

Hazardous Solid Waste from Agriculture

by Raymond C. Loehr*

Large quantities of food processing, crop, forestry, and animal solid wastes are generated in the United States each year. The major components of these wastes are biodegradable. However, they also contain components such as nitrogen, human and animal pathogens, medicinals, feed additives, salts, and certain metals, that under uncontrolled conditions can be detrimental to aquatic, plant, animal, or human life. The most common method of disposal of these wastes is application to the land. Thus the major pathways for transmission of hazards are from and through the soil. Use of these wastes as animal feed also can be a pathway. While at this time there are no crises associated with hazardous materials in agricultural solid wastes, the potential for problems should not be underestimated. Manpower and financial support should be provided to obtain more detailed information in this area, especially to better delineate transport and dispersal and to determine and evaluate risks.

Introduction

In examining this topic, several definitions are necessary to identify both the boundaries and the focus of the discussion. Of particular importance are the definitions of the terms, "agricultural waste" and "hazardous."

In the context of this paper, agricultural wastes are defined as the residues from the growing and first processing of raw agricultural products such as fruits, vegetables, meat, poultry, dairy products, and crops. They are the nonproduct outputs of production and processing that may contain material that can benefit man but whose economic values are less than the cost of collection, transportation, and processing for beneficial use. Agricultural wastes can be in the form of liquids, slurries, or solids. Agricultural solid wastes are the focus of this paper.

The definition of the term hazardous requires answers to questions such as: hazardous to whom or what? under what conditions? at what levels? When discharged to the environment, agricultural wastes can be both beneficial and detrimental to living matter. Agricultural wastes are not restricted to specific locations but are distributed widely. They can affect surface and ground waters, soils and crops, as well as animals and humans. There are many direct and indirect pathways (Fig. 1) by which constituents in animal wastes can contact living matter and ultimately be hazardous. This paper will

attempt to analyze those characteristics in solid agricultural wastes that may be hazardous, and their potential for resulting in hazardous conditions.

Quantities and Characteristics

The magnitude of the problem can be grasped by identifying the quantities and characteristics of the agricultural solid wastes that are produced. Table 1 summarizes the general types of these wastes that are generated, methods used for disposal, and the pertinent components in the wastes.

The major components of agricultural solid wastes are biodegradable organics. These are unlikely to result in hazardous conditions except when there are inadequate oxygen resources to assimilate the wastes. When this occurs in streams, inadequate dissolved oxygen and high ammonia concentrations can and have caused fish kills.

Other components in agricultural solid wastes that have resulted in hazardous conditions to some form of life are nitrogen, human and animal pathogens, medicinals and feed additives, and salts. Animal manures, meat processing wastes, and leather tanning wastes are the agricultural solid wastes that have the greatest potential to result in hazardous conditions.

The most common means of disposal for these wastes is on the land, by one or more methods. Thus the major pathways for transmission of hazards are from and through the soil. Hazards to man can occur either directly via water or indirectly via crops and animals fed or grazing on the crops.

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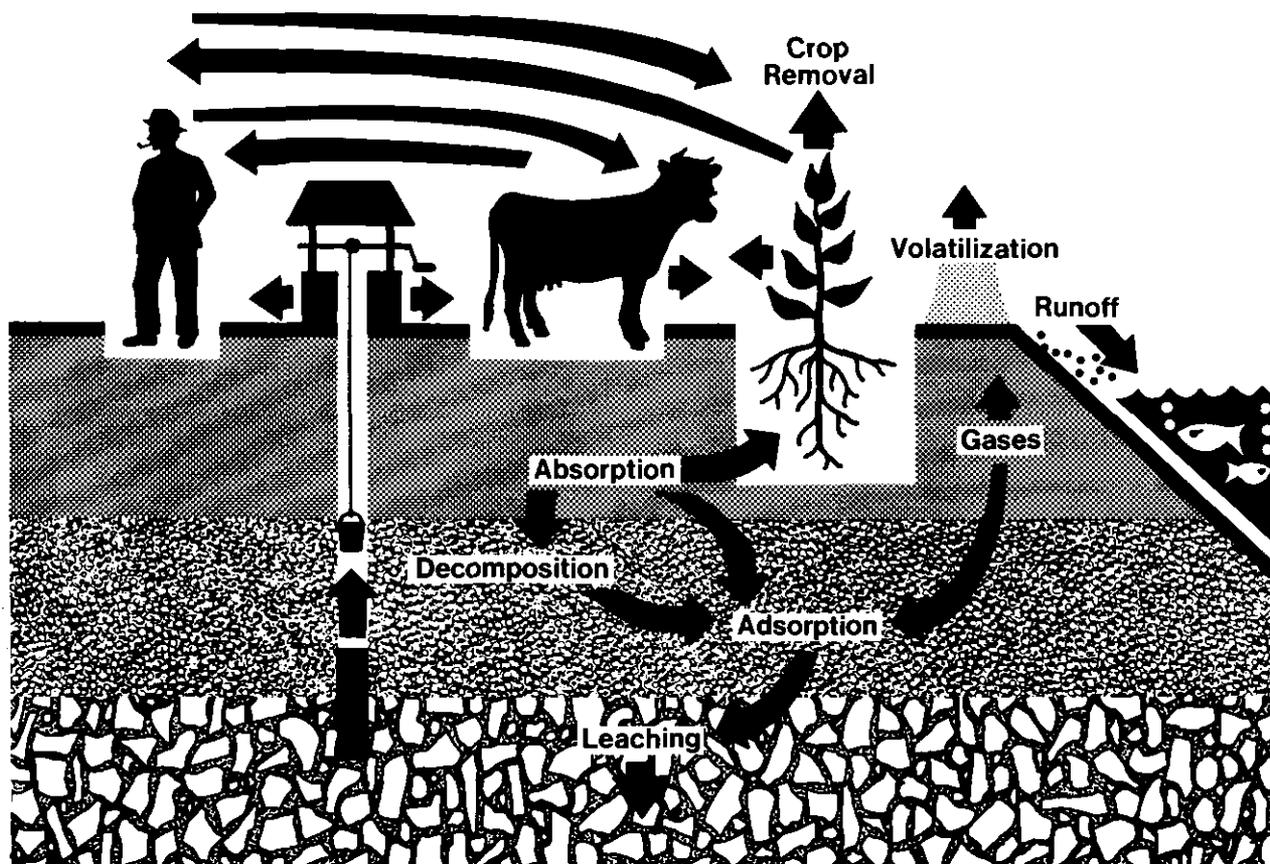


FIGURE 1. Degradation, transformation, and transmission of wastes in the environment.

