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Project Summary

Resource Conservation and Utilization in Animal Waste Management

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This study critically evaluated potential resource conservation and utilization opportunities that could be part of manure management systems and thereby reduce the pollution potential of animal manures. This work was accomplished by a detailed evaluation of literature and by laboratory studies. The following areas were investigated: (a) manures as a component of animal feeds, (b) conservation of plant nutrients in manures, (c) enhancement of manure nutritive value, and (d) energy production.

When manures are considered as feedstuffs, they are best compared to corn silage and forages rather than to energy or protein feeds. Such utilization of manures is feasible only when they constitute a small fraction, less than 20%, of an animal ration. Broiler litter can be feasible at higher fractions.

The amino acid content of animal manures is enhanced by short-term (less than 7-day retention time) aerobic stabilization. The essential amino acid concentration increased as much as 36% and constituted a greater percent of the total amino acids, as a result of the aerobic treatment.

Chemical stabilization and conservation of the ammonia in manure occurs primarily as a function of decreased pH rather than the type of chemical used. Air stripping of ammonia followed by capture in an acid solution appears to be an effective way of conserving manurial ammonia.

Some form of moisture loss is a prerequisite for any thermochemical energy production process using manures. With thermochemical processes, the monetary value of plant nutrients that are lost is an opportunity cost that must be considered when energy conversion processes are evaluated. The economic feasibility of biogas production depends upon the energy source that is replaced, and the quantity of biogas that is utilized. The digester effluent does not have value as an animal feedstuff.

This Project Summary was developed by EPA's Robert S. Kerr Environmental Research Laboratory, Ada, OK to announce key findings of the research project that is fully documented in three separate reports (see Project Report ordering information at back).

Introduction

Through the 1950's, animal production units were relatively small, large in number, located in relative isolation, and the source of few identifiable environmental problems. Developments over the past two decades have changed this situation. The number of animal production units—farms and feedlots—has declined dramatically, resulting in fewer but much larger operations and more animals per production unit. In turn, this has resulted in an increased amount of manure that must be handled and disposed of in a manner that does not cause air and water pollution problems.

Unfortunately, improper handling and disposal has occurred and has contributed to water quality concerns such as fish kills and increased eutrophication, and to air quality concerns such as odors. As a result, technical approaches to negate or minimize such environmental problems have been developed. These approaches have included systems to control feedlot and barnyard runoff, aeration units to control odors and stabilize the manure, drying systems for odor control and potential product use, ensiling of manure for use as a feedstuff, anaerobic units for storage, stabilization and possible methane generation, and soil injection systems to reduce odors. Many of these approaches have been successful, have reduced the obvious environmental problems associated with manure management, and have been integrated into existing animal production units.

Such animal manure management systems developed in the past two decades in an era of apparent resource and energy abundance, did not always consider energy efficiency or resource conservation. The usual aim of manure management was minimum treatment and disposal, rather than resource conservation and utilization.

The increasing concerns about energy limitations, adequate food, and environmental pollution have emphasized the inadequacies of such a minimum treatment and disposal approach. The idea of a "finite earth" has brought attention to manure management methods that will minimize environmental problems and conserve resources. Today's treatment and disposal methods stress conservation of nutrients and energy in manures used as fertilizer, feed, and fuel.

Many existing manure management systems have resource conservation "possibilities" (Figure 1). The objectives of resource conservation and environmental protection can be complimentary. For example, effective conservation and utilization of manurial nitrogen for crop production will reduce the quantity of this nutrient lost to the environment. In the past, with few exceptions, the resource conservation aspects of specific manure management processes have not been critically evaluated.

The objective of the project described herein was to identify and evaluate potential resource conservation and utilization methods which could be adapted to manure management systems. This objective was accomplished by a detailed evaluation of information in the literature and by laboratory research on possibilities that appeared to deserve greater attention. The following specific possibilities were evaluated: (a) use of as-collected and processed manures as a component of animal feed, (b) conservation of plant nutrients in manures, (c) energy production from manures, and (d) microbial enhancement of manures to increase the protein content.

