Bacterial and Viral Pathogens Associated with Land Application of Organic Wastes[1]

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ABSTRACT

Bacterial and viral pathogens may be present in animal, and especially municipal, wastes. This requires that caution be exercised when using these materials for crop production. These wastes should not be applied to root crops during the current growing season, or to above-ground crops 1 month before harvest. Animals should not be allowed to graze areas for 2 to 3 weeks after waste application. Waste should be applied on the basis of crop fertility requirements based on optimum nutrient utilization, thereby minimizing pathogen-loading rates. Disease outbreaks have occurred when crops grown on soils receiving raw sewage were eaten raw, or when an area was grazed shortly after waste application. No incidence of disease has been reported from land application of treated wastes. Thus, treatment of municipal waste before application is important. A zero-tolerance for pathogens in wastes land-applied for crop growth would seem unnecessary when proper management is used.

Additional Index Words: waste loading rates, crop growth, pathogen hazard, virulence, aerosols, waste utilization.

The practice of using organic wastes for crop nutrients is not new. Centuries ago, the Romans recognized that crop growth was improved when manure was added to the soil. During the era of inexpensive fertilizers and energy, it was more convenient to regard municipal and animal wastes as disposal problems rather than resources. Now, where suitable crop-producing areas are available, wastes are considered valuable resources. Unfortunately, utilization of municipal and animal wastes is not without problems, e.g., whether the application of municipal and animal wastes to cropland presents unique pathogen hazards, and whether the soils become disease vectors.

Historically, utilization of animal wastes for crop production has been an accepted practice, and people are not normally disturbed by animals feeding and defecating in the same area (Menzies, 1977). However, in municipal wastes human pathogens are more concentrated, and there are social and aesthetic pressures against using these wastes for crop production. In this discussion, we will attempt to assess the potential bacterial and viral health hazards associated with utilization of animal and municipal wastes for crop production, and to describe management techniques for prevention of health hazards. Here the term *pathogen* is used to describe bacteria and viruses capable of causing human or animal infection.

Much more is known about bacterial pathogen survival in soil than about viruses, primarily because virus detection and study methods are not as precise and are more difficult and expensive to perform. Bacterial and viral pathogens and indicator organisms generally associated with wastes, and the survival of some of these organisms, has been reviewed by Bitton (1975), Gerba et al. (1975), Burge (1974), Cornforth (1974), Bernarde (1973), Miller (1973), Foster and Engelbrecht (1973), and Sepp (1971). Generally, bacterial pathogens will survive in soil or water from a few days to 5 or 6 months, with some reports indicating survival as long as 5 years. However, 2 to 3 months is apparently sufficient to decrease numbers to a negligible level; much depends on temperature, inoculum level, timing, application rate, and soil conditions. Data on soil survival of viruses are limited. Enteroviruses can survive up to 170 days, while f_2 survives over 175 days (Gerba et al., 1975); it is likely 170 days is the maximum under most conditions. The spectrum of human pathogens is neither as broad nor as numerous in animal wastes as it is in human wastes.

Often pathogens can be isolated from fields receiving waste applications, and it is easy to assume a health hazard will exist. As Bernarde (1973) stated: "One must be chary of the type of microbiological thinking that equates the mere presence of microbes with illness or the potential for illness. The fact is that illness is an unusually complex phenomenon that does not have a 1:1 relationship to microbes."

Effects of Waste Treatment on the Removal and Survival of Bacterial Pathogens

Before soil application, most organic wastes are treated, or animal wastes are stored for a time. Treatment or storage alters the environment for indigenous organisms and causes population shifts. By their nature, most pathogens are poor competitors outside the host and, if they do not die, multiplication is unlikely. However, pathogens can be isolated from wastes that have undergone rather severe treatment, like activated sludge, trickling filter oxidation, or chlorination, and the end products could pose health problems (Dunlop, 1968; Miller, 1973; Popp, 1973). However, aerobic compost maintained at 60 to 70C for 3 days seems to eliminate pathogens (Wiley and Westerbey, 1969).

The effect of treatment on some representative bacterial pathogens in sewage is shown in Table 1. Chlorina-

Table 1—Estimated waste water pathogens applied to soil

Pathogen	Number of organisms per 3,636,363 liters (million gallons)†				
	Raw waste water	Primary effluent	Secondary effluent	Disinfection‡	Organism applied per ha per day §
Salmonella	2×10^{10}	1×10^{10}	5.0×10^{8}	5.0×10^{5}	9.75×10^{3}
Mycobacterium	2×10^{8}	1×10^{8}	1.5×10^{7}	1.5×10^{4}	3.0×10^{2}
Virus	4×10^{10}	2×10^{10}	2.0×10^{9}	2.0×10^{6}	4.0×10^{4}

† Source: Foster and Engelbrecht, 1973.
‡ Conditions sufficient to yield a 99.9% kill.
§ Applied at a rate of 5.1 cm/week (2 inches/week).

