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FARM ANIMAL MANURES IN THE CANADIAN ENVIRONMENT

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SUMMARY AND RECOMMENDATIONS

Farm animal manure has for centuries been valued as a source of plant nutrients and as a soil amendment. Until recent years methods and practices for the storage and uses of manure were mainly developed for crop production. Current agricultural trends to intensify and concentrate livestock, swine and poultry production have, however, created potential hazards associated with the storage and disposal of large quantities of manure within a limited land base. In this document the more acute problems created by farm animal waste have been presented along with warnings and recommendations on its storage, management and usage. Numerous areas for research have been identified. Those specifically relating to a section of the text are listed in Table-A. Recommendations and other areas for research are presented below in capital type.

Several instances of water pollution arising from improperly located animal production enterprises, improper manure storages and faulty management practices in land spreading of manure have been cited. Concern is expressed that manure may be a contributing source of organic matter and nutrients (N and P) to water bodies, rendering them unsuitable for some forms of aquatic life and recreational purposes. The composition of animal manures, transformations during decomposition, release of nutrients and their transport to a water body by surface runoff or by leaching through the soil to the water table have been well documented. In regulating the use of manure to protect environmental quality, a complicating factor is the dependence of suitable management practices on soil, crop and climatic conditions. ENVIRONMENTALLY TOLERABLE AMOUNTS OF MANURE NEED TO BE MATCHED WITH SOIL REQUIREMENTS AND CROPS TO BE GROWN UNDER DIFFERENT SOIL, HYDROLOGICAL AND CLIMATIC CONDITIONS AND DIFFERING CROPPING SYSTEMS. GUIDELINES AND TECHNOLOGY MUST BE CLOSELY INTEGRATED WITH INDIVIDUAL FARM OPERATIONS. ENGINEERING, TECHNOLOGICAL SERVICES AND ENVIRONMENTAL EXPERTISE REQUIRE STRENGTHENING AND INTEGRATION WITH CURRENT AGRICULTURAL SERVICES TO ENSURE THAT MANAGEMENT PRACTICES ARE IN HARMONY WITH ENVIRONMENTAL CONSIDERATIONS. Such services are required to resolve known problems and to monitor suspected problem sites. Improved manure storage systems are required.

Anaerobic decomposition in liquid manure handling systems produces gases (CO2, CH_4, NH_3 and H_2S) which are hazardous to the health of both animals and man. Permissible levels for these gases in animal houses and their effects on various animal species have yet to be established (Table A). Alternatively, aerobic decomposition of manure is relatively odorless and gasless. To create year-round conditions for the latter in Canada's cool climate is, however, too costly. As a consequence, the development of a method to convert or inhibit the noxious gases produced anaerobically would be a most welcome technological breakthrough.

Table A. Identified areas for research.

Section	Area of investigation
2.2.2.2	Determine the mechanism whereby manure provides more 0.01 M $CaCl_2$- soluble P in soil than fertilizer can provide
3.1.3	Establish permissible levels of manure gases in confinement buildings for animals.
3.1.3	Determine the effects of various manure gases (H_2S, NH_3, CH_4 and CO_2) on different animal species and assess permissible concentrations.
3.1.3	Investigate the elimination or conversion of noxious gases produced by the anaerobic decomposition of manure in cold climates.
3.2	Improve and standardize the methodology for the sensory evaluation of nonhazardous nuisance odors produced from manure.
4.4	Establish micronutrient contamination of water from manure treated soils.
5.6	Determine the persistence and residual effects of excreted hazardous organic compounds in manure on soil, soil organisms, crops, animals and man when manure is applied to the land.
5.6	Establish the possibility of genetic transfer of drug resistance from nonpathogenic microbial strains in manure to pathogenic strains of certain species.
7.1.4	Determine the role of wildlife in the transmission of viruses by fecal contamination of pastures and habitats of domestic livestock.
7.2.5	Demonstrate the role of oxidation through aeration as a factor in the" spontaneous" inactivation of viruses in manure.
7.3	Determine the effects of various handling and treatment procedures on the survival of livestock viruses in manure.
8.1.1	Establish the role of the intermediary metabolism of infective parasitic larvae in relation to their survival.
8.3.5	Determine the effectiveness of anaerobic decomposition in the control of parasitic eggs and larvae in manure.
8.3.7	Determine the effectiveness of chemical treatments in the control of free-living stages of parasites in manure.

Micronutrients and heavy metal contents of animal manures in relation to the tolerable levels in soils and crops have been documented. Data on micronutrients from manure in water were found to be lacking. Only one potential hazard to soil quality and crop production was noted -- the use of manure from hogs fed supplementary copper. Permissible application rates of such copper-enriched manure need to be established and the copper-concentration in the manure, the treated soil and the crops should be monitored.

Manure is a potential source of hazardous organic chemicals. Significant concentrations of these compounds: organopollutants in feeds, pesticide residues in feeds, growth stimulants in feeds, topically applied insecticidal sprays, antibiotics and medications are incorporated into manure. Although the dangers of these compounds in manure may be lessened by adsorption and decomposition in the soil, information on their persistence and residual effects on the biological processes in manure, in manure treated soils, on plants and on the health of animals and humans is inadequate. The potential of manure as a possible source of resistant organisms to induce genetic transfer of their resistance to pathogenic strains has not been determined.

Current slurry systems of handling manure have increased the survival capacity of many pathogenic organisms and weed seed species destroyed by the heat generated in older conventional solid manure storage systems. THE GENERAL RECOMMENDATION IS MADE THAT MORE EXTENSIVE USE OF EDUCATIONAL AND EXTENSION SERVICES AND REGULATIONS WOULD MINIMIZE THE SPREAD OF PATHOGENIC ORGANISMS AND WEED SEEDS AND ENSURE BETTER MANAGEMENT OF ANIMAL PRODUCTION ENTERPRISES AND DISPOSAL OF MANURE. THE DISPOSAL OF MANURE FROM INFECTED ANIMALS SHOULD RECEIVE PARTICULAR ATTENTION AND TREATMENT TO ISOLATE AND DESTROY THE PATHOGENS. PARTICULAR CARE SHOULD BE EXERCISED AT ALL TIMES TO AVOID THE DISPOSAL OF MANURE IN ANY MANNER WHICH COULD INTRODUCE PATHOGENIC ORGANISMS INTO WATER BODIES. INFORMATION ON THE SURVIVAL AND INFECTIVITY OF MANY PATHOGENIC ORGANISMS IN MANURE IS LACKING, PARTICULARLY WITH REFERENCE TO THE INFLUENCE OF MANURE, SOIL, WATER AND THE EFFECTS OF INTERACTIONS WITH OTHER ORGANISMS.

1.0 INTRODUCTION

This document deals with animal manure as a valuable resource material for land application. It is interesting to note that one of the early publications of the Experimental Farms Service, Canada Department of Agriculture was entitled "Barnyard manure: its nature, functions, composition, fermentation, preservation and application" (Shutt 1898). Many field experiments with manure treatments were conducted across the country during the first half of the century. Perhaps by coincidence, the effective practices developed for the use of manure in crop production were in harmony with environmental needs.

More recently, with the intensification of livestock and poultry operations, problems have arisen in the disposal of large quantities of animal manure in excess of requirements of the associated land base. This development has coincided with a greater public awareness that water bodies must be protected from enrichment with nutrients and organic matter. Thus, this document gives attention to the storage and use of animal manures for crop production in conformity with environmental considerations. These discussions relate to manure gases and odors, pathogens in manure, pesticides and other organopollutants in manure, microelements and heavy metals in manure, the fertilizer potential of manures and the dispersal and introduction of weed seeds.

The value of animal manure for crop production may be illustrated by estimates of the quantities of nitrogen, phosphorus and potassium in the yearly production of livestock and poultry manures in Canada. Based on the animal population (Statistics Canada 1976) and using appropriate coefficients for conversion, the estimated quantities were 530,849 tonnes of nitrogen, 117,227 tonnes of phosphorus and 505,673 tonnes of potassium. The total value of these manurial nutrients amounts to about $575 million (assuming fertilizer prices of 55 cents.kg^{-1} for nitrogen and phosphorus (P_2O_5) and 22 cents.kg^{-1} for potassium (K2O)). Although this estimate could be reduced considerably by losses during storage, it emphasizes the economic importance of good management practices in both the storage of manure and its use in crop production.

Land spreading for crop production is currently the most practical use for animal manures, but other uses, for example, animal feed (Azevedo and Stout 1974; Hamblin 1980; Helmer 1980), and the production of ammonia, methane or other fuels (Whetstone et al. 1974; Azevedo and Stout 1974; van den Berg 1980) may become important in the future.

2.0 THE FERTILIZER POTENTIAL OF ANIMAL MANURES AND ENVIRONMENTAL CONSTRAINTS ON THEIR USE

A.J. MacLean [α], M.H. Miller [β] and J.B. Robinson [β]

2.1 THE COMPOSITION AND PROPERTIES OF MANURE

The properties of manure differ among animal species as well as being influenced by diet. Changes in composition begin as soon as manure is excreted and conditions of storage have a marked effect on the kind and rate of change which can be expected. The addition of dilution water or of bedding materials can also change manure properties. It is, therefore, impossible to generalize the composition and properties of manure although for a certain animal species one may predict, within fairly narrow limits, the physical and chemical properties of freshly excreted manure.

2.1.1 DIGESTION PROCESSES

The digestive mechanisms of ruminant farm animals (cattle and sheep) differ markedly from those of nonruminants (poultry, pigs, horses). By virtue of their highly differential four-compartmented stomachs, ruminants are able to metabolize a large proportion of the cellulose in the plant material on which they feed. The process begins in the first compartment, which acts as an effective fermentation vessel. The large microbial population in the rumen fluid hydrolyzes cellulose in the feed to soluble carbohydrates, which are then rapidly converted to organic acids, providing energy to the host ruminant. Protein in the feed may be enhanced since nonprotein nitrogen is converted to microbial protein in the rumen. This protein, along with growth factors and other requirements synthesized in the rumen, is available to the animal in the remaining stomach compartments where normal mammalian digestion occurs. The amount of roughage surviving digestion and then excreted is much reduced because of the rumen function. However, an appreciable amount of ruminant manure organic matter is made up of microbial cells.

Nonruminant (monogastric) animals differ from ruminants in that microorganisms play a much smaller part in their digestive processes. For that reason, pigs and poultry require diet components which include readily digestible energy sources and adequate protein and growth factors. Cellulose materials which provide bulk to the diet, appear in the feces in a relatively unchanged form. An exception to this rule among domestic monogastric animals is the horse, which

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The urinogenital tracts of birds differ from those of mammals and are similar to those of reptiles. This is important for manure characteristics because the kidneys of birds excrete through ureters into the cloacal chamber where the urine is mixed with the feces before being excreted through the single vent. Furthermore, the principal nitrogen-containing component of the excreta in birds is uric acid while mammals excrete urea as a component of the urine.

2.1.2 DIETARY EFFECTS

Animal diets affect manure composition markedly and the manure composition of a particular class of animals can be roughly predicted from the digestion coefficients for the feed components. Some caution is necessary because digestion coefficients are influenced by the proportion of other ingested nutrients. Excretion rates of major nutrients for different species are shown in Table 2-1. For most animal classes, about 2/3 of the ingested nitrogen and phosphorus and 4/5 of the ingested potassium are excreted. The use of digestion coefficients presupposes a reasonably balanced diet; if, for example, the diet contains large surpluses of protein, the proportion of N excreted will be much greater than that shown in Table 2-1.

2.1.3 PHYSICAL PROPERTIES OF MANURE

The physical properties of manure vary over a wide range depending on animal species, diet, bedding, and storage conditions. However, to provide a basis for facilities design, certain characteristics have been averaged and published by expert panels. The American Society of Agricultural Engineers (1981) published such a list, now widely accepted in the USA; in Canada, an equivalent source is the recently revised Canada Animal Waste Management Guide (1979). Manure production volumes for various classes of animals along with moisture contents, taken from these two sources, are shown in Table 2-2.

Azevedo and Stout (1974) estimated the proportions of total raw manure, dry matter and water excreted as feces and urine, respectively, by different livestock species (Table 2-3). Tietjen (1966) showed that these proportions vary with the age of the animal and stage of lactation. About 9/10 of the dry matter in manure is excreted in the feces.

2.1.4 CHEMICAL COMPOSITION OF MANURE

Manure differs from chemical fertilizer in its organic nature and its greater variety of chemical elements. For example, Whetstone et al. (1974) showed that the total solids portion of dairy cattle manure may contain up to 20% lignin, 31% cellulose, 24% fibre and 12% protein. From dairy cattle (455 kg live weight), the total solid portion amounts to about 42 $kg.d^{-1}$. The C:N ratio of beef cattle manure was over 15:1 and the Biochemical Oxygen Demand (BOD) was 0.73 $kg.d^{-1}$/animal. The microelement content of manure is discussed in Chapter 4.0.

Table 2-1. Proportion of nutrients ingested which are excreted by farm animals (Smelski 1976, personal communication).

	% excreted		
	N	P	K
Veal calves	40	36	82
Beef feeders	80	61	93
Dairy cows	71	73	90
Feeder pigs	65	69	86
Broiler chickens	61	69	80
Laying hens	70	68	87
Turkey broilers	59	71	75
Heavy turkeys	60	67	79

Table 2-2. Animal manure characteristics (feces and urine, as voided).[α]

Animal	Volume of manure ($L.d^{-1}$/animal)	Moisture content % by weight
Beef or dairy calf		
(0-3 months)	5.4	
(0-6 months)	7.1	
Beef feeder or dairy heifer	14.2	
(6-15 months)		
(15-24 months)	21.2	
Beef cow (545 kg)	28.3	
Dairy cow (545 kg)	45.3	87
Pig	1.1	
3-6 weeks (5-10 kg)		
8-22 weeks (20-90 kg)	5.1	91
12-16 weeks (36-55 kg)	5.1	
20-22 weeks (81-90)	9.1	
Sow	11.3	
Chicken	0.08	25 (litter)
Broiler (0-1.8 kg)		
Laying hen(1.8 kg)	0.14	77
Turkey	0.13	
Broiler (0-14 weeks)		
Breeder	0.34	
Sheep(ewe)	2.8	75
Horses	26.0	80

[α] Compiled from a list prepared by the American Society of Agricultural Engineers in 1981 and the Canada Waste Management Guide (1979).

Table 2-3. Distribution of raw manure, dry matter, and water between urine and feces of various farm animals (Azevedo and Stout 1974).

	Livestock species			
Manure Component	Horse	Cattle	Sheep	Swine
Total raw manure				
percent excreted as feces	81	71	63	63
percent excreted as urine	19	29	37	37
Dry matter				
percent excreted in feces	91	88	82	92
percent excreted in urine	9	12	18	8
Water				
percent excreted in feces	79	70	55	59
percent excreted in urine	21	30	45	41

In addition to supplying nitrogen, phosphorus and potassium (the major plant nutrients), manure contains appreciable amounts of calcium, magnesium and sulfur. The dry matter of chicken manure was found to contain 8.1% Ca, 0.63% Mg and 0.68% S (Azevedo and Stout 1974). The corresponding figures for manure from fattening cattle were 0.55% Ca, 0.46% Mg and 0.39% S. Whetstone et al. (1974) reported NaCl concentrations of 2.2% in the total solids of dairy cattle manure and 3.83-4.94% in the solids of poultry manure.

Table 2-4 gives estimates of the N, P and K concentrations in fresh manure from different livestock species and poultry. The concentrations of N and K are considerably higher in the urine than in the feces of the horse, cow and sheep. Over half of the N and about 4/5 of the K excreted by the cow are in the urine. On the other hand, P is excreted largely in the feces of the different animal species; only small amounts are found in the urine. All the animal manures contain more N than K and are low in P. Poultry and sheep manure contain considerably more of the three nutrients, particularly N, than does cow manure. The P content of poultry manure is comparable in magnitude to the K content. The comprehensive compilations of Azevedo and Stout (1974) and Whetstone et al. (1974) also show that the composition of manure depends on the animal, its stage of growth and its feed.

The composition of manure is influenced by the bedding used and the degree of retention of urine during storage. Nutrients are generally present in urine in a soluble form (e.g. N is present as urea), but in the feces, N is bound in the undigested feed. Other factors contributing to variability among samples include the moisture content of fresh manure and the presence of bedding straw which containsonly about 0.5% N, 0.01% P and 0.8% K.

The efficiency of conversion of vegetable protein to animal protein will have a marked effect on the N concentration of the manure. As discussed by Azevedo and Stout (1974), the conversion ratio for the productive life of the dairy cow is about 4:1 and as low as 1.1:1 in her early life; for feedlot cattle the conversion ratio is 8:1. Thus, the concentration of N is usually higher in steer than in dairy cattle manure. Again, the N is usually higher in broiler manure than in the manure of laying hens. Growing animals usually receive more N in their feed than do dairy cows or laying hens. The same authors, citing Hays and Swenson (1970), suggest that P in ruminant manures is generally lower than in poultry or swine manures because ruminants can extract organically-bound phosphorus from plant feeds. NaCl in livestock and poultry rations will increase the amount of this salt in the manure. The high Ca salt content of poultry rations is reflected in a high concentration of Ca in the manure of laying hens.

Table 2-4. Composition of fresh manure (wet basis) (MacLean and Hare 1974).

	Proportions		Nitrogen (N)		Phosphorus (P)		Potassium (K)	
Component	%	$kg.t^{-1}$	%	$kg.t^{-1}$	%	$kg.t^{-1}$	%	$kg.t^{-1}$
Horse	80	800	0.55	4.40	0.13	1.05	0.33	2.65
Feces								
Urine	20	200	1.35	2.70	trace		1.00	2.00
Total		1000	0.71	7.10	0.13	1.05	0.47	4.65
Cow	70	700	0.40	2.80	0.09	0.61	0.08	0.58
Feces								
Urine	30	300	1.00	3.00	trace		1.12	3.36
Total		1000	0.58	5.80	0.09	0.61	0.39	3.94
Pig	60	600	0.55	3.30	0.22	1.31	0.33	1.99
Feces								
Urine	40	400	0.60	2.40	0.04	0.17	0.37	1.49
Total		1000	0.57	5.70	0.15	1.48	0.35	3.48
Sheep	67	670	0.75	5.03	0.22	1.46	0.38	2.51
Feces								
Urine	33	330	1.35	4.46	0.02	0.07	1.74	5.75
Total		1000	0.95	9.49	0.16	1.63	0.83	8.26
Poultry			1.47	14.7	0.50	5.0	0.40	4.0

2.1.5 CHANGES OCCURRING DURING STORAGE

Manure may be stored in solid, semi-solid or liquid forms. Manure handling systems for beef cattle, dairy cattle, swine and poultry have been described in detail in the Canada Animal Waste Management Guide (1979). As soon as it is voided, manure undergoes rapid changes in composition as it decomposes through the action of bacteria, fungi, and other organisms. The process of decomposition towards formation of simple end products will depend on the nature of the manure, the temperature and particularly the oxygen supply.

The changes in manure during decomposition have been discussed by Azevedo and Stout (1974). In the presence of dissolved oxygen, aerobic organisms using the organic matter as an energy source in biochemical and oxidation reactions synthesize new microbial bodies and release carbon dioxide and water. These microbial bodies will in turn be decomposed by other microbes. Mineralized decomposition products from the manure are utilized by the microorganisms in synthesizing their own protoplasm. The more readily decomposable organic constituents of manure such as starches, hemicellulose, cellulose and proteins provide a ready source of carbon, but lignins, resistant to attack by aerobic species, will remain behind in the decomposing of mass. Because the efficient fungi and bacteria require oxygen, anaerobic decomposition is much less efficient than the aerobic process. Residual compounds such as alcohols and organic acids formed from the breakdown of carbohydrates, as well as pyridines, indoles, ammonia and amines formed from protein decomposition under aerobic conditions, require oxygen for further breakdown. End products of anaerobic decomposition include methane, carbon dioxide, hydrogen, traces of hydrogen sulfide, ammonia, and water in addition to inert solids and synthesized microbial bodies.

In manure piles, some sections may have anaerobic conditions whereas others at the surface may be aerobic, so that conversions may occur through both anaerobic and aerobic processes simultaneously. Data cited by Azevedo and Stout (1974) show that, upon decomposition, sheep and horse manure contain markedly reduced amounts of hemicellulose and cellulose but sustained large increases in resistant lignin and ash. In comparing the pollution potential of manures of different animal species, the authors found higher BOD values per unit of weight for poultry and swine manures than for cattle, horse or sheep manures.

As organic nitrogen compounds are oxidized, the loss of ammonia by volatilization greatly reduces the supply of readily available N when the manure is used as a fertilizer. On the other hand, phosphorus and potassium accumulate in the ash when mineralization proceeds, provided there is no leaching from the storage structure. If the storage structure is not sealed to prevent leaching, losses of soluble N and K in the urine will appreciably decrease the quality of the manure. Azevedo and Stout (1974) showed that leaching of dairy cattle feces with water removed some N and P but considerably more K. Being present in organic form in the feces, N and P were less subject to leaching. The N in urine is present as urea except for poultry manure where it is in the form of uric acid, although it is rapidly converted to urea. Urea in turn is readily hydrolyzed to ammonia. Azevedo and Stout (1974) suggest that ammonia is the common source of nitrogen used in the synthesis of microbial protoplasm. With the low C:N ratio in manures, some ammonia in excess of that required for microbial activities will be released. Loss of ammonium-nitrogen to the atmosphere by volatilization is increased by temperature, drying and alkaline conditions. For instance, Azevedo and Stout (1974) showed that 49.4% of the ammonia-nitrogen was lost from fermented manure in 12 hours at a temperature of 20ºC and a 13.7 km.h^{-1} wind. Under aerobic conditions, some ammonia may be oxidized to nitrate, some will be lost by volatilization and some will be synthesized into microbial protein. If nitrate-nitrogen leaches into a deeper section of the manure pile with anaerobic conditions, it may be denitrified to nitrogen or nitrous oxide gases with subsequent loss to the atmosphere.

The hazards to humans and animals of carbon dioxide, ammonia, hydrogen sulfide and methane escaping from manure storage facilities are discussed in Chapter 3.0.

2.2 EFFECTS OF LAND-SPREAD MANURE ON SOIL PROPERTIES

At present in Canada, there are few practical alternatives for the disposal of the very large quantities of manure produced by livestock and poultry other than applying it directly to agricultural land. Small amounts are composted and sold for use in urban areas. In the future, comparatively small amounts may also be used for production of methane gas. The residue from the latter, containing most of the original nutrient value, will probably be spread on agricultural land. Composting and methane production are not likely to use more than a fraction of a percent of the manure produced in the foreseeable future.

The spreading of livestock and poultry manure on agricultural land provides not only nutrients required for plant growth, but also a major beneficial effect on soil tilth. The organic materials contained in manure, or the products from their microbial decomposition, act as binding agents in stabilizing soil structure; hence, they maintain the desired porosity for retention of water and for penetration and development of plant roots. Presently there is concern in Ontario that many soils, which are being increasingly cash-cropped without manure additions, are deteriorating and that this will result in serious reductions in crop yields. Levels of organic matter are also declining in soils of the prairie provinces. Erosion, resulting from loss of structure and stability, is of major concern in the Maritimes as well as in Ontario and other provinces. The judicious application of manure would help alleviate these growing problems.

