

A Review of Poultry Manure Management: Directions for the Future

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1. *Introduction*

Poultry manure production occurs as a result of the normal everyday processes of the poultry industry. It is a valuable by-product of this industry and has valuable potential uses beyond the traditional one of fertilizer⁵. It is always interesting to note that if one were looking strictly at the fate of the nutrient inputs, the major product of any animal feeding system is manure, not animal protein²⁶. Often manures are considered waste materials and a place to dispose of them has to be found. However, if the manure is considered a by-product of the industry, a possible use for it in a market economy can be found. The problem in today's mass production poultry farms is that alternative uses for poultry manure must be employed as most of these farms do not own enough land to simply use the poultry manure as fertilizer. These large quantities of poultry manure production pose serious socio-economic problems, the most prominent of which is the protection of our environment and our environmental resources.

Poultry manure is produced during the normal operation of hatcheries, broiler production and egg laying production. It also occurs in turkey and waterfowl production. Since a majority of poultry manure is produced in broiler and layer operations, special attention will be paid to these two specific parts of the poultry industry.

There is a basic difference in the set-up of layer and broiler operations which leads to a difference in the type of litter produced. Caged systems are used mostly for laying operations but their use is growing in the broiler industry as well. In the laying systems, each cage contains 1-25 birds and is suspended above a pit²⁴. The cage configurations vary from stair step, modified stair step, single deck, double deck with dropping boards to colony cages²⁴. The depth of the pit will vary with the form in which the manure is handled. A shallow pit usually means a liquid type of flushing is used every few days while a deep pit means the manure is handled in solid form and need only be cleaned out once or several times a year²⁴.

Litter or floor systems are used mostly for broiler production. An absorbent litter material is usually laid down on the floor and the choice of absorbent litter depends on the needed absorption and commercial availability²⁴. The removal of this litter is handled in solid form and can be done after each brood or yearly or can be left for longer periods to add more litter and produce a "deep littering" system. A summary of the waste collection alternatives for poultry is found in Appendix I.

In both operations, a typical hen produces about 55 kg/hen/year of manure¹⁵. A very rough estimate of the amount of poultry manure produced in Canada for 1989 was approximately 5.5 million tonnes per year (See Appendix II). Comparatively, in the United States in 1980, 158 million tonnes of manure were produced, of which over 7 million tonnes were attributed to broiler and layer production¹⁰. These numbers do not take into account hatchery wastes, turkey or waterfowl manure. From the Canadian estimate, it can be seen that a large amount of poultry manure is produced in this country. Not all of this manure can be deposited on pastures as most of it is concentrated in very specific areas. Obviously, since the trend is towards the confinement of large poultry production farms, several alternative uses for the poultry manure must be employed.

There are several systems that can be used to solve the problem of manure production in high density, large volume poultry operations.

Table 1: Systems used in high-density, large volume poultry operations

Dry Systems

High Rise Houses
In-House Drying
Dehydration

Liquid Systems

Aerobic
Oxidation Ditch
Surface Aeration
Anaerobic
Soil Injection
Anaerobic Digestion

(Ostrander, 1975)

All of these methods of processing poultry manure will be discussed in greater detail later in this review. It is important to note that all of these systems have merit. A certain system may work for a particular operation but not for another operation because of certain circumstances, such as location, climate, size, land availability, crops, and markets. All of these factors greatly influence the way poultry manure is collected, handled and processed. Each system of collection, handling and processing has its own merits and uses. They all attempt to solve the problem of poultry manure management in their own specific fashion.

This review on poultry manure will look at several parts of the poultry manure problem. The review will provide some general information with regards to the chemical composition of poultry manure. It will study guidelines and legislation in Canada, the United States and Great Britain with respect to manure management. This review will study the systems of poultry manure processing and handling previously described. It will also look into the environmental impact of poultry manure production as well as some management aspects. The review will conclude with two specific topics in the application of poultry manure: poultry manure as fertilizer, and poultry manure as feedstuff.

The amounts and composition of poultry manure are a strong indication that this product of the industry can be used in a market economy. When one has a product, one looks for a use on the markets²⁶. All of the systems which will be looked at attempt to find a use or a market for poultry manure. In this day and age where sustainable agricultural development has become such an integral part of sound farming practices, it is important to emphasize that what was previously thought of as a waste can be used in many varied, environmentally friendly ways so as to minimize waste and environmental impact.

2. *The Chemical Composition of Poultry Manure*

The chemical composition of poultry manure has been extensively analyzed in the past 30 years or so. Several studies have identified and presented data as to the chemical composition of poultry manure^{16,19,21}. It is necessary to emphasize that the chemical composition of poultry manure will vary because of several factors:

- 1) Source of manure;
- 2) Feed of animals;
- 3) Age of animals;
- 4) Condition of animals;
- 5) Manner of storage and handling; and
- 6) Litter used.

(Mariakulandai and Manickam, 1975)

Most of the product resulting from poultry feeding operations is manure and not animal protein²⁶.

Table 2: Approximate % of intake nutrients excreted in the manure of poultry

	<u>N</u>	<u>P</u>	<u>K</u>
Chicken Broiler	61	69	80
Laying Hen	70	68	87

(Robinson and Beauchamp, 1982)

A very detailed analysis of the chemical composition of dried poultry waste and broiler litter can be found in Appendix III. Fresh poultry manure contains 20-23% dry matter¹⁵. Of this dry matter, the most important aspects are the nitrogen, potassium, and phosphorus levels in terms of fertilizer.

Table 3: Manure production and fertilizer elements in kg/hen/year

Manure	Crude Ash	Organic Matter	N	P ₂ O ₅	K ₂ O
54.8	3.84	8.60	0.62	0.48	0.30

(Kroodsma, 1986)

Fresh poultry manure contains 77-80% water. Of the fresh manure, 1% is nitrogen, 0.9% is phosphorus and 0.5% is potassium. As a measure of the overall dry matter, 5% is nitrogen, 3.9% is phosphorus, and 2.4% is potassium.

In a layer system, a typical laying hen will consume feed which contains 1.1 kg N while producing approximately 250 eggs¹⁸. In a broiler system, a typical broiler year (6.7 birds sent to market per year) will also consume 1.1 kg N per year of which 0.6 kg N is excreted and 0.5 kg N are assimilated into body tissues¹⁸.

The macronutrient and micronutrient (see appendix III) values provided strongly indicate that poultry manure is very rich in terms of nitrogen, phosphorus, and potassium, as well as some other elements. Poultry manure should not be considered a waste but should be considered a product which is a nutrient-rich resource.

The chemical composition of poultry manure is important in that it has very direct bearings on the environmental effects of poultry manure as well as the specific applications of poultry manure. Because it is so high in certain macronutrients, excessive land applications can lead to water pollution and soil toxicity. The components of poultry manure cause it to produce various toxic gases as well as noxious odours. Also, because of its chemistry, poultry manure is a good fertilizer and can be a very useful, inexpensive feedstuff for animals.

Before poultry manure can be applied in these beneficial ways, it must be processed in one of many various ways. These methods of processing dictate what kind of use the poultry manure will be subject to later on.

3. Processing Poultry Manure

There are several ways in which poultry manure can be collected and processed. Several factors such as operation size, climate, animal type etc. will determine what type of system is used in what kind of circumstances. It should be noted that in many instances, the strongest influence on which system is used is the economics (costs) of the system. Each system has its own merits and costs, but careful consideration must be used in order to select a system which will make the most efficient use of the factors in which it will be operated. This review will discuss several of these systems. These include both anaerobic digestion (lagoons, digesters) and aerobic digestion (lagoons, ditches, composts) as well as dehydration and incineration.

a) Anaerobic Processing of Poultry Manure

Anaerobic processing of manure occurs in almost all storage piles, pits and ponds⁶. The idea behind anaerobic processes is that they occur in the absence of oxygen and they rely on the degradation of the manure by anaerobic bacteria. There are two basic types of bacteria involved in the process. The first type convert fats, carbohydrates and proteins in the manure into simpler compounds and are rapidly reproducing bacteria that are not sensitive to environmental changes⁶. They produce the highly odorous gases and volatile substances associated with ordinary manure storage units⁶. The second type are methane-producing bacteria which control odours and produce energy. They are small in number, reproduce slowly, and are generally sensitive to their environment, especially oxygen⁶. If the anaerobic process is functioning properly, the end products are methane, carbon dioxide, water, new bacterial cells, inert solids, traces of hydrogen and hydrogen sulfide, ammonia, water vapour and other gases⁶. The two most widely used anaerobic systems for manure management are anaerobic lagoons and anaerobic digesters.

i) Anaerobic Lagoons

In anaerobic lagoons, the bacterial activity reduces solids but often results in the production of odorous gases which makes a lagoon unsuitable except in isolated areas¹. Anaerobic lagoons liquefy and break down manure solids, but not all wastes are totally degraded. The unprocessed solids settle at the bottom of the lagoon and accumulate as sludge. A lagoon has low initial cost and is easy to operate. Further labour can be saved by using irrigation to dispose of liquids¹⁷. Long storage times permit pumping flexibility while bacteria break down solids, which results in a high degree of stabilization, resulting in a reduction of odours during spreading¹⁷. The process also leads to a great reduction in the amount of nitrogen present, which is an advantage if the liquid is to be spread over a small area. This avoids large nitrogen leaching. In Canada, because of low temperatures, the decomposition rate is very low, which results in the filling of the lagoon with unstable solids which produce obnoxious odours⁶. Often, because of poor design and management, these lagoons simply become holding basins. Another disadvantage to the anaerobic lagoon system is that the nutrient value of the liquefied manure is greatly reduced. Up to 80% of

the nitrogen is lost in an anaerobic lagoon, while most of the phosphorus precipitates to the bottom and can only be recovered when the bottom sludge is removed¹⁷.

With respect to poultry, an anaerobic lagoon is used anytime a water wash system is used in a pit system (see Appendix II). If a liquid pitting system is to be used, the manure is flushed from the poultry house every 1-3 days²⁴. With a medium-depth pit, manure can also be diluted with water to form an "indoor lagoon" within the poultry house which is drained once or several times a year²⁴. In this case, special precautions must be adopted as the production of noxious gases and fumes can greatly affect the laying chickens. In any case, if an anaerobic lagoon is being considered, there are special requirements. It should not be used close to living areas and should be located where space for expansion is available⁶. Surface drainage should be prevented from entering and the lagoon contents should not be able to escape. A properly designed and managed anaerobic poultry lagoon presents an effective and cost-efficient way of treating poultry manure. But on the other hand, when an anaerobic lagoon is properly functioning, it is wasteful of the manure nutrient content. In cases where high-density large volume poultry operations function in areas where little agricultural land for manure spreading exists, the use of anaerobic lagoons is an economically viable and environmentally adequate alternative.

ii) Anaerobic Digesters

The second anaerobic processing system which is widely used for manure management is the anaerobic digester. The digester itself is usually a circular, airtight structure which varies in height and volume. A digester is equipped with various types of mixing and heating devices to keep the manure at 35°C⁶. The primary motivation for constructing a digester and keeping the temperature around 35°C is to utilize poultry manure to produce biogas²⁸. In this case, the anaerobic digestion produces a biogas which is a combination of methane and carbon dioxide. There are three realistic options for using poultry biogas:

- Use it directly for cooking, lighting, space heating, water heating, grain drying or gas-fired refrigerating and air-conditioning;
 - Transform it into electricity by burning it in an engine that turns a generator; or
 - Vent it into the atmosphere.
- (C.A.M.M.G., 1979)

In most digesters, a generator is used to produce electricity and the heat from the generator engine is used to maintain the 35°C temperature of the digester. Poultry manure also produces more biogas per unit liveweight than any other common manure²⁸.

There are several advantages to operating an anaerobic poultry manure digester. It is a stable and reliable process as long as the digester is loaded daily with a uniform quantity of waste; the digester temperature is kept constant, and antibiotics in the waste do not slow down biological activity¹⁷. The process converts the biodegradable organic portion of poultry manure into biogas. The remaining semi-solid is relatively odour-free and retains all the nitrogen, phosphorous, and potassium of the original poultry manure which can be spread on agricultural fields⁶.

There are several disadvantages to operating an anaerobic poultry manure digester, of which the cost of such a system is the most prohibitive. The cost of the digester will depend on several factors:

- The degree of automation required;
- The amount of dilution necessary, and therefore the size of the digester;
- The investment in addition to the manure handling costs;
- The intended use of the biogas.

(C.A.M.M.G., 1979)

In Canada, other factors such as digester insulation, because of cold weather, also influence the final cost of such a system. To be economical, digester capital cost must be offset by energy savings, fertilizer use, and bedding replacement¹⁷. Another disadvantage is that fresh poultry manure can be hauled as solid manure, but if digested, the dilution water would increase the original volume by about four times⁶. As well, the biogas produced has low energy per unit volume and can only be used for on-site operations such as running an electrical generator. Other problems associated with digesters include manure handling-pumping, grinding, mixing, and screening of miscellaneous debris¹⁷. A major problem encountered with poultry manure digesters is manure grit which must be removed by a settling tank or the digester will have to be cleaned on several occasions²⁸. Other problems are gas leakage (methane is explosive at 5-15% in air) and pipe and valve corrosion.

