the manure, extensive degradation of nitrogen-containing compounds develops as shown in **Table 2**. This microbial activity causes a rapid breakdown and formation of volatile fatty acids and ammonia. Between 60 and 75% of the nitrogen in excreted manure is converted into ammonia, of which between 25 and 40% is lost during storage and an additional 20 to 60% is lost during spreading. In addition to ammonia, there are over eighty other compounds that are found in manure. Of these, ten presented in **Table 2** are considered important contributors to odor nuisance. The potential risk of these volatile compounds in animal manure is health and malodor.

Feeds for livestock contain ingredients of plant origin. Phytate is the salt of phytic acid and serves as the primary storage form of phosphorus in plants, accounting for 46 to 80% of the total phosphorus (**Table 3**). It serves

Table 1: Intake, excretion, and retention of nitrogen and phosphorus in pigs

	Piglet (9 - 25 kg)	Growing pig (25 - 106 kg)	Breeding sow (19.6 piglets/yr)
Nitrogen			
intake (kg)	0.94	6.32	27.78
excretion (kg)	0.56	4.24	22.42
retention (%)	40	33	19
Phosphorus			
intake (kg)	0.21	1.22	6.56
excretion (kg)	0.13	0.82	5.42
retention (%)	39	33	17

Jongbloed and Lenis, 1993

Table 2: Characteristics of volatile compounds in animal waste

Component	Form	Smell	Target organs
Acetic acid	colorless liquid	pungent; acrid	respiratory system
Butyric acid	colorless oily liquid	pungent	skin; eyes
Propionic acid	colorless oily liquid	rancid	respiratory system; eyes
Phenol	colorless to pink crystals	odor	respiratory system; eyes
p-Cresol	colorless to pink crystals	carbolic odor	respiratory system; eyes; skin; liver; kidneys
Ammonia	colorless gas	pungent	respiratory system; eyes
Nitrogen dioxide	red brown gas	toxic	respiratory system; lungs; eyes; skin
Ethyl mercaptan	colorless liquid	garlic odor	respiratory system; eyes; mucous membranes
Methyl mercaptan	colorless gas	nauseous smell	Whole system
Hydrogen sulfide	colorless gas	offensive odor	respiratory system; eyes

Tamminga and Verstegen, 1992

Table 3: Phytate phosphorus contents of grain legumes and oilseeds

Ingredient	Phytate P (g/100)	Phytate P as % of total
Barley	0.23	63
Corn	0.21	68
Oats	0.22	61
Rye	0.22	61
Wheat	0.23	65
Wheat bran	0.99	80
Field peas	0.19	46
Soybean meal	0.39	60
Canola meal	0.54	52

Adapted from V. Ravindran (1996)

several important physiological functions during dormancy and germination of seeds. These include initiation of dormancy, antioxidant protection during dormancy, and storage of phosphorus for use during germination. Available phosphorus in these ingredients is not sufficient to obtain good performance in pigs and poultry, therefore, additional inorganic phosphorus is supplied. The low digestibility of phosphorus in cereal grain is due to the fact that about 66% of it is found in the form of phytate-phosphorus (myo-inositol hexabisphosphate) which forms poorly soluble salts of phytic acid with very limited digestibility and availability for pigs and poultry. Therefore, the main part of phosphorus excretion is fecal because of its relative low digestibility (30–40%) in cereal grains and legumes.

Dietary effects on manure volume and content

Dietary manipulation to "fine tune" the nutritional requirements of livestock to reduce the digestive and metabolic losses of nutrients and maximize animal productivity include the following tactics:

- Breeding and selecting livestock for better feed conversion and nitrogen retention
- Increasing use of digestible feedstuffs
- Increasing use of amino acids and reducing protein content of feed
- Using exogenous enzymes
- Formulating diets closer to the animal's requirements
- Using new feed processing technologies such as extrusion and micronization
- Altering animal utilization of nutrients by use of growth promoters

The potential effects of using these strategies to reduce nitrogen and phosphorus excretion are shown in **Table 4**.