The spreading of manure on the land in Canada presents one major problem - that of distribution. In some areas excessive amounts of manure are being applied while most of the land in Canada receives little or no manure. This results from the growing trend to concentrate the production of livestock and poultry on a regional and even a farm basis. While some cash-croppers are recognizing the value of manure and are paying the high cost of transportation, the distance over which manure can be moved economically is limited to a few miles. Increased costs of fertilizers and a growing realization of the soil deterioration will increase this distance by only a relatively small degree. The costs, in terms of energy, to dehydrate or otherwise convert the manure to a more transportable form will remain prohibitive. Hence, the problems of manure distribution are likely to continue. The following sections summarize the effects of manure on soil properties asa background to the discussion in Section 2.3.

2.2.1 SOIL PHYSICAL PROPERTIES

The addition of manure obviously increases the organic matter content of the soil. This organic matter, and perhaps more important, the products of its microbial decomposition, react with the soil's mineral particles to increase the aggregation of the soil as well as the stability of aggregates. Guttay et al. (1956) found that amendment of soil with stable manure and sweet clover for almost 20 years increased the proportion of aggregates greater than 0.5 mm, from 37.5% to 60.4%. Hafez (1974) found an increased aggregation of soil particles into granules greater than 0.25 mm in a clay soil when amended with various types of animal manures and incubated for 3 weeks. In addition to increasing the proportion of larger sized aggregates, additions of manure may increase the stability of aggregates present prior to manure additions (Bhatnagar 1979) (see Table 2-5).

Manure did not effect the proportion of aggregates in each size fraction as determined by dry sieving. However, there was a major increase in stability of the aggregates to water, particularly at the higher rates of manure application. This effect occurred within a few days of manure addition and persisted up to 275 days, during which the soil underwent weekly wetting and drying cycles and received some light disturbance. Although the rates of application used are higher than the usual field rates, similar increases in aggregate stability would be expected by repeated application at lower rates.

This effect of manure on aggregate size and stability will influence several soil properties of significance to plant growth. The increase in proportion of larger sized aggregates results in a greater amount of larger-sized pores. This increases the rate of infiltration and percolation of water and the rate of transfer of oxygen as well as the removal of toxic gases from the root zone. It also enhances the penetration of roots into the soil, thus increasing the volume of soil water and

Table 2-5. Influence of liquid poultry manure additions on water stability of soil aggregates (Bhatnagar 1979).

	% Water stable aggregrates after incubation of			
Manure addition	27-days	65-days	93-days	235-days
$t.ha^{-1}$				
0	29.7	27.4	30.6	29.2
25	35.9	29.1	32.2	35.8
50	39.0	31.9	34.9	37.0
100	44.0	34.2	36.7	35.2
200	45.9	49.1	55.9	53.0
400	50.5	78.4	65.3	59.6

nutrients that can be exploited by the roots. The extent of this influence will depend upon the type of soil and its initial condition. Coarse-textured (sands and sandy loams) soils are seldom deficient in permeability and hence would benefit least from increased aggregation whereas fine-textured soils usually have low permeability and hence would benefit most. Soils which have been in rotation, including sod crops, usually have much better structure than soils under continuous cropping and thus would benefit less.

As well as to affecting the permeability of soils, addition of manure will usually increase the available water holding capacity. The available water in the soil is defined as that which is retained in the soil against the force of gravity but which can be extracted by plants. This water is held at potentials between approximately 10-1500 kPa (-0.1 and -15 bars) which corresponds to water held in pores ranging from 60 to 0.2 µm. Manure may increase the amount of pore space within this range through its effect on aggregation but it may decrease the amount of pore space by increasing the proportion of pores which drain freely, i.e. pores with a diameter greater than 60 µm. Manure also increases the water holding capacity of soils because the water holding capacity of organic materials is several times that of mineral soil on a weight basis. This effect is particularly important in sandy soils which are generally low in organic matter.

The increased stability of the aggregates resulting from manure addition increases the resistance of the soil to compaction and to soil crusting (Hafez 1974). Nuttall (1970) and Hafez (1974) found that manure reduced the forces necessary to break soil crusts, as determined by laboratory measures of modulus of rupture. These experimental values were correlated with seed emergence.

Another important effect of the increased aggregate stability resulting from manure addition is the reduction in erosion by water. The erosion process involves the breakdown of soil particles and the transport of the finer particles in the runoff water. By increasing the stability of surface aggregates, manure reduces soil breakdown. Manure also increases water infiltration (as discussed earlier), hence reducing the amount of runoff water.

These effects of manure on soil physical properties, either singly or in combination, can explain the many observations of manure additions increasing yields to an extent greater than those attributable to the fertilizer nutrients contained in the manure (Swanson 1954; Bunting 1963; Ketcheson 1969).

2.2.2 NUTRIENT AVAILABILITY

2.2.2.1 Nitrogen

Manure contains considerable amounts of nitrogen in both organic and inorganic forms.

A considerable portion of the nitrogen in the NH_4^+ form can be lost by volatilization when applied to the soil surface and not incorporated. The amount of volatilization is higher at high temperatures, at higher soil pH values, and at lower soil moisture contents. Hence, volatilization losses are difficult to predict and few direct measurements have been attempted under field conditions. Studies have shown that greater yield responses are obtained when manure is incorporated than with surface application (Beauchamp 1979). This is due in part to reduced volatilization of NH_3, although other factors such as improved physical condition and greater availability of phosphorus and potassium cannot be discounted.

Once in contact with moist soil, the NH_4-N is quickly converted to nitrate (NO_3^-) nitrogen by the process of nitrification as represented by the following equation:

$$\mathbf{NH_4^+} \xrightarrow[\underline{\text{Nitrosomonas}}]{} \mathbf{NO_2^-} \xrightarrow[\underline{\text{Nitrobacter}}]{} \mathbf{NO_3^-}$$

Under most soil conditions, the conversion of NO_2^- to NO_3^- is more rapid than the conversion of NH_4^+ to NO_2^-. Hence, NO_2^- does not normally accumulate in soils. However, high levels of NH_3 may selectively inhibit Nitrobacter organisms, resulting in the accumulation of $N0_2^-$ which is highly toxic to plants. Such levels of NH_3 will occur only with very high rates of application or where clumps of manure exist.

The organic fraction of the nitrogen in manure is converted to NH_4^+ by a wide range of soil microorganisms. Because the nature of the nitrogen-containing compounds varies widely, the rate of mineralization also varies widely. Of major significance is the C:N ratio of the manure. The microorganisms that decompose manure require a C:N ratio of less than 20 to 1 in the substrate before NH_4 can be split off and released in significant quantities. Manures with considerable litter or bedding have C:N ratios considerably higher than 20. Addition of these materials to the soil may result in a temporary depletion of available soil nitrogen as microorganisms draw upon it. This nitrogen will be slowly released at later times as the carbon is converted to carbon dioxide. This mobilization process was used by Martin (1972) to explain differences in the availability of low-nitrogen cattle manure and high-nitrogen poultry manure.

As indicated earlier, the NH_4-N initially present, as well as that from the mineralization of organic forms, is rapidly converted to nitrate-nitrogen. Nitrate-nitrogen does not react to a significant extent in the soil and hence moves freely in the soil water. It is readily leached out of the rooting zone and into the groundwater. Many theoretical and empirical studies have been conducted on the rate of transport of NO_3-N in soils and other porous media. Although nitrate does not react with the soil, the process of dispersion whereby the nitrate diffuses into water held in fine pores within aggregates may markedly reduce the overall rate of transport.

Another reaction that NO_3-N undergoes in the soil is denitrification. If oxygen is limiting, certain microorganisms use oxygen from the nitrate molecule, resulting in conversion of the nitrate to nitrogen or nitrous oxide gases. This process will occur under any condition where O_2 becomes depleted either from a reduction in supply, as in water-logged soils, or from a rapid utilization, such as when large amounts of readily decomposable organic material are applied. The latter condition may occur when large quantities of manure are applied to medium or fine-textured soils in which oxygen diffusion may be restricted.

2.2.2.2 Phosphorus

Phosphorus in manure exists in both organic and inorganic forms. The inorganic P will be adsorbed on soil particles in a manner similar to that of fertilizer P. The organic fraction is also adsorbed onto soil particles or can be physically absorbed into soil aggregates. Because of its nature, the organic P is not immediately available for plant use. Hence, an application of manure will not immediately increase the available P in the soil to the same extent as an equivalent amount of fertilizer P. Bhatnagar (1979) added equivalent amounts of P to a silt loam soil in forms of poultry manure slurry and inorganic P, and incubated the soil at 30ºC with weekly wetting and drying cycles. Eight days after application, the inorganic source increased the $NaHCO_3$-extractable P by approximately 2 times that of the manure P. However, after 27 days of incubation at the lower P rates and 60 days at higher rates, the amounts of extractable P in the soil from the two sources were equal. Furthermore, the extractable P from the inorganic source decreased with time while that from the manure increased.

Long-term studies have also shown that manure additions increase the extractable P in the soil to the same extent as equivalent rates of fertilizer P. A 117-year experiment at Barnfield, Rothamsted Experiment Station was conducted with manure and superphospate treatments as shown in Table 2-6. Both the total P and $NaHCO_3$-extractable P were increased to approximately the same extent by both manure and fertilizer sources. The 0.01 M $CaCl_2$-soluble P was increased to a much greater extent by the manure source, an observation that is consistent with many other studies. The mechanism responsible for this effect is not clear. It has been suggested (Anderson et al. 1974) that the presence of organic phosphate causes the formation of octacalcium phosphate

Table 2-6. Long term effects of manure and superphosphate on P levels at Barnfield, Rothamsted [α].

Annual P Rate Manure	(1843 to 1959) Fertilizer	Extractable P in soil: Equilibrated in 0.01 M $CaCl_2$ solution	Extractable P in soil: 0.5 M $NaHCO_3$	Extractable P in soil: Total P in soil
$t.ha^{-1}$	$kg\ P.ha^{-1}$	$mol.L^{-1}x10^6$	$mg.kg^{-1}$	$mg.kg^{-1}$
0	0	0.6	23	780
31	0	13.2	83	1240
31	33	20.0	132	1840
0	33	1.9	66	1220

[α] Manure contained about 40 kg $P.ha^{-1}$ (Warren and Johnston 1962).

whereas inorganic sources of P form less soluble reaction products.

The higher solubility of reaction products from manure sources of P has several implications. The absorption of P by plants is closely related to the concentration of P in solution. Hence, although the $NaHCO_3$-extractable P is the same from the two sources, the rate of P absorption by plants would be expected to be greater from the manure P. The second implication is that the movement of P into the subsoil would be greater with the manure addition. Cooke (1967) stated that P leached into subsoils at Rothamsted only when manure was applied. This effect would be of considerable benefit to crops if downward movement was appreciable. A third implication is that the soluble P content of runoff from manured fields is likely to be higher than that from fields receiving the equivalent amount of fertilizer P.

Recent evidence by Bhatnagar (1979) indicates that phosphorus added as manure is preferentially absorbed by larger sized aggregates. The $NaHCO_3$-extractable P of larger aggregates was increased by manure-P addition to a greater extent than that of smaller aggregates, as indicated in Table 2-7. Inorganic P was absorbed equally by aggregates of all sizes.

2.2.2.3 Potassium

The potassium in manure is almost entirely in the inorganic form and is highly soluble. Hence, it reacts in a manner similar to inorganic sources of fertilizer.

2.2.2.4 Micronutrients

The micronutrient content of manure and the influence of manure on micronutrients in soils are discussed in Chapter 4; comments here will be very brief. Manure contains all elements essential for plant growth and manure applications will generally prevent occurrence of micronutrient deficiencies on soils that are marginal in supply.

2.3 AGRONOMIC AND ENVIRONMENTAL IMPACT OF LAND APPLICATION OF MANURE

2.3.1 INTEGRATION OF MANURE USE INTO A CROP PRODUCTION SYSTEM

The value of manure in terms of a fertilizer replacement is shown in Table 2-8, using 1980 fertilizer prices. In practice, its value will depend on retention of nitrogen, phosphorus and potassium in the manure. Optimum management practices reduce losses of nitrogen and potassium from leaching as well as loss of nitrogen through volatilization and can greatly increase the returns

Table 2-7. $NaHCO_3$-extractable P content of wet-sieved aggregrates following 93-day incubation with varying rates of P as fertilizer or manure (Bhatnagar 1979).

Aggregate Size m	Rates of P (µg $P.g^{-1}$)					
	Fertilizer			Manure		
	0	50	100	0	50	100
	(µg $NaHCO_3$-Ext.$P.g^{-1}$)					
> 4.8	9.7	18.7	23.2	9.5	22.3	36.7
2.0 - 4.8	9.2	17.7	26.7	9.5	19.0	30.8
1.0 - 2.0	8.6	17.3	27.7	9.0	16.8	27.3
0.25 - 1.0	8.8	17.3	25.7	8.5	15.2	23.0

Table 2-8. Fertilizer value of manure produced by 1 dairy cow in 365 days (based on 1980 prices).

	Excreted kg	Value [α] $
Nitrogen (N)	77	46.00
Phosphorus (P)	15	20.00
Potassium (K)	67	19.00
	TOTAL	85.00

[α] Assumes a value of N– \$0.60. kg^{-1}, P- \$1.40.kg^{-1}, K- \$0.28.kg^{-1}.

NOTE: 1 dairy cow excretes about 18 tonnes of manure per year. Thus a value of about \$4.75.t^{-1} of undiluted manure is the maximum value assuming no loss and 100% availability. In practice it is assumed that 50% of the N, 40% of the P and 90% of the K is available in the first year of application.

from manure application. These include storage and application systems that minimize loses as well as application at the most appropriate times and rates to make most effective use of the nutrients present. The data in Table 2-8 illustrate the importance of animal manure as a resource, particularly at a time when we have become more conscious of the need for conservation. In addition to N, P and K, manure provides other nutrients and organic matter to the soil.

Incorporation of fresh manure into the soil at the appropriate rate will minimize loss of nutrients from the manure. Under Canadian conditions this is not possible during much of the year. Thus, it is important to provide proper storage of the manure to guard against volatilization of ammonia nitrogen, as occurs from solid manure under dry loose conditions, and to guard against loss of soluble nitrogen and potassium by leaching from an unsealed pit, particularly when exposed to precipitation. In an experiment in Ottawa, exposed cow and horse manure mixed together lost 9% more organic matter, 17% more nitrogen, 12% more phosphorus (P_20_5) and 33% more potassium (K_2O) than did corresponding manure in a weathertight shed during a 12-month period (MacLean and Hore 1974). An advantage of using stored instead of fresh manure is that it allows for more flexible use of the material in the overall planning and farm management in accordance with weather conditions, and soil and cropping systems.

The most effective use of animal manures on cropland must be guided by decisions at the farm level. Influencing factors include the particular site and its slope; the soil's supply of available nutrients and its permeability; the climatic conditions; the particular crop to be grown and its nutrient requirements; and the supply of nutrients in the manure. Gilbertson et al. (1979) prepared a manual for the U.S. Department of Agriculture and the Environmental Protection Agency to assist in the development of management guidelines on the use of animal wastes on cropland and pastures. In general, the approach and techniques employed for the effective use of chemical fertilizers also apply to the use of manure, provided that adjustments are made for the differences in the availability of nutrients, particularly nitrogen, in fertilizers and manure.

Manure should be incorporated into the soil soon after spreading to avoid loss of nitrogen by volatilization and the loss of phosphorus and potassium as well as nitrogen through water runoff. Obviously, this becomes particularly important on sloping land and with impermeable clay soils subject to water erosion. Addition of manure to frozen soil should be avoided. Azevedo and Stout (1974) cite summarized data of Gilbertson et al. (1979), showing a loss of 24% of the nitrogen in broadcast manure after 4 days, as compared with only 5% when the broadcast manure was cultivated immediately into the soil. The nitrogen in manures is subject to a slow biological release in contrast to the ready availability of fertilizer nitrogen for plant growth. Manures containing much bedding material may have a C:N ratio too high (over 20) for release of ammonia from the organic nitrogen compounds in amounts beyond the requirements of the microorganisms. Poultry manures, which contain more nitrogen than do manures of dairy cattle, may be expected to provide nitrogen to crops in the early stages of growth more effectively than dairy cattle manure. On the other hand, when compared with fertilizer, animal manures will provide a slow release of nitrogen for crops over a longer period of time, since readily soluble nitrogen in fertilizer can be leached from the upper soil layers and transported below the root zone.

After reviewing literature comparing manure and fertilizer in numerous field experiments, Azevedo and Stout (1974) concluded that nitrogen in manures was about 20 to 50 per cent as effective as commercial fertilizer nitrogen in influencing the short-term yields of crops. In contrast, phosphorus and potassium in manures were considered to be equally as effective as the forms in mineral fertilizers. In a long-term experiment at Ottawa, a manure treatment containing considerably more nutrients than a fertilizer treatment was only slightly more effective than the fertilizer in influencing the yields of mangels, oats, clover, and timothy grown in rotation (Table 2-9). In a subsequent pot experiment using soil from the experimental plots, the yield of alfalfa in the previously fertilized soil was only 58% of that obtained in the previously manured soil. Apparently, the manure provided a greater supply of residual nutrients, particularly phosphorus and potassium, for the alfalfa than did the fertilizer. The residual effect of manure in supplying nitrogen from the organic material by nitrification has long been recognized, although in short-term experiments manure may be only 30-40% as effective as fertilizer in supplying nitrogen (Azevedo and Stout 1974).Gilbertson et al. (1979) presented decay constants to estimate manure nitrogen availability to crops (Table 2-10) (Pratt et al. 1973). The series of decay constants for dairy manure (0.50, 0.15, 0.05, 0.05) implies that 50% of the nitrogen will be available in the first crop year, 15% in the second year, and 5% in each of the third and fourth years. Although decay constants for a manure will vary with climate and cropping conditions, they illustrate the differences between manures in their capacity to supply more readily available nitrogen in the first year of cropping and residual nitrogen in subsequent years.

If the quantity of animal manure for use in crop production is limited, it is preferable to apply it at only a moderate rate and to supplement with chemical fertilizer. This allows one to adjust the supply of different nutrients to attain the best balance for the particular crop. Also, it is good practice to use the manure for those crops which have high nitrogen requirements, for example, corn and forage grasses rather than beans or cereals. Manure may be better than fertilizer as a source of nitrogen in sandy soils which are subject to nutrient leaching. In longer rotations, manure may be used more effectively by splitting the application between a row crop such as corn and hay

Table 2-9. Comparison of manure and fertilizer for 4-year crop rotation on sandy loam soil at Ottawa, 1913-1952 (Cordukes et al.1955).

Treatment [α]	Mangels	Oats	Clover	Timothy
	$t.ha^{-1}$	$L.ha^{-1}$	$t.ha^{-1}$	$t.ha^{-1}$
Manure	48.1	5510	8.6	7.0
Fertilizer	45.7	5410	7.2	5.9

[α] Manure - 24 $t.ha^{-1}$ for mangels; fertilizer - 73 kg N, 24 kg P and 35 kg K for rotation.

Table 2-10. Decay constants to estimate animal manure nitrogen availability to crops (Gilbertson et al. 1979).

Manure	N in Manure (dry weight)	Decay Constants in Years After Application			
		1	2	3	4
	%				
Poultry (hens)	4.5	0.90	0.10	0.05	0.05
Poultry (broilers, turkeys)	3.8	0.75	0.05	0.05	0.05
Swine	2.8	0.90	0.04	0.02	0.02
Dairy, fresh	3.5	0.50	0.15	0.05	0.05
Dairy, anaerobic	2.0	0.30	0.08	0.07	0.05
Beef feeders, fresh	3.5	0.75	0.15	0.10	0.05
Beef feeders, dry corral	2.5	0.40	0.25	0.06	0.03
	1.5	0.35	0.15	0.10	0.05
	1.0	0.20	0.10	0.05	0.05

crops which follow later in the crop rotation. In the former Experimental Farm Service, Agriculture Canada, it was common practice to apply rotted livestock manure to the farm fields at a rate of 9 $t.ha^{-1}.a^{-1}$(4 $ton.acre^{-1}.a^{-1}$), i.e. corn in a 4-year rotation would receive 36 t (manure).ha^{-1}(16 $ton.acre^{-1}$). Currently, with many intensive livestock operations, disposal of manure in excess of crop requirements presents problems since it becomes a question of how much manure can be added beyond crop requirements without loss of nutrients to groundwater or nearby water bodies.

2.3.2 MINIMIZING ENVIRONMENTAL IMPACT

2.3.2.1 Detrimental Effect of Excess Manure on Soils and Crops

In heavy manured land, some forage species may accumulate NO_3-N in excess of that utilized by protein production and levels may reach above 0.30% (dry weight), which could cause nitrate poisoning in cattle. Azevedo and Stout (1974) cited instances of ammonia toxicity in germinating seeds and young seedlings following application of moderate to high rates of poultry manure. A delay of 4 weeks between the date of manure application and the date of planting was recommended so that the ammonia would be converted to nitrate. When manure is applied repeatedly at rates sufficient to assure an adequate supply of nitrogen for crop needs, with allowance for nitrogen losses in storage or open field application, then phosphorus, potassium and other elements not subject to loss from the manure by volatilization will tend to accumulate in the soil. This may give rise to an improper balance of soil nutrients. For example, accumulated potassium may give a high K:Mg ratio in forage, favoring conditions for the incidence of grass tetany in cows. Accumulated phosphorus may induce a zinc deficiency in some crops. Instances of salt injury to crops following heavy additions of manure have been reported. However, soluble salts are not apt to be a problem in humid regions and, if the problem arises in arid regions under irrigation, the farmer has the expertise from previous experience with salts to adjust practices accordingly. As discussed in Chapter 4, microelements in manure are not likely to present any problems with the exception of copper, following heavy applications of manure from swine that were fed copper as a growth stimulant.

2.3.2.2 Effect of Animal Manures on Water Quality

Instances of infantile methemoglobinemia or blue-baby disease have been associated with nitrate in drinking water, particularly from shallow rural wells. Levels should not exceed 1 $mg.L^{-1}$ nitrate-nitrogen. In a survey of 484 wells in Ontario, Johnson (1955) found that 13.8% of the well water contained more than 1 $mg.L^{-1}$ nitrate-nitrogen. Manure pits in the vicinity of farm wells could be a likely source of contamination. Nitrate poisoning of cattle drinking water in low spots in pasture has been reported (Azevedo and Stout 1974). Where biological conditions are favorable for conversion of nitrogen in manure to nitrate, water may contain high amounts of nitrate arising from the manure or dissolved nitrates washed into the depressions by rain. A level of 500 $mg.kg^{-1}$ nitrate was considered to be toxic. Excess nitrate in the pasture grasses will aggravate the problem.

