Nutrient Recycling : The North American Experience* - Review -

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ABSTRACT : Options available for utilization of animal wastes include sources of plant nutrients, feed ingredients for farm animals, substrate for methane generation, and substrate for microbial and insect protein synthesis. The wastes have the most economic value for use as animal feed. Performance of animals fed diets containing animal wastes is similar to that of animals fed conventional diets. Processing of animal wastes to be used as animal feed is necessary for destruction of pathogens, improvement of handling and storage characteristics, and maintenance or enhancement of palatability. Feeding of animal waste has not adversely affected the quality and taste of animal products. In the USA copper toxicity has been reported in sheep fed high-copper poultry litter, but this is not a serious problem with cattle. Potential pathogenic microorganisms in animal wastes are destroyed by processing such as heat treatment, ensiling and deep stacking. Incidents of botulism, caused by *Clostridium botulinum*, have been reported in cattle in some countries, and this problem was caused by the presence of poultry carcasses in litter. This problem has not occurred in the USA. With appropriate withdrawal, heavy metal, pesticide or medicinal drug accumulation in edible tissues of animals fed animal wastes is not a problem. Feeding of animal wastes is regulated by individual states in the USA. The practice is regulated in Canada, also. With good management, animal wastes can be used safely as animal feed. (*Asian-Aus. J. Anim. Sci. 1999. Vol. 12, No. 4 : 642-650*)

Key Words : Animal Waste, Feeding, Recycling, Safety, Processing

INTRODUCTION

In North America animal wastes were regarded as valuable sources of plant nutrients in the early part of this century and were used extensively as fertilizer. Following the introduction of intensive confinement systems during the past 40 to 50 years the wastes became a liability rather than an asset. The change was due to availability of low-cost commercial fertilizers and the high cost of handling and transporting the wastes. The wastes were identified as a concern in control of water, soil and air pollution (Freeman and Bennett, 1969). Estimates vary concerning the amounts of animal waste produced annually, but the amount is substantial. In the U.S. over 100 million tons of animal waste dry matter are produced per year (Fontenot and Ross, 1980). About 50% of the wastes are collectable, and in some enterprises such as poultry, virtually all of the wastes are collectable.

Recycling of animal wastes refers to making further use of the nutrients in the wastes. Options available for recycling the nutrients in animal wastes include: 1) sources of plant nutrients, 2) feed ingredients for farm animals, 3) substrate for methane generation, and 4) substrate for microbial and insect protein synthesis. Although it is technically feasible to use animal wastes to produce microbial and insect protein, in North America the practice is not economically feasible (Calvert, 1979). Likewise, methane generation from animal wastes is technically feasible (Fontenot and Ross, 1980), but the wastes possess low monetary value for this purpose. Thus, the most feasible methods of recycling animal wastes in North America are as sources of nutrients for plants and animals.

Renewed interest has been shown in the use of animal wastes as fertilizer because of the increased cost of fossil fuel used in manufacturing fertilizer. However, although collection of wastes from large concentrated animal production enterprises is possible, in some areas of concentrated animal production use of all of the wastes as fertilizer may not be possible due to insufficient land area in close proximity to the enterprises. Application of excessive amounts may contaminate water supplies and may even decrease crop yields (Mathers and Stewart, 1971). Nevertheless, under some situations recycling of animal wastes for use as fertilizer may be economically feasible, especially if the wastes do not need to be transported for long distances.

Over 75 yr ago the value of animal wastes was recognized as a source of vitamins when it was observed that feces of normal rats contained "fat soluble A and water soluble B" (McCollum, 1922). Due to the high fiber and non-protein nitrogen content of the wastes, ruminants are best suited for utilization of the wastes. Reviews on feeding animal wastes include those prepared by Bhattacharya and Taylor (1975), Smith and Wheeler (1979), Fontenot et al. (1983) and Fontenot (1991). Reviews concerning health aspects of feeding animal wastes were published by Fontenot and Webb (1975) and McCaskey and Anthony (1979).

