REPORT NO. 118

EVALUATION OF SOIL SYSTEMS FOR LAND DISPOSAL OF INDUSTRIAL AND MUNICIPAL EFFLUENTS

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B. L. CARLILE and J. A. PHILLIPS

Department of Soil Science
Agricultural Experiment Station
School of Agriculture and Life Sciences
North Carolina State University
Raleigh, North Carolina 27607

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The University of North Carolina
Water Resources Research Institute
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ABSTRACT

The suitability of soils of North Carolina for application of industrial and municipal wastes was studied. In the Coastal Plain soil resource area, soil drainage is the most critical physical parameter in determining suitability of field sites for waste applications.. Well-drained soils of the region can be successfully utilized as waste application sites if certain design criteria are followed. Soils classified as moderately well drained can be used for waste application fields if either adequate storage of wastewater is provided to allow resting of the field during extended rainy periods or the soil is modified to act as a well drained site. Soils classified as very poorly, poorly, or somewhat poorly drained cannot satisfactorily function as waste fields without artificial improvement in drainage.

Of the seven field sites investigated, five were located in the Coastal Plain soil resource area and two in the Piedmont soil resource area. Design loadings which can be utilized at these sites varied considerably, including hydraulic loadings of one inch per week on the Piedmont sites and up to four inches per week on the rapidly drained sands of the Coastal Plain. Organic loadings which could be successfully utilized on each site ranged from about 1100 lb/a/wk to about 4000 lb/a/wk of total oxygen demanding material, again with the lower rates required on the Piedmont soils.

Of the sites investigated, salt problems were responsible for more operational problems than any other design parameter. Wastewater containing up to 500 mg/l of sodium ions can be successfully applied on most field sites if either proper balances of Ca + Mg are maintained in the water or by application of soil amendments to the field. Total salt loads of up to 3000 mg/l can be applied to fescue pastures without restricting plant growth.

If the above parameters as well as nutrient and heavy metal loadings are balanced to site capabilities and if sound management practices of the soil-crop, irrigation, and other operational functions followed, land application of wastewater can be a technically and economically sound system for treating waste loads at many industrial and municipal sites in North Carolina.

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SUMMARY AND CONCLUSIONS

The objectives of this study were to evaluate the feasibility of land application as a viable waste treatment alternative for industrial and municipal wastes and to conduct field investigations at sites utilizing this method of waste treatment to enhance predictions of soil-waste interactions under varying loading parameters.

Field investigations were conducted at seven major industrial sites in North Carolina and South Carolina, all using land application as the primary waste disposal system. The effluent was characterized as to significant waste components and flow regimes; the field sites were characterized by soil properties and topography; climatic information, including rainfall, ET and temperature, was developed for each site; and total design and operational loadings for significant parameters were evaluated.

Several design parameters must be considered in the successful operation of a land application system including:

a) Soil suitability (useable soils available within the field area)
b) Hydraulic loading
c) Organic loading
d) Nutrient loading
e) Salt loading
f) Heavy metal loading
g) Vegetative cover

One or more of these parameters can be limiting and each site will have specific loading capacities for each component depending on soil capabilities, topographic position, crops selected and the management levels employed. A minimum investigation required for site planning include a detailed soil survey of the area, location and depth of localized restrictive horizons in the soil, depth to seasonal groundwater, location of needed interceptor drains, including suitable outlets, and suitable sites for storage lagoons.

Of the physical-chemical parameters listed above, salt loading problems, particularly Na imbalances of the applied wastewater, have resulted in the most severe problems of the land application systems surveyed. Combined overloadings, both hydraulic and organic, have resulted in some systems experiencing temporary problems within spray fields, but are much easier and quicker to remedy than with salt overloadings. Nutrient and heavy metal loadings are not presently creating major problems in land application systems but must be considered in design criteria to prevent future environmental problems.

Based on information from this survey and basic knowledge of soil capabilities of the state, the following range in design loadings can be utilized on most well-drained soils of the state:

Component	Design range
Soil	Well-drained or modified to react as a well-drained soil
Hydraulic loading	1 - 4 inches/wk (depending on soil)
Organic loading	1100 - 4000 lb TOD/a/wk (depending on soil)
Nutrient loading	1.5 times crop requirement of N
Salt loading	1200 - 3000 mg/l (depending on crop)
	< 500 mg/l Na (with use of suitable chemical amendments)
Heavy metal loading	Soil and sludge specific
Vegetative cover	Management specific

Soils of lower drainage capabilities may be used for waste applications if either the natural drainage is improved by artificial drainage or sufficient storage capacity is provided to eliminate the necessity of irrigation during wet periods of the year. Soils classified as moderately well drained could be used if storage facilities of six to eight weeks are provided for the wastewater whereas soils classified as very poorly, poorly or somewhat poorly drained cannot satisfactorily function as waste fields without artificial improvement in drainage. Depending on the permeability of the subsurface soil horizons, some of the poorer drained soils can be substantially improved by artificial drainage whereas others cannot function as waste fields due to restricted internal drainage.

Poor management of land application systems appears to be responsible for reduced performance on more sites than any other factors, including design loadings. Total management of a system to include soil and crop management, waste application system operation, monitoring equipment maintenance and other mechanical equipment maintenance associated with the farm or waste treatment operation must have high priority and responsible personnel in charge to ensure successful operation.

If design loadings are balanced to site capabilities and sound management practices followed, land application of wastewaters can be an environmentally safe and economically sound system for treating waste loads from industrial and municipal sites in North Carolina and surrounding states.

RECOMMENDATIONS

The results of the study indicated that land application systems for muncipal and industrial wastewater treatment are feasible on certain soil in North Carolina and surrounding states. The following recommendations can be made as a result of information and procedures developed during the course of this project:

1. Develop guidelines for evaluating field sites for potential use in land application systems. Based on loading parameters and procedures developed in this report, guidelines should be written that are suitable for use by regulatory agencies, consulting engineers and others directly involved in implementation of waste treatment alternatives, including land application.

2. Develop inventories of soil capability areas of the state in terms of regions most suitable for land application sites. This information should be readily available to planners, industrial consultants and engineering firms.

3 Inventory major industrial and municipal waste sources of the state to include significant waste characteristics and flow volumes and evaluate the potential of land application of these wastes as an alternative to other waste treatment systems and potential benefits to agricultural production.

4. Continue research in the area of soil-waste interactions including unsaturated hydraulic conductivities, oxygen diffusion rates, salt interactions and heavy metal adsorption of major soils of the state to further refine soil loading parameters.

5. Conduct workshops, short courses, on-site study tours and specific industrial training for personnel directly involved in the design, review, management or research of operational programs of land application.

INTRODUCTION

The Federal Water Pollution Control Amendments of 1972 states that "the discharge of pollutants into navigable waters be eliminated by 1985." Effluent limitation guidelines have been established for many point source discharges as to the degree of effluent reduction attainable through the application of "the best practicable technology" and "the best available technology economically achievable" over the life of the works. For certification and cost-shared funding under this legislation, waste treatment plans must include evidence that all viable alternatives are considered and evaluated toward advancing the goal of "zero discharge."

Land application is recognized as an alternative method for effective treatment of wastewater and for ultimate disposal of solid wastes in the prevention of surface water pollution. While the idealized goal of "zero discharge" is neither practical nor completely desirable, successfullly operated land application systems may approach this concept in terms of eliminating point source discharges from our rivers and allowing contaminants to be treated and diffused slowly into natural waters without creating shock loads. As an "economic achievable system" land treatment is capable of providing high-level treatment at a relatively lower cost than other advanced or tertiary treatment systems (Young and Carlson, 1975).

The more accurate description of land application of wastewaters is that of an advanced treatment system and not a "zero discharge" system since all land areas periodically contribute water and its inclusions to the ground or surface water. Application of wastes to land does not automatically ensure that there will be no movement of waste constituents or products into the environment in the form of run-off, percolation, or gaseous discharges. The design of land application systems to ensure environmental protection is a precise scientific and engineering operation involving an evaluation and giving due consideration to many factors including soil biophysical parameters, engineering design, environmental controls, social and economic parameters, and political-legal constraints.

Numerous cases of both trouble-free and unsatisfactory systems for land application of wastes have been reported in North Carolina as in adjacent states. This study was initiated to increase our knowledge concerning biophysical parameters of land application of wastes and to determine those factors most critical in the successful operation of such systems. This information is needed to provide a better basis for consideration of land application as a viable alternative to other approaches in waste management in North Carolina and in the southeast.

Emphasis in this document is directed towards utilization of agricultural processing, industrial, and municipal wastes through application on agricultural land. While animal wastes systems were not included in this study, criteria for soil-waste loadings would apply equally to all wastes types.

REVIEW OF LITERATURE

Industrial and Processing Wastes

Industries which have utilized land as a waste disposal system include pulp and paper, meat slaughtering and packing, cotton processing, canning, dairy products, sugar refining, frozen fruits and vegetables, poultry processing, artificial fibers, and hides, leather and wool scouring. Waste treatment and disposal problems are a main concern with all of these industries; the problems generally are characterized by large volumes of wastewater with high BOD, large amounts of suspended solids and various inorganic constituents including nitrogen and phosphorus (Knapp, 1970).

In 1973, Sullivan et al. (1973) conducted an on-site survey of 20 different industries which were using land application of wastewater and reported that land application could be a viable alternative for many industries and that land application may use less total energy than other alternative treatment systems. Of the 20 industries surveyed, all had design flow rates of less than 5 mgd and could be generally categorized into: 1) vegetable processing, 2) dairy processing, 3) pulp and paper, and 4) organic chemical manufacturing. Also included were a tannery and a fiberboard plant. The study revealed that the small industries surveyed generally found land application more economical and that they have located generally in low population densities where open lands are available within a short distance and at a relatively low cost.

Thomas and Law (1968) report that many industrial sites utilizing pretreatment and stream discharge of wastes have exceeded the assimilative capacity of many streams and pose a serious threat to our water supplies. They report that by encouraging more application of these wastewater to agricultural land, multi-benefits would result including: 1) promote growth of crops, 2) conserve water and nutrients normally wasted, 3) provide economical treatment of the wastewater, and 4) reduce the pollution load on surface water supplies..

Processing and industrial wastewater may contain a variety of components, some of which may be phytotoxic or create severe problems in terms of soil physical and chemical properties. Wilcox (1959) summarized the effects of a variety of industrial pollutants and recommended pretreatment systems for a variety of effluents to be used for irrigation. He concluded that industrial wastewaters which are high in naturally occurring organic constituents, such as pulp and paper processing and food processing, generally are best suited for land application.

Spray irrigation of cannery and food processing wastes has been practiced in this country for a number of years (Bell, 1955; Bolton, 1947; Canham, 1955). Canham, 1955, in a review of early methods, grouped soil-waste systems as those using a) absorption beds, b) ridge and furrow, and c) spray irrigation. He cites cases where wastes were pumped three miles to the spray sites, and sprayed on slopes as high as 7-8 percent. Rest periods of 5 to 7 days between irrigation were recommended for most systems.

Spray irrigation was the most common method of application of wastewaters to land in systems studied by Sullivan et al., 1973. However, other types of application systems were being used including flood irrigation, ridge and furrow irrigation, and overland flow. Water application rates varied from 0.75 to greater than 10 inches per week, but a more common hydraulic loading was about two inches per week. Crops grown on these waste application sites included pasture grasses such as fescue and reed canarygrass, row crops such as corn and soybeans, and natural vegetation.

Drake and Kieri, 1952, surveyed several vegetable canneries in Minnesota and reported that there are several economic and physical limitations to the use of spray irrigation of wastewater on agricultural crops. Problems which were reported were 1) roots of plants may rot if the soil is watered too often, 2) organic matter from the wastewater may accumulate on plants and provide harborage for fungi and other harmful organisms, 3) plant diseases may be spread from processed products to crops being irrigated, and 4) soil structure may deteriorate under prolonged irrigation of a particular field.

Forest areas have been used more recently for waste application sites. Norris et al., 1972, reported that effluents from a pulp bleaching plant may be disposed of by irrigation on forrested lands without detrimental effects on microorganisms in the three forest soils studied. Wilson, 1971, reported that stream water quality during low flow periods in the summer could be protected better by irrigating forest areas of both hardwoods and softwoods with paper mill effluent in lieu of stream discharge.

A more recent development in land treatment of wastewater is the overland flow or spray-runoff system. This system operates best on sloping terrain of 2-6 percent grade and terraced to separate short slope runs from 100 to 300 feet long. The wastewater is applied along the upper reaches of each slope segment and flows in a thin sheet over the surface toward the collecting terrace at the bottom. This system does require considerable land forming to ensure uniform slopes between terraces and to prevent water from concentrating in rills rather than in sheet flow. This system does allow use of soils such as those with heavy clays and eroded surfaces for waste application. The system can be successful in treating a variety of wastewater and returning a substantial portion of the purified wastewater to a receiving stream (Gilde, 1970).

Municipal Wastes

The application of high levels of municipal wastes to soil creates considerable concern among the public as well as regulatory agencies involved in the protection of the public health and the total environment. These concerns relate to the possible contamination of soil, groundwater, surface water or the atmosphere with pathogenic organisms, toxic organic substances, soluble salts, trace metals, and plant nutrient elements.

The current knowledge of the health implications of sewage disposal has recently been summarized in extensive literature reviews (Hanks, 1967; Law,

1968). In a review concerned with the agricultural uses of sewage effluent and sludge, Law (1968) concluded:

a. Raw, untreated sewage should not be used on cropland.
b. If handled properly, the use of treated sewage effluent will pose no hazards to the operators or farm laborers.
c. Sewage effluent receiving primary treatment may be used on crops not for human consumption.
d. The use of primary treated sewage effluent on feed and pasture crop for livestock consumption is safe and should be encouraged.
e. Treated sewage effluent may be used on any crop if it is first chlorinated.

Law further concludes that it is not advisable to apply digested sludge directly on root crops or any vegetable crop that is to be eaten raw, although, incorporation of the sludge into the soil well ahead (at least three months) of planting time does allow destruction of these pathogenic organisms.

The recent interest in disposing of sewage sludges in soil has been largely centered around the disposal of anaerobically digested sludge (Ewing and Dick, 1970). Merz, 1959, states that the maximum recommended rate of slude application depends on the various soil, plant, and climatic factors but that generally 100 tons of dry solid digested sludge can be applied without impairing crop growth and that 25 tons of dry solids is comparable to normal fertilizer rates on agricultural crops.