When wastes are applied to the land in a controlled manner to serve as fertilizers, soil conditioners, or erosion control, few hazardous conditions should result. It is only when they are applied in an uncontrolled concentrated manner that the conditions may be hazardous to living matter.

With the increasing interest in utilization rather than disposal of these wastes, the potential for other concerns can increase. Many organic solid wastes can be processed and used for animal feed. Transmission of medicinals, chemicals, hormones, and bacteria by the proposed feed to the secondary animals or their products can have detrimental effects on those animals and on humans who use those animals and their products for food.

Information on the quantity of agricultural solid wastes is not plentiful. Tables 2 and 3 provide estimates of the livestock, crop and timber residues that are generated in the United States. It is generally stated that over two billion tons (1.8 Pg) of manure (wet basis) are generated by the livestock in the U. S. each year. That figure is conservative, since, as indicated by the data in Table 2, the manure gen-

erated by all the cattle is approximately that amount. In addition, manure from swine, poultry, horses, and other animals also is generated. Considerable bedding or litter can be mixed with the manure increasing the amount of livestock wastes requiring disposal.

Much of the livestock manure is generated and left in fields and pastures where it is absorbed naturally and does not result in any hazardous conditions. However, livestock production is becoming concentrated in larger operations, becoming specialized in certain geographical areas, and using long distance transportation of inputs and outputs. The result has been increased confinement feeding of livestock, increased numbers of animals per livestock operation, and concentrated amounts of manure requiring handling and disposal. It is these livestock wastes that can cause environmental problems. Estimates of the wet and dry weight of manure generated daily by animals produced in confinement, and its nitrogen and phosphorus content, are presented in Table 2.

Table 3 indicates the quantities of crop and timber

Table 1. General characteristics of agricultural solid wastes and methods of disposal.

Agricultural activity	Types of solid waste generated	Methods of solid waste disposal	Pertinent components in the solid waste
Leather tanning	Fleshings, hair, raw and tanned hide trimmings, lime and chrome sludge, biological sludge, grease	Rendering, by-product recovery, landfills, land spreading	Biodegradable organics, chromium, grease, sulfide, nitrogen, bacteria, chlorides
Dairy product processing	Biological sludges	Landfill, land spreading	Biodegradable organics
Meat processing	Biological sludges, grease, product trimmings, feathers, hides, bones	Rendering, by-product recovery, landfill	Biodegradable organics, nitrogen, bacteria, chlorides
Animal production (feedlots)	Manures	Land application, processed animal feed	Biodegradable organics, bacteria, nutrients, medicinals, salts, inorganic additives such as copper, arsenic
Grain processing	Biological sludges, spilled grain	By-product recovery, animal feed, landfill	Biodegradable organics
Sugar processing (beet sugar, raw cane sugar, cane sugar refining)	Biological sludges, bagasse, soil, pulp, lime mud, filter mud	Landfill, burning, composting animal feed	Biodegradable organics, bacteria, nutrients
Fruit and vegetable processing	Biological sludges, trimmings, peels, leaves and stems, soil, seeds and pits	Landfill, animal feed, land application, burning	Biodegradable organics, nutrients, bacteria, salts, grease, pesticides
Crop production and harvest	Straw, stover	Land application, burning, plowing under	Biodegradable organics, bacteria
Timber production	Branches, leaves, small trees	Left in place, burned in place, crushed	Slowly biodegradable organics
Wood processing	Bark, sawdust, small pieces	Burned, pulp, particle board, landfill	Slowly biodegradable organics

Table 2. Estimated quantities of livestock manures.

	Manure generated per day (feces and urine, no bedding), tons (Gg) ^a					
	Dairy cattle ^b	Beef feeder ^b	Swine	Poultry		
				Layer	Broiler	Turkeys
Raw manure (wet weight)	644,000 (584)	276,000 (250)	540,000 (490)	37,600 (34)	55,200 (50)	37,000 (34)
Total solids (dry weight)	82,000 (74)	32,000 (29)	50,000 (45)	9,600 (8.7)	13,700 (12)	
Total nitrogen	3,200 (2.9)	1,560 (1.4)	3,700 (3.4)	500 (0.45)	1,000 (0.91)	
Total phosphorus	550 (0.5)	500 (0.45)	1,200 (1.1)	200 (0.18)	210 (0.19)	

^a Estimated average manure produced per animal (1) and 1974 or 1975 species population data (2).

^b All cattle, about 5 million tons (4535 Gg) wet weight and 0.72 million tons (653 Gg) dry weight of manure generated per day.

residues that are generated each year. The quantity is considerably larger than that of livestock wastes. Most of the crop residues are left on the land, are widely distributed, and have not been identified with adverse environmental or hazardous conditions.

A national, county-by-county summary of the crop, forest, and wood product, and livestock and poultry manures generated in the U. S. has been prepared (4). Table 4 indicates some of the results. Of the crop residues, almost 75% is returned to the soil, with an additional 19% fed to livestock without

sale. In the case of forestry, about one-third consists of logging residues left in the forest, and two-thirds are mill residues. The mill residues and wood processing wastes are concentrated at the mill and processing plant locations and can be the cause of air and water pollution.

About two million tons (1.8 Tg) of food processing solid wastes are generated each year (Table 5). Nearly all of this waste is disposed of by dumping on land, by landfilling, or by land spreading. Tomatoes, corn, white potatoes, and miscellaneous vegetables contribute about 40% of the food pro-

Table 3. Estimated quantities of crop and timber residues.^a

	Residues, ton/yr (Tg)
Crop residue	
Corn stover	144,000,000 (131)
Total crop residue	1,183,000,000 (1073)
Timber	
Logging residue from growing stock	18,140,000 (16.5)
from saw timber	3,490,000 (3.2)
from nongrowing stock	18,140,000 (16.5)
Primary wood processing plant residue	43,210,000 (39.2)
Secondary wood processing plant residue	10,210,000 (9.3)
Bark residues—22,680,000 tons per year	22,680,000 (20.6)

^a Data of Roller et al. (3).