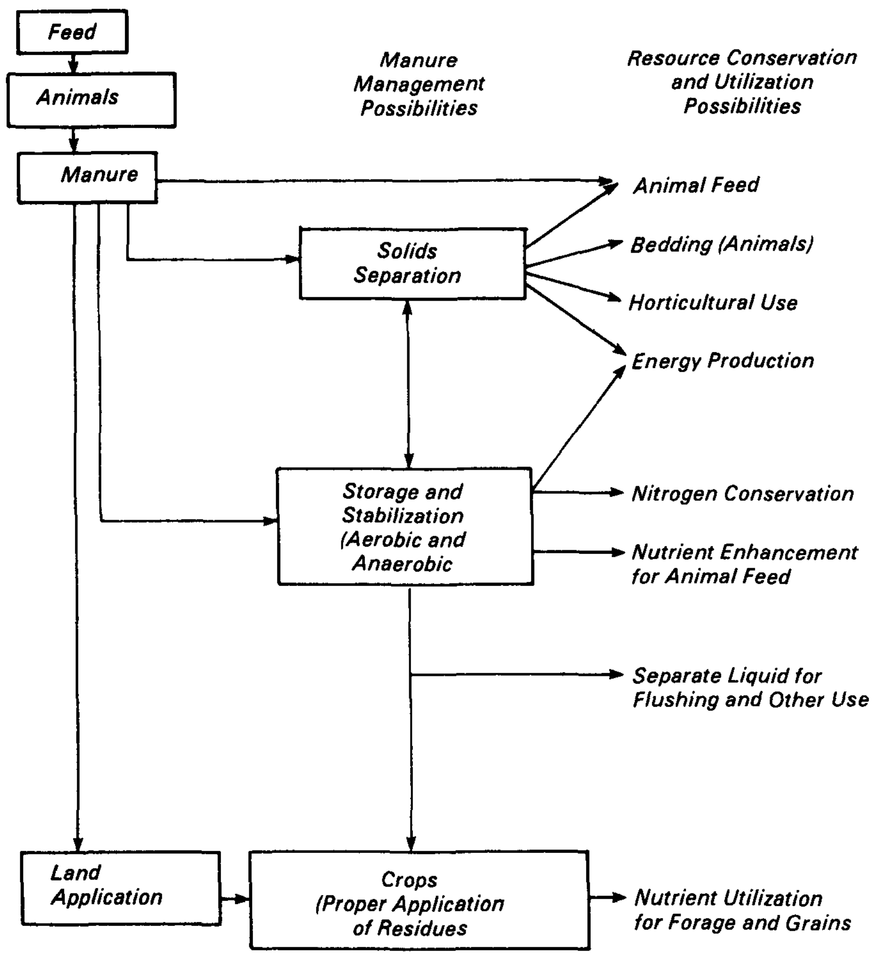

Figure 1. Resource conservation and utilization possibilities associated with animal production and manure management.

Manures as Feedstuffs

The use of animal manures as feedstuffs has the potential to reduce feed costs and to provide a partial solution to manure management and environmental problems. During the past forty years, a number of nutritional and economic studies have evaluated the possible use of manures as feedstuffs. These studies evolved from the detection of "unknown growth factors" to identification of the nutrient content and nutritional value of specific manures. Although a substantial data base exists as a result of these studies, the data are not consistent. As a result, neither the nutritional and economic value of manures as feedstuffs, nor the alleviation of water and air pollution problems that might result from the use of manures as feedstuffs is clear, and the realization of benefits from use of manures as feedstuffs remains elusive.

In this study, available information on the nutrient characteristics of manures and their utilization as feedstuffs was assembled and critically reviewed. The evaluation focused on dairy cattle, beef cattle, and caged laying hen manures and on broiler litter, since these manures represent approximately 85% of the economically recoverable manure produced annually in the U.S. Sheep manure was not evaluated, although results from digestibility trails utilizing sheep as a species fed manures were included in the evaluation.

The value of manure as feedstuffs was determined by an assessment of: (a) nutrient characteristics of animal manures to determine if they should be classified as protein, energy, or forage substitutes, (b) animal performance in reported feeding trails, (c) economic benefits that might result from reduced feed costs and from increased revenue from sale of meat, milk, or eggs, and (d) potential pollution control benefits. The general types of manures that were evaluated included solid or semi-solid manure that was as-collected, dried, composted or ensiled, and liquid manure that was aerobically or anaerobically stabilized.

