

STRATEGIES TO REDUCE ENVIRONMENTAL POLLUTION FROM ANIMAL MANURE : PRINCIPLES AND NUTRITIONAL MANAGEMENT — A REVIEW* —

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Summary

The animal industry must be environmentally sound to ensure its long-term sustainable growth. Livestock wastes mostly manure, can be a valuable resource as well as a potential hazard to environment.

The first option of manure management is developing an 'environmentally sound' feeding program and feeds so there are less excreted nutrients that need to be managed. Once the manure is produced it can be best utilized as a fertilizer of a soil conditioner. In many countries the amount of manure that can be spread on land depends on the nutrient requirements of the crop being grown. The laws specify maximum application rates and not animal stocking rates. Farmers who reduce the N and P component of manure can release pressure on the environment without having to reduce the number of animals. There are alternative systems for housing and manure treatment which generate manure that are easier to handle and have less pollutants or more economic value. Treated animal waste may also be used as a feedstuff or fuel source.

Most of the options of waste management result in increased costs to implement. It is necessary to assess the economics in order to find an acceptable compromise between the increased costs and the benefit to the environment. Animal welfare is also becoming more and more of an issue and it will lead to systems where animals are kept in less confined environment. The new systems will have a great impact on the waste management system in the future.

(Key Words: Environment, Animal Manure, Animal Waste, Nutritional Management, Nitrogen Control, Phosphorus Control, Feed Enzymes)

Introduction

Environmentally, the emphasis in sustainable agriculture should be in both reducing inputs of non-renewable resources, and also increasing nutrient utilization on the farms in order to minimize adverse environmental impacts. Animal industry utilizes a small amount of non-renewable resources but a lot of waste and by-products which are not or can not be used for human consumption. Animals contribute substantially to reducing potential pollutants originating from industries such as

food processing industry, slaughter houses, milling industry, etc. The concept that animal excreta is a pollutant has risen only in the past 20 years (Williams, 1995). Previously the term manure was used to describe excreta which was predominantly used as fertilizer and soil conditioner. The change from fertilizer to pollutant occurred as systems of animal production intensified and the composition of animal feedstuffs has diversified. In many instances, the quantity and composition of excreta produced exceeds the areas of land capable of using them as fertilizer and it can truly be described as a contaminant or a pollutant. Now environmental pollution from animals manure is a global concern and becomes a more serious issue in countries with high concentrations of animals on a limited land base for manure disposal.

Environmental concerns relate to water quality, soil degradation, air pollution and rural-urban interface issues. Land application of excessive quantities of nutrients is subject to surface run-off and leaching that may

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contaminate ground or surface waters. Nitrate leaching has been considered a major nitrogen (N) pollution concern with livestock farms. Ammonia toxicity to fish and altered effectiveness of chlorination are other concerns. Phosphorus (P) entering surface waters can stimulate growth of algae and water plants. Decomposition of them results in an increased oxygen demand, which may interfere with the well-being of fish and wildlife. Excessive contributions of some minerals from animal manure can create high salt concentration in the soil. High concentration of copper sulphate in the pig diet can cause accumulation of copper in the soil. Manure can be a major source of methane and nitrogen oxides which contribute to the accumulation of greenhouse gas. Volatilization of ammonia causes acid rain which results in forest dieback in western Europe (ApSimon et al., 1987). Animal husbandry in that region is responsible for 50% of sources of acid precipitation. Among the animal husbandry, cattle contribute 60%, pigs 27%, poultry 12% and calves 1% to the acid precipitation (Poultry International, 1992). Emissions of nitrous oxide (N₂O) during nitrification and denitrification cause depletion of the stratospheric ozone layer (Christensen, 1983). Manure can be a source of odours which contribute to friction between urban and rural residents.

As described above, animal manure can be a valuable resource while it can be a major obstacle in the future development of animal industry if the impact on environment is not properly controlled. To control agriculturally derived pollution, legislation is being enacted in several countries, which both restrict agricultural activity and penalises farmers for exceeding limits related to waste disposal. Major efforts are required to adopt all best available technologies capable of reducing excretion of pollutants, especially N and P, from animal industry before further restrictive legislation is enacted to control the problem. There are a number of possible solutions to this problem, such as changing feeding techniques (nutritional management), better manure treatment, manure storage and distribution and modifications to livestock housing systems. The present paper is aimed to review principal strategies with emphasis on the nutritional management in dealing with animal manure to reduce environmental pollution.

Principles of Manure Management

A. Environmentally sustainable animal industry

Food producing systems must be environmentally sustainable. Current and future animal industries must ensure that they are environmentally healthy for long-term

sustainable growth and development. Without environmental sustainability, the economic viability of the industry will inevitably deteriorate and the socio-economic structure of rural communities will be threatened.

Current environmental issues that are faced at the national and international levels are:

- Stratospheric ozone depletion
- Air quality
- Climate change
- Energy inefficiency
- Lack of alternative energy sources that minimize pollution
- Loss of genetic diversity
- Narrowing of the genetic basis for agriculture

Any agri-food industry must consider the above environmental issues and be encouraged to develop policies and programs that maintain and enhance the quality of environment.

Sustainable agri-food systems can be defined as: "those that are *economically viable*, and meet society's need for *safe and nutritious food*, while conserving or enhancing natural resources and the quality of the *environment for future generations*" (Strategy Towards Environmental Sustainability, 1993).

Animal industry produce various kinds of by-products which can cause environmental pollution. Livestock manure is the major source of pollution if it is not properly managed. The above definition may be applied to the management of wastes in animal industry as well as in other sectors of agricultural industry.

B. Regulations on the Pollutants from Manure

The pollution problem is being approached in various ways with some countries adopting very strict measures in the control of animal waste disposal. An EC directive (COM [88] 708) will limit the number of manure-producing animals per hectare of land available for manure spreading (table 1) equivalent to a limit of 170 kg of total N/ha/year (including that deposited while grazing) in zones deemed vulnerable with regard to nitrate leaching. Land available for spreading will be specified and different limits will be set for zones vulnerable to water pollution from N compounds.

In the UK a *Code of Good Agricultural Practice for the Protection of Water* and a *Code of Good Agricultural Practice for the Protection of Air* have been published and provided to farmers. The code suggests a guideline of 250 kg/ha of total N in applied organic manure per year as a maximum which farmers should not exceed. This translates into typical average figures of land required for spreading of poultry manure of 2.3 ha/1,000 laying hens

places and 2.1 ha/1,000 broiler places. These are typical figures which will vary depending on both diet and management system. Furthermore, a closed season for manure application will probably be established (Archer, 1993; Williams, 1995).

TABLE 1. MAXIMUM NUMBER OF MANURE PRODUCING ANIMALS PER HA OF LAND FOR MANURE SPREADING IN EC

Animals	Maximum number of animals per ha
Dairy cows	2
Young stock/beef	4
Fattening pigs	16
Sows with piglets	5
Turkeys, ducks	100
Laying hens	133
Young hens, 0-16 wk	285

Cited by Williams (1995).

According to a 1993 environmental law (Vlaren II), the Netherlands limits manure spreading based on P as shown in table 2. To convert the limit of P to number of pigs per unit of land, a factor of 7.1 kg P₂O₅ per growing pig is used. Concessions are given to farmers who use environmentally friendly feeds which have reduced N and P input in their formulation. Such an incentive measure was also adopted in Germany. According to the Rohprotein Abgeschickte Mischfutter (RAM system), a contract between the farmer, local administration, feed producer and Chamber of Agriculture, the use of low protein feed gives a 25% concession on norms (Williams and Kelly, 1994). In an effort to solve environmental problems by the end of this decade, the Netherlands needs two billion guilders. Part of the expense must be contributed by farmers in the form of levies based on the phosphate (P₂O₅) surplus. For example, a farm with 35,000 layers produces approximately 15.2 ton of surplus phosphate a year. The levies will be 13,700 Dfl for slurry manure and 3,200 Dfl for dry manure (>50% DM). The levy applied is different because production costs of standardised manure from slurry are high as are slurry distribution costs (Poultry International, 1992).

Donham (1989) listed exposure thresholds for environmental contaminants: for ammonia, the thresholds were 7.0 and 11.0-25.0 ppm for human and pig health, respectively. Levels in excess of values given were associated with a higher proportion of work-related

diseases, pig diseases or lower productive parameters. Regulations introduced in Great Britain limit the exposure of humans to atmospheric ammonia to a mean level of 25 ppm over an 8 h work shift and 35 ppm for 10 min exposure (Health and Safety Executive Guidelines, 1986).