Table 4. Agricultural residues generated in the U. S.^a

Type	Residues, millions of tons/yr (Tg)		
	Total	Available	Collected
Crop	322 (292)	278 (252)	7 (6.3)
Manures	36 (33)	26 (24)	26 (24)
Forestry	116 (105)	114 (103)	76 (69)
Total	474 (430)	418 (379)	109 (99)

^a Data of Alich and Witwer (4).

Table 5. Food processing solid wastes generated per year.^a

Item	Solid wastes, 1000 tons (Gg)
Vegetable	1037 (941)
Fruit	526 (477)
Specialty products	93 (84)
Seafood	25 (23)
	1681 (1525)

^a Data of Hudson (5).

Table 6. Source of fish kills in the U. S.^a

Year	1964	1965	1968	1969	1970	1971	1972	1973
Total fish kill reports, all sources	590	625	542	594	635	860	760	749
Reports attributable to								
Insecticides	95	74	51	80	63	63	51	91
Fertilizers	5	4	5	5	6	8	10	18
Manure, silage drainage	29	29	21	29	38	41	46	52
Food products	41	60	35	37	32	25	31	19
Percent of fish killed by agricultural sources	8	12	2.5	15	20	1.5	12	6

^a Data of Loehr (6).

cessing solid waste, while peaches, apples, citrus, and pears account for another 25% of the total. Snap beans, beets, cabbage, and carrots each account for 2–4% of the total.

Hazards

General

Agricultural solid wastes can be real and potential hazards to aquatic, plant, animal, and human life. These occur as a result of the transmission and transformation of constituents of the solid wastes in the environment and through the food chain. The following summarizes some of the situations that have occurred or may occur as a result of uncontrolled handling and disposal of agricultural solid wastes.

Fish Kills

Indiscriminate discharge of agricultural wastes and runoff from animal confinement areas have resulted in a number of fish kills. Table 6 indicates the number of fish kills that have occurred in the United States over a ten year period. Liquid agricultural wastes were the cause of many of the fish kills. Uncontrolled insecticide discharges, runoff from fertilized fields, and manure and silage drainage also caused some of the fish kills.

Data from other countries indicate a comparable impact of agricultural wastes. Of the agricultural sources in Switzerland for the period 1962-1967, runoff from manure accumulations were the greatest cause of fish kills. The readily identified agricultural sources—manure liquids, silage juice, insecticides and herbicides—caused 39% of the fish kills (7).

Although agriculture was the cause of significant fish kills—as much as 20% of the total in the U. S.

(Table 6)—industrial or municipal waste discharges were the primary cause of the fish kills in the years shown. On a national basis, municipal and industrial pollution sources clearly are a more important source of water pollution, as measured by fish kills, than are agricultural sources.

However, on a regional basis, runoff from confined animal feeding operations (feedlots) can be a serious source of water pollution, fish kills, and water unable to be used for human or animal use. An early investigation illustrated the water quality changes that can occur when feedlot runoff reaches surface waters. Considerable lengths of streams were devoid of oxygen due to the runoff. BOD (biochemical oxygen demand) and ammonia concentrations were as high as 90 and 12 mg/l., respectively. Ammonia concentrations from the runoff were detectable before other parameters. Such runoff provides little warning to downstream users and can trap game fish in the polluted waters.

Figure 2 illustrates the characteristics of beef cattle feedlot runoff. The impact of this material on the quality of a stream can be grasped when it is recognized that the BOD of an uncontaminated stream is less than 2 mg/l., that the BOD discharged from a secondary municipal wastewater treatment plant is required to be no more than about 30 mg/l., and that the BOD of untreated municipal wastewater is about 200 mg/l. As Figure 2 and other data indicate, the BOD of feedlot runoff generally ranges above 5000 mg/l. This oxygen demand, as well as the ammonia and bacteria in the runoff, can have adverse results on stream quality to the detriment of human, animal, and aquatic use.

Runoff and percolation are not the only ways that feedlot contaminants can affect water quality. Feedlots can contribute ammonia, amines, and odorous sulfur compounds to the atmosphere (9, 10). Such compounds are potential pollutants to waters in the area and can have an effect on nearby plants and animals. Aliphatic amines were a significant fraction of the volatilized nitrogen. Similar results can be expected from other accumulations of manure exposed to the atmosphere.

The water pollution hazard of feedlots is related to the waste production per animal, the number of animals in the confinement unit, days confined, frequency of cleaning, climate, waste characteristics, and waste degradation in the lots. The contribution of feedlot runoff to surface water pollution is a function of the temperature, magnitude of rainfall, slope of the confinement area, surface area of the feedlot, type of lot surface, and management practices. Range-fattened cattle represent a smaller runoff pollution problem than feedlot cattle since they are more widely distributed on the land. As the

density of animals per acre decreases, the wastes are less concentrated and nature can absorb more of the wastes. The trend, however, is toward confinement livestock feeding.

Nitrogen

Nitrogen compounds are of concern due to the ammonia toxicity to fish, health problems for humans and animals, nitrogenous oxygen demand in receiving waters and its impact on aquatic life, and the role of nitrogen as a controlling nutrient in eutrophication. Nitrogen in agricultural wastes can be a source of these problems. Figure 3 indicates the major components of the nitrogen cycle.