A more widespread current concern is the contribution of animal manure to the enrichment of streams and other water bodies with nitrogen, phosphorus and organic matter. Nitrogen and phosphorus are essential major nutrients for the growth of aquatic plants in water bodies, some of which are used for fishing or other recreational purposes. Amounts of nitrogen and phosphorus considered limiting for algal growth are about 0.3 and 0.01 $mg.kg^{-1}$, respectively. Because of its organic nature, manure may contribute organic matter to waters and increase the BOD of the water. Decomposition of this organic matter by waterborne microorganisms reduces the oxygen content of the water. Enrichment of waters with nutrients from manure promotes additional aquatic plant growth which, on decomposition, further depletes the oxygen supply. The lack of oxygen or reduced oxygen tension in the water results in the death of fish. Azevedo and Stout (1974) suggested that animal operations were the cause of numerous fish kills in the United States. In a number of cases manure has been deliberately dumped on fields sloping towards streams and rivers. This has resulted in fish kills extending as far as 8 km downstream.

Pollution of water by animal manure may arise from leaching or, more likely, from runoff from barnyards and feedlots as well as from the land application of manure. A common cause of manure spillage is the overflow from liquid manures storage tanks. Neglected tanks on farms fill up with rain water and overflow.

(a) Barnyards and feedlots - These sites represent the main point sources of pollution of waterways by animal manures. The pollution, if any, from the site will depend on the exposure of the manure to climatic conditions (temperatures favorable for mineralization of nitrogen in particular); the amount and intensity of rainfall; topography of site; soil conditions, permeability favorable for leaching and impermeability favorable for runoff; and hydrological conditions, depth of water table and underlying strata influencing vertical and horizontal movement of the water carrying the contaminants. Thus, the selection of the barnyard or feedlot site, its distance from any waterway, and the soil and hydrological conditions favorable for control of leaching and runoff are of prime importance. The most suitable structure for manure storage and the attendant control measures to prevent loss of manure nutrients by leaching or runoff will differ from one operation to another. The structural and management aspects of manure handling systems for beef cattle, dairy cattle, swine, and poultry are described and discussed in the Canada Animal Waste Management Guide (Canada Committee on Agricultural Engineering Services 1979). A summary in the same publication covered the provincial regulatory programs on management practices to control pollution from animal units.

Townshend et al. (1970) discussed the problems and management of feedlots in Ontario. Instances of contamination of water by feedlots usually arose from faulty management. In a 4-year study of two sites used during the past 30 years for solid manure storage, one on concrete and the other on a gravel base at the Central Experimental Farm, Ottawa, there was no evidence of serious groundwater contamination with excess nutrients (Sowden and Hore 1976).The water table at both sites was usually above a depth of 2.75 m. Water from piezometers at depths of 2.75 and 4.25 m near the gravel base was always low in nitrate and ammonium but sometimes there were appreciable amounts of nitrate in the water at a 1.22 m depth. Water at depths of 1.22 and 2.75 m near the concrete base usually contained nitrate and ammonium. Water in piezometers installed slightly beyond 200 m from the storage areas, in the direction of groundwater flow, contained little nitrate or ammonium. The authors suggested that much of the nitrate originating from the storage sites was denitrified at or near the water table. The movement of nitrate from a barnyard (near Guelph, Ontario) used for manure storage for 50 years was in the direction of groundwater flow, which followed bedrock slope (Gillham and Webber 1969). The bedrock was at a depth of 4.9 m and the water table was at a depth of 2.4 m. Upstream, at a distance of 30.5 m, the water was uncontaminated, whereas downstream, a distance of at least 183 m was required before obtaining water of satisfactory quality. Preliminary data obtained a decade ago showed high concentrations of nitrogen and phosphorus in the soil and groundwater under and near feedlots in the vicinity of Lethbridge, Alberta, but rarely did these nutrients move in the soil for a distance greater than 122 m (Research Station, Lethbridge 1971). Of more serious concern was the possible runoff from catch basins near feedlots and it was suggested that such runoff should be diverted from streams and allowed to seep into the soil.

Coote and Hore (1978) studied the runoff and pollution potential of a paved and an unpaved feedlot and two manure storages in southern Ontario. Runoff comprised about 60% of the rainfall with the mean amounts withheld before runoff varying from 1.5 mm for the paved and 7.1 mm for the unpaved feedlot. Runoff from the storages occurred mostly when they were mainly empty in the summer. BOD in the runoff was higher for the paved than for the unpaved feedlot (Table 2-11). The concentrations of nitrate were low but those of ammonium, total phosphorus and soluble phosphorus were high and represented a potential source of pollution. The concentrations of phosphorus were related to the amounts of total solids in the runoff. In monitoring the shallow groundwater down slope from another unpaved feedlot, the same authors found an increase in the concentration of nitrate-nitrogen with distance from the feedlot, reaching a peak of 60 mg.L^{-1} at a distance of 20 m. But within the same zone, ammonium-nitrogen decreased with distance from the feedlot. Evidently, nitrification was a dominant process at the 10-20 m distance. There was no evidence of contamination of the groundwater with phosphorus.

Table 2-11. Water quality of runoff from feedlots and manure storages in southern Ontario (means, mg.L^{-1}) (Coote and Hore 1978).

	Feedlot		Manure Storage	
Component	Paved	Not paved	With bedding	No bedding
BOD	4971	1366	3243	2285
Ammonia-N	264	86	411	240
Nitrate-N	0.97	0.53	0.81	0.47
Total P	133	102	83	87
Soluble P	53	47	39	42

Azevedo and Stout (1974) reviewed considerable literature on the incidence of water pollution arising from corrals, barnyards and feedlots, and discussed management techniques for its control. They emphasized the importance of moisture in the manure. For example, there is considerable evidence that under alkaline and drying conditions, significant amounts of ammonium may be volatilized from a feedlot and be deposited in surrounding surface waters. Feedlots with a concrete surface may shed more runoff than those on an unpaved irregular surface which may hold water. While a dry manure surface is difficult to wet and a water saturated manure surface will favor runoff, moist manure will absorb considerable water and reduce runoff. The authors suggest that a moist but aerobic corral surface with a compact anaerobic subsurface will encourage nitrification in the surface area and the nitrate-nitrogen on reaching the subsurface layer will be denitrified and lost to the system.

(b) Land-spread manure - Animal manure is a valuable resource for maintenance of soil fertility. Its judicious use for crop production is in harmony with safeguarding water quality. To avoid loss of nitrogen by volatilization and of nitrogen, phosphorus and organic matter by runoff, manure should be incorporated into the soil soon after its application. Equipment is available for injecting liquid manure into the soil; the soil cover will minimize runoff. In fact, manure has been shown to reduce runoff (Ripley et al. 1961).

Particular attention should be given to management practices in the use of manure on land adjoining a waterway. Manure on the surface of land sloping in the direction of a waterway, on a flood plain or on frozen soil will contaminate nearby water bodies. A grassed buffer zone between the waterway and heavily manured land can be effective in minimizing pollution of the water. Mention should be made of manure deposited directly by animals on pastures. Although the amounts of nutrients in the manure will not compensate fer those removed from the pasture by the animals, concentrations of livestock can deposit considerable manure near a waterway. This manure can find its way into the water along with manure deposited directly by the animals having access to a waterway for drinking purposes. Obviously, livestock should not have direct access to a water body.

To minimize leaching of nutrients, particularly nitrate-nitrogen, and to avoid contamination of ground water, the rate of manure to be used should be based on quality of the manure and the nutrient requirements of the particular crop in relation to nutrient supply in the particular soil, including residual nitrogen from previous manure additions. Soil testing services as well as information and recommendations of government departments of agriculture and environment can assist operators in adjusting management practices so as to avoid additions of manure in excess of the needs of the crop. It should be noted, however, that phosphorus is quite immobile in mineral soils and will not move down the soil profile readily to contaminate groundwater. Ammonium enters into exchange reactions in soils and can be bound particularly in clays. Furthermore, there is considerable evidence that nitrate nitrogen leached into anaerobic subsurface soil layers may be denitrified and escape to the atmosphere instead of contaminating groundwater.

From the foregoing, it can be seen that with good management, manure can be used to meet crop needs without impairing water quality. With current intensification of livestock and poultry operations, however, the amount of manure produced is often in excess of the requirements of the associated land base. To provide for disposal of excess manure, it has been proposed that manure be applied to corn and forage crops at rates up to some maximum, at which the amount of nitrogen will be beyond crop requirement but will not impair yield or water quality (Webber and Lane 1969; Barnett 1975). Obviously, the acceptable maximum rate will vary with climatic and soil conditions. Soils with deep water tables, with impermeable subsurface layers less subject to leaching, and with conditions favoring denitrification will be most suitable for disposal of excess manure.

At the Central Experimental Farm, Ottawa, an experiment was conducted for 5 years on rates and times of application of liquid dairy cattle manure for corn on a sandy loam soil underlaid by clay loam at a depth of 0.8 m (Phillips et al. 1981). The concentrations of nitrogen and phosphorus in snow-melt water in four events of early spring runoff, from plots receiving manure on frozen ground in winter, increased appreciably with increasing rate of manure used (Table 2-12).There were increases in phosphorus concentrations in the runoff water with increasing rates even when the manure was plowed under. Time of application had no effect on the nutrient concentration of the water component of runoff during two June storms except that the combined nitrate and ammonium nitrogen concentration increased slightly with the rate of application in water from spring-manured plots but not in the water from the others. Phosphorus concentrations increased consistently with increasing rate. The mean P concentration for the 3 times of application was 0.12 $mg.L^{-1}$ for the control plot as compared with 1.07 $mg.L^{-1}$ for the highest phosphorus rate, supplying 218 $kg.ha^{-1}.a^{-1}$. The concentrations of nutrients in tile drain effluent during three springtime events were not affected by time of manure application. The mean concentration of nitrate nitrogen for the 3 times of application increased from 8.4 $mg.L^{-1}$ in the effluent from the control plot to 20.8 $mg.L^{-1}$ in that from the plots receiving the high rate of nitrogen (892 $kg.ha^{-1}.a^{-1}$). The data for phosphorus concentrations in the tile drain effluent were inconsistent, but on the average for all times and rates of application, the concentration was 0.07 $mg.L^{-1}$ as compared with only 0.01 $mg.L^{-1}$ for the control. In summary, there was enrichment of early runoff with soluble nitrogen and phosphorus from winter applied manure. There was evidence of some enrichment of tile drain effluent with soluble phosphorus as well as nitrogen from the manured plots.

Table 2-12. Average concentration of nitrogen and phosphorus in snow-melt water in four events of runoff from plots receiving liquid dairy manure at different rates and times of application at Ottawa [α].

Nutrient measured	Nutrients added kg.ha^{-1}.a^{-1}	Time of Application [β]		
		Fall	Winter	Spring
	Nitrogen			
$(NO_3 + NH_4)$-N mg.L^{-1}	0	2.9	2.9	2.9
	227	-	6.6	4.0
	555	5.0	12.5	3.4
	892	2.0	26.5	5.3
	Phosphorus			
PO_4- P mg.L^{-1}	0	0.06	0.06	0.06
	53	0.25	2.25	0.65
	136	0.84	3.54	0.30
	218	0.75	11.16	0.81

[α] Adapted from Phillips et al. 1981.

[β] Except for winter applications, manure was plowed under immediately.

2.3.2.3 Contribution of Nutrients from Livestock Operations to Enrichment of Water Bodies

Up to this point, the discussion has centered on loss of nutrients from livestock waste in relation to prevailing conditions and management practices in a farm operation considered as a unit. It is important that potential contaminants of a waterway be minimized at their source. However, in seeking the source of nutrient enrichment of a water body, there is a question concerning the collective nutrient contribution originating from several farms, a sub-basin, a basin or a watershed. A few years ago, this question was posed by the International Joint Commission's International Reference Group on Pollution from Land Use Activities (PLUARG) and studies were subsequently conducted by various researchers in Ontario. Reference will be made to a few of the projects relating to water pollution from livestock operations. The reported findings of the authors do not necessarily reflect the views of PLUARG.

Patni and Hore (1978) studied the movement of nitrogen and phosphorus to subsurface and surface waters in large-scale livestock operations at the greenbelt Farm of the Animal Research Institute, Agriculture Canada, Ottawa. Split manure applications in spring and fall at the rate of 500 kg $N.ha^{-1}.a^{-1}$ for corn on flat fine-textured soil for 3 years did not cause excessive deterioration in the quality of tile drain effluent, provided that only low rates of nitrogen have been added to the field in previous years. The quality of stream water leaving the intensively cropped drainage area of the flat, tile-drained, and fine-textured soil was not generally impaired to unacceptable levels. However, depending on the flow, substantial amounts of nitrogen could be lost in spring runoff.

In another study, 26 sampling stations were established to monitor loadings to surface waters from 17 farm operations representing beef and dairy cattle, swine, and non-livestock controls in the Little Ausable River Sub-basin in southwestern Ontario (Beak Consultants Limited 1977). There was no significant difference between the export of nitrogen from the livestock and non-livestock areas, the mean estimated nitrogen export being 45 kg $N.ha^{-1}.a^{-1}$. The export of phosphorus from the non-livestock areas was estimated to be 0.33 kg $P.ha^{-1}.a\text{-}^{1}$ compared with 0.33 to 2.33 kg $P.ha^{-1}.a^{-1}$ for the livestock areas. Most of the phosphorus export occurred in the spring with snowmelt and rain showers. Nitrogen export occurred mainly in the winter and spring. The authors of the report suggested that phosphorus export was related to distance from watercourse, improper subsurface drainage, winter manure spreading in close proximity to water courses, winter manure spreading upon a floodplain, streams flowing through open pastureland, and the location of feedlots and manure storage. Phosphorus export appeared to depend more on management practices than on the type and density of livestock.

Robinson and Draper (1978) developed a model to estimate inputs of phosphorus to the Great Lakes from feedlots, barnlots, manure storages and winter-spread manure. Runoff from manure spread on unfrozen land was included in another model developed for cropland. An attempt was made to estimate input to streams by grazing cattle separately. Inputs of phosphorus were calculated based on information on livestock type and numbers. When the model was applied to the Ontario Great Lakes Basin, the estimated input of phosphorus was 0.08 or 0.22 kg per animal unit depending on whether a distance of 30.5 m or 122 m was assumed for complete attenuation of phosphorus during overland transport. From the mean of these values, it was estimated that the annual total-P loading to the Great Lakes from livestock in the Ontario Basin was 318 t. It was concluded that remedial measures designed to prevent runoff from barns and feedlots within 100 m of stream channels, and eliminating winter manure spreading near stream channels would eliminate much of the inputs of phosphorus from livestock sources.

3.0 MANURE GASES AND ODORS

J.B. McQuitty [α] and A.J. MacLean [β]

In liquid manure handling systems, manure stored in collection pits, holding tanks, and storage lagoons undergoes anaerobic decomposition with the accompanying production of gases (potentially hazardous to human and animal health) and of odors. The literature on manure gases in the animal environment was reviewed in detail by Nordstrom and McQuitty (1976). Subsequently, McQuitty and Feddes (1978) related the known information to practical management and warned that manure gases are dangerous (in this connection it was reported in October 1982 that an Eastern Ontario farm worker was rendered unconscious by the toxic gases and drowned in a vat of manure). A concise discussion of the topic in the Canada Animal Waste Management Guide (Canada Committee on Agricultural Engineering Services (1979)) reflects the present state of knowledge. Thus, the publications cited above will serve as the main source of scientific information and opinion in this presentation.

3.1 GASES

In the decomposition of liquid manure by anaerobic microorganisms, a number of noxious gases and volatile compounds are produced from proteins, carbohydrates and fats in the organic portion of the manure (Figure 3-1).The principal gases of concern in animal confinement buildings are H_2S, NH_3, CH_4 and CO_2. In addition to the gases arising from decomposition of the manure, the animals may produce appreciable amounts of CH_4 and CO_2. A cow, for example, may produce up to 50 L of CH_4 and about 300 L of CO_2 per day largely through eructation (Blaxter 1962). Gas production from manure is increased by increasing temperature and is influenced by hydrogen-ion concentration. Some properties of these gases and their physiological response on humans are summarized in Table 3-1.

3.1.1 ASPHYXIANTS

The gases CO_2 and CH_4 are asphyxiants. Carbon dioxide is not considered to be a critical problem in animal housing. In normally ventilated buildings the concentrations of CO_2 appear to be in the 500-2000 $\mu L.L^{-1}$ range, although they may increase to 3000 $\mu L.L^{-1}$ at animal level when the manure is agitated (McQuitty and Feddes 1978). Methane also is not considered hazardous

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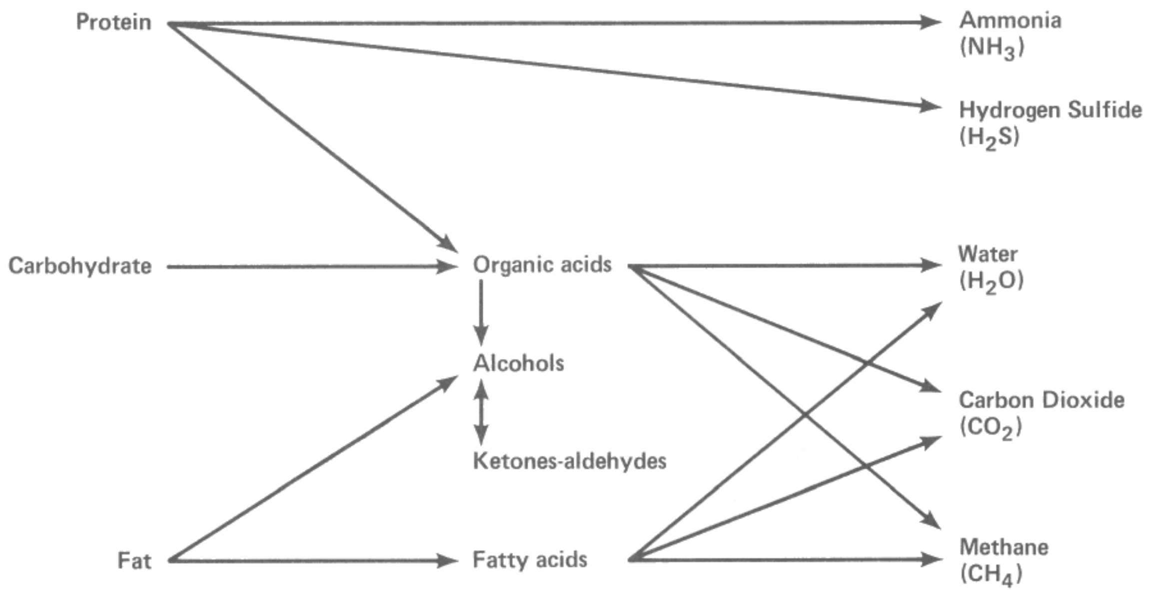

Figure 3-1. Anaerobic degradation of manure organics (Barber and McQuitty 1974).

Table 3-1. Properties of the principal manure gases and their physiological response on adult humans[α] (Canada Animal Manure Management Guide).

Gas	Specific gravity[β]	Odor	Color	Affinity for water	Limits of inflammability[γ] (% by volume)		Threshold limit value[δ] µg.L^{-1} [ϵ]	Excursion factor	Time-weighed average limit[η] µg.L^{-1}	Gas concentration µg.L^{-1} and physiological response	
					Lower	Upper					
Ammonia (NH_3)	0.6	Sharp pungent	None	Highly soluble	15.5	27.0	25	1.5	37.5	IRRITANT	
										5 - 50	- least detectable odor
										100 - 500	- irritants to mucous surfaces in 1 hour
										400 - 700	- immediate irritation of eyes, nose and throat
										2000 - 3000	- severe eye irritation, coughing frothing at mouth could be fatal
										5000	- respiratory spasm, rapid asphyxia may be fatal
										10000	- rapidly fatal
Carbon dioxide (CO_2)	1.5	None	None	Moderately soluble	-	-	5000	1.25	6250	ASPHYXIANT	
										20,000	- safe
										30,000	- increased breathing
										40,000	- drowsiness, headaches
										60,000	- heavy asphyxiated breathing
										300,000	- could be fatal (30 minute exposure)
Hydrogen sulfide (H_2S)	1.2	Offensive rotten egg smell	None	Highly soluble	4.3	45.5	10	2	20	POISON	
										0.01-0.7	- least detectable odor
										3 - 5	- offensive odor
										10	- eye irritation
										20	- Irritation to mucous membrane and lungs
										50-100	-irritation to eyes and respiratory tract (1 hour exposure)
										150	- olfactory-nerve paralysis, fatal in 8-48 hours
										200	- dizziness(1 hour) nervous system depression
										500-600	- nausea, excitement, unconsciousness, possible death, (30 minutes)
										700-2000	-rapidly fatal
Methane (CH_4)	0.6	None	None	Slightly soluble	5.0	15.0	-	-	-	ASPHYXIANT	
										500,000	- headache, non-toxic

[α] Source: Nordstrom, G.A. and J.B. McQuitty. 1976. Manure gases in the animal environment - a literature review. Research Bulletin 76-1. Department of Agricultural Engineering. University of Alberta, Edmonton, Alberta. 80 pp.115 ref.

[β] Specific gravity: the ratio of the weight of pure s to standard atmospheric air, per unit volume. If value is less than 1.0 the gas is less dense than air: if greater than 1.0, it is more dense than air.

[γ] The range within a mixture of the gas with atmosphere air can ignite or explode in contact with a flame or spark. Source R.C. Weast (Ed.).1973-74. Handbook of Physics and Chemistry, 54th Edition, CRC Press, Cleveland.

[δ] Threshold limit value (TLV) represents conditions under which nearly all workers may be repeatedly exposed for an 3-hour day and 40-hour work week without apparent adverse effects.

[ϵ] µg.L^{-1} of gas in atmospheric air. to convert gas concentration to percent by volume, divide by µL^{-1} by 10,000

[ζ] Excursion factor defines the magnitude of the permissible excursion above the TLV.

[η] Time-weighed average (TWA) limit defines the maximum concentration permitted for a short period TLV multiplied by the excursion factor equals TWA.

NOTE: When two or more hazardous gases are present, and in the absence of information to the contrary, the effects of the different gases should be considered as additive: that is, the sum of
$C_1/T_1 + C_2/T_2 + ... C_n/T_n$ exceeds unity, then the TLV of the mixture should be considered as being exceeded.

C = observed atmospheric concentration and T = corresponding TLV for each gas, n.

to health in normally ventilated buildings. The detrimental effects of both CO_2 and CH_4 arise from the exclusion of available oxygen which should not go below 18% by volume. A more significant concern over buildup of CH_4 in the atmosphere lies in its flammable and explosive properties. High CH_4 concentrations may occur under the head space of covered manure storages. As a safeguard around such manure storage facilities, open flames and smoking should be prohibited and explosion-proof electric motors should be used on equipment. In addition, proper ventilation is important, and particular care must be taken before using a barn that has been used for manure storage and has been left empty without ventilation.