All of the studies on feeding trials that were located in the literature were not utilized in the evaluation. The following criteria were used to select studies appropriate for detailed evaluation: (a) an accurate description of the experimental design was stated, (b) a positive control group was utilized, (c) the feedstuffs used in the rations were conventional and the percentages utilized were reported, and (d) sufficient animal performance data were reported to enable a nutritive evaluation. The available data were analyzed to identify the "optimum" and "maximum" nutritional level at which the manure could be included in the feed ration. The maximum level was defined as the maximum percent of manure that could be included in a feed ration without adversely affecting the animal performance as compared to controls. The optimum level was defined as the percent of manure in a ration that would provide the highest level of animal performance as compared to controls. The optimum level of manure was less than the maximum level in a feed ration. In many studies only the maximum level was able to be defined.

Nutrient Evaluation

Evaluation of the nutrient composition of manures indicated that they are: (a) more comparable to corn silage and typical forages (alfalfa, timothy and bermudagrass hay) for ruminants than they are to energy or protein feedstuffs, and (b) a source of amino acids and minerals for laying hens. The estimated economic value of these manures, based on their nutrient content was positive when used to replace corn silage and forages in ruminant rations and was highest when dried poultry wastes (DPW) were used to replace a portion of the meat and bone meal in diets of laying hens.

Animal Evaluation

The results of feeding trials indicated that while animal manures have nutritive value as a feedstuff, the method of preparing or processing the manures as feed constituents (drying, composting, ensiling, etc.) influences their value. Table 1 summarizes maximum and optimum levels of manures incorporated into rations for laying hens and ruminants. Generally, the maximum level of manures incorporated into animal feed rations is less than 20%. Broiler litter is an exception and can be incorporated at higher levels without adversely affecting animal performance.

Table 1. *Maximum and Optimum Levels of Incorporating Manures in Laying Hen and Ruminant Rations Based on Animal Performance*

Type of Manure	*Species Fed*	*Maximum Level of Incorporation into Rations (%)*	*Optimum Level of Incorporation into Rations (%)*
Dried Poultry Manure	*Laying Hen*	*14-20*	*10-12.5*
	Steers	*5*	*LT 5*
	Heifers	*	*
	Dairy Cows	*10-12*	*LT 11*
Broiler Litter			
-as-collected	*Steers*	*18-22*	*LT 18*
-dried	*Steers*	*11-16*	
-ensiled	*Steers*	*25-52*	*10-30*
	Heifers	*1-10*	*LT 10*
-composted	*Beef Heifers*	*75*	*
	Brood Cows	*80*	*
Beef Cattle Manure			
-as-collected	*Steers*	*0*	*0*
-dried	*Steers*	*0*	*0*
-ensiled compared to			
-corn silage	*Steers*	*16-24*	*
-corn grain	*Ruminants*	*	*

**Unable to be determined from existing data.*
LT-less than.

Economic Assessment

The economic value of manures used as feedstuffs is summarized in Table 2. Dried poultry manure, broiler litter, and possibly aerobically processed swine and laying hen manure have an economic value as feedstuffs that equals or exceeds their value as a fertilizer. The economic value of beef cattle manure and anaerobically processed manures when used as a feedstuff is less than their value as a fertilizer and frequently results in poor animal performance.

Conclusions

When animal manures (DPW, broiler litter, dairy cow and beef cattle manure) are used as a feedstuff, they are most comparable to corn silage and forages, such as alfalfa, timothy and bermudagrass

Table 2. *Economic Assessment of Using Manures as a Feedstuff Based Upon Animal Performance*