King and Morris, 1972, applied liquid sewage sludge to coastal bermudagrass and rye at rates up to 20 cm depth per year (48 tons dry solids/acre) in a comparison with conventional fertilizer treatment. From the aspect of both pollution control and crop production, 5 cm/yr was the best of the four rates used. At the higher rates, large amounts of NO_3-N accumulated in the soil profile and reduced rye yields, apparently from Zn toxicity. The sludge applications had little effect on in-vivo digestibility of the forage and there was no significant survival of coliform bacteria on the forage at harvest.

In studies by Walker et al., 1972, digested sewage sludge was incorporated into clay soils at rates up to 120 tons dry solids per acre. Ultimate growth of rye was best at the 40 tons-per-acre rate; no nitrogen, bacterial, or viral contamination of groundwater occurred during the first season. The investigators state that heavy metal build-up may ultimately determine how much sludge can be applied to soil for maximum benefit and minimum hazard to man and plants.

The magnitude of soil and water pollution by organic substances as a result of the application of sewage to fields, has received relatively little study. Butler et al., 1954, reviewed several aspects of the underground movement of chemical pollutants. These workers noted reports of leaching from organic waste deposits traveling several miles in the soil. They conclude that many of the decomposition products from complex organic materials

such as sewage sludge are simple, water soluble compounds which are likely to be mobile in the soil environments.

The majority of research thus far conducted on treated sewage and waste sludge as possible fertilizing materials in the United States had dealt with only applications covering a short span of time. Research dealing with trace elements in soils has been aimed at the beneficial use of the trace elements as plant nutrients. Perhaps because of the relatively short experience of farm utilization, no clear evidence of toxicities and yield reduction to crops have been reported in the literature. Braids et al., 1968, however, did report sludge treated soils to have higher concentrations of heavy metals with some increased concentration in plants and leachates.

Long-term application of sewage to farm land has been experienced in Europe. Rohde, 1962, attributes the reduced fertility at the Berlin and Paris sewage farms to accumulation of copper and zinc. At Rickmansworth, England approximately 7000 acres of farmland is treated yearly with liquid digester sludge and early research work established the now-accepted guidelines of "zinc equivalents" as long-term loading criteria for sludge applications (Sullivan et al., 1973). This work, which appears to be the only well-documented report of heavy-metal toxicity to plants induced by long-term application of sewage to agricultural land, established that nickel is four times and copper two times more toxic to plant life than zinc. Horn, 1968, suggests that estimates of relatively short-term (less than 50 years) effects of sludge on soil properties can be based on existing knowledge of soil composition and the chemical, biochemical, and physical systems operative in natural soils.

Lunin et al., 1968, suggested a program for acceptable limits of trace elements in irrigation wastewater based on two types of soil groupings that may be irrigated: a) well-drained soils, primarily sands, loamy sands, or sandy loams; and b) slowly drained soils, primarily those with fine textures. The limits for individual trace elements in water to be used on each type of land was calculated assuming that steady state would be approached in a relatively short period of time on group "a" lands; therefore, the concentrations in irrigation waters approximate that of soil solution. Upper limits on group "b" lands were more arbitrary and were developed for conditions where fixation was greater and steady state would not be approached until time periods exceeding 20 years.

While most of the long-term studies on municipal waste applications to land have occurred in European countries, the use of irrigation to treat and dispose of secondary effluent from municipalities has been practiced at some location in the United States for at least forty years (Gray, 1968). While most of these systems have been located in the Southwest where water is a premium (Pound and Crites, 1973), Malhotra and Myers, 1974, reported that more than forty municipal land irrigation systems were in operation in the state of Michigan. This is in an area where the effluent must be stored for 20 to 25 weeks/year due to weather conditions preventing field applications.

Pennsylvania State University has been conducting research on land application of municipal effluents since 1962 and report spray irrigation can be successfully used in both forest and on cropland in the humid east to offer advanced treatment of the effluent prior to recharge of groundwaters (Sopper and Kardos, 1973).

Several informative reports were published in the last four years on land application systems for municipal waste treatment. The U. S. Army Corps of Engineers published two reports which present a thorough review of the physical, chemical, and biological interactions involved in land treatment systems (Reed, 1972; and Driver et al., 1972). Several survey reports were published by the U. S. Environmental Protection Agency concerning field reviews of existing systems of land application (Sullivan et al., 1973; Pound and Crites, 1973) and presenting the current state-of-the-art on engineering and economic considerations of land application design (Pound et al., 1975; anon., 1975).

Several workshops and symposiums have been conducted in the past several years on land application of municipal wastes. Proceedings of these conferences contain a number of papers by various authors, in which a wide range of different topics on this subject are discussed. The following six recent conferences provide proceedings which generally cover current programs of study in this country.

1. First Annual IFAS Workshop on Land Renovation of Wastewater in Florida. Tampa, Florida, June, 1972.

2. International Conference on Land for Waste Management. Ottawa, Canada. October, 1973.

3. Proceedings of Conference on Land Disposal of Municipal Effluents and Sludges. Rutgers University. March, 1973.

4. Proceedings of the Joint Conference on Recycling Municipal Sludges and Effluents on Land. Champaign, Illinois. July, 1973.

5. Recycling Treated Municipal Wastewater and Sludge Through Forest and Cropland. University Park, Pennsylvania, 1973.

6. Workshop on Recycling Municipal Wastewater on Land. South Atlantic-Gulf Region of WRRI. Atlanta, Georgia. June, 1974.

These reports give a broad overview of the current knowledge available concerning land disposal of municipal wastes and indicate a growing interest among regulatory agencies for systems which might serve as an alternative to conventional treatment of domestic wastes. All reports indicate, however, the continuing need for research before such systems can be widely implemented.

PROCEDURES

Three basic interrelated parameters will be discussed relative to the design criteria or site selection of a land application system. These include: 1) landscape features, 2) properties of the soil, and 3) system management aspects. This document is not intended to provide final design criteria and information which could be used to totally design and manage a land application system. Rather it is intended as an information vehicle to provide the principles of land application design. Information presented is a combination of professional experiences of the authors combined with specific on-site evaluations of operating systems.

Detailed field investigations were conducted at several processing and industrial sites in North Carolina and South Carolina which utilize land application as a means of advanced treatment and ultimate disposal of waste products. Investigation of systems included two vegetable processing plants, two meat processing plants (one located in South Carolina), and a synthetic fiber plant in the Coastal Plain soil resource area and a fruit processing plant, and a fiber board plant in the Piedmont soil resource area. Site visits were also made to a textile mill, a meat processing plant and a pulp and paper mill in South Carolina, all using land application systems to some degree.

No significant operations of land application of municipal wastes were in operation in the region during the period of this study. Two experimental sites utilizing spray irrigation of domestic wastes onto forest sites were initiated in the region during the latter stages of this study but these sites are for recreational areas and will receive limited use. Samples were collected and analyzed from several municipal treatment plants for heavy metal and nutrient content of the sludge and will be discussed under appropriate sections of the report.

The approach used in this study was to examine various components of waste, regardless of source, pretreatment, or type of wastes and describe or predict the interactions of these components with various soil parameters under the environmental conditions of North Carolina. The ultimate objective was to use this information plus current existing knowledge to develop recommendations or guidelines for utilizing soil as a medium for treatment of specific waste components in a manner that would not endanger the quality of the environment and would maintain or improve production capacity of the soil system.

Waste Characterization

Because of the nature of their origin, waste effluents are quite variable and as such offer a great challenge to the analyst in obtaining representative samples and reliable data. A detailed sampling and analyses program was conducted at three sites under this study to develop sufficient background data on significant components in the waste stream. These sites included two vegetable processing plants and a fiber board plant. At four other sites

investigated, data furnished by the industry was used as a basis for determining loading rates on the field site. Since industrial operation permit requirements provided through the North Carolina Division of Environmental Management specify a weekly or monthly reporting of effluent quality, this information was judged to be satisfactory for this study.

Parameters which should be considered for design purposes in application of wastewater to land are given in Table 1. Other analyses should be made if the presence of certain elements or compounds are suspected in the particular effluent. Generally, a knowledge of the source of the wastes is sufficient to identify the analyses that should be made. Most of the analytical procedures which would be required are published in "Methods for Chemical Analysis of Water and Waste" (EPA, 1975).

In addition to the composition of the effluent, daily flow volumes are equally important in the design of land application systems. Flow rates which were determined or estimated in this study included daily average flow, maximum weekly flow, seasonal variation in flow, and storage capacity.

Land Site Evaluations

Site investigations and selection must consider those characteristics of the soil and landscape that will promote the decomposition and ultimate treatment of the waste components without creating environmental problems outside the site perimeter or impair the ability of the soil to substain adequate vegetative cover. In land used for waste applications, the soil functions as a natural filter and as a medium for the biological and chemical reactions which result in waste treatment and renovation. The suitability of each site investigated was, therefore, evaluated in terms of the physical, chemical and mineralogical characteristics of the soil. Physical characterization included:

1. Texture and structure of the surface and upper subsurface horizons.
2. Infiltration and permeability of the surface and other limiting soil horizons.
3. Depth to limiting soil horizons or pans.
4. Drainage characteristics.

Chemical characterization of the soils included:

1. pH.
2. Soluble cations.
3. Cation exchange capacity.
4. Electrical conductivity of saturated extracts.

Table 1. Parameters to consider for wastewaters to be used in land application.

Parameter	Recommendation for Analyses
COD	Yes
BOD	To determine BOD-COD ratio
Total dissolved solids	Yes
Total suspended solids	Yes
pH	Yes
Total N	Yes
NO_3-N	Yes
NH_4-N	Yes
Total P	Yes
K^+	Yes
Na^+	If conductivity exceeds 250 μ mho/cm
Cl^-	If conductivity exceeds 250 μ mho/cm
Ca^{++}	If conductivity exceeds 250 μ mho/cm
Mg^{++}	If conductivity exceeds 250 μ mho/cm
B	Municipal effluents and if suspected in others
Heavy metals	Municipal sludges and if suspected in others
Toxic organics	If suspected

5. Organic matter content.

6. Available nutrients.

In addition to the soil characterization, a description of each site investigated was recorded to include field size, type and quality of vegetation, and topographical features.

Climatic information was developed for each area of the state to include precipitation, evapotranspiration rates, and temperature. At three sites, rain gauges were installed; at the others, data from the nearest weather station were utilized.

Design Loadings

All systems investigated in this study used spray irrigation as the method for application. A loading rate for each system was established for the significant parameters as follows:

1. Hydraulic loading.

2. Organic component loadings.

3. Nutrient loadings.

4. Salt applications.

5. Heavy metal loadings.

Application techniques, as well as significant management problems, were determined for various sites including intervals of operation, land management procedures, crop harvesting, pretreatment systems and waste storage capacity and frequency.

At three sites, soil treatment capabilities were monitored by collecting samples of the applied effluent during application, soil samples at specific intervals during the project period to detect changes in physical and chemical properties, and samples of the soil solution from various depths in the soil profile. To determine levels of contaminants moving through the soil, porous cups were inserted at specified depths in the soil to sample the water as it percolated through the soil toward the groundwater. Adjacent sites not receiving waste applications were also sampled to compare quality of leachates. Effluent samples were installed at three locations within each spray field to measure uniformity of wastewater applications and measure wastewater loadings at specific sites where porous cup samples were installed. Rain gauges were installed near the spray fields at each site but general evidence of vandalism and contamination of these installations placed some doubt on the validity of the measurements.

RESULTS AND DISCUSSION

Seven major land application systems were investigated in varying detail during the course of this project. Table 2 summarizes the industry type, size of the spray field, soil resource area, and major soil types of the fields for each location. Sites 1, 2 and 3 were studied in more detail by placing effluent samplers and soil suction cups at several locations within each field to measure wastewater application rates and soil-waste interactions. Small plot areas were harvested at each sampling site for yield and quality of forage.

Soils and Topography

The landscape position or topography of the site is of major importance because of the influence it has on surface and subsurface water movement (hydrology). Topography will also have a major influence on runoff, soil erosion, and the amount of waste components leaving the site by surface drainage. Landscape position asserts a secondary influence through the control of development of specific soils in the watershed.

The major topographic positions which are of major importance for land application sites in the Coastal Plain are the convex slopes on the broad ridges of the area and the concave slopes of the broad flats of intrastream divides. Soils on the convex landscape positions of the Coastal Plain are usually the better sites for waste application since they are better drained, better oxidized, more permeable and have generally higher infiltration rates. The convex ridges are broad and relatively flat and have slight erosion hazards. Soils on the concave positions of broad flats are often poorly drained, poorly aerated and often have much less permeable horizons within their soil profile. Artificial drainage is often necessary for these sites to function as waste application sites.

The most important criteria in judging the suitability of a site for waste application is the physical, chemical and mineralogical characteristics of the soil. Of the physical soil properties, texture is one of the most important aspects of site selection because of its influence on infiltration, percolation, aeration, adsorption reactions, and water holding properties.

The coarse textured soils which include the sands, and loamy sands, have the best hydraulic properties for spray irrigation sites but may exhibit poor waste renovation capacities at high hydraulic loadings. The fine textured soils include clay, silty clay, and sandy clay and are not generally well suited for land application sites due to the poor internal drainage properties. Utilization of such sites for spray irrigation systems would require several months storage capacity to handle waste loads when the soil is too wet for irrigation. Also, the fine textured soils are generally not suitable for artificial drainage due to the slow rate of water movement within the profile. The loamy soils include the sandy loams, silt loams, silts, clay loams, sandy clay loams, and silty clay loams. This class of soils comprise the major portion of surface textures found in North Carolina and will be the most

Table 2. Summary of type of industry, size of spray field, soil resource area and major soil type for each system studied.

Site No.	Type of Industry	Size of Spray Field	Soil Resource Area	Major Soils of the Site
1	Vegetable Processing	36 Ac	Coastal Plain	Norfolk sl
2	Vegetable Processing	24 Ac	Coastal Plain	Norfolk sl and Wagram sl
3	Fiberboard	22 Ac	Piedmont	Georgeville sil
4	Synthetic Fiber	12 Ac	Coastal Plain	Rains ls
5	Fruit Processing	20 Ac	Piedmont	Cecil fsl and Altavista sl
6	Poultry Processing	110 Ac	Coastal Plain	Lakeland ls and Wagram ls
7	Poultry Processing	360 Ac	Coastal Plain	Lakeland s

the most likely sites for land application systems. The loamy class of soils will have a wide range of characteristics and therefore will require detailed field investigations in addition to a basic soil survey of the site to determine permissable waste loadings.