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tion of secondary effluent significantly lowers pathogenic bacteria numbers; however, the viruses are more resistant to chlorination. Therefore, while chlorination reduces numbers, significant numbers remain.

Pathogen survival has been followed in livestock manure treatment facilities, but not extensively, likely because few problems have occurred. Will et al. (1973) found *Salmonella* survived in model oxidation ditches for 17 to 47 days, and in sludge for 87 days. Diesch (1971) found *Leptospira* could survive up to 18 days in a model oxidation ditch, and 11 days in effluent and sludge. However, *L. icterohaemorrhagiae* survived only 24 hours at 26C in fecal emulsion; the determining factor seemed to be overgrowth by competing organisms. Rankin and Taylor (1969) reported salmonella survived in cattle manure slurry for 12 weeks. When stabilization ponds were operated in series with detention ponds, *S. typhi* numbers decreased 99.5% in 20 days. *Escherichia coli* was decreased 99.98% during the same period but, in heavily polluted water, *S. typhi* was more resistant to die-off than *E. coli* (Rankin and Taylor, 1969). These results stress that indicator organisms are not always reliable for determining the presence or absence of a pathogen. This is true for municipal wastes, also.

Effects of Waste Treatment on Virus Survival

Although virus numbers are reduced by waste treatment, generally they are more resistant to treatment than indicator bacteria (Table 1). Viruses vary greatly in sensitivity to chlorination. Kabler et al. (1963) reported that 3 to 100 times more Cl is required to kill most viruses than to kill *S. typhosa* or *Shigella disenteriae*. Wellings et al. (1974) found that chlorinated and unchlorinated effluent from activated sludge contained 6,089 and 18,106 PFU (plaque-forming units/100 liters, respectively. This is only a threefold reduction—less than the reduction shown in Table 1. The difference can be explained by organic matter load, pH, contact time, temperature, and Cl level. With coxsackie virus serotype B, a 0.5 ppm residual Cl contact for 8 hours is considered adequate for inactivation (Bush and Isherwood, 1966). Grab samples of primary effluent and secondary-chlorinated sewage effluent contained enterovirus but, after sewage percolated through 61 cm of soil, no virus was detected (McMichael and McKee, 1965). Soil can be a very effective filter, although, as Duboise et al. (1974) pointed out, virus breakthrough can occur in soil. Bitton (1975) concluded that research on adsorbents for virus removal is needed: soil clays are very effective. Christie (1967) found that the poliovirus titer in field lagoons was decreased from 10^5 to approximately 10^3/ml. Bush and Isherwood (1966) stated that virus in municipal wastes could be controlled by filtering sludge through sand, but this may not be a fool-proof method.

Even though most viruses are resistant to treatment, Clarke and Kabler (1964) reported that the only documented cases of waterborne viral outbreaks have been from viral hepatitis. Viruses must be given important consideration with waste utilization when > 100 identifiable viruses can be isolated from human feces (Bernarde, 1973).

Factors Affecting Bacterial Survival in Soil

There is much variability in pathogen soil survival, which likely reflects the organism's ability to survive for nonparasitic periods. Obligate parasites, like some *Neisseria*, live only a few minutes outside the host, while sporeformers such as *Bacillus antracis* live in the soil for years. Fortunately, enteric pathogens generally do not survive long outside the host (Sepp, 1971). It is difficult to objectively discuss pathogen survival in soil because investigators commonly used inoculated systems which did not duplicate natural processes; inoculum levels were often high and accompanied by protective substances from the culture medium. However, Gerba et al. (1975) stated that it appears 2 to 3 months in the soil is sufficient to reduce most bacterial pathogens to negligible numbers.

Several factors influence organism survival in soil and waste material: treatment, moisture, sunlight, pH, temperature, antibiotics, toxic substances, competitive organisms, nutrients, and organic matter, of which moisture is the most important (Gerba et al., 1975). The effects of some of these factors are easier to measure than others. Generally, drying decreases pathogen numbers, and sunlight is strongly bactericidal. Alkaline pH, within limits, is more favorable for pathogen survival, and organic matter will normally protect the organisms. Low temperatures also promote survival of these organisms (Gerba et al., 1975). This subject was reviewed in detail by authors mentioned earlier.

Factors Affecting Virus Survival in Soil

Presently little information exists on factors influencing virus persistence in soil. Much research is needed here. In comparison with the factors which influence bacterial survival, one can readily eliminate nutrient availability, microbial antagonism, and antibiotics. Gerba et al. (1975) reviewed the literature and found kaolinite clay and cations can prolong virus survival in sea water and in sand saturated with distilled water. Also, virus survival in soils seems primarily dependent on the nature of the soil, moisture, pH, and temperature. Gratzek (1967) stated that, in general, viruses do not survive long outside the host. But Wellings et al. (1974) demonstrated viruses can survive aeration and sunlight, and later showed that virus survived 13 days in caked sludge exposed to Florida sunlight (1976).