3.1.2 IRRITANTS

Ammonia and H_2S are irritants. Ammonia acts as an irritant on moist tissues, particularly the eyes and respiratory tract. The concentrations in animal barns with good ventilation appear to be in the range of 10-20 $\mu L.L^{-1}$ but levels above 100 $\mu L.L^{-1}$ are possible during agitation of manure slurry prior to emptying. Acute effects of NH_3 exposure in barns and storages appear to be unlikely. Nevertheless, there is evidence that subacute levels of NH_3 may have a detrimental effect on the animals and their production. In the presence of dust, concentrations of 50 $\mu L.L^{-1}$ NH_3 appeared to reduce daily weight gains in pigs and to increase the incidence and severity of pneumonia (McQuitty and Feddes 1978). These authors suggested that a concentration above 20 $\mu L.L^{-1}$ in animal housing is probably undesirable. They refer to interesting and occasional incidents in pig barns where NH_3 apparently goes into solution in water vapor which has condensed on cold surfaces and is then oxidized to nitrate or other methemoglobin-forming compounds which, if ingested, may be fatal to the pig. As a safeguard against excess NH_3, rapid removal of manure, adequate floor slopes to ensure drainage, liberal bedding and adequate ventilation are recommended.

Hydrogen sulfide is potentially the most dangerous of the manure gases. It has been involved in fatalities of humans and animals in Canada and other countries. While H_2S is not released in large amounts from undisturbed liquid manure, agitation causes sudden and rapid release of the gas; deadly concentrations in excess of 1,000 $\mu L.L^{-1}$ may occur. Normally, H_2S may not be detected in an animal barn although concentrations of 2-5 $\mu L.L^{-1}$ are not uncommon. In acute exposure, H_2S is a poison and the most dramatic effect is respiratory paralysis. At lower concentrations, H_2S acts as an irritant and affects, with varying severity, the eyes and respiratory tract. Constant exposure to concentrations of H_2S as low as 1 to 2 $\mu L.L^{-1}$ is suspected of causing illness and reduced productivity of livestock. As a safeguard against excessive H_2S concentrations, agitation should be avoided while emptying liquid manure pits within barns or else the livestock should be removed. In any event, maximum ventilation should be provided during emptying of the pits.

3.1.3 EFFECTS ON HUMANS AND ANIMALS

The danger of manure gases to humans is reflected in reports of fatalities from Canada and United Kingdom where farm workers entered manure storage tanks (Nordstrom and McQuitty 1976). The effects of increasing concentrations of the gases on humans are summarized in Table 3-1.Permissible levels of the gases in confinement buildings for animals have not been established; present guidelines are based on data for humans. However, the fact that animals are confined and exposed continuously with no means of escape from a hazardous situation should be noted. There is a need for research on the effects of the different manure gases on different animal species and an assessment of permissible concentrations.

Although considerable research has been done towards creating conditions for aerobic decomposition of manure, which is an essentially odorless process with no attendant evolution of dangerous gases, operating costs in a cold climate have imposed serious limitations to this alternative (McQuitty and Fedde 1978). In the quest for renewable energy sources, research on the anaerobic digestion of manure for the production of usable methane gas has indicated it is a practical method for the treatment of agricultural wastes and concomitantly odors are reduced (Kennedy et al. 1981; van den Berg 1980; van den Berg and Kennedy 1981). Several other promising avenues for investigation include (a) inhibiting the production of a noxious gas such as H_2S by eliminating or minimizing the activity of the bacteria that are responsible for its production, and (b) converting the gas before it is released from the manure to some other less objectionable form by chemical ionization or oxidation or by precipitation.

3.2 ODORS

Of the gases discussed, only NH_3 and H_2S have odors, that of NH_3 being sharp and pungent and that of H_2S being like the smell of rotten eggs. Cited chromatographic analysis of volatile substances over animal dairy waste (White et al. 1971) identified H_2S and several organic compounds, of which dimethyl sulfide was considered the main component of anaerobic dairy waste odor. Bulley (1977) presented a critical assessment of the methodology of sensory measurement for evaluating odors from livestock systems. Although sensory methods relying on the human olfactory system are subjective, alternative attempts to measure odors using physico-chemical techniques have not been very successful; the results in any event would need to be correlated to olfactory response. In the use of sensory methods, the author places considerable emphasis on sample collection, sample manipulation for presentation to a panel of testers, response and its interpretation, and presentation of results. He states: "Until more regard is given to the selection of sensory method to be used, sample collection, selection of a panel, presentation of odorant to panel,

panel response, and reporting of procedures used during the sensory evaluation, a great deal of research time and effort will be wasted".

Odors are not so much hazards to health as a nuisance which can be lessened by practical measures. Removal of manure and general hygienic practices within animal quarters will do much to lessen the nuisance there. The nuisance to the public can be alleviated by proper location of the animal establishment relative to encroaching residents. Distance as well as wind direction can be important. Objections to odors from spreading manure on land can be minimized by the choice of timing, including consideration of wind direction, and by immediate incorporation of the manure into the soil.

4.0 MICRONUTRIENTS AND HEAVY METALS IN LIVESTOCK AND POULTRY MANURES

M.D. Webber [α] and L.R. Webber [β]

Animal manures contain a wide range of micronutrient and non-nutrient elements, but their concentrations are seldom considered when determining manure application rates to land. The micronutrients include the metals Fe, Mn, Zn, Cu, Co, Cr and Mo, and the non-metals B, Cl and Se. The non-nutrients include the metals Ni, Cd, Pb and Hg, and the non-metal As. This review assesses the potential for buildup of these elements in the soil and the potential for toxicity to plants and animals when manures are used on land.

High levels of Cd, Cu, Ni, Zn, Co, B and Cl in soils are toxic to plants and may severely reduce crop yields (Webber 1972; Chaney 1974). Moreover, levels of Cu and Cd in plants, which are too low to reduce plant yields, may be toxic to animals. High levels of Mo and Se in soils may be taken up by plants and cause animal toxicities. However, Cr, Pb, Hg and As are almost completely excluded from the edible portions of plants. Manganese may cause plant toxicity but soils generally contain large amounts of both Fe and Mn and their solubilities are related to soil conditions (Leeper 1972).

Micronutrient and heavy metal buildup in sewage-treated soils or in soils located near mining or industrial operations represents a serious hazard to soil quality for crop production and may cause toxicities to plants and animals. Buildup occurs insidiously and damage results only after the soil quality has been reduced. The elevated levels persist indefinitely and no practical technology has been devised to reduce them. Thus, the only rational approach to protect soil quality is prevention of practices that would cause deleterious buildup.

4.1 ELEMENTS IN SOILS AND MANURES

A comparison of the micronutrient and heavy metal contents of Canadian soils and animal manures is presented in Table 4-1 and Figure 4-1.

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Table 4-1. Micronutrient and non-nutrient contents of Canadian manures and soils (mg.kg^{-1}, dry wt.).

Trace element	Manure [α]		Soil [β]	
	Range	Average	Range	Average
Fe	240 - 1,075	580	500 - 122,000	26,000
Mn	6 - 549	166	19 - 1,600	511
Zn	30 - 450	117	8 - 275	78
Cu	6 - 41	15	2 - 78	23
Ni	0.3 -4.7	2.8	1 - 86	21
Co	0.3 -4.7	1.2	1.7 - 60	21
Cr	1.1-5.2	3.0	5 -141	44
Mo	0.7-15.8	2.5	0.3- 0.9 [γ]	0.6 [γ]
B	4.5 - 52	20	n.a.[δ]	n.a. [δ]
Se	0.10 -1.48	0.43	0.02 -2.2	0.30
Cd	0.25-1.3	0.5	<0.3	< 0.3
Pb	2.5 -27	9.3	1.9 -51	20
Hg	n.a.[δ]	n.a.[δ]	<0.005 - 4.6 [є]	0.081 [є]

α Data obtained from Atkinson et al. (1954), Halstead (1975), W.M. Langille, Nova Scotia Agricultural College, Truro, N.S. and M.D. Webber, Wastewater Technology Centre, Burlington.

β Data obtained from J.A. McKeague, Land Resource Research Institute, Ottawa except as indicated otherwise.

γ M.D. Webber unpublished data for 6 soils.

δ Data not available.

є Data taken from McKeague and Kloosterman (1974) with the exclusion of one 14 mg.kg^{-1} value.

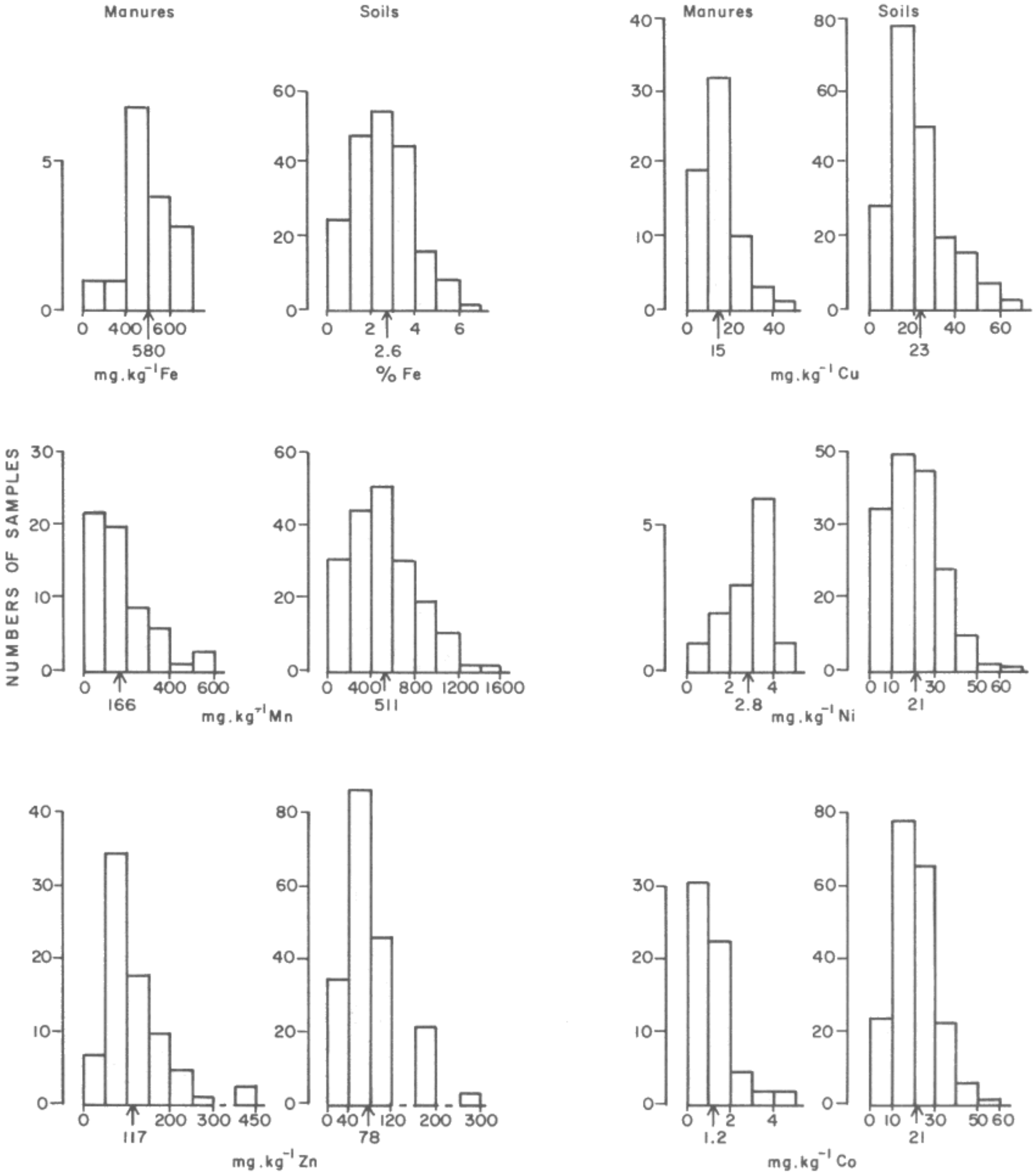

Figure 4-1. Histograms showing the frequency distribution of concentrations of trace elements in Canadian manures and soils. Average values are indicated by arrows.

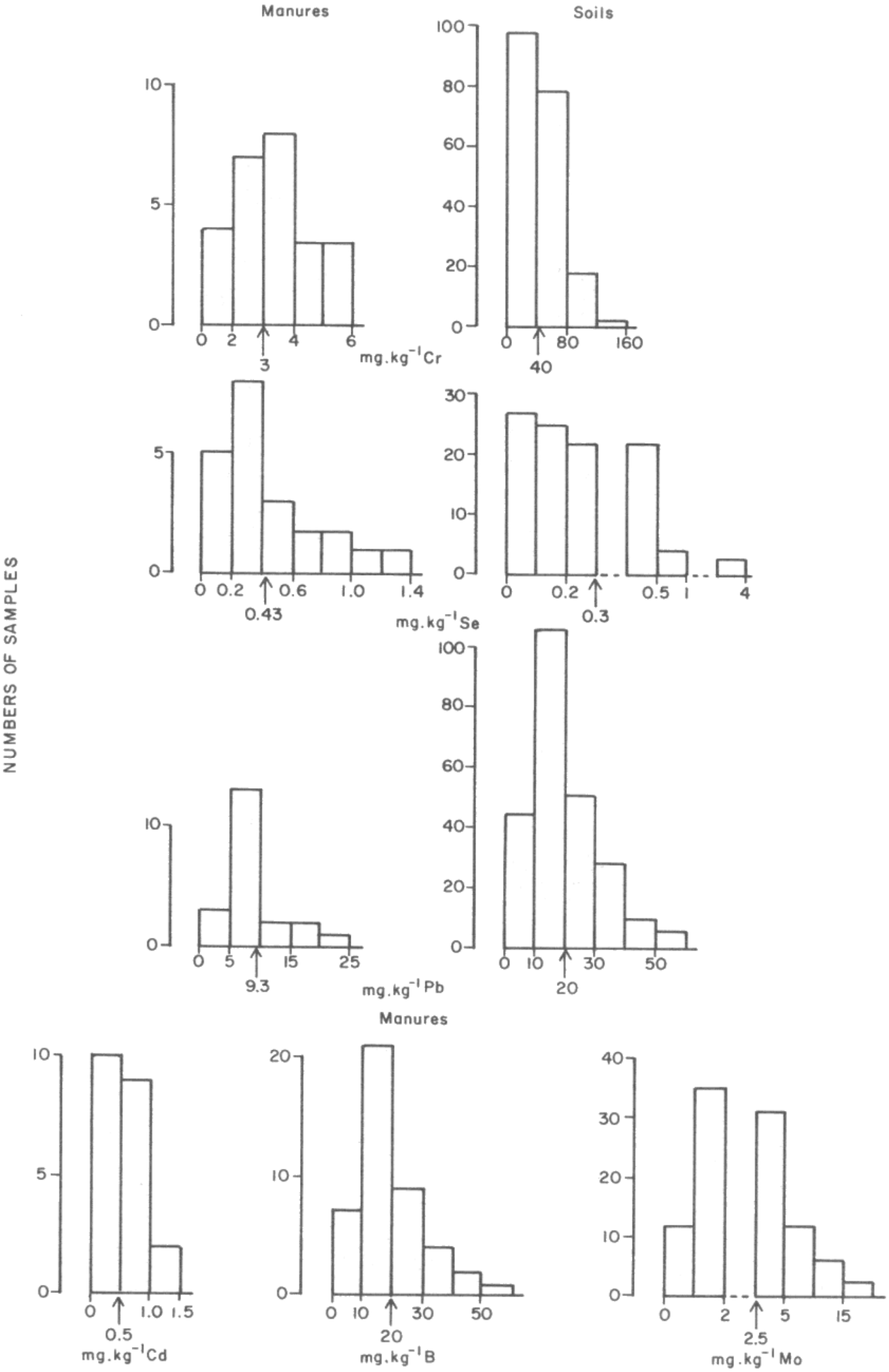

Figure 4-1. (cont'd). Histograms showing the frequency distribution of concentrations of trace elements in Canadian manures and soils. Average values are indicated by arrows.

4.1.1 SOILS

The soil data are total concentrations in horizon samples of seventy-three soils obtained from all provinces and the Northwest Territories. The soils were chosen to represent a variety of types, textures and mineral compositions. Care was taken to avoid sampling sites likely to have received elemental contamination from outside sources.

In general, the soils contained large amounts of Fe and Mn, intermediate amounts of Zn, Cu, Ni, Co, Pb and small amounts of Mo, Se, Cd and Hg. The data showed good agreement with ranges and typical contents reported by Berrow and Webber (1972). Although values were not available, it is likely that B contents of the Canadian soils were within the 2 to 100 mg.kg^{-1} range reported by them.

Frank et al. (1976), reporting on agricultural soils in Ontario, found that elevated metal contents were associated with pesticide and sludge use but not with manure or fertilizer use. Aerial fallout contributed to elevated levels of Ni, Co and Cu on three farms. Mean background levels of metals in the soils were reported as: Fe, 14470; Mn, 530; Zn, 53.5; Cu, 25.4; Ni, 15.9; Co, 4.4; Cr, 14.3; Cd, 0.56; Pb, 14.1; and Hg, 0.08 mg.kg^{-1}. The mean concentration of As was 6.3 mg.kg^{-1}. These values as well as others for Ontario soils (Whitby et al. 1978) are in good agreement with those reported in Table 4-1.

4.1.2 MANURES

Minor element data for Canadian livestock manures are sparse. The values summarized in Table 4-1 are from various sources, as indicated by the footnotes. Samples of horse, cow, hog, sheep, chicken and mixed manures were analyzed by several different procedures. Not all elements were measured in each sample. The manures contained large amounts of Fe, Mn and Zn, intermediate amounts of Cu, B and Pb and small amounts of Ni, Co, Cr, Mo, Se and Cd. This order is the same as that given by Mitchell (1951) for the trace element contents of plants. Copper contents were low (8 to 14 mg.kg^{-1}), indicating that there probably were no data for pig manure. The values showed general agreement with reports from the United States (Lunt 1959; Hileman 1967; Hensler et al.1970; Kornegay et al. 1975; Wallingford et al. 1975a); England and Yugoslavia (Hemingway 1961; Stojkovaska and C6-Re 1958); India (Mann et al.1973); Japan (Takijima etal. 1973); Czechoslovakia (Cumakov 1969)and Poland (Zmigrodzka et al 1972; Mazur 1972a, b).

A comparison of the minor-element contents of different animal manures using only Canadian data was not possible because too few of the samples were identified. Consequently, a comparison

Table 4-2. Micronutrient and non-nutrient contents of various manures.

	Elements										
Manure	Fe	Mn	Zn	Cu	Cr	Mo	B	Se	Cd	Pb	
Poultry, laying house litter (22)		233±78	307±114	66±4							El Sabban et al.(1969)
Poultry, laying house litter, 82-88% solids (3)		405-468	457-713	63-84							Hodgetts (1971)
Poultry, caged layers		318	341								Long et al.(1975)
Poultry, caged layers (4)						5.1-12.9		0.48-1.48			M.D. Webber (unpublished data) C
Poultry, layers				241					3.5		Webber and Beauchamp (1975) C
Poultry, broiler house litter (164)		321	272	127		8	36				Stuedemann et al. (1975)
Poultry, broilerhouse litter (33)		225±86	235±61	98±71							El-Sabban et al. (1969)
Poultry, broiler house litter (4)		320 408	280-309	179			53				Shortall and Liebhardt (1975)
Poultry, broilerhouse litter		296	228	32.3		6.4	27				Wilkinson et al. (1971)
Poultry, broilerhouse litter (2)	1000-1000	175-280	105-145	25-39		2-5	32-56				Hileman (1967)
Poultry, unspecified		381	263	27							Bates et al. (1974)C
Poultry, unspecified	443-460	39-398	425-450	6-31	3.9-5.0	6-18			0.6-1.3	5-9	Halstead (1975) C
Turkey, unspecified		45	30	45	15				42	20	Bates et al. (1974)C
Hog,(4)						5.6-11.1		0.69-1.33			M.D. Webber (unpublished data)C
Hog, unspecified (20)		114-561	128-981	22-636		0.2-0.5			0.3-2.4	4-42	Pearce (1975)
Hog, unspecified (5)		333	737	<100-690							Bates et al. (1974)C
Hog, finishing (2)	2310		439	59-1330							Kornegay et al. (1975)
Hog, finishing				643-1575							Batey et al. (1972)
Hog, finishing (23)				675							Berryman (1970)
Cattle, dairy (5)		129	146	18							Bates et al. (1974)C
Cattle, dairy		114	45	17		14	20				Long et al. (1975)
Cattle, dairy	354	106	135	21		4	73				Hensler et al.(1970)
Cattle, dairy (5)			110-225	17-32	1.1-3.2	1.4-2.8		0.16-0.28	40.5	8.2-22.4	M.D. Webber (unpublished data) C
Cattle, beef (2)		87	100	68							Bates et al.(1974)C
Cattle, beef-feedlot	3000-10,300	43-234	35.7-102	10.9-29.3							Wallingford et al.(1975a)
Cattle, unspecified (9)	240-1075	6-65	30-72	7-16	2.3-5.2	7-16			0.3-1.2	5-27	Halstead (1975) C
Cattle, unspecified (2)						0.8-1.7		0.14-0.23			M.D. Webber (unpublished data) C
Sheep, unspecified (5)	133-560	8-61	55-287	9-15	2.0-3.1	5-11.4			0.5-0.7	3-11	Halstead (1975) C
Sheep, breeding stock (4)						1.5-2.4		0.38-0.43			M.D. Webber (unpublished data) C

Data are expressed as ppm, dry wt. unless indicated otherwise. Numbers in parentheses indicate the numbers of samples analyzed.
C following the citation indicates Canadian data.

involving Canadian and other data is presented in Table 4-2. These data indicated a wide range of Fe contents in manures; however, the very high contents in beef-feedlot manure probably reflect contamination by soil. In general the Mn, Zn and Cu contents of poultry and hog manures were higher than in cattle and sheep manures, probably reflecting differences in diet. The effect of diet on manure composition is best illustrated by the high level of Cu in manures from hogs known to have received a Cu supplement (Pearce 1975; Kornegay et al. 1975; Batey et al. 1972; Berryman 1970). Kornegay et al. (1975) reported 59 mg.kg^{-1} Cu in manure from hogs receiving no supplement and 1330 mg.kg^{-1} Cu in manure from hogs receiving 300 mg.kg^{-1} Cu in their feed. The manures contained moderate levels of Mo and B and low levels of Cr, Se, Cd and Pb. In addition to the data in Table 4-2, the literature contains analyses of manures for selected metals: Ni, 10 mg.kg^{-1} and Hg, <1 mg.kg^{-1} in turkey manure (Bates et al. 1974); Co, 1 mg.kg^{-1} in broiler house litter (Hileman 1967); Co, 2.2 to 15.2 mg.kg^{-1} in twenty samples of hog manure (Pearce 1975); and As, 15 to 30 mg.kg^{-1} in broiler house litter (Morrison 1969). It appears that except for hog manure containing high levels of Cu, and possibly poultry manure containing As, poultry, hog, cattle and sheep manures contain similar levels of elements.