Infiltration, permeability and drainage classes are all related in determining the suitability of land sites for waste application. Texture plus structure are the main factors in controlling rate of water movement in soil and therefore have a major influence on the internal drainage rates of the soil. Land sites may have soils with good textural properties but still have poor drainage due to topographic position and excess water accumulation such as a high water table. The drainage class can be improved on soils with good permeability using artificial drainage but may not be improved on soils with low permeability requiring that the drainage classification of a soil be accompanied by additional information on soil permeability to determine if the conditions can be improved. Soils classified as very poorly, poorly, or somewhat poorly drained cannot satisfactorily function as waste fields without some artificial drainage. The soils classified as moderately well drained will have excessive wetness problems during several weeks of the year and additional irrigation with effluents during this time would create severe field problems. If the application periods are such that wastewater is only applied during the active growing season of the vegetative crop, these soils may be suitable sites for irrigation.

Restrictive layers in the soil profile may adversely affect the rate of water movement, especially under increased hydraulic loadings with wastewater irrigation. The most common restrictive layer in soils of North Carolina is a zone of clay accumulation (argillic horizon). Other restrictive layers include the plow pan, a compacted zone just below the surface resulting from repeated heavy equipment traffic, and the fragipans, a restrictive zone resulting from natural soil forming processes in silty or fine loamy materials. A third type of pan encountered occasionally in the Coastal Plain areas is the spodic horizon, a zone of cemented organic-ferrous iron accumulations. These pans are usually described in the detailed soils report of a field but must be considered as to the impact they will have on water movement within the profile.

An on-site inspection by a qualified soil scientist is a minimum requirement in defining the limitations of the soils at the site for accepting waste loads. While a published soil survey will define the general suitabilities of particular sites for specific uses, special considerations may be needed on groundwater hydrology or public health considerations and specialists in these fields should be consulted.

Climatic Data

An evaluation of climatic factors, such as precipitation, evapotranspiration and temperature is important for the determination of 1) water balance, 2) storage capacity requirement, 3) irrigation intervals, and 4) the appropriate growing season.

Sufficient climatic data are generally available for most locations in the country, from three publications of the National Oceanic and Atmospheric Administration (formerly the Weather Bureau).

The National Summary of Climatic Data provides daily weather summaries of every weather station in a given area such as total precipitation, maximum and minimum temperatures, relative humidity and evaporative data where available.

The Climatic Summary of the United States provides 10-year summaries of the above data including mean monthly precipitation, temperature and degree days for the above stations.

The National Climatic Center at Asheville, North Carolina in 1973 published state summaries of climatological data for each of the 51 states giving mean temperature, monthly precipitation normals and heating and cooling degree days for the period covering 1941-1970. Some 100 stations in North Carolina are reported in this publication.

Data on evapotranspiration (ET) rates are more difficult to obtain for specific locations. Figure 1 shows the potential ET versus precipitation for the U. S. which indicates that North Carolina is in an excess rainfall area. Rainfall exceeds ET by some 7 to 20 inches (18 to 51 cm) depending on the location within the state. Average annual rainfall of the state is shown in Figure 2.

The best source of information on local ET data is the publication Weather and Climate in North Carolina, North Carolina Agricultural Experiment Station Bulletin 396, 1971. Information is presented in this bulletin on specific ET from vegetative sites at various locations in the state. A summary of these data is presented in Table 3, and will be utilized in the calculations of water budgets in later sections of this report.

Wastewater Loadings

Based on wastewater characteristics either measured from samples collected during land application or of effluent analysis supplied by the industry, wastewater application rates and waste component loadings were calculated for each of the seven sites investigated. The application rates were calculated on the basis of total reported acreage of the spray field at each site. This procedure assumes 100 percent efficiency of application within the field area, a figure certainly not achieved at any of the sites studied. The problem of irrigation efficiency and uniformity of waste loadings is discussed in a later section on management considerations.

The application rate of wastewater and the loading parameters of specific waste components were calculated for those components considered most severe in terms of the soil and plant capacity to remove and assimilate the contaminant, the discharge requirements to groundwater and surface water, and the ultimate effect on the ability of the soil to sustain vegetative growth. A

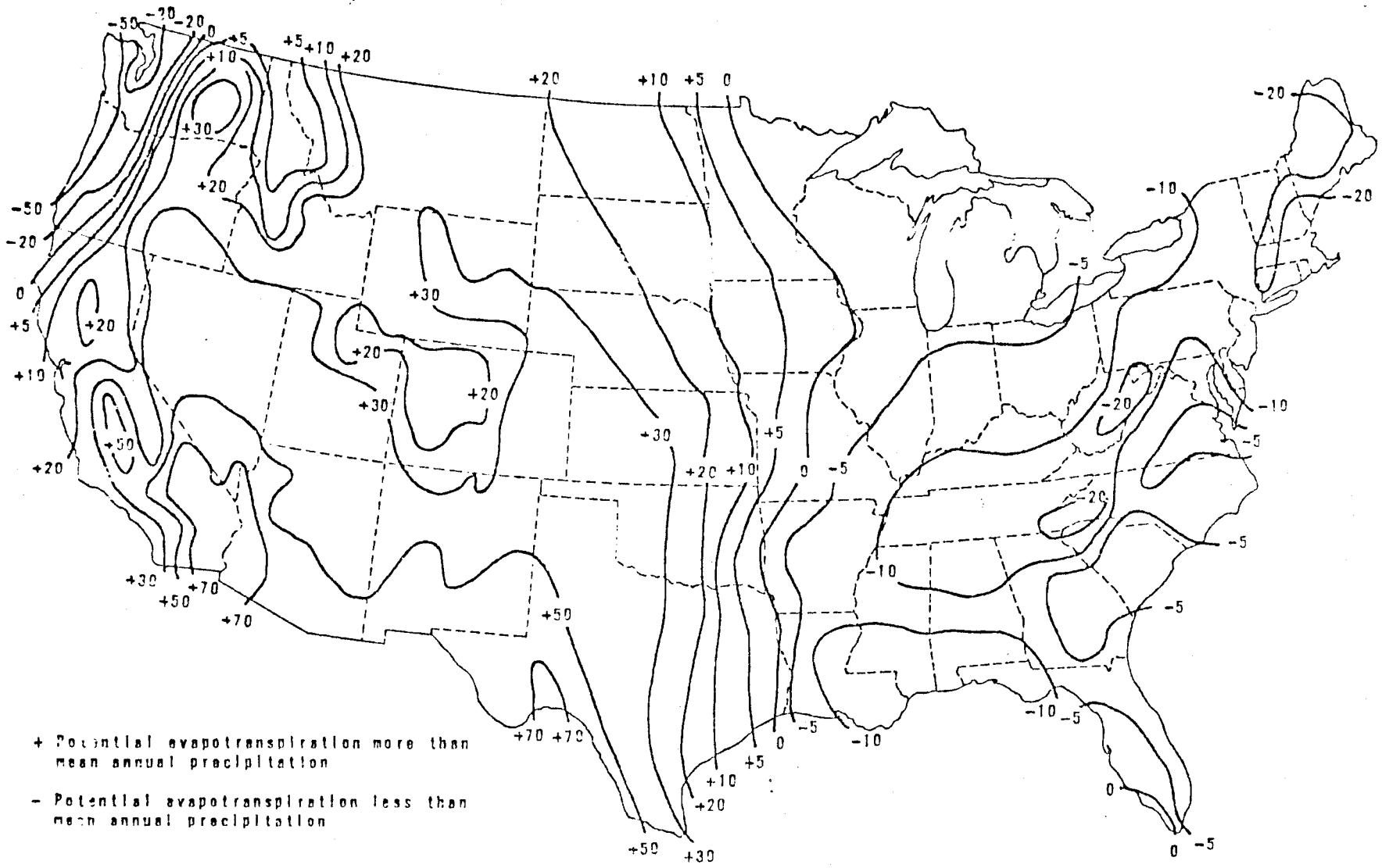

FIGURE 1. POTENTIAL EVAPOTRANSPIRATION VS. MEAN ANNUAL PRECIPITATION (INCHES)
Adapted from Pound and Crites, 1975.

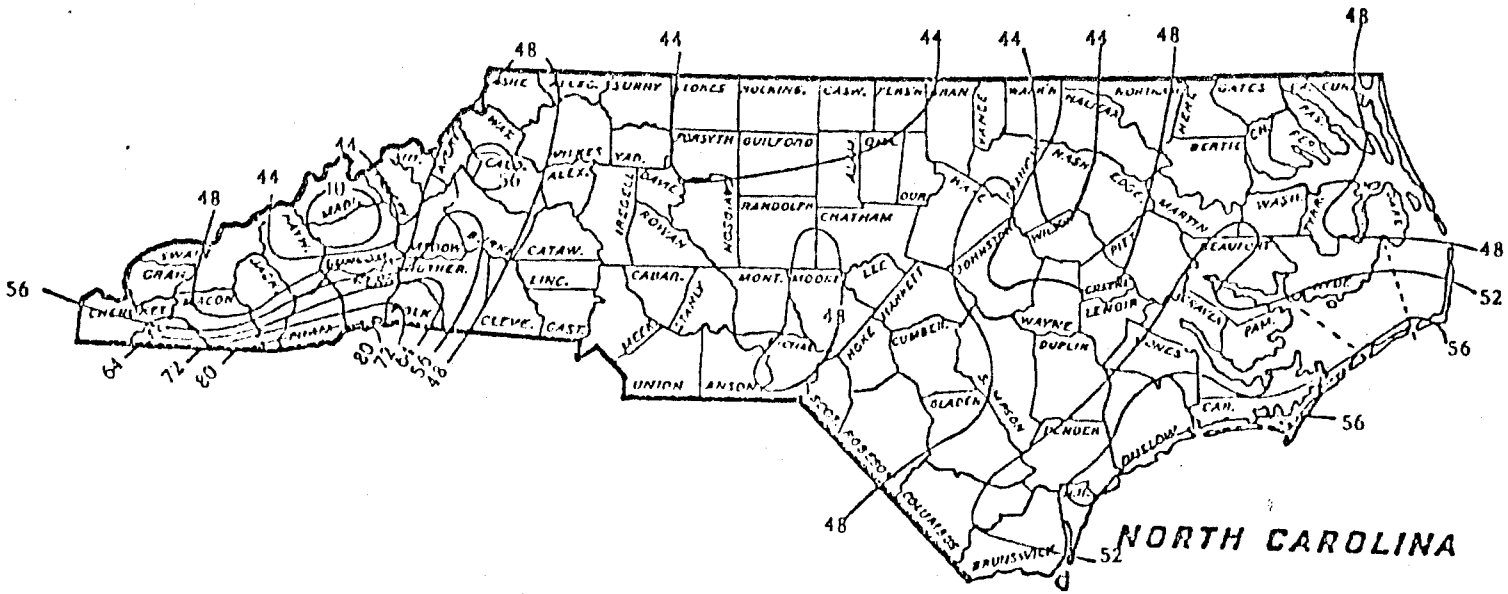

Figure 2. Average annual precipitation in North Carolina (inches). Adapted from Hardy and Hardy, 1971

Table 3. Average evaporation from vegetation growing in moist soils in North Carolina.

Month	Asheville	Charlotte	Raleigh	Wilmington
	(Estimated values, inches per month)			
Jan.	0.93	0.93	0.93	0.93
Feb.	1.40	1.40	1.40	1.68
March	2.17	2.48	2.17	2.79
April	3.30	3.30	3.30	3.60
May	3.72	4.34	4.34	4.65
June	4.50	5.10	4.80	5.10
July	4.34	4.96	4.65	4.96
Aug.	3.72	4.34	4.03	4.34
Sept.	3.00	3.00	3.30	3.60
Oct.	1.86	2.17	1.86	2.17
Nov.	1.20	1.20	1.20	1.50
Dec.	0.62	0.62	0.62	0.93
Totals	30.76	33.84	32.60	36.25

Source: A. V. Hardy and J. D. Hardy, Weather and Climate in North Carolina. Bulletin 396. 1971. North Carolina Agricultural Experiment Station.

listing of the sites surveyed and the more important loading parameters calculated for each site are presented in Table 4. Each of the major effluent loading constraints are discussed in the following sections.

It is evident that a wide range of loading characteristics were utilized in the sites surveyed for this project. Sites 1, 2, and 5 are vegetable and fruit processing plants, and as such, only operate seasonally for 4 to 8 months. The reported field loadings are only for the period of operation. Storage capacity as reported indicates the total capacity of the storage area, not the operating capacity. Most lagoons were normally full of effluent and therefore afforded little reserve storage. They do serve as detention areas for the effluent and equalize the varability of effluent quality on a day to day basis.

Hydraulic Loadings

For effective renovation of wastewater by spray irrigation, the wastewater must first infiltrate into the soil and then percolate through 3 to 4 feet of the soil profile. Application schedules should allow sufficient residence time for waste constituents to interact with the soil components, for the soil to drain and aerobic conditions restored. Application rates should not exceed the soil's capacity to accept water without runoff or without ponding for more than a few hours.

Hydraulic loading may be higher during the summer and early fall when evapotranspiration is high (Table 3) but will be less during the remainder of the year when rainfall exceeds evapotranspiration. Wastewater organics must be effectively degraded by biological activity, thus requiring longer intervals between applications during colder weather than at normal growing season temperatures. The interval between irrigations depends on the soil properties, the waste characteristics, climatic conditions, and the crop. This interval may need to be only two to three days on the deep permeable sands to several weeks on the more poorly drained sites. The concept of resting periods between waste applications will be discussed in more detail in the section on organic loading.

The most important criteria in design hydraulic loadings is the amount of water drained from the soil profile per unit time at various water contents. While hydraulic conductivities of saturated soil samples from different horizons in the majority of North Carolina soils have been determined (Lutz, 1970), the more important question becomes one of determining the rate of drainage from the soil at less than saturated conditions. The unsaturated hydraulic conductivity of soils is dependent upon soil water content and is essentially unknown for most soil systems in North Carolina due to the difficulty and time consumed in the measurement. Work is progressing in this area (Dr. D. K. Cassel, personal communications) but it will be some time yet before this information is available for the major soil types in the state.

Other measurements can help in interpretations of soil water movement and ultimate permissible hydraulic loadings. One of the concepts most useful is

Table 4. Summary of the major loading parameters at seven land application sites surveyed.