In the United States, the 1987 Chesapeake Bay Agreement pin-pointed agriculture as a main source of 'controllable N and P'. This agreement is the birthplace of the agriculture nutrient management plan which includes a 40% reduction of N and P. Pennsylvania's Nutrient Management Law -- 'Act 6 of 1993' (PA) is mandatory and limiting livestock density at 2,000 lb live weight/acre. Nutrient Management Plan (PA) includes; nutrient application to soil, manure management, methods for the use or disposal of excess manure, storm water runoff control and laws, regulations, ordinances (Brubaker, 1995).

TABLE 2. NORM (VLAREN II, 1993) OF MANURE SPREADING BASED ON PHOSPHORUS IN THE NETHERLANDS, P₂O₅ (kg / ha / yr)

Land class	Jan. 1991	Jan. 2000
Grassland	200	125
Silage maize	200	125
Arable	125	125

(Cited by Williams and Kelly, 1994).

C. Options of manure management

1. Nutritional management

The first waste management option to consider is to reduce the amount of nutrients in the manure. Feed composition and dietary regimens can be more closely adapted to the animals' nutrition requirements to avoid overfeeding and to reduce excretion of undigested components. The use of enzyme preparations such as phytase can help improve digestibility of organic phosphorus. The nitrogen content of animal feeds can be reduced with addition of synthetic amino acids and enzymes. Details of such nutritional management systems will be discussed later.

2. Fertilization or disposal option

As animal agriculture becomes more intensive, large amounts of animal manure that are distributed on small land holdings are global concerns. Agricultural systems are complex and the parameters that are selected can change the interpretation of whether the addition of manure is perceived to be beneficial or a potential environmental threat. Once the manure is produced from

the animals, the first choice a producer must make is to either dispose of waste, or use the waste as a fertilizer at rates that meet crop requirements. One of the most potential applications of the manure is their use as a fertilizer or soil conditioner. However, any activity that puts waste on crop or tree production land exceeding the amount required by the crop or tree is considered disposal which requires a permit in many countries.

2.1. Effects of manure on soil and the environment

For most agricultural practices, the soil should have a reasonable clay content (15-30%), organic matter content (3 + %), a near neutral pH and good drainage, to avoid excess need for fertilizer and to retain important minerals for organisms that rely on their nutrition from the soil. Significant, also, is the balance of availability of mineral nutrients and not merely their total amounts. Clay minerals and humus provide the surfaces by which minerals are retained and made available to the organisms in the soil.

In general, commercial fertilizers produce acids when added to the soil. This can cause toxicity of Al and some other trace minerals. A common remedial measure is to apply lime (Ca-carbonate), which not only supplies an important plant nutrient (calcium) but raises the pH, making, Al, Cd, Cu, etc. less available to the growing crop and less mobile in drainage water.

The addition of animal manure is an age-old practice, and one that is encouraged for effective crop production and the maintenance or even improvement of "soil health". However, too much of a "good thing" may become harmful to both the crop and the soil-water systems because it increases the concentration of N, P and the chemical oxygen demand of surface runoff from land (Lavkulich, 1995).

2.2 Complying with the code

When spreading manure on cropland there are three concerns that need to be addressed. Firstly, is pollution likely to occur due to weather, topography, soil conditions, or the rate of application (i.e. runoff of manure from fields)? Secondly, is the time of year reasonable for fertilizing the crop? And thirdly, is the manure going to be spread at a rate that would be considered fertilization? To comply with these three concerns, farmers need adequate storage and access to enough cropland.

There are many types of storage facilities the size of which depends on: the amount of waste being generated daily, extra water that needs to be stored from outside livestock yard runoff, precipitation that will fall directly into the storage, and the amount of time storage is going

to be required. There is no reason to fertilize grassland or cropland after October and through the winter in northern hemisphere. The bare ground should not be fertilized until just before a crop is planted. Manure spread during the rainy season has a high risk of running off into watercourses. Hence, when using manures as a fertilizer farmers may require at least 3-6 months storage capacity.

Manure application rates need to take the following into account: nutrient requirement of the crop grown, nutrient content of the manure, soil nutrient status, and other fertilizers being applied. For example, based on the N balance of crop field the rates are equivalent to one sow (farrow-to-finish) per hectare for grain and some vegetable crops, to a maximum of 4.3 sows per hectare for high-yielding grass crops (Kleec, 1995).

3. Treatment options

Options for the treatment methods of manure depend on the species of animal, housing (e.g. bedding system vs. flushing and deep pit system in pigs), manure handling system (e.g. slurry system vs. conveyor belt system with forced-air in poultry) and the purpose of treatment (e.g. disposal vs. commercial organic fertilizer). In most cases, however, the purpose of the treatment of manure is to reduce the amount of nutrients and the volume of manure. If, after obtaining as much cropland as possible within a reasonable distance of the farm, one still doesn't have access to enough land, some form of treatment will be required.

One reason for treating waste is to make it easier to transport and market the comparatively small volume of nutrient-rich solids that are produced. Another reason for treating waste is to reduce the manure odour, so the treated waste can be used as a fertilizer in populated areas. Some of the different treatment options are shown in table 3 with the expected nutrient reduction.

TABLE 3. TREATMENT OPTIONS FOR NUTRIENT REMOVAL FROM LIQUID MANUE

Option	N reduction	P reduction	K reduction
Remove solids with separator	5-25%	5-15%	5-15%
Remove solids using polymer	15-25%	50-75%	5-20%
Precipitate phosphorus	0- 5%	90-95%	0- 5%
Sequencing batch reactor system	75%	76%	25%

(Kleec, 1995).

In Europe a considerable emphasis has been placed on fermentation of manure both through controlled composting and biogas production. In general, and because of the nature of manure production on the farm and its composition, biogas producing anaerobic fermentation is easier with swine and cattle liquid manures where the total solids is much less than in poultry manure and where drying is less feasible. On the other hand, aerobic fermentation involved in composting is easier with poultry solid manures. Evaluation of a pilot plant for composting and drying manure showed that the process costs 2 to 3 times more than aeration of liquid manure (Naber, 1988).

Following are some of the technologies applied to the treatment of animal waste.

3.1. Composting

Composting is biological process employing organisms ranging from microscopic bacteria and fungi to earthworm to convert complex organic matter into a simpler, biologically stable humus-like material. The major outputs of the composting process are heat, carbon dioxide, water and humus. The objectives of the composting process are to:

- Stabilize putrescible organic matter.
- Destroy pathogens and weed seeds.
- Conserve available N, P and K.
- Produce a relatively dry, uniform product that is free of objectionable and harmful components.
- Reduce malodours during storage and spreading.

Composting can be done using one of the following three methods:

3.1.1. Aerobic composting

Aerobic decomposition by microbial agents converts biodegradable organic matter in animal waste to oxidized by-products such as carbon dioxide and water and results in a stable humus like product. Ideal conditions for thermophilic bacteria are established at 45 to 50°C (Naber, 1988) but thermophilic temperatures of 55-70°C are commonly achieved, which results in pathogen kill and weed seed desiccation. Due to the oxidation that occurs, odour creation is limited compared to anaerobic systems. The primary factors that affect the rate at which aerobic composting occurs include moisture content, bulking agents, aeration, nutrient balance, pH, and temperature.

3.1.2. Anaerobic composting

Anaerobic decomposition occurs without the presence of oxygen, and temperatures of less than 55°C are achieved. The process yields only partially reduced and

oxidized compounds which may continue to break down after treatment. Anaerobic conditions occur when sufficient oxygen cannot enter pore spaces (voids) due to excess moisture, fine particles size or compaction. Anaerobic digestion of poultry manure produces biogas which is mainly composed of methane (55-70%) and carbon dioxide (Shih, 1988). The main disadvantage of anaerobic decomposition is that the by-products of the process (such as fatty acids, aldehydes, hydrogen sulphide and ammonia) often create offensive septic odours.

3.1.3. Vermicomposting

Vermicomposting is a variation of aerobic composting in which earthworms are added to animal manure to promote rapid decomposition of organic materials. In addition to feeding on the microorganisms found in the manure, the earthworms fragment particle agglomerations which results in a more homogenous texture. After a period of 10 days or more, the earthworms are removed from the compost, the material is draught dried, filtered through a sieve, and then packaged and marketed.