In the U.S. in 1984, ten poultry manure digesters had been constructed, of which only four were operating²⁸. The reasons the others were not functional were due to poor system design and prohibitive economics. In a large enough poultry operation, if the digester is coupled to an electrical generator, the electrical energy produced above daily requirements may be sold to local utilities which would allow for a payback of the system in the long term. In Canada, because of extra costs and disadvantages, the use of anaerobic poultry digesters cannot be recommended for use with normal poultry operations⁶.

Although the costs of building and managing an anaerobic poultry digester are very high, if proper planning of energy and processed manure occurs, the digester can be a very effective and efficient way of treating poultry manure. Not only can it produce energy in the form of biogas (which can be converted to electricity), but the resulting processed manure is odourless and retains all of the original nutrients. In Canada, such a system would probably be best if used for high density, large poultry operations that would have

access to large agricultural fields in order to spread the processed poultry manure. Although economically prohibitive, poultry manure digesters are environmentally friendly as well as possibly being a good on-site energy source.

b) Aerobic Processing of Poultry Manure

Aerobic processing of poultry manure requires the presence of bacteria that need oxygen in order to decompose organic matter. The decomposition occurs when a mixture of diluted organic wastes is supplied with oxygen⁶. When these conditions occur, the aerobic bacteria use the diluted poultry manure as a food source in various biochemical and oxidation reactions to reproduce themselves. When the aerobic processing of poultry manure is functioning properly, the end products are: new bacterial cells, carbon dioxide, and, primarily, water⁶. In reality, not all of the poultry manure will be digested aerobically and a certain accumulation of these stabilized solids along with fixed solids will occur⁶. There are several ways in which poultry manure can be aerobically processed. The various methods which will be discussed in this review are: aerobic lagoons, aerobic ditches, composting and dehydration of poultry manure. As well, the topic of poultry manure incineration will be briefly discussed in this section.

i) Aerobic Lagoons

The aerobic lagoon works very much on the same principle as does an anaerobic lagoon except that the aerobic lagoon is aerated in some way. There are basically two types of aerobic lagoon. They are: the naturally aerated lagoon (sometimes called an oxidation pond), and the mechanically-aerated lagoon⁶.

The naturally-aerated lagoon is very similar in construction to an anaerobic lagoon except in depth. They are usually shallow (up to 1 m in depth) and bacteria and algae are expected to process the organic matter⁶. The advantages of a naturally aerated lagoon are its flexibility, its capability to minimize odours, and its low initial costs. Unfortunately, the lack of a long warm summer in Canada and the ease with which it is possible to overload naturally aerated lagoons has limited their success here for poultry manure management⁶. Another disadvantage to the naturally aerated lagoon is that in the winter time, it is subject to freezing, which completely stops the decomposition process.

The mechanically aerated lagoon is also very similar in construction to the anaerobic lagoon. In this case, a mechanical aerator which is a pump or blower is designed to float in place in the lagoon⁶. There are several advantages to mechanically aerated lagoons. There is a certain flexibility with regard to existing building as well as fairly low initial costs⁶. There is also a very large reduction in the total organic content and nitrogen content when compared to the original poultry manure. Along with these reductions, another benefit of the mechanically aerated lagoon is the ability to control decomposition odours. If not properly planned and operated, a mechanically aerated lagoon can become unsightly. In Canada, as with naturally aerated lagoons, mechanically aerated lagoons are subject to freezing in the winter. In order to prevent growth of odour-producing bacteria

and to restart the aerobic decomposition process, the aerator in the lagoon should be started as soon as possible in the spring⁶.

In the United States, mechanically aerated lagoons are often used in poultry operations where odour control and land for application are at a premium. It has been found that in poultry operations over 90% of the organic content can be removed along with over 80% nitrogen removal⁴. The large decrease in organic content is due to aerobic bacteria action while the high level of nitrogen loss is due to ammonia volatilization by the surface aerator⁴. Not only are the organic content and nitrogen levels greatly reduced in mechanically aerated lagoon, but odours are also undetectable in properly-maintained lagoons⁴.

In the case of both the naturally and mechanically aerated lagoons, properly designed and managed systems are an effective and cost-effective way of treating poultry manure. The aerobic action in both types of lagoon removes most of the constituents out of the poultry manure which are useful in normal manure application. In regions where high density, large volume poultry operations function and a premium is placed on odour control and terminal land application, the use of aerobic lagoons is economically inviting and is an adequate method of treating poultry manure.

ii) Oxidation Ditches

The oxidation ditch is very similar in function to the mechanically aerated lagoon. It is an open channel pit shaped like a racetrack in which a paddle, brush type rotor or an air pump supplies oxygen to the liquid manure and keeps the liquid contents of the ditch in circulation⁶. They are often used under caged floor systems for poultry⁶. There are several advantages to oxidation ditches, such as:

- A properly designed, installed and operated oxidation ditch can reduce odour production dramatically.
- Similar to aerobic lagoon, the organic content and the nutrient content of the poultry manure can be significantly reduced by the aeration of the ditch by a rotor.
- The ditches generally require less space than a lagoon and the costs of collection and transfer are fairly low.
- The system works well in cold climates provided that a majority of the ditch is within the confinement facility.
(C.A.M.M.G., 1979)

There are also several disadvantages to oxidation ditches which include:

- Not only can the construction and installation costs be high, but maintenance can be a problem.
- Foaming and scum formation of the ditch contents often occur.
- A ditch that is not properly designed, installed, and maintained can become a hazard to livestock and an eyesore.
(C.A.M.M.G., 1979)

A properly designed and managed oxidation ditch can be an effective method for treating poultry manure. Although costly in construction and maintenance, it has reduced manure collection and transfer costs. The aerobic action of the bacteria reduces organic and nitrogen levels. Again, in regions where high density, large volume poultry operations function and premiums are placed on odour control and land application, oxidation ditches are a feasible way of treating poultry manure. The cost effectiveness of this system can be enhanced if a reimbursement occurs from the pasture upon which the treated poultry manure is applied. As it stands, oxidation ditches are too costly for normal Canadian poultry operations.

c) Composting of Poultry Manure

One of the most promising ways in which to aerobically process poultry manure is by composting it. Composting is a relatively fast aerobic process in which organic matter is degraded by bacteria and fungi to produce a relatively stable humus-like material. The aeration of the poultry manure can be achieved in several ways. It can be done by mechanical scraper or windrower⁶. High rate composting can be accomplished by using a large rotating drum into which forced air is supplied¹⁷. The composting process is self heating to about 60°C and can produce compost in about ten days if favourable conditions are maintained⁶. Poultry manure can be effectively composted if the moisture level is kept between 50-60% and a good mixing ingredient such as bedding or paper wastes is mixed with it. The composting of poultry manure can achieve several advantageous objectives including:

- Stabilizing putrescible organic matter.
 - Killing pathogens and weed seeds.
 - Producing a uniform, sterile, relatively dry end product, free from odours.
 - Conserving the nutrient content and organic matter found in the raw poultry manure.
 - Conducting the process free from insects, rodents, and odours, as inexpensively and dependably as possible.
 - Producing a valuable fertilizer and soil conditioner.
- (Livestock Waste Facilities Handbook, 1985)

Compost addition to soils improves moisture retention of light soils and pore volume of heavy soils while providing a soil structure which is relatively stable and resists erosion¹⁷. The extent and speed of the composting cycle are affected by moisture content, particle size, aeration temperature and initial carbon-nitrogen ratio¹⁷. There are disadvantages to composting. They include:

- The process can become expensive if high rate composting is desired. It requires special equipment for the aerating and mixing of the compost.
- Composting is both labour-intensive and time consuming. Good composting usually requires daily mixing⁶.

- The compost is not rich in fertilizer value, containing 0.5% nitrogen, 0.4% phosphorous, and 0.2% potassium. (Livestock Waste Facilities Handbook, 1985)

Composting is gaining wide popularity as a means of recycling bio-degradable wastes. It only makes sense that composting poultry manure would be an environmentally and economically desirable way of processing poultry manure. It may not be cost effective to compost poultry manure in high density, large volume poultry operations, but it would be an effective means of processing poultry manure in a normal Canadian poultry operation. The application of the compost could be to improve land owned by the poultry operation. If land is at a premium, poultry manure compost could be sold on the market to be used by consumers or used as a principal ingredient in animal feedstuff. The latter case will be discussed later on in this review.

d) Dehydration of Poultry Manure

Poultry manure has a higher dry matter content than any other manure. It is costly to add water to poultry manure because:

- Water is expensive, adds weight and volume.
- Liquid poultry manure requires special collection transfer, processing, and disposal equipment, which can be costly.
- In several circumstances, water addition allows for anaerobic processes to start in the manure, leading to high nutrient loss and decomposition odours. (Kroodsma, 1986)

It is obvious that poultry manure would have a great potential in its drier form. Poultry manure is highest in nutrients, the driest to begin with, and can be further dried in the poultry house by several methods of ventilation and heating⁶. There are several ways in which poultry manure can be dehydrated. These include: the deep pit system over high rise poultry buildings, the in-house manure drying system on slats, the in-house manure drying-system on belts, and the dehydration of poultry manure by mechanical dryer systems.

The deep pit system over high rise poultry buildings involves having the collection of poultry manure under the cages in deep pits. Air drying occurs when circulating fans in the pit dry the poultry manure to a moisture content of 50% or less¹⁷. With sufficient circulation and ventilation, the dried poultry manure can be handled as a solid and the problem of ammonia and odours of wet pits are avoided. As well, a better overall environment for staff and stock is provided when poultry manure is dried⁸. The advantages of this system include:

- Collection, transfer, and processing costs are low.
- The dried material is easy to stockpile and the air pollution is low⁷.

- The dried poultry manure can be used for animal feeds if dried to 10% moisture, or can be used for horticultural products if dried to 35%.
(Akers et al, 1975)

There are several disadvantages to natural air drying of poultry manure, including:

- Nitrogen losses are high.
- Nutrient energy losses are high.
- Dried material may contain pathogens.
- Dried manure may contain large chunks which may require pulverization before use.
- Slow drying rates limit feasibility.
- Successful natural drying is limited to arid and semi-arid regions.
- Only the solid fraction is utilized.
(Day, 1980)

In the case of the deep pit system of drying, air circulation by fans is necessary to dry the poultry manure and stirring the poultry manure by mechanical means enhances the drying effect.

The in-house manure drying system on slats is an efficient and economical method of in-house manure drying⁸. It is a more efficient and economical way than drying poultry manure in the deep pits system. It requires less mechanical drying and uses the existing ventilation for drying on wooden slats.

The system uses slats of wood to collect the poultry manure. The wooden slats are set up on a two-level system. On the top level, slats and gaps of 10 cm are used to allow half the manure to pass on to the lower level and provide unrestricted air circulation⁸. The lower level has 12.5 cm slats with 7.5 cm gaps. The manure collects in tall columns and is continuously dried until the manure is removed. The efficiency of the system derives from the facts that:

- Fresh manure adheres continuously, producing tall columns with a large surface area.
- The warm ventilation air passes over these columns before being exhausted below the slats through windproof outlets in the pit walls.
- Heat is provided by stock as they metabolise the energy of the food, and air movement by the existing ventilation system.
(Elson and King, 1975)

When the birds are removed from the house, the slats are removed and the manure is deposited on the pit floor. The manure can then be handled in solid form by tractor and loader. A certain amount of poultry manure is deposited on the pit floor originally. Normal poultry manure has enough moisture for it to adhere to the manure columns on

the slats. The poultry manure which does not adhere to the columns is much drier and falls directly into the pit. Narrow slats with narrow gaps result in faster drying, but because of the narrow gaps, "bridging" of the poultry manure occurs and the drying process slows down or the slats have to be emptied earlier⁸. A slatted sample which has been dried for six months has the analysis which is shown in Table 4.

Table 4: Analysis of a typical sample of slat-dried poultry manure

	<u>%</u>
Moisture	15.0
Nitrogen	4.9
Phosphorus	2.1
Potassium	2.3

(Elson and King, 1975)

The slat drying method overcomes the problem of ammonia encountered in deep pit high rise houses. The manure is in a much drier form and consequently less ammonia is produced⁸. Since the levels of ammonia are lowered, a very significant decrease of in-house odour will result⁸.

The slat system of in-house poultry manure drying has several advantages, such as:

- Manure moisture content can be reduced to 12-15 percent at no fuel cost.
- The dried material produced is convenient to handle and can be ground to yield a pleasant, odour-free product.
- This product has an enhanced value over wet manure and can be utilised as a fertilizer or feed ingredient.
- An amenable pollution-free house environment is provided for staff and stock.
- The drying system does not produce offensive odours as in wet pit houses.

(Elson and King, 1975)

There are a few disadvantages to using the slat system, such as:

- Although the system is not costly or labour intensive, the wooden slats and forms must be purchased and constructed.
- Usually, the slats must be emptied every six months or so to avoid "bridging" of the poultry manure.
- Several of the disadvantages listed in the natural air drying in the deep pit system are also applicable here.

(Elson and King, 1975)

The slat drying system is a cost-effective and environmentally friendly way of simply drying poultry manure. This dried product can then be used as a fertilizer or feed ingredient. It appears that this system is a very cheap, effective way of processing poultry manure.