Industry	Hydraulic* Loading, in/wk	Organic* Loading, lbs COD/a/wk	Nitrogen Loading, lbs N/a/yr	Total Dissolved Solids mg/l	Potential Storage Capacity wks
Vegetable Processing (Site 1)	0.8	600	350	300	0
Vegetable Processing (Site 2)	0.6	1400	430	2100	8
Fiberboard (Site 3)	1.5	500	800	700	36
Synthetic Fiber (Site 4)	1.4	1600	20,000	2500	12
Fruit Processing (Site 5)	1.0	800	800	200	4
Poultry Processing (Site 6)	2.1	600	1,600	400	2
Poultry Processing (Site 7)	9.3	1800	4,900	200	0.1

*Based on average effluent loading rates during actual operation of the spray field.

the evaluation of "field capacity." As defined by Baver et al., 1972, field capacity (FC) is "the water content of a soil profile, usually the rooting zone, which has been thoroughly wetted by irrigation or rainfall and after the subsequent rate of drainage out of the profile has become neglibibly small." Therefore, drainage rates are involved in field capacity determinations although there is often much difficulty in deciding when the rate of drainage from the soil profile has become negligibly small. The "water holding capacity" of the soil is then defined as the amount of water, usually expressed as a percent by volume, retained in the soil after drainage to field capacity.

While the term "field capacity" is now obsolete in technical literature, it is still an important concept in hydraulic loadings since it attempts to define the percentage of water remaining in a soil after free drainage becomes negligibly small. The most important factor determining the water content at FC is the percentage of larger pores in the soil. The difference between the water content at saturation and FC represents the water drained from the large pores and thus represents the approximate volume of soil pores that would drain freely following a rain or irrigation.

The volume of soil pores drained at FC is the maximum volume of water that can be replaced by applications of wastewater or rainfall. This value does not, however, indicate the time required for free drainage to cease. Other workers have investigated this problem and Cassel and Sweeny, 1974, reported that for sandy textured soils, the FC is normally reached within 12 to 24 hours. For medium textured soils, including sandy loams and loams, 2 to 3 days were required to reach FC and up to 5 days for a silt loam soil. The fine textured soils such as clays and silty clays did not reach drainage equilibrium in over 20 days time, therefore, field capacity has little meaning for these soils. If hydraulic loadings were to be designed on fine textured soils, drainage times of at least 10 to 12 days should be considered.

The information on water lost during drainage to FC plus the general knowledge of rates of drainage for various textured soils were used to estimate the hydraulic loading capacity of many of the soil in North Carolina. Table 5 is a listing of some of the physical properties, including water contents at 0, one-tenth, and one-third atm tension, for selected soils from spray fields of this study. One-tenth and one-third atm tension values are derived from laboratory analysis of sieved soil samples and are used to estimate FC on coarse and medium textured soils, respectively. These particular sites were selected for their wide diversity in soil characteristics.

While the rate of drainage at each site is normally controlled by the most restrictive horizon in the soil profile, the surface or A horizon is the most critical zone in terms of drainage and reaeration for plant growth, waste treatment, and ability to withstand traffic. Utilizing the drainage rates observed for various textures and data from Table 6 which summarizes the water lost from saturation to the one-tenth atm value in Table 5, a rate of drainage can be estimated as shown in Table 7, considering that drainage and reaeration is required in the A horizon but that drainage rates are generally controlled by the B horizon.

Table 5. Physical characteristics of soils at five spray field sites.

Soil Depth	Bulk Density	Particle Size			Water Content Soil Moisture Tension (atm)		
		Sand	Silt	Clay	0	1/10	1/3
in	g/cm^3	%			% by Volume		
0-12 (A)	1.55	75	7	18	40.4	18.5	16.0
13-26 (B)	1.62	62	6	32	37.8	22.5	16.6
Site 1. Norfolk sl - Typic Paleudults, fine-loamy, siliceous, thermic							
Location - Harnett County, North Carolina							
Topography - Nearly level (1-2% slope)							
0-8 (A)	1.46	77	15	8	41.2	16.4	15.8
9-18 (B)	1.51	49	23	28	42.2	24.2	18.8
Site 2. Norfolk sl - Typic Paleudults, fine-loamy, siliceous, thermic							
Location - Wilson County, North Carolina							
Topography - Nearly level (1-2% slope)							
0-9 (Ap)	1.38	23	61	16	47.8	33.5	29.8
10-18 (Bi)	1.35	5	51	44	48.2	41.1	37.2
Site 3. Georgeville sil - Typic Hapludults, clayey, kaolinitic, thermic							
Location - Nash County, North Carolina							
Topography - Gently rolling (3-5% slope)							
0-10 (A)	1.68	78	15	8	38.1	22.1	17.8
11-24 (B)	1.79	55	14	31	32.4	25.1	22.5
Site 4. Rains ls - Typic Paleaquults, fine loamy, siliceous, thermic							
Location - Brunswick County, North Carolina							
Topography - Flat (<1% slope)							
0-8 (Ap)	1.51	75	16	9	42.1	23.1	18.4
10-16 (Bi)	1.47	46	20	34	43.8	31.4	29.1
Site 5. Cecil sl - Typic Hapludults, clayey, kaolinitic, thermic							
Location - Lincoln County, North Carolina							
Topography - Gentle rolling (3-5% slope)							
0-8 (A)	1.51	81	15	4	41.8	12.1	9.9
9-24 (AC)	1.57	92	5	3	38.5	13.4	8.8
Site 6. Lakeland ls - Typic Quartzipsamments, siliceous, thermic, coated							
Location - Robeson County, North Carolina							
Topography - Nearly level (1-2% slope)							

Table 6. Water lost at soil tensions of one-tenth and one-third atm.

Soil Type	Water lost between tension of: 0 - 1/10 atm % by volume	0 - 1/10 atm inches	1/10 - 1/3 atm % by volume	1/10 - 1/3 atm inches
Norfolk sl 0 - 12 in.	21.9	2.63	2.5	0.3
Georgeville sl 0 - 9 in.	14.3	1.28	3.7	0.3
Rains ls 0 - 10 in.	16.0	1.60	4.3	0.4
Cecil fsl 0 - 8 in.	19.0	1.52	4.7	0.4
Lakeland ls 0 - 8 in.	29.7	2.37	2.2	0.2

Table 7. Approximate drainage times and water loss to reach field capacities of selected soils.

Soil Type	Drainage Time to reach FC	Water Lost During drainage (A horizon)
	Days	Inches
Norfolk sl	3	2.63
Georgeville sil	5	1.28
Rains ls	3	1.60
Cecil fsl	4	1.52
Lakeland ls	0.5	2.37

By combining drainage times with reaeration times developed in the section on organic loadings, monthly estimates of drainage rates can be determined and water balances can then be attempted for specific field sites. Using an estimated three days requirement for reaeration of the soil after draining to field capacity, total monthly drainage rates desirable in the spray field are given in Table 8.

Water lost by drainage will actually be greater than shown in Table 8, since some additional drainage will occur during the three day reaeration time. However, these losses will be small since drainage rates are very low at tensions greater than one-tenth atm.

Since rainfall cannot be predetermined, some flexibility must be designed into the irrigation program to allow for rainy periods when drainage and reaeration times cannot be accomplished as desired. Also, many soils in the Coastal Plain of North Carolina, due to topographical position or internal soil characteristics, have inadequate drainage to handle normal rainfall and therefore stay saturated to near the surface for significant periods during winter. Naturally, these soils cannot handle additional wastewater during these periods without some means of artificial drainage.

Many of our Piedmont soils have slow internal drainage due to clay accumulations in the B horizon of the profile. However, due to rolling topography, much of the applied water or rainfall moves laterally down slope through the A horizon, which helps alleviate any drainage problem. While this may create seeps on some downslope sites, this problem can normally be handled by a few well-placed interceptor drains.

Using the data presented in Table 8, plus the climatic data presented previously, a desirable water budget was developed for three sites in this study, comprising the Norfolk, Cecil, and Lakeland soil types. These data are presented in Table 9.

These data indicate the wide range in hydraulic loading rates which may be permissable on particular soils of North Carolina. The Norfolk and Lakeland soils, being two of the better soils of the state for land application, may accept hydraulic loads in the range of 2 and 4 inches (5 and 10 cm) per week respectively as a limiting rate for winter irrigation while a common Piedmont soil type, Cecil sl, may only accept 1 inch (2.5 cm) per week. Other factors may limit application rates on the excessively permeable Lakeland soils due to the lower treatment capabilities for various waste components.

Water balance tables similar to these can be developed for any application site in the state. However, a detailed on-site field investigation is still a requirement to determine the soil and topographical variability in any field site.

Table 8. Drainage rates estimated for selected soils.

Soil Type	Drainage Time	Reaeration Time	Time Required Between Hydraulic Loadings	Water Lost Per Drainage Period	Water Drainage Per Month
	Days	Days	Days	Inches	Inches
Norfolk sl	3	3	5	2.63	13.15
Georgeville sil	5	3	8	1.28	4.8
Rains ls*	3	3	6	1.60	8.0
Cecil sl	4	3	7	1.52	6.5
Lakeland ls	0.5	3	3.5	2.37	20.3

*Drainage time applicable only if artificial drainage is provided.

Table 9. Water budgets for three field sites in North Carolina.

Site 1. Norfolk sl
Location - Harnett County, North Carolina

Month	Water Losses ET	Drainage	Total	Water Additions Precip.	Irrigation	Total
			in			
Jan.	0.93	13.15	14.08	3.13	10.95	14.08
Feb.	1.40	13.15	14.55	3.44	11.11	14.55
March	2.17	13.15	15.32	4.04	11.28	15.32
April	3.30	13.15	16.45	3.27	13.18	16.45
May	4.34	13.15	17.49	3.41	14.08	17.49
June	5.10	13.15	18.25	4.72	13.53	18.25
July	4.96	13.15	18.11	5.99	12.12	18.11
Aug.	4.34	13.15	17.49	5.83	11.66	17.49
Sept.	3.00	13.15	16.15	4.27	11.88	16.15
Oct.	2.17	13.15	15.32	2.65	12.67	15.32
Nov.	1.20	13.15	14.35	2.96	11.39	14.35
Dec.	0.62	13.15	13.77	2.98	10.79	13.77
Totals	33.53	157.80	191.33	46.69	144.64	191.33

Site 6. Lakeland ls
Location - Robeson County, North Carolina

Month	Water Losses ET	Drainage	Total	Water Additions Precip.	Irrigation	Total
			in			
Jan.	0.93	20.3	21.33	2.09	18.25	21.23
Feb.	1.68	20.3	21.98	3.39	18.59	21.98
March	2.79	20.3	23.09	4.02	19.07	23.09
April	3.60	20.3	23.63	3.36	20.27	23.63
May	4.65	20.3	24.95	3.21	21.74	24.95
June	5.10	20.3	25.40	5.00	20.40	25.40
July	4.96	20.3	25.26	6.31	18.94	25.26
Aug.	4.34	20.3	24.64	5.18	19.46	24.64
Sept.	3.60	20.3	23.90	4.19	19.71	23.90
Oct.	2.17	20.3	22.47	2.81	19.66	22.47
Nov.	1.50	20.3	21.80	2.83	18.97	21.80
Dec.	0.93	20.3	21.23	2.90	18.33	21.23
Totals	36.25	243.6	279.85	46.19	233.66	279.85

Table 9. Cont'd.

Site 3. Cecil sl
Location - Lincoln County, North Carolina

Month	Water Losses ET	Drainage	Runoff*	Total	Water Additions Precip.	Irrigation	Total
	in				in		
Jan.	0.93	6.5	0.57	8.00	3.81	4.19	8.00
Feb.	1.40	6.5	0.62	8.52	4.15	4.37	8.52
March	2.48	6.5	0.71	9.69	4.73	4.96	9.69
April	3.30	6.5	0.59	10.39	3.97	6.42	10.39
May	4.34	6.5	0.50	11.34	3.36	7.98	11.34
June	5.10	6.5	0.65	12.25	4.34	7.91	12.25
July	4.96	6.5	0.77	12.23	5.13	7.10	12.23
Aug.	4.34	6.5	0.72	11.53	4.82	6.74	11.56
Sept.	3.00	6.5	0.57	10.07	3.82	6.88	10.07
Oct.	2.17	6.5	0.43	9.10	2.89	6.21	9.10
Nov.	1.20	6.5	0.45	8.15	3.01	5.14	8.15
Dec.	0.62	6.5	0.59	7.71	3.90	3.81	7.71
Totals	33.84	78.0	7.17	119.01	47.93	71.08	119.01

*Based on runoff coefficient of 0.15 for gently rolling land with good vegetative cover.

Organic Loadings

Organic compounds are found in all wastewaters. These may be in the form of suspended solids or as dissolved compounds. The suspended solids are filtered out near the soil surface and will normally not move more than a few inches into the soil. At these shallow depths, oxygen diffusion rates are generally high and organic decomposition adequate.

The soluble oxygen demanding organics may be carried to greater depths into the soil with the water. The compounds which are cationic or basic in nature are retained by cation exchange mechanisms whereas the large molecules and polar compounds are removed from the wastewater by adsorption mechanisms. For these compounds to be decomposed quickly within the soil profile requires unsaturated soil moisture conditions at the soil surface and sufficient time for oxygen to diffuse to the zone of microbial activity.

Organic overloads can occur in a soil system by either suspended solids or by soluble organics. If suspended solids create slime formation at the soil surface that exceed the respiratory capacity of microbial populations, anaerobic conditions can develop, infiltration capacity may decrease and severe odor and loss of vegetation can occur. At lower depths in the soil, reduced aeration in the root zone may impair growth of the crop and result in eventual loss of the vegetative cover. Aeration of the root zone is most important to agricultural crops which in general show adverse effects from inadequate oxygen at levels of oxygen less than 10 percent in the soil atmosphere (Letey, Stolzy and Kemper, 1967). The more water tolerant plants, such as tall fescue and reed canarygrass, have a majority of their roots near the surface and a decrease in oxygen is less detrimental than for deeper rooted crops.

To determine the permissable organic loading of a soil, oxygen requirements of the soil-plant system prior to waste loadings should be known. Clark and Kemper, 1967, reported that the rate of oxygen use in soil containing growing plants is of the order of 4 to 6 pounds of oxygen per acre per hour (4.5 to 6.7 kg/ha/hr), with about one-half of this used by the plant roots and one-half by the microorganisms closely associated with root surfaces. They also developed an equation for estimating the time required to depleat the soil reservoir of oxygen to the point of damaging plant roots, assuming no diffusion of oxygen from the soil surface. It is:

$$T = \frac{0.38\ dS\ (C_p - 10)}{R}$$

where T is the time in hours, d is the depth to a saturated zone in feet, S is the air filled porosity, C_p is the percent oxygen in the soil air, and R is the rate of oxygen use by plants and microorganisms.