Virus retention by soils was studied by Drewry and Eliassen (1968). Virus adsorption by soil was affected greatly by the soil-water system pH, with adsorption being more rapid at lower pH. However, virus adsorption to soil particles does not mean virus inactivation. Bagdasar'yan (1964) reported that enteroviruses adsorbed on loamy and sandy loam soils were considerably stable, even when temperature was changed. Survival of the virus in sterile and nonsterile soil was almost the same. Schaub et al. (1974) showed that viruses adsorbed to clay were just as infectious as free viruses. Virus particles adsorbed to sand also are capable of infecting tissue cultures (Lefler and Kott, 1974). Thus, conceivably, virus adsorption to soil may prolong survival, but soil adsorption generally effectively removed the virus from host contact. Depending

on conditions, viruses have been shown to survive 25 to 170 days in soil (Bagdasar'yan, 1964). Soil adsorption of viruses will be considered more completely under field application.

Aerosols

Aerosol production has been one concern with waste treatment and waste disposal by sprinkler irrigation. Sorber and Guter (1975) felt the probability of inhaling aerosols containing pathogens near spray irrigation sites was significant, especially if the aerosol contains *Mycobacterium tuberculosis*. Sorber et al. (1974) concluded that to minimize virus aerosol risk, virus should be removed or destroyed before spraying. When Merz (1957) studied an irrigation sprinkler with a 9.1-m spray radius by using a bacterial indicator, he found that a 8.3- to 16.6-kmh wind extended the mist zone 32 m downwind. Others[3] (Randall and Ledbetter, 1966; Adams and Spendlove, 1970; Napolitano and Rowe, 1966) reported that sewage trickling filters, aeration tanks, and laboratory-created sprays left no aerial bacterial buildup seconds after spray cessation.

Exposure of workers who handle wastes is possibly the best indicator of potential aerosol danger. Burge (1974) stated: "It has been estimated that a man working within 1.5 m of the downwind edge of an aeration tank would inhale a viable bacterial pathogen every two breaths. Yet there are no special programs in the United States to immunize workers exposed to such hazards." Bernarde (1973) cites examples showing that waste workers do not experience unusual health problems.

Aerosols containing pathogenic viruses and bacteria are exposed to environmental factors. When a microbe encounters a situation where the cell is unable to function normally, the cell usually dies. However, Foster and Engelbrecht (1973) concluded that airborne viruses can have relatively long virability. It was demonstrated that polio virus aerosols persisted for > 34 hours at a high relative humidity (RH). Some viruses are not significantly inactivated at any RH, and others are very sensitive to RH changes. The primary factor in virus stability to inactivation at different RH is the lipid composition. Lipid-containing viruses are less sensitive to low RH than lipid-free viruses (DeJong et al., 1973). DeJong et al. (1973) listed five possibilities for inactivation of virus in aerosols: oxidation, surface inactivation, dehydration, crystallization processes, and reaction with highly concentrated media components. In more recent work, DeJong et al. (1976) found *Semiliki* forest virus was rapidly inactivated at 40 and above 70% RH. They felt that at RH below 20% dessication was the probable inactivation mechanism, while at higher RH inactivation was due to damage of the virus coat.

In general, the effect of aerosols is minimal when effluents are dispersed by sprinkler irrigation on days with low wind velocity, warm, bright sunlight, and a RH between 40 and 60%. Irrigation equipment spraying the largest droplet size that is practicable is desired to decrease aerosol dispersion.

Field Application of Wastes

Stern (1974) concluded that, although there is no evidence that land-spreading of digested or otherwise stabilized sludge has caused disease to man or animals, it cannot be overlooked that remaining pathogens may contribute to the disease. Conversely, Walker (1975) stated that ". . .although pathogens are present in sewage sludges, the threat to human health seems low." Processed sludges can be applied to soil with much less concern than unprocessed sludges, and most pathogens in sludge-amended soils will perish or be in insignificant number in 2 to 3 months.

In actual field studies, Dunlop et al. (1951) and Dunlop and Wang (1961) recovered salmonella from a significant portion of irrigation water samples contaminated with raw sewage and primary-treated and chlorinated effluents. However, Dunlop and Wang (1961) isolated salmonella from only 1 of 97 samples of vegetables irrigated with this water. Dunlop et al. (1951) were unable to recover salmonella from vegetables furrow-irrigated with the water, but postulated that root crops could be contaminated.

Rudolfs et al. (1951a), who applied sewage effluent and fecal suspensions to fruit and leaves, concluded that if irrigation or night soil application is terminated 1 month before harvest, it was unlikely that the fruit would transmit human bacterial enteric disease. Rudolfs et al. (1951b) concluded that vegetables eaten raw can be grown without health hazard in soils receiving sewage applications the year before. They said that salmonella and *Shigella* will not survive on vegetable surfaces > 1 week; Sorber and Guter (1975) agreed with their findings.