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NUTRITIONAL VALUE OF ANIMAL WASTES

Nutritional value of wastes produced by animals in confinement is given in table 1. Miron et al. (1990) reported higher values for digestibility of organic matter (64%) in poultry litter than the TDN values (60%) reported by Bhattacharya and Taylor (1975). Poultry wastes are higher in crude protein and available energy than other animal wastes. All of the wastes are good sources of phosphorus. Calcium is especially high in caged layer waste. Macro- and micromineral contents usually reflect levels in the diet. The amount of bedding used in broiler houses affects the composition of litter, especially crude protein and fiber. In Alabama, crude protein, dry matter basis, of broiler litter averaged 25% (Ruffin and McCaskey, 1990), compared to 30% in Virginia (Fontenot et al., 1971), apparently due to a difference in quantity of bedding, which was reflected in differences in fiber levels. In Mexico broiler litter contained 30.7% crude protein (Morales-Trevino et al., 1997). *In vitro* organic matter digestibility averaged 71.4%.

Table 1. Nutritional value[a] of animal wastes

Item	Kind of waste				
	Broiler[b]	Dehydrated caged layer waste[b]	Steer waste[b]	Cow waste[b]	Swine waste[c]
Crude protein, %	31.3	28	20.3	12.7	23.5
True protein, %	16.7	11.3		12.5	15.6
Dig. protein, %	23.3	14.4	4.7	3.2	
Crude fiber, %	16.8	12.7			14.8
Ether extract, %	3.3	2		2.5	8.0
NFE, %	29.5	28.7		29.5	38.3
Dig. energy, kcal/g	2440[d]	1884[d]			2134[e]
Metab. energy, kcal/g	2181[d]				2088[e]
TDN,%d	59.8	52.3	48	45	
Ash,%	15.0	28	11.5	16.1	15.3
Calcium, %	2.4	8.8	0.87		2.72
Phosphorus, %	1.8	2.5	1.60		2.13
Magnesium, %	0.44	0.67	0.40		0.93
Sodium, %	0.54	0.94			
Potassium, %	1.78	2.33	0.50		1.34
Iron, ppm	451	2000	1340		
Copper, ppm	98	150	31		63
Manganese, ppm	225	406	147		
Zinc, ppm	235	463	242		530

[a] Dry matter basis.
[b] Adapted from Bhattacharya and Taylor (1975).
[c] Adapted from Kornegay et al. (1977).
[d] For ruminants.
[e] For swine.

Performance of ruminants fed different levels of animal wastes was summarized by Smith and Wheeler (1979). Feeding diets containing an average of 24% poultry litter (dry matter basis) to beef cattle resulted in a 5% depression in rate of gain and 10% increase in feed dry matter per kilogram gain, probably reflecting the lower energy value of litter than of the portion of the diet that was replaced. Morales-Trevino et al. (1997) reported that daily gain and feed conversion were not affected by including up to 30% broiler litter in the diet of Holstein bulls. Daily gains were 1.07 and 1.10 kg, respectively, for control and experimental cattle fed caged layer waste (Smith and Wheeler, 1979). Respective feed to gain ratios were 7.25 and 6.49. Brosh et al. (1993) reported similar liveweight gains before and after calving for beef cows fed 15, 30 or 45% poultry litter, dry matter basis.

Milk production was similar for dairy cows fed 0 or 12% caged layer waste (dry matter basis) (Smith and Wheeler, 1979). Arave et al. (1990) reported that feeding lactating dairy cows up to 17% poultry excreta had no effect on dry matter intake, fat-corrected milk yield or milk fat.