Composting reduces the weight and volume of litter by an average of approximately 50%. The P and K content are not affected by composting. Some N will be lost due to volatilization of ammonia N. The amount of loss depends on various factors including the C:N ratio, temperature, and pH of the litter. The loss can be more than 50% of the N. The remaining N is approximately 80-90% organic and 10-20% inorganic. Organic forms of N, P and S contained in the composted manure are not available to plants. But soil microorganisms convert these nutrients to inorganic forms that plants can absorb.

Composting can be carried out in windrows or bins with aeration provided by mechanical turning and forced aeration. Aerated bins with mechanical equipment for turning and/or aeration are generally more efficient yet more expensive than windrow composting. Supplies of manure or sludge and bulking agents as well as market demand for the finished compost should be carefully investigated before producers invest heavily in composting equipment (Sweeten, 1988).

Deep-litter system: One practical form of composting in managing animal waste is the deep-litter system for swine housing. The animals are kept on a 40 to 70 cm thick layer of sawdust, woodshavings or finely chopped straw. In the litter, an aerobic fermentation process takes place in which the feces and urine are fermented. This process involves heat production, which increases the temperature of the bedding up to 30-40°C. The heat is also used to evaporate the water in the excreta produced by the animals. For control and stimulation of this process

microbial products are added on a regular basis to liberate the energy available in the excreta. The bedding material needs to be mixed every week to incorporate oxygen, and for homogenization. The bedding material will stay in the pig house for approximately 1-1.5 years.

To obtain optimal performance of this system, two factors have shown to be critical (Schajik, 1993), i.e.;

- Ventilation - Ventilation is needed to remove moisture from the pig house and to provide the bedding material with sufficient oxygen.
- Mixing - To distribute the excreta evenly over the full bedding horizontal mixing is needed. To incorporate oxygen and the excreta into the layer vertical mixing is required.

In this system, if conditions are optimal, the processes of nitrification and denitrification which prevent emission of ammonia can occur (Groenestein, 1993). In terms of health risks to stock persons, this system improved the working environment with respect to dust levels. However, routine bed management gave counts of thermophilic actinomycetes in respirable air that may be associated with sensitization to farmer's lung disease (Kay and Thomas, 1993).

3.2. Activated sludge process

The activated sludge process may be described as a process in which wastewater, containing biodegradable organic compounds, is brought into contact with a fluidized mixed-culture of microorganisms in an aerobic environment. In a tank known as an 'aeration tank', an assimilative process removes from the water a portion of chemically-bound N, P and micronutrients, together with organic carbon.

Biological purification in the activated sludge process is accomplished in the following manner.

- coagulation and flocculation of small particulate matter
- oxidation of carbonaceous matter
- sometimes, a further oxidation of ammonia nitrogen to nitrate (nitrification) may take place.

A well balanced substrate is necessary to foster proper growth of bacterial cells. That is, the BOD, N, P content of the raw wastewater must be balanced. Generally, a BOD : N : P ratio of approximately 100 : 5 : 1 is considered adequate for good organic removal. Although the activated sludge process is quite versatile and can handle a wide array of wastes, its performance can be adversely affected by excessive levels of certain metals and a host of other pollutants. Temperature and pH also influence treatment performance. The activated sludge system functions most efficiently when the pH prevailing

in the aeration tank is 7-8. Cold temperature can definitely reduce BOD removal efficiency (B & L Information Services, 1981).

As a result of fermentation in an aeration tank, biomass is formed and simultaneously, other compounds, both organic and inorganic, are adsorbed by various mechanisms. For that reason the resulting biomass has a very diversified composition and can hardly be compared to the biomass cultivated on pure or simple substrates. Biomass is separated from the liquid phase supernatant in a settling tank. Part of it is recycled to the aeration tank and the rest is continually wasted from the system.

Treatment and disposal costs of this sludge are high because of its low solids concentration (0.5-2%). Good settling properties of the sludge can increase the DM content. By gravity thickening, the DM content of the sludge can be brought up to about 4%, thus remarkably reducing the volume. The next step may be mechanical dewatering. By centrifuges, vacuum filters or bandpresses a final product with 10-40% DM can be reached. The sludge should be conditioned prior to treatment by adding chemicals such as lime, iron-salts, polyelectrolytes, etc. Only a filterpress can reach a final product with 35-50% DM. A final product with more than 50% DM is only produced by heat drying. It reduces the water content to a minimum, but the costs are very high (Vriens et al., 1989).

3.3. Sequencing batch reactor (SBR) treatment

The SBR is a treatment system comprising a single vessel in which altering phases of aerobic and anaerobic conditions can be provided. The SBR is considered as a viable alternative to conventional continuous flow activated sludge treatment for the efficiency of 5-day biochemical oxygen demand (BOD₅) reduction and suspended solids removals, nitrification, denitrification, and chemical precipitation of P (Irvine et al., 1983).

In order to reduce both C and N compounds (Fernandes and McKyes, 1991), and P (Manning and Irvine, 1985) in a single stage reactor, it is necessary to provide diverse environmental conditions including aerobic and anoxic states in a cyclic fashion. The SBR treatment has been found to be an efficient and flexible method for treating various dilute wastewater. The SBR system features sequences of partial filling of the single reactor with waste liquid, followed by a react phase which is fully or partly aerated, a settle phase, and then decanting the treated supernatant. An optional idle period can precede the next fill sequence. Before filling, the reactor contains an active and sizeable microorganism population which will biodegrade the influent wastewater.

At start up, microorganisms must be seeded in the reactor from a suitable source such as a full-scale wastewater treatment facility. Once operating, however, the biomass remains in the reactor from cycle to cycle. The cyclic nature of the SBR process allows control over the duration of operating conditions including the air supply and mixing, and it is thus possible to design a series of specific states in order to achieve a particular set of biochemical reactions on a given waste material.

3.4. Reverse osmosis (RO) system

The RO is a naturally occurring process, which was later developed by scientists to remove certain portions of constituents in liquids, such as desalinization of sea water and removing colours from red wines. The principle is that the feeding water (wastewater) first enters the membrane vessel where the membrane is designed so that it allows only certain molecules to pass through. The external pressure pushes some liquid through the membrane and it become cleaned liquid. The portion remaining in the vessel becomes concentrated and is discharged.

The RO system has been tested in Europe and Canada to treat hog slurry. The application of the RO system to the treatment of hog slurry has advantages and disadvantages.

Advantages : Fairly easy to operate and maintain.

After going through RO unit, there are two streams, i.e., the clean water and the concentrate; Clean water - The test results have indicated that the product water is so clean that it can be either reused on farm or discharged.

Concentrate-After going through the RO, the slurry becomes concentrated which reduces its volume by about 40% to 70%. This will save storage space.

Disadvantage : Need a fairly complex system or a long period of time to treat the hog slurry before the RO unit can handle it directly.

The amount of suspended solids in the slurry is the limiting factor of RO application. A combination of settling, separation, anaerobic and aerobic processes may substantially reduce the suspended solids. Processes such as SBR and advanced ponding systems could be used (Yu, 1995).

3.5. Value-added product

Poultry manure is a bulky, low value material to be shipped economically. An option to overcome this constraint is to produce a value-added product by mixing poultry manure with chemical fertilizers. The resulting high nutrient, slow release fertilizer product could be

targeted at the home market (primarily for lawn use) or at selected commercial markets such as sod farms or golf courses.

The Tennessee Valley Authority (TVA) in Alabama has been working to develop such a product in association with Auburn University. The poultry manure is first composted, mixed with chemicals and then pelleted. In tests, the TVA has mixed the manure with a variety of other inputs including urea, ammonia sulphate, ureaform, phosphorus fertilizers (11-52-0 and 0-46-0), phosphoric acid, potassium chloride, and potassium sulphate. Through various combinations, a number of slow-release chemical fertilizers have been developed including 8-8-8, 8-14-8, 12-4-6, and 12-4-8. In most of the mixes, poultry manure comprised 50% of the end product. The end products are considered a slow release fertilizer to the extent that about 1.5% N is in slow release form from the compost. A greater portion of the nutrients can be held for slow release by substituting a slow-release form of N for urea and potassium sulphate for potassium chloride.

The 8-8-8 product developed by the TVA was marketed at an average price of about U.S. \$200 per ton. The nutrient value may be increased to 10-10-10, which would reduce the volume of poultry manure to 40 to 45% of the end product (FERENCE Weicker & Co. 1994).