Another system which is used to dehydrate poultry manure is in-house manure drying on belts. This system is based on a two-phase drying system. The first phase involves the predrying of the poultry manure on belts by means of air¹⁵. The second phase involves the postdrying of the manure in covered storage by means of internal heating¹⁵. This method requires heat exchangers to speed up the drying process. The poultry manure is allowed to accumulate and dry on the belts for one week. After drying on the belts for one week, the poultry manure has a dry matter content of about 45%¹⁵. Manure with a dry matter content of about 45% is unsuitable for transport and storage in the open air. Anaerobic processes readily take place in such manure, the result being a sticky, malodorous manure which is difficult to process¹⁵. The manure is further dried by storing in sealed containers and allowing spontaneous internal heating to occur. This heating process begins quickly in stored manure and is promoted by the fact that a new layer of manure is dropped on the heating pile every week¹⁵. After a heating period of six weeks, poultry manure is obtained with a dry-matter content of 55-60%¹⁵. This manure can now be easily transported and stored as a solid without objectionable odours. In the spontaneous heating process, high temperatures in the top layers have been recorded (>60°C) while the layers below vary between 30 and 50°C¹⁵.

There are several advantages to dehydrating poultry manure on a belt system. They include:

- The overall process is speeded up when compared to the deep pit method and the slat method.
 - It is a method that is applicable anywhere in the world, including humid areas.
 - Because of frequent removal, the environment for staff and flock in the house is good.
 - Odour emissions are limited.
 - This product can only be used as fertilizer and must be further dried if it is to be used as a feedstuff.
 - Like composting, the internal heating process can destroy some weed seeds and pathogens.
 - The manure belt batter drying system is less expensive than even the deep pit drying system.
- (Kroodsma, 1986)

There are also disadvantages to using a belt drying system, such as:

- The cost of purchase and construction of the drying system including the belts and covered store for internal heating.

- It is more labour intensive because of frequent manure removal from the belts.
 - This method requires energy in order to more rapidly dry the poultry manure.
 - As with the other air dry systems, the nitrogen and nutrient losses can be high.
- (Kroodsma, 1986)

The losses of nutrients can be minimized if frequent manure removal from the belts occurs. Experience with in-house manure drying systems has demonstrated that 50% of organic matter and nitrogen are lost during prolonged storage in-house¹⁵. The spontaneous heating process used in this system stimulates the drying process without promoting excessive nutrient loss.

The belt drying system for dehydrating poultry manure is an economical and environmentally safe way of treating poultry manure. The obtained product can be used as a substitute feedstuff. It requires a greater energy input than do the previous two dehydrating systems but is cost-efficient because of the rapid drying of the poultry manure.

The last method of drying poultry manure to be discussed is the use of mechanical dryers. The dryer is a container which is heated to a certain temperature in order to dry poultry manure. The dried product can be used for horticultural needs or for animal feeding needs. There are certain characteristics which are desirable in a mechanical dryer which include:

- Sterility - for animal feeds, by maintaining a high enough temperature for a sufficient time.
- No odour problems - the drying process should not emit odours or should be amenable to easy treatment for odour removal.
- Low labour requirement and simple-to-operate (especially for on-farm units).
- Flexibility - dryer should be capable of handling a variable composition feed and giving an adjustable product moisture content.
- Dryer should be capable of handling "foreign bodies".
- Materials of construction should be compatible with product specification and have good corrosion resistance.
- Farm units should have simple, quick start-up/shut-down procedures to maintain efficiency.
- Economy - in terms of capital cost, installation and running costs.

(Akers et al, 1975)

Compared to the three previously discussed methods of dehydrating poultry manure, the mechanical dryer system is a much more energy intensive system. Because of this heated air drying principle, there are special advantages and disadvantages to using such a mechanized system. The advantages include:

- Dry material is easy to incorporate as fertilizer or feed. It is also easy to stockpile.
 - High temperature kills pathogens.
 - Dry material is deodourized.
- (Akers et al, 1975)

The disadvantages to using such a system are:

- Air pollution may occur during processing, requiring odour control equipment.
 - Processing (dehydration) plant may be affected by zoning and/or regulatory restrictions.
 - Drying energy costs are high (these may be prohibitive in the future).
 - Equipment is fairly costly.
 - Time and energy requirements are high for collecting and for transporting to and from dehydrators.
- (Day, 1980)

The economics and suitability of a dryer system will depend on the costs of the system, the size of the operation, and the overhead associated with this system. Small scale dryers have the advantage of low overhead and applicability to the "small man" while large industrial size dryers gain the benefits of "scale economy" and the control over product quality (e.g. analysis and sterility)⁷.

There are several ways which have application in manure drying on a scale of 50,000 poultry head or more. They include: Tray dryers, continuous band dryers, batch agitated dryers, direct heated rotary drum dryers and pneumatic (flash) dryers.

Tray dryers are of relatively low capacity being applicable to the drying of fine chemicals². They are inappropriate to the drying of poultry manure because of costs, high labour, utility requirements and odour problems².

Continuous hand dryers present odour problems due to low gas velocity. Afterburners, stacks, filters and scrubbers require high gas velocities². Drying rates are low and labour requirements are high making this type of dryer unattractive².

The batch agitated dryer seems to be best suited for farm use because of its flexibility of operation. The advantages of such a system are:

- Operates satisfactorily at intermittent rates, with variable feed moisture content, and with foreign matter other than stones.
 - Low labour, running capital costs.
 - Almost certain product sterility.
- (Akers et al, 1975)

There are also several disadvantages to the batch agitated dryer system. They include:

- Maximum capacity is limited, thus losing economy of scale.
 - Low thermal efficiency.
 - High depreciation rate.
 - Nutrient losses can be high.
- (Akers et al, 1975)

It is believed that the batch agitated dryers are the most attractive means of drying poultry manure for small scale farmers (with less than 50,000 head).

Another system of drying poultry manure is the direct heated rotary drum dryer. It uses very high heat to dry the poultry manure. Because of high heating, product cooling is necessary as the material is discharged at 100°C².

There are several advantages to using the direct heated rotary drum dryer system, which include:

- Product quality is very high and the system can handle variations in feed moisture.
 - Labour requirements are low.
 - Foreign matter is readily handled.
 - Dryers can be constructed from various materials.
- (Akers et al, 1975)

The direct heated rotary drum dryer system also has some inherent disadvantages, which include:

- Capital costs are high in comparison to batch agitated and pneumatic dryers.
 - Thermal efficiency is poor during intermittent operation.
 - Nutrient losses can be high.
- (Akers et al, 1975)

From a technical point of view, rotary drum dryers are the most acceptable for poultry manure drying². The low labour requirements for the small scale farmer and the capital costs to the large scale farmer make this drying system economically non-competitive².

The last mechanical dryer system to be discussed are the pneumatic (flash) dryers. This type of dryer system has several advantages including:

- They can approach 90% thermal efficiency when run continuously.
 - Low gas flow rate and high velocity help in odour control.
 - The space requirements are low.
 - It is a gentle drying process and reduces nutrient loss.
- (Akers et al, 1975)

There are also several disadvantages to using a pneumatic dryer. They include:

- Problems of sterility due to short residence times and relatively low temperatures.
 - Tendency to form balls.
 - Necessity to macerate foreign matter in the feed.
- (Akers et al, 1975)

It is believed that with further development, the pneumatic dryers' problem of product sterility can be solved. The dryer system represents the best drying system for large scale farms (over 1 million head)².

Mechanical drying of poultry manure is becoming more feasible with the rising prices of animal feeds and fertilizers. The trend towards recycling and protecting the environment makes the drying of poultry manure suitable as well as economically advantageous. Depending on the size and requirements of the poultry farm, there is a dryer system which could provide an appropriate means of processing the poultry manure produced by such a facility.

e) Incineration

The burning of poultry manure is a very wasteful and ineffective way of processing the manure. The incineration of the manure allows for the escape of all the beneficial nutrients into the atmosphere. It produces air pollution due to odours and the release of particulate matter⁶. Since poultry manure has a high organic content, incineration still yields a product which is very high in ash content. The result is that 10-30% of the initial dry matter still remains as ash⁶. As well, collection and transportation of the manure to the incineration site make burning an expensive way to process poultry manure. Now that most Canadians have become more environmentally conscious and government appears to be developing policies which promote environmental quality and environmental sustainability, the burning of poultry manure as a means of processing and disposal appears to be very unsuitable as a proper manure management alternative.

4. *Handling Poultry Manure*

Manure handling systems operate in a very common sequence: collection, transfer, storage, removal, transport and incorporation. The system which is selected by a operation should be based on economics, engineering, public reaction and regulation as well as numerous factors related to agriculture and the operation¹⁷. The principles behind the selection of a poultry manure handling system are:

- Most systems use the poultry manure as a soil fertilizer. Only a few systems currently have other end uses such as refeeding.
- All of the systems are compromises between investment, labour, convenience, aesthetics, and regulations.
- No system is best. Each has advantages and disadvantages. The ideal system for a specific operation depends on capital and labour, waste sources, soil type, cropping practices, personal preferences, and a number of other factors.
(Livestock Waste Facilities Handbook, 1985)

A good summary of poultry manure handling systems is located in Appendix IV. It provides a quick outline of what will be discussed in depth in this section of the review.

The manure handling system starts with the feeding system. The idea behind poultry production is that feeds are converted to poultry products under controlled conditions. An integral part of making the system work is to have manure handling under control⁵. The birds are usually situated near to water and feed while eggs and birds are kept away from the manure⁵. Providing a litter material aids in the drying of manure by moisture absorption and release⁵.

In most cases, the moisture content of the manure is the determining factor on the selection of handling equipment and facilities to be used by an operation. The manure is handled either in liquid, solid or semisolid form. Liquid manure is usually obtained by adding water to poultry manure. Solid manure is obtained by either adding litter or drying of the poultry manure. Usually, poultry manure is not handled in a semisolid state.

This section of the review will be concerned with looking at the various components involved in poultry manure handling. As poultry manure is a valuable by-product of poultry production, this section should provide insight on how manure handling systems become an integral part of poultry management⁵.

a) Collection

A very brief summary on how poultry manure is collected in cages and broiler systems has already been presented in Appendix I. Most of the caged poultry systems involve a pitted system. The manure is then treated as a liquid or solid and is transferred and stored depending on its consistency.

The manure movement to the pits below the cage row happens in one of four ways:

- Straight drop.
 - Deflecting chutes.
 - Mechanically scraped dropping boards.
 - Collecting trays between decks, conveyed mechanically to one end of the cage row.
- (Bird, 1982)

For the deep pit or "high rise" houses, which has long term storage below the cages, the process of manure collection is completed here. The other types of pits (shallow and medium depth) are lumped together under the category of "conventional" houses. For these systems the collection is completed by the use of:

- Cable pit scrapers and cross auger.
 - Garden tractor with wing-type scraper blades and cross auger.
 - Self propelled pit scraper and cross auger.
 - Hydraulic flushing.
- (Bird, 1982)

Some of these methods work best when the manure is in solid form while others work best when it is in liquid form. The pit scraper is the only method that will work with floor supported cage rows⁵. It is generally operated in the range of daily to weekly intervals⁵. The garden tractor or self propelled scraper is used with suspended cages and is operated in the range of weekly to monthly intervals⁵. The hydraulic flushing system has a very limited use because of the odours evolved in the pits of the systems⁵. Tractor scrapers, cable scrapers and cross augers work easier with wet manure or very dry manure. Since very dry manure is hard to obtain, these methods are best suited to liquid manure systems⁵.

The litter or floor systems of poultry manure collection involve the simple accumulation of poultry manure mixed with litter to control the moisture content. This mixture collects on the floor of the poultry house and can be removed after each brood or can be left for a long period of time. The manure can then be collected by using either a tractor-mounted manure loader or scraper, elevator stacker or piston pump¹⁷. It is very

important that proper planning for the facility be observed so that convenient access for the loading and handling equipment is provided.

The collection of poultry manure involves basically the caged and litter systems. Most facilities employ either pits in the caged system or simply the floor in the litter system. The systems diverge in their transfer and storage facilities depending on the moisture consistency of the obtained poultry manure.

b) Transfer and Storage

The collected manure is transferred and stored in various methods depending on whether it is in liquid or solid form. As already discussed, there is no further need for transfer for poultry manure in "high rise" houses as it is usually stored in the deep pits.

In the more "conventional" type houses, the manure is transferred to storage by a cross auger⁵. This completes the manure collection by receiving the manure and conveying to the side of the house where it is elevated into a liquid manure storage tank⁵. If a below-ground storage tank is used for storage, no cross auger is necessary⁵.

In the litter system, the transfer is accomplished by using a tractor and bucket loader if the storage area is close. If the storage area is located at a distance, then the manure must be loaded onto a dump truck or manure spreader to be hauled to storage⁵.

The high-rise house uses "in-situ" storage for the poultry manure. In most cases, the manure is deposited on the floor of pits located under the cages. The manure is then air dried in this storage area. This system requires a circulation and exhaust system to further dry the manure and to remove airborne odours and chemicals. Poor drying conditions occur in hot, humid weather⁵. As well, excessive water consumption and spillage can result in water collection within the pits. This gives rise to odour production due to anaerobic conditions as well as the production of certain noxious chemicals such as ammonia.