Type of Manure	*Species Fed*	*Economic Value as a Feedstuff*
Dried Poultry Manure	*Laying hens, steers, dairy cows, heifers*	*Far exceeds its value as a fertilizer; has value as a substitute for meat and bone meal and also for silages and forages when used at optimum level; positive but less than at optimum level when used at the maximum level*
Broiler Litter -as-collected, dried ensiled, composted	*Steers, heifers, brood cows*	*Positive; more than its value as a fertilizer and comparable to the value of corn silage and forages*
Beef Cattle Manure	*Ruminants (steers)*	
-as-collected and dried		*Negative; adverse animal performance*
-ensiled		*Negative; unable to compete with low cost of forages or corn silage, may have positive value when used at low levels as a substitute for grain corn*
Processed Manures		
-aerobically	*Swine, laying hens*	*Possibly positive, requires further study*
-anaerobically	*Steers*	*Negative, poor animal performance*

hays, and not to energy or protein feeds. DPW used as a feedstuff for laying hens is an exception, and is best described as a source of minerals and amino acids.

The economic value of DPW and broiler litter as feedstuffs is greater than their value as a fertilizer. The value of beef cattle manure and anaerobically digested manures as a fertilizer is greater than their value as feedstuffs. Available data indicate that their use as a feedstuff can impair animal performance.

Utilization of animal manures as feedstuffs is nutritionally and economically feasible only when such manures constitute a relatively small fraction of the ration, typically less than 20%. Broiler litter, however, is feasible at higher levels. The nature of manure management prior to utilization as a feedstuff affects its nutritional and economic value.

The utilization of manures as feedstuffs does not appear to be a management practice that will reduce potential water and air pollution problems caused by improper handling and disposal of such manures. Only a low level of such manures will be incorporated into animal rations, and the potential pollution abatement impact will be minimal.

Enhancement of the Nutritive Value

Introduction

Previous research results have suggested that the nutritive value of animal manures, particularly the amino acid content, can be enhanced during aerobic stabilization. Batch and continuous flow laboratory experiments were undertaken to determine the nature of the amino acid transformations that occur as animal manures are aerobically stabilized, and to identify aeration system operating parameters that may be utilized to maximize amino acid content and quality.

Fresh manure collected from caged White Leghorn laying hens was used as the substrate for both studies. Continually mixed and aerated four-liter capacity reactors were used. A measurable dissolved oxygen concentration (0.5 mg/liter) was maintained in the units at all times. The studies were conducted at ambient laboratory temperatures, 22 ± 2°C. For each batch study, 2.7 liters of slurried poultry manure was combined with 0.3 liters of mixed liquor from an oxidation ditch stabilizing caged laying hen manure. The latter served as a source of an active, adapted microbial population. The initial mixed liquor total solids concentrations in all units was 30 g/liter (3%). Samples were obtained for analysis daily for the first four days and at less frequent intervals later in the 10- to 15-day experiments.

The continuous flow reactors were operated at retention times of 3, 5, 7, and 10 days without solids recycle; therefore, the hydraulic and solids retention times were the same. The influent total solids concentration for all continuous reactors was 30 g/liter.

Batch Studies

An example of the data from one batch study is presented in Table 3. In each study, the total amino acid concentration increased slightly during the initial stages of aeration but decreased thereafter. The essential amino acids increased considerably, as much as 36%, in the first few days of aeration and were not less than the initial concentration until after about seven days of aeration.

Of equal interest is the fact that after initial increases occurred, essential amino acids as a percentage of total amino acids and mixed liquor volatile solids did not decrease but rather remained relatively constant with time.

Continuous Flow Studies

Results from the continuous flow studies (Table 4) also showed that both the total and essential amino acid content of poultry manure can be increased by aeration with the essential amino acid content increased significantly. The retention time at which increases were maximum was short, 3 days or less, which agrees with the results of the batch studies. As retention time increased, both total and essential amino acid concentrations decreased.

Conclusions

These studies have shown that short-term aerobic stabilization has the potential to increase the amino acid content of laying hen manure. Both the quantity of amino acids and the quality, expressed in terms of essential amino acids as a percentage of total amino acids, is increased as compared to freshly excreted laying hen manure (Table 5). On a dry-matter basis (amino acids as a percent of dry matter), the amino acid profiles for aerobically stabilized laying hen manure and soybean meal are comparable (Table 5).