Feedstuffs and digestibility

The use of protein in a feedstuff is limited by the availability of the protein in the material and the contribution of the amino acids in the feedstuffs to the overall amino acid composition of the diet. If the protein is in a form that cannot be digested, then nitrogen will be excreted. Therefore, the use of more-digestible feedstuffs can reduce the amounts of nitrogen and phosphorus excreted in manure. The digestibility of feedstuffs can be enhanced by using supplemental feed enzymes which either support the animal's endogenous enzymes or supply a digestive capacity non-existent in the host animal. The use of enzymes, therefore, reduces the excretion of undigested nutrients. **Table 5** shows the effect of microbial enzymes (xylanase and amylase) on the utilization of hulless barley by pigs from 8 to 60 kg liveweight. The pigs fed the enzyme-supplemented diet required 10% less feed for the same amount of gain as the pigs fed the control diet. These

Table 4: Potential effects of various strategies to reduce the nitrogen and phosphorus content of manure

Factors	Estimated reduction in manure (%) Nitrogen	Phosphorus
Supplements		
Synthetic amino acids and reduced protein levels in feed	20 - 25	
Enzymes		
Cellulases	5	25 - 30
Phytases	5	5
Growth promoting substances	5	5
Systems		
Formulation closer to requirement	10 - 15	10 - 15
Phase feeding	10	10
Use of highly digestible raw materials	5	5

Adapted from Williams and Kelly, 1994

Table 5: Effect of enzymes on utilization of hulless barley by pigs

Growth phase (kg)	Control	Feed Efficiency + Enzyme	Response (%)
8 - 20	1.54	1.39	10
20 - 40	2.00	1.89	5.3
40 - 60	2.4	2.3	3.0

Baidoo et. al 1998.

Table 6: Effect of wheat phytase on the digestibility of phosphorus

Feed	Digestibility (-) phytase	(+) phytase	% improvement
Wheat	27	50	46
Maize + soybean meal + 40% wheat	31	49	36
Wheat middlings	19	33	42
Maize + soybean meal + 20% wheat middlings	32	40	20

Jongbloed, Everts and Kemme, 1991

results also confirm the observation that younger pigs benefit more from exogenous enzyme supplementation of feedstuffs than older pigs.

In the presence of a more specific enzyme system, exogenous phytase, phytic acid is hydrolyzed to inositol and orthophosphate and subsequently absorbed. The inclusion of phytase in diets for pigs and poultry significantly improved apparent total tract digestibility of feedstuffs as shown in **Tables 6** and **7**. Furthermore, it is reported that inclusion of phytase will also increase digestibility of dry matter (+1.8%), organic matter (+1.6%), crude protein (+2.3%), calcium (+4.3%), total phosphorus, and amino acids. The effects on crude protein and amino acid digestibility may indicate that phytate-protein bindings were to some extent cleaved by phytase activity or by reducing the activity of phytic acid's inhibitory influence on trypsin and pepsin. Therefore, phosphorus supply in a diet with phytase can be considerably less than in diets without phytase.

Table 7: Effects of phytase on ileal digestibility of selected essential amino acids in broilers

Amino acid	Phytase (U/kg) 0	450	% improvement
Lysine	80.7	82.8	2.6
Methionine	82	83.8	1.9
Threonine	70.1	73.6	5.0
Isoleucine	76.4	80.3	5.1
Leucine	82.6	84.4	2.2
Arginine	85.9	87	1.3

Adapted from Kornegay et. al. 1996

Feeding to requirements

The balance of amino acids in protein is the most important factor affecting the utilization of dietary protein. Animals do not have a requirement for protein per se, but for the amino acids that make up the proteins. The more closely the amino acid composition of the diet matches the requirement for maintenance and production (i.e., in the "ideal protein"), the less protein the animal effectively needs and the less nitrogen will be excreted in the urine.

Plant proteins rarely supply amino acids in the required ratio; therefore, feedstuffs are combined to meet the animal's needs for the limiting essential amino acids. This practice usually results in a diet with a higher than required protein content due to the presence of other amino acids in excess. The use of commercially available synthetic amino acids such as lysine, methionine, threonine, and tryptophan provides a means for increasing the efficiency of utilization of dietary protein, allowing lower protein inclusions and a better utilization of the protein in the diet. In a study in The Netherlands, dietary crude protein for pigs was lowered from 13.9% to 11% when the low protein diet was supplemented with methionine, threonine, lysine, and tryptophan. In the low protein diet, there was no reduction in weight gain or feed efficiency, but nitrogen excretion was reduced by nearly 30%. Recent studies confirmed that, compared with a control crude protein level of 17.8%, dietary crude protein can be reduced to 13.6% plus supplementation with lysine, methionine, threonine, and tryptophan without any adverse effects on performance or carcass composition of growing-finishing pigs. The two low protein diets reduced overall nitrogen excretion by 18 and 33% compared with the control of 17.8% crude protein. Feeding according to amino acid requirements, rather than total protein requirements can, therefore, reduce the nitrogen content of manure. About 1% reduction in total protein content of growing and finishing diets is possible with the use of synthetic lysine, methionine, threonine, and tryptophan. Such a reduction in dietary protein can result in a decrease of 16% for the growing period and 19% for the finisher period in urinary nitrogen excretion.