3.6. Biofilter

The most common methods for composting used to be the open systems of windrows and aerated static piles. More recently, large-scale in-vessel composting systems have been applied to convert agricultural wastes, municipal solid waste and sewage sludge to useful products. While the in-vessel composting method can produce a high quality product, its potential for unpleasant or harmful odour emission as a form of air pollution remains a major concern, which can threaten the existence of composting plants. Besides the aesthetic undesirability of the odour-causing compounds, their presence on the compost mass surface attracts nuisance insects such as fruit and house flies. Odorous effluents from composting plants tend to be one of the most frequent sources of air pollution complaints. Much of the odour problem can be reduced by incorporating a proper odour control biofilter in the design process (Lee, 1995).

The experiences in Europe (Germany and the Netherlands in particular) have demonstrated that biofiltration has economic and other advantages over existing air pollution control technologies, more so if applied to off-gas streams that contain only low concentrations of air pollutants that are easily biodegradable. As odorous or contaminated off-gases from

the emitting source are passed through a biofiltration medium, two basic removal mechanisms occur simultaneously; they are absorption/adsorption and biooxidation. Given sufficient residence time, the air contaminants will diffuse into a wet, biologically-active layer (water film) which surrounds the filter particles after these contaminants have been adsorbed on the particle surface. Microorganisms, principally bacteria, actinomycetes and fungi, are attached to the filtering medium. This medium acts as an organic nutrient supply and/or organic substrate for the microorganisms, thereby supplementing those nutrients which may or may not be present in the gas stream being treated (Ottengraf, 1986). As odorous compounds are oxidized (aerobic degradation), adsorptive sites in the biofilters become available for additional odorous compounds in the gas stream, thereby self-regenerating the filter's odour removal capacity. End products from the complete biodegradation of air contaminants are CO₂, water and microbial biomass. The oxidation of reduced sulphur compounds and chlorinated organic compounds also generates inorganic acidic compounds such as nitrate and sulphate. In steady state operation, the rate of microbial degradation of the sorbed odorous compounds must equal or exceed the absorption/adsorption rate in order to maximize odour removal rates. If filters are overloaded, absorption sites are filled faster than they are regenerated by biooxidation, thereby resulting in the escape of odorous constituents in the gas stream into the atmosphere (Bohn and Bohn, 1988; Kuter, 1990).

4. Use of animal waste as a feed

4.1 Poultry litter as a cattle feed

Cattle have a unique digestive system that allows them to use waste and other types of by-products as source of nutrients. Since poultry wastes contain substantial levels of fiber and non-protein nitrogen, they are best suited for use by ruminants. Broiler litter has been used in some areas of U.S. as a cattle feed for more than 35 years (Fontenot, 1988). For example, in Rockingham County in Virginia about 20% of 68,000 ton of broiler litter produced are sold for use as a cattle feed. Broiler litter is primarily used in backgrounding and very little litter is included in the diets of finishing beef cattle.

4.1.1. Major advantages of broiler litter as a cattle feed :

a. Poultry manure contains high levels of fiber and NPN and the highest nutritive content of any animal manure. For example, poultry litter can have a crude protein level of up to 38%. A description of the nutrient

content of broiler litter, based upon samples taken in Alabama is provided in table 4.

b. Broiler litter is a low cost feed compared to traditional feed ingredients. Litter can serve as a partial replacement for feeds which have a value of perhaps more than U.S. \$40 per ton. In Alabama and Virginia, processed poultry manure can be obtained at the price of up to \$40 which includes the cost of transportation.

c. When mixed with other ingredients, poultry manure has been found to be a palatable feed for cattle.

TABLE 4. AVERAGE NUTRIENT CONTENT OF POULTRY WASTES

Components	Broiler litter ^a		Broiler litter ^b DM basis	Layer waste ^b DM basis
	Average	Range		
Moisture (%)	19.5	4.70-39	—	—
Dry matter (%)	80.5	61-95	100	100
DE (kcal/kg)	—	—	2,440	1,884
ME (kcal/kg)	—	—	2,181	—
TDN (%)	50	36-64	59.8	52.3
Crude protein (%)	24.9	15-38	31.3	28
Bound nitrogen (%)	15	5-64	—	—
True protein (%)	—	—	16.7	11.3
Digestible protein (%)	—	—	23.3	14.4
Crude fiber (%)	23.6	11-52	16.8	12.7
Ether extract (%)	—	—	3.3	2
Ash (%)	24.7	9-54	15	28
Calcium (%)	2.3	0.81-6.13	2.4	8.8
Phosphorus (%)	1.6	0.56-3.92	1.8	2.5
Potassium (%)	2.3	0.73-5.17	1.78	2.33
Magnesium (%)	0.52	0.19-0.88	0.44	0.67
Sodium (%)	—	—	0.54	0.94
Sulphur (%)	0.5	0.22-0.83	—	—
Copper (ppm)	437	25-1,003	98	150
Iron (ppm)	2,377	529-12,604	451	2,000
Manganese (ppm)	348	125-665	225	406
Zinc (ppm)	315	105-669	235	463

^a Alabama Cooperative Extension Service (1974).

^b Bhattacharya and Taylor (1975).

4.1.2. Constraints associated with the use of poultry litter :

a. While broiler litter is widely used in U.S., layer litter is the only animal waste product approved as a livestock feed ingredient in Canada. Broiler litter is considered to be a single ingredient feed according to the Feeds Act and Regulations and must receive clearance

from the Feed and Fertilizer Division of Agriculture and Agri-foods Canada before it can be considered an acceptable ingredient for use in feeds and offered for sale. For broiler waste to be evaluated as a feed ingredient, a submission must be made demonstrating safety of the product with regard to drug residues and consistency of product quality.

b. Layer litter has a very high moisture content (51% on average). According to the Feeds Act and Regulations of Canada, layer litter must be thermally dehydrated to a moisture content not exceeding 12%. The costs of drying layer waste to a 12% moisture content have precluded its use as a cattle feed in the U.S.

c. According to the Feeds Act and Regulations of Canada, layer litter cannot comprise more than 20% of the complete feed of beef cattle. It cannot be fed to dairy cows or replacement heifers under any circumstances. Use of the product must be discontinued at least 15 days before beef cattle are slaughtered for use in food.

d. Methods of waste handling and storage can greatly affect the quality of the material as a feed ingredient. Some of the more common problems include :

- Inclusion of foreign material such as wire, glass, tools, and plastics in the litter that the cattle may ingest.
- A high ash content in the litter. Ash in litter is made up of minerals from feed, broiler excrement, bedding material, and soil. Ash content should be kept as low as possible and litter with an ash content of over 28% should not be fed to beef cattle.
- Mixing soil in with the litter during the clean-out and handling process. Large amounts of soil will greatly increase the ash content and reduce the nutritive value of the litter.

4.1.3. Processing methods of litter to eliminate pathogenic organisms :

a. Deep stacking for a period of at least 20 days. This is considered the most economical means of processing. However, excessive heating can reduce the digestibility of the dry matter in the litter. Fresh stacked litter develops heat spontaneously. Chemical additives such as urea or acid as well as other procedures, have been tried to limit the heating of stacked litter.

b. Mixing litter with other feed ingredients and ensiling to encourage acid production. Litter typically comprises 20% to 30% of the dry matter of the silage crop. Litter can be directly acidified to achieve essentially the same effect.

c. Heat treating the litter through mechanical drying or pelleting of feeds.

4.2. Biomass from manure fermentation as animal feed

Anaerobic digestion processes, which operate conventionally at mesophilic (30-35°C) or ambient (15-20°C) temperature, are generally easier and cheaper, but yield less profit and are hampered by the discharge of effluent, or even solid waste, which is incapable of anaerobic conversion (Brown, 1972). Anaerobic bacteria which grow well at an elevated temperature (45-65°C) could be selected and they usually metabolize substrates at a high rate (Shih, 1988). On the other hand, aerobic processes are necessary when manure (cattle manure for example) is rich in ligno-cellulosic constituents which are digestible only by aerobic action (Muller, 1980).

As a result of fermentation, a biomass of microorganisms is formed. Animal wastes are high in complex populations of wild microorganisms. For example, activated sludge consists of a mixture of zoogloal bacteria, filamentous bacteria, protozoa, rotifera and miscellaneous higher forms of life. Types and number of organisms vary with the characteristics of the wastewater treated and with culturing conditions. For that reason the resulting biomass has a very diversified composition and biomass from sludge of manure can hardly be compared to the biomass cultivated on pure or simple substrates. From the view point of using the sludge for animal feeding, it is rich in proteins and vitamins but also various chemicals can be present. The chemicals of greatest concern are heavy metals, chlorinated organics and pesticides. Pathogenic microorganisms are completely destroyed during thermophilic (aerobic or anaerobic) digestion.