The inclusion of 12% cattle waste, dry matter basis, did not substantially affect daily gain in cattle (1.16 kg for controls vs. 1.14 kg for waste fed) (Smith and Wheeler, 1979). Average feed dry matter per unit of gain was slightly higher for the cattle fed cattle waste, indicating that cattle wastes are lower in energy value than the traditional components of the diet. Treating cattle waste with sodium hydroxide, calcium hypochlorite, or sodium chlorite resulted in increased dry matter digestibility of the waste (Smith et al., 1971; Lucas et al., 1975). Poultry do not utilize fiber and nonprotein nitrogen efficiently. The metabolizable energy (ME) content of dried poultry wastes for layers was reported to be only 6% of that for corn (Rinehart et al., 1973). Digestibility of energy of swine feces by swine was 46.7% (Kornegay et al., 1977).

PROCESSING ANIMAL WASTES

Processing is necessary for destruction of pathogens, improvement of storage and handling characteristics, and maintenance or enhancement of palatability (CAST, 1978). Processes that have been used include dehydration, pelleting, ensiling alone or with other ingredients, deep stacking, and composting.

Dehydration

Heat drying has been used to process poultry wastes (Fontenot and Ross, 1980). The resultant product has good keeping qualities but is rather dusty. Pelleting would be helpful in alleviating this problem. Heat drying may result in loss of nitrogen, at least with poultry wastes, but acidifying the waste before drying was shown to decrease the nitrogen loss (Harmon et al., 1974).

Ensiling

Ensiling animal wastes alone or in combination with other ingredients has been successful. Good silage was made by mixing corn forage and broiler litter (Harmon et al., 1975a). For good ensiling the level of waste should probably not exceed 30% of the dry matter. Feeding this kind of silage has resulted in efficient nitrogen utilization in sheep (Harmon et al., 1975b)and performance in finishing cattle was similar to that of cattle fed corn silage plus conventional protein supplement (McClure and Fontenot, 1985). Poultry litter can be ensiled alone, and the moisture level should be about 40% for good ensiling (Caswell et al., 1978). Satisfactory ensiling was achieved with a mixture of broiler litter and rumen contents (Chaudhry, 1990). The final pH value was 5.6. Dry matter digestibility was similar for diets containing broiler litter ensiled alone, with molasses or rumen contents (Chaudhry et al., 1996).

Caged layer waste has been successfully ensiled with hay (Saylor and Long, 1974), sugarcane bagasse (Samuels et al., 1980), corn stover (Moriba et al., 1982), corn forage (Goering and Smith, 1977), and sorghum forage (Richter and Kalmbacher, 1980).

Deep stacking

Deep stacking is used commonly to process poultry litter. The litter is stacked at a depth of a minimum of 1.5 meters, in a building with ample ventilation. Maximum temperature is reached after a few days, after which the temperature in the stack gradually decreases until it reaches ambient temperature. In an early experiment maximum temperature of 50°C was reached 4 to 8 days after deep-stacking broiler litter to a depth of 1.2 meters (Hovatter et al., 1979). The maximum temperature appears to be related to moisture level. The highest temperature recorded for litter deep stacked at 15% moisture was 57.5°C, compared to 61.2° and 60.2°C for litter deep stacked at 25 and 35% moisture, respectively (Chaudhry, 1990). Increasing the moisture above 35% appeared to result in lower maximum temperatures (Abdelmawla, 1990). Highest temperatures at 46 cm from the top of 1.2 meter stacks were 65.9°, 63.9° and 62.8°C, for litter stacked at 35, 40, and 45% moisture, respectively. Chaudhry et al. (1996) reported lower apparent digestibility of organic matter and crude protein by sheep fed diets containing deep-stacked broiler litter than for those fed diets containing ensiled broiler litter. Nitrogen utilization was similar for ruminants fed poultry litter ensiled or deep stacked (Abdelmawla et al., 1988). Performance was similar for finishing cattle fed ensiled broiler litter-corn forage or ensiled corn forage and deep-stacked broiler litter (McClure and Fontenot, 1985).