The type of storage facility used for "conventional" type houses is a liquid manure tank. The location of such a tank should be convenient to the house but at a site where expansion of the facilities and storage areas can occur⁶. It should be easily accessible to allow easy transport to and from the storage area. The storage facility should be located far enough away from local residences that it will not be a nuisance. In below-ground storages, areas with a high water table and surface runoff should be avoided⁶. In above-ground storages, the soil should be compacted enough to prevent settlement of the storage structure⁶. In the liquid storages, agitation or aeration may be required to control odour emissions. As well, it may be necessary to cover these storage areas to avoid odour emissions and rain water collection. If an earthen storage is used, it must have manure-tight soil conditions or a water proof lining is required.

The type of storage facility used for broiler litter can range from an open pile on a well drained site to a covered storage facility⁵. An existing concrete slab or a horizontal silo

also make good storage areas. Storage next to a bucking wall is recommended so that loading of the manure by a tractor-mounted bucket is easier¹⁷. It is also highly recommended that if the litter is already fairly dry, it should be stored in a covered area in order to keep the litter dry and relatively odour free⁵.

The transfer and storage of poultry manure is dependent on the liquid and the solid consistency of the manure. In a solid system, the poultry manure is usually stored in a dry location for further processing or for application as fertilizer. In a liquid system, the manure is stored in a tank or lagoon where it is left until it can be applied as a liquid fertilizer.

c) Removal, Transport, and Incorporation

As with collection, storage and transfer, the removal, transport and incorporation of poultry manure is fully dependent on the form in which the manure has been stored.

The "in situ" storage of dried poultry manure usually presents special removal problems. These problems are related to the very large volume of manure to be removed by loader bucket and the long travel distance required to retrieve each load in large "high rise" poultry barns⁵. This removal time can be shortened if more than one removal entrance to the poultry house is provided. Since most "high rise" houses allow their poultry manure to collect for several months or years, the removal of the poultry manure can be expected to take a fairly lengthy amount of time⁵.

The dry poultry manure can be transported and spread with any conventional type of box spreader⁵. They can also spread wastes by flail type spreaders, dump trucks, earth movers, or wagons¹⁷. The poultry manure should be spread as evenly as possible. The application of the solid poultry manure is usually by broadcast with plowdown or disking, or by broadcast without plowdown or disking¹⁷. To avoid excessive nutrient loss, the poultry manure should be spread at a time when the land can be immediately plowed or tilled⁵. The poultry litter which is obtained from broiler operations can be removed, transported, and incorporated in the same way as caged layer solid waste. Compared to other dry manures, broiler litter is likely to be spread more thinly⁵. In order to control odours and to preserve plant nutrients, quick incorporation after spreading should occur.

The liquid poultry manure can be handled as a liquid if the wastes are up to 4% solids¹⁷. From 4-15%, the waste is semi-solid but can be handled as a liquid provided special equipment such as chopper pumps for cutting fibrous materials and piston pumps for handling waste with bedding is used¹⁷. If large quantities of liquid are to be handled, it may be preferable to use a pipeline instead of tank transports.

Irrigation equipment disposes of liquid poultry manure while adding fertilizer and water to crops. This system can help pay for itself by improved crop production resulting from the irrigation. There are several ways of irrigating agricultural land with poultry manure. These methods include:

- Surface irrigation.
- Sprinkler irrigation.
- Soil injection.

Surface irrigation is delivered through a portable or stationary pipe and spread by a gated irrigation pipe or an open ditch with siphon tubes. There are several advantages to using a surface irrigation system. These include:

- Low cost.
 - Low power requirements.
 - Few mechanical parts.
- (Livestock Waste Facilities Handbook, 1985)

However, surface irrigation systems also have several disadvantages, such as:

- They require a high degree of management skill to avoid runoff and to get uniform distribution.
 - They are inflexible with respect to land area.
 - They require a moderate amount of labour.
 - They cannot be used on lands with greater than a 2% slope.
- (Livestock Waste Facilities Handbook, 1985)

Unless quickly absorbed by the soil, there can be a high degree of nutrient loss with respect to irrigation methods.

Table 5: Nitrogen losses during land application

Percent of N applied that is lost within four days of application

Application Method	Type of Waste	Nitrogen Loss (%)
Broadcast	Solid	15-30
	Liquid	10-25
Broadcast With Immediate Cultivation	Solid	1-5
	Liquid	1-5
Knifing	Liquid	0-2
Sprinkler Irrigation	Liquid	15-35

(Livestock Waste Facilities Handbook, 1985)

Table 5 is highly indicative that nutrient losses occur rapidly when any kind of manure irrigation system is used and the manure is not quickly cultivated into the soil.

Sprinkler irrigation allows for the distribution of liquid poultry manure on rolling and irregular land. There are advantages to using sprinkler irrigation, which include:

- Labour requirements are low.
- Some systems can be automated.
- Application can be more uniform.

(Livestock Waste Facilities Handbook, 1985)

There are also several disadvantages to using sprinkler systems. They include:

- Initial and operating costs are higher than for surface irrigation.
- Odours from sprinkled manure can be a nuisance.
- Nutrient losses from a sprinkler system can be very high.

(Livestock Waste Facilities Handbook, 1985)

There are several kinds of sprinklers available for use with poultry manure. These include:

- Sprinkler nozzles.
- Handmove sprinklers.
- Towline.
- Stationary big gun.
- Towed big gun.
- Travelling big gun.

(Livestock Waste Facilities Handbook, 1985)

A brief discussion of the advantages and disadvantages of each of these sprinkler systems follows. A picture of the various sprinkler systems and of surface irrigation can be found in Figure 1.

Sprinklers range in size up to large gun-type sprinklers with over 1" nozzles and over 1,000 gallon per minute capacity¹⁷. Sprinkler systems usually have many small nozzles while big gun systems have one large nozzle for long distance sprinkling. Larger nozzles are less likely to become plugged than smaller nozzles.

The handmove sprinkler system has several advantages, such as:

- Low initial investment.
- Few mechanical parts to malfunction.
- Low power requirements (50 psi at the sprinklers).
- Adaptable to field shape. Different lengths can be set and run in almost any direction to get to isolated corners.
(Livestock Waste Facilities Handbook, 1985)

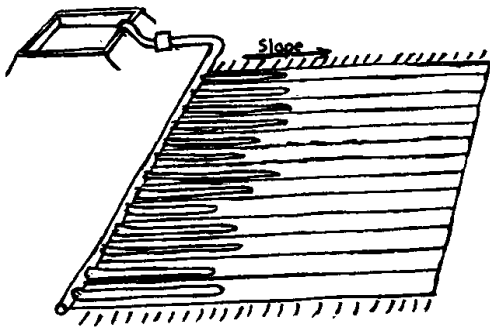
There are also disadvantages to using a handmove sprinkler, which include:

- High labour requirement; individual pipe section are moved, which can be a very unpleasant task with waste.
- Small sprinklers can plug up.
(Livestock Waste Facilities Handbook, 1985)

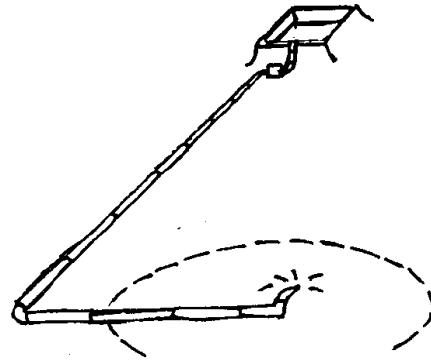
Another system which is very similar to the handmove system is the towline sprinkler system. The advantages of this system are:

- Low initial investment.
- Lower labour requirement than the handmove system; the operator does not have to work in mud and manure to make moves.
- Few mechanical parts to malfunction.
- Low power requirements (50 psi at the sprinklers).
(Livestock Waste Facilities Handbook, 1985)

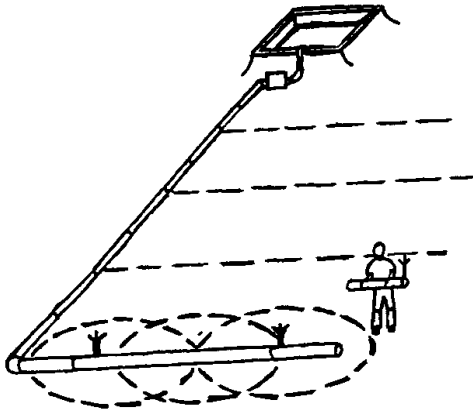
FIGURE 1: LIQUID POULTRY MANURE IRRIGATION SYSTEMS



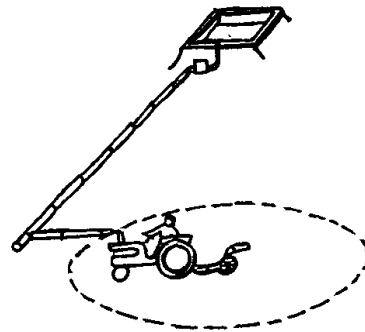
Surface system



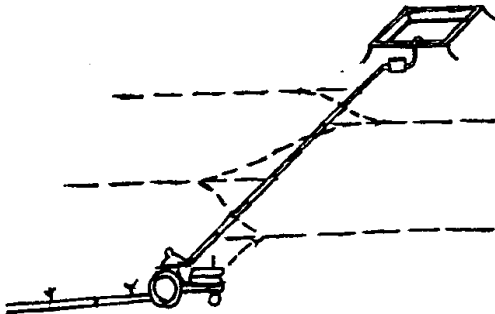
Stationary big gun



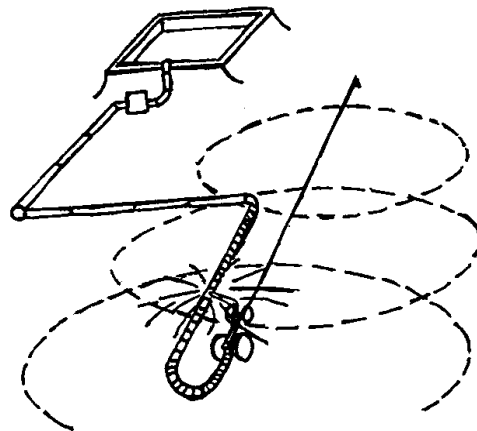
Handmove system



Towed big gun



Towline system



Traveling big gun

(Livestock Waste Facilities Handbook, 1985)

The towline sprinkler system also has several disadvantages, such as:

- Irregularly shaped fields can be a problem because of fixed lateral length.
- Small sprinklers can plug up.
- Driving lanes for the tractor are required in tall row crops. (Livestock Waste Facilities Handbook, 1985)

The next sprinkler system to be looked at is the stationary big gun sprinkler system, which is applicable to many waste disposal systems. The advantages of the stationary big gun sprinkler system include:

- Few mechanical parts to malfunction.
- Few plugging problems with large nozzle.
- Flexible with respect to land area.
- Pipe requirements are slightly less than with small sprinklers.
- Moderate labour requirement. (Livestock Waste Facilities Handbook, 1985)

The stationary big gun sprinkler system also has some disadvantages, which include:

- Moderate to high initial investment.
- High power requirement (90 psi at the sprinkler).
- Uneven distribution in windy areas. (Livestock Waste Facilities Handbook, 1985)

Another sprinkler system to be looked at is the towed big gun, which is a towline where the small sprinklers have been replaced by a big gun sprinkler nozzle. The advantages of the towed big gun sprinkler system include:

- Few mechanical parts to malfunction.
- Lower labour requirements than handmove or stationary big gun systems.
- Few plugging problem with large nozzle.
- Pipe requirements are slightly less than with small sprinklers. (Livestock Waste Facilities Handbook, 1985)

The disadvantages of the towed big gun sprinkler system include:

- High power requirement.
- Not as flexible with respect to land area.
- Driving lanes are required for tractor. (Livestock Waste Facilities Handbook, 1985)

The last sprinkler irrigation system that will be looked is the travelling big gun sprinkler system. This system is best suited for very large field acreages which require irrigation several times a year. The travelling big gun sprinkler system has the following advantages:

- Lowest labour requirement of all of the systems listed.
 - No plugging problem with the large nozzle.
 - Flexible with respect to land area.
- (Livestock Waste Facilities Handbook, 1985)

The travelling big gun sprinkler system also has some disadvantages. These include:

- Higher initial cost than the other systems.
 - High power requirement.
 - More mechanical parts than the other systems, especially with an auxiliary engine.
- (Livestock Waste Facilities Handbook, 1985)

Sprinkler systems are a very efficient way of delivering liquid poultry waste to farm acreages. If such a sprinkler system is used that is well planned and managed, then it can also be an efficient way of irrigating the field with liquid poultry manure. Table 5 clearly indicates that nutrient loss can be minimized in a liquid system when the fluid can be quickly incorporated into the land. Simply irrigating using liquid poultry manure is a very wasteful procedure. A little proper planning and management can make any of the irrigation systems efficient as well and environmentally responsible.