4.2.1. Biomass from aerobic fermentation

The conversion of manure to an acceptable biomass or single cell protein (SCP) has been proposed on several occasions. Aerobic processes produce from 1 ton of manure (DM) about 500 kg of dry product (SCP and yeast) containing 50% crude protein (Muller, 1980). Aerobic solid-state fermentation was proposed for beef and swine waste (Weiner, 1977). The product was deficient in lysine and methionine. Another approach was the thermophilic treatment of poultry waste (Miller, 1975). Carbohydrates (ground wheat or molasses) were added to adjust the C:N ratio. Kargi et al. (1980) and Shuler (1979) proposed a two-stage or a continuous aerobic process to convert poultry waste, supplemented with molasses, to a highly nutritious product. The oven-dried product was incorporated in diets for broiler chicks (De Vries and Mulder, 1987). Birds were fed for 6 wk diets containing 0, 7.5 and 15% dried poultry sludge. No

adverse effects were found which could be attributed to the use of the sludge.

El-Deek et al. (1993) produced SCP from poultry manure. Poultry manure was mixed with water and inoculated with *Candida utilis*. After incubation for 6 days at 30°C the culture was dried and ground. Compared with the dried poultry manure, the fermentation product had high protein content (24.9 vs. 19.1%), and low NPN (8.7 vs. 9.6%) and uric acid content (0.3 vs. 7.2%)

4.2.2. Biomass from anaerobic fermentation

A batch process for fermentative conversion of feedlot manure filtrate into protein feed supplement for ruminants has been developed by Erdman and Reddy (1978). The process involves dilution of feedlot wastes with water (1:1), agitation and filtration. The filtrate is fortified with a carbohydrate source (in this case, cheese whey) and fermented under anaerobic conditions. The indigenous microflora inherited from the filtrate and whey is used as a productive microorganism. A constant pH is maintained by continuous addition of ammonia as a buffer to neutralize volatile fatty acids generated during the anaerobiosis. The best yields were obtained at pH 7 and 43°C, at a concentration of fermentable carbohydrates of 3.5-10.0%. The process yielded biomass rich in crude protein, of which however 60-70% was in the NPN form (ammonium salts or organic acids), while the residue consisted of microbial cells.

Moore and Anthony (1970) fermented cattle manure under anaerobic conditions for 3 days, and found a significant increase of protein, from an original 16.99% in fresh manure to 43.26% in fermented manure with a net increase of amino acids more than 20% on a DM basis. The level of volatile fatty acids indicated that during the anaerobic process a very intense synthesis of organic acids occurred resulting in a drop of pH from 6.25 to 4.00.

Prior et al. (1978) reported the development of a successful process for converting animal waste into methane and protein concentrate by thermophilic anaerobic fermentation and centrifugation. Protein level of the products were 31.5% (26.7% in organic protein) from fermenter effluent and 18.5% (14.8% in organic protein) from centrifuge cake, both on a DM basis.

The sludge from anaerobic digestion of poultry manure can be recovered and dried by the biogas heat to become a solid by-product (SBP). Typically, the SBP has 50% organic and 50% inorganic matter. It has about 18.75% crude protein, 10% true protein, 4% P, 3% K and 18% Ca. By feeding SBP as the sole source of P, it was determined that the P in SBP is 90% bioavailable for growing chicks. No toxicity or adverse effects were

detected in chicks when fed a 10% level of SBP in the diet. The liquid effluent put into a fish pond at a proper rate could support the growth of tilapia fish without additional feeding (Shih, 1988).

The feeding value of anaerobically digested pig manure (ADPM) was evaluated with broiler chicks. The composition of ADPM was shown to be 16.2% crude protein, 2.81% ether extract, 21.7% crude fiber, 15.7% ash, 8.12% acid-insoluble ash and 43.0% NFE. When the ADPM was used in the broiler diet replacing coconut oil cake and rice bran on an iso-nitrogenous basis, weight gain was improved with up to 15% inclusion of ADPM (Ravindran et al., 1987).

5. Manure as a fuel

The disposal of manure by direct use as a fertilizer or by landfill can, in some circumstances, have an adverse environmental impact. Waste-to-energy schemes which generate revenue from the energy produced and may provide fertilizer as a valuable byproduct offer an alternative and environmentally acceptable means of disposal. The energy value of manure depends on the composition of the litter and the moisture content. Samples of air dried broiler litter have 13.5 GJ/tonne (i.e. about half that of coal). Combustion produces an ash which retains most of the P and K present in the original litter; its N content is both small and variable, and its loss on combustion is considered advantageous. As the by-product is more concentrated, sterile and easier to handle, its transport costs are lower and it is therefore likely to enjoy a larger market than conventional poultry litter fertilizer (Dangall, 1993).

Nutritional Management to Reduce Pollution from Manure

A feeding strategy, i.e. nutritional management, is the beginning point in reducing environmental pollution from animal wastes. In the past, feeding program and diet formulations were aimed at maximizing production performance without special concern for nutrient oversupply. Environmental constraints now necessitate a close adjustment of nutrient supply to requirements so as to obtain the lowest level of nutrient excretion. There are measures that can be taken to reduce the amount of pollutants excreted by farm animals, particularly N and P in poultry and swine. Some feed additives can be used to control odour from manure. Minerals in special forms can be used at lower levels than those in inorganic forms, resulting in reduced excretion of minerals. The potential reductions in N and P pollution that could be achieved by

employing the various measures are shown in table 5.

TABLE 5. POTENTIAL EFFECTS OF NUTRITIONAL STRATEGIES TO REDUCE THE N AND P CONTENT OF MANURE

Factors	Estimated % reduction in manure	
	N	P
Supplements;		
Synthetic amino acids and reduced protein in feeds	20 - 25	
Enzymes - Cellulases	5	
Phytases		25 - 30
Growth promoting substances	5	5
Systems;		
Formulation closer to requirements	10 - 15	10 - 15
Phase feeding	10	10
Use of highly digestible feed ingredients	5	5

(Federation Européenne des Fabricants d'Adjuvants pour la Nutrition Animale, 1992)

The principles of nutritional management for the feeding of poultry and livestock to limit the impact of animal manure on the environment can be summarized as followings (Blair and Jacob, 1995):

- Use superior stock so that they grow fast and convert the dietary nutrients efficiently.
- Formulate diets as close as possible to requirements, and avoid excesses that will show up in the manure.
- Use highly digestible feeds.
- Keep the animals as healthy as possible and raise them according to approved management procedures.
- Use approved growth promoters.
- Maximize the inclusion of amino acids in diets to allow the dietary protein (N) to be minimized.
- Use supplemental enzymes in the feed to allow for better digestion of the nutrients (particularly P) and thus their reduction in the manure. Some enzymes also have the benefit of reducing the total amount of manure excreted.
- Phase-feed animals, i.e. use diets tailored to their stage of production. This avoids over-feeding and the excretion of unwanted nutrients in the manure.

A. Manure Output Reduction

Overall nutritional management can result in the reduction of manure output. A proven and more direct

method is enzyme supplementation. Reducing the DM content of the digesta in the intestinal tract with supplemental feed enzymes has a marked impact on excreta volume and composition. In a trial offering wheat or wheat/barley-based diets to broilers, fresh excreta weight was reduced 17-28%, resulting in a reduction in DM output of 12-15% (table 6). The direct production benefits of lower excreta output and reduced fecal DM are seen in some broiler trials where observations on the frequency of hock lesions and breast blisters are recorded. Reductions in manure output and water content will improve litter quality, and possibly decrease carcass downgrade.

TABLE 6. EXCRETA OUTPUT OF BROILERS FED WHEAT OR WHEAT/BARLEY-BASED DIETS WITH AND WITHOUT ENZYME SUPPLEMENTATION AT 19-21 DAYS OF AGE

	Wheat control	Wheat + Enzyme	Wheat/Barley control	Wheat/Barley + enzyme
Fresh excreta (g)	221	184	258	185
Excreta DM (%)	42.4	45.2	39.8	47.3
Dry excreta (g)	94.0	83.0	102	87.0

(Lakeside Research Center, Canada cited by Wyatt, 1995).