Thus, a moderately well drained soil in the Coastal Plain might have the following conditions:

d = 3 feet (depth to water table)
S = 18 percent (air filled porosity)
C_p = 19 percent (initial O_2 content of soil air)
R^p = 5 lb/a/hr (biological rate of O_2 use)

therefore:

$$T = \frac{(0.38)\ (3)\ (18)\ (19\text{-}10)}{5} = 36 \text{ hours}$$

The surface could probably be sealed off by irrigation or rainfall for about 36 hours before the oxygen content of the soil air would be lowered to below 10 percent, the damaging level for plant roots

Another factor to be resolved before organic loadings can be determined is that of oxygen diffusion rates in soil. Research has revealed that diffusion is the most important mechanism in soil aeration and that diffusion rates are dependent upon the fraction of the soil which is occupied by gas. The oxygen diffusion coeffieient in water is about 2.56×10^{-5} cm^2/sec and about 1.89×10^{-1} $cm/^2$sec in air, or approximately 10,000 times greater in air than in water. Van Bavel, 1952, reported that the diffusion of vapors through the soil mass can be described by the equation

$$D_p = 0.6\ S\ Do$$

where D_p is the effective diffusion coefficient through the soil mass, Do is the diffusion coefficient in air and S is the air filled porosity.

McMichael and McKee, 1966, used the above equation and Fick's law of gaseous diffusion to derive the equation

$$M = 2\ Co\ \left(\frac{D_p T}{\pi}\right)^{1/2}$$

as the amount of oxygen M diffusing into the soil during time T where Co is the surface concentration of oxygen and the soil air concentration of oxygen is zero. However, this equation provides for a maximum gradient and since soil oxygen must be greater than 10 percent to prevent adverse plant root reactions, a more realistic diffusion rate would be described by the equation

$$M = 2\ (Co - Cp)\ \left(\frac{D_p T}{\pi}\right)^{1/2}$$

where

M = gm O_2/m^2 moving into soil
Co = mgO_2/liter in air above ground
Cp = MgO_2/liter in soil air
D_p = m^2/day oxygen diffusivity for soil
T^p = Time in days

The oxygen in the atmosphere above ground is about 21 percent by volume of the air or about 300 mgO_2/liter (300 gm/m^3). The diffusion coefficient for oxygen in air is about 1.62 m^2 per day (17.5 ft^2 per day) as given in the Handbook of Chemistry and Physics, 1971. To maintain soil oxygen sufficient for plant growth, C_p must be 10 percent or greater or about 143 mgO_2/liter. For these boundary conditions, the above equation can now be solved to determine the amount of oxygen entering the soil as a function of time.

Solving this equation for the Norfolk sl at site 1, data from Table 6 gives the air filled porosity at field capacity or 0.1 atm as:

$$S = 0.22$$

therefore

$$D_p = 0.6\ S\ Do = 0.6\ (.22)\ (1.62) = 0.214\ m^2/day$$

for T = 1 day

$$M = 2\ (300\text{-}143)\ \left[\frac{0.214\ (1)}{\pi}\right]^{1/2} = 82\ gm\ O_2/m^2/day$$

The same data calculated for the Georgeville sl yields:

$$S = 0.14$$
$$D_p = 0.6\ (.14)\ (1.62) = 0.136\ m^2/day$$
$$T^p = 1\ day$$
$$M = 2\ (300\text{-}143)\ \left[\frac{0.136\ (1)}{\pi}\right]^{1/2} = 64\ gm\ O_2/m^2/day$$

and for the Lakeland ls:

$$S = 0.30$$
$$D_p = 0.6\ (0.30)\ (1.62) = 0.292$$
$$T^p = 1\ day$$
$$M = 2\ (300\text{-}143)\ \left[\frac{0.292\ (1)}{\pi}\right]^{1/2} = 96\ gm\ O_2/m^2/day$$

These data indicate some of the variation in oxygen diffusion rates and the order of magnitude of oxygen transfer into soil systems that have drained to field capacity. The above analysis is not completely realistic when applied to the behavior of soil-waste system since the soil-air content of oxygen will not be maintained at a constant 10 percent as described in this equation. Also, by the nature of the diffusion process, the upper soil horizons have a considerably greater opportunity to be reaerated than the deeper soil zones. Since the above equation only described the transfer of oxygen into the surface soil, the rate of transfer to lower depths will be somewhat less. The total process of reaeration of applied effluent in an unsaturated soil is very complicated and a lack of knowledge of all the physical parameters involved prevent the evaluation of precise models. However, using the data from the above equation, summarized in Table 10, as the best information available

on soil reaeration, calculations can be made of possible loadings of organic materials in soils of the area. Based on total oxygen demand (TOD) of the applied wastewater plus oxygen requirements of the soil-plant system, permissable loadings of TOD are calculated for the same soils and presented in Table 11.

These data cannot be interpreted to mean that effluent having these TOD rates can be applied each day to field sites because vitually no oxygen diffusion occurs during and immediately following water application by rainfall or irrigation. At this time, water is held in the larger pores thus blocking oxygen diffusion. Drainage times listed in the previous section show requirement of from 0.5 days to 5.0 days to drain the soil to field capacity. Oxygen diffusion rates would be restricted during this period and TOD loading calculations should be conservatively based on reaeration times after drainage is complete. This would allow weekly TOD loadings as shown in Table 12.

The total oxygen demand (TOD) of a wastewater is normally measured by the biochemical oxygen demand (BOD) exerted over a period of time (up to 100 days) in a BOD bottle. This demand is approximately equal to the chemical oxygen demand (COD) plus the oxygen required to convert all ammonia and organic nitrogen to nitrates (NOD). Although this demand may extend over 100 days in a BOD bottle, most of it appears to be exerted very rapidly in percolation through well-aerated soil. Therefore, there appears to be good justification in calculating TOD for land application systems by the following formula:

$$TOD = COD + NOD$$

Two mols of oxygen (O_2) per mol of nitrogen (N) are required to oxidize the nitrogen to nitrate. Thus 1 mg N requires 4.56 mgO_2 to satisfy its oxygen demand. Therefore:

$$TOD = COD + 4.56\ (Org\ N + NH_4 - N)$$

The normal BOD exerted in a five day BOD test is exerted in less than two days in a well aerated soil and the ammonium NOD is normally satisfied in at least three days in the presence of adequate oxygen. The organic nitrogen is not totally oxidized in three days in most soil systems but due to the extreme variability in waste decomposition rates, total organic nitrogen should be included in TOD loadings as a safety factor. Therefore by allowing three days of reaeration after soil drainage before applying another waste load and keeping the TOD loadings at or below the calculated rates, spray field sites can be maintained in aerobic states which allow good renovation of the wastewater and a vigorous growing gound cover.

The treatment capabilities of a well-aerated soil for removing carbon from applied wastewaters is evidenced in Fig. 3. At field site 1 where the applied wastewater had a total organic carbon content of over 1100 mg/l and a weekly TOD loading of 950 lbs/a/wk, leaching through only six inches of the well aerated Norfolk sl top soil afforded over 90 percent reduction in soluble

Table 10. Calculated O_2 transfer rates at 0.1 atm water tension.

Soil	O_2 Transfer Rates	
	$g/m^2/day$	lbs/a/day
Norfolk sl	82	732
Georgeville sil	64	571
Lakeland ls	96	857

Table 11. Oxygen available for waste TOD and plant requirements.

Soil	O_2 Transfer Rate at 0.1 atm water tension	O_2 Requirement of Soil-Plant System	O_2 Available for Waste TOD
		lb/a/day	
Norfolk sl	732	144	588
Georgeville sil	571	144	427
Lakeland ls	857	144	713

Table 12. TOD loadings based on required reaeration times.

Soil	Relative Reaeration Time Per Week	Permissable Weekly TOD Loadings
	Percent	lb/a/wk
Norfolk sl	50	2058
Georgeville sil	37	1106
Lakeland ls	86	4292

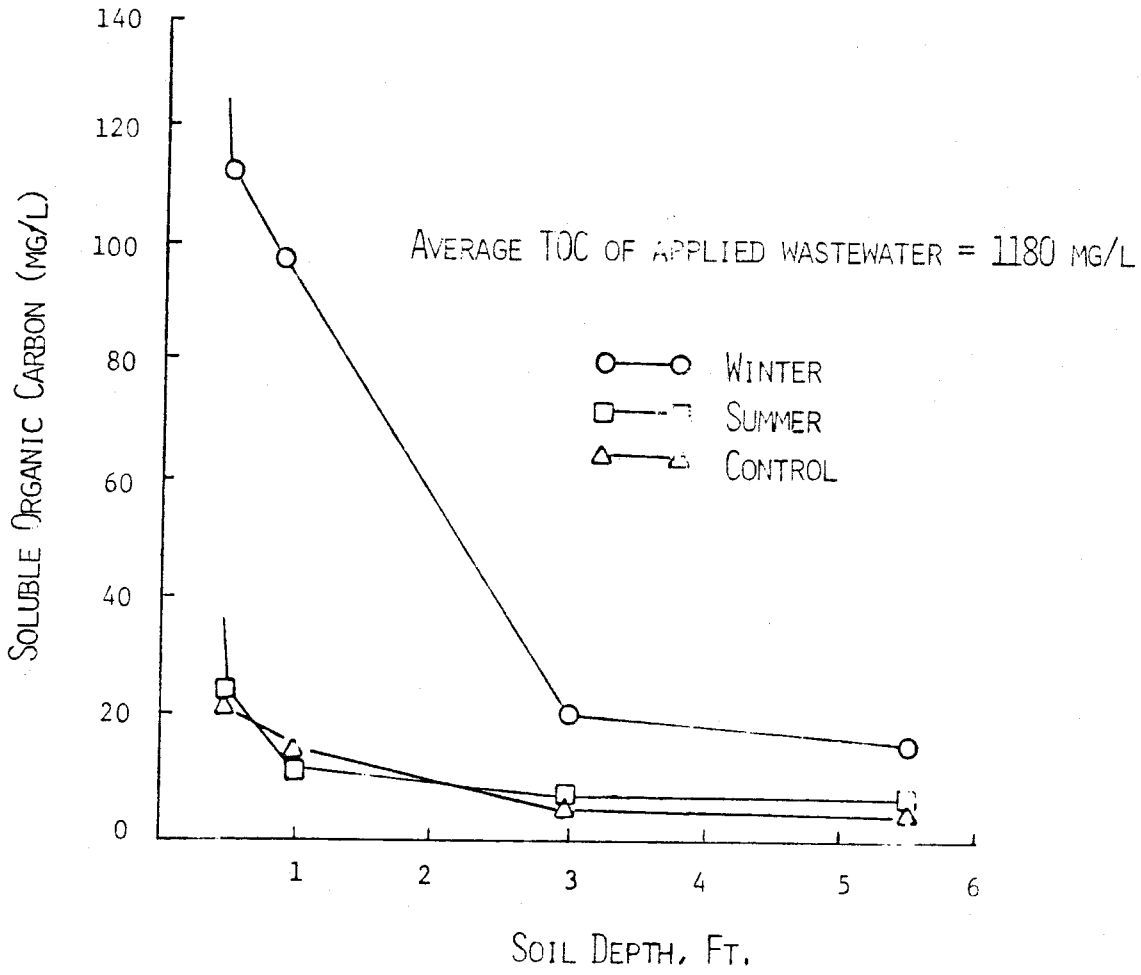

Fig. 3. Soluble organic carbon content of soil leachate from site 1.

organic carbon as measured in collected leachate samples during early winter applications. Some additional removal of soluble organic carbon was accomplished at lower depths during leaching to bring total organic removal efficiency to over 98 percent in the top three feet of the soil. Summer time efficiency for carbon removal was even greater, with all samples showing no evidence of increased carbon concentration above that of the control plots.

Nutrient Loadings

nitrogen

Nitrogen is the critical element in determining nutrient loadings on land application sites and the nitrate form is the most important because of its solubility and mobility in water, its stability and health implications in ground waters, and its implications for eutrophication and animal health in surface waters. The other mineral forms, ammonium and nitrite, are usually converted to nitrate rather quickly in well or moderately well aerated soil. All three forms are taken up by most plants. In the presence of high amounts of rapidly decomposing organic matter and reduced soil aeration, nitrate and nitrite may be reduced (denitrified) to gaseous forms and recycled back into the atmosphere. Both nitrification and denitrification are biological processes carried out by microorganisms which are not very active at temperatures below 10°C.

All inorganic nitrogen (NH_4 + NO_3 + NO_2) applied in wastewater is immediately available for crop uptake similar to adding commercial fertilizer nitrogen. Depending on the carbon-nitrogen ratio and the rate of decomposition of wastewater carbonaceous material, as little as twenty percent to as much as fifty percent of the organic N applied in wastewater may be released (mineralized) as ammonium and nitrified to nitrate the first year. The remainder will be retained (immobilized in residual humus). This humus will continue to decompose and release mineral forms of N in subsequent years, but at much reduced rates. In the presence of rapidly decomposing carbonaceous materials such as may be added as wastes, the rates of initial and residual release are substantially reduced.

In low rate irrigation of wastewater, nitrogen not removed from the site by harvest of vegetation will tend to build-up in the system. For design purposes, inputs of N should not exceed the capacity of the vegetation to take it up plus some allowance for denitrification and immobilization. If crops are harvested, the overall capacity of the soil-crop system to remove N can be estimated at 150 percent the expected removal by harvest (Walcott and Cook, 1975). Some N will be lost through denitrification, perhaps 15 to 50 percent if inputs do not greatly exceed the N required for optimum plant growth. If vegetation of plant products are not harvested, some arbitrarily lower figure will need to be used. Actual removal will vary with many factors of site and management and can only be determined by monitoring the system's operation.

In Table 13, the amount of nutrients harvested for various crops is given. However, design estimates of harvest removal should be based on yield

Table 13. Removal of nutrients in certain harvested crops.