High concentrations of ammonia in surface waters can be lethal to fish. A portion of the fish kills noted in Table 6 has been due to the high ammonia

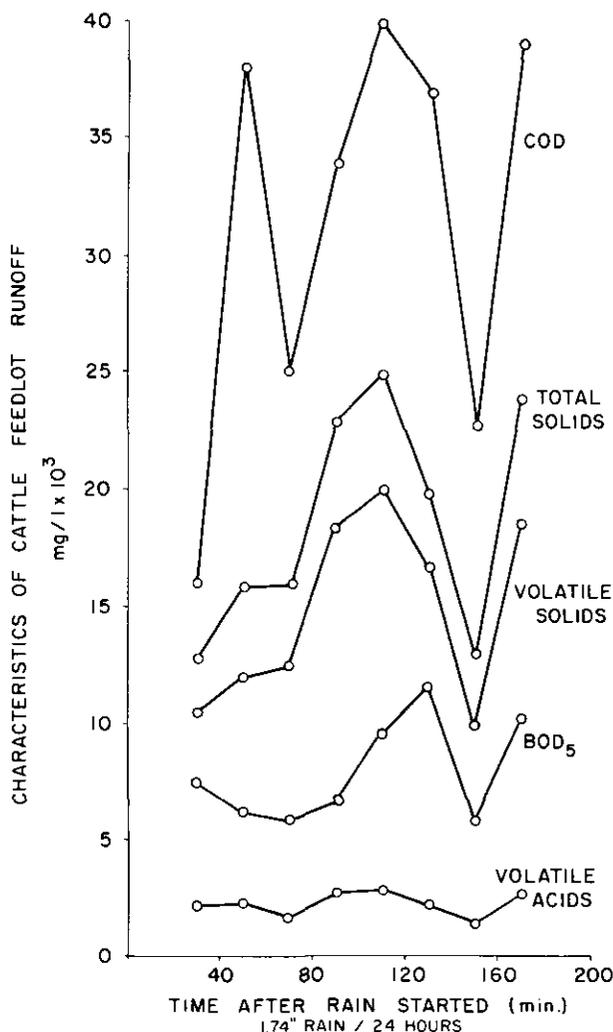


FIGURE 2. Characteristics of beef cattle feedlot runoff (6).

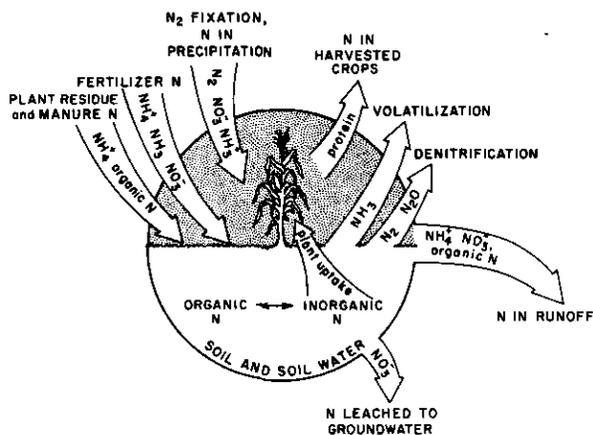


FIGURE 3. Schematic of the nitrogen cycle for agriculture (6).

concentrations that resulted from the feedlot runoff. The pH of the water has been found to be important in determining the concentrations of ammonia that are toxic. The phenomenon of the pH effect of ammonia toxicity appears ubiquitous. Ammonia at low pH levels is usually toxic only in large quantities, while at high pH levels, smaller amounts may be lethal.

The toxicity of ammonia depends upon the quantity of ammonia that enters the organism or plant cell. Cell membranes are relatively impermeable to ionized ammonia (NH_4^+), whereas un-ionized ammonia (NH_3) passes through cell membranes. Ammonia toxicity to fish is increased markedly at low dissolved oxygen concentrations.

Water quality standards generally restrict the total ammonia in receiving waters to a maximum of 2.0 mg/l. at pH 8.0 or greater. A higher concentration of ammonia will have increasingly adverse effects on fish and other aquatic life.

Nitrogen can affect humans and animals primarily by the concentrations of nitrite and nitrate nitrogen that are ingested. In the United States, a nitrate concentration of 45 mg/l. as NO_3 has been established as the maximum concentration that should be in potable waters. Maximum acceptable concentrations of nitrate reflect public health concerns and are based upon the judgement of public health officials. Acceptable concentrations vary among nations. High nitrate concentrations have caused methemoglobinemia in infants and have caused problems with animal health. In each area the problem is the same, difficulties in transport of oxygen in the blood. Nitrate-reducing bacteria in the intestinal tract of humans and animals reduce nitrate to nitrite. The nitrite can oxidize hemoglobin in the blood to methemoglobin, which is unable to transport oxygen. Although nitrite is the cause of

the problem, nitrites are rarely found in food and water. Water quality standards are placed on nitrate since it can be present in foods and water and is the precursor of nitrite. High nitrates in leafy foods such as spinach and forage crops also can be a cause of the problem. Once high nitrate concentrations exist in surface waters and ground waters, few practical processes exist for routine nitrate reduction or elimination. Generally the water supply is abandoned and other potable supplies are sought.

Overapplication of agricultural wastes, such as manure to crop land, can result in a decrease in crop production due to inhibitory amounts of ammonia or nitrite nitrogen or salts in the soil. The application of feedlot runoff and manure to permeable loams and clay loams also can reduce the permeability of these soils. This can have an adverse effect on crop growth since water movement and the aeration capability of the soil is reduced.

When feedlot manure was applied to grain sorghum, grain yield was depressed when the manure was applied at annual rates of 120 and 240 tons/acre (27 and 54 kg/m^2) for two years. Early growth depression was observed on plots receiving 30 and 60 tons/acre (6.7 and 13.4 kg/m^2). This depression was attributed to high ammonium and salt concentrations in the seed zone (11). For most conditions, it was suggested that an appropriate rate of beef cattle feedlot manure disposal or irrigated grain sorghum was 10 tons/acre (2.2 kg/m^2) every three years in the Texas high plains area.

In Kansas, maximum yields of irrigated corn silage occurred at beef cattle manure application rates of between 100 and 130 tons/acre (22 and 29 kg/m^2) (12). Larger applications depressed yields due to accumulations of soluble salts in the soil. Potentially toxic accumulations of ammonium ion were found in the surface twelve inches of the soil when larger application rates were used.

Disposal of excessive quantities of manure or poultry litter can result in animal health problems. Crops grown for silage using high rates of manure may contain enough nitrate to be a health problem for livestock. Heavy application of broiler litter to pastures in the southeast can result in beef cow health problems of grass tetany and/or nitrate toxicity (13). These problems are due to excess salts, excess nitrogen and a chemical imbalance. As a consequence, annual broiler litter disposal rates greater than 9 tons/acre (2 kg/m^2) are not recommended on fescue pasture (14).