B. Nitrogen Control

Improving N utilization on livestock farms may reduce N pollution of soil, air and water and may reduce the requirement for external N inputs, making the farm more economically and environmentally sustainable. Calculation of N flow on two mixed farms showed that 17% (dairy and beef farm) to 22% (poultry and swine farm) of imported N (feed, livestock, fertilizer fixed N, seed N, N deposition) was exported as farm products (animal products and manure). Unrecovered N is lost via ammonia volatilization, denitrification and nitrate leaching which pollute air and water. Developed N cycling model showed that improving N utilization by animals (through changes in diet) will have the greatest influence on reducing the amount of N unaccounted for (unrecovered) in agriculture, and therefore reduce the risk of N pollution (Paul and Beauchamp, 1995).

1. Amino acid supplementation and protein restriction

1.1. Pigs

When trying to identify possible methods for reducing the level of N excretion by pigs it is important to understand where the excreted N comes from. Data

reviewed by Jacob (1995) indicate that of the total N consumed by a growing-finishing pig, about 20% is excreted in the feces and 50% in the urine. Fecal N is of three main forms: undigested dietary protein, microbial protein and endogenous protein. Up to 80% of fecal N in the pig is in the form of bacterial protein.

On the basis of the information obtained to date, the following methods can be identified as having potential for reducing N excretion:

- Meeting the animal need for amino acids without providing excesses (i.e. providing "ideal protein")
- Increasing protein digestibility
- Reducing endogenous N excretion

A one percentage unit reduction in total protein content of growing finishing diets is possible with the use of synthetic lysine and methionine. Such a reduction in dietary protein content can result in up to an 8.5% decrease in N excretion. With the use of synthetic threonine and tryptophan in addition to lysine and

methionine, it is possible to lower the crude protein level by two percentage units, thereby reducing N excretion by approximately 20%. Koch (1990) demonstrated that in pigs, by using a diet low in protein (11 vs. 13.9%) but supplemented with the most limiting four amino acids (lysine, methionine, threonine and tryptophan), there was no reduction in live-weight gain or feed conversion efficiency but N excretion was reduced by nearly 30%.

The amino acid requirements of a pig will change as it grows. This has led to the introduction of phase feeding. For example, the use of a grower diet from 45-70 kg live wt and a finishing diet from 70-106 kg instead of one growing-fattening diet from 45-106 kg results in a reduction in excretion of N. Multiphase feeding with weekly mixing of two feeds (17 and 13% crude protein) reduces N output by 10-20% compared with a two-phase feeding. Table 7 shows an example of the reduction of N excretion through protein restriction, amino acids supplementation and change of feedstuffs.

TABLE 7. OPTIONS IN FEEDING PROGRAM AND PROTEIN LEVEL (%) OF PIG DIETS AND N EXCRETION (kg/pig)

Feeds	Present situation, 1990	Protein restriction	Supplementation with 2-4 synthetic AAs ¹	Additional AAs plus selected feedstuffs
Starter feed	17.5	16.0	15.0	14.0
Grower feed	17.0	15.5	14.5	13.5
Finishing feed	16.0	14.5	13.5	12.5
Fattening feed	16.6	—	—	—
N excretion	4.5	3.9	3.5	3.1

¹ Amino acids

(Jongbloed and Lenis, 1992)

1.2. Poultry

Considerable work has been carried out to determine the levels to which dietary protein can be reduced without adverse effects on animal performance. The possibilities of reducing N excretion and environmental pollution from poultry by dietary supplementation with individual amino acids was reviewed by Leclercq and Tesseraud (1993). These authors calculated that poultry used feed protein with an overall efficiency approaching 45% but that the conversion by poultry of dietary protein to human consumable protein was in the order of 27%. They calculated that in theory, by the use of pure amino acids and reducing the protein content of a grower diet from 22 to 16%, it was possible to achieve a 72.2% efficiency of utilization of protein with a concurrent reduction in N excretion by a factor of 1.7. However, results of experiments indicated that it is difficult to achieve this level of improvement in practice.

Table 8 shows the effect of dietary protein and amino acid levels on nitrogen excretion of broiler during the grower phase (Jacob et al., 1994). Broilers fed the reduced protein diets (20.5% vs. 18%) with increased amino acid levels performed as well as, if not better than, the broilers on the control diets and showed a significant reduction in total N output. The N of the excreta was composed of urea/ammonia N (9.67%), uric acid N (61.05%) and residual N (29.27%). On a daily basis, the reductions of N excretion by lowering protein content were 22.8% for total N, 25.4% for uric acid N, 17.2% for urea/ammonia N and 18.2% for other N components.

A similar experiment with laying hens indicated that dietary protein can be reduced from 17 to 13.5% with no loss in egg production or egg quality, as long as essential amino acid levels are maintained (table 9). The reduction in dietary protein resulted in more than a 30% reduction in daily N output.

TABLE 8. THE EFFECT OF DIETARY PROTEIN AND AMINO ACID LEVELS ON THE GROWTH AND NITROGEN EXCRETION OF BROILERS DURING THE GROWER PHASE

Dietary protein (%)	Amino acid supplement	Final body weight (g)	Feed : Gain ratio	Total N in feces (% DM)	N Excreted (g / bird / day)
20.5	+ 10%	2,230	2.26	5.16	2.87
	Control	2,217	2.29	5.04	3.09
	- 10%	2,224	2.22	5.53	3.25
	Average	2,221	2.26	5.25	3.07
18.0	+ 10%	2,230	2.17	5.60	2.08
	Control	2,200	2.34	4.46	2.45
	- 10%	2,172	2.43	4.10	2.58
	Average	2,201	2.31	4.72	2.37

(Jacob et al., 1994).

TABLE 9. THE EFFECT OF DIETARY PROTEIN AND AMINO ACID LEVELS ON THE EGG PRODUCTION AND NITROGEN EXCRETION OF LAYING HENS

Dietary protein (%)	Amino acid supplement	Egg production (%)	Total N output (g/bird/day)
17.0	+ 10%	90.3	6.96
	Control	89.0	6.90
	- 10%	90.2	6.88
	Average	89.8	6.91
13.5	+ 10%	89.4	4.60
	Control	87.7	4.17
	- 10%	88.6	4.42
	Average	88.6	4.40

(Blair et al., 1995).

2. Enzymes

The digestibility of amino acids in the protein of the major components of pig and poultry diets can be enhanced by using supplemental feed enzymes such as carbohydrases and proteases. This will result in increased productivity of animals and decreased N excretion as well as overall reduction of the amount of excreta from animals.

2.1. Carbohydrase

Non-starch polysaccharides in some feed grains (e.g. pentosans or arabinoxylans in wheat and rye, and β -glucans in barley and oat) are soluble fibers. Their presence can either block digestion of other nutrients (e.g., protein and starch), or can seriously inhibit absorptive

capacity. It was found that the results of using enzymes (xylanase or β -glucanase) did not stem from complete hydrolysis of the non-starch polysaccharides but that relatively minor hydrolysis altered the ability of the medium to form a viscous solution and act as a barrier to endogenous enzyme activity. Low and Longland (1990) reported that N retention of pigs was slightly increased by enzyme supplementation.

In the past few years a number of different feed enzymes have been developed. The use of multi-enzyme preparations in traditional wheat-based diets was examined (Graham, 1992). The results demonstrated that with a diet based on 60% wheat, a mixed enzyme preparation was capable of increasing the rate of live-weight gain (+17%) and at the same time reducing feed conversion ratio (1.46 to 1.29). There was also an increase in the N utilization percentage (37.4 to 45.3%). Such improvements were attainable even after pelleting which in itself was capable of solubilizing starch (Pettersson et al., 1991). A commercial multi-enzyme preparation from *Trichoderma viride* contained 11,150 U/g cellulase, 27,600 U/g glucanase and 37,150 U/g xylanase. This multi-enzyme product was tested with layers fed a barley-based diet (Brufau et al., 1994) and a wheat-based diet (Paik et al., 1996). The results showed that barley and wheat can replace corn as an energy source in layer diets if the enzyme is properly supplemented.

For the better utilization of enzymes in feed industry, commercial enzyme preparations should be customized depending on the animal species, age of animals and major feed ingredients. Enzyme products which contain β -glucanase and xylanase in different proportion were produced from *Trichoderma longibrachiatum* and *Bacillus subtilis*. They were used with different diets (wheat-based

or barley-based) in different animal species of different ages (poultry, starting pigs or growing-finishing pigs). Enzyme products supplemented to the respective diets reduced the viscosity caused by non-starch polysaccharides and increased amino acid availability as well as energy and P availability (Creswell, 1994).