Harvested	Crop						
	Corn grain	Corn silage	Wheat grain	Soybeans	Coastal Bermuda grass	Tall Fescue	Hardwood forest* (annual uptake)
Yield	100 bu	25 T	60 bu	35 bu	10 T	7 T	---
Nitrogen, lb/a	110	165	72	120	400	250	84
Phosphorus, lb/a	20	30	13	12	30	56	8
Potassium, lb/a	25	150	14	36	166	250	26
Calcium, lb/a	2	25	2	5	90	44	22
Magnesium, lb/a	9	30	4	6	37	40	5

*Sopper, W. E. 1973.

goals which local agricultural specialists indicate can be achieved with good management on particular soils. The potential for harvesting nutrients with perennial crops is generally greater than with annuals since annuals utilize less of the growing season for active nutrient uptake.

In general, agricultural crops produce more harvestable dry matter with higher nutrient content than tree species grown for timber. Legumes can fix all the N they need from the air, but they are active scavengers for mineral nitrogen if present as well as phosphate. Large harvest removals can be achieved with both legumes and perennial grasses if they are cut at early growth stages when their nutrient content is high.

Little nitrate removal is expected during periods when actively growing vegetation is not present. Consequently, any level of nitrate exceeding 10 mg/l N (drinking water standards) should be considered a serious hazard in application to land without vegetative cover.

In review of nitrogen loadings applied on sites of this study, it is evident that a wide range in loading rates are practiced. These nitrogen loadings ranged from a low of approximately 350 lb/a/yr to over 20,000 lb/a/yr. All sites utilized fescue or a combination of fescue and reed canarygrass as a cover crop. No vegetation was removed from any of the fields although most of them were mowed regularly during the growing season.

At field sites 1, 2, and 3, detailed sampling of the soil, forage and soil water was conducted to determine if a buildup of nitrogen had occurred in the system of sufficient magnitude to create excess loss of nitrates to the groundwater or uptake in the forage. Field site 3 is a new sytem and spray application began during the time of this study and probably had not reached steady state conditions during this study period. Sites 1 and 2, however, had been in operation for five years when this study began and conditions should indicate if nitrogen accumulation was becoming a problem. Figures 4 and 5 show the NO_3-N content of soil leachate with depth at various seasons of the year for site 1 and 2. It is evident that some excess nitrate is leaching through the profile during the winter season, although concentrations are still below the critical 10 mg/l NO_3-N in all cases at site 1. At site 2, where N loadings averaged over 400 lb/a/yr, NO_3-N levels at the five foot depth reached a maximum of 28 mg/l at one sampling location during the winter months, with an average concentration of over 15 mg/l at four locations indicating that excess nitrogen had accumulated in the soil and leaching was occurring during high rainfall seasons when plant uptake was minimized. During the actively growing periods, NO_3-N levels were always below the critical levels of 10 mg/l. Nitrate-N concentrations in discharges from tile drains located in this field were less than 3 mg/l and normally was below 1 mg/l

phosphorus

Many wastes may contain considerably more phosphorus relatively to the nitrogen needs of most crops. Waste applications based entirely on N requirements of the crop may often over-fertilize with respect to P. However,

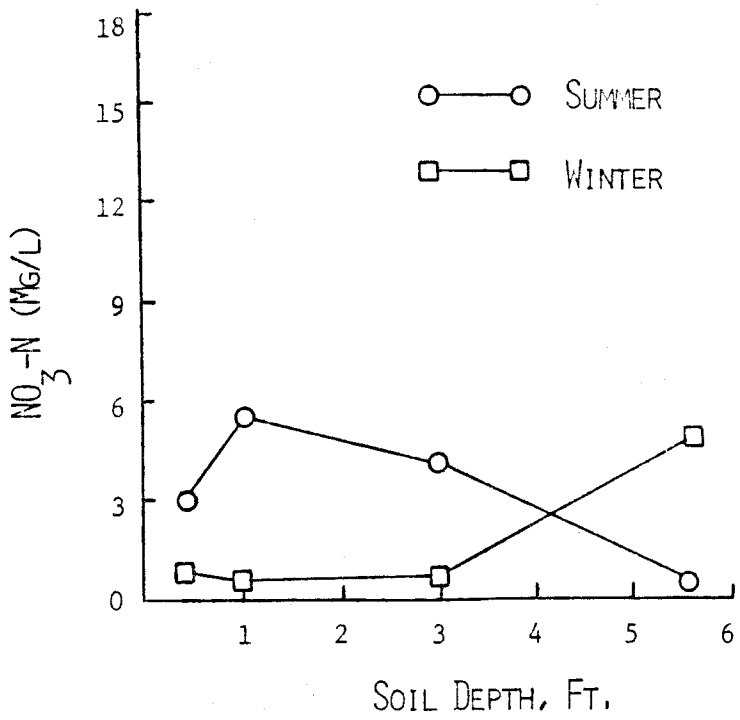

Fig. 4. Nitrate nitrogen content of soil leachate at field site 1.

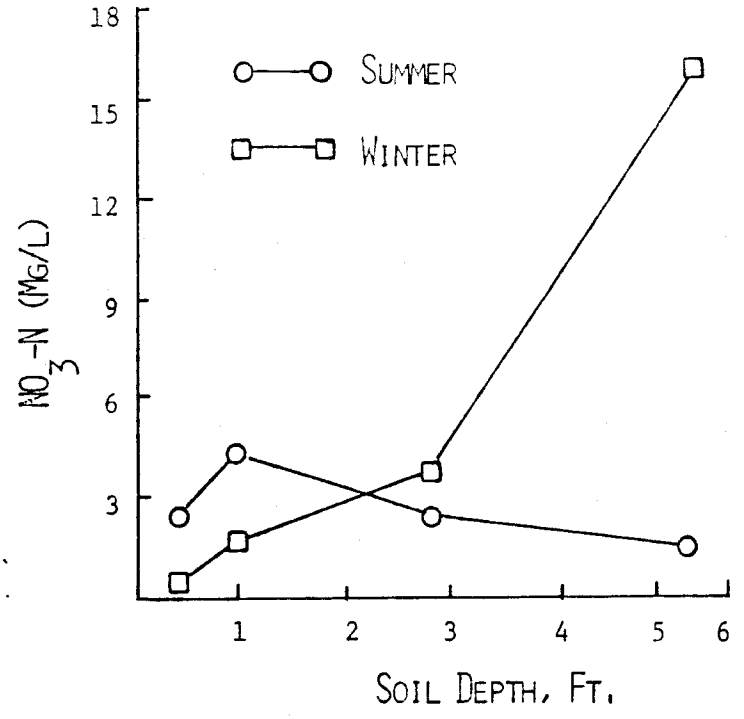

Fig. 5. Nitrate nitrogen content of soil leachate at field site 2.

Table 14. Yield and nutrient uptake of fescue pasture at site 1 for 1974-1975 growing season.*

Yield (d.m.) lb/a	Nutrient Uptake lb/a				
	N	P	K	Ca	Mg
15,760	246	51	504	36	32

*Total annual production measured by three cuttings and averaged over three sampling sites.

unless very high amounts of waste phosphorus are applied, this should present little problem in terms of leaching since P is both utilized by crops and adsorbed or precipitated by the soil. All of the applied inorganic P in wastewaters would be expected to be quickly immobilized in the soil through conversion to orthophosphate and adsorption by the soil or plant system. Organic P applied in the wastewater may be converted to orthophosphate more slowly but is retained by the soil until conversion. Under extremely heavy application rates, some wastewater including organic P may pass through the soil before sufficient time has elapsed for the conversion of all of the phosphate. However, at moderate application rates, the P will be adsorbed and removed by the soil with little danger of immediate loss to the drainage waters. Over fertilization with P should not present problems for many years although at high loadings, soils from each particular site should be examined with respect to their ability to adsorb P.

All land application sites investigated had phosphorus application rates of less than 200 lb/a/yr with exception of site 7, where the application rate was approximately 1400 lb/a/yr. A detailed sampling of this field (Page, 1971), revealed that a majority of the phosphorus had accumulated in the 0-6 inch soil depth with a slight build-up in the 6-10 inch soil depth. The soil at this site is a Lakeland sand, which although having a relatively low phosphorus fixing capacity is still capable of fixing and/or absorbing all of the phosphorus that would be added in this wastewater over a 50 year period at the current application rate.

Well managed land application fields can yield very large quantities of dry matter forage as evidenced in Table 14. Dry matter yield from replicated plots at site 1, showed quantities of near 8 tons per acre, over twice the yield for normally fertilized fescue pastures. Much higher uptake of N and K were also evident in these field samples, indicating some build-up of these elements in the soil.

Salt Loadings

Soluble salts generally do not accumulate in the soil of the Southeast since precipitation exceeds evapotranspiration in fall, winter, and spring and leaching will remove most of the salts. However, in local situations, salts from specialized industrial or processing units may give rise to abnormal concentrations in the wastewater plus evapotranspiration processes may further concentrate these salts in soils during the summer months. Tables 15 and 16 show the yield decrement to be expected for field crops and forages due to salt problems in applied irrigation water. As these data show, salt injury to sensitive crops can occur if wastewater containing more than about 1200 - 1400 mg/l of dissolved solids (electrical conductivity > 2.0 m mho/cm) is applied regularly during the summer months. Salt injury of tall fescue appears at a level of about 3000 mg/l (EC > 4.5).

An even greater problem with many industrial wastewaters is an imbalance of salts, especially Na in relation to Ca + Mg. This balance is measured by sodium adsorption ratios (SAR) and is calculated according to the following equation:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}}$$

with all concentrations expressed as me/l.

An example for the calculation of an SAR for a typical wastewater is shown below:

Na = 100 mg/l
Ca = 25 mg/l
Mg = 10 mg/l

$$SAR = \frac{\frac{100 \text{ mg/l Na}}{23 \text{ mg/me Na}}}{\sqrt{\frac{\frac{25 \text{ mg/l Ca}}{20 \text{ mg/me Ca}} + \frac{10 \text{ mg/l Mg}}{12 \text{ mg/me Mg}}}{2}}}$$

$$SAR = \frac{4.35}{1.02} = 4.26$$

Wastewater with SAR values greater than 10-12 become critical in terms of potential detrimental effects on soil structure and ultimate reduction in permeability and infiltration rates of soils. Only in soils having horizons

Table 15. Yield decrement to be expected for field crops due to salt concentration of applied water (Ayers, 1973).

Crop	Yield Decrement 0% ECw[1]	0% TDS	10% ECw	10% TDS	25% ECw	25% TDS	50% ECw	50% TDS
Barley	5.3	3,392	8	5,120	10.7	6,848	12	7,680
Sugarbeets	4.5	2,880	6.7	4,288	8.7	5,568	10.7	6,848
Cotton	4.5	2,880	6.7	4,288	8	5,120	10.7	6,848
Safflower	3.5	2,240	5.3	3,392	7.3	4,672	8	5,120
Wheat	3.1	1,984	4.7	3,008	6.7	4,288	9.3	5,952
Sorghum	2.7	1,728	4	2,560	6	3,840	8	5,120
Soybean	2.5	1,600	3.7	2,368	4.7	3,088	6	3,840
Sesbania	1.8	1,152	2.7	1,728	3.7	2,368	6	3,840
Rice (paddy)	2.2	1,408	3.3	2,112	4	2,560	5.3	3,392
Corn	2.2	1,408	3.3	2,112	4	2,560	4.7	3,008
Broadbean	1.5	960	2.3	1,472	3	1,920	4.3	2,752
Flax	1.3	832	2	1,280	3	1,920	4.3	2,752
Beans (field)	.7	448	1	640	1.3	832	2.3	1,472

[1] ECw = electrical conductivity of applied water in m mho/cm. ECw x 640 $\cong$ TDS in mg/l.

Table 16. Yield decrement to be expected for forage crops due to salt concentrations of applied water (Ayers, 1973).

Crop	Yield Decrement 0% ECw[1]	0% TDS	10% ECw	10% TDS	25% ECw	25% TDS	50% ECw	50% TDS
Bermuda Grass	5.8	3,712	8.7	5,568	10.7	6,840	12	7,680
Tall Wheat Grass	4.9	3,136	7.3	4,672	10	6,400	12	7,680
Crested Wh. Grass	2.7	1,728	4	2,560	7.3	4,672	12	7,680
Tall Fescue	3.1	1,984	4.7	3,008	7	4,480	9.7	7,208
Barley (hay)	3.5	2,240	5.3	3,392	7.3	4,672	9	5,760
Perennial Rye	3.5	2,240	5.3	3,392	6.7	4,288	8.7	5,568
Harding Grass	3.5	2,240	5.3	3,392	6.7	4,288	8.7	5,568
Birdsfoot Trefoil	2.7	1,728	4	2,560	5.3	3,392	6.7	4,288
Beardless Wild Rye	1.8	1,152	2.7	1,728	4.7	3,008	7.3	4,672
Alfalfa	1.3	832	2	1,280	3.3	2,112	5.3	3,392
Orchard Grass	1.1	704	1.7	1,088	3	1,920	5.3	3,392
Meadow Foxtail	.9	576	1.3	832	2.3	1,472	4.3	2,752
Clover	.9	576	1.3	832	1.7	1,088	2.7	1,728

[1] ECw = electrical conductivity of applied water in m mho/cm. ECw x 640 $\cong$ TDS in mg/l.

of at least 90 percent sand in the top 120 cm can high SAR waste be used without detrimental effects or the need for chemical amendments.

At SAR values from 5 to 15, soil structure can be impaired in soil horizons of loam or finer textures (>10 percent clay) by repeated applications over several years. Chemical amendments are recommended to prevent decline in soil percolation capacities at lower SAR values, especially in moderate to fine-textured soils. Ellis, 1973, reported one case of 25 percent reduction of infiltration rates resulting from 14 years of irrigation on moderately fine textured soils with SAR values of 3.

Other than excessive hydraulic loadings, high SAR values have created more problems with systems investigated in this study than any other physical or chemical factor. It is the waste component most often ignored in characterization of effluents and is usually thought of as a problem occurring only in the arid or semi-arid regions of the country. High SAR wastewater have been directly responsible for the near failure of at least two field sites in this study and only through an accelerated program of chemical alteration and resting of the spray field was the system salvaged.

It is much easier to treat the problem of Na imbalance in wastewater than it is to correct the effect. Once a soil has been deflocculated and the structure damaged, it is very slow and tedious procedure to partially restore the soil to its original condition. If the zone of damage is at the soil surface, the corrective problem is much easier since calcium salts can be surface applied and mechanically incorporated in the soil to immediately lower the sodium percentage of the soil adsorption sites. By means of mechanical manipulation and alternative wetting and drying procedures, the spray field may be restored to partial use in a matter of a few months.