4.1.3 COMPARISON OF MANURE AND SOIL VALUES

With the exceptions of Fe and Cr in the manures and Fe and Mn in the soils, frequency distributions of micronutrients and heavy metals were not normally distributed about the average values (Figure 4-1). For the remaining elements, a majority of the samples contained less than the average amount and a few contained very much more. For example, of 78 manure samples exhibiting an average of 117 mg.kg^{-1} Zn, 42 contained less than 100 mg.kg^{-1} and 4 contained between 250 and 450 mg.kg^{-1}. Similarly, of 195 soil samples exhibiting an average of 78 mg.kg^{-1} Zn, 123 contained less than 80 mg.kg^{-1} and 3 contained between 200 and 300 mg.kg^{-1}.

The soils contained larger amounts of Fe, Mn, Ni, Cr and Co than did the manures but the amounts of Zn, Cu, Pb, Cd, Mo and Se were about the same in the soils and manures (Table 4-1 and Figure 4-1). However, pig manures from animals fed Cu-enriched diets contained much larger amounts of Cu than did the soils. Thus, it appears that manuring is unlikely to cause appreciable buildup of Fe, Mn, Ni, Cr and Co in soils but might cause buildup of Zn, Cu, Pb, Cd, Mo and Se, particularly where excessive rates are applied for many years. Heavy rates of pig manures containing high levels of Cu would cause appreciable buildup.

4.2 EFFECTS ON CROP AND ANIMAL PRODUCTION

Copper-enriched hog manure slurry applied on three occasions to grassland at 112,000 L.ha^{-1} supplied 12.2 kg Cu.ha^{-1} and increased the EDTA-extractable Cu from 2.1 to 7.3 mg.kg^{-1} in soil samples taken toa depth of 7.5 cm (Batey et al. 1972). Copper in herbage dry matter increased from 9.1 to 21.2 mg.kg^{-1}(mean of 5 cuts), but much of the additional Cu was thought to be derived from external contamination. These levels were well below those required to cause either crop or animal toxicities and it was suggested that applications of Cu-enriched hog manure slurry to soil involved little risk. The greatest risk to susceptible livestock would seem to arise from ingesting either grazed or harvested herbage contaminated with slurry. To avoid possible hazards from Cu buildup in soil, it was suggested that a maximum of 9.5 kg Cu.ha^{-1} applied annually not be exceeded until more is known about its availability to crops. Hog manure containing 2310 mg.kg^{-1} Fe, 439 mg.kg^{-1} Zn and 1330 mg.kg^{-1} Cu and applied to corn land at 14 t.ha^{-1}.a^{-1} (dry wt.) for three years increased the levels of Zn and Cu but not of Fe in the soil (Kornegay et al. 1975).The increased levels were well within those recommended for good crop production. The Zn content of corn grain was increased from 21 to 25 mg.kg^{-1} and that of the ear leaf was increased from 30 to 44 mg.kg^{-1} but the Cu content of the grain was not increased. The Cu content of the ear leaf was increased from about 8 to 12 mg.kg^{-1} but this level is well within the safe range for use as silage.

Field application of farmyard manure at 15 t.ha^{-1}.a^{-1} for 6 years increased the dithizone - ammonium acetate-extractable Zn in the soil and increased its uptake by maize and wheat (Sharma and Meelu 1975). Similarly, 60 t.ha^{-1}.a^{-1} of dung applied during 40 years resulted in a level of 19 mg.kg^{-1} available Zn measured by the Aspergillus niger method, whereas soils receiving only mineral fertilizers exhibited only 5-6 mg.kg^{-1} (Nowosielska 1966). Poultry manure applied at a rate of 44 t (fresh wt.) to soil in the greenhouse was beneficial for the correction of Fe and Zn deficiency. There was evidence that the organic fraction of manure was important in rendering these elements more available to plants (Miller et al. 1969). Beef-feedlot manure and lagoon water increased the DTPA-extractable Fe, Mn and Zn in the soil of a field site and were sources of these elements for corn (Wallingford et al. 1975a). A range of application rates was tested and the largest cumulative amounts applied during three years were 2200 t.ha^{-1} manure (dry wt.) and 1.29 m.ha^{-1} lagoon water. The manure supplied approximately 14,200, 330, 120 and 36 kg.ha^{-1} of Fe, Mn, Zn and Cu respectively, and the lagoon waste 23, 2, 4 and 7 kg.ha^{-1} of Fe, Mn, Zn and Cu respectively, but there was no evidence of reduced crop yield.

Adding 240 t.ha^{-1} (fresh wt.) of farmyard manure to soils in the greenhouse increased the levels of water-soluble B and of total Cu, Zn and Mo but not of total Co or total, exchangeable or easily reducible Mn (Atkinson et al. 1958). Reduced concentrations of Mn and B and increased concentrations of Mo in ladino clover grown on the manured soils were attributed to increased pH. Similarly, the Fe, Mn, Zn, Cu, B and Mo concentrations in corn plants grown in the greenhouse exhibited no consistent effects of dairy-cattle manure applied at rates from 0 to 613 t.ha^{-1} (Hensler et al. 1970). The manure contained 11.1 % dry matter and 354, 106, 135, 21, 73 and 4 mg.kg^{-1} (dry wt.) of Fe, Mn, Zn, Cu, B and Mo respectively, and was applied to limed and unlimed soil. Liming reduced the Mn and Zn concentrations in corn plants and increased the Mo concentration. It was suggested that for near neutral soils, very large application rates of manure can be used in crop production and soil improvement with relatively little danger of plant toxicity.

Application of 34 t.ha^{-1} farmyard manure to soil supplied more Mn, Cu and Mo and almost as much Zn as the cumulative uptake by crops of wheat, barley, clover, potatoes and kale (Williams et al. 1960). The concentrations of these micronutrients however, were similar in plant materials grown with the manure treatment and with a NPK fertilizer treatment which contained almost no micronutrients. In general, both treatments increased the Mn and decreased the Zn, Cu and Mo contents of the crops. Similarly, field applications of 67 t.ha^{-1}.a^{-1} of farmyard manure for 10 years did not affect the concentrations of Fe, Zn and Cu in the laminae of red beet, cabbage, carrot, lettuce and onion (Page 1966).Manganese concentrations were reduced and this effect was attributed to increased soil pH.

Most of the Se in dung of Se-fed sheep was in an insoluble inorganic form; in greenhouse experiments there was a negligible uptake by ryegrass within 53 days (Butler and Peterson 1961) or by three pasture species within 75 days (Peterson and Spedding 1963). The As contents of soils and crops were not affected by the use of poultry litter containing 15-30 mg.kg^{-1}. As as a fertilizer for 20 years (Morrison 1969). Moreover, the As contents of poultry tissues and feathers were not increased when birds were raised on this type of litter.

Beef cattle rations frequently contain 1% or more NaCl, much of which is excreted in the urine. Peterson et al. (1971) warned that heavy rates of manure application to land may reduce seed germination and seedling growth.

4.3 CRITERIA FOR MANURE USE

The solubility of many of the micronutrients and metal elements in soils and their uptake by plants are influenced by soil properties and by differences among plant species. For example, availability of the elements to plants, except for Mo, decreases with increasing soil pH and uptake is reduced by liming. (The uptake of Mo is increased by liming). The addition of phosphate increases the solubility of Zn in soils but reduces its uptake by plants. The influence of organic matter on the retention or release of metals in soils is widely recognized. Thus, sewage sludge, because of its organic constituents, can be effective in reducing the toxic effects of metals on plants (Chaney 1973).As the organic matter decomposes, however, toxic amounts of metals may be released. Availability of most of the elements to plants is increased with increasing aeration. Vegetable crops usually take up larger amounts of trace elements than do field crops and grasses take up the smallest amounts.

Guidelines for land application of manure in Ontario are based upon (1) efficient use of the nitrogen for crop production and (2) disposal without contributing to environmental pollution (Webber and Lane 1969). Assuming that dairy-cattle, beef-cattle or hog manures, containing 6 kg N.t^{-1}(wet wt) (Peterson et al. 1971), were used to supply 174 kg N.ha^{-1} for corn production, the annual application rate would be approximately 30 t.ha^{-1}(wet wt) or 6 t.ha^{-1} (dry wt). Assuming further that the manure contained the average amounts of micronutrients and non-nutrients presented in Table 4-1, it was calculated that a very large number of applications (Table 4-3) would be required to attain the additions recommended as maxima for Ontario sewage-treated soils. Sheep, broiler chicken and laying hen manures contain approximately 12 kg N.t^{-1} (Peterson et al. 1971) and would require half as many applications to attain the maximum additions. Two hundred and fifty applications of poultry manure, containing 20 mg.kg^{-1} As (dry wt) would be required to contribute the 15 kg.ha^{-1} maximum addition. Thus, it appears that most manures applied at the 174 kg N.ha^{-1} crop utilization' rate or even at the 347 kg N.ha^{-1} ‘pollution control' rate would increase the microelement contents of soils only very slowly. However, hog manure containing 1000 mg.kg^{-1} Cu and applied at the pollution control rate would add the maximum recommended addition of Cu to soil in only 14 applications and would probably represent a hazard to agricultural crop production. Furthermore, feeding Cu to pigs may increase the Cu concentration in the manure to above 0.07% (wet wt) and inhibit manure decomposition (Robinson et al. 1971). Except for hog manure highly enriched with Cu, it appears that manure spreading is unlikely to cause buildup of toxic elements in soils or plant and animal toxicities.

4.4 EFFECTS ON WATER QUALITY

Micronutrient and heavy metal contamination of water has not been identified as a problem resulting from land application of animal manures. Despite the large amount of information concerning nitrogen, phosphorus, salt and organic matter in runoff and drainage waters from manure treated soils, the authors were unable to find corresponding information for the microelements. This lack of information is exemplified by the fact that there was no discussion of these elements during the "Work Planning Meeting on Land Application of Manure" sponsored by Agriculture Canada, and held in Ottawa, December 5-6, 1978.

It is very unlikely that land application of manure represents a significant micronutrient or heavy metal hazard to waters. Although studies with manure have not been reported, studies with sewage sludges, which usually contain much larger concentrations of microelements than does manure, have been reported and offer little cause for concern. For example, a study conducted during 1973 to 1977 at the University of Guelph indicated that total concentrations of Zn, Cu, Pb, Cd, Ni and Hg in runoff waters from sludge-treated plots with 2% and 6% slopes were generally

Table 4-3. Maximum recommended additions of micronutrients and non-nutrients to Ontario soils and the numbers of manure applications to attain them.

Element	Maximum recommended [α] additions	Applied with 6 metric $t.ha^{-1}$ dry wt. of	Applications to attain maximum recommended
As	14	-	-
Be	-	-	-
B	-	-	-
Cd	1.6	0.003	530
Co	30	0.007	4,290
Cr	210	0.018	11,670
Cu	150	0.090	1,670
F	-	-	-
Hg	0.8	-	-
Mo	4.0	0.015	270
Ni	32	0.017	1,880
Pb	90	0.056	1,610
Se	2.4	0.003	800
Zn	330	0.702	470

[α] Obtained from the March 1981 Guidelines for Sewage Sludge Utilization on Agricultural Lands. Prepared by Ontario Ministry of Agriculture and Food and Ontario Ministry of the Environment.

low and in many instances near the detection limit (Bates et al. 1978). The larger concentrations were observed mainly during the summer and were attributed to larger sediment losses at this time than at other times of the year. Measurements prior to and following 0.45 µ filtration indicated that a large proportion of all metals with the exception of Hg adhered to the sediment. Lysimeter studies conducted at the Wastewater Technology Centre, Burlington, indicated that land application of heavy rates of sewage sludge did not result in metal contamination of leachates (M.D. Webber, unpublished data). The Cd, Cr, Cu, Ni, Pb and Zn concentrations in leachates from soils treated with sludge during 1973 to 1978 did not increase with time and were similar to concentrations for a commercial fertilizer control treatment. The maximum concentrations observed did not exceed the maximum permissible concentrations for drinking water. The largest metal additions to soil to the end of 1978 were 10, 620, 300, 1580, 340 and 1100 $kg.ha^{-1}$ for Cd, Cr, Cu, Ni, Pb and Zn, respectively. Late in 1976, soil samples were taken at narrow intervals down the profile. Analysis indicated that there had been no downward movement of metal beyond 5 cm into the soil and that almost all of the metal was associated with the sludge cake and surface 1 cm of soil. These results are compatible with those in the CAST (1976) report and in many of the publications reviewed by Kirkham (1977). However, a few publications report minor movement, particularly of Zn and Cu into soil and groundwater (Sidle and Kardos 1977 and Kirkham 1977).

Any potential hazard of metal contamination of waters through land application of manure is minimized by the relatively low concentrations of metals in manure and the formation of stable complexes of the metals with organic matter in the soil (Stevenson and Ardakani 1972). Thus, land application of manure does not likely represent a significant micronutrient or heavy metal hazard to waters. Even sewage sludges, which usually contain much larger concentrations of microelements than manures, offer little cause for concern. Contamination of water with metals could occur from manure droppings of livestock having access to streams or other drinking water sources. Restriction of such practice becomes necessary from consideration of constituents other than metals in the manure, namely, nitrogen, phosphorus, organic matter and pathogens.

5.0 PESTICIDES, ORGANOPOLLUTANTS, DRUGS AND FEED ADDITIVES IN MANURE

R. Frank[α]

Animals may be exposed to various organic substances through: (1) pesticide residues in feed; (2) organopollutant residues in feed; (3) feed and water additives; (4) topical insecticide sprays or medicinal treatments; and (5) injections of pesticides, drugs, etc.

5.1 PESTICIDE RESIDUES IN FEED

Residues in feed are usually confined to pesticides that were applied to the crop and have persisted, hence being consumed along with the feed. The persistent organochlorines are no longer used in agriculture but their residues in soil often turn up in feed. The removal of DDT, aldrin, and heptachlor in 1969-70 resulted in a rapid decline in their residues in milk in the Province of Ontario (Frank et al. 1975). When consumed, organochlorine insecticide residues are absorbed only partially. A considerable portion is passed out with the feces as parent compound or as slightly changed metabolites (Richardson and Robinson 1971). Absorbed organochlorines are stored in the fatty tissues and slowly removed as water-soluble metabolites in the urine.

Organophosphorus and carbamate insecticides rarely appear in animal feed and are not likely to be found in manure. Corn silage with residues of chlorpyrifos and its pyridinol metabolite at 1.85 and 1.75 $mg.kg^{-1}$ respectively failed to appear in urine or feces when passed through dairy cattle (Johnson et al. 1974). Feeding corn silage to dairy cows with up to 50.6 $mg.kg^{-1}$ fonofos, Johnson et al. (1973) found only 0.03 $\mu L.L^{-1}$ and 0.020 $mg.kg^{-1}$ of fonofos and its metabolites in urine and feces, respectively. One week after removal of the silage, residues could no longer be detected in urine and feces. Whitacre et al. (1974) reported that leptophos residues were rapidly metabolized and excreted in the urine of rats and that the bulk of the remainder was eliminated in the feces. Relatively little of the parent compound remained intact.

Several cases have been reported where animals consumed plant tissues treated with the herbicide picloram and then the compound was excreted in the feces to remain toxic to plants grown on the manured land (Costa et al. 1974). An unreported case occurred in Ontario in which treated grain straw was used for litter and the manure was used on fields producing tobacco. The tobacco developed typical symptoms of picloram injury (Frank 1973). In humans, 75% of an administered dose of 2,4-D was excreted unchanged in the urine over a 96-hour period (Kohli et al. 1974).

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Atrazine and the hydroxy metabolite were excreted in urine (66 and 78%) and in feces (20 and 5%) respectively when fed to rats (Bakke et al. 1972).

5.2 ORGANOPOLLUTANT RESIDUES IN FEED

Many industrial chemicals can find their way into feed, either by human error or as the result of chemical fallout on crops. Currently there are many potentially very hazardous compounds, three of which are polybrominated biphenyl, polychlorinated biphenyl and Mirex.

1. The accidental addition of polybrominated biphenyl to feed in Michigan led to considerable contamination of manure. Jackson and Halbert (1974) suggested that only a small percentage was absorbed through the gut.
2. After consumption of food containing PCBs, humans excreted PCBs predominately through the feces with only 6.2% of the total excretion appearing in the urine (Price et al. 1972). Diets contained up to 840 $\mu g.d^{-1}$ and the loss in urine and feces was up to 5.8 and 87 $\mu g.d^{-1}$ respectively.
3. Mirex, an insecticide and a fire-retardant industrial chemical, was given to a lactating cow at 0.2 $mg.kg^{-1}$ of the diet (Dorough and Ivie 1974) in labelled form. The residue in the feces reached a maximum 50% of the consumed dose after 3 weeks and remained at that level until the treatment was terminated.

5.3 FEED AND WATER ADDITIVES

The use of feed additives for the control of flies breeding in dung has been extensively investigated for many years. Knipling (1938) and Bruce (1939) tested phenothiazine for the control of horn flies (Haematobia irritans L.). Drummond (1963) found that insecticides fed to cattle could control the larvae of flies breeding in cattle manure. Research work has been done on coumaphos, chlorpyrifos, dichlorovos, methoprene and tetrachlorvinphos. These have been added to water and feed in various forms including encapsulation (Breeden et al. 1975; Butler and Greer 1973; Miller et al. 1970a, b, 1976; Miller and Gordon 1972a, b; Miller and Uebel 1974; Sherman and Herrick 1973).

Miller and Gordon (1972b) reported that feeding 30 to 90 $mg.kg^{-1}$ tetrachlorvinphos resulted in 10 $mg.kg^{-1}$ of the insecticide in the manure. This residue declined to 0.5 mg.kg-^{1} in 8 days. With encapsulated tetrachlorvinphos 15% was recovered in the manure while 0.3% was found if a wettable powder was added to the feed. Feeding 60 $mg.kg^{-1}$ tetrachlorvinphos in the feed resulted in 2.24 $mg.kg^{-1}$ in the manure (Miller and Gordon 1972a).

Xylene, a disinfectant fed to livestock in the diet at 1000 mg.kg^{-1}, was shown to pass through the animals since it destroyed Brucella organisms in the liquid manure tanks holding the effluent (Plommet 1972).

In pot experiments using pig and broiler manure containing antibiotics and other drugs arising from feed additives, Tietjen (1975) found beneficial or detrimental effects on the yield and nitrogen content of oats, depending on the particular additive and its concentration. Dry matter was increased markedly by carbadox while higher nitrogen contents were related to flavophospholipol, oxytetracycline, and oleandomycin. The author suggests that antibiotics and other additives in the diet may modify the biodegradation of the excrements as well as their manuring effect in crop production. However, Warman et al. (1977) found that amprolium, a coccidiostat, in poultry manure had no adverse effect on the respiratory activity of a soil treated with the manure.

In a recent study, the feces of cattle receiving chlortetracycline and oxytetracycline contained levels of 5.3 and 11.3 ug.g^{-1} respectively (Patten et al. 1980). When the feces were added to a soil, the antibiotics had no effect on the numbers of total bacteria, total and fecal coliforms or fecal streptococci nor on the rate of nitrogen mineralization, but they increased the evolved carbon by 20% over that in the control during a 70-day period. In a pot experiment, the antibiotics had no effect on growth, yield or elemental composition of corn seedlings. In a 1978 study on methane gas production, Bio-Gas of Colorado used manure from hogs fed 40 g of lincomycin per ton of feed in their digesters. The digesters went sour and this was attributed to the 5-2 mg.kg^{-1} of lincomycin found in the hog manure.

The use of synthetic hormones to increase efficiency of conversion of vegetable protein to animal protein by meat animals has raised some health issues and has led to instances of banning of diethylstilbestrol, for example, as a feed additive (Azevedo and Stout 1974). Nevertheless, the same authors, after citing a review of the subject by Dinius (1971), suggested that estrogens in land-spread manure are not apt to be hazardous to man or animal.

5.4 TOPICAL INSECTICIDE SPRAYS AND MEDICINAL TREATMENTS

The following insecticides are used on livestock as topical sprays: carbaryl, coumaphos, crotoxyphos, crufomate, dichlorvos and naled or fenchlorphos.In addition, toxaphene has been used in back rubbers.

Toxaphene, an organochlorine insecticide, accumulates in fatty tissues. Crowder and Dindal (1974) reported that on first exposure, excretion of ingested toxaphene by the rat was largely in the feces

(71%) and the remainder was via the urine (29%). However, on redosing, up to 47% was excreted in the urine and 53% in the feces. The first dose had been removed in 9 days while redosing took 20 days before removal was complete. Fenchlorphos applied as a 'pour on' on dairy cattle was excreted as water-soluble metabolites in the urine and feces. Urine contained 50-60% of the application while feces contained only 2%. The predominant form was as hydrolyzed fenchlorphos (Avrahami et al. 1974).

The elevation of residues in mushrooms precipitated a study by Frank et al. (1974) on horse manure derived from racing stables. It was found that where liniments and medications containing mercury were applied to horses, the level of mercury in the manure was elevated. Horse manures contained from 0.049 to 0.42 mg.kg^{-1} mercury as inorganic mercury. Normally, the residue levels should have ranged from 0.04 to 0.08 mg.kg^{-1}.

5.5 INJECTION OR MEDICAL APPLICATION

Crotoxyphos is a systemic organophosphorus insecticide used to control warble fly grubs. Rumsey et al. (1974) reported that following the injection of crotoxyphos into beef heifers, 62% of the dose was excreted in the urine within 24 hours and approximately 84% was excreted within 5 days, 74% in the urine and 10% in the feces. The insecticide was excreted as the hydrolyzed metabolite.

5.5.1 TREATMENT OF THE MANURE

Manure may be treated for two main reasons: (1) to control the breeding of flies, and (2) to deodorize or to mask the odor.

(1) Use of Insecticide - Methoprene, dichlorvos and diazinon have been used on manures to control flies. Miller and Uebel (1974) used between 1-10 mg.kg^{-1} methoprene to control house flies. Butler and Greer (1973) added 72 mg.kg^{-1} dichlorovos to control Diptera larvae.

(2) Deodorants - A wide range of manure additives are available to deodorize animal wastes or to mask the odor. These include cultures of bacteria, enzymes and organic and inorganic chemicals of unknown composition. Potassium permanganate is one of the inorganic ingredients.

5.6 POTENTIAL HAZARD OF ORGANIC SUBSTANCES

The foregoing information showed that many potentially hazardous organic compounds consumed by farm animals are voided in the manure. But the effect of these chemicals on soil organisms, plants, animals, and humans when manure is applied to land is difficult to evaluate. Scant attention has been paid to these organic compounds in the literature on the evaluation of environmental effects of animal-waste utilization on cropland.