The last irrigation method to be discussed is soil injection (or knifing) of liquid poultry manure. This method involves the use of soil injectors which push the liquid poultry manure, while under pressure, from the tanker through tubes located behind deep cultivator teeth⁶. This type of system using soil injection has several advantages such as:

- This holds the greatest potential for odour control.
 - It can lengthen the time manure can be applied in the spring.
 - It can incorporate liquid manure into hay and pasture crop without completely destroying the crop.
 - It also achieves an acceptable rate of application.
- (C.A.M.M.G., 1979)

Although soil injection is the best ecological way of irrigating fields with liquid poultry manure, the system still has a few drawbacks. These disadvantages include:

- Refinements are still needed to avoid buildup ahead of the injector unit.
 - Work is needed to ensure that there is adequate coverage behind the injector unit.
 - Injectors should be made suitable for row crop application under a wide range of crop types, crop sizes, and soil conditions.
- (C.A.M.M.G., 1979)

Since poultry manure is a valuable product of poultry production, farmers have adopted very practical ways of collecting, storing and utilizing the manure. Most of the handling

systems deal with poultry manure in liquid, solid or semisolid states. In liquid and semisolid states, poultry manure is used as a fertilizer to enrich farmland. In the solid state, poultry manure can be used either as a fertilizer or can be used as a feed ingredient for livestock. Considering that most of the nutrients contained in poultry feed are processed into manure, it only makes sense that using this product to fertilize agricultural lands or to feed livestock is a very good, sustainable environmental approach.

5. *Poultry Manure Management - Guidelines and Legislation*

There are several regulatory programs which cover manure management practices. It is beyond the scope of this review to analyze and discuss the legislation covering manure management practices. Legislation programs will be pointed out; if the reader requires further information, he or she can seek out the appropriate legal documents. This review will provide a brief overview of the guidelines and legislation of manure management in Canada. Management practices are both federally and provincially regulated. As well, U. S. and British legislation will be pointed out where their appropriate management practices are different than those in Canada. This section of the review is meant to be a very general overview and will not in any way attempt to present and discuss specific sections of legislation.

In Canada, the federal government plays a small part in the legislation of manure management. There are basically two acts which have implications in all parts of Canada; namely, the Fisheries Act and the Canada Water Act. The Fisheries Act provides legislation that covers control of pollution in water frequented by fish⁶. The Canada Water Act provides for the conduct of cooperative federal-provincial watershed studies which can be used to establish water quality standards⁶.

Provincial governments in Canada have a majority of the responsibility for the regulation of farm nuisance and pollution problems⁶. Provinces tackle the problem by regulating farm pollution problems through guidelines and education programs as opposed to the use of specific and detailed regulations⁶. A growing number of provinces are adopting a certificate of compliance program wherein written approvals are given to operations that comply with recognized standards⁶. A summary of relevant provincial guidelines and legislation can be found in Appendix 6.

Most provinces regulate waste management through several agencies and acts. Although the agencies may be different, the methods are quite similar. All provinces realize that land has a limited ability to accept manure without causing problems such as water pollution. Many provinces have distance requirements which properly distance manure facilities from public residences, roads, and waterways. Several provinces have legislation regarding both liquid and solid manure handling systems. It is realized that careful planning and sound management can go a long way in preventing possible problems associated with manure production. As well, most provinces have some kind of legislation on how and when manure should be spread in order to protect water courses. It is obvious that all of the provinces are involved in many ways in protecting the environment from poor manure management practices. All provinces follow basic premises in order to achieve this objective. It is important to note that most of the legislation and regulations regarding poultry manure management are really common sense and that proper design and management usually prevent problems associated with poultry manure.

In the United States, the legislation and regulations about poultry manure management are very similar to those in Canada. Federally, poultry manure is legislated by the Environmental Protection Agency (EPA) under the Federal Water Pollution Control Act

Amendments of 1972³. As well, federal regulation is legislated by the United States Department of Agriculture (USDA) under several agencies such as the Animal Waste Subcommittee of the USDA Environmental Quality Committee¹⁰. It appears that in the U.S., the federal government plays a larger role in regulating poultry manure management.

The individual states also have agencies and acts to regulate poultry manure management. The similarities between the U.S. and Canada are very obvious and will not be discussed.

What will be briefly discussed is the legislation of the Food and Drug Administration (FDA) on poultry manure. The U.S. is more heavily involved in the use of poultry manure as an animal feed ingredient. In 1967, a policy was passed by the FDA stating that it did not sanction the use of poultry litter as an animal feed ingredient³¹. Because of public interest and strong indication that poultry manure feeding was widely practised, the policy was revoked in 1980 and the regulation of animal waste refeeding was left to the individual states³¹. Because of the intensity of production of poultry facilities in the U.S., it was though prudent to expand the uses of poultry manure beyond its typical fertilizer use to a more progressive idea of waste refeeding.

In the United Kingdom, the legislation and regulations pertaining to poultry manure are again very similar to those in Canada. Federally, poultry manure is regulated by:

- Rivers (Prevention of Pollution) Acts 1951 and 1961
- Clean Rivers (Estuaries and Tidal Waters) Act 1960
- Water Resources Act 1963
- Salmon and Freshwater Fisheries Act 1975
- Public Health Act 1961
- Deposit of Poisonous Waste Act 1972
- Countryside Act 1968
- Building Regulations 1976
- Control of Pollution Act 1974
(Grundey, 1980)

It is apparent that even more so than the U.S. federal government, the British federal government is very involved in legislating farm wastes such as poultry manure. As opposed to Canada, the British have centralized more of the regulatory power within the federal government than in regional governments.

The most interesting part of the British legislation which differs from Canada's is their Control of Pollution Act of 1974. Most of their other acts pertain mostly to waters and fisheries which is very similar to Canada. In Canada, pollution legislation would be covered by provincial legislation, but in Britain this legislation is federal. Because of this difference, this act will be briefly discussed.

The Control of Pollution Act of 1974 is wide-ranging to improve the control of pollution and nuisance¹². It consists of several sections which include:

- Part 1 - Waste on Land
 - Part 2 - Pollution of Water
 - Part 3 - Noise
 - Part 4 - Pollution of the Atmosphere
 - Part 5 - Supplementary Provisions
 - Part 6 - Miscellaneous
- (Grundy, 1980)

Agriculture is mostly affected by Parts 1 and 2 but can be affected by Parts 3 and 4. It was realized that the established farming practice was to apply manure to the land as part of the production of food¹². Unfortunately, land is the water table for a nation's drinking water. This dilemma was resolved by concept of a Code of Good Agricultural Practice so that if a farmer is charged with having caused water pollution, then it will be sufficient defence for him to show in the lower courts that the pollution occurred while he was operating in accordance with the Code¹². The code is very similar to the Canadian certificate of compliance except that it can be used in court as a defence.

It should be noted that it appears that waste disposal in Britain is more heavily regulated than it is in Canada or in the United States. This is probably due to the fact that the size of the country limits the opportunity for land applications and suitable alternatives must be found. As well, poultry manure is produced in high volume, high density amounts and probably cannot all be applied to land owned by the producer. This is not yet as big a problem in Canada or the United States, but is a considerable problem in countries with a high population density and a relatively small land area, such as Britain and the Netherlands.

It is obvious that with the growing demands of consumers for poultry products, the problems of poultry manure production will increase. Countries such as Canada, the United States, and Britain have guidelines and legislation to control the effects on the environment from the disposal of these wastes. Basically, all three countries achieve this legislation by the same means. Their only real differences are that some countries have a more decentralized government which requires local or regional governments to legislate waste disposal while other countries use a strong federal government to achieve the same end results. It is most important to note that countries recognize that intense farming practices can be detrimental to the environment and they are willing to set up guidelines and legislation to protect the environment, while at the same time contributing to sustainable agriculture.

6. Environmental Poultry Manure Management

It is important to realize that poultry manure is a resource that we need to learn to use economically and efficiently³. The resulting manure from poultry productions can become a hazard to the environment as well as being detrimental to the health and safety of both humans and animals⁶. Although properly planned and managed, manure management systems can still experience difficulties that are out of control of the hands of poultry farmers. Becoming aware of the potential hazards and problems associated with poultry manure management can greatly help in the understanding and developing of sound poultry management practices. The solution to many of the potential hazards or problems is first to recognize their existence and second to exercise care and common sense to avoid them⁶.

This section of the review is given to considering some of the hazards and problems associated with the management of poultry manure. The topics to be covered in this section of the review include:

- Water pollution.
- Manure gases.
- Odours.
- Other concerns.
- Management principles.

Producers have had to change their operations to include ways of properly handling and disposing of animal manure without causing air and water pollution or health-related problems³. With environmental awareness as well as the ever increasing price of energy and fertilizer, it is now easily apparent that there are substantial physical and economic benefits of manure management. It is now regarded as a resource as opposed to its deficits as a waste³.

a) Water Pollution

The high solubility of poultry manure in water provides a strong possibility for the occurrence of water pollution. The application of excessive amounts of poultry manure can result in the leaching of nutrients through the soil and into the local groundwater. Efficient manure management ensures that manure or its constituents cannot gain access to rivers, streams, lakes, or water supplies⁶.

Pollution of water by poultry manure application can occur in several ways. The causes of water pollution are more obvious in certain circumstances than in others. Obvious examples of water pollution include:

- Direct dumping into surface water.
- Providing animals direct access to streams for drinking.

- Runoff from feedlots or stockpiles.
- Overflow from manure storages of inadequate capacity.
(C.A.M.M.G., 1979)

There are also more subtle ways of creating water pollution. The less obvious ways include:

- Spring surface runoff following the winter application of manure on frozen ground sloping towards a stream.
- Seepage from excessively high application rates on land.
- Seepage from lagoons and detention ponds constructed in porous soils.
- The possible absorption of airborne manure constituents by a nearby body of water downwind from the poultry operation.
(C.A.M.M.G., 1979)

These examples of obvious and not-so-obvious water pollution are by no means exhaustive. There probably exist several ways in which water pollution can occur that we have not fully studied or understood yet.

The addition of poultry manure constituents such as nitrates and phosphates may cause or contribute to eutrophication and the resultant unsightly growth of algae⁶. Excess nutrients in surface water can cause algae blooms, impaired fisheries, fish kills, odours and increased turbidity¹⁷. It has been found that certain agricultural practices cause higher nitrate concentrations in the ground water. The application of poultry manure to a field has increased the ground water nitrate concentrations to higher levels than commercial fertilizer²⁵. The reason that increased levels of nitrates were found in the water table is that there is excessive application of poultry manure beyond the nutrient requirements of the crop²⁵. Usually, the application rates are based on maximizing crop yields. This can result in excess soil nitrogen because the parameters limiting the application rate are other than soil fertility³⁰.

Water pollution by poultry manure can result in several consequences. The oxygen level in the water is depleted because bacteria decomposing the manure constituents demand oxygen for the process. If dissolved oxygen concentrations are seriously depleted, the water may no longer support desirable aquatic life such as fish, but instead becomes septic and unpleasant⁶.

The pollution of water resulting from poultry manure can also present a health hazard to both humans and livestock. There are several diseases that might infect both animals and man that can be transmitted in waterborne livestock waste¹⁷. The cycle of infection can be interrupted if proper land application management is used and water pollution is prevented¹⁷.

As well, the pollution of water by poultry manure may be responsible for nitrate poisoning in both animals and humans, particularly infants⁶. The nitrate pollution of water by

excessive nitrogen application may cause infant cyanosis (blue babies) and perhaps chemical diarrhoea¹⁷.

Finally, the pollution of water by poultry manure can greatly affect drinking water quality. Manure can impart taints and odours to drinking water⁶.

It is obvious that proper poultry manure management must be practised as it is easy for excess manure constituents to pollute our water. Usually, sound planning leads to the minimization of hazards involved in the application of poultry manure to agricultural lands.

b) Manure Gases

After poultry manure has been excreted by the animals, it quickly begins to undergo some type of microbial decomposition. The principle behind the decomposition is that the complex molecules in the poultry manure are broken down into simpler compounds. Often this process is characterized by the production and evolution of gases⁶. The decomposition of the poultry manure can take place in one of two ways. If oxygen is present then the decomposition is said to be aerobic. The aerobic decomposition of poultry manure is basically an odourless process which produces stabilized organic matter, some carbon dioxide and water. On the other hand, most manure practices involve anaerobic decomposition. Anaerobic decomposition is typical of liquid manure handling systems and characteristic of collection pits, holding tanks and storage lagoons⁶. The anaerobic decomposition process is characterized by obnoxious odours and the production of considerable amounts of gases which are hazardous to both man and livestock. The gases that will be discussed in this review are:

- Carbon dioxide.
- Ammonia.
- Hydrogen sulfide.
- Methane.
- Carbon monoxide.