The more common problem in soils of North Carolina, as well as the southeast, is that of structure deterioration of the upper B horizon (subsoil) due to high sodium loadings. The problem then becomes one of applying calcium salts to the soil surface and relying on natural leaching to move the soluble calcium down to the problem zone, some 8 to 16 inches below the surface. Since movement of water through the deflocculated zone is severely restricted, it may require one to two years to restore the soil percolation to reasonable rates.

The more reasonable solution to the problem of high SAR wastewaters is to reduce the Na problem at the source or apply adequate soil amendments to the field to maintain the proper Na to Ca + Mg balance. The material commonly used to apply to spray fields for proper salt balance is gypsum ($CaSO_4 \cdot 2H_2O$). This material is available at relatively low cost and offers a more soluble source of calcium than agricultural lime. The solubility of pure gypsum is approximately 2000 mg/l of which about 465 mg/l of calcium would be solubilized by rainfall or applied irrigation water.

To maintain wastewater SAR's at levels below 5 requires approximately equivalent weights of calcium to sodium. Using gypsum as the source of calcium

solubility limitations would restrict Na levels to less than 450 mg/l in the wastewater to maintain proper ratios in the soil leachate. This assumes that applied wastewater is fully saturated with Ca upon infiltration into the soil, which is probably not the case due to limited contact time of the wastewater with gypsum particles. There will, however, be additional gypsum solubilized by rainfall and leached into the soil profile. The limitation of 500 mg/l Na for maximum concentrations applied to soil appears to offer enough safety factor when using gypsum as the soil amendment for balancing Na-Ca ratios. At higher Na concentrations, a more soluble source of Ca and/or Mg could be used but total salts may then become a limiting factor.

The only industries surveyed in this study which showed problems with salts were those using NaOH as a part of the peeling operation in vegetable processing or as a cleaning agent in the daily cleanup of special equipment. Of the two vegetable processing plants investigated, both used "lye peel" processes for potatoes and one effluent showed an SAR of about 22 and Na concentration of 750 mg/l whereas the other plant had effluent SAR's of only 3 and Na concentrations of 35-40 mg/l. The main difference in the two plants was the better segregation and screening of peel wastes of the latter whereas much of the peel waste plus Na was included in the effluent discharged to lagoons and subsequently applied to the land at the former site. Even with liberal applications of gypsum to the spray field, deterioration of soil permeability was observed over the period of this study.

Table 17. Chemical composition of digester sludge from several municipalities in North Carolina.

Element	Municipality						
	High Point	Fayetteville	Morganton	Aberdeen	Roxboro	Raleigh	Chapel Hill
	Number of Samples						
	6	2	3	2	2	2	5
	Range in composition, % on dry weight basis						
N	1.2 - 5.2	1.05	7.5	2.6	3.3	2.0	1.89 - 2.79
P	1.6 - 1.7	1.48	1.0	1.9	1.9	1.5	1.9 - 2.9
Ca	1.6 - 1.7	1.70	0.39	1.1	1.1	2.7	2.01 - 2.57
Mg	0.36 - 0.37	0.12	0.18	0.19	0.2	0.2	0.17 - 0.23
Fe	2.7 - 3.2	1.72	1.17	1.6	1.6	1.9	1.5 - 2.0
K	0.07 - 0.27	0.04	0.26	0.34	0.10	0.11	0.09 - 0.11
Na	0.16 - 0.26	0.03	0.19	0.32	0.10	0.04	0.009 - 0.01
Zn	0.26 - 0.43	0.36	0.07	0.13	1.44	0.11	0.13 - 0.18
Mn	0.03 - 0.04	0.01	0.01	0.02	0.24	0.04	0.04 - 0.06
Cu	0.12 - 0.17	0.66	0.04	0.27	0.47	0.07	0.03 - 0.05
Ni	0.08 - 0.11	0.003	0.001	0.002	0.006	0.007	0.002 - 0.003
Pb	0.08 - 0.10	0.05	0.01	0.038	0.048	0.12	0.02 - 0.03
Cd	0.002 - 0.003	0.001	0.003	0.0013	0.0009	0.003	0.0007 - .001
Cr	0.15 - 0.23	0.01	0.003	0.006	0.34	0.11	0.008 - 0.009
Cd/Zn	.007	0.003	0.004	0.01	0.0006	0.027	0.005

Heavy Metal Loadings

While there were no municipalities in North Carolina which utilize land application as a primary system for disposal of effluents or sludge, several cities have investigated the possibility of using this method as a future means of sludge disposal. Samples of sludge were analyzed from several municipalities in North Carolina which requested information on land application techniques and expressed interest in developing a major program on land application of waste sludge. Some of this data is presented in Table 17.

The question which concerns all municipalities contemplating land spreading of sludge are the number of acres required on an annual basis to accept the sludge and the ultimate life of the site considering heavy metal accumulation. A recent draft of guidelines for municipal sludge management were published in the Federal Register under joint USDA-EPA authorship (see Appendix A). If these criteria are adapted as presented in the initial draft, maximum cumulative sludge loadings as well as annual loading rates could be calculated, knowing the cation exchange capacity of the soil, the crop to be grown, and the heavy metal and nitrogen content of the sludge to be applied.

The suggested guidelines list two categories of land application of sludge: 1) application to privately owned land, and 2) application to publicly owned or leased land dedicated to sludge application. For privately owned land, no greater amount of sludge-borne metals may be applied than those shown in Table 18.

Table 18. Maximum cumulative sludge metal applications for privately owned land.[1]

Metal	Soil Cation Exchange Capacity (meq/100g)[2]		
	0 - 5	5 - 15	>15
	Maximum metal addition, kg/ha		
Zr	250	500	1000
Cu	125	250	500
Ni	50	100	200
Cd	5	10	20
Pb	500	1000	2000

[1]Section 2-4.2 of the EPA Technical Bulletin on Municipal Sludge Management.

[2]Determined on unsludged soil using the method utilizing pH 7 ammonium acetate for a weighted average to a depth of 50 cm.

It is further suggested that sludges having cadmium contents greater than 25 mg/kg (dry weight) not be applied to privately owned land unless their Cd/Zn is <0.015.

To calculate annual rates of sludge application on land, the EPA guidelines suggest the lower of the following two values:

1. Cadmium loadings on land should not exceed 1 kg/ha/yr (0.9 lb/a/yr) from liquid sludge and not more than 2 kg/ha/yr (1.8 lb/a/yr) from dewatered sludge.

2. Nitrogen requirement of the crop, calculated on the basis of 100 percent availability of inorganic N and 20 percent availability of organic N of the sludge. If surface applied, sludge should be added at no more than 150 percent of the crop requirement for N and 100 percent of the crop requirement when sludge is incorporated.

The metal additions apply only to soils that are adjusted to pH 6.5 or greater when sludge is applied and managed at pH 6.2 or greater thereafter.

On publicly controlled land, up to five times the amounts of sludge-borne metals listed in Table 18 may be applied if the sludge is mixed into the 0-6 in (0-15 cm) surface soil. Where deeper incorporation is practiced, the recommended total metal application may be proportionally higher. Other criteria for sludge applications on public land are listed in the EPA guidelines (see Appendix A).

Using, as an example, sludge analyses from the municipal sludge digestors at High Point, North Carolina, calculations can be made as to allowable sludge applications on both private and public lands. These rates would be applicable to most of the Piedmont soils of North Carolina, which have soil cation exchange capacities in the range of 5-15 meq/100g in the top 50 cm. Cumulative application rates on Coastal Plain soils would probably be only one-half of these rates since the exchange capacity is normally below 5 meq/100g.

Based on analyses of sludge given in Table 17, concentration of significant elements in High Point digestor sludge are shown in Table 19.

Sludge Applications to Private Lands

Based on soil cation exchange capacities in the 5-15 meq/100g range in the top 50 cm of soils and using the recommended maximum cumulative sludge metal applications from Table 18, and the sludge composition from Table 19, the following cumulative sludge applications could be applied to most land areas of the Piedmont:

$$Zn = \frac{500 \text{ kg/ha} \times 0.405 \text{ ha/a}}{3.2 \text{ kg/ton}} = 63.5 \text{ tons/a}$$

$$\text{or } \frac{500 \text{ kg/ha} \times 0.405 \text{ ha/a}}{0.67 \text{ kg/1000 gal}} = 302{,}000 \text{ gal/a}$$

Table 19. Elemental composition of High Point digestor sludge.

Element	Dry Weight Basis		Liquid Basis	
	lb/ton	kg/ton	lb/1000 gal	kg/1000 gal
Organic N	80	36	16.7	7.6
NH_4-N	20	9.1	4.2	1.9
Zn	7.0	3.2	1.47	0.67
Cu	3.0	1.4	0.63	0.29
Ni	2.0	0.9	0.42	0.19
Pb	1.8	0.8	0.38	0.17
Cd	0.05	0.023	0.01	0.005

Cd/Zn = 0.007

$$Cu = \frac{250 \text{ kg/ha} \times 0.405 \text{ ha/a}}{1.4 \text{ kg/ton}} = 72.3 \text{ tons/a}$$

$$\text{or } \frac{250 \text{ kg/ha} \times 0.405 \text{ ha/a}}{0.29 \text{ kg/1000 gal}} = 349{,}000 \text{ gal/a}$$

$$Ni = \frac{100 \text{ kg/ha} \times 0.405 \text{ ha/a}}{0.9 \text{ kg/ton}} = 45 \text{ tons/a}$$

$$\text{or } \frac{100 \text{ kg/ha} \times 0.405 \text{ ha/a}}{0.19 \text{ kg/1000 gal}} = 213{,}000 \text{ gal/a}$$

$$Pb = \frac{1000 \text{ kg/ha} \times 0.405 \text{ ha/a}}{0.8 \text{ kg/ton}} = 506 \text{ tons/a}$$

$$\text{or } \frac{1000 \text{ kg/ha} \times 0.405 \text{ ha/a}}{0.17 \text{ kg/1000 gal}} = 2{,}382{,}000 \text{ gal/a}$$

$$Cd = \frac{10 \text{ kg/ha} \times 0.405 \text{ ha/a}}{0.02 \text{ kg/ton}} = 176 \text{ tons/a}$$

$$\text{or } \frac{10 \text{ kg/ha} \times 0.45 \text{ ha/a}}{0.005 \text{ kg/1000 gal}} = 810{,}000 \text{ gal/a}$$

Based on the sludge content of heavy metals, nickel would limit total accumulative sludge additions to private land to rates of 45 tons/a dry basis or 213,000 gal/a liquid volume, assuming soil pH's are adjusted to 6.5 or greater when sludge is applied and maintained at pH 6.2 or greater thereafter.

Annual rates of sludge applications on private land will be controlled by the lower of the following two values:

a) Cadmium loadings not to exceed 1 kg/ha/yr, using liquid digestor sludge

$$Cd = \frac{1 \text{ kg/ha/yr} \times 0.405 \text{ ha/a}}{0.023 \text{ kg/ton}} = 18 \text{ tons/a/yr}$$

$$\text{or } \frac{1 \text{ kg/ha/yr} \times 0.405 \text{ ha/a}}{0.005 \text{ kg/1000 gal}} = 81{,}000 \text{ gal/a/yr}$$

b) Nitrogen requirement of the crop

Nitrogen requirements are based on 100% of crop requirement when sludge is incorporated or 150% when sludge is surface applied. Due to the stability of the sludge organics, sludge nitrogen availabiltiy is based on 100 percent of inorganic N + 20% of organic N. This sludge would then have the following N availability:

$$\text{Organic N} = 2000 \text{ ppm} \times .20 = 400 \text{ ppm}$$

$$NH_4\text{-N} = 500 \text{ ppm} \times 1.0 = \underline{500} \text{ ppm}$$

$$\text{Total available N} = 900 \text{ ppm}$$

$$900 \times 10^{-6} \times \frac{8340 \text{ lb}}{1000 \text{ gal}} = 7.5 \text{ lb N/1000 gal}$$

Dependent on the crop to be grown, soil nutrient requirements are as shown in Table 20.

Table 20. Annual nitrogen requirement for certain crops.

Crop	100% N Requirement lb/a	150% N Requirement lb/a
Corn, grain	150	225
Corn, silage	200	300
Fescue pasture	200	300
Small grains	100	150
Coastal bermudagrass	400	600

Annual recommended sludge application rates could then be calculated as given in Table 21.

Table 21. Annual application rates of sludge based on nitrogen requirements of selected crops.

Crop	Sludge, Incorporated		Sludge, Surface Applied	
	tons/a/yr	1000 gal/a/yr	tons/a/yr	1000 gal/a/yr
Corn, grain	4.2	20	6.3	30
Corn, silage	5.6	26.6	8.3	40
Fescue pasture	5.6	26.6	8.3	40
Small grains	2.8	13.3	4.2	20
Coastal bermuda-grass	11.1	53.3	16.7	80

Nitrogen loadings would control annual sludge applications in all instances. Under continuing yearly sludge applications, some nitrogen would be available from previous years application and annual loadings would be reduced accordingly.

Sludge Applications on Public Controlled Lands

If certain criteria are met, sludge may be applied to publicly controlled lands at rates up to five times the amounts of sludge metals listed in Table 18. These rates may be used only if:

a) The sludge is mixed into the 0-15 cm of surface soil.
b) The soils are adjusted to pH 6.5 or greater when sludge is applied.
c) Metal analyses will be provided to purchasers of marketed products.

If these criteria are not met, then total cumulative sludge applications will be as recommended for privately owned land. Annual application rates would also be under the same limitations as for private lands. By adhering to the above criteria, total cumulative sludge applications could be made to public lands up to 225 tons/a with nickel loadings again being the limited element.

A consideration in any sludge program should be in terms of reducing heavy metal concentrations in the sludge to allow greater utilization on agricultural land. One objective of a publicly owned sludge field would be for it to have a usable life span of at least 25 years. Also minimum annual sludge application rates should be at least 10 tons/a (dry wt. basis) to

supply nitrogen requirements of the crop and minimize land area needed. Based on these concepts, permissable metal concentrations in a sludge to be applied to soils with CEC's of 5-15 meq/100g are shown in Table 22.

Table 22. Maximum allowable concentrations of heavy metals in sludge applied to soils with CEC of 5-15 meq/100g.

Element	Allowable Concentration	
	Dry. Wt. Basis	Wet Wt. Basis
	ppm	
Zn	892	45
Cu	446	23
Ni	178	9
Pb	1784	90
Cd	13.4	0.68

These metal concentrations represent values which are only 20 to 25 percent of the level presently measured in many sludges in North Carolina. If a publicly controlled sludge application site is to be utilized in municipal programs, either considerable reduction in metal concentrations should be encouraged or the site should be strictly managed such that sludge rates could be applied at the higher rates as presented in the USDA-EPA guidelines for public lands.