Table 3. *Changes in Total and Essential Amino Acid Concentrations During Aerobic Stabilization of Poultry Manure - Batch Study I*

	Total Amino Acids		*Essential Amino Acids**		
Time of Aeration days	*Fraction of Initial Concentration†*	*% of Mixed Liquor Volatile Solids*	*Fraction of Initial Concentration†*	*% of Total Amino Acids*	*% of Mixed Liquor Volatile Solids*
0	1.0	16.14	1.0	38	6.11
1	0.91	16.36	1.09	44	7.29
2	1.0	20.51	1.28	48	9.90
2.5	1.06	23.81	1.36	48	11.53
3	0.98	22.13	1.25	48	10.69
4	0.95	24.65	1.20	48	11.90
7	0.76	22.64	0.95	47	10.68
10	0.69	23.27	0.87	47	11.05

**Essential for poultry.*
†Concentration at aeration time t/concentration at time zero.

Table 4. *Changes in Total and Essential Amino Acid Concentrations During Aerobic Stabilization of Poultry Manure Under Continuous Flow Conditions*

	Total Amino Acids		Essential Amino Acids*		
Retention Time, Days	Fraction of Initial Concentration†	% of Mixed Liquor Volatile Solids	Fraction of Initial Concentration†	% of Total Amino Acids	% of Mixed Liquor Volatile Solids
3	1.37	32.71	1.72	45.1	14.8
5	1.08	25.27	1.27	42.4	10.72
7	0.99	20.94	1.22	44.6	9.34
10	0.44	9.16	0.52	43.2	3.96

*Essential for poultry.
† Concentration in mixed liquor/concentration in freshly excreted manure.

Table 5. *Comparison of the Amino Acid Profiles of Ground Corn, Soybean Meal, and Aerobically Stabilized Laying Hen Manure, % of Total Amino Acids*

			Laying Hen Manure		
	Ground Corn	Soybean Meal (49%)	Batch (Day 2.5)	Continuous Flow (3-day HRT)	As Excreted
Arginine*	4.8	6.8	5.7	6.1	4.0
Glycine	0.0	4.9	6.6	8.2	25.2
Histidine*	2.4	2.6	2.1	1.7	1.8
Leucine*	10.9	7.7	9.0	7.8	6.2
Isoleucine*	4.8	4.9	6.5	5.7	6.0
Lysine*	2.4	6.1	6.2	5.4	4.6
Methionine*	1.2	1.2	1.9	2.6	1.6
Phenylalanine*	4.8	5.0	5.0	4.1	3.2
Tyrosine	4.8	3.1	3.6	3.0	2.4
Valine*	3.6	4.9	6.9	6.4	4.6
Alanine	9.6	4.9	7.8	10.2	7.0
Proline	10.9	5.8	4.7	4.5	4.6
Glutamic acid	33.7	18.6	13.2	13.0	11.4
Serine	1.2	5.2	4.4	4.6	4.0
Threonine*	3.6	3.9	5.1	5.0	4.0
Aspartic acid	2.8	13.0	11.2	11.4	9.3
Total amino acids, % dry matter basis	9.47	56.23	17.32	20.76	15.11
Essential amino acids, % of total	38.9	43.1	48.4	45.1	36.1

*Amino acids essential for poultry.

Conservation of Plant Nutrients

Estimated Losses

Historically, livestock and poultry manures have been important by products of animal production and have been applied to cropland for centuries in order to utilize their nutrient content. In contrast, the extensive use of inorganic fertilizers has occurred only in the past 30 years. As recently as 1950, the combined consumption of nitrogen, P_2O_5, and K_2O in the U.S. was only 2.6 million metric tonnes annually. By 1973, the combined consumption increased to 17.5 million metric tonnes annually, with nitrogen representing almost 50% of the consumption. During this period the cost of inorganic fertilizer nitrogen decreased substantially. As a result, manures were not as widely returned to cropland since their transport and distribution costs exceeded their monetary return. As increased costs for energy are translated into higher prices for inorganic fertilizers, interest in the use of manures as fertilizers has been renewed.

Only between 40 and 50% of the manurial plant nutrients annually are collectible and thus potentially available for utilization. About 50% of the collectible nitrogen and 10% of the collectible phosphorus and potassium in manures is lost during collection, storage, and disposal of the manure. This latter fraction of the collectible nutrients offers the greatest potential for conservation, recovery, and use. This quantity is not insignificant. The quantity of potentially recoverable manurial nitrogen in the U.S. is about 1.3 million tonnes annually, represents about 17% of the fertilizer nitrogen consumed annually in the U.S., and represents a monetary loss of close to $800 million.