Excessive heating may occur during deep stacking, resulting in a dark, charred-appearing litter, which may reduce dry matter digestibility (Ruffin and McCaskey, 1990). Evidence was obtained that the nitrogen in "charred" litter from a stack exposed to the weather was less soluble and lower in rumen degradability than normal deep-stacked litter (Kwak, 1990). When charred litter was fed to sheep, apparent digestibilities of dry matter, acid detergent fiber, and crude protein were lower than for sheep fed normal deep-stacked litter from the same stack (G. A. Bargahit and J. P. Fontenot, unpublished). However, no significant difference was obtained in nitrogen retention. Covering the stack with polyethylene resulted in lower temperature in the stack (Rankins et al., 1993).

Composting

This process involves initial stacking of the wastes and mixing to enhance aerobic fermentation. Composting is described as the "rapid but partial decomposition of most solid organic matter by the use of aerobic microorganisms under controlled conditions" (Anonymous, 1970). This process has been used to process animal wastes for land application, but animal wastes may be composted for use as animal feed (CAST, 1978). Considerable loss of nitrogen may occur during composting. Composting litter by stacking, mixing after 2 days, then at weekly intervals for 6 weeks resulted in a 15% decrease in crude protein concentration (Abdelmawla et al., 1988). Apparent digestibilities of dry matter and crude protein, and nitrogen utilization were similar for sheep fed composted litter and deep-stacked litter.

QUALITY OF ANIMAL PRODUCTS

In an early experiment, Fontenot et al. (1966) found that feeding broiler litter to finishing beef steers did not adversely affect carcass quality or taste of the meat. In a subsequent experiment cattle were fed mixtures with 25 or 40% broiler litter with different litter materials (peanut hulls, corn cobs, grass hay, soybean hulls). Carcass grades and dressing percentages were similar for these cattle as for those fed a control diet. Carcass quality was evaluated in an experiment in which cattle were fed diets containing 0, 25 and 50% broiler litter (Fontenot et al., 1971). Carcasses graded USDA low choice for the cattle fed the different levels of litter. Percent fat was lower for cattle fed 50% broiler litter, a reflection of lower rate of gain. Dripping losses were lower for the meat from these cattle, probably due to lower fat content. In taste (organoleptic) tests no differences were detected by a taste panel. Cross et al. (1978) reported no differences in carcass grade, marbling, ribeye muscle area or back fat in steers fed diets with 0 to 50% broiler-litter silage, dry matter basis. No significant differences were recorded by a taste panel in tenderness, juiciness and flavor of the meat.

Bull and Reid (1971) reported that feeding up to 4.1 kg dried caged layer waste had no adverse effect on milk composition or flavor. Silva et al. (1976) reported that feed flavor in milk was less in milk from cows fed 30% dried layer waste than in milk from cows fed no waste. Overall flavor quality scores were similar for milk from cows fed 0, 10, 20 or 30% poultry waste. Flavor of milk from dairy cows fed a diet containing dried layer waste was similar to that of cows fed diets not containing waste (Thomas et al., 1972). Arave et al. (1990) reported no adverse effect of feeding up to 17% processed poultry litter to dairy cows on milk flavor. Milk odor, color and taste were not adversely affected in ewes fed poultry litter (Muwalla et al., 1995). In fact, only two of 14 taste panel members scored milk from ewes fed poultry litter as unacceptable, compared to 8 of 14 for milk from control-fed ewes.

Flegal and Zindel (1971) reported that egg weight and shell thickness were not adversely affected by feeding diets containing up to 40% dried poultry waste to laying hens. A taste panel did not detect differences in taste of eggs from hens fed diets containing 0, 10, 20 and 30% dried poultry waste. Trends for lower percentage of large eggs (63.6 vs. 60.3%) and for lower Haugh units (83.4 vs. 82.1) were reported for hens fed a diet containing 25% dried poultry wastes (Biely et al., 1972).