Some of these manure gases have produced fatalities and near-fatalities, involving both man and livestock, which have resulted in property damage and loss⁶. Some of the effects and properties of these gases on humans are given in Appendix 5. The accidents resulting from these gases are usually due to excessively high concentrations within enclosed buildings. Humans can be overcome by the high concentrations of these gases because they do not suspect their presence as all of these gases are colourless. In an environmentally controlled building, noxious gases usually do not reach lethal or even harmful levels except with ventilation failure or vigorous manure pit agitation¹⁷.

i) Carbon dioxide

Carbon dioxide is highly soluble in water and is released from manure decomposition and animal respiration¹⁷. Rarely is carbon dioxide a serious problem in a well ventilated facility. Problems can occur if failure of the ventilation system occurs. Death due to

carbon dioxide asphyxiation occurs very rarely. Often in a poorly ventilated facility or a facility with a malfunctioning ventilation system, any death will probably be the result of heat stress and oxygen deficiency⁶. The effects of carbon dioxide in humans is shown in Appendix 5.

ii) Ammonia

Ammonia is also highly soluble in water and can be explosive at higher concentrations¹⁷. It has a sharp, pungent odour and acts as an irritant to moist tissues at relatively low concentrations⁶. It is released from fresh manure and during the process of anaerobic decomposition. Because of its high water solubility, ammonia can be more easily controlled in liquid systems than in solid systems. Low concentrations can greatly affect animal health and performance. There are several ways in which the concentration of ammonia can be controlled. These methods include:

- Rapid manure removal from the facility.
 - Adequate floor slopes to ensure good drainage.
 - Liberal use of bedding and increased ventilation rates.
 - Use of a liquid system to solubilize the ammonia.
- (C.A.M.M.G., 1979)

The effects of ammonia on humans are shown in Appendix 5.

iii) Hydrogen sulfide

Of all of the manure gases, hydrogen sulfide is the most toxic and is potentially the most dangerous. It is also soluble in water so that it can be somewhat controlled by high dilution rates¹⁷. The gas smells of rotten eggs. It is flammable and can be explosive in an oxygen mixture¹⁷. Hydrogen sulfide is produced during the anaerobic decomposition of manure. High concentrations can be released by agitation and pumping of liquid wastes¹⁷. The greatest risks from this gas occur when emptying tanks and pits, above which concentration levels can reach lethal levels in as little as a few minutes⁶. There are several ways to minimize the hazards of hydrogen sulfide. These include:

- Do not agitate when emptying pits located within a building. At the same time, provide maximum ventilation.
 - Remove stock from facility if agitation is necessary. If stock cannot be removed, use a windy day to ensure maximum air exchange through open doors and windows.
 - Use gas traps in sewage channels between covered outside pits and barns to prevent gas back-up.
 - Empty pits as frequently as possible, especially in warm weather.
- (C.A.M.M.G., 1979)

The effects of hydrogen sulfide on humans is also shown in Appendix 5.

iv) Methane

Methane is not very soluble in water and is highly flammable. At low concentrations, it burns with a blue flame but at higher concentrations there is a real danger of explosions⁶. The majority of methane gas is the result of the decomposition of animal manure. A very minute amount of methane can be exhaled from ruminant animals¹⁷. Since methane is lighter than air, it has a tendency to rise and pool at the top of stagnant corners or in tightly enclosed manure storage pits¹⁷. There are many ways in which methane-related risks can be controlled, which include:

- Prohibit smoking or use of naked flames in and around manure building and storage facilities.
- Use explosion-proof electric motors on fans and equipment.
- Adequately vent covered storages to outside air.
- Use U-bends or gas traps to prevent re-entry of gases from outside tanks to the facility.
- Ensure that a facility with inside manure storage is continuously ventilated.

(C.A.M.M.G., 1979)

The effects of methane on humans is also presented in Appendix 5.

v) Carbon monoxide

The last gas that will be briefly discussed is carbon monoxide. Carbon monoxide is a colourless gas of about the same density as air¹⁷. This gas is not produced directly by poultry manure but can be the result of poultry manure operations. It is exhausted from gas engines, gas, oil and coal heaters. The best way of preventing a toxic buildup of carbon monoxide is to ensure that all engines are vented to the outside of the facility. If this is not possible, then sufficient ventilation to prevent gas buildup should be provided.

Entering poultry manure storage areas and pits at any time is extremely dangerous, especially during or following emptying of the storage. As all gases produced are colourless, extreme caution should be taken when entering these facilities. There are several precautionary steps which are recommended. These include:

- Always enter such a facility with an air-breathing apparatus and harness.
- Omit the breathing apparatus only when positive ventilation is provided to ensure that manure gases are purged.
- Ensure that there is a constant supply of fresh air to the facility.
- Do not follow an animal that has fallen into a manure collection pit.
- Do not enter the facility alone. Ensure that someone is there to pull you out if you become dizzy.

- Never introduce a flame or spark near a manure collection area unless it has been ventilated first.
(Livestock Waste Facilities Handbook, 1985 & C.A.M.M.G., 1979)

The production of manure gases is inevitable because of the aerobic and anaerobic decomposition processes. The solution to the potential hazards caused by these gases is to recognize that they exist and to exercise some common sense to avoid their effects. The use of solid poultry manure management principles is the best defence against the potential hazards and risks associated with manure gases.

c) Odours

The greatest public complaint about most poultry production facilities is about the smell that surrounds such an establishment. The odours are the result of the biological breakdown of the poultry manure under anaerobic conditions within storages, whether these be piles, lagoons, or indoor pits⁶. Most of the public complaint results when the manure is being spread as a fertilizer on an agricultural field. There are components of odours which are relevant to research. These are: odour quality - comparing with a known odour; odour strength - the amount of fresh air needed to dilute the odourous air to the threshold odour level; and odour occurrence - the frequency and total length of time the odour persists¹⁷.

The odour perceived from livestock production enterprises is the result of a mixture of odourous compounds²². Some substances such as ammonia and hydrogen sulfide are produced in easily detectable quantities while others, such as mercaptans and amines, are present in concentrations of parts per billion that are only detectable by sophisticated equipment⁶. Although they are produced in small quantities, these substances can still be perceived as offensive to the human nose. Most odours in poultry manure are the result of gases or vapours. However, particles and aerosols can also affect the sense of smell.

There are several sources of odour coming from the manure resulting from the everyday poultry operation. These sources include:

- Feed odours associated with feeding of waste materials or fermented products.
- Odourous compounds from manure-covered surfaces or treatment facilities.
- Roofed facilities often have high odour production because of high animal density, large manure inventory, and limited air exchange.
- Other structures such as manure storage tanks, anaerobic lagoons and manure-covered floors produce obnoxious odours.
- Any wet area supports widespread anaerobic decomposition and can be a source of odours.
(Miner, 1980)

The potential sources of odours in the manure of poultry operations can be controlled by various techniques. These odour control principles include:

- Some volatile compounds can be converted to a less volatile form by pH control, chemical conversion or biological conversion to a less odourous or less volatile compound.
- Another method is to inhibit the anaerobic decomposition of manure.
- A third potential for odour control is the physical confinement of the odour sources. Covered manure storage tanks and anaerobic manure treatment devices are effective in controlling the escape of odourants.

(Miner, 1980)

In recent years, manure odours have been the subject of intense research around the world. Widespread attention has been put on adding odour control chemicals to manure storage tanks or animal feeding areas²². Materials preventing the release of odourous compounds, inhibiting their formation, or masking their odour are most effective in odour control.

Oxidizing agents such as potassium permanganate have potential as odour control chemicals²². Some of these agents have been found to significantly suppress the release of odourous gases.

Enzymes and other digestive aids have also been proposed for controlling livestock production odours²². Unfortunately, product secrecy prevents manufacturers from disclosing the composition of these agents, which makes these products hard to evaluate²². In most cases, these products do not significantly reduce manure odours and most of these agents are expensive.

Since each poultry producing facility is unique, each operation will have a different approach to applying odour control techniques. Perhaps the most critical and effective means of reducing odour complaints occurs by proper site selection²². It is always necessary to consult regional and provincial regulations to properly establish a site for poultry operations.

In terms of odours, wind direction is very important in evaluating a site²². Facilities should be located downwind of residential developments. Most odour complaints occur because of poultry manure application to cropland which is offensive to residents in the neighbouring regions. Morning application of manure is more desirable than late afternoon application, which limits potential drying time²². Neighbours are generally most sensitive to odour problems in the early evening when utilizing outdoor recreational facilities²². As well, spreading of manure on land adjacent to residences or main roads should be avoided unless it is directly injected into the soil or it is immediately cultivated⁶. These methods not only limit odour production, but also minimize nutrient losses.

Odours can also become a problem within the poultry production facility. This can best be controlled by a high standard of hygiene within the facility⁶. The thorough cleaning and frequent manure removal to storages coupled with good drainage and the liberal use of bedding or litter where appropriate all contributes to maximizing the hygienic effects within a facility⁶.

The proper planning and operation of a poultry producing facility offers considerable opportunity for exercising odour control. When a properly developed system is maintained in functional order, very few odours are produced and there is less chance of complaints²². If all regulations and by-laws are observed, then the minimizing of odour nuisance comes down to basic common sense and a respect for the rights of others⁶.

d) Other Concerns

There are two other concerns about poultry manure that will be briefly discussed. Two inherent problems of poultry manure are dust and manure as a substrate for insects.

Dust, to a degree, is a feature of animal production units⁶. It can be a severe problem in poultry operations, particularly in an operation where a dry manure end product is produced. The dust is not only a physical nuisance, but it can also carry odours and certain pathogens⁶. Good air circulation and adequate ventilation will limit the effects of dust on both the poultry flock and the human operators. Proper management with a high standard of hygiene can greatly reduce the problems of dust associated with poultry manure.

The second concern is that manure makes an ideal substrate for various living things to breed and feed upon. It is an ideal breeding ground for various insects, including flies, and tends to attract birds and even rodents⁶. All of these living things tend to be a nuisance, but more importantly, they can become carriers of disease⁶. The solution to this potential problem lies again in the proper planning and management of poultry manure.

Although these concerns might not be as obvious as gases, odours and water pollution, they can become very serious. These can be controlled by proper planning and managing of poultry manure. After a system has been developed to properly take care of these concerns, it is a simple matter of keeping the system in working order to avoid the development of possible problems.

e) Management Principles

The operation of poultry facilities will always have some environmental impact. The extent to which this impact is detrimental will depend on the way the poultry operation is managed⁶. Although most poultry operations will have some common features, each operation will be unique in some way. The best way to minimize the environmental hazard from poultry manure is to examine the management options in each case. These options involve the following:

- When possible, use cropland for manure application, having regard for water pollution and making for the most efficient use of the plant nutrients in the manure.
 - If the land base is insufficient, investigate alternative means of manure disposal to arrive at an environmentally satisfactory solution.
 - Ensure sufficient manure storage capacity to eliminate uncontrolled release of manure into the environment. Storage must be of a type that will eliminate seepage into ground water.
 - Avoid land application of manure during winter and permit most effective crop use of nutrients.
 - Locate poultry production facilities to avoid nuisance complaints about odours, dust, flies, noise and aesthetics, by providing adequate separation and suitable screening.
 - Use weather conditions to best advantage to minimize odour nuisance during field spreading of manure.
 - Use soil injection or rapid soil cover of manure, and gain the benefits of greatly reduced nitrogen losses and control of possible pollution arising from surface runoff.
 - Control manure gases, particularly from stored liquid manure, to ensure the safety and health of both humans and animals, either by frequent transfer of manure from animal facilities to separate storages or by exhausting enough air from the headspace in indoor storages to prevent gas build-up.
 - Provide adequate drinking facilities for animals on pasture so they won't drink from, and contaminate, streams or lakes.
- (C.A.M.M.G., 1979)

In any specific poultry operation, some or all of these management principles may require closer scrutiny to achieve both an economically and environmentally acceptable poultry manure management system⁶. The problems associated with poultry manure management are greatly reduced in a properly planned and managed operation. The management of poultry manure can provide substantial physical and economic benefits. Since the emphasis has now rightly shifted onto sustainable agricultural development, it is quite obvious that environmental poultry manure management plays an integral part in minimizing the impact of poultry manure operations on the environment.

7. *Specific Topics Of Applications Of Poultry Manure*

a) Poultry Manure As Feedstuff

i) Dehydration

As was previously discussed in this review, poultry manure has great promise in a drier form as it is already the driest of all of the common animal manures. It can be used in its dry form as a fertilizer or alternatively, it can be used as a feedstuff ingredient for animals.

The use of animal manures as feedstuffs is conceptually attractive because it has the potential to reduce feed costs and to provide a partial solution to manure management and environmental problems²¹. The value of manures as feedstuffs can be determined by the assessment of:

- Nutrient composition of animal manures to determine sound utilisation strategies and to estimate their value.
- Monetary benefits that could result from reduced feed costs and increased revenue from meat, milk or eggs as indicated by feeding trial results.
- The pollution control benefits that might result from a refeeding strategy.

(Martin et al, 1983)

There have been several refeeding experiments using dehydrated poultry manure as a component of feedstuff. The dried manure has been considered comparable to protein feeds such as soyabean and cottonseed meals because of similarities in crude protein content²¹. It was assumed from an economics point of view that dried poultry manure was comparable to these protein feeds. Unfortunately, this is extremely inaccurate as it places emphasis on only one aspect of the manure nutrient composition²¹.

In reality, dried poultry waste appears to be nutritionally most comparable with forages such as corn silage and hays rather than with energy or protein feeds²¹. This comparison resulted from the discovery that dried poultry manure has a low digestible protein level and a fairly low energy content. The levels of protein and energy are shown in Appendix III. The dried poultry manure has a positive value as a feed material that equals or exceeds its value as a fertilizer.

It is important to realize that dried poultry manure used as a feedstuff can only be tolerated by animals up to certain concentration levels. Three specific studies that used poultry manure as a feedstuff will be briefly discussed in order to provide further insight into the uses of poultry manure for refeeding.

It has been found that the maximum and optimum levels of incorporating dried poultry manure into laying hen and ruminant rations, on the basis of animal performance, varied from 5% to 20%²⁰. Typically, when the level of dried poultry manure exceeds these

levels, the consumption of feed will increase while the production will decrease. This results in dried poultry manure not being as economically viable as when the percentage of dried poultry manure in the feeds is kept below these threshold levels. Economic analyses indicated that when dried poultry manure was used at its optimum level, its monetary value as a feed exceeded its monetary value as a fertilizer²⁰.