Considering the progress made in use of animal wastes as feed for livestock (Helmer 1980), serious hazardous effects of organic additives in manure applied to land would seem unlikely. The potential capacity of soils either to adsorb many of these compounds or to decompose them may lessen the danger. The utilization of animal wastes for feed must proceed with caution, however, with monitoring for pesticides, antibiotics, etc. Likewise, application of manure containing these organic compounds to cropland should proceed with some caution. Furthermore, there is a need for research on the fate of these chemicals in soils and their uptake by plants. The possible detrimental effect of antibiotics on the microorganisms involved in decomposing the manure or in the normal biological processes in the soil merits attention. Of particular concern in the use of drugs for growth promotion is the possible genetic transfer of resistance from non-pathogenic to pathogenic serotypes of certain species (Bromel et al.1971).

6.0 BACTERIAL AND FUNGAL PATHOGENS OF ANIMALS IN MANURE

R.G. Bell[α]

Bacterial and fungal pathogens may pose a hazard to human and animal health at the site of manure storage or land application or at some distance if the organisms remain viable and are transported away from the animal production unit. Some background information on the causative organisms the diseases, and control measures will be discussed briefly.[β] This will serve to emphasize the role of good animal management in minimizing the potential hazard of the pathogens in manure.

6.1 BACTERIA

Table 6-1 gives the results of a survey of the relative occurrence in Canada of 21 bacterial diseases of livestock and poultry transmission is associated with manure. Causative agents of diseases to be discussed are named in accordance with the 8th Edition of Bergey's Manual (Buchanan and Gibbons 1974) and, where the name differs from that used in veterinary practice, the "practical" name is given in parenthesis. The Merck Veterinary Manual (Siegmund 1979) and the Textbook of Microbiology (Burrows 1973) have been used extensively for disease descriptions and microbiological details.

6.1.1 NEONATAL DISEASES

a) Scours (Colibacillosis)

The enteropathogenic serotypes of Escherichia coli are the most common cause of scours, a disease of the newborn. Since the causative organism is a common commensal of the healthy adult, it is normally present in animal manure.

b) Septicemia (Navel III, Joint Ill, Polyarthritis, Sleepy Foal Disease)

Neonatal septicemias are produced most commonly by E. coli, Streptococcus spp., Staphylococcus spp., Corynebacterium spp., Fusobacterium necrophorum

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[β] Fecal pathogens from wild life sources are not included in this review.

Table 6-1. Ratings[α] for bacterial diseases, of Canadian farm animals spread in feces and urine (based on survey of Provincial departments of agriculture).

Disease	Provincial Department of Agriculture										Can. Dep. Agric
	Nfld	NS	NB	PEI	PQ	Ont	Man	Sask	Alta	BC	
Cattle, Sheep, and Swine											
Neonatal scours	3	1	1	1	1	1	1	1	1	1	1
Neonatal septicemias	4	1	1	2	2	1	1	2	2	2	1
Foot rot	2	1	1	1	4	3	2	1	2	4	1
Erysipelas	2	3	1	1	4	3	2	1	2	4	1
Clostridial enterotoxemias	1	-[β]	2	2	3	5	1	4	3	3	1
Clostridial toxemias	4	3	2	3	3	3	1	2	2	3	3
Bovine winter dysentery	3	2	2	1	4	3	2	4	3	5	1
Swine dysentery	3	4	4	3	3	3	3	3	3	4	1
Salmonellosis	5	4	3	4	4	2	2	4	5	3	1
Leptospirosis	5	-	4	4	4	3	3	4	5	3	1
Brucellosis	4	-	5	5	4	4	3	3	4	4	4
Johne's disease	5	-	5	5	5	4	3	5	4	4	4
Tuberculosis	5	-	5	4	5	5	4	4	5	5	5
Anthrax	5	-	5	5	5	5	5	5	5	5	5
Poultry											
Ulcerative enteritis	5	-	4	4	3	1	1	4	3	4	1
Fowl cholera	5	3	4	3	4	2	3	2	3	3	2
Salmonellosis	5	5	3	5	4	2	2	4	3	3	1
Tuberculosis	5	5	3	5	4	2	2	4	3	3	1
Avian vibrionichepatitis	5	-	4	4	5	5	4	5	5	5	3
Spirochetosis	5	-	5	-	5	5	5	4	5	4	3
New duck syndrome	5	-	4	5	5	3	5	4	5	5	5

[α] Numerical scale from 1 (common) to 6 (very rare).

[β] No assessment available.

(Sphaerophorus necrophorus),and Pasturella spp., which gain entry via the umbilicus or by ingestion. Polyarthritis of young animals is caused by the chlamydium, Chlamydia psittaci and like the bacterial form is accompanied by diarrhea. Sanitary management of parturition and treatment of the umbilical cord with an antiseptic agent are prophylactic measures for preventing these neonatal diseases.

Pasturella multocida, commonly isolated from healthy birds, is the causative organism of hemorrhagic septicemia in poultry where the disease is accompanied by copious watery diarrhea (fowl cholera). Pasturella anatipestifer produces a septicemic condition in young ducks. Control of fowl cholera involves exclusion of wild bird carriers from poultry houses, sanitation, and prophylatic vaccination.

6.1.2 FOOT-ROT (NECROTIC PODODERMATITIS, FOWL OF THE FOOT)

Foot-rot applies to a number of necrotic conditions of tissues within and around the hoof produced by a mixed infection of gram negative anaerobes, Fusobacterium necrophorum (Sphaerophorus necrophorus),which occurs in natural cavities of man and animals, and Bacteriodes nodusus (Fusiformis nodusus)and the spirochete Spirochaeta penortha. In bovine foot-rot, F. necrophorum gains entry via a break in the skin which may arise from skin degeneration resulting from prolonged exposure to mud and manure. This pathogen is a common contaminant in areas heavily stocked with sheep. B. nodusus, however, is unable to survive in soil or manure.

Control measures include frequent cleaning of pens, elimination of depressed areas that contain stagnant water, covering rough concrete floors with dry litter with added disinfectant (Greenfield and Bigland 1977), routine hoof trimming, and vaccination (Egerton and Roberts 1971).

Veterinarians and others handling diseased animals can become infected with F. necrophorum through small abrasions of the skin.

6.1.3 ERYSIPELAS

The causative organism, Erysipelothrix rhusiopathiae (E. insidiosa), is widely distributed in nature and survives for long periods in the soil, especially in alkaline soils (Wood and Packer 1972).The disease is associated most commonly with swine but man, sheep, and poultry, particularly turkeys, can also be infected. Swine erysipelas occurs in four distinct forms and may affect the skin, heart and leg joints. Infected animals excrete E. rhusiopathiae in their feces but the organism has also been isolated from the feces of healthy swine (Wood 1974). Lambs and turkeys are infected through skin abrasions and the presence of diarrhea in turkeys facilitates the development of epidemics among growing range birds in the fall.

Control measures include avoidance of contaminated soil areas, sanitation including disinfection of pens, slaughter of infected stock, vaccination, and prompt administration of penicillin upon diagnosis. Human infections can be traced to contact with contaminated animal products such as meat, hides, bones, or manure.

6.1.4 CLOSTRIDIAL DISEASES

a) Enterotoxemias

This group of diseases results from enterotoxins (Table 6-2) produced particularly in the intestinal tract of neonate animals after prolific development of some of the six biotypes of the anaerobic, spore-forming bacterium Clostridium perfringens. This organism is part of the normal intestinal flora of man and animals and is also readily isolated from the soil.

Control measures include vaccination of dams during gestation to provide passive immunity to newborn lambs, increasing the roughage in the high carbohydrate diet for feedlot lambs, the use of antibiotics in water and feed for poultry and the sanitation and removal of contaminated litter from the pens.

b) Toxemias

This group of diseases is caused by exotoxins produced in wounds through the growth of Clostridium species which are not infrequently present in the gut flora of animals. Table 6-3 lists the diseases under the main pathogen, although many of the diseases may result from mixed infections. Control measures are vaccination and sanitation, including removal of manure.

6.1.5 DYSENTERY

a) Bovine winter dysentery (winter scour)

The bacterium Campylobacter fetus subsp. jejuni (vibrio jejuni), a species found in normal intestinal flora of animals, is believed to be a principal pathogen of bovine winter scours in cattle of all ages.

b) Swine dysentery (bloody scours)

The prime causative organism is the spirochete Treponema hyodysenteriae (Taylor and Alexander 1971; Harris et al. 1972). This organism persists in manure pits and lagoons. The disease is contracted by ingestion of infected feces.

Table 6-2. Enterotoxemias caused by the Clostridium perfringens biotypes.

Biotype	Disease	Species infected
A	Ulcerative enteritis	Poultry, especially quail
B	Lamb dysentery	Neonate lambs, calves, and foals
C	Struck(Hemorrhagic enterotoxemia)	Neonate lambs and calves
D	Pulpy-kidney	Neonate and feedlot lambs
E	Doubtful pathogen	Sheep and cattle
F	Enteritis necroticans	Man

Table 6-3. Toxemias caused by Clostridium spp.

Causative organism	Disease	Species infected
Cl. septicum	Malignant edema (Braxy)	Cattle, swine and sheep
Cl. chauvoei	Blackleg	Cattle and sheep
Cl. haemolyticum	Infectious hemoglobinia	Cattle
Cl. novyi	Infectious necrotic hepatitis	Sheep
Cl. sordelli	Big head	Sheep
Cl. tetani	Tetanus	Cattle, swine, sheep,
Cl. perfringens plus others	Gas gangrene	Man

c) Avian vibrionic hepatitis

This poultry disease which strikes mature birds can be confused with fowl cholera. It is caused by Vibriosp., possibly Vibrio cholerae biotype proteus (V. metchnikovii), and is characterized by parenchymal degeneration and necrosis of the liver.

6.1.6 SALMONELLOSIS

Any one of a large number of Salmonella spp. is able to produce disease in man and animals. Some species are host specific; S. typhi infects man (typhoid fever), S. dublin infects cattle, often resulting in abortion (Hinton 1975), while S. pullorum infects poultry. Although there are many sources of infection, including contaminated feed, the initial source is the feces of infected animals. Once introduced, the disease is spread rapidly by diarrhea contaminating feed, water and pasture. The salmonella are able to survive, especially in manure, for many months (Taylor and Burrows 1971; Tannock and Smith 1972). Possible control measures include prophylatic medication, regular disinfection, quarantine of replacement stock, and vaccination.

6.1.7 LEPTOSPIROSIS

The leptospiroses are a widely distributed group of diseases of man and animals caused by Leptospira spp. (Busch 1970). Only one species, L. interrogans, is officially recognized and many isolates are probably serotypes rather than true species. In cattle, swine, and sheep, leptospirosis is often asymptomatic. The natural host of most pathogenic leptospires are rodents, for example the rat (Rattus norvegicus) and the field mouse (Microtus orvalis). The latter is the principal host of L. grippotyphosa which infects cattle and man (swamp fever).

The leptospires can survive for long periods in water and the disease leptospirosis is often considered as a waterborne disease (Craun 1976). Survival outside the host under dry conditions is short and the organism has been shown to persist for only 11 days in aerated cattle manure (Diesch et al. 1971). Control of the disease may require elimination of the rodent reservoir, and fencing of contaminated surface waters. Vaccination is an appropriate prophylatic measure. Water contaminated with infected urine may result in human infections (Nelson and Ager 1973).

Another pathogenic spirochete, Borrelia anserina, the cause of spirochetosis in poultry, is favored by damp conditions, and transmission of the disease is through moist droppings as well as by the bite of blood-sucking insects.

6.1.8 BRUCELLOSIS

Brucellosis (Biberstein and Cameron 1961) is contracted by direct contact or by ingestion of the partially host specific Brucella abortus (cattle), B. suis (swine) or B. melitensis (goat) which are present in feed and water contaminated by infected animals. The brucellae are able to survive for only 2 hours in bright sunlight but they can survive up to 2 months within a decomposing fetus or in moist manure (Plommet 1972).

Control of brucellosis is based on the protection of clean herds by vaccination and strict quarantine of replacement stock. Slaughter of infected animals, sanitation, especially safe and prompt disposal of aborted fetuses and contaminated manure, and disinfection are necessary to restrict outbreaks. Human infection (undulent fever) can be caused by the three Brucella species. It is a occupational disease of those handling infected animals. The organisms can penetrate unbroken skin.

6.1.9 MYCOBACTERIAL DISEASES

Johne's disease is a chronic infection of cattle, sheep and goats caused by Mycobacterium paratuberculosis and characterized by thickening of the intestinal wall, diarrhea, and progressive weight loss. The causative organism is excreted in the feces and is able to survive for at least 1 year in the soil or fecal material. Johne's disease is usually introduced into a clean herd by an infected replacement.

Other members of the genus Mycobacterium produce tuberculosis in a number of animal species. Bovine tuberculosis is of considerable public health interest because man can contract the bovine disease from contaminated milk. The tubercle bacilli are unable to multiply outside their hosts but may exist in the environment. However, infected animals and man are the principal reservoirs of the diseases. Tuberculosis in Canadian livestock has been controlled by a test and slaughter program.

The primary lesion of avian tuberculosis is usually intestinal while that in man and livestock is more often pulmonary. Infected poultry excrete the causative organism M. avium in their feces. M. avium persists in contaminated soil for up to 4 years. Tuberculosis is not a serious problem to the commercial poultry industry because of the rapid population changes and improved sanitation.

6.1.10 ANTHRAX

Outbreaks of this rare disease in Canada (Table 6-1) are associated with depressed wet areas in alkaline soils where the Bacillus anthracis spores can undergo vegetative growth (Van Ness 1975). Infection of livestock results from ingestion of feeds contaminated with the spores. Diseased animals are treated with antibiotics and healthy ones are vaccinated. During an outbreak, prompt disposal of dead animals, destruction of manure and bedding by burning, and sanitary procedures for workers in contact with the disease are essential. Human anthrax is an occupational disease contracted by contact with diseased animals and contaminated animal products.

6.2 FUNGI

The true fungi, the Eumycetes, of medical and veterinary importance are mainly saprophytes or commensals that can become opportunistic pathogens. The normal habitat of most pathogenic fungi is believed to be the soil (Ajello 1956), where they exist as saprobes growing on keratinized animal tissues and other organic matter.

The major mycoses of man and his animals, with the exception of the dermatophytes, are not contagious but are contacted after exposure to fungal spores released from their natural habitat. Mycoses contracted from the external environment, by inhalation or wound penetration, are referred to as the exogenous mycoses, while those caused by organisms of the internal environment, e.g., the digestive tract, are referred to as the endogenous mycoses (Ainsworth and Austwick 1973).

6.2.1 EXOGENOUS MYCOSES

Most exogenous mycoses are contracted by inhalation of spores released from the soil, e.g. blastomycosis, coccidioidomycosis and histoplasmosis; or spoiled feed, e.g. aspergillosis; or mycotic abortion caused by Petriellidium boydii. Except under localized epidemic situations, exogenous mycoses must be regarded as being uncommon. The association between these diseases and manure is not immediately obvious since few infect the gastrointestinal tract or are contracted by ingestion. Manure simply acts as an organic substrate which, when added to soil, supports the proliferation of fungi, some of which may be pathogenic. Manure itself may contain pathogens that originated in spoiled feed, e.g. Mucor pusillus(Bell 1975) and Petriellidium boydii (Bell 1976a). If manure is allowed to decompose within the confines of an animal production unit under conditions conducive to fungal growth, it may become a source of exogenous fungal pathogens.

6.2.1.1 Apergillosis

In poultry, aspergillosis is primarily a respiratory infection most commonly caused by the thermotolerant species Aspergillus fumigatus. The most important syndrome in cattle is abortion as a sequel to pulmonary infection. Exposure to feedstuffs spoiled by fungi places animals as well as man at the risk of contracting the disease (Emmons et al. 1970).

6.2.1.2 Cryptococcosis

This disease is usually a chronic and often fatal infection of cattle, horse and swine but in man a transitory mild pulmonary form is more common. The pathogenic yeast Cryptococcus neoformans is strongly associated with old pigeon nests and droppings (Emmons 1955). It has been isolated from milk and has been associated with mastitis in cattle (Ainsworth and Austwick 1973).

6.2.1.3 Histoplasmosis

The development of the fungus Histoplasma capsulatum in soil is associated with avian or bat feces (Ainsworth and Austwick 1973). In Canada, the fungus is primarily centered in the Lower Great Lakes Basin. This disease of cattle, horses and man is not common but could become more so if current poultry manure disposal practices in the endemic area are not modified (Bell 1976b).

6.2.2 ENDOGENOUS MYCOSES

6.2.2.1 Candidiasis (Moniliasis)

Members of the yeast genus Candida, especially C. albicans, are part of the normal microflora of the alimentary canal of domestic animals. Explosive proliferation of the pathogen can occur when antagonistic bacterial flora are removed. The disease affects the upper alimentary tract, particularly the crop, of young turkeys, chicks and geese but has no diagnostic symptoms. It is controlled by copper sulfate in drinking water (Hart 1947) or by additions of nystatin to the feed (Kahn and Weisblatt 1963). Swine are often infected. Candidiasis is a widespread disease and Candida spp. have been implicated in mycotic mastitis and mycotic abortion (Ainsworth and Austwick 1973).

6.3 CONCLUSION

The results of the provincial survey (Table 6-1) indicated that the bacteria that form part of the normal intestinal flora of healthy animals are the cause of the more common manure-associated diseases. Therefore, the more quickly the animals are separated from their excrement the better.

The less common bacterial diseases in which the subclinically infected carrier animal plays a major role in transmission appear to be caused by more obligate pathogens. Sanitation alone will not prevent an outbreak of these diseases but will restrict their spread within a herd or flock, e.g. brucellosis or Johne's disease. Preventing this group of diseases from becoming established within a herd by quarantine of replacements and vaccination is the key to their control. Prophylatic administration of antibiotics and other drugs leaves the herd susceptible to fresh infection when the drug is withdrawn and the continued administration of antibiotics can result in the development of resistant strains of pathogenic microorganisms.

The fungal pathogens have their major impact on the poultry industry, where both candidiasis and aspergillosis have a significant economic influence. The major involvement of fungi in livestock health is as a cause of mastitis and abortions (Miller and Quinn 1975) resulting from the inhalation of fungal spores released from spoiled feed. The specific systemic and deep-seated mycoses are not common but should not be totally disregarded. The more common exogenous infections that produce mastitis and abortion can be eliminated most effectively by the use of good quality feed and by preventing stock access to manure decomposing under conditions that favor fungal development.

Manure presents a much greater hazard to livestock than to man because of the more intimate contact. People in the most immediate and serious danger are members of the animal production and processing occupations who are directly exposed to the pathogens. The public at large is protected from indirect exposure by the strict regulations for food processing and retailing. However, they are at risk from those bacteria that escape from the confines of the animal production units and become widely dispersed in the environment, e.g. tetanus, during times of war.

7.0 VIRAL PATHOGENS OF ANIMALS IN MANURE

H.J. Smith [α]

Viruses are a unique group of living agents having their genetic material consisting of either deoxyribonucleic acid (DNA) or ribonucleic acid (RNA) but not both. The smaller viruses contain only one of these two constituents while more complex viruses may contain lipid, polysaccharides and trace elements also. Animal viruses contain no enzymatic systems and demonstrate no independent metabolism. They utilize the metabolic syntheses of living cells for their multiplication and they have no metabolic activities in the extracellular position (Gratzek 1967; Rhodes and van Rooyen 1968).

Viruses have been classified in recent years into many different groups such as poxviruses, herpesviruses, adenoviruses, picornaviruses, myxoviruses, caliciviruses, rhabdoviruses, and parvoviruses. They range in size from the small picornaviruses (13 to 35 nm) to the large poxviruses (200 to 300 nm).

7.1 VIRUS TRANSMISSION

7.1.1 VIRUS EXCRETION

In acute viral infections, it is usual for the virus to be excreted during the acute phase of the disease and sometimes during convalescence but usually excretion ceases soon thereafter. In certain diseases, however, the virus may continue to be excreted either continuously or intermittently for months or years. Viruses may be excreted by infected hosts through the skin, nasopharyngeal secretions, saliva, conjunctival secretions, milk, urine and feces. Viruses excreted in feces include picornaviruses (enteroviruses), reoviruses, herpesviruses, adenoviruses, rotaviruses, and myxoviruses. Important livestock diseases that may be transmitted through feces include Teschen disease, transmissible gastroenteritis of swine, avian encephalomyelitis, hog cholera, African swine fever, foot and mouth disease, vesicular exanthema and rinderpest (Blood and Henderson 1963). In some other diseases, the virus is normally not shed in feces but nevertheless may infect feces and bedding via nasal secretions, saliva, skin debris, etc. This group includes such diseases as equine viral rhinopneumonitis, infectious bovine rhinotracheitis, contagious ecthyma, influenzas of various species and Marek's disease of chickens.

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7.1.2 ARTHROPOD TRANSMISSION

Flies may play an active role in the spread of certain viral diseases, either mechanically on their bodies or by regurgitation of ingested material. It appears that enteroviruses excreted in feces can survive and even multiply in the blowfly (Phormia) and are excreted for some weeks by the blowfly (Rhodes and van Rooyen 1968).

Other arthropods, such as ticks, sandflies and mosquitoes, are essential or biological hosts (arboviruses), or mechanical transmitter of other viruses (rabbit papilloma, rabbit fibroma, fowlpox, infectious equine anemia) but do not become infected via contact or contamination with feces (Fenner et al. 1974).

7.1.3 NEMATODE TRANSMISSION

Swine influenza is a highly and regularly contagious disease which was believed to persist within third stage lungworm larvae within their intermediate host, the earthworm (Shope 1965). In this way it was postulated that swine influenza persisted from one epizootic to another. Likewise, it was believed that the hog cholera virus was also able to be transmitted by the swine lungworm (Shope 1965). It now appears more likely that convalescent carriers act as the reservoirs of the virus between epizootics (Blood et al. 1979).

7.1.4 WILDLIFE

Some viruses show a marked host specificity but many are capable of establishing in a variety of different hosts. The role that wildlife may play in the transmission of viruses by fecal contamination of pastures and habitats of domestic livestock is largely unknown.

7.2 FACTORS AFFECTING SURVIVAL OF VIRUSES

7.2.1 ULTRAVIOLET (UV) LIGHT

UV inactivates viruses by direct effects in contrast to X-rays and is characteristically exponential. The rate of inactivation by UV is usually stable and a characteristic property of a virus (Gard and Maaløe 1959).

7.2.2 DAYLIGHT

Normal daylight can inactivate viruses but its effect depends on the virus and other factors. Unfiltered fresh suspensions of egg-grown strains of vesicular stomatitis, influenza, Newcastle disease and fowl plague viruses were strongly inactivated by exposure to daylight for 4 hours while foot and mouth virus was made more stable (Gard and Maaløe 1959). In suspensions containing living cells, some viruses were protected, while others were not. When Newcastle disease viruses were illuminated in the presence of oxygen, their infectivity disappeared before the hemagglutinating activity. In the absence of oxygen, no inactivation was observed (Gard and Maaløe 1959).