Falk (1949) applied *S. cerro* to growing tomatoes and was unable to isolate the organism 7 days after application. He stated: "Tomatoes grown on soils receiving night soil or sewage sludge would yield fruit which, if eaten raw, would not be likely vectors for the transmission of human bacterial enteric diseases." Müller (1957) applied settled sewage to carrots, cabbages, potatoes, and gooseberry bushes, and detected salmonella in the soil and on living potato tubers after 40 days, on carrots after 10 days, and in cabbage leaves and gooseberries after 5 days. Sepp (1971), in a review of microbial health hazards from the use of wastes for crop nutrients, concluded that the consumption of raw vegetables irrigated with sewage has caused outbreaks of typhoid and worm infections. As early as 1936, Diehl recommended that, for current use on garden crops, sewage should be sterilized or filtered.

Hales (1974) pointed out that the handling of dried sludges is no more dangerous than the work carried out daily by slaughtermen and poultry packers, but the potential danger is more obvious. Wierzbicki (1952) described a sewage land-irrigated system in Lower Silesia that has been operating since 1906. Various vegetables were grown but not irrigated during the growing season. Workers employed in the fields for over 30 years did not have an illness or disease outbreak that could be attributed to the agricultural utilization of these wastes. After Wells

[3]C. R. Albrecht. 1958. Bacterial air pollution associated with the sewage treatment process. M.S. Thesis. Univ. of Florida, Gainesville.

(1961) reviewed the literature on health hazards in sewage irrigation, he felt the use of sewage for growing crops was not hazardous.

The hazards to animals that are grazing areas on which sewage has been applied may not be as great as many fear. For 6 months Crawford and Frank (1940) fed raw sewage, treatment plant effluent, and sludge to pigs and cattle without apparent harm. Foster and Engelbrecht (1973) cited an example where grass was sprayed with 4.3×10^7 tubercule bacilli/m^2 (4×10^6/$feet^2$), and fed to guinea pigs with no apparent effects, but at heavier inoculations they died. In contrast, Maddock (1933) sprayed grass with $12{,}912 \times 10^2$ *Bacterium tuberculosis* organisms/m^2 (120×10^3/$feet^2$) and, after 14 days, the grass could still infect guinea pigs. When he applied 10^6 organisms/g of soil, he recovered *B. tuberculosis* 6 months later. While virulent mycobacteria have been found on grasses receiving municipal effluent or sludge, it is generally accepted that animals can safely graze such areas 2 weeks after application. Predicted values for tubercule bacilli in unchlorinated effluent are about six orders of magnitude below the levels which had no effect on guinea pigs. A source of *mycobacterium* is sewage from sanitariums; it would seem reasonable that sewage from these sources should receive special treatment before entering the system.

Several cases of animal sickness have occurred when fresh sewage was applied to pastures, or when sewage accidentally overflowed onto pastures. When human sewage overflowed onto an area where milk cows were grazing, 30 out of 90 cows became infected with *S. aberdeen* (Bicknell, 1972). Kenner et al. (1971) measured the persistence of salmonella in grassy areas treated with three different sludges from Nov. to June; salmonella was detected for 56 to 112 days after application. Hales (1974) stated that some degree of danger of salmonella infection in livestock can be expected if animals are grazed on pastures to which liquid digestor sludge is freshly applied without a 1- to 3-week waiting period. He cited the case of a farmer who used digested sludge for 5 years on pasture and cropland, and has not yet encountered a case of salmonellosis in his dairy herd. A known disease outbreak has never occurred from the application of anaerobically digested sludge to the land. When 2 or 3 weeks restriction before grazing is practiced after municipal waste application, animal disease problems have not been evident.

Several recent studies have been conducted on the fate of viruses when effluent or other virus-containing solutions are applied to soil. Drewry and Eliassen (1968) applied T_1, T_2, and f_2 bacteriophages to nine different soils in columns. They found all the soils tested removed significant quantities of virus, but removal was generally dependent on pH, cation concentration, cation exchange capacity, clay content and organic matter content. Bitton et al. (1976) found pH 6.5 sandy soil columns retained T_2 and poliovirus type 1, but virus adsorption decreased substantially when the percolating solution was secondary effluent. Lance et al. (1976) found most of poliovirus type 1 remained in the top 5 cm of 250-cm calcareous sand columns percolated with spiked secondary effluent. However, five of forty-three 100-ml effluent samples contained the virus; most desorption was prevented by adding $CaCl_2$. They found a 99.99% or more reduction of virus could be expected with the columns. Gerba et al. (1975) summarized their laboratory viral studies. They said soils vary in their ability to adsorb viruses, with sand being least effective. However, viruses can pass through soil columns and will differ in ability to pass through. They concluded that intermittent loading of soils with effluent may be more effective for virus removal. From their studies, Duboise et al. (1974) suggested that, for land application, the intermittent use of large irrigation systems over large areas of land would be advantageous for maximum soil absorption of virus.

Gerba et al. (1975) cited an example where poliovirus type 1 survived at least 32 days in soil irrigated with effluent. They also pointed out a study in the Soviet Union which showed enterovirus could be isolated from a field irrigated with municipal effluent. They indicated they felt viruses do not normally move far in the soil.