Dried poultry manure can be used along with other materials to provide an unconventional feedstuff. It has been found that using cardboard boxes, whole dates and dried poultry manure in the diets of sheep is an economical way of saving money¹⁴. Again, it must be emphasized that dried poultry manure can only be incorporated into the diet of sheep up to a certain maximum level. This results in poultry manure being of significant economic benefit as a feed ingredient. This benefit is quickly reduced as the amount of dried poultry manure in the feed is increased above optimum levels.

Dried poultry manure can also be used as a refeeding component of poultry diets. Results concluded that dried poultry manure can be safely included up to 10% in broiler rations without any detrimental effect on their growth rate, feed efficiency and performance²⁹. The inclusion of up to 10% dried poultry manure in broiler feed reduced the costs of feed considerably²⁹. In the case of broilers, when the level of dried poultry manure is increased above 10%, there is a very significant depression of growth rate which greatly reduces the benefits associated with using dried poultry manure in feedstuff²⁹.

When dried poultry manure is used in animal feeds, it is important to optimize the levels in the feeds and not to maximize the amounts in the feeds. As well, it should be noted that dried poultry manure can be a carrier of disease if it has not been processed properly. It is obvious that great care and planning must be used in order to successfully supplement the diets of animals with dried poultry manure. Use of this product is both economically viable as well as being an environmentally attractive way of disposing of poultry manure.

ii) Ensiling

Another way that poultry manure can be used as a feedstuff is by ensiling it. Ensiling consists of adding 20% poultry litter and 30% cage layer manure to 50% ground corn while adding some molasses and bacteria to ferment the mixture³². After mixing and storing in sealed containers, the mixture is left for 3 weeks to ferment³². The process of ensiling has several advantages over dehydration. These include:

- Nutrient losses are low.
- Ensiling improves palatability and decreases pathogens.
- Ensiling is economical and uses less fuel than dehydration.
- It provides a procedure other than dehydration that is applicable for use in animal feeds.
- Ensiling allows for a use of a greater proportion of poultry manure to be used.
- Material can be stockpiled.
- Odours are controlled.

- Liquid and solid fractions are utilized.
(Day, 1980)

There are also several disadvantages to using ensiling which include:

- Diluting material is often used at ensiling time.
- Proper ensiling takes time. It can be reduced from 6-8 weeks to less than 3 weeks by adding molasses and the proper bacteria culture.
- It requires a suitable storage container which is fairly air-tight to prevent contamination.
- Handling or labour is required for harvesting, transport to storage, ensiling material, transport from storage to feedbunk.
- Forage diluting materials are not always available because of seasonality.
(Day, 1980)

The process of ensiling can actually produce a more complete feed¹¹. The digestibility of ensiled materials is very good and the nitrogen available in the poultry manure is efficiently utilized¹¹.

Ensiling of poultry manure is another way in which the manure can be used as a component of feedstuff. It is a process which is very economical and is an environmentally friendly way of disposing of poultry manure.

iii) Processing

Other than dehydrating and ensiling, there are other ways of converting poultry manure into animal feedstuff. Although dehydration occupies a vast majority of the waste refeeding market and ensiling is a distant second, processing of poultry manure does occur in small quantities. These methods include: cooking, autoclaving and chemical processing.

The process of cooking poultry manure is very simple. It is processed by cooking 2 parts manure in 1 part water¹³. After it has been cooked for 24 hours, it is dried by oven. This process has several advantages such as:

- Nutrient losses are fairly low.
- Dry material is easy to incorporate into diet and stockpile.
- Dry material is deodorized.
- Boiling temperature of water kills pathogens.
- Animal acceptance is good.

There are also several disadvantages to cooking poultry manure. These include:

- Cooking and drying energy costs are high.
- Equipment for cooking and drying is costly.

- Time and energy requirements are high for collecting and transporting.

Although not as prevalent as the methods of dehydrating and ensiling, the cooking of poultry manure may in some cases be an acceptable way of treating poultry manure in order to refeed it to animals.

The second processing method which is very seldomly used is autoclaving. It is a method of quickly drying poultry manure. The advantages and disadvantages of this method of treating poultry manure are much the same as they are in the use of dryers. It is a very expensive process which appears to only be useful on the small scale²⁹. It is only mentioned in passing because some scientific experiments use this process in order to obtain dried poultry manure to be used in refeeding studies.

The last processing method which will be discussed is the use of chemical treatment in order to process poultry manure into animal feed. In this method, the poultry manure is collected and is chemically treated with substances such as Grazon⁷. Other ingredients such as corn are mixed in to form the desired ration. The advantages to using the process of chemical treatment of poultry manure to produce animal feeds include:

- Process increases animal acceptability.
 - Immediate harvesting and refeeding reduce losses.
 - No storage is required.
 - Odour is controlled.
 - Energy and labour requirements are low.
 - Liquid and solid fractions are utilized.
- (Day, 1980)

There are also several disadvantages to using chemical treatment methods of poultry manure to produce animal feeds. These include:

- Daily harvesting and processing are required.
 - Short shelf life does not permit extensive stockpiling.
 - Mixing equipment is required.
 - Chemicals are costly.
- (Day, 1980)

In this instance as well, the treatment of poultry manure by chemicals to produce an animal feedstuff is practiced on a very small scale when compared to dehydration and ensiling. In some cases, it can be a very acceptable way of treating poultry manure in order to refeed it to animals.

The poultry production system that is in use throughout the world produces a large quantity of poultry manure. Since many of the production facilities have a very limited land base, it is very important that we develop alternative uses for poultry manure that its usual application as a fertilizer. Poultry manure has great potential as an animal feedstuff.

It is believed that its economic value as a feed material outweighs its economic value as a fertilizer in the markets of today. Although this may be true from an economic standpoint, it should be noted that there is still very strong opposition to using poultry manure in animal feed. It is still primarily used as a fertilizer. When the application of poultry manure to available land is properly planned and managed, it can be a very positive influence on crop growth and yield. On the other hand, as feed prices keep increasing in cost, poultry manure as a substitute feed becomes increasingly attractive. The use of poultry manure as a means of refeeding in the poultry production cycle presents a very sound, sustainable, environmentally friendly way of maintaining a specific branch of agriculture which is the poultry industry.

b) Poultry Manure As Fertilizer

The most convenient and practical way of disposing of poultry manure is to spread it on agricultural land as a means of fertilizing the soil. The constituents of poultry manure that make it a suitable fertilizer are its levels of nitrogen, phosphorus and potassium. Crops generally have a higher requirement for nitrogen than for the other major elements⁶. To better understand the use of poultry manure as a fertilizer, it is necessary to understand a few basic principles about soil nutrient chemistry.

The nitrogen in freshly excreted manure is in organic form which is converted to ammonium-nitrogen. Ammonium is firmly adsorbed to soil particles but can volatilize and vast quantities can be lost from the soil in this way⁶. Bacteria in the soil convert the ammonium-nitrogen to a nitrate form which is readily used by plants. This form of nitrate does not adsorb to soil particles and is easily subject to leaching by water movement⁶.

The phosphorus in the soil is usually taken up by plants in the form of mineral phosphates which usually arise from the weathering of bedrock⁶. Phosphates are virtually immobile in soils, so that at any time, a small proportion of the soil phosphorus will be available to plants⁶.

The potassium stores of the soil are generally on the order of 10 times greater than are the nitrogen or phosphorus stores⁶. A majority of the potassium added to the soil in poultry manure is readily available and will either be used by the crop or will be adsorbed on the soil to be used on another occasion⁶. Potassium is not subject to leaching like nitrogen.

i) Non-Treated

When managed properly, poultry manure is an effective means of fertilizing agricultural soils. It has been recognized for a long time that poultry manure is a very good source of nutrients for the production of corn, small grains, fruits and vegetables³⁰. The most important nutrient in poultry manure for crops is nitrogen. The problem with applying poultry manure to a crop occurs when the applied manure exceeds the crop requirements. This results in the leaching of soil nitrates which can lead to the contamination of groundwater.

The application rates of poultry manure have often been based on the amount required to maximize crop yields³⁰. Unfortunately, this can result in an excessive amount of nitrogen being applied to the soil. The best approach to applying poultry manure to crop lands would be to optimize crop yields. This requires careful planning and management. One needs to know how much nitrogen is in the soil and in the manure as well as knowing how much nitrogen the growing crop will require³⁰. It has been found that only small amounts of poultry manure are needed to optimally fertilize most crop lands. It has also been found that manure rates in a properly planned and managed system approached the lower limits at which current manure application equipment can uniformly apply poultry manure to cropland³⁰.

There is no question that applying poultry manure can be an effective way of fertilizing croplands. The problem is that there is often excessive applications which ultimately lead to pollution and groundwater contamination. The over-application of manure to any soil over a long term will build up the nutrient content (the phosphorus level is also of concern) far beyond crop requirements⁶. This may cause water pollution resulting from excessive phosphorus as well⁶. There is a great need for research into management techniques for poultry manure. Several factors such as: manure type, soil type, soil drainage, precipitation etc... will greatly affect how poultry manure is applied to a specific crop. To prevent excessive application and pollution, the farmer needs to know and understand all of these factors to properly and safely fertilize his croplands using poultry manure. The goal of effective agronomic management of poultry manure should be to estimate the rate needed to supply an adequate amount of nitrogen, based on a realistic yield goal and any specific management considerations (tillage, irrigation) that may affect crop nitrogen requirements³⁰.

ii) Composted

Historically, the spreading of poultry manure on land as a fertilizer has been the method used for poultry waste management⁷. One of the problems with using poultry manure as a fertilizer, is that high levels of nutrients can be lost with normal methods of collection, storage and spreading on the land⁷. To avoid, high nutrient loss, manure should be harvested frequently and used immediately⁷. One way to try and limit the nutrient losses is by composting poultry manure.

The composting of poultry manure has already been discussed in the section on 'Processing Poultry Manure'. Although composting does not totally stop the nutrient loss of the poultry manure, it stabilizes the nutrient levels and prevents the further losses experienced in the spreading of untreated poultry manure on the land as a fertilizer.

The advantages of composting poultry manure for fertilizing include:

- Stockpiling is possible.
 - Composted material is deodorized.
 - The process is relatively simple.
- (Day, 1980)

These benefits make the composting of poultry manure a very sound way of processing the material to be used as a fertilizer. To prevent nutrient losses, untreated poultry manure must be removed, spread and incorporated into the soil almost immediately. Composting allows for a lag period between removal and spreading because the composted material can be stored. As well, untreated poultry manure must be incorporated into the soil immediately or the spreading can produce complaints from the odours released by the manure. Again, composting allows for later soil incorporation because the composted material is fairly stable and it is relatively odourless.

Composted poultry manure is as good if not a better fertilizer than is untreated poultry manure. Its advantages make it more suitable for a system which requires longer storage and ease of application. The only problem associated with composting is that it requires additional storage areas and can require special equipment. Composting is a very good way of processing poultry manure into a form which is excellent in terms of its use as a fertilizer.

iii) Digested

Both anaerobically and aerobically digested poultry manure are used as land fertilizer after they have been treated. The nutrient value of the obtained treated liquid depends on the treatment method used. In both anaerobic and aerobic digestion, there can be a large amount of nutrient loss from the system. This loss is inherent in the processing, handling and storage systems. The loss of nutrients results in a smaller volume of liquid that needs to be spread on the land. The obvious exception to this nutrient reduction is the use of a closed anaerobic digester system.

In the anaerobic digester, only 1% of the original nitrogen is lost while virtually all of the phosphorus and potassium remain⁶. It has been reported that digested manure is a better fertilizer than regular untreated manure based on the digested manure having a larger percentage of inorganic nitrogen that is readily available to plants⁶. Anaerobically digested poultry manure has also been used to show that application of the digested material increases both soil phosphorus adsorption as well as plant phosphorus availability⁹.

It is very obvious that anaerobic and aerobic digestion of poultry manure produces large quantities of liquid fertilizer which need to be applied to croplands for disposal. As in the case of all manures, the loss of nutrients results from the handling, processing, storing and land spreading of the liquid. When these losses are minimized, the proper application of liquid poultry manure is an effective means of fertilizing crop fields. Again, it must be stressed that proper planning and management of the whole system is needed in order to prevent waste and pollution. When a liquid obtained from anaerobic or aerobic digestion is properly applied to a crop, it is a very effective and efficient way of maintaining a sustainable method of poultry waste disposal.

iv) Dehydration

Dehydrating poultry manure is another way one can obtain soil fertilizer. The methods of dehydrating have already been discussed earlier in this review. Although dehydrating poultry manure can remove a large amount of the nutrients from the original manure, the dried form is very easy to use as a solid fertilizer. To explain in more detail how one can obtain a dehydrated fertilizer from poultry manure, the Dynamic Lifter Canada Inc. company's system of dehydration will be discussed as an example.

This company is a branch of a company that has been operating 5 processing plants in Australia for 17 years and currently produces 45,000 tons of dried poultry manure fertilizer annually²⁷. The first Canadian plant will be commissioned in Abbotsford, British Columbia, in late summer 1990. The fertilizer is produced from 100% poultry manure collected from breeder, layer or broiler birds²⁷. The process begins with the installation (free of charge) of a patented water system in the breeder or layer houses which reduces the moisture levels in the poultry manure from 70 to 30%²⁷. The company then pays a contractor to remove the poultry litter and deliver it to a centralized processing plant.