Phase feeding

Amino acids requirements vary with age and physiological status. Therefore, to keep unnecessary nitrogen losses to a minimum, amino acid supply has to change almost continually, which can be achieved by phase feeding. Recent experimental results, presented in **Table 8**, shows considerable benefit from phase feeding. Multiple phases improved feed efficiency by approximately 7%. By reducing protein and supplementing the diet with synthetic amino acids, multiphase feeding systems for growing-finishing pigs resulted in a reduction in nitrogen and phosphorus excretion by 12%.

Phase feeding can also be beneficial in reducing nitrogen excretion of breeding sows. The nutrient requirements for nitrogen per kilogram of feed are much lower during pregnancy than lactation. The use of separate diets for pregnancy and lactation, compared with one diet for both, has been reported to reduce nitrogen excretion by 15 and 21%, respectively, without influencing reproductive traits between sows on one- and two- phase feeding.

Enhancing animal utilization of nutrients

The number of animals required to produce useful animal products will be reduced if conversion of feed to animal products is enhanced. Although manipulation of digestion is both easier to achieve and generally more acceptable to society, a number of approaches have been identified to alter metabolism of nutrients. These include the use of feed additives such as nutrient repartitioners or agents which could optimize endocrine balance and reduce waste of nitrogen. Such agents—called growth promoters—include antibodies, hormones, and beta-agonists. Growth promoters have effects on nitrogen accretion which result in improvements both in the efficiency of nitrogen retention and in the rate of gain. Both factors have positive effects in terms of the reduction in nitrogen excretion. The use of growth promoters, such as ractopamine (beta-agonist) and recombinant porcine somatotropin (rpST) for swine and monensin sodium (ionophore) and recombinant bovine somatotropin (rbST) for cattle, resulted in reductions in pollutant output ranging from 11.6 to 33.5% in swine and 4.2% to 11.7% in growing cattle as presented in **Table 9**. Furthermore, the use of rbST to increase milk yield in dairy cows can reduce nitrogen excretion per liter of milk produced by 15% by reducing the number of cows required to produce the same amount of milk by a quota system.

Table 8: Phase feeding and pig performance between 20 - 105 kg with different lysine levels

	Phases, (kg liveweight)		
	20 - 60; 60 - 105		20 - 40 - 60 - 80 - 105
	Lysine (g MJ/DE)		
	0.55 / 0.47	0.88 / 0.70	0.92 / 0.84 / 0.74 / 0.66
Feed intake (kg)	2.6	2.6	2.6
Daily gain (kg)	0.89	1.03	1.08
Feed : Gain	2.93	2.57	2.04
Cost ($ / kg gain)	0.44	0.43	0.40

Baidoo, Onischuk and Crow, 1995

Table 9: Use of growth promoters to reduce nitrogen and phosphorus excretion of pigs and cattle

Factors	ADG (kg/d)	DMI (kg/d)	Feed saved/hd (kg DM)	Manure saving/hd (kg DM)	% of control
Beta-agonists and porcine somatotropin to reduce nitrogen excretion of pigs					
beta-agonist (ractopamine: 64-95 kg)					
Control	0.99	2.41			
+ beta-agonist	1.10	2.08	9.32	.68	86
Porcine somatotropin (25-55 kg)					
Control	0.91	2.13			
+ pST	1.10	1.90	8.95	.56	88.4
Porcine somatotropin (60 - 98 kg)					
Control	1.06	3.38			
+pST	1.22	2.61	25.73	1.61	77.4
Ionophores and recombinant bovine somatotropin (rbST) to reduce nitrogen excretion of beef cattle					
Ionophore (monensin sodium) (231-380 kg)					
Control	1.30	7.90			
+ ionophore	1.33	7.57	37.3	14.0	95.8
Recombinant bovine somatotropin (231-399 kg)					
Control	1.30	7.90			
+rbST	1.50	8.05	-16.8	-1.26	101.9

Adapted from Williams and Kelly, 1994

Dietary effect on manure odor

Odors associated with swine and cattle operations come from a mixture of urine, fresh and decomposing feces, and spilled feed. Anaerobic microbial decomposition of feces appears to be the source of the more objectionable smells. Compounds identified in livestock manure include fixed gases, such as methane, ammonia, and hydrogen sulfide; alcohols, including methanol and ethanol; acids, including C2 - C5 fatty acids; amines, including methylamine; aldehydes and ketones; esters; sulfur containing compounds, such as dimethyl sulfide and methyl mercaptan; and heterocycles, such as indole and skatole.

The reduction of substrates for the anaerobic microbial activity will reduce the emission of these malodorous compounds. The use of various feeding strategies, reduction in nitrogen intake, use of synthetic amino acids, phase feeding, use of repartitioning agents, good genetics, and various feed additives may reduce excretion of nitrogen for formation of malodors.