The nitrogen losses associated with various storage and stabilization alternatives for animal manures are noted in Table 6. The variability of manurial nitrogen losses for specific systems suggests that management is an important variable affecting these losses. As ammonia is the principal form in which manurial nitrogen is lost, laboratory studies were conducted to evaluate various alternatives for reducing volatilization of manurial ammonia. The option of air-stripping of manurial ammonia followed by recovery also was examined.

Table 6. *Nitrogen Losses Associated with Various Animal Waste Management Alternatives*

	Observed Nitrogen Losses, %
Storage Systems	
1. Stacking (dairy manure)	*5-29*
2. Liquid manure slurries	*1-60*
3. In-house drying (laying hen manure)	*22-75*
Aerated Systems	
1. Aerated lagoons	*5-65*
2. Oxidation ditches	*25-81*
3. Liquid composting	*13-43*
Anaerobic Lagoons	*25-62*
Anaerobic Digestion	*0-21*
Composting	*3-37*
Pyrolysis	*64-89*

Chemical Stabilization

Studies earlier in this century suggested that the addition of chemicals such as calcium sulfate (gypsum) and calcium phosphate as well as phosphoric and sulfuric acids to manures could reduce ammonia volatilization losses. The objective of calcium sulfate and calcium phosphate additions was to form ammonium sulfate or phosphate which are less soluble than ammonium carbonate or hydroxide. In some studies, superphosphate fertilizer material which contains gypsum and calcium phosphate as principal ingredients was utilized. The results of these early studies were highly variable. To reevaluate the potential of this approach, a series of laboratory experiments using the noted compounds were conducted with anaerobically digested dairy cow manure which had a high concentration of ammonia nitrogen.

The effectiveness of the noted chemicals to stabilize manurial ammonia was evaluated by comparing the quantities of ammonia nitrogen that could be removed from treated and untreated manure samples by drying and air-stripping. Drying studies were conducted using 100 ml samples which were dried at 103°C for 24 hours. Dried samples were reconstituted with distilled water for subsequent analysis. For the air-stripping trials the following conditions were standard: sample volume, one liter; airflow rate, 425 standard liters per hour (SLH); duration, 24 hours, and total solids concentration, 20 g/liter. The nitrogen loss for each sample was determined by the difference between initial and final total Kjeldahl nitrogen (TKN) and ammonia nitrogen concentrations. Initial and final pH values also were measured.

Results of drying studies in which phosphoric and sulfuric acids were added to digested dairy cow manure showed that pH reduction can substantially reduce nitrogen losses. Both acids were added to manure samples to obtain initial pH levels of 7.0, 6.5, and 6.0. Nitrogen losses of the control (pH 7.6) and pH 7.0 samples approaches 100%. Reducing pH to 6.5 reduced losses only slightly. However, by reducing the pH of the samples to 6.0 before drying, nitrogen losses were reduced to 60 and 52% respectively.

Results of air-stripping studies also showed that using acid to reduce manurial pH was effective in reducing nitrogen losses. The TKN and ammonia losses were lowest for the samples with the lowest initial and final pH. In all instances, pH increased during aeration. Illustrative data from experiments in which acids were used for pH adjustment are noted in Table 7.

Also air-stripping studies were conducted to assess the effectiveness of calcium sulfate and calcium phosphate additions to reduce manurial nitrogen losses. These compounds were added at rates of 50, 100, and 200% of the stoichiometric requirements for converting the ammonia nitrogen in the sample into sulfate or phosphate salts. Results of these studies showed that additions of these chemicals have almost no effect on reducing nitrogen losses. Due to low solubility of superphosphate fertilizers, studies involving these chemicals were not pursued.