Generally, however, toxic conditions resulting from agricultural solid wastes can be prevented by applying these wastes to land at rates at which the components are utilized in crop production. Such wastes should be considered as resources to be

utilized rather than as wastes for disposal. Desirable application rates generally are those in which nitrogen is the controlling parameter, i.e., rates consistent with utilization for the applied nitrogen by the crops or grasses. These application rates will avoid the environmental problems and hazards noted above.

Good practice guidelines have been developed by both agricultural organizations and governmental agencies (15-18). Minimum land areas are identified to assure that the fertilizer content of the applied wastes are utilized. Suggestions relating to application rates, spreading on snow or frozen ground, and type of crop frequently are included.

Salts

Certain agricultural wastes, such as those from the lye peeling of fruits and vegetables and where salt may be used for food processing and pickling, may contain high concentrations of sodium ions which can produce deleterious changes in soil structure. The application of high concentrations of animal urine to soils has the potential for similar problems. High concentrations of sodium cause dispersion of the soil particles, change of the effective pore size, and influence the permeability of the soil. The reduction in permeability decreases the value of irrigation and can decrease crop growth. High sodium concentrations can be toxic to plants; however, effects on permeability generally occur first.

Undiluted feedlot runoff can be a salinity hazard when used for irrigation. Total salts rather than sodium are the more serious salinity hazard. The salt tolerance of grasses and crops varies considerably; therefore the salinity hazard level in a specific location should be considered before irrigating with feedlot runoff. Any use of feedlot runoff for irrigation requires close watch on salts in the water and soil. Examples of salt hazards associated with animal wastes have been cited earlier (11-13).

The problem is greatest in areas with minimum precipitation to remove the accumulated and applied salts. Salt hazards can be minimized by avoiding over application of wastes containing high concentrations of salts and by following good practice guidelines developed for specific locations.

Bacteria

The list of infectious disease organisms common to man and livestock is lengthy and includes several that can be transmitted from animal excreta to man or from animal to animal. In the management of

animal and poultry waste, precautions should be taken against the introduction of viable pathogenic organisms into the environment. When drainage or runoff from animal production units reaches a watercourse, a potential chain for the spread of disease has been initiated. Salmonella organisms have been isolated from fecal specimens, runoff from animal confinement operations, carcasses of dead animals, and from waterholes from which animals drank. Two organisms, *S. dublin* and *S. typhimurium* were the salmonella organisms most commonly found in the cattle and contaminated water investigated. *S. dublin* is essentially a pathogen of cattle but can cause meningitis and septicemia in humans. Children are more susceptible than adults. *S. typhimurium* can infect practically all species of birds, animals, and man.

S. typhimurium has been found to survive in soils up to 110 to 160 days depending upon soil characteristics. Soils with a low pH (5.3-5.5) and of an inorganic nature had the greatest rate of salmonella die-off. *S. dublin* and strains of hemolytic *E. coli* have been isolated from dairy cattle manure slurries (19). Although none of these pathogenic bacteria appeared to multiply in the slurry, they survived for up to 12 weeks. Because manure slurries are applied to land, movement of pathogenic bacteria would occur primarily with soil particle movement.

Methods of handling manure to avoid odors and to stabilize the solids can increase the health hazards to animals and humans in confined animal production units due to the dispersion of pathogenic microorganisms into the confinement area. An analysis of liquid and drying systems for poultry wastes (20) indicated that numerous organisms including staphylococcus and salmonella could be isolated from the atmosphere of confined egg-laying houses. Particles having a mean diameter of less than 5 μm accounted for 70% to 78% of the total particulate matter content of the samples. Such particles can penetrate the human respiratory system and may be potentially hazardous for the health of workers exposed to such an environment for prolonged periods. There has, however, been no indication of any health problems to the birds, or to humans who have worked in the confinement buildings.

A possible stabilization system for animal wastes is the oxidation ditch which is a liquid, aerated biological treatment system. Studies with *Staphylococcus aureus* and *S. typhimurium* (20) have shown that the oxidation ditch liquid is a hostile environment for these organisms.

Investigations in Europe (21) also have documented that animal wastes can be a reservoir of pathogenic organisms. Studies in confined pig

production units in Romania have identified specific microbial pathogens in the pig manure. One hundred and six strains of salmonella belonging to 12 serotypes were isolated. Thirty-two strains of leptospira of the type *Leptospira pomona* and *Leptospira tarassovi* also were isolated. These results document that the raw and partially treated waste from animal confinements possess microorganisms which are pathogenic for man and animals. The findings are illustrative of results of other studies.

Epidemiological problems involved in large animal feedlots are closely associated with those of animal waste disposal. Incidence of latent infections increases when animals of homogeneous populations are concentrated in confinement. Figure 4 indicates the pathways by which pathogens in animal manures pass to other animal production units and to man.

Control of infected agricultural wastes is necessary as illustrated by the following cases (21). In Germany a severe salmonella outbreak in a dairy herd with 50 cows has occurred. The source of infection was meat-meal from a rendering plant. In England an outbreak of *S. typhimurium* occurred in cattle grazing on a pasture which had been irrigated with manure slurry three weeks earlier. *S. typhimurium* was isolated from the slurry system and from four carrier cows after the outbreak.

Another severe case of transmission of salmonella through slurry has been reported in Sweden. In a dairy farm more than 50 out of 96 cows became ill within three days during grazing. Twenty cows died within two days. Bacteriological examinations proved *Salmonella choleraesuis* to be the cause of the disease outbreak. The effluent of an infected pig farm had flowed into a pond which had connections with an open ditch system in the dairy

farm pastures. Heavy rain caused the contents of the pond to enter the ditches of the pastures to which the cows had access.

These and other examples indicate that animal manures have an epidemiological significance which should not be underestimated.

The land can assimilate considerable amounts of contaminants. Evidence indicates that the animal waste environment or the soil environment is not very hospitable to the survival of these pathogens. The disease potential inherent in the disposal of animal wastes on land is unknown but is considered not to be critical. Organism survival in soil is determined by the viability of organisms in the soil environment, their interaction with the soil, and the nature of their transport. Bacteria and viruses in soil have moved from inches to several hundred feet from the point of disposal on or in the land. Salmonella species have survived over 40 days in soils with high organic content. When adequate land is available for adequate application of manures, the transmission of pathogens has not been a major problem.