7.2.3 TEMPERATURE

Viruses may be inactivated by heat; however, many show remarkable resistance to high temperature, e.g., most Streptococcus phages can withstand normal commercial pasteurization of milk, 62ºC for 30 minutes (Gard and Maaløe 1959). Inactivation depends on a number of factors, including the concentration of the virus, the medium or material carrying the virus, hydration, and the ionic environment. For example, poliovirus is considerably more resistant in ice cream than in aqueous suspension. In the dried state, some poliovirus particles are highly resistant to temperatures between 40 and 60ºC. Because many factors may influence the resistance of viruses to the effects of heat, it is difficult to project threshold temperatures for heat inactivation.

On the other hand, most viruses in a neutral medium are quite stable at temperatures near 0ºC. Damage to viruses resulting from freezing, storage in cold, and thawing is a result either of a high salt concentration created when most of the water is crystallized out, or of enzymatic activities which may continue at significant rates if the storage temperature is not too low. However, inactivation during storage due to the latter can be stopped by decreasing storage temperature to about -40ºC or lower. The rate of cooling also has some influence on the resistance of viruses to low temperatures, e.g., rapid cooling to -40ºC or slow cooling to -80 to -90ºC did not cause significant titre loss of influenza virus, but rapid cooling to temperatures above -40ºC or slow cooling to temperatures above -80ºC caused definite titre loss (Gard and Maaløe 1959).

7.2.4 DESICCATION

Many viruses can tolerate complete drying and can survive indefinitely in such a state at low temperatures. If a protective agent is present, many viruses tolerate drying well.

7.2.5 OXIDATION

Oxidation through aeration is supposed to be one of the contributing factors in the "spontaneous" inactivation of viruses, although the evidence for this is mainly indirect. It is known, for instance, that viruses are more sensitive to other more potent oxidants, and the preservative effect of lyophilization or the addition of reducing substances also point in this direction (Gard and Maaløe 1959).

7.3 SURVIVAL OF VIRUSES OUTSIDE THE HOST

In general, viruses do not survive for long periods outside their animal hosts (Gratzek 1967) and undoubtedly this applies for most of the important viral pathogens of livestock. Nevertheless, spread of viruses through feces and other excreta is extremely important in many epizootics. Some viruses will survive in sewage and may be readily recovered from this source (McLean 1973).In cool climates, many viral diseases show a tendency for a summer seasonal prevalence (Rhodes and van Rooyen 1968). It is known, for instance, that the virus of poliomyelitis will survive for some months in water stored in the laboratory and contaminated water has been shown to spread infectious hepatitis virus (McLean 1973; Rhodes and van Rooyen 1968). The virus of contagious ecthyma is perhaps a good example of an extremely resistant virus. This virus withstands drying and is capable of surviving at room temperature for at least 15 years (Hart et al. 1949).Scabs from the lesions of this disease are highly infective for long periods.

Little investigation, apparently, has been done on the survival of livestock viruses in manure subjected to various handling and treatment procedures. Undoubtedly, the inactivation of most viruses is greatly speeded up by the storage, heating, desiccation, composting, anaerobic processing, and chemical treatments to which manure may be subjected.

8.0 PARASITIC PATHOGENS OF ANIMALS IN MANURE

H.J. Smith [α]

A parasite is an animal that lives in (endoparasite) or on (ectoparasite) another at the expense of the second animal. Most endoparasites are nematodes, trematodes, cestodes, or protozoans with both parasitic and non-parasitic stages of their life cycle. The free-living stage usually commences with shedding of cysts, eggs, or larvae in the feces or urine of the host. Some parasites may also spend part of their life cycle in one or more intermediate hosts.

Nematodes, perhaps the most important group of parasites in livestock, undergo several developmental stages during the free-living phase of their life cycle. The egg hatches into a first stage larvae that moults to a second stage larva and this, in turn, moults to a third or infective stage larva. The morphologic characteristics and development of the various nematodes differ and consequently there are differences in their ability to survive adverse environmental conditions. Ascarid and whipworm eggs have extremely thick shells and infective larvae develop within the eggs and hatch only after ingestion. Consequently, ascarid and whipworm eggs are some of the most resistant nematodes known. The eggs of other worms, such as the thread-necked intestinal worms, Nematodirus spp., are also very resistant to adverse conditions; in this instance again, hatching occurs after the infective larval stage has been developed. Most nematode eggs, however, hatch after the first stage larvae develop, with each subsequent stage living free in the environment. The third or infective stage larvae are more resistant to adverse influences than the two non-infective larval stages.

The eggs of trematodes and cestodes are shed in the feces but most, if not all, of them spend part of their life cycle in one or more intermediate hosts before returning to the definitive host.

The free-living stages of protozoans start when oocysts or other forms are shed in the feces. In the coccidia, the free-living stage is called sporogony; the oocysts shed in the feces sporulate to form sporants that in turn develop to form sporoblasts and finally sporozoites. The sporulated oocyst is more resistant to adverse conditions than are the unsporulated oocysts. In other protozoans, vegetative forms may be shed in the feces but encyst or develop into cysts after exposure to environmental stimuli.

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8.1 FACTORS AFFECTING SURVIVAL OF FREE-LIVING STAGES OF PARASITES

8.1.1 PHYSIOLOGIC REQUIREMENTS

a) Food. Those worm eggs in which development is completed within the egg shell, e.g. ascarids and whipworms, have large food reserves and consequently may live for prolonged periods of time (5 to 10 years or longer) without external food supplies. Eggs that do not have large food reserves hatch immediately to first stage larvae. In the first two larval stages, bacterial cells probably form a large part of their diet (Rogers 1962). Infective larvae do not feed but subsist on food reserves stored in their intestinal cells.

B) Oxygen. The eggs of those species studied have been found to consume oxygen (Rogers 1962). When the pO_2 (percent O_2) in the environment is lowered, development is slowed. Development stops under anaerobic conditions and resumes when oxygen is available; ascarid eggs can survive without oxygen for more than 6 weeks. Little is known about the oxygen requirements of free-living first and second stage larvae, but oxygen is consumed when available by filariform infective larvae. Such larvae do not survive for long periods under anaerobic conditions.

C) Metabolism. Carbon dioxide is produced by free-living larvae and eggs. Ascarid eggs have been shown to use carbon dioxide during development. The respiration of eggs that hatch outside the host, and of infective larvae is strongly inhibited by cyanide. Carbon monoxide in the dark is also an effective inhibitor. The inhibitory action of these substances is largely reversible. Little is known about the intermediary metabolism of infective larvae (Rogers 1962).

8.1.2 TEMPERATURE

Most worm eggs and larvae seem to be susceptible to temperatures that greatly exceed host body temperatures. All eggs and larvae of equine strongyles are destroyed in 4 days, except those in the outer 5 inches, by the natural heat (as high as 41.6ºC) generated by heating manure (Cameron 1940). Canine whipworm eggs can survive for 12 days at 50ºC (Soulsby 1965).

Heat is lethal to all forms of parasites and, in the form of very hot water or live steam, is one of the most efficient disinfectants available. It is the only practical disinfectant against ascarids. Ascarid eggs can be killed experimentally in one second at 70ºC, 2 seconds at 65ºC and 5 seconds at 60ºC (Cameron 1940).

On the other hand, many parasitic species exhibit remarkable ability to withstand very low temperatures for long periods. In general, sporulated oocysts may survive up to 14 days at -12 to -20ºC, while unsporulated cysts are killed in 4 days (Soulsby 1968). Whipworm eggs can survive at -20ºC for a long time, while ascarid eggs have been shown to survive temperatures from -20 to -30ºC for 90 days (Soulsby 1965). The thread-necked intestinal worm of sheep, Nematodirus filicollis, survived at -6.5ºC even after repeated thawing and freezing. At continuous freezing, 22% of a sample survived for 22 weeks (Soulsby 1965).

8.1.3 DESICCATION

Complete desiccation is extremely lethal to all species of parasites. Desiccated parasite eggs and larvae are also much more susceptible to other factors, such as temperature and sunlight. For example, a few Taenia pisiformis eggs survived for more than 7 days at a temperature of 38ºC and a relative humidity (RH) of 33%, but some eggs were still viable after 300 days at 4ºC and a RH of 90% (Comon 1975). Even such resistant thick-shelled eggs as ascarids and whipworms are susceptible, although many can remain alive for very long periods in dry feces. The author demonstrated that Ascaris suum eggs remained viable in dry pig feces that had remained undisturbed in a vacant stable in the Maritimes for over 5 years (unpublished data). Outbreaks of trichuriasis (whipworm infections) have occurred in calves feeding on a hot, dried-out manure pack and in sheep feeding off the ground under drought conditions (Smiths and Stevenson 1970).

8.1.4 SUNLIGHT

Direct sunlight is lethal to parasite eggs and larvae. Coccidial oocysts may be killed in as little as 4 hours by direct sunlight, while Ascaris eggs will succumb within a few weeks (Soulsby 1965). In spite of the lethality of direct sunlight, many parasitic larvae are positively phototrophic to mild light while repelled by strong sunlight. This explains why more larvae are found on grass in early morning or late in the evening than at other times of the day. Free-living larvae migrate onto grass in greatest numbers at a light intensity of 670 lx. (62 footcandles).

8.1.5 CLIMATIC CONDITIONS

A great variation in the number of eggs and larvae surviving and consequently available to susceptible livestock occurs from season to season depending upon the prevailing weather. The amount of snowfall plays an important role in overwinter survival of parasites on pasture. Ground temperatures under a snow cover are at or below 0ºC, while exposed ground temperature fluctuates with air temperatures (Swales 1940).Marked fluctuations in temperature, even under summer conditions, have a detrimental effect on parasites, apparently accelerating the use of their energy resources.

The amount of rainfall is crucial to the number of parasites that may persist on pastures. In addition to contributing to the moisture available, rain affects the rate of growth of vegetation. The amount of vegetation in turn is important because of its influence on the microenvironment. A thick mat provides an area of high humidity that may be maintained even after weeks of dry weather. The changes of temperature within such a microenvironment may be limited, whereas a difference of as much as 6ºC may occur between that in the mat and the air temperature. In contrast, short grass is less favorable than long grass for parasite survival, as it provides less protection from sunlight and desiccation. However, short herbage forces animals to graze more closely to where the parasites are more concentrated.

Even in periods of very dry conditions or drought, parasites may remain viable and undeveloped in feces for a long time. Under such conditions, the outside of the feces may cake and rapidly form a thick, dry crust, trapping sufficient moisture within the fecal pad or droppings to sustain eggs and larvae for a long time (Cameron 1940; Campbell 1960).

The presence of dew on herbage can make a significant difference in the number of larvae available to grazing animals. When the vegetation is dry, larvae descend lower into the mat and are not as accessible.

8.2 FECES OR MANURE DEPOSITED OR SPREAD ON PASTURES

Pastures become contaminated with parasite eggs and larvae when infected feces are deposited by grazing animals or as manure. The infectivity of manure varies with the treatment it was subjected to prior to application to the land. The extent of contamination of pastures by grazing animals depends upon a number of factors.

8.2.1 HOST SPECIFICITY

Most parasites exhibit considerable host specificity, so that contaminated pastures have the greatest infectivity for the species of animal from which the feces came. Thus, pasture management and selective manure disposal are important in parasite control.

8.2.2 CROSS TRANSMISSION

While many parasites exhibit a marked host specificity, some species may be found in several hosts, e.g. Trichostrongylus axei in ruminants, horses and rabbits. Cross transmission of certain bovine gastrointestinal parasites to sheep has been shown to occur but marked clinical signs of disease did not develop, suggesting that annual rotation of pastures between such hosts is a valuable control procedure(Smith and Archibald 1965a). On the other hand, the establishment of certain parasites in abnormal hosts may cause very severe clinical disease, e.g. porcine ascarids in cattle (Allan 1962; McCraw and Lautenslauger 1971; Morrow 1968).

8.2.3 TRANSMISSION BY WILDLIFE

While transmission of parasities from wildlife to domestic livestock may be regarded as not a regular occurrence because of host specificity, grazing habits, and range, there have been some important outbreaks attributed to this method of transmission. The introduction of the large liver fluke, Fascioloides magna, to domestic ruminants in a number of areas in Ontario resulted from the introduction of infected wapiti and other wild cervids, which in turn infected local snails and eventually caused several enzootics in domestic livestock and other indigenous animals (Kingscote 1950). Another example is the occasional infection of sheep with Parelaphostrognylus tenuis, a normal parasite of white tail deer (Kennedy et al. 1952; Nielsen and Aftosmis 1964).

8.2.4 EFFLUENTS

Parasitic eggs and larvae often gain access to otherwise parasite-free pastures via drainage or runoff from manure piles.

8.2.5 SURVIVAL OF PARASITES ON PASTURES

The survival of parasitic eggs and larvae on pastures varies depending upon the various factors described in Section 8.1. Nevertheless, some parasites normally survive for long periods. It has been shown that Ascaris suum may live in humid soil at temperatures ranging from 5 to 20ºC for 2 years (Soulsby 1965). In Eastern Canada, many ruminant nematodes readily survive overwinter (Smith 1972, 1974; Smith and Archibald 1965b, 1969; Swales 1940). Indeed, Smith (1972) showed that the bovine thread-necked intestinal worm, Nematodirus helvetianus, may survive on pastures over 2 winters in the Maritimes. It is safe to say that one cannot depend upon adverse climatic conditions to sterilize the environment of infective parasites.

8.2.6 VECTORS

Various crustaceans, arachnids, insects, earthworms, snails, and other animals serve as essential intermediate hosts for the flatworms (trematodes and cestodes) and many roundworms. Many of these parasites are thus able to remain alive for extended periods on pastures within the second host. The eggs of the porcine lungworm, Metastrongylus apri, are thick-walled and capable of surviving for long periods. However, this worm may extend its survival considerably within its intermediate host, i.e. the earthworm. Experimentally, infected earthworms have lived for 15 months. It is known that some earthworms may live from 4 to 10 years (Soulsby 1965).Flies may serve as mechanical carriers of worm eggs (e.g. Ascaris) and as actual intermediate hosts of worms (e.g. Habronema) Spirurid nematodes are largely carried by dung-frequenting insects. Consequently, vectors play an important role in the dissemination and survival of parasites. Control programs directed at the vectors often successfully control the parasite.

8.2.7 PLOUGHING MANURE UNDER

Manure should be ploughed under whenever possible, although this procedure cannot be guaranteed to keep eggs and larvae below ground. Larvae are capable of a certain degree of upward movement and earthworms may bring some to the surface. Ostertagia and Nematodirus can regain the surface after being ploughed under and have been known to survive for 8 months in this manner in soil in England. Ascarids and whipworms undoubtedly could survive longer. Horse strongyles have been demonstrated to live for 4 years when ploughed under (Cameron 1940). Embryonated porcine lungworm eggs remained viable for 2 years in permanently moist soil.

Upward migration of larvae depends upon the type of soil. Horse strongyles show practically no upward migration in clay provided there are no cracks in the soil, but in sandy clay they can migrate 10 cm, and in sandy loam, 12.7 cm upward (Cameron 1940). On the other hand, dung beetles, if present in large numbers, significantly reduce the number of infective larvae available to grazing animals in the southern United States by carrying the infected feces below ground level (Fincher 1975).

8.3 TREATMENT OF MANURE TO CONTROL PARASITES

8.3.1 STORAGE

Manure storage for a sufficient length of time without any treatment will destroy all helminth eggs and larvae. Unfortunately, the time factor is too long to be practical in most instances.

8.3.2 HEATING

Heating is an excellent method of destroying parasitic eggs and larvae, provided that the manure generates enough heat. With the exception of those in the outer 15.2 cm, all eggs and larvae of the strongyle type are destroyed in 4 days by the natural heat generated in horse manure (Cameron 1940). If the manure is confined within wooden boxes either above or below ground, all except the outer 7.6 cm become hot enough to destroy the parasites. If the boxes are insulated (double walled with sawdust between), all parasites are killed within 1 week. It has been suggested that in compact manure piles, which have the outer 15.2 cm turned in every 5 days or so, an extremely high percentage of eggs and larvae will undoubtedly be killed.

The practice of mounding the manure towards the center of large feedlot pens (Jensen and Mackey 1971) would appear to be an excellent example of this method. The heat of fermentation within the mound and the prolonged periods that such mounds may exist would undoubtedly kill the parasitic eggs and larvae, except perhaps for the most recently added feces on the surface of the pack.

Experimentally, artificial heat, such as steam at 103 kPa, destroyed all eggs and larvae in a special manure box (Cameron 1940). The use of heat has the disadvantage of requiring special apparatus which entails some expense and perhaps has a limited application. Likewise, incineration would also appear to have a limited or restricted application (Canada Committee on Agricultural Engineering Services 1979).

8.3.3 DEHYDRATION

Drying is effective in killing eggs and pre-infective larvae so it is essential that manure be dried daily before later parasitic stages develop. This method has greatest application in countries with a hot, dry climate. Commercial driers specifically for manure are available (Canada Committee on Agricultural Engineering Services 1979), but field experience in their use and practicality has yet to be gained.

8.3.4 COMPOSTING

In composting, a dry material with a high carbon content (chopped straw, ground corncobs, or other crop residue) is usually required for manure. When properly managed, composting under aerobic conditions is relatively fast, with the material naturally heating to reach temperatures from

49 to 71ºC (Canada Committee on Agricultural Engineering Services 1979).These temperatures would seem to be more than adequate to kill parasitic eggs and larvae in manure.

8.3.5 ANAEROBIC PROCESSING

Based on the known oxygen requirements of parasitic eggs and larvae studied to date, it follows that anaerobic processing of manure might have potential for controlling parasites that may be present. This is a procedure that deserves further study.

8.3.6 FERMENTATION

Ensiling poultry litter as fodder for ruminants has recently been reported (Cross and Jenny 1976; Harmon et al. 1975). During hot fermentation of liquid cattle manure by aeration at a temperature of 35-40ºC, the average survival of strongyle eggs has been shown to be 4 days; 3rd stage strongyle larvae, 10 days; eggs of Fasciola hepatica and sporulated oocysts of Eimeriatanella, 14 days; eggs of Ascaris suum, Trichuris suis and Taenia hydatigena, more than 14 days (Enigk et al. 1975). At temperatures above 45ºC, only 3 days are needed for all resistant forms except Trichuris and Taenia eggs which require 5 days. Heule (1975) showed that after storage in fermenting pig manure for 90 days at 15-19ºC (summer) or 60 days at 7-8ºC (winter), 50 and 80% respectively of Ascaris eggs were still able to develop. In field trials in the summer, Ascaris eggs were dead after 75 days storage in fermentative manure. Heule concluded that under practical farming conditions, it is necessary to store liquid manure for at least 2.5 months in order to kill all helminth eggs.

8.3.7 CHEMICAL TREATMENT

Chemical control of free-living stages of parasites appears to have considerable promise. Study of this approach is needed, although considerable very worthwhile basic research was done on this subject in Canada many years ago using the eggs of horse sclerostomes as the test objects (Cameron 1940).

The addition of a chemical to feces containing worm eggs may have varied effects on the eggs and larvae, depending not only on the nature, but also on the quantity, of the chemical. These effects may vary from negligible (e.g. with ground limestone, raw rock phosphate, pyrethrum powder and derris root) to extremely strong (e.g. with chloropicrin, calciumcyanide, naphthalene, ortho-and paradichlorobenzene and iodine salts). When available in sufficient quantities, urine has all the possible advantages of an effective chemical; however, due to changes in its composition the parasiticidal effectiveness of urine varies considerably, not only according to the species but also according to the food and health of the animal from which it is taken. Generally speaking, addition of urine at about 30 to 40% of the weight of fresh feces kills the free-living stages of sclerostomes.

A practical group of agents is the artificial fertilizers, since if care is taken to avoid loss of nitrogen, part or all of their cost may be recovered in increased manurial value. Of the artificial fertilizers, urea is the most potent, requiring about 0.75% by weight of the feces to sterilize them against sclerostomes. Calurea should be used at the rate of 1.25%, and powdered cyanamide at about 2% (2.5% if the granular form is used). A high grade kainite ($KCl.Mg\ SO_4.3H_20$) at the rate of 5% of manure is one of the most lethal fertilizers. With the addition of some alkali fertilizers to feces, there will be a loss of ammonia. With urea and calurea, much ammonia escapes as gas.

In many cases, the quantities mentioned in the foregoing would be too great for it to be practical to treat all the manure, but since heat of fermentation, lack of oxygen, and other factors prevent the development of larvae in the center of well built manure heaps, it should be necessary to treat only the outer layer of the manure pile with the fertilizer.

The method of applying fertilizers to manure is important. Larvae may escape the action of the chemical if they are in lumps of feces and thus avoid contact with the chemical. Thorough mixing to evenly distribute the chemical throughout the manure is essential.

While chemical treatment of feces to kill worm eggs and larvae has potential, it has not been a widely used technique except under certain specific conditions, e.g. control of hookworm larvae in kennels and exercise runs by periodically treating the soil with sodium borate (Soulsby 1965).

9.0 PATHOGENS OF ANIMALS IN MANURE: ENVIRONMENTAL IMPACT AND PUBLIC HEALTH

A.J. MacLean [α]

Although pathogens in manure are hazardous to animal and human health within the animal production unit, they need not be a matter of public concern since advice on control measures is readily available from veterinarian and medical services. The public is protected from indirect exposure in food products by strict regulations for food processing and retailing. A more particular environmental concern is the possible escape of pathogens in runoff from manure pits, feedlots, and manure-treated land, to ground water and surface water used for drinking and recreational purposes.

Reference to survival of pathogens in manure, soil, and water in the preceding three chapters may be summarized as follows. The spirochete, Treponema hyodysenterae, is the causitive organism of swine dysentery and is known to exist in manure pits and lagoons. Salmonella spp. survive in manure for many months. Brucella species survived up to 2 months in moist manure but only for 2 hours in bright sunlight. Mycobacterium paratuberculosis, causing Johne's disease, survives for at least a year in manure or soil, and M. avium, excreted by poultry, persists in soil for as long as 4 years. Clostridium perfringens, causing enterotoxemias, is readily isolated from soils and Erysipelothrix rhusiopathiae, causitive organism of Erysipelas, survives for long periods in alkaline soils. The soil is believed to be the normal habitat for most pathogenic fungi. The parasite Ascaris suum may live in humid soil at 5-20ºC for 2 years, and horse strongyles have lived in soil 4 years after being plowed under. Ruminant nematodes survive over winter in pastures in the Maritime provinces. Some parasites survive in an intermediate host such as the earthworm. The leptospires, bacterial organisms, survive for long periods in water but not in a dry environment. Generally, viruses are not considered to survive long outside their hosts, but their spread from feces is recognized and some live in water for a long time, e.g. the virus of poliomyelitis.

The potential hazards of the escape of pathogens from the animal production unit and manure-treated land will be discussed further in the following sections.

9.1 ANIMAL PRODUCTION UNIT

Until recent decades, manure was highly valued for its nutrient content and its use was important in maintaining soil fertility. Storage of manure in pits constructed to prevent leaching

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and runoff was promoted as a conservation measure, the attendant advantage to the environment being incidental. As commercial fertilizers came into common use and labor costs of handling manure increased, the disposal of manure created a problem which was accentuated with concentration of a large number of animals in a limited area. The Canada Animal Waste Management Guide (Canada Committee on Agricultural Engineering Services 1979) describes manure handling systems in current use.