Aeration

The effect of aeration rate on ammonia nitrogen losses was evaluated, using rates of 142, 283, 425, and 566 SLM/liter of mixture. The TKN losses did not vary significantly with these rates ranging from 40 to 46% for the digested dairy cow manure, and from 48 to 54% for the anaerobic laying hen manure. However, there appeared to be a linear increase in the ammonia nitrogen loss as the airflow rate increased. The ammonia losses for the two manures increased from 59 to 90% and from 51 to 91% as the airflow rate increased from 142 to 566 SLH/liter. The ammonia losses also increased as the aeration period increased from 24 to 96 hours.

The feasibility of air-stripping of ammonia without pH control followed by recovery of the stripped ammonia in an acid solution (0.1 N H_2SO_4) was evaluated in another set of experiments. These studies were conducted in completely mixed units. Compressed air was used to strip the ammonia from the dairy and poultry manures. In each unit, the pH increased, undoubtedly as a result of stripping of carbon dioxide. The pH increase occurred within the first hour and remained relatively constant at a pH of 8.4 or 8.5 thereafter. In the experiments, almost all of the stripped ammonia could be recaptured indicating that even if ammonia volatilization does occur, the gaseous ammonia can be captured if the off gases or ventilation air are passed through an acid media.

Conclusions

Results from laboratory studies indicate that the ammonia volatilization losses are more a function of the pH of a manure mixture and therefore the quantity of free ammonia able to be lost than of the type of chemical used to inhibit the loss or to complex the ammonia. Therefore, manure management approaches and chemical additions that maintain a low pH (less than 6.5) will minimize ammonia losses. The use of superphosphates was not feasible due to their minimal solubility in water and manure slurries.

Table 7. *Nitrogen Losses and pH Changes* - Anaerobically Digested Dairy Cow Manure*

	pH			
Treatment	*Initial*	*Final*	*TKN Loss, %*	*NH_3-N Loss, %*
Sulfuric Acid				
Control	*8.0*	*8.6*	*30.0*	*66.3*
pH 7.0	*7.0*	*8.6*	*28.3*	*60.7*
pH 6.5	*6.5*	*7.5*	*11.3*	*24.2*
pH 6.0	*6.0*	*7.2*	*2.7*	*5.8*
Phosphoric Acid				
Control	*7.9*	*8.7*	*29.3*	*63.8*
pH 7.0	*7.0*	*8.6*	*25.6*	*55.8*
pH 6.5	*6.5*	*8.4*	*9.5*	*20.7*
pH 6.0	*6.0*	*6.8*	*0.8*	*1.8*

**Air-stripped for 24 hours at air flow rate of 425 liters of air/hr/liter of slurry.*

Energy

Introduction

The quantity of collectible manure that is potentially available as feedstocks for energy production is worthy of consideration. Assuming an average heating value of 17.2 GJ/tonne of manurial solids, the potential energy of the collectible manure in the U.S. is about 7.2 x 10^8 GJ/year. This is equivalent to 1.1 x 10^8 barrels of crude oil/year.

Several options are possible for converting manures into usable forms of energy, i.e., thermochemical processes such as direct combustion and pyrolysis, and anaerobic digestion, a biological process.

Thermochemical

All thermochemical conversion processes have three basic components: drying, thermal decomposition, and recovery and utilization of the resultant energy. The first two components are endothermic and require close attention when evaluating net energy production from a thermochemical process. Before temperatures can be reached at which thermal decomposition will occur, reduction of moisture, such as by evaporation, is necessary. Therefore, the manure moisture content used in thermochemical processes is critical.

The moisture content of manure must be below 50% on a wet basis (WB) for any appreciable quantities of recoverable energy to be produced. For pyrolysis to occur, it has been estimated that about 0.9 MJ/kg of total solids is required in addition to energy inputs for evaporation of moisture. As produced, livestock and poultry manures range in moisture content from 75% (WB) for broilers and laying hens to 91% (WB) for swine. Thus, some form of moisture loss is a prerequisite to thermochemical energy conversion processes using manures as feedstocks.

One of the less desirable aspects of using animal manures for thermochemical processes is the loss of primary plant nutrients. As noted earlier, considerable losses of nitrogen can occur in drying processes. In addition, combustion will destroy a portion of the other nutrients as well as all of the organics. When the option of using manures as fertilizer materials is available, the monetary value of the plant nutrients lost is an opportunity cost that must be considered in evaluating energy conversion processes. Thermochemical processes are, at best, only marginally attractive economical energy conversion processes for manures. When the opportunity costs associated with plant nutrient losses are included, even the economics of direct combustion of manure are not attractive.