However, on a number of farms, especially in parts of Europe, the number of animals is excessive compared to the available agricultural acreage for land application. As a consequence, the potential for pathogenic bacteria transmission and contamination of surface and ground waters is increased. In some parts of Germany the number of animals confined per hectare is high as is the potential hazard for soil and water contamination and pathogen transmission. Legislation is in preparation which will allow only the "usual rate" of animals per hectare defined by the ratio of three "manure livestock units" (MLU) (21). One MLU is equivalent to a yearly excretion of 80 kg N and 70 kg P₂O₅. Because

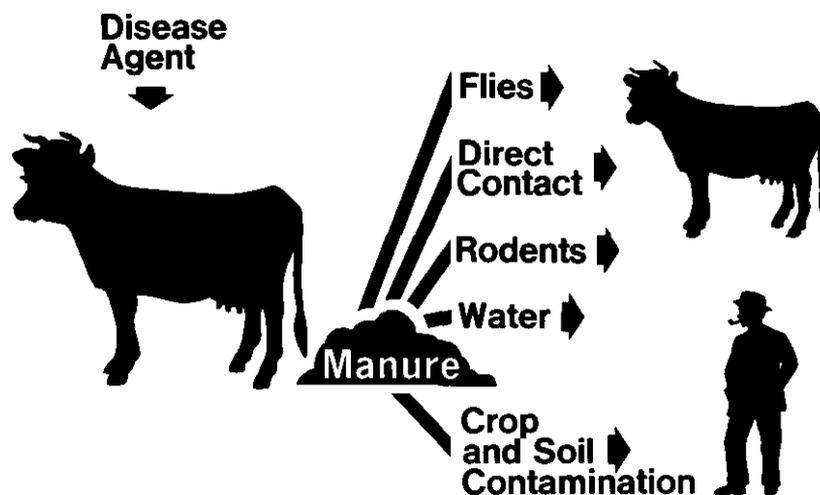


FIGURE 4. Pathways of animal pathogen transmission to animals and humans.

of the heavy manure load on the fields in some parts of the Netherlands, farmers ship their surplus manure to other parts of the country. The organizational basis of this transfer, so-called "manure banks," was established to act as a brokerage between farms with manure surplus and those which need organic fertilizers. In Holland in 1973-74, 75,000 tons (68 Gg) of manure slurry were transported with tank wagons, 75% over a distance between 8 to 20 km and 25% between 20 and 50 km. In 1975 the slurry transactions increased to 395,000 tons (360 Gg).

In northwest Germany, many farms have a manure surplus. These farms are not able to ship their slurry to other parts of the area since most of the communities already have an animal population of between 2 and 3 MLU/ha (2-3 MLU/hm²). Thus the chance to ship manure to other areas is very limited. If the number of animals to be kept per hectare is not limited by law in these areas, public and animal health hazards steadily will increase. Similar constraints could occur in the United States as animal confinement units increase in size and there is inadequate land for disposal of the manure.

Another potential problem related to the pathogens is the use of antibiotics in feeds. In the early 1950's, the feeds containing low levels of antibiotics were found to increase the growth of farm animals and were a major breakthrough for commercial animal feedlots. The widespread use of antibiotics for nontherapeutic purposes can result in the development of microorganisms which are resistant to antibiotics. Bacteria in solid and liquid wastes from farm animals have been screened for resistance to antibiotics commonly used as growth promoting feed supplements. In one study, 80% terramycin resistance was exhibited by solid waste isolates, with 30% terramycin and 100% sulfamethazine resistance shown by the liquid waste isolates (22). There has been concern that such resistant organisms may limit the usefulness of antibiotics in combating later infections in man and animals.

However, such antibiotic resistant bacteria generally are not able to compete with the normal intestinal flora in humans. Therefore, it is not likely that animals will be a major source of resistant bacteria for man. Only in the personnel of agriculture or slaughterhouses, who are professionally in close contact with the animals, may resistant strains of bacteria of animal origin be found.

Microelements

There is concern over the potential for accumulation of toxic elements in soils and plants as a result of organic solid waste applications. Examples of

both enhanced and damaged animal nutritional status have been documented which were traced to application of organic residues on agricultural land. Examples involving human health and nutrition are rare.

Many of the problems with potentially toxic materials result from the application of organic sewage and industrial sludges which contain a variety of metals and other elements. Such problems are less with agricultural solid wastes since such wastes are the result of processing uncontaminated agricultural products—crops, fruit, vegetables, animal feed. In addition, with agricultural waste collection and processing, there rarely is any concentration of potentially toxic elements such as can occur with municipal or industrial waste processing and treatment. The maximum concentration might be with animal waste. Animals usually digest about one-half of their diet, so the concentration of potentially toxic elements in the excreta on a dry weight basis is limited to about double the concentration in the diet itself.

Where the organic material is incorporated into the soil, potentially toxic elements must be taken up by plant roots and translocated to the edible part of the plant before they are hazardous to animals and humans. The toxicity of these elements to plants provides a major barrier against toxicity to consumers of the plants. This barrier is very selective with some elements being substantially more toxic to plants than to animals, while other toxic elements may be taken up and incorporated into edible parts of plants in concentrations that may be acutely or chronically toxic to the person or animal that eats the plant. Many of the common food and feed crops, if they show fairly normal growth and have not been contaminated, are sufficiently low in Pb, As, F, Zn, B, and Cr to represent no acute hazard from these elements when the crop is eaten by people or animals. Copper is more toxic to plants than to monogastric animals, but ruminants may be injured by Cu in certain plant species. On the other hand, plants of normal appearance and yield may contain concentrations of NO₃⁻, Mo, Se, and possibly Cd and other elements that are damaging in human and animal diets. Plant toxicity is therefore an important but imperfect barrier to movement of potentially toxic materials from organic residues to human and animal diets.

The remainder of this section briefly will discuss some of the microelements that are in agricultural wastes and that can have adverse effects on plants, animals, and humans. This discussion draws heavily upon the information summarized by Allaway (23). The primary element of concern is Cu, since it can be added to animal diets. Comment also will be

made concerning As, since it can appear in pesticide residues and in animal diets. Other elements are in low concentrations and unlikely to cause toxicity problems when the organic agricultural residues are applied to land at reasonable rates.