Feed additives and manure odor control

There are numerous commercial products that are alleged to abate and/or control manure related odors. These products can generally be classified as chemical, enzymatic, or microbial in composition. Furthermore, these additives can generally be grouped into categories such as masking agents, counteractants, digestive deodorants, adsorbents, feed additives, and chemical deodorants. Some of these products, under appropriate environmental and management conditions, may be effective in reducing odor intensity and/or improving odor quality. Some of the feed additives under study include oligosaccahride sources, such sugar beet pulp; soy bean hulls; and Jerusalem artichoke.

Oligosaccharide sources

It appears that oligosaccharides (e.g., fructans) promote the growth of certain non-pathogenic micro-organisms, particularly bifidobacteria, while reducing the numbers of less desirable micro-organisms. In turn, this may alter the pool of nutrients available to the host animal, change in the gut environment, 'and/or change the digesta/fecal composition. Studies have shown that addition of oligosaccharides to the diet of animals decreases blood urea concentration, favoring a net transfer of urea into cecal lumen. The ammonia generated by bacterial urease is used for bacterial protein synthesis, thus trapping nitrogen for elimination in the feces.

Jerusalem artichoke

Jerusalem artichoke (*Helianthus tuberosus* L.) is a plant native to Canada. It has a tuber that develops below ground. The tuber is rich in the carbohydrate inulin. Inulin can be broken down chemically to the simple sugar called fructooligosaccharide. Feeding Jerusalem artichoke to pigs has been shown to increase body weight and feed efficiency. In addition, there are reports that feeding inulin-containing feedstuffs encourages the growth of bifidobacteria in the pig which reduces diarrhea in pigs and also reduces malodors from swine manure. In a sensory evaluation study, the smell of fresh (less than 4 h) manure from pigs fed 3% and 6% Jerusalem artichoke was sweeter, less sharp and pungent, and had less of a skatole smell than manure from pigs fed the control diet (**Table 10**). The observed changes in pig manure may be due to the positive influence of Jerusalem artichoke on bifidobacteria in the intestinal microflora.

Zeolites

Zeolites are a family of minerals of volcanic origin that combine a high level of porosity with a capacity for both absorption and ion exchange. In a pilot study at Mcgill University, 5% zeolite (tektosilicate), as a feed additive in swine diet produced manure that released less ammonia than that of the control pigs by 21%. Zeolite has also been shown to absorb phenolic compounds. The exact functions of zeolite in controlling diarrhea and reducing manure odor requires physiological and biochemical investigation. However, the ammonium selectivity of clinoptitolite suggests that it might act as a nitrogen reservoir in the digestive system of the animal, allowing a slower release and more efficient use of ammonium ions produced by the breakdown of ingested rations in the development of animal protein.

Dietary electrolyte balance

Altering the dietary electrolyte balance (Na + K – Cl) generally reduces pH of the urine and slurry, therefore lowering the emission of ammonia from the slurry. Research has shown that $CaSO_4$ or $CaCl_2$ are more effective in reducing slurry pH than using $CaCO_3$ in the diet.

Yucca extracts

Extracts and preparations of the desert plant *Yucca schidigera* have been reported to reduce gastrointestinal or fecal ammonia levels in pigs, poultry, and dairy cattle. The proposed mechanism of action includes the inhibition of microfloral urease, the direct binding of ammonia, and enhanced microfloral nitrogen utilization. In a study reported in **Table 11**, dietary *Yucca schidigera* extract was effective in reducing ammonia levels and improving pig performance.

Table 10: Sensory evaluation of the smell of manure of pigs fed diets containing Jerusalem artichoke

	Diet		
Characteristic	**0%**	**3%**	**6%**
Sweet	3.9	4.3	5.0
Earthy	2.5	2.4	2.4
Sour	2.9	2.9	3.3
Sharp, pungent	5.4	4.3	4.1
Skatole	6.0	4.0	3.9

Farnworth, Modler and Mackie, 1995

Conclusion

Nutritional management of livestock can substantially contribute to the reduction of nitrogen and phosphorus excretion by adopting technologies to improve the efficiency of nutrient use. Such technologies should focus on the following:

- Increasing the nutrient utilization of the diet by reducing nutrient excretion
- Manipulating the diet to alter microbial fermentation in the lower GIT
- Reducing excretion of odor-causing compounds
- Altering the physical environment of urine and feces to suppress odor emissions

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Table 11: Environmental ammonia levels and pig performance with and without dietary *Yucca schidigera* extract

	Control	***Yucca schidigera* extract**
Ammonia at start (ppm)	31.2	30.1
Ammonia at finish (ppm)	30.0	19.6
Daily live weight gain (g/d)	817.3	847.3

Cole and Tuck, 1995

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