SAFETY OF FEEDING ANIMAL WASTES

Toxicity

Copper toxicity has been documented in sheep fed broiler litter with high Cu levels (Fontenot and Webb, 1975). The litter, which was fed at levels of 25 and 50% of the diet, contained 195 ppm copper, resulting from feeding high levels of copper to chicks. The first fatality occurred after 137 days on test. At the end of 254 days 64% of the ewes fed the higher level of litter and 55% of those fed 25% litter had died. Suttle et al. (1978) reported elevated copper levels in livers of lambs fed dried battery or broiler waste, but no signs of toxicity were observed. Feeding molybdenum and sulfate may help in preventing the copper toxicity problem with sheep. Copper accumulation in the liver of ewes fed poultry litter was decreased by about 50% from feeding 25 ppm molybdenum and 5 g sulfate per kilogram of diet (Olson et al., 1984).

The problem would not be as severe in cattle since they are not as sensitive to high dietary Cu. In the USA a few cases of copper toxicity have been reported on farms where poultry litter was fed. Copper toxicity was reported in a herd of Holstein cows fed broiler litter containing 620 ppm copper and in crossbred steers fed litter containing 685 to 920 ppm copper (Banton et al., 1987). In a controlled experiment, beef females were fed diets containing high levels of broiler litter with high copper levels with or without additional copper during the winter period for 7 yr with no deleterious effects (Webb et al., 1980). Liver copper was increased in the spring in cows fed high-copper diets, but the levels decreased in the fall after the grazing season. The cows were not fed litter on pasture (7 to 8 mo). Rankins et al. (1993) reported increased liver copper in cattle fed high-copper litter for 84 days, but they did not report any clinical signs of copper toxicity. Practicing veterinarians have reported a limited number of cases of copper toxicity in cattle fed poultry litter (Pugh et al., 1994b), but most veterinarians did not observe such toxicities.

In Israel, cardiomyopathy was observed in cattle fed litter from broilers fed the coccidiostat, maduramycin (Shlosberg et al., 1992). The coccidiostat is frequently found in higher concentrations in litter than in the original feed, whereas monensin concentration in litter may be up to 25% of the concentration in the original feed. Other coccidiostats are available which are effective for poultry.

Hypocalcemia in beef cows has been reported on farms when broiler litter was fed (Ruffin et al., 1994). In research in beef cows, feeding high levels of broiler litter resulted in decreased blood serum calcium, but no physical signs of milk fever were seen (Pugh et al., 1994a). Pregnant beef cows were fed 8 kg of a mixture of 80% broiler litter and 20% corn plus a small amount of long hay (Wright, 1996). A sharp drop in serum calcium occurred, but there were no physical signs of milk fever. Thus, although feeding of litter has been associated with sporadic cases of milk fever, the disturbance has not occurred under controlled feeding conditions.

Pathogenic bacteria

Poultry wastes are potential sources of pathogenic microorganisms. However, a recent report in which 86 samples of poultry litter obtained in Georgia (USA) were analyzed for the presence of pathogens indicates that the presence of pathogenic microorganisms is not a serious problem (Martin et al., 1997). No *Salmonella* or *E. coli* 0157/H7 was isolated from any of the 86 samples. They concluded that poultry litter does not appear to be a source of harmful microorganisms when fed to beef cattle.

Heat processing destroys potential pathogens (Fontenot and Webb, 1975). Proper ensiling of animal wastes also appears to be effective in destroying pathogens (McCaskey and Anthony, 1979). It appears that a pH of 4 to 4.5 and a temperature of over 25°C are important for destruction of *Salmonella*. Apparently, due to the ammonia and minerals in poultry wastes it is rather difficult to reach a pH of less than 5 without additional materials such as whole plant corn forage. However, ensiling of broiler litter with added water has been shown to destroy coliforms even when the pH did not go below 5.4 (Caswell et al., 1978). Deep stacking has been shown to destroy coliforms (Hovatter et al., 1979; Chaudhry et al., 1996) and *Salmonella* (Chaudhry et al., 1996).