Arsenic or arsanilic acid is recommended as a feed additive for swine to promote increased weight gain and feed efficiency and to aid in the prevention of infectious and parasitic diseases. Tissue retention of As is related to the level that is fed. Withdrawal of arsanilic acid from the ration of the animal a few days before slaughter greatly reduces the amount of As in the meat of the animal. Organic arsenicals also are used in poultry feeds and are the principal source of As in poultry wastes. Concentrations of 15 to 30 ppm As have been reported in poultry house litter. Where poultry litter of this type had been applied to soils for as much as 20 years, no increase in the As concentration in alfalfa and clover was detected.

Evidence points to plant toxicity as the first effect of accumulation of As in soils. Crop failure or diminished yields usually precede the production of crops that have hazardous levels of As in the edible portion. Soil tests for predicting the phytotoxicity hazard of As residues have been developed. Use of these tests to monitor As accumulations and prevent development of phytotoxic levels offers substantial protection against food chain damage from As in organic residues.

Arsenic in soils is dissipated by the normal processes of leaching and reduction to arsine. The proper use of As compounds does not appear to increase the normal daily intake of As as part of plant proteins.

Most of the concern over Cu in agricultural wastes results from possible use of high levels of (>200 ppm) in hog rations for growth stimulation or antibiotic effects. Approximately one-third of the pigs in the United Kingdom are fed high levels of copper. There appears to be little danger of Cu toxicity in animals as a result of using manure from Cu-supplemented pigs on crop land, unless the slurry is topdressed on growing grass. Incorporation of Cu-supplemented pig manure into the soil did not consistently increase the Cu concentration in forage grasses.

Monogastric animals including man are not highly susceptible to Cu toxicity, and the primary ill effect of diets containing high concentrations of Cu generally is a correctable interference with absorption of Zn or Fe. Phytotoxicity of Cu will ordinarily inhibit plant growth before potentially toxic Cu concentrations are found in plants. Ruminants, especially sheep, are more susceptible to Cu toxicity and may be affected adversely by dietary Cu concentrations

found in plants growing on Cu polluted areas.

Several management approaches can be used if microelements are in potentially hazardous amounts in agricultural wastes. Organic residue application procedures that involve incorporation into the soil will permit fixation of potentially toxic elements by the soil solids thereby reducing transmission to the crop. Application of animal manure to forage crop fields and as topdressing to permanent pasture has been used for many years without serious problems. Food chain hazards associated with microelements in agricultural solid wastes are not likely to occur. However, wastes with excessively high microelement concentrations can be diverted to use with ornamental plants, fiber crops, forests, or for other uses that do not involve a potential hazard to the food chain.

Feed Additives

Many feed additives that are approved by the Food and Drug Administration to maintain animal health and to increase animal weight gain or production of animal products such as eggs and milk. These additives have not been shown hazardous to the animals, and it has been assumed that they will not be hazardous to individuals working with the animals and their wastes. There is little information to substantiate or refute the latter assumption. The literature contains no evidence that penicillin in food-producing animals has caused adverse effects due to recycling or land application of waste from such medicated animals. Penicillin is extremely labile and readily inactivated under environmental conditions. Another common antibiotic, oxytetracycline, is rapidly decomposed by soil microflora and therefore is not expected to cause hazardous situations. Plants do not absorb from the soil measurable quantities of antibiotics fed to animals.

Estrogenic hormones have been used to increase the rate of weight gain of cattle and for other purposes such as estrus synchronization. It is possible for hormones such as diethylstilbestrol (DES) to accumulate in animal body tissue. Such compounds are generally withheld from the animal feed for a prescribed period before slaughter to lessen the possibility of elevated levels in the meat.

Estrogens have been detected in the urine and feces of animals. Hormones excreted by animals are of interest since they can be recycled through plants and back to man or animals. Both natural and administered synthetic hormones are excreted by animals. Generally the greater the amount of hormone that is administered, the greater the proportion excreted in the urine and feces.

The average dairy cow excretes approximately 30

mg estrogens/day in urine and feces. This amounts to an estrogen concentration of about 5 mg/kg of waste material on a dry weight basis. A steer fed 10 mg of DES will excrete about 75% of the dose in an active form.

Experiments to date have indicated that uptake of synthetic estrogens from soil by plants is insufficient to be harmful to animals or humans consuming the plants. Greater care needs to be taken when animal wastes are used as feed supplements since the natural degradation process in the soil and the protection provided by the barrier of plant roots does not exist in such cases. Specific processing steps may be required to avoid transmission of active hormones.

Although the medicinal drug residue problem does not appear to be hazardous, more detailed studies are needed in this area.

Utilization

Traditionally, wastes have been regarded as inevitable by-products and the usual aim of waste management has been minimum treatment and disposal. In only a few cases has residue utilization been practiced as a waste management policy. However, the concerns of adequate food and of environmental pollution have emphasized the inadequacies of a minimum treatment and disposal approach and have resulted in an examination of alternatives. The idea of the "finite earth" is becoming accepted, and increasing attention is being paid to the development of policies and practices that will minimize the problems of pollution and the wasting of natural resources.

Agricultural solid wastes are widely recognized as a potential source of nutrients for direct or indirect use in production of animals. The traditional method of increasing livestock production by supplementing forage and pasture with grains and protein concentrates may not meet increasing world meat protein needs. Use of the grain and protein for human food will compete with such use for animal feed. Increased use can be made of various processed and unprocessed wastes, as animal feed. Many organic wastes, such as paunch manure, fish meal, oil seed meal, whey, and vegetable processing residues, can be used directly for animal feeds. In addition, other direct and indirect approaches exist to use agricultural residues for animal feed such as refeeding of processed and unprocessed animal wastes.

When nutritional principles are followed, a portion of animal wastes can be used as a feed supple-

ment for animals. Certain unknowns related to transmittal of drugs, feed additives, and pesticides to the second animal and to the agricultural product, such as eggs and milk, remain to be clarified. Some of the specific nonnutritive feed additives that may pose potential problems in recycling animal wastes as feed include: pellet binders, flavoring agents, enzymes, hormones, tranquilizing drugs, antibiotics, arsenicals, antifungals, coccidiostats, and antioxidants.