There are several benefits to the farmer who would want to be part of this type of system. They include:

- Great reduction in odours, flies and maggots because of the reduced moisture content of the poultry manure.
 - Monetary savings on bedding materials such as wood chips, which are no longer needed.
 - Monetary savings on pickup and cleaning, for which in this case the company pays for.
 - Much healthier birds.
 - The farms can be cleaned and stocked at any time of the season.
- (Romani, 1990)

In this specific example, the company simply requires the farmer to sign a contract for the rights to all of the poultry manure for the life of the poultry house.

After the poultry manure has been delivered to the processing plant, it is: composted, dried, classified and pelleted. In its final form, it has become a concentrated organic fertilizer. Its final moisture content is around 7%²⁷. It can be stored, packaged and stacked in any way without nitrate run-off and methane gas smell²⁷. The granulated and pelletized organic manure can be spread by conventional means such as broadcasters, seed drills or aerial spreading²⁷. It can be treated exactly like any other type of solid fertilizer. Because of its pelleted form, there is a controlled slow release of the nutrients in the pellet which optimizes plant growth. As well, it is possible to add nutrients to change the specifications of the fertilizer to meet custom needs of certain customers²⁷.

Although the use of poultry manure as a fertilizer is not a new concept, this company's process of altering its characteristics to improve its performance and quality as a fertilizer

as well as its aesthetically pleasing form certainly is a very well thought out approach. The dried fertilizer is practical to use and is very easily transported. It is environmentally friendly in that its slow nutrient release decreases the chances of the contamination of ground water through nitrate leaching.

The majority of other operations that dry poultry manure do not process it as much as Dynamic Lifter Canada Inc. does. The obtained dried manure can also be spread by conventional means but often it is not in pelleted form. It is fairly easy to handle in solid form and is odourless. As with any fertilizer, careful planning and management must be used in order to prevent excessive dried manure applications. These can also lead to soil toxicity and ground water contamination.

There are basically two proper uses for poultry manure. Poultry manure can be used either as a substitute feedstuff or as a fertilizer. In both cases, when a management system is properly planned and carried out, they are excellent ways of disposing of poultry manure. Both applications can have detrimental effects but with education, they can be efficient uses of poultry manure. As environmental awareness is growing, it is very positive to see a trend towards the recycling and re-using of what was once thought of as a waste to be disposed of. The use of poultry manure as a feedstuff and as a fertilizer is a strong indication that not only is the environment becoming a very serious concern but that the message of sustainable agricultural development is beginning to filter through to the general agricultural community.

8. *Conclusions*

It is inevitable that with large volume high density poultry productions, there will be large quantities of poultry manure produced in Canada and throughout the world. Poultry manure is a valuable by-product of the industry especially if one considers that a majority of the the poultry feed nutrients end up in the manure and not as animal protein.

The chemical composition of poultry manure with its levels of nitrogen, phosphorus and potassium make it very suitable as a fertilizer or as a feedstuff. Unfortunately, this nutrient richness can also lead to soil and water pollution if the disposal of the poultry manure is not properly planned and managed.

There are several ways of handling poultry manure. These vary from liquid to solid handling systems. All of the methods of manure handling have inherent strengths and weaknesses. As each poultry operation is different, each poultry operation will use a handling system that is best suited for its individual needs. Because a certain system is more environmentally friendly or cost efficient, does not mean that it is the most suitable system to use in all cases. Although very diverse, all of the poultry manure handling systems have a common trait. They all attempt to provide a system by which the poultry manure can be handled.

As in the handling of poultry manure, there are several ways of processing poultry manure. These also vary from solid to liquid processing as well as from anaerobic to aerobic processing systems. Again, all of the processing systems have their own advantages and disadvantages. One particular system may suit an operation but may be totally unsuitable for another operation. All of the systems achieve the common goal of poultry manure processing through different means.

The legislation and guidelines regarding the management of poultry manure are governed both federally and provincially. These laws are very concerned about the possible pollution effects and problems that can be associated with the disposal of poultry manure. It is really surprising to note that most provinces simply use common sense and a well thought out management practice to determine their legal policies with regards to the production and disposal of poultry manure.

Poultry manure is ideal to be used as either fertilizer or as a feedstuff because of its chemical composition. The fertilizer can be in solid or liquid form. Poultry manure can be processed into feedstuff by several different ways which make it palatable to animals. As with all other aspects of poultry manure management, there are advantages and disadvantages to using poultry manure as a fertilizer or as a feedstuff. The application of excessive fertilizer can lead to pollution while improperly processed poultry manure can carry disease and pathogens that could be harmful to the animals while refeeding.

This review provided a basic overview of the topic of poultry manure within the broader context of the agricultural system. It should be emphasized that all of the systems discussed with regards to some integral part of poultry manure management have their

own inherent strengths and weaknesses. Each operation must consider several factors before choosing which type of system is most suitable for its planned management scheme. Once chosen, if this management system is properly planned and maintained, it can become a strong integral part of a sustainable agricultural system which is both efficient as well as being environmentally friendly. It is gratifying to see that poultry manure, which was previously considered a waste product, can be effectively managed in a way so as to protect the environment while at the same time being an important cog in the wheel of a continuously growing agricultural industry.

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Summary of Waste Collection Alternatives (Poultry)¹

Confinement Housing: Caged

Shallow pit - flush
Shallow pit - scrape

Medium pit - collector water - drain
Medium pit - scrape
Medium pit - dropping boards - scrape

Deep pit - scrape
Deep pit - collection water - drain

Confinement Housing: Litter or Floor Systems

Litter - scrape

Deep Litter - scrape

1 Overcash et al, 1983

Estimate of Canadian Poultry Manure Production

Each bird produces about 55 kg of manure/year (Kroodsma, 1986).

1989 Broiler Production:

369,545,504 birds

divided by 6.7 broiler flocks per year (Manure Management Guidelines - B.C.)

$369,545,504 / 6.7$

$= 55,156,045$ per cycle

$\times 55$ kg

$= 0.303 \times 10^{10}$

1989 Egg Production:

476,572,000 dozen

$= 0.572 \times 10^{10}$ eggs

Since average egg production/hen/year

$= 250$ eggs (Manure Management Guidelines -
Province of British Columbia)

therefore, number of laying birds $= (0.572 \times 10^{10})/250$

$= 22,875,456 \times 55$ kg

$= 0.126 \times 10^{10}$

A very rough estimate of broiler and layer poultry manure production per year in Canada is, therefore:

0.303×10^{10}

0.126×10^{10}

0.429×10^{10} kg

or approximately 4.3 billion kg of poultry manure (4.3 million tonnes) per year.

All tables from Martin et al, 1983 - Animal Manures as Feedstuffs: Nutrient Characteristics.
Agricultural Wastes 6, 131-166

Nutrient Composition of Manures

	DPW	Broiler Litter
Composition of Dry Matter (%)	Mean	Mean
Crude protein	28.0	26.8
True protein	14.6	15.8
Digestible protein (ruminant)	12.6	22.6
NPN x 6.25	9.7	7.6
Ammonia x 6.25	-	5.1
Ether extract	2.2	2.4
Crude fibre	13.0	21.2
NFE	33.4	27.5
TDN	52.3	58.9
ADF	24.7	30.4
NDF	52.4	47.4
Lignin	1.4	9.7
Energy (kcal kg ⁻¹)		
Gross Energy	3047	3652
Digestible Energy (Ruminant)	2456	2440
Metabolisable Energy (Poultry)	1309	-
(Ruminant)	1900	1627
Dry Matter (%)	84.7	80.6

Mineral Composition of Manures

Composition of Dry Matter (%)	DPW	Broiler Litter
	Mean	Mean
Ash	27.6	18.6
Aluminum	0.11	0.05
Calcium	8.07	2.60
Chlorides	0.87	0.35
Iron	0.54	0.07
Magnesium	0.50	0.39
Phosphorus	2.29	1.81
Potassium	2.24	1.78
Sodium	0.60	0.38
Sulphur	-	0.24
Arsenic (ppm)	1.5	4.1
Cadmium (ppm)	0.94	0.86
Chromium (ppm)	4.9	6
Copper (ppm)	66.0	50
Lead (ppm)	4.6	2.3
Manganese (ppm)	320	211
Mercury (ppm)	<0.04	0.06
Selenium (ppm)	0.68	0.44
Zinc (ppm)	376	187

Amino Acid Composition of Manures

	DPW	Broiler Litter
Amino Acid, Dry Matter (%)	Mean	Mean
Arginine*	0.39	0.84
Cystine	0.06	0.22
Glycine	1.65	2.12
Histidine*	0.20	0.29
Leucine*	0.64	1.11
Iso-Leucine*	0.40	0.64
Lysine*	0.41	0.69
Methionine*	0.16	0.30
Phenylalanine*	0.38	0.64
Tyrosine	0.31	0.48
Valine*	0.52	0.88
Alanine	0.67	0.94
Proline	0.58	1.34
Glutamic Acid	1.33	2.66
Serine	0.52	0.76
Threonine*	0.45	0.67
Aspartic Acid	1.03	1.27
Tryptophan*	0.53	-
Total Amino Acids	10.23	15.85
Essential Amino Acids (% of total)	3.63 35.5	5.39 34.0

* Essential Amino Acids

Manure Handling Systems for Poultry

Type of animal management	Type of manure	Collection and transfer	Storage	Removal and transport to land	Comments
Floor housing with bedding (broilers, replacement pullets, breeders)	Dry litter	On floor, tractor loader to truck or spreader to storage	On floor (current broiler batch): interim storage in stockpile on curbed slab	Tractor loader to spreader to land	Stockpile storage required only if housing must be cleaned and repopulated during period when manure cannot be spread
Heated floor housing, no bedding (broilers)	Dry droppings	On concrete or wood floor	On floor (current broiler batch): interim storage in waterproof shed	Tractor loader to spreader to land	Floor slab heated by circulating hot water in steel or plastic piping
Ceiling suspended or floor supported cages (layers)	Liquid manure	Shallow trench, tractor shuttle scraper (for ceiling-suspended cages) or cable shuttle scraper (for floor-supported cages) to opening into storage or cross conveyor to storage	Storage tank or earthen storage	Pump-agitator to tank to land or vacuum tanker to land	Add dilution water during agitation, as required for pumping
	Semisolid manure	Shallow trench, tractor shuttle scraper (for ceiling-suspended cages) or cable shuttle scraper (for floor-supported cages) to opening into storage or cross conveyor to storage	Stockpile in walled storage	Tractor loader to spreader to land	Avoid adding excess water
	Semisolid manure	Droppings directly into deep pit below		Tractor loader to spreader to land	Avoid adding dilution water to minimize odour. Maximum ventilation in pit area to assist drying of manure
Tiered cages (layers)	Semisolid manure	Moveable belt to cross conveyor. Dropping boards, mechanical scraper to cross conveyor	Stockpile in walled storage	Tractor loader to spreader to land	Avoid adding excess water
Wire or wood slat floor. Partial or total floor area (breeders)	Semisolid manure	On floor, tractor loader to truck to storage or spreader to land	On floor (current flock): interim storage in stockpile on curbed slab	Tractor loader to spreader to land	Stockpile storage required only if housing must be cleaned and repopulated during period when manure cannot be spread
	Stockpile runoff	Surface drain and/or sewer	Retain in storage or drain to detention tank or earthen basin	Vacuum tanker to land	Avoid dilution water

(C.A.M.M.G., 1979)

Properties of the Principal Manure Gases and their Physiological Response on Adult Humans

Gas	Specific Gravity	Odour	Colour	Affinity for Water	Limits of Inflammability % by volume		Threshold limit value (ppm)	Excursion factor	Time-weighted average limit (ppm)	Gas concentration (ppm) and physiological response	
					Lower	Upper					
Ammonia	0.6	Sharp pungent	None	Highly soluble	15.5	27.0	25	1.5	37.5	5-50 100-500 400-700 2000-3000 5000 10000	IRRITANT - least detectable odour - irritations to mucous surfaces in 1 hour - immediate irritation of eyes, nose and throat - severe eye irritation, coughing and frothing at mouth, could be fatal - respiratory spasm, rapid asphyxia, may be fatal - rapidly fatal
Carbon dioxide	1.5	None	None	Moderately soluble	-	-	5000	1.25	6250.0	20000 30000 40000 60000 300000	ASPHYXIANT - safe - increased breathing - drowsiness, headaches - heavy, asphyxiated breathing - could be fatal (30 minute exposure)
Hydrogen sulfide	1.2	Offensive rotten egg smell	None	Highly soluble	4.3	45.5	10	2.0	20.0	0.01-0.7 3-5 10 20 50-100 150 200 500-600 700-2000	POISON - least detectable odour - offensive odour - eye irritation - irritation to mucous membranes and lungs - irritation to eyes and respiratory tract (1 hour exposure) - olfactory nerve paralysis, fatal in 8-48 hours - dizziness (1 hour), nervous system depression - nausea, excitement, unconsciousness, possible death (30 minutes) - rapidly fatal
Methane	0.6	None	None	Slightly soluble	5.0	15	-	-	-	500000	ASPHYXIANT - headache, non-toxic

(C.A.M.M.G., 1979)