The potential risks of clostridia in ensiled waste-containing diets was suggested by an alleged botulism outbreak in cattle fed poultry wastes in Israel (Egyed et al., 1978a). Vaccination of calves against *Clostridium botulinum* prevented botulism (Egyed et al., 1978b). A major outbreak of type C botulism was reported in cattle fed ensiled poultry litter in Northern Ireland (McLoughlin et al., 1988). The outbreak occurred 24 hours after the introduction of purchased ensiled litter. Decomposed poultry carcasses were observed in the purchased litter. The authors emphasized the importance of removal of poultry carcasses from litter before it is fed to animals. Neill et al. (1989) obtained data indicating there was uneven distribution of botulism toxin in the litter. They stated that it is essential that the silage be made carefully and be free from poultry carcasses.

In Quebec, Canada, 28 deaths were reported in cattle that had been fed a diet of poultry litter, crushed corn and straw (Bienvenu and Morin, 1990). Botulism was suggested as the cause of the problem. The litter fed when the problem occurred contained numerous chicken carcasses, and the presence of *Clostridium botulinum* type C was determined in a feed sample. Intoxication by *Clostridium botulinum* type C was reported in Quebec, Canada in cattle fed broiler litter (Jean et al., 1995). Outbreaks of a paralytic disease, suggested to be botulism, occurred on three farms in Australia (Trueman et al., 1992). Poultry litter was included at 4% in the diet on one of the farms, and chicken carcasses were found in the litter.

Clegg et al. (1985) and Hogg et al. (1990) reported that botulism was diagnosed in the United Kingdom in cattle grazing on pasture that had been fertilized with poultry litter. They suggested that the source of the toxin was ingestion of poultry carcasses containing types C and D *Clostridium botulinum*. An outbreak of botulism occurred in Scotland in cattle grazing stubble pastures on which poultry litter was applied (Appleyard and Mollison, 1985). Smart et al. (1987) reported botulism in England in cattle grazing pastures fertilized with poultry litter. Type C *Clostridium botulinum* was found in chicken carcasses on the pasture. The probable source of toxin was poultry carcasses in litter. McIlroy et al. (1987) reported botulism in Northern Ireland in cattle grazing pastures fertilized with poultry litter. They suggested that the source of toxin was decomposed poultry carcasses. Ruffin and McCaskey (1990) suggested that broiler litter used for composting of dead birds not be used as a source of feed for beef cattle. No botulism problem has been reported in animals fed waste-containing diets in the USA.

Residues in animal products

Mycotoxins pose no greater problem in poultry litter than in common feedstuffs (Lovett, 1972). Poultry litter has been shown to detoxify aflatoxin-contaminated corn (Jones et al., 1996). The time needed for alflatoxin disappearance was related to the moisture content of the mixtures. No evidence of pesticide accumulation in wastes or in animal tissue from animals fed wastes has been reported (Fontenot et al., 1983). Heavy metals have not been found to be sufficiently high in poultry litter to present a problem (Westing et al., 1985). The metals did not accumulate in fattening cattle fed broiler litter. Liver copper was increased by feeding poultry litter with high copper concentration. Feeding a diet containing dried poultry waste to dairy cows did not significantly affect cadmium, copper, lead, zinc and tocopheral in milk (Bruhn et al., 1977).

Medicinal drug residues were present in broiler litter in variable amounts if the drugs had been included in the broiler diet (Webb and Fontenot, 1975). However, residues of the three drugs that were in litter, namely, chlortetracycline, nicarbazin, and amprolium, did not accumulate in animal tissues of finishing beef cattle after a 5-d withdrawal. Thus, it appears that with a modest withdrawal period there is no serious tissue residue problem from feeding broiler litter. Litter should not be fed to cows producing milk or hens producing eggs for human consumption since insufficient data are available on these aspects.

Regulation of feeding animal waste in the USA

The U.S. Food and Drug Administration (FDA) published a policy (21 CFR 500.4) in the September 2, 1967 Federal Register not sanctioning the use of poultry litter as animal feed (Kirk, 1967). Broad interpretation subsequently extended this policy to include all animal wastes used as ingredients in animal feeds. The FDA took this position because the amount of information then available was not believed adequate to conclude that animal wastes were safe when used as feed ingredients. The FDA (1980) revoked 21 CFR 500.4 on the use of poultry litter as an animal feed ingredient on December 30, 1980 (45 FR 86272) and left the regulation of feeding animal wastes to the individual states. Most states follow the Association of American Feed Control Officials (AAFCO) (1990) model regulations for processed animal wastes. In other states the regulations are similar to the AAFCO (1990) regulations.