Information about the reuse of animal wastes as an animal feed supplement, including problems associated with antibiotics, arsenicals, hormones, larvacides, and other feed additives, has been gathered in a succinct review (24). The review discusses the opportunities of refeeding animal wastes to poultry, swine, and cattle. Few problems related to the transmission of hazardous chemicals, biologicals, and pathogens to animals and humans have been reported. This is due to the fact that animal wastes generally are processed to inactivate the hazardous materials before refeeding and to the fact that only small amounts of animal waste are currently used as feed supplements.

The use of poultry and animal wastes as feeds or feed ingredients is not sanctioned by the U. S. Food and Drug Administration, since these feeds are considered adulterated under Section 402 of the Federal Food, Drug, and Cosmetic Act. Several states have approved the use of dried poultry waste (DPW) for livestock feed. As of 1976, these states were California, Colorado, Georgia, Iowa, Mississippi, and Oregon. Such approval is only for intrastate sale and use and strict production regulations have been developed. As a minimum, the resultant product will not be permitted to contain levels of pathogenic organisms, toxic metabolites, pesticides, drugs, or other substances shown to be of concern in the recipient animal or in the product consumer.

The emphasis on resource recovery and residue utilization will increase the potential use of agricultural solid wastes as animal feeds and hence increase the risk of transmission of potentially hazardous materials to animals and humans. Caution and vigilance is needed to assure that hazardous conditions do not result. The Robert S. Kerr Environmental Research Laboratory, Environmental Protection Agency, currently is evaluating the environmental hazards associated with the reuse of animal wastes and the application of animal wastes to land. (Information may be obtained from Mr. Lynn Shuyler, Animal Production Section, Robert S. Kerr Environmental Research Laboratory, U. S. Environmental Protection Agency, Ada, Oklahoma.)

Risk Assessment

The problems associated with the disposal of agricultural solid wastes have increased due to greater specialization of agricultural production and greater quantities of animals, fruits, vegetables, crops, and forests being grown and/or harvested. Recent legislation has narrowed the acceptable waste management alternatives and raised the consciousness concerning the possibilities of pollutants and toxic material in the environment. At the present time, the major agricultural solid waste management option is the application of the wastes to land and the beneficial utilization of their nutrient, water, and soil conditioning characteristics.

It is clear that there are components of these wastes that are or may be hazardous to living matter. There is a seductive temptation to generate and to assign maximum allowable concentration values for each of the components that are perceived to be potentially hazardous to some element of the population. Management decisions are then made on the basis of whether any particular option would or would not cause the maximum allowable concentration to be exceeded. The implied ease of enforcement is, however, illusory. There is no sharp division between safe and unsafe that is appropriate for all contexts. Moreover, perceptions of such distinctions are by necessity clouded by the uncertainties of limited knowledge and perceptual bias. It may be more appropriate to assess management decisions on the basis of measures of probability, i.e., the probability that certain adverse effects will follow specific management decisions.

In developing controls of hazardous compounds in wastes, it is desirable to develop an evaluation approach that will: allow the identification and characterization of waste generation, disposal and management as a stochastic system; identify the probabilistic nature of various aspects of the system; and express system output in terms of probabilities that certain well defined events will occur. By expressing system output in this manner, decision makers may design management and control options with an explicit consideration of associated risk. Suggested proposals and decisions may then be evaluated by use of well defined value judgments on acceptable loss, or requisite safety, to society.

All decision makers must operate under certain constraints. Almost all significant decisions are made in the absence of complete information. It is this fact that puts so great a burden on the decision maker, especially in protecting the public from hazardous material. Society, however, also limits the amount of time and money available to the deci-

sion maker in accumulating data and coming to a decision. Decisions will continue to be made with less than complete information. Thus decisions should more logically be made on the basis of probabilistic analyses.

For any hazardous waste decision making, the management decision system should consist of at least six component subsystems: waste generation, waste management, environmental transport and dispersal, dose-response data, risk determination, and a risk evaluation subsystem. The first three subsystems may be associated with identifiable physical systems and/or engineering works. The fourth and fifth subsystems consist primarily of analytic/management information systems. The last is a sociotechnical valuation system that defies simple characterization.

The information available to determine probabilities for these subsystems for hazardous agricultural solid wastes components varies but generally is meager. Few studies have obtained the necessary data, especially for the transport and dispersal, the dose response, and the risk determination subsystems. However, to make better decisions and devise equitable control procedures, such information is necessary and will have to be acquired.

Summary

Agricultural solid wastes have been and generally continue to be considered as something to be disposed of rather than resources to be considered for possible use. With notable exceptions, the usual approach for agricultural waste management has been discharge to the environment with or without treatment. The need is to consider wastes as potential resources rather than undesirable and unwanted, to avoid contamination of our air, water, and land resources, and to avoid transmission of hazardous materials. This will require better use of technology and incentives, a change in philosophy and attitudes, and better approaches to assess risks.

There are components of agricultural solid wastes that can be hazardous to living matter, and there are examples where such hazards have occurred. However, to date the hazards have not been extensive nor of continuing national significance. Where such hazardous conditions do exist, such as fish kills or nitrogen contamination of water, or where they may exist, such as through feed additives, bacteria, or land application, existing federal and state regulations and existing technologies appear adequate for their abatement and control. No new legislation appears necessary.

Americans generally have a crisis mentality. We

respond to crises, such as missile, environmental, oil or food crises, with enthusiasm and resources, and we expect reasonably immediate results and solutions. Such enthusiasm and resources rarely are for preventive or anticipatory studies such as are needed in this area. At the present time there is no "crisis" associated with hazardous materials in agricultural solid wastes. However, this does not mean that no attention should be paid to this problem or that no resources should be utilized for research on this topic. Epidemiologic information is weak, there are disease reservoirs in animals, there are many unknowns in the area of transport and dispersal, dose response, risk determination and risk evaluation, and much of the available information is based upon controlled laboratory, rather than "real world," studies.

Manpower and financial support should be provided to obtain more detailed information on this topic, especially in the above areas. Such anticipatory investigations are needed to better understand the risks that are involved and to avoid future "crises" that may develop. Without such information we are essentially like the ostrich and can only hope that severe problems will not result.

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