Contents of moisture and N were lower in the litter of birds given diets supplemented with β -glucanase. Measurement of ammonia release from the litter indicated that when a second flock of birds was raised on the same litter, the presence of a glucanase in the diet reduced the level of ammonia release by 80% (Williams and Kelly, 1994).

An experiment was conducted to test the possible interaction of an enzyme complex and feed antibiotics on growth and metabolic parameters of broilers. The basal diet contained barley at a level of 40%. Both supplements, when added together in the diet, had almost an additive effect on growth parameters, and energy, fat and N utilization (Vukic Vranjes and Wenk, 1993).

2.2. Protease

Proteases of bacterial origin have been shown to be effective in increasing digestibility of energy and crude protein and amino acids of potatoes in pigs. A combination of a protease with α -amylase significantly improved the digestibility of lysine and of methionine (Jost et al., 1993). A fungal protease was added to the broiler diet containing bitter lupin (*L. mutabilis tarwi*). The alkaloids in the lupin did not impair digestibility or metabolizability of energy and N in the feed. The addition of protease did not improve the performance but had a slightly positive effect on the utilization of the N in the diet (Pfirter et al., 1993). Feathers are composed almost exclusively of a protein termed keratin. Keratin is particularly resistant to the digestive process of the alimentary canal, largely due to the presence in the protein of covalent chemical bonds termed disulphide bonds, which stabilize the molecular structure. Pathogenic fungi have been the source of most of the enzymes that break down keratin. Regulatory agencies have prohibited the large-scale propagation of these fungi. However, a recent breakthrough in feather digestion has been the development of a pre-treatment that breaks the disulphide bond thereby exposing the protein. A neutral protease is then added at a relatively low level (0.1% for 4 h) to bring about total solubilization of feathers (Lyons and Walsh, 1993).

3. Growth promoters

Growth-promoting compounds, such as antibiotics, β -

agonists and recombinant somatotropin, increase the ability of the animal to utilize the available dietary protein. Some of the growth-promoting antibiotics have a protein-sparing effect which results in reduced excretion of total nitrogen.

The effects of different anabolic agents on N excretion are shown in table 10. The use of β -agonists and recombinant somatotropin induces an increase in muscle growth which increases both N retention and growth rate. These two complementary responses have differing levels of effect on N excretion. Increased N retention by the animal results in approximately 5% reduction of N excretion. The major response in pigs treated with porcine somatotropin (PST) is increased growth rate and reduced time to slaughter: both feed intake and maintenance N contribution are reduced, resulting in over 30% reduction in N excretion. The use of bovine somatotropin (BST) to increase milk yield in the dairy cow has a similar beneficial environmental impact. Whilst overall N excretion is increased in BST-treated cows, as a result of the increased feed intake, the N excretion per liter of milk is reduced by 15%. Under a quota situation this would result in an overall decrease in N excretion.

TABLE 10. EFFECTS OF ANABOLIC AGENTS ON NITROGEN EXCRETION OF LIVESTOCK

Anabolic agents	Animal species	Reduction of N Excretion (%)
Beta-agonist (Clenbuterol)	Pigs, 60-105 kg	14
rPST	Pigs, 48- 84 kg	32
rPST	Pigs, 65-102 kg	35
β -agonist	Cattle (bull)	7.4
β -agonist	Calves	7.0
rBST	Dairy cows	15

(Williams, 1995).

4. Others

Factors which are thought to increase endogenous nitrogen secretion, and thus decrease protein utilization, include various fiber sources, trypsin inhibitors, tannins and lectins. They are known as antinutritional factors. Some of these factors can be reduced or eliminated from diet by avoiding the use of particular feedstuffs. Some can also be destroyed by various feed treatments or enzyme supplementations.

C. Phosphorus control

Feedstuffs of plant origin contain adequate levels of P but about two thirds of it is in the form of phytate-P

(myoinositol hexabiphosphate) which has a low availability in non-ruminant animals. This low availability is due to the absence of phytase in the gastrointestinal tract of non-ruminant animals.

1. Enzymes (Phytase) supplementation and phosphorus restriction

Phytase is an example of a specific enzyme which is used to target phytate to release free phosphorus with excellent results in pigs and broiles (Simons et al., 1990; Keteran et al., 1992). There are several options available for increasing the phytase activity of diets-either the diet can be supplemented with phytase-rich cereals, or phytase of microbial sources can be added.

Plant phytase activity, especially that of wheat, has been known for some considerable time. Seed phytase activity varies greatly from one species to another. In fact, few dormant seeds contain phytase activity, except for wheat and rye and their hybrid, triticale (table 11).

To date, experiments on the effects of phytase have been carried out using a microbial form of phytase supplied by either *Aspergillus ficuum* (Simmons et al., 1990; Nasi, 1990) or *Aspergillus niger* (Beers and Jongbloed, 1992). A problem with this preparation has been the sensitivity of the organism and the enzyme to temperature and hence the loss of activity above 80°C, a temperature often experienced during the process of feed

pelleting. An interesting development which may herald a new era in the use of enzymes in animal feed was recently reported when the gene coding for phytase activity in *Aspergillus niger* was engineered into tobacco seeds. The enzyme was expressed as 1% of the soluble protein in mature seeds. Supplementation of broiler diets with transgenic seeds resulted in an improved growth rate, comparable to diets supplemented with fungal phytase or P (Pen et al., 1993).

1.1. Pigs

Cereals that contain phytase such as wheat, triticale, rye or their by-products, result in better phytate utilization when included in pig diets. Pointillart et al. (1993) designed diets which contained decreasing amounts of inorganic P and increasing dietary phytase activity by altering the dietary proportions of wheat, wheat by-products (bran and shorts), and rye bran. The proportion of inorganic P in the diet ranged from 0 to 0.3%. There was no effect on pig performance in the period to slaughter and no effect on bone density or strength at slaughter in pigs given the diet with low inorganic P supplemented with cereals containing phytase compared with the pigs given a standard diet supplemented with inorganic P. Pigs fed diets with and without added phytase commencing at 25 kg live weight showed that supplementation with phytase resulted in significant improvements in growth performance only at the lower levels of available P (Williams and Kelly, 1994). In an experiment to establish the P equivalency of *Aspergillus-niger*-phytase in pigs, digestibility of P increased up to approximately 1,000 U/kg, with no further significant response beyond 1,000 U/kg. The mean P-equivalency calculated from various sources, using treatments with phytase activity up to 500 U/kg, was $432 \pm 169 \text{ U} = 1 \text{ g P}$ (Hoppe and Schwarz, 1993). In several experiments conducted with growing pigs of 11-70 kg, microbial phytase supplementation at a level of 800-1,550 U/kg diet improved bioavailability of P and Ca by 22-56% and 10-16%, respectively (Soares and Hughes, 1995).

With phytase supplementation of the diets, growing-finishing pigs and pregnant sows may need little or no supplementary inorganic phosphate. By using phytase supplementation researchers have achieved the same performance as with a control feed while reducing P excretion by 30%. The use of phytase in liquid feeding systems for pigs appears to be particularly interesting, because phytase may already be liberating phytate P as soon as the feed has been mixed. As with N, phase feeding can result in a reduction in P excretion. The use of a grower diet from 45-70 kg and a finishing diet from

TABLE 11. PHYTATE PHOSPHORUS AND PHYTASE ACTIVITY IN THE MAJOR COMPONENTS OF ANIMAL FEEDS

Ingredients	Phytic P (g/kg)	Phytic P, % of total P	Phytase activity (U/kg)
Wheat	1.7 - 2.5	60 - 77	700 ± 100
Maize	1.7 - 2.2	66 - 85	n
Oats	1.9 - 2.3	55 - 63	n
Barley	1.9 - 2.5	51 - 66	400 ± 200
Triticale	2.5 - 2.6	65 - 68	1,500 ± 170
Rye	2.2 - 2.5	61 - 73	4,900 ± 620
Sorghum	1.8 - 2.2	60 - 74	-
Peas	1.2 - 1.7	40 - 50	n
Wheat bran	8.1 - 9.7	70 - 90	1,200 ± 150
Wheat shorts	4.7 - 5.8	66 - 85	1,900 ± 140
Rye bran	7.6	71	6,300 ± 1,100
Soybean meal	3.2 - 3.8	51 - 61	n
Rapeseed meal	6.0 - 7.3	60 - 73	n
Sunflower meal	6.2 - 9.2	73 - 80	n
Peanuts meal	3.2 - 4.3	47 - 69	n

(Pointillart, 1993).

70-106 kg instead of one fattening diet from 45-106 kg results in a 6% reduction in excretion of P.