In Florida, Wellings et al. (1974) sprinkled 5 to 28 cm/week of waste water effluent on a sandy soil. After very heavy rains, they found poliovirus in 305- and 610-cm-deep wells. They said the soil/water ratio is very important in maintaining virus adsorption to soil particles. Obviously, when more water passes through, the risk of passing virus is greater. After about 8 years operation, in 1974, renovated waste water at Flushing Meadows was assayed for virus every 2 months (Gilbert et al., 1976a, 1976b). No viruses or *Salmonella* sp. were detected in the renovated waste water; fecal coliforms, fecal streptococci, and total bacteria were reduced about 99.9% after passage through 9 m of soil. The loading rate was extremely heavy—about 6.9 m of municipal effluent every other 14-day period. The secondary sewage effluent averaged 2,118 PFU/100 liters, including poliovirus type 3, poliovirus type 2, echovirus type 7, echovirus type 15, coxsackie virus B_4, Reovirus types 1 and 2, and undetermined Reovirus types. They felt human viral pathogens do not move through soil to ground water, and are apparently adsorbed and degraded by soil. Bitton (1975) reviewed the literature and indicated virus movement through a continuous stratum of common soil should present no great hazard to underground water supplies.

There are some contradictions in the literature, but virus movement through the soil must be a function of virus- and water-loading rate. If crop production is the goal, virus-loading rates will be low. For example, Gilbert et al. (1976a) found an average of 2,118 PFU/100 liters secondary sewage effluent, while Wellings et al. (1974) found 6,089 PFU/100 liters chlorinated effluent, 18,106 PFU/100 liters unchlorinated effluent, and 7,455 PFU/100 liters raw sewage, which would amount to 538, 1,546, 4,599, and 1,894 PFU/m^2 per 2.54 cm applied, respectively. At application rates to meet crop needs, virus-loading rates would not seem overwhelming. Obviously, where soils are underlain by fractures or fissures potentially leading to ground water supplies, other methods of disposal are recommended. Also, waste application areas must be located to prevent surface runoff into surface waters.

The critical consideration is waste-loading rate. Whenever possible, application rates should be adjusted to crop

requirements for maximum resource utilization and pathogen dilution. Higher rates only increase runoff possibilities, the size of the area requiring intensive management, and chemical pollution problems. Where high application rates are necessary, alternate disposal schemes should be used. The management schemes devised at the Flushing Meadows project, for example, would seem a viable alternative.

Virulence

Figure 1 depicts the factors necessary for land application of wastes to present a pathogen hazard. First, pathogens must be present in the waste, which is the case. However, the pathogens must be virulent and present in sufficient numbers to cause infection. Many pathogens lose virulence when the organism is removed from the host. Thus, even though the organism is detected, if it is not virulent the organism's presence is academic. However, few studies assessing pathogens in wastes, on plants, and in soil have measured virulence of recovered pathogens. Before tissue-culture methods were developed for detection of virus, animal inoculations were commonly used. Tissue culture studies do not always indicate viral virulence, and even established virulence is not sufficient evidence of a hazard. The organism must be virulent and present in sufficient numbers to cause disease, and the host must be susceptible to the disease.

If the organisms in waste are virulent and present in infective numbers, more questions should be answered. Does the organism retain virulence in the soil at infective numbers? If not, a problem does not exist. Mallman and Litsky (1951) established that *S. typhosa* retained its virulence in soil under their experimental conditions. They inoculated several soils with *S. typhosa*, and found it persisted for 12 to 50 days and retained the Vi antigen (antigen denoting pathogenicity). Viruses adsorbed to clay and sand also have maintained virulence for 25 to 170 days (Bagdasar'yan, 1964; Schaub et al., 1974; Lefler and Kott, 1974). Even though initially virulent, the organism must remain virulent and survive in the soil in infective numbers. The soil is a hostile environment for most pathogens and causes pressure on the organism to maintain infective numbers. If the organism can retain virulence and survive in infective numbers, historical evidence of disease outbreaks must be available. The only evidence of disease outbreaks has been when raw wastes have been placed on crops eaten raw too soon after waste application, or when the area has been grazed shortly after raw waste application. No incidence of disease has been reported from application of secondary activated, anaerobically digested, or chemically treated sewage plant effluents (Burge, 1974; Menzies, 1977). Using Table 1, one can calculate that < 1 salmonella organism would be applied per m^2 of ground per day at the irrigation rates used.

Using the perspective outlined, one can see why disease outbreaks have not occurred. When pathogens are isolated in the waste, or from a waste application, hazards are presumed. As shown, this is not a reasonable assumption. We do not intend to unjustifiably deemphasize the fact that pathogen hazards exist with improperly utilized wastes, but with proper utilization pathogens are not a problem.