The salient points of the AAFCO regulations are: 1) the waste must be processed so it will be free of pathogenic organisms, 2) if the waste does not contain drug residues, no withdrawal period is required and the waste can be fed to any class of animals, 3) if the waste contains drug residues a 15-d withdrawal is required prior to slaughtering animals or prior to using milk or eggs for human consumption. This would usually apply to feeding broiler litter. Caged layer waste can be fed to any class of animals since the hens usually are not fed any drugs. However, documentation would be needed that no drugs are present in the waste. A questionnaire was sent to feed regulatory officials in the 50 states in the U.S. Response was received from 33 states. A summary of the responses follows:

- No state prohibits use of animal waste as feed.
- Twenty three states follow the AAFCO Regulations.
- Five states stipulate a 15-day withdrawal and three states stipulate a 30-day withdrawal if drugs are present in the waste.
- One state requires that drug levels in the waste must be at levels which will not be harmful to the animals and will not result in harmful residues in edible products.
- One state has no regulation.

Regulation of feeding animal waste in canada

According to the regulation for Canada dried layer waste may be fed to beef cattle and broilers (Anonymous, 1983). A 15-day withdrawal is required before slaughter.

ECONOMIC CONSIDERATIONS OF FEEDING POULTRY WASTES

Although it has been shown that nonruminants can utilize certain wastes, the high fiber and frequently high nonprotein nitrogen in animal wastes indicate that ruminants are best suited for utilization of wastes. In the USA animal wastes are usually fed to cattle. Smith and Wheeler (1979) estimated the monetary value of different kinds of animal wastes when used as feed. These values were compared to the value of wastes for alternate uses (Fontenot and Ross, 1980). Values given in table 2 show that the wastes have considerable monetary value and are much more valuable as sources of feed than for fertilizer or methane generation. Zimet et al. (1988) estimated the value of broiler litter as cattle feed ingredient, using computer simulation, which was much higher than the value estimated by Smith and Wheeler (1979).

Table 2. Relative value of animal wastes utilized for different purposes

	U.S. dollars per metric ton		
Kinds of waste	Fertilizer[a]	Feed[b]	Methane[a]
Beef cattle	25.06	118.14	13.73
Dairy cattle	17.00	118.14	12.74
Swine	18.61	136.57	17.17
Caged layer	36.45	155.14	17.93
Broiler litter	26.54	159.57	16.29

[a]Adapted from Fontenot and Ross (1980).
[b]Adapted from Smith and Wheeler (1979).

Any of the collectible animal wastes can be used as animal feed, however, poultry litter is the primary waste presently used extensively in North America. It is the most nutritious, and the low-moisture content facilitates handling, processing, and storage. One of the problems has been the conception that poultry litter had to be fed in close proximity to the poultry houses from which it was collected. However, when the values of the wastes given in table 2 are considered, obviously the litter can be transported for considerable distances. In some states it is being sold and transported to other locations, where it is fed to cattle. A program was initiated jointly by the U.S. Environmental Protection Agency (EPA), Virginia and some other states to reduce contamination of the Chesapeake Bay (Shuyler, 1994). One of the programs in Virginia under this effort is subsidizing of structures to store poultry litter. The structures are well suited for deep-stacking litter, since they are very well ventilated. They vary in capacity, up to 1,000 tons. Litter from these structures is sold after deep stacking. This method provides a continuous supply of litter which has been processed. The litter is transported for distances varying up to over 300 kilometers. Even after transporting for 300 kilometers, the price of litter, including transportation, (about US $30/ton) is only about 30% of its value (H. J. Gerken, Jr., personal communication).