Anaerobic Digestion

Using anaerobic digestion to produce biogas (methane and carbon dioxide) from livestock and poultry manures has received considerable attention and evaluation. As a result, the technical feasibility of using animal manures for biogas production has become firmly established, and system design and operating parameters have been delineated and refined. The economic feasibility remains unclear, the greatest uncertainty being effective gas utilization.

For anaerobic digestion to be economically attractive, revenue generated by biogas sale or onsite utilization must provide a suitable rate of return when compared to capital, management inputs, or other options. The amount of revenue generated by biogas utilization is dependent on the conventional energy source replaced and the quantity of biogas utilized.

Methane and carbon dioxide are the principal constituents of biogas which also contains small amounts of hydrogen, hydrogen sulfide, nitrogen, ammonia, and water vapor. The composition of biogas is about 50 to 70% methane and 30 to 50% carbon dioxide. Biogas, assuming 60% methane and 40% carbon dioxide, has an energy density of 22.23 MJ/m^3, which is less than liquid fuels such as liquified petroleum gas. Even with carbon dioxide removal and compression to 4054 KP, absolute, the resultant energy density of 1482 MJ/m^3 still is not adequate to realistically consider biogas as a potential fuel for trucks, tractors, etc. Only liquified methane has an energy density approaching conventional liquid fuels. Liquification of methane is energy-intensive requiring over 30% of the energy available in the methane.

Thus, available biogas utilization options are limited to sale as synthetic natural gas (SNG) or onsite utilization as a boiler fuel or to generate electricity. The potential for marketing manurial biogas as SNG appears limited due to gas purification and compression requirements. When biogas is used as a boiler fuel, it has a variable monetary value dependent on the conventional fuel replaced. For example, biogas used in place of No. 2 fuel oil has a value of \$6.68/GJ and of \$2.77/GJ when used in place of anthracite coal.

Frequently, onsite generation of electricity is suggested as a biogas utilization alternative because on-farm demand for electricity is relatively constant and excess electricity has the potential to be sold. Generation of electricity using biogas also appears attractive because internal combustion engine waste heat may be used to satisfy digester heating requirements with the result that total biogas production is available for utilization.

The thermal efficiency of converting biogas to electricity is only about 14.5%. Thus, the value of biogas used to produce electricity having a unit cost of \$12.06/GJ is only \$1.75/GJ. Substantial levels of waste heat recovery and utilization are necessary to offset the low thermal efficiency of converting biogas to electricity.

Most cost analyses of producing biogas from animal manures show that the value of biogas produced is not adequate to offset production costs. Several investigators have suggested that producing biogas from animal manures is economically feasible if the digester effluent has value as a feedstuff or a source of plant nutrients. Comparison of the feedstuff and plant nutrient composition of manures before and after anaerobic digestion has shown that the value of manure as feedstuffs or plant materials is at best unchanged. Therefore, the opportunity cost associated with using manure as a feedstock for biogas production as an alternative to direct use as a feedstuff or a fertilizer material should be included in these cost analyses if the effluent is considered to have any monetary value.

Conclusions

1) Thermochemical processes are generally not applicable for converting manures into usable forms of energy due to the high initial moisture content of the manures. Exceptions are feedlot manures produced in arid and semi-arid climates, and broiler litter. When opportunities to use manures as fertilizer materials are available, the opportunity cost associated with plant nutrient losses that result from the thermochemcial processes offset much of the value of the energy produced.
2) The attractiveness of anaerobic digestion of animal manures is limited by biogas utilization alternatives. On-farm energy demands are primarily for liquid fuels. Thus, onsite biogas utilization alternatives which will provide the highest rate of return to invested capital and labor are limited. Monetary returns from sale of biogas as synthetic natural

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gas or electricity to public utilities are significantly lower than those from onsite utilization. Using anaerobic digestion to produce biogas from animal manures can be attractive, however, in situations where an onsite operation provides a constant and substantial energy demand.

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