SYSTEM MANAGEMENT

Management of land application systems includes management of the soil, crop, irrigation, monitoring equipment, pretreatment waste systems, and any other mechanical equipment associated with the farm operations. Generally, no one person is usually qualified in all of these areas, yet in most sites investigated, one employee had all of this responsibility. Management problems appears to be responsible for poor performance of a majority of land application systems rather than design loadings.

Management problems can be classified into four major categories including: a) the irrigation system, b) field management, including both crop and soil, c) in-plant errors and malfunctions, and d) natural phenomena.

The irrigation system probably offers the greatest problem, starting with poor initial design and including the day to day operations. Theoretically, the system is designed to add wastewater uniformly over the spray field, but this is seldom achieved. Due to inadequate line pressure,

improperly spaced or sized sprinklers, and/or frequent start-up and shut-down of the system, water application rates increase rapidly from the perimeter of the sprinkler area inward to the sprinkler head in many spray fields. This results in an overload in an area around the sprinkler which may destroy the vegetation and a progression of better vegetation toward the perimeter. Reducing the number of system start-ups and shut-downs may alleviate some of this problem whereas other sites needed a major renovation of their total system. Systems designed to "dose" a field, i.e., apply a weeks hydraulic load during one day tend to offer a more even distribution of material and better renovative capacity of the soil-plant system.

Other problems occasionally encountered include leaking control values (especially butterfly valves), air leaks in pneumatic systems, nozzle clogging, broken sprinkers and risers, malfunctioning timers, and negligent switching of field lines. These problems may be minor but can have serious consequences if not discovered and corrected immediately.

Field management problems are usually more subtle and may go unnoticed by an untrained eye. Such things as improper application of fertilizer nutrients and soil amendments, poor coordination of crop harvesting with wastewater applications, selecting improper type of crop, and improper treatment of disease and insect problems all tend to reduce the effectiveness of the system. Because the field system, including both the soil and crop, is the heart of a land application system, consultation with appropriate agricultural experts should be a planned aspect of managing the system.

Crop selection should be based on the degree of management placed on the field program. Vigorous, water-tolerant grasses which form dense sods are ideal for waste application. Tall fescue appears most promising under climatic conditions for most of North Carolina because of its high productivity under continuously moist conditions. Reed canarygrass was interplanted with tall fescue on several field sites investigated but disappeared after a few years, apparently from disease problems. Coastal bermudagrass can be a higher productive crop than tall fescue in terms of yield, nutrient uptake, and value of the product. However, the management must be at a much higher level than normally practiced on spray fields because this grass must be removed or harvested and does not tolerate poor internal drainage. The growing season for Coastal bermudagrass is much shorter and will require overseeding with winter grasses if year-around applications of water are required. Row crops such as corn or forage sorghums may be produced on the field but will require much higher levels of management and coordination if they are to be produced successfully.

In-plant malfunctions or errors can have disastrous effects on the spray field if no pretreatment or short detention times are practices prior to irrigation. Under such systems, in-line safety monitors are needed to shut down the system before the toxic material reaches the field.

Natural phenomena include severe freezing, extended rainstorms and other uncontrollable problems such as vandalism. These can be handled through preplanning and frequent inspections of the field system.

PUBLIC HEALTH

Public health aspects of applying sewage wastes to land was not a major emphasis of this study since no municipal systems of land spreading were in operation during the period of the project. However, potential disease hazards from such applications are a major concern to those involved in safeguarding the environment against either known or theoretical hazards.

The ability of certain pathogenic organisms, especially viruses and certain bacteria, to survive wastewater treatment processes including chlorination, coupled with a lack of knowledge as to their ultimate role in disease outbreaks adds greatly to our concern in extensive land spreading of sewage wastes. This uncertainty makes even more questionable the continued discharge of sewage effluents into surface waters used as a water supply and contact recreation for a majority of the population of the state.

Two extreme positions have been taken on land application of sewage. One extreme view would ban the use of sewage wastes on land unless it could be shown that no disease producing organisms were present. The other would permit any application of sewage wastes to land as long as the practice had not been known to result in appreciable disease outbreaks. The more satisfactory position would be somewhere between these extremes, using our most current knowledge on soil-pathogen interactions and applying these to develop alternative systems to economically reduce the number of viable pathogens reaching our water supplies and recreation areas.

There are several highly qualified scientists currently involved in studies on the health aspects of applying sewage wastes on land. A recent review of this work was presented by Burge, 1974, at a workshop in the North Central Regional Conference. A reprint of the summary and conclusions of this paper is presented in Appendix B, and generally summarized the current thoughts of the more knowledgeable scientists in the area of health aspects of land spreading of wastes.

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GLOSSARY

Abbreviations (units)

a	-	acre(s)
bu	-	bushel(s)
cm	-	centimeter(s)
cm^2	-	square centimeter(s)
g	-	gram(s)
gal	-	gallon(s)
ha	-	hectare(s)
hr	-	hour(s)
kg	-	kilogram(s)
l	-	liter(s)
lb	-	pound(s)
m^2	-	square meter(s)
me	-	milliequivalent(s)
mg	-	milligram(s)
ppm	-	parts per million
sec	-	second(s)
T	-	ton(s)
µmho	-	micro-mho(s)
wk	-	week(s)

Terms

atm	-	Atmosphere(s)
BOD	-	Biochemical Oxygen Demand
CEC	-	Cation Exchange Capacity
COD	-	Chemical Oxygen Demand

d.m.	-	Dry Matter
EC	-	Electrical Conductivity
ET	-	Evapotranspiration
FC	-	Field Capacity
ls	-	Loamy Sand
NOD	-	Nitrogen Oxygen Demand
SAR	-	Sodium Adsorption Ratio
s	-	Sand
sl	-	Sandy Loam
sil	-	Silty Loam
TDS	-	Total Dissolved Solids
TOD	-	Total Oxygen Demand

APPENDICES

Appendix A

USDA SUGGESTED DRAFT OF SECTION 2-4.2 OF THE

EPA TECHNICAL BULLETIN ON MUNICIPAL SLUDGE MANAGEMENT

Suggested Draft of Section 2.4:

2.4 Additional Requirements for Sludge Application to Agricultural Land. The application of sludge to agricultural lands which may be used to grow crops must be accomplished so as to ensure that cropland resources are protected and harmful contaminants are not accumulated in the human food chain.

Additional Requirements for Sludge Application for Forested Land

Current knowledge is inadequate to permit setting precise limits of heavy metal application to lands dedicated to forest production. Disposal on forest lands of sludge containing those metals listed in Table A is considerably less hazardous than on cropland.

Forest vegetation is not a principal food for domestic animals, so food chain considerations are of relatively little concern. In the event the land is converted to food crop production the limits set for agricultural land would apply. Prevention of damage to trees and associated forest vegetation and to wildlife must be assured. Current knowledge suggests that the maximum sludge application to forested sites may be determined by the nitrogen content of the sludge.

Whenever land disposal of sludge is extensively or repeatedly practiced, effects on wildlife population should be monitored and controlled. Water quality must also be monitored and controlled; and soil erosion, overland flow, and rapid percolation of contaminants into shallow ground water aquifers must either be prevented or controlled.

2-4.2. Protection of Agricultural Lands. The following interim criteria are based on recommendations of the U. S. Department of Agriculture. These limits are based on experiments directed at the determination of levels of heavy metals which are toxic to plants or absorbed by plants. Because of the great uncertainty concerning the appropriate level of intake by humans of these heavy metals as part of their diet, EPA cannot say that these levels constitute the appropriate levels for human intake. To the extent, however, that the limits represent an attempt to keep the levels of heavy metals in foods at a lower point than would otherwise be the case, these limits will make a contribution to the protection of public health. There will be two categories of land application of sludge: (1) Application to privately owned land (hereafter denoted privately owned land) and (2) Application to land dedicated to sludge application, e.g., publicly owned or leased land (hereafter denoted publicly controlled land).

1. Application criteria for privately owned land.
No greater amount of sludge-borne metals may be applied than those shown in Table A:

Table A. Maximum cumulative sludge metal applications for privately owned land.

Metal	Soil Cation Exchange Capacity (meq/100g)*		
	0 - 5	5 - 15	>15
	Maximum metal addition, kg/ha		
Zn	250	500	1000
Cu	125	250	500
Ni	50	100	200
Cd	5	10	20
Pb	500	1000	2000

*Determined on unsludged soil using the method utilizing pH 7 ammonium acetate for a weighted average to a depth of 50 cm.

It is suggested that sludges having cadmium contents greater than 25 mg/kg (dry weight) should not be applied to privately owned land unless their Cd/Zn is ≤ 0.015. Annual rates of sludge application on land should be lower of the following two values (1 or 2):

1. Nitrogen requirement of the crop (inorganic N + 20% organic N).

   a. When incorporated - sludge should be applied at no more than 100% of the crop requirement for N.
   b. When surface applied - sludge should be added at no more than 150% of the crop requirement for N.

2. Cadmium loadings on land should not exceed 1 kg/ha/yr from liquid sludge and not more than 2 kg/ha/yr from dewatered sludge.

Sludge having a cadmium content greater than 1.5 percent of its zinc content should not be applied on a continuing basis unless there is an abatement program to reduce the quantities of cadmium in the sludge to an acceptable level. These metal additions apply only to soils that are adjusted to pH 6.5 or greater when sludge is applied, and are to be managed at pH 6.2 or greater thereafter (soil pH determined by 1:1 water, or equivalent method).

Growing leafy vegetables on sludge treated land is not recommended without monitoring the metal content of the crop.

Sludge should not be applied to soils with less than 50 cm of depth.

II. Application criteria for publicly controlled land.

On publicly controlled land, up to 5 times the amounts of sludge-borne metals listed in Table A may be applied if the sludge is mixed into the 0-15 cm surface soil. Where deeper incorporation is practiced, proportionally higher total metal applications may be made. These metal applications apply only to soils that are adjusted to pH 6.5 or greater when sludge is applied.

If the sludge metal application rates exceed those recommended for privately owned land, metal analyses shall be provided to purchasers of marketed products. Purchasers may wish to consult the appropriate state and federal agencies concerning the relevance of these analyses.

These comments and recommendations are based on best available information and should be subject to revision as new information becomes available.

Appendix B

HEALTH ASPECTS OF APPLYING SEWAGE WASTES TO LAND[1]

Wylie D. Burge[2]

Summary

There is a great deal of evidence that processed sewage wastes, including chlorinated effluents and digested sludges, still contain viral, bacterial, protozoan, and helminthic agents of disease. It appears, however, that the great majority of illinesses associated with sewage have been attributable to application of raw sewage wastewater, raw sludges, and night soil to crops to be consumed raw; to contamination of private water supplies by septic systems; and to consumption of raw shellfish grown in sewage-polluted waters. Further, despite the presence of disease organisms in sewage wastes, their appears to be little hazard to sewage plant workers who certainly receive a maximum of exposure. There is a paucity of literature on the hazards of infection for workers irrigating with chlorinated effluents or land-spreading sludges, but the apparent lack of disease incidence among sewage plant workers indicates that there is little hazard for these people. There also seems to be little hazard to the people of communities adjacent to land disposal systems.

Although much needs to be defined about how soils remove pathogens, particularly viruses, from percolating waters, the evidence indicates that sewage sludges or effluents can be applied to soils, if the soils are not extremely coarse textured, without resultant contamination of the ground water with pathogens. Amoeba cysts and helminth ova are large enough to be removed by filtration. Bacteria and viruses are small enough to move in the pore systems of most soils but are adsorbed from the percolating waters by the soil material. While bacteria and viruses may be removed in a meter or less of the vertical percolation of water, saturated lateral flow of water through the soil induced by impervious layers may carry the organisms for much greater distances. The greatest hazard, however, for movement of pathogens results from soil runoff of water; provisions should be made for capturing and retaining or recycling the runoff water onto the utilization site.

The threat of infection to sprinkler irrigation-site workers and to the surrounding communities through exposure to pathogens containing aerosols has not been completely defined, but experience and available literature seem to indicate that the threat is minimal. The communities can be protected by borders, plantings of bushes and trees for screens, and use of spray-irrigation systems designed to minimize aerosol production and movement.

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[1]Presented North Cen. Reg. Cont. Workshop, "Educational Needs Associated with Utilization of Wastewater Treatment Products on Land," Kellog Center, Mich. St. Univ., East Lansing, Mich., Sept. 23-26, 1974.

[2]Soil Scientist. Biological Waste Management Laboratory, Agricultural Environmental Quality Institute, Agricultural Research Service, U. S. Department of Agriculture, Beltsville, Md.

Disinfection of sewage effluents is mainly by chlorination but is seldom complete. Sludges can be partially disinfected by heat drying, liming, chlorination, composting, or completely disinfected by pasteurization. Heat drying is costly but is effective. Liming is mainly used for stabilization of raw sludge prior to disposal by land fill. Chlorination is used in a few sewage plants in the United States and besides lowering pathogen content, tends to stabilize the sludge, possibly preventing odor production. Composting produces an esthetically pleasing product, and is effective in pathogen destruction if conducted properly. Pasteurization is very effective in killing pathogens but does not stabilize the sludge. Pasteurization may be a desirable method for sludges to be applied to crop lands for growth of vegetables to be consumed raw or to dairy pastures.

In general, there appears to be little danger either to workers or people of surrounding communities when chlorinated sewage effluents are used for irrigation, or when anaerobically digested sludges or sludges whose pathogen content has been greatly reduced by other means are applied to soils for production of crops not to be consumed raw directly by humans. The application of raw sewage wastewater, night soil, septic tanks pumping, and raw sewage sludges has, however, been associated with the spread of disease. Their utilization on farm land presents unacceptable risks.

The number of states regulating the use of sewage wastes on food crops is growing. The regulations usually prohibit the use of raw sewage on growing crops and provide that partially disinfected effluents shall not be used to water food crops to be consumed raw. In the absence of regulations, it would seem wise to follow the above guidelines. The question of how long land treated with anaerobically digested or partially disinfected sewage wastes should remain out of production of food crops for consumption raw is being debated. The time adopted will more than likely not be less than a year and could be much longer. Most pathogens will perish or be at very low numbers in a year's time. Some ascaris ova may remain viable in soil for much greater lengths of time. Whether they can be a significant source of infectivity after a year is part of that debate.