Changing to a modern system of manure handling tends to enhance survival of pathogens. For example, instead of using bedding, the manure may be washed down with water and stored as a slurry. Salmonella species were found to survive 30 to 50% longer in dilute wastewater than in the raw state with little added water (Hojovec 1977).Earlier, workers in England pointed to possible danger of spraying manure infected with pathogens after storage in a liquid state (Jack andHepper 1969; Haig 1972). Results of studies cited by Coote and Zwerman (1975) indicated that leptospires in an oxidation ditch survived for 61 days and salmonellae in liquid manure survived from 77 to 345 days, depending on serotype and temperature. In the conventional system of the past, when manure was stored in raw state without dilution with water, the heat generated killed many pathogens (Strauch 1977). Water is considered to be an important mode of transmission of the causative bacterial organisms of salmonellosis, leptospirosis, anthrax, erysipelasand colibacillosis and the viruses of poliomyelitis and hepatitis (Diesch 1970). Since many pathogens survive for some time in manure and in water, it is imperative that animal housing, feedlots, manure storage systems, pastures and animal water supplies be arranged with particularattention to location as well as soil and hydrological conditions in order to minimize the escape of pathogens to water. All operations of the animal production unit must be managed so as to restrict movement ofpossible pathogens to ground water or surface water by leaching or runoff.

9.2 LAND APPLICATION OF MANURE

The most appropriate use of animal manure is on the land. Considering its value in maintaining soil productivity, manure should be regarded as a resource instead of a waste. This viewpoint is in harmonywith the current need for conserving resources and energy. Nevertheless, the confining of large numbers of animals in a restrictedarea, as in a feedlot, often produces an amount of manure in excess of the optimum amounts required by crops on the available land area and inexcess of the soil's capacity to retain soluble manurial constituents against leaching to groundwater. The possible health hazard of applyingmanure to land depends on the pathogens present, the method and period of manure storage, land characteristics, soil properties and the rate and method of application.

9.2.1 IRRIGATION WITH LIQUID MANURE

The spraying of crops with a manure slurry will present a greater hazard to animal and human health than will incorporation of themanure into the soil. In a reported outbreak of Salmonella typhimurium infection of cattle in England, it was found that the cattle had grazed pasture which had been irrigated excessively with slurry 3 weeks before (Jack and Hepper 1969). The causative organism was isolated from the slurry and from 4 carrier cows after the outbreak. In tests in the same country, calves grazing pasture contaminated with slurry containing 10^6 S. dublin organisms per mL became infected within a few days (Haig 1972). When the concentration was lowered to 1×10^3 organisms per mL, none of the calves became infected. In a subsequent test with grazing on pasture which had been contaminated one week before, using a concentration of $1 \times 10^5 .mL^{-1}$, none of the animals became infected although the organisms were present at a grass level below 25.4 mm for at least a month.The results indicated that a large number of the organisms were required to establish infection. In a review of the literature, Strauch (1977) cited reports from Germany and other countries of several instances of animals infected with salmonellae from pastures which had been irrigated with slurry. Salmonellae and other pathogens, including viruses, survived in a slurry for many months. The attendant danger to animal and human health arising from irrigation of crops with untreated slurry was emphasized. On-site treatment of liquid manure by chemical or physical methods was recommended. To minimize the dangers of infection, the Ministry of Agriculture in Britain recommendedthat 6 months should pass after applications of liquid manure to pastures before they are grazed (Jack and Hepper 1969). Obviously, food crops should not be sprayed with untreated slurry. In contrast to the reports of contamination of pasture following slurry irrigation, spreading of feedlot manure at a rate of 125 $t.ha^{-1}$ on orchard grass in Western Canada did not contaminate the grass with enteropathogenic bacteria after irrigation (Bell et al. 1976).

9.2.2 MANURE INCORPORATED INTO SOIL

In land application of manure, environmentally it is advantageous to incorporate it into the soil.In a recent review of pathogen survival in soils, Morrison and Martin (1977) found considerable variability in the reported literature. To illustrate the variability, they presented selected survival times for some bacterial pathogens in soils as reported by different researchers. They cited Waksman's view (Waksman and Woodruff 1940) that the microbiological population in a normal soil has a destructive effect upon pathogens. Other reports (Elliott and Ellis 1977) suggested that soil application decreases pathogen survival and virulence. Despite any hostile aspects of the soil environment to pathogen survival, there is considerable documented evidence to show that many pathogens (bacterial, viral, fungal and parasitic) persist in soils long enough to become a source of animal and human infection. In the review by Morrison and Martin (1977), a reference was made to the persistence in soils of anthrax, clostridium and salmonella organisms among others. There is evidence that viruses may be absorbed by soil components and remain infectious although removed effectively from a host contact (Elliott and Ellis 1977). The persistence of parasites in soils has been discussed by Smith in Chapter 8. The survival of many pathogens in soils appears to be favored by low temperature, moist conditions and a near neutral pH.

Unless manure is incorporated into the soil, it should not be applied to sloping land where runoff has access to nearby lakes or streams. Furthermore, large amounts of manure should not be applied to highly permeable sandy soils or soils that have been tile drained since pathogens may move to subsurface layers and contaminate groundwater. From a review (Coote and Zwerman 1975) of various cited reports, it would appear that bacteria and viruses may be adsorbed by clays with high surface area, e.g. montmorillonite, but they have been shown to move as much as 15.2 m in sandy soils. In an experiment with soil under saturated conditions, it was found that added streptomycin-resistant strains of Escherichia coil and Streptococcus faecalis moved through the soil profile in the direction of groundwater flow (Hansen and Hagedorn 1977).Both bacterial indicators survived in appreciable numbers throughout two 32-day sampling periods. In another experiment, the concentrations of Escherichia coli and enterococci, in water from a subsurface field drain of a pasture on sandy clay loam, were affected by flow rate and the spraying of large volumes of semiliquid pig manure (Evans and Owens 1972).There was a 30- to 900-fold increase in the concentrations of fecal bacteria in the drain discharge within 2 hours of the start of spraying the pasture. These results illustrated the susceptibility of ground water to contamination with pathogens from manured land.

9.3 IMPACT OF ANIMAL PRODUCTION AND MANURE DISPOSAL ON THE ENVIRONMENT

Information relating the presence of pathogens in streams and lakes to an agricultural source is confined mostly to instances of human and animal infection. A human infection may often be traced to contaminated water used for recreational purposes or for drinking. For example, Diesch (1970) refers to reports in the United States of leptospirosis in people after they had been swimming in water contaminated by infected cattle, and of salmonellosis from drinking water suspected of being contaminated from cattle feedlots. In an outbreak of leptospirosis on a cattle ranch, the organism, Leptospira pomana, was identified in the urine excreted by the cattle and in the surface water of pools and swift-flowing streams to which the infected cattle had access (Gillespie et al. 1957). In Western Britain where salmonellosis is enzootic in adult cattle, surveys were conducted on two rivers in the area to find the extent of contamination by Salmonella dublin (Hooper 1970). The organism was recovered from at least one site on one river on 14 out of 20 occasions and from at least one site on the other river on 9 out of 17 occasions. It was observed that many farms in the area rely on streams to provide water for grazing stock and that river water is a likely source of infection of cattle. The above cited reports served to illustrate that animal production units can be a source of pathogens in water and that contaminated water can be a source of infection for animals and man.

With respect to the spread of animal pathogens, it should be mentioned that some are airborne, for example, the Q fever intracellular parasite in animal waste attached to dust, the Newcastle disease virus in chicken down and dust, and the fungal spores or systemic mycotic diseases (Diesch 1970). The airborne spread of Newcastle disease is discussed in some detail by Lancaster and Alexander (1975). When liquid manure was applied by sprinkler irrigation, there was some concern over workers inhaling aerosols containing viruses and bacteria (Elliott and Ellis 1977). However, the effect of aerosols was considered to be minimal when the work was carried out on days with low wind velocity, warm bright sunlight and a relative humidity between 40 and 60%.

It should be noted that the presence of a particular animal pathogen in soil or water does not necessarily imply transmission of disease to animals or man brought in contact. The viability of the organisms, the numbers present, host susceptibility and many other factors may play a role in infection.

10.0 PHYTOPATHOGENS AND WEED SEEDS IN MANURE

M.D. Sutton [α]

Manuring of fields provides an economical means for the disposal of farm animal wastes. The attendant benefits of this cultural practice, namely increased crop yields and improved soil productivity, have been recognized by farmers for centuries. The benefits of applying manure to the land can, however, be offset by 1) phytotoxic effects on seed germination and the development of young seedlings (Azevedo and Stout 1974; Chaney 1974; Costa et al. 1974; Frank 1973; Petersen et al. 1971 and Webber 1972), 2) the dissemination of plant pathogenic organisms to infect the soil and crops (Baker and Snyder 1965; Baker 1968; Edgington and Leach 1981; Haghiri et al. 1978; Ryerson 1977 and Walker 1969) and 3) the dispersal of weed seeds (McLean and Ivimey-cook 1956; Salisbury 1964 and Warwick 1982, personal communication).

10.1 PHYTOTOXICITY

A number of phytotoxic or negative effects of manuring have already been mentioned in this document (Sections 2.3.2, 4.0 and 5.0). Poultry manure applied at moderate to high rates has been reported to cause ammonia toxicity in germinating seeds and young seedlings (Azevedo and Stout 1974). A zinc deficiency induced in some crops by the accumulation of phosphorus in the soil may result from repeated manuring. Reduction in germination and yields in corn fields grown for forage and in other crops has been attributed to salt accumulation in soils heavily treated with manure from beef feedlots (Mather et al. 1970; Petersen et al. 1971 and Wallingford et al. 1975).Rations for beef cattle frequently contain one percent or more NaCl, most of which is passed in the urine (Petersen et al. 1971). Costa et al. (1974) reported a number of cases of picloram toxicity to plants grown on land treated with manure from animals fed plants treated with this herbicide. Frank (1973) has also reported residual picloram toxicity in tobacco grown in fields treated with manure. The picloram was traced to grain straw from treated fields which had been used as litter for the farm animals and incorporated in the manure. The toxic effects on plants and animals of heavy metals and micronutrients, built up in the soil as a result of repeated manuring and applications of sewage sludge, have already been reviewed in Section 4.0.

10.2 PHYTOPATHOGENS

The improper disposal of infected plant refuse or the use of infected plant material for feed or bedding are the primary sources of plant pathogens found in manure.

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Only a few phytopathogens gain direct access to manure and retain their viability after passage through the digestive tracts of farm animals (Table 10-1).

Most plant pathogens found in manure, namely fungi, bacteria and viruses come from infected plant debris added to farm animal wastes. When animal barns, sheds and pens are cleaned, the manure becomes contaminated with infected plant debris, e.g. bedding material (cereal, bean and pea straw) and feed refuse (corn, apples, potatoes, root crops, etc). Man may also be the unwitting agent of contamination and vector of disease when he disposes of infected garden and crop sanitation wastes on manure piles. Under favorable environmental conditions contaminated manure spread on the land becomes a potential source of inoculum and outbreaks of plant diseases may result.

As noted earlier in this document, pathogenic organisms located in the peripheral 10 to 13 cm of manure piles (or in liquid manure) are not exposed to the lethal and decontaminating effects of the relatively higher temperatures of 41.6ºC and over generated within heating manure piles (Cameron 1940; Canada Committee On Agricultural Engineering Services 1971). Virulent pathogens exposed to the lower, non-lethal temperatures near the periphery of manure piles (or in liquid manure) remain viable sources of inoculum. When this infectious manure is applied to the land it has the potential to initiate outbreaks of plant disease and/or infect the soil.

Table 10-2 lists a number of plant pathogens reported to overwinter in infected crop wastes. Once manure is contaminated with infected waste, a potential source of virulent inoculum is established and the risk of a plant disease outbreak is increased. In addition to a source of inoculum, a disease outbreak would, however, require a suitable host in large numbers and favorable environmental conditions for the development and spread of the pathogen. To this end the cultivation of a single crop species greatly favors the effective dispersal of phytopathogens.

10.3 WEED SEEDS

Farm animals ingest large numbers of weed seeds in their feed, both in the barn and in the field. Some weed seeds, representing diverse species, retain their viability after passage through the digestive tracts of animals and are dispersed in the feces (Table 10-3). The germination of some seeds, e.g. those with hard test as, often improves as a result of passage through an animal's body. Dispersal in feces is one of several means by which seeds are distributed by animals (zoochory) in nature. As a group, birds distribute more seeds in this way due to their particular mode and speed of travel. Mammals are second in effectiveness in distributing weed seeds via excreta (McLean and Ivimey-cook 1956).

Table 10-1. Viable plant pathogens in manure after passage through the digestive tracts of farm animals.

Name of Pathogen	Common name of plant disease	Animal passage	Origin of inoculum	Reference
Sclerotium cepivorum	White rot of onion, shallot, garlic	Yes (sheep, goat and likely by cattle)	Sclerotia in infected crop refuse eg. bulbs. Subsists for long periods as sclerotia in soil	Mikhaelet al.1974 Walker 1969 Harrison 1954
Sclerotium rolfsii [α]	Southern sclerotium rot of sugar beets	Yes (cattle and sheep)	Sclerotia in infected beet roots and tops used as feed	Leach and Mead 1936
Sphacelotheca reiliana	Head smut of corn	Yes -	Corn seed heavily infected with smut spores and used as animal feed	Edgington and Lynch 1981
Streptomyces scabies	Common scab of potato	Yes -	Infected tubers fed to farm animals. Pathogen may persist in soil indefinitely	Walker 1969

[α] This disease not reported in Canada.

Table 10-2. Plant diseases which may originate from infected crop refuse in manure [α].

Name of pathogen	Common name of disease	Inoculum
Alternariasolani	Early blight of potato and tomato	Overwinters in infected plant debris, on tomato seed and in potato tubers. Infection may enter directly from infected debris in the soil
Asochyta pinodella Ascochyta pisi	Ascochyta disease of pea	Overwinters in seed and infected plant debris. Primary infection from pycnospore inoculum in infected debris e.g. refuse from pea straw stacks and pea-vine silage stacks
Colletotrichum lindenmthianum	Bean anthracnose	Overwinters on seed and in infected plant debris. Infection by wind blown of water-borne conidia
Diplodia macrospora Diplodia maydis	Diplodia disease of corn (seedling blight; root, stalk and ear rot)	overwinters primarily in seed and in diseased stalks and infested soil. Airborne pycnospores infect plants. Seedling infection mostly of seed-borne origin
Gibberella moniliforme	Gibberella disease of corn (seedling blight; root, stalk and ear rot on corn)	overwinters in seed and on infected debris e.g. corn stalks. Perithecial ascospores are primary airborne inoculum. Macroconidia and microconidia serve as secondary airborne inoculum
Gibberellaroseum	Gibberella diseases of corn and small grains - Headblight (scab), seedling blight and foot rot on barley, wheat, rye and some varieties of oats	
Mycosphaerel la pinodes	Mycosphaerella disease of pea	Overwinters in seed and infected plant debris, e.g. refuse from pea straw stacks and pea-vine silage. Infection from pycnospores and perithecia in infected debris.
Phytophthora infestans	Late blight of potato and tomato	Overwinters as mycelium in infected potato tubers in soil of refuse tubers from storage in spring. Infection by colidiophores and zoospore production.
Scerotinia sclerotiorum	Sclerotinia disease of vegetables and field crops (potato, tomato, turnip, cucumber, cabbage, rutabaga, clover, sunflower, beans, peas)	Overwinters as sclerotia in soil or infected plant material. Distributed on man, animals, implements, seed and by irrigation water. Inoculum primarily ascospores from apothecia at soil surface
Septoria apiicola	Late blight of celery	Overwinters in seed and infected crop refuse. Infection by pycnospores and conidia disseminated by wind and rain
Synchytrium endobioticum	Black wart of potato	Contaminated manure and infested soil disseminate this phycomycete
Ustilago maydis	Corn smut	Fungus adaptable as a saprophyte. Teliospores persist on crop refuse and in soil. Spores produced on refuse and manure. Primary inoculum air and water-borne spori dia
Tobacco Mosaic Virus	Tobacco mosaic (TMV)	Infected plant debris in soil, refuse from warehouses and certain manufactured products are sources of primary inoculum
Xanthomonas campestris	Black rot of crucifers	Overwinters in seed and in plant refuse infected with the bacterial phytopathogen
Erwinia carotorora [β]	Soft rot of vegetables (most root crops, lettuce, cabbage, celery, tomatoes etc)	Easily spread by manure contaminated with plant refuse infected with the soft rot bacterium

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[α] Information from Walker 1969 (except for g). [β] Pyenson 1977.

Table 10-3. Weed seed species occurring in Canada that have been recovered from farm animal excreta [α].

Botanical Name of weed	Animal source of excreta	Common Canadian name of weed
Achillea millefolium L.	horse	yarrow
Agrostemma githago L.	cattle	purple cockle
Anthemis arvensis L.	cattle	corn chamomile
Atriplex patula L.	cattle	spreading atriplex
Avena sativa L.	horse	oats
Barbarea vulgaris R. Br.	cattle, horse, pig	yellow rocket
Capsellabursa-pastoris (L.) Medic	cattle, goat	shepherd's-purse
Chenopodium album L.	cattle, horse, pig	lamb's-quarters
Chrysanthemum leucanthemum L.	horse	ox-eye daisy
Daucus carota L.	horse	wild carrot
Erysimum cheiranthoides L.	cattle, horse	tall wormseed mustard
Fumaria officinalis L.	cattle	fumitory
Galeopsis tetrahit L.	cattle	hemp-nettle
Galium aparine L.	cattle	cleavers
Geranium pusillum L.	cattle	small-flowered geranium
Juncus bufonius L.	cattle, horse	toadrush
Lithospermum arvense L.	sheep	corn gromwell
Matricaria matricarioides (Less.) Porter	horse	pineapple weed
Pimpinellas axifraga L.	cattle	burnet-saxifrage
Plantago lanceolata L.	cattle	narrow-leaved plantain
Plantago major L.	cattle, horse, goat	broad-leaved plantain
Poa annua L.	cattle, horse	annual bluegrass
Polygonum aviculare L.	cattle, horse	prostrate knotweed
Polygonum lapathifolium L.	cattle	pale smartweed
Polygonum persicaria L.	cattle	lady's-thumb
Ranunculus repens L.	cattle, horse	creeping buttercup
Raphanus raphanistrum L.	cattle	wild radish
Rumex acetosa L.	cattle	garden sorrel
Rumex acetosella L.	cattle, horse, goat, pig	sheep sorrel
Rumex obtusifolius L.	cattle	broad-leaved dock
Sagina procumbers L.	horse	bird's-eye pearlwort
Sinapis arvensis L.	cattle	wild mustard
Spergula arvensis L.	cattle, horse, pig	corn spurry
Stellaria media (L.) Vill.	cattle, horse, pig	chickweed
Taraxacum officinale Weber	cattle, horse	dandelion
Thlaspi arvense L.	cattle, horse	stinkweed
Urtica dioica L.	cattle	stinging nettle
Urtica urens L.	cattle	dog nettle
Veronica agrestis L.	cattle, horse	field speedwell
Veronica arvensis L.	cattle	corn speedwell
Vicia sativa L.	horse	common vetch
Viola arvensis Murr.	cattle	field violet

[α] from Alex et al. 1980 and Salisbury 1961.

Weed seeds passed in farm animal excreta are augmented in numbers by those from hay and straw bedding, refuse feed and other plant litter when they are incorporated into manure. Weed seeds during storage in manure are exposed to the high temperatures generated in the core of the pile and lose their ability to germinate. A significant number of seeds exposed to the lower temperatures which prevail near the periphery of manure piles do, however, retain their viability.

It is not uncommon for manure, in excess of the requirements of the land on which it is produced, to be transported to other sites by truck or rail. Beef feedlots and chicken farms are operations which in general have excess manure. The hazards associated with the transportation of manure far from its site of origin in relation to the introduction and dispersal of weed species to new sites are obvious.

Of current concern in Canada is the introduction and spread of new problem weeds like triazine-resistant lambs'-quarters, (Chenopodium album) and pigweed (Amaronthus spp.) or a new weed species such as velvetleaf (Abutilon theophrasti Medic).

Velvetleaf, for example, was reported in Ontario in the late 1950s. By the 1970s this weed had become a serious problem throughout southwestern Ontario. Velvetleaf has now spread to twenty-eight counties of Ontario and to many of the counties of Quebec. Infestation of a number of these areas has been attributed to the disposal of the weed seeds in manure and contaminated feed. Velvetleaf has been observed growing on piles of both beef and chicken manure. In 1982 a serious outbreak of velvetleaf was reported in Nova Scotia. Itis believed this introductionand infestation originatedin a shipment of feed corn from an area already infested with velvetleafand dispersal of the weed seeds into the fields was via manure (Warwick 1982, personal communication).

With respect to the increases of velvetleaf noted above, the following observations by Holm et al.(1977) on increases of Solanum nigrum (black nightshade) and A. theophrasti (velvetleaf)in lima bean fields suggest a possible alternate cause for the observed increased incidence of velvetleaf: "In the Great Lakes region of northern United States, S. nigrum and Abutilon theophrasti have been the subject of an interesting ecological shift in weed species as a result of herbicide use. Prior to 1962 lima beans were weeded with a combination of dinitrophenol herbicides, cultivation, and hand-hoeing. The two weed species were seldom seen in bean fields. Trifluralin,CDAA (an acetamide, 2-chloro-N,N-diallylacetamide),and chloramben (a benzoic acid) came into use after 1962 and, as a consequence, farmers were no longer required to do much cultivating and weeding with hand tools. Solanum nigrum and Abutilon theophrasti began to appear in 1965 to 1966 and are now the principal weeds of lima beans fields."

LIST OF METRIC ABBREVIATIONS, TERMS AND EQUIVALENTS

kPa = kilopascal = 0.01 bars = 0.0145 psi
mL = millilitre = 0.0352 fluid ounces (Imp)
L = litre = 0.22 gallons (Imp)
g = gram = 0.0353 ounces
kg = kilogram = 2.205 pounds
t = tonne = 1000 kg = 0.984 ton (Imp)
cm = centimetre = 0.394 inches
m = metre = 1.09 yards
km = kilometre = 0.62 miles
ha = hectare = 2.471 acres
d = day = 24 hours
a = annum = 365 days
lx = lux = 0.092 903 foot candles
kg.t^{-1} = 2.24 lbs.ton (Imp) $^{-1}$
km.h^{-1} = 0.6214 miles per hour
t.ha^{-1} = 0.398 ton (Imp).acre^{-1}
kg.ha^{-1} = 0.892 lbs.acre^{-1}
1 mg.kg^{-1} = 1 ppm
1 mg.L^{-1}(H_2O) = 1 ppm
1 µL.L^{-1} = 1 ppm, by volume
1 million = 10^{6}

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SUBJECT INDEX

N.B. References indicate CHAPTER, SECTION, SUBSECTION, etc., e.g. 343 indicates Chapter 3, Section 4, Subsection 3.