Table 12 shows an example of the reduction of P excretion through different options.

TABLE 12. OPTIONS IN FEEDING PROGRAM AND P LEVEL OF PIG DIETS AND P EXCRETION

Feeds	Situation in 1990	Phosphorus restriction	Phytase supplementation	Phytase + P restr. + selected feedstuffs
Starter feed (%)	0.60	0.58	0.47	0.40
Grower feed (%)	0.50	0.46	0.44	0.40
Finishing feed (%)	0.46	0.42	0.40	0.35
Fattening feed (%)	0.50	—	—	—
P excretion (kg/pig)	0.83	0.70	0.60	0.49

(Jongbloed and Lenis, 1992).

Although the use of phytase is targeted specifically at the availability of P, the presence of the enzyme can have effects on the digestibility of other dietary components. Nitrogen digestibility was significantly higher in pigs receiving diets supplemented with phytase but without inorganic P supplementation (Nasi, 1990). A number of other investigations have indicated that there is often strong binding between phytic acid and protein. The effects of phytase on protein and amino acid digestibility may indicate that phytate-protein binding were to some extent cleaved by phytase activity or that the inhibitory activity of phytic acid on trypsin and pepsin was diminished. It was also suggested that the digestibility of a number of other mineral components, such as Ca and Mg, may be improved by the addition of phytase.

The presence of Ca and Vitamin D in the diet strongly interact with P utilization and may affect phytate-P utilization in weanling pigs (Lei et al., 1994) as well as chicks (Edwards, 1993). A normal level of Ca in the pig diet greatly reduced the efficacy of supplemental phytase. Raising vitamin D in the diet partially offset this effect but did not produce the further improvement when the Ca level was low. The introduction of high levels of vitamin D into the diet may enhance Ca absorption thereby removing the possible Ca-phytate interaction in the gut and resulting in improved phytate P availability.

The interaction between a phytase and a carbohydrase in relation to the digestibility of nutrients and the growth performance of individually kept growing pigs were investigated. The results showed that the combination of the carbohydrase with the phytase was not favorable concerning growth performance and digestibility of nutrients. Possibly a negative interaction between the two enzyme mixtures existed. It seemed that the carbohydrase reduced the analyzed phytase activity in the diets (Wenk et al., 1993).

1.2. Poultry

In broiler chickens, phytase supplementation at a level of 1,000 U/kg diet increased the bioavailability of P and Ca by 60% and 26%, respectively (Simons et al., 1990). The beneficial effects of phytase supplementation were illustrated by Zyla and Korelski (1993). The performance of birds fed available P deficient diets was improved by the addition of phytase to the diets. The *in vitro* activity (i.e. ability to dephosphorylate phytate) was also demonstrated, confirming the proposed mode of action of this enzyme. The direct benefits of dietary phytase supplementation on bone mineralization have been shown by Farrel and Martin (cited by Annison and Choct, 1993) who reported that tibial ash deposition was enhanced in birds fed phytase supplemented diets. Simons and Versteegh (1993) summarized the results of several experiments conducted in Netherlands. A microbial phytase product from *Aspergillus niger* was added to broiler feed with a low inorganic P level. The availability of total P could be increased up to 70%. In comparison with feed with increased levels of inorganic feed phosphates, a significantly larger amount of the P consumed was absorbed. Improved utilization of P decreased its excretion by 40% or more. Growth and feed conversion ratios were comparable with feed to which inorganic feed phosphate was added. In layers the degradation of phytate and the absorption of P was slightly decreased by higher amounts of Ca in the diets (4.0% vs. 3.0% Ca in feed), nevertheless at both levels the efficacy of phytase addition was satisfactory. In broilers up to 500 units of phytase per kg feed, 250 units phytase was equivalent for P absorption with 0.5 g monocalcium phosphorus (MCP) P per kg feed. Addition of up to 300 units phytase per kg feed for laying hens resulted in a minimal equivalency of 0.3 g MCP P per 100 units phytase.

In a feeding trial with laying hens the effectiveness of microbial phytase in diets based on corn-soya and wheat-soya was tested (Peter and Jeroch, 1993). The supplement of phytase (500 U/kg diet) or inorganic P (0.1% of diet) had a positive effect on the performance of the corn-soya group but no effect on that of the wheat-soya group. The highest breaking strength of the egg shell was recorded with hens that received the phytase supplement in the corn-soya group. Mineralization of the tibia bone was also improved with phytase addition. Provided phytate P content and plant phytase activity are taken into account, it should be possible to mix phytase supplemented layer diets which do not require additional inorganic P sources.

Although microbial phytases have shown an ability to enhance P availability in many varied situations, several technical problems still exist that prevent the universal application of such enzymes. These include instability to gastric pH and a severe loss in activity at elevated, present day processing temperatures. Such difficulties present a challenge to producers of microbial phytases, which the tools of biotechnology can address (Power, 1993).

D. Control of other nutrients

When the levels of N and P have been reduced in animal manure, potassium (K) may become the factor limiting the amount of manure that can be spread on the land. There is very little research to date, however, on the possibilities of reducing the K content of animal manure.

Some micromineral supplements are produced in the form of protected forms. Metal amino acid chelate (Ashmead, 1992), metal proteinate and metal polysaccharide complex are protected minerals. The protected minerals may be more available and not react with digesta due to both their chemical (electrically neutral, ligand and metal make up) and physical structures (size and ligand source). If this is the case, we could use less to achieve the same result. This would be excellent as potentially it would save world resources and reduce pollution (Lowe, 1993).

High levels of copper sulphate have been widely used as growth promotants in pigs and broilers. Copper polysaccharide complex (sequestered Cu) at a level of 62.5 ppm of Cu was as effective as 200 ppm Cu in the form of copper sulphate in weanling pigs and broilers (Paik and Kim, 1993). The performance enhancing effect of methionine-Cu complex at a level of 100 ppm Cu was greater than that of copper sulphate at a level of 200 ppm Cu in broilers. The excretion of copper was significantly less in the methionine-Cu treatment than in the copper sulphate treatment (Min et al., 1993, 1994).

E. Odour control

Ammonia release from animal manure should be controlled to avoid air pollution and conserve N in the manure for use as fertilizer. The smell of pig slurry has four times the intensity of cattle, broiler and poultry manure (Pain, 1990). In terms of odour control, ammonia reduction may only play a contributory role since Schaefer (1977) correlated odour intensity with the concentrations of volatile fatty acids (C_2-C_5), phenol, *p*-cresol, indole, skatole and ammonia, the highest correlations were obtained with *p*-cresol. Conservation of N in manure is important because P or K usually limit use of poultry manure for crop production and other sources of N are needed when the manure application is limited to needs for fertilizer elements. Ammonia release from manure can be limited by using additives, by drying and by acidic conditions.

Research into minimizing air pollution from animal waste is continuing and taking many different paths. In the Netherlands, for example, they have identified a microorganism (aerobic denitrifier) which, under aerobic conditions, converts the nitrogen of ammonia and other nitrogen containing compounds into nitrogen gas. Nitrogen gas can be released into the atmosphere without causing pollution problems. Adding such bacteria to manure would reduce the emission of ammonia and reduce the nitrogen content of the manure. They are looking at the possibility of adding these bacteria to the feed (Holthuijzen, 1993).

The ammonia-binding properties of the *Yucca* extract have been widely studied. The earlier reports on the action of a *Yucca* extract to prevent the accumulation of ammonia erroneously attributed its action to an inhibition of urease by its component three steroid saponins, i.e. sarsapogenin, smilagenin and hecogenin. But Headon et al. (1991) reported that the *Yucca* extract does not inhibit urease activity and that saponin-free De-Odorase had an ammonia-binding capacity similar to that of the unfractionated De-Odorase. Recent work by Headon and Power (unpublished, cited by Leek, 1993) demonstrated that the binding agents in the *Yucca* extract are glycoconponents. Because the ammonia-binding action starts to decline slowly from fourth day onwards, atmospheric ammonia levels within the houses can be significantly reduced by including this product in the diet.

Zeolite products have been used at a level of 1 to 2% of the diet to improve pelleting quality. It is also believed that zeolite may improve the litter condition and environment of the barn. Due to a high ion-exchange capacity, it is expected that zeolite may bind ammonium ion in the litter (Moon et al., 1991). However, dietary

supplementation of zeolite or top dressing of zeolite on the broiler litter did not significantly influence the level of ammonia produced from the broiler litter (Blair and Jacob, unpublished).

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