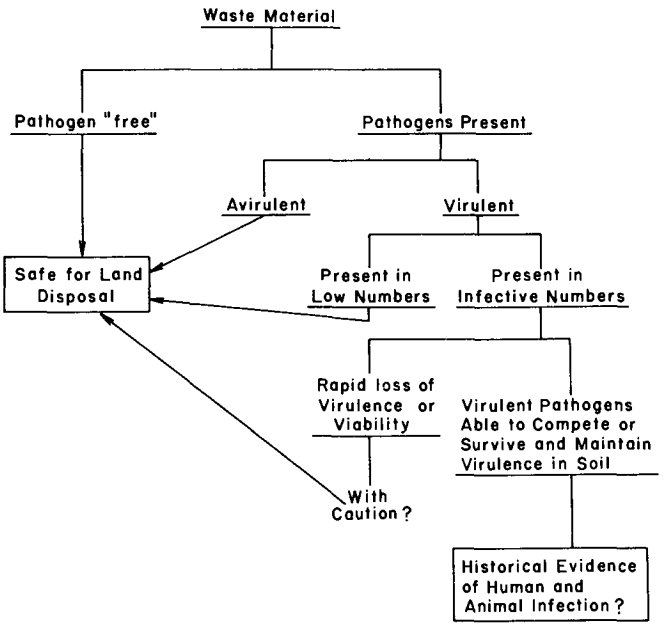

Fig. 1—Factors necessary for land application of wastes to present a pathogen hazard.

Conclusions

Pathogens are present in fresh wastes, treated wastes, soil, water, and aerosols. However, disease outbreaks have only occurred when crops grown on soils that have received raw sewage were eaten raw, or when cattle have grazed an area shortly after raw waste application. No incidence of disease has been reported from the application of treated wastes (Menzies, 1977). Waste treatment and soil application generally decrease pathogen survival and virulence. A zero-tolerance requirement has been mentioned for some pathogens in wastes applied to soil, but this would be unrealistic because pathogens have been isolated from pristine areas.

The problem of waste disposal on the land must be evaluated by historical evidence, which indicates that animal and properly treated municipal wastes can be utilized at rates required for optimum crop growth with a minimum of pathogen hazard. However, these wastes should not be applied to root crops during the current growing season, or to above-ground crops 1 month prior to harvest. Animals should not be allowed to graze these areas for 2 to 3 weeks after application. Waste should be applied on the basis of crop fertility requirements and/or water needs, whichever is less. This will keep pathogen-loading rates minimal. If economics dictate higher loading rates, sanitary landfills or alternate methods are more desirable because less area will have to be managed. Runoff from waste application areas should be prevented.

In conclusion, Menzies (1977) stated that the "return to the land of organic wastes generated by living organisms is part of the natural cycle. In 'uncivilized' nature, the soil decomposes these residues for recycling and decontaminates them of any disease organisms that they

may contain. One does not need to be a dedicated organic farmer to recognize the fundamental importance of both these functions. No system of waste management that either avoids or abuses this cycle can be considered permanent." Bernarde (1973) said: "From a communicable disease standpoint, land disposal is far less hazardous than disposal in rivers and streams."