PRACTICAL FEEDING OF POULTRY LITTER IN THE USA

Poultry litter is the main animal waste used as animal fed. It can be fed to any class of beef cattle, with withdrawal periods imposed where applicable. However, it is used mainly for feeding beef cows and stocker cattle. Diets have been developed to use poultry litter (Gerken, 1992; Ruffin and McCaskey, 1990.) Beef cow wintering diets probably offer the greatest potential for the use of broiler litter (Gerken, 1992). Cows may be wintered on a mixture of 80% broiler litter and 20% ground corn or other palatable concentrate. The reason for mixing grain with the litter is to insure adequate consumption since litter alone would meet the protein and energy needs of pregnant beef cows if they ate enough of it. A small amount of hay or other forage (1 kg dry matter) should also be fed for normal digestion and health. Pregnant cows should be fed 6 to 7 kg of the litter-corn mixture per head per day along with 1 kg of hay or equivalent forage. For cows nursing calves, the amount of the litter-corn mixture should be increased to 8 to 9 kg per head daily while continuing to feed a small amount of hay or other roughage. Ruffin and McCaskey (1990) suggested feeding a mixture of 65% litter and 35% corn grain plus limited coarse roughage to lactating beef cows.

Calves may be successfully fed during the winter on a diet of 50% broiler litter and 50% ground corn along with hay fed free choice (Gerken, 1992). Feeding 3 kg of the mixture per day to 180- to 225-kg calves should produce gains of 0.5 kg/d. The mixture could also be fed with as little as 2 to 4 kg of silage per head daily. The amount of the mixture will need to be adjusted, depending on the amount of hay or silage fed.

Poultry litter is usually not fed to fattening cattle. However, broiler litter may comprise up to 20 or 25% of the dry matter in beef cattle finishing diets. It can be fed either as litter ensiled with corn forage or by mixing deep-stacked litter with silage or other ingredients at feeding time. When fed with corn silage plus concentrates such as ground corn at 1% of body weight, 30% broiler litter in the diet, dry matter basis, will provide the protein needed to balance the diet.

The beef cattle producer needs to know the amount of litter available in order to plan a feeding program. About 0.9 kg of dry broiler litter is produced per bird during a production cycle (Van Dyne and Gilbertson, 1978), hence, approximately 900 kg of broiler litter dry matter are produced per 1,000 chicks during a production cycle. Assuming that the litter will contain 80% dry matter as it is taken from the house, the number of cattle that could be fed could be calculated.

Most of the poultry litter fed is used directly by livestock producers. However, the feed industry could make use of substantial amounts of poultry litter. Some processing would be required to reduce the moisture to a level suitable for storage and to destroy the pathogens. Litter could be blended with other ingredients and pelleted. The pelleting process, including cooling the pellets, would probably reduce moisture to a level low enough for safe storage. Availability of sufficient quantities of uniform litter is essential for a feed manufacturer to start blending feeds containing animal wastes. In 1995, 7 billion broilers were produced in the USA (USDA, 1997). Thus, 7,000,000 tons of litter dry matter were produced per year. As the trend for constructing storage structures continues, a constant supply of uniform litter should be available.

The feasibility of recycling nutrients in broiler litter to the soil by feeding the waste to beef cattle on pastures is being studied (Fontenot et al., 1996). Composition of the forage and performance and blood serum levels of grazing steers fed broiler litter were similar as for cattle grazing pastures fertilized with the waste or inorganic fertilizer.

CONCLUSIONS

Animal wastes can be used as feedstuffs for animals if processed properly to eliminate pathogens. Performance for animals fed animal wastes is similar to that of control animals if the nuitrient levels are equalized. With good management and appropriate withdrawal, feeding wastes does not result in harmful residues in animal products. The higher value of wastes as feedstuffs than fertilizer justifies transportation of the wastes outside of areas where the wastes are produced. Potentially, feeding wastes such as poultry litter to animals on pasture can be used as a method to apply plant nutrients to the soil.

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