LITERATURE CITED

1. Adams, P., and J. C. Spendlove. 1970. Coliforms emitted by sewage treatment plants. Science 169:1218-1220.
2. Bagdasar'yan, G. A. 1964. Survival of viruses of the enterovirus group (poliomyelitis, ECHO, Coxsackie) in soil and on vegetables. J. Hyg. Epidemiol. Microbiol. Immunol. 7:497-505.
3. Bernarde, M. A. 1973. Land disposal and sewage effluent: Appraisal of health effects of pathogenic organisms. J. Am. Water Works Assoc. 65:432-440.
4. Bicknell, S. R. 1972. *Salmonella aberdeen* in cattle associated with human sewage. J. Hyg. 70(1):121-126.
5. Bitton, Gabriel. 1975. Adsorption of viruses onto surfaces in soil and water. Water Res. 9:473-484.
6. Bitton, G., N. Masterson, and G. E. Gifford. 1976. Effect of a secondary treated effluent on the movement of viruses through a cypress dome soil. J. Environ. Qual. 5:370-375.
7. Burge, W. D. 1974. Pathogen considerations. p. 37-50. *In* Factors involved in land application of agricultural and municipal wastes. USDA-ARS, Nat. Prog. Staff, Soil, Water, and Air Sci., Beltsville, Md.
8. Bush, Albert F., and John D. Isherwood. 1966. Virus removal in sewage treatment. J. Sanit. Eng. Div., Am. Soc. Civ. Eng. 92:99-107.
9. Christie, A. E. 1967. Virus reduction in oxidation lagoon. J. Water Pollut. Control Fed. 105(5):45.
10. Clarke, N. A., and P. W. Kabler. 1964. Human enteric viruses in sewage. Health Lab. Sci. 1:44-50.
11. Cornforth, I. S. 1974. Hazards associated with spreading animal waste slurries on land in Great Britain. p. 253-264. *In* J. Tomlinson (ed.) Proc. Int. Conf. Land for Waste Manage., Oct. 1973. Agric. Instit. Can. Pub., Ottawa.
12. Crawford, A. B., and A. H. Frank. 1940. Effect on animal health of feeding sewage. Civil Eng. 10:495-496.
13. DeJong, J. C., T. Trouwborst, and K. C. Winkler. 1973. Mechanisms of inactivation of viruses and macromolecules in air. p. 124-130. *In* J. F. P. Hers and K. C. Winkler (ed.) Airborne transmissions and airborne infection. John H. Wiley and Sons, Inc., New York.
14. DeJong, J. C., M. Harmsen, A. D. Plantinga, and T. Trouwborst. 1976. Inactivation of Semiliki forest viruses in aerosols. Appl. Environ. Microbiol. 32:315-319.
15. Diehl, P. A. 1936. Treatment required for sewage reused for irrigation purposes. Sewage Works J. 8:502-503.
16. Diesch, S. L. 1971. Survival of leptospires in cattle manure. Am. Vet. Med. Assoc. J. 159(11):1513-1517.
17. Drewry, W. A., and R. Eliassen. 1968. Virus movement in groundwater. J. Water Pollut. Control Fed. 40:R257-R271.
18. Duboise, S. M., B. P. Sagik, B. E. D. Moore, and J. F. Malina, Jr. 1974. Virus migration through soils. p. 233-240. *In* J. F. Malina and B. P. Sagik (ed.) Virus survival in water and waste water systems. Vol. 7. Center for Res. in Water Resour., Austin, Tex.
19. Dunlop, S. G. 1968. Survival of pathogens and related disease hazards. p. 107-122. *In* C. W. Wilson and F. E. Beckett (ed.) Municipal sewage effluent for irrigation. Louisiana Tech. Alumni Found. Tech. Stn., Ruston, La.
20. Dunlop, S. G., R. M. Twedt, and W. L. Wang. 1951. *Salmonella* in irrigation water. Sewage Ind. Wastes 23:118-122.
21. Dunlop, S. G., and W. L. Wang. 1961. Studies on the use of sewage effluent for irrigation of truck crops. J. Milk Food Technol. 24:44-47.
22. Falk, L. L. 1949. Bacterial contamination of tomatoes grown in polluted soil. Am. J. Public Health 39:1338-1342.
23. Foster, D. H., and R. S. Engelbrecht. 1973. Microbial hazards in disposing of waste water on soil. p. 247-270. *In* W. E. Sopper and L. T. Kardos (ed.) Recycling treated municipal wastewater and sludge through forests and cropland. Pennsylvania State University Press, University Park, Pa.
24. Gerba, C. P., C. Wallis, and J. L. Melnick. 1975. Fate of wastewater bacteria and viruses in soil. J. Irrig. and Drainage Div., Am. Soc. Civ. Eng. IR3:157-174.
25. Gilbert, R. G., C. P. Gerba, R. C. Rice, H. Bouwer, C. Wallis, and J. L. Melnick. 1976a. Virus and bacterial removal from wastewater by land treatment. Appl. Environ. Microbiol. 32: 333-338.
26. Gilbert, R. G., R. C. Rice, H. Bouwer, C. P. Gerba, C. Wallis, and J. L. Melnick. 1976b. Wastewater renovation and reuse: Virus removal by soil filtration. Science 192:1004-1005.
27. Gratzek, J. B. 1967. General aspects of viral diseases. p. 582-588. *In* I. A. Merchant and R. A. Packer (ed.) Veterinary bacteriology and virology. 5th ed. Iowa State University Press, Ames.
28. Hales, D. 1974. Salmonellae in dried sewage sludge. J. Assoc. Health Inspections (Great Britain) 82(11):213-215.
29. Kabler, P. W., S. L. Chang, N. A. Clarke, and H. F. Clark. 1963. Pathogenic bacteria and viruses in water supplies. p. 72-78. *In* Quality aspects of water distribution systems. Proc. 5th Sanit. Eng. Conf. Univ. of Illinois Eng. Exp. Stn. Circ. 81.
30. Kenner, B. A., G. K. Dotson, and J. E. Smith. 1971. Simultaneous quantification of *Samonella* species and *Pseudomonas aeruginosa*. II. Persistance of pathogens in sludge-treated soils. Rep. Water Qual. Off., EPA Nat. Environ. Res. Center, Cincinnati, Ohio.
31. Lance, J. C., C. P. Gerba, and J. L. Melnick. 1976. Virus movement through soil columns flooded with secondary sewage effluent. Appl. Environ. Microbiol. 32:520-526.
32. Lefler, E., and J. Kott. 1974. Virus retention and survival in sand. p. 84-91. *In* J. F. Malina and B. P. Sagik (ed.) Virus survival in water and waste water systems. Center for Res. in Water Resour., Austin, Tex.
33. McMichael, F. C., and J. E. McKee. 1965. Final report of research on wastewater reclamation at Whittier Narrows. State of Calif. Water Qual. Control Bd. Pub. 33.
34. Maddock, E. C. G. 1933. Studies on the survival time of the bovine tubercle bacillus in soil, soil and dung, in dung, and on grass, with experiments on the preliminary treatment of infected organic matter and the cultivation of the organism. J. Hyg. 33:103-117.
35. Mallmann, W. L., and W. Litsky. 1951. Survival of selected enteric organisms in various types of soil. Am. J. Public Health 41:38-44.
36. Menzies, James D. 1977. Pathogen considerations for land application of human and domestic animal wastes. p. 573-586. *In* L. F. Elliott and F. J. Stevenson (ed.) Soils for management of organic wastes and waste waters. Am. Soc. of Agron., Madison, Wis.
37. Merz, R. C. 1957. Third report on the study of waste water reclamation and utilization. California State Water Pollut. Control Bd. Pub. 18. Sacramento, Calif. 120 p.
38. Miller, R. H. 1973. The soil as a biological filter. p. 71-94. *In* W. E. Sopper and L. T. Kardos (ed.) Recycling treated municipal waste water and sludge through forests and cropland. Pennsylvania State University Press, University Park, Pa.
39. Müller, Gertrud. 1957. Die infection von gemusepflanzen durch die beregnung mit haeuslichem abwasser (Infection of vegetables by application of domestic sewage as artificial rain). Staedth (Hamburg) 8:30-32.
40. Napolitano, P. J., and D. R. Rowe. 1966. Microbial content of air near sewage treatment plants. Water Sewage Works 113: 480-483.
41. Popp, L. 1973. Uber die elimination von Salmonellen durch biologische Abwasser-behandlung. Abt. Bakt, Hyg. I. Abt. Orig. B 157:184-195.
42. Randall, C. W., and J. O. Ledbetter. 1966. Bacterial air pollution from activated sludge units. Am. Ind. Hyg. Assoc. J. 27: 506.
43. Rankin, J. D., and R. J. Taylor. 1969. A study of some disease hazards which could be associated with the system of applying cattle slurry to pasture. Vet. Rec. 85:578-581.
44. Rudolfs, W., L. L. Falk, and R. A. Ragotzkie. 1951a. Contamination of vegetables grown in polluted soil. I. Bacterial contamination. Sewage Ind. Wastes 23(3):253-268.
45. Rudolfs, W., L. L. Falk, and R. A. Ragotzkie. 1951b. Con-

tamination of vegetables grown in polluted soil. VI. Application of results. Sewage Ind. Wastes 23:992-1000.

46. Schuab, S. A., C. A. Sorber, and G. W. Taylor. 1974. The association of enteric viruses with natural turbidity in aquatic environments. p. 71-83. *In* J. F. Malina and B. P. Sagik (ed.) Virus survival in water and waste water systems. Center for Res. in Water Resour., Austin, Tex.
47. Sepp, E. 1971. The use of sewage for irrigation: A literature review. Bur. Sanit. Eng., California State Dep. Public Health, Berkeley.
48. Sorber, C. A., and K. J. Guter. 1975. Health and hygiene aspects of spray irrigation. Am. J. Public Health 65(1):47-52.
49. Sorber, C. A., S. A. Schaub, and H. T. Bausum. 1974. An assessment of a potential virus hazard associated with spray irrigation of domestic waste waters. p. 241-252. *In* J. F. Malina and B. P. Sagik (ed.) Virus survival in water and waste water systems. vol. 7. Center for Resour. in Water Resour., Austin, Tex.
50. Stern, G. 1974. Pasteurization of liquid digested sludge. p. 163-169. *In* Proc. Munic. Sludge Manage., Pittsburgh, Pa.
51. Walker, J.M. 1975. Sewage sludges: Management aspects for land application. Compost Sci. J. Waste Recycling 16:12-21.
52. Wellings, F.M., A. L. Lewis, and C. W. Mountain. 1974. Virus survival following waste water spray irrigation on sandy soils. *In* J. F. Malina and B. P. Sagik (ed.) Virus survival in water and waste water systems. Center for Res. in Water Resour., Austin, Tex.
53. Wellings, F. M., A. L. Lewis, and C. W. Mountain. 1976. Demonstration of solids-associated virus in waste water and sludge. Appl. Environ. Micro. 31:354-358.
54. Wells, W. N. 1961. Irrigation as a sewage refuse application. Public Works 92:116-118.
55. Wierzbicki, J. 1952. Sewage disposal by land irrigation. Gaz. Wada. Tech. Sanit. (Warsaw) 25:34. *In* Sewage Ind. Wastes 24:1554 (Abstr.).
56. Wiley, B. B., and S. C. Westerbey. 1969. Survival of human pathogens in composted sewage. Appl. Microbiol. 18:994-1001.
57. Will, L. A., S. L. Diesch, and B. S. Pomeroy. 1973. Survival of *Samonella typhimurium* in animal manure disposal in a model oxidation ditch. J. Am. Public Health Assoc. 63:322-326.