UNC-WRRI-94-282

ASSESSMENT OF MUNICIPAL SLUDGE MANAGEMENT PRACTICES IN NORTH CAROLINA

CASE STUDIES

BY

J.P. Zublena
Department of Soil Science
A.R. Rubin
Department of Biological and Agricultural Engineering
North Carolina State University
and
C.R. Campbell
M.R. Tucker
North Carolina Department of Agriculture
Agronomic Division

The research on which this report is based was financed by the Water Resources Research Institute of The University of North Carolina.

WRRI Project No. 70102

March 1994

One hundred fifty copies of this report were printed at a cost of $1,313.50 or $8.75 per copy.

ACKNOWLEDGEMENTS

This project was funded by the University of North Carolina Water Resources Research Institute. A special note of appreciation is expressed to Drs. David Moreau and Robert Holman for their patience and support.

Appreciation is also given for the conscientious and diligent efforts of John Hunt, who collected much of the field data, to J. Barrett Richards, who computerized the data base and developed the graphics, and to David A. Crouse, who performed the nitrate extractions and analyses.

ABSTRACT

An evaluation of municipal wastewater treatment operators and land application sites was initiated to: 1) assess operator knowledge and attitude and 2) examine the effect of municipal sludge and its management on soil pH, and soil and plant nutrient and heavy metal concentrations.

An evaluation of training needs for wastewater treatment plant operators found inadequate knowledge of sludge management options as a major problem. Over 60% of the operators had 5 years experience and 40% had completed a college degree program. Approximately 90% of the facilities required some sludge management.

Evaluation of 28 soil sites receiving sludge has generally shown increases in concentrations of P, Zn, Cu, Ni, Pb and Cd compared to untreated checks. The increased concentrations have tended to remain in the surface 0.0-1 feet of soil and show little movement to greater depths. Some exceptions existed especially for P. Concentrations of most heavy metals were not high enough to pose plant toxicity symptoms with the distinct exception of Zn.

Eleven of the 28 treated areas had <10 mg/kg NO_3-N at all depths sampled. Nine additional areas had >10 mg/kg NO_3-N between 0.0 and 3.0 feet. The remaining eight treated areas had >10 mg/kg NO_3-N below three feet, indicating nitrogen management problems at the site.

The most common soil profile accumulation pattern for nitrate showed decreasing nitrate concentrations from the surface, followed by a concentration increase and subsequent decrease. Eleven untreated and 17 treated areas exhibited this accumulation pattern. The next most prevalent pattern showed high nitrate concentrations in the surface with decreasing concentrations thereafter. Twelve of the untreated areas and four of the treated areas had this pattern. The remaining nitrate accumulation patterns were less common.

Twenty-two of the field sites were also evaluated using plant tissue analysis. Crops being grown on sludge amended soils were generally low or deficient in N and had adequate P for plant growth. Copper levels were generally sufficient. Nickel and Pb concentrations in plants were low. Zinc and Cd, however, have been found at concentrations of concern. Zinc concentrations in plant tissues were considered in excess of plant nutrient needs in 50% of the treated areas. Cadmium concentrations in 32% of the treated samples and 9% of the untreated samples had concentrations above the 0.5 ppm Cd Maximum Dietary Levels for Livestock.

Approximately 71% of the treated soils had pH values below agronomicly acceptable levels for plant growth.

TABLE OF CONTENTS

LIST OF TABLES

SUMMARY AND CONCLUSIONS

The evaluation of existing land treatment facilities and practices was initiated with the following objectives.

1) To evaluate operator knowledge and attitudes regarding wastewater treatment system operation and sludge management practices.

2) To examine existing land application sites to assess the influence of municipal sludge and its' management on soil pH, nutrient and heavy metal concentrations.

3) To examine existing land application sites to assess the influence of municipal sludge and its' management on plant concentrations of nutrients and heavy metals.

A survey of wastewater treatment plant operators was conducted in 1988 to assess their knowledge and attitudes of wastewater treatment. A total of 808 responses were collected. Sludge management was listed as a frequent cause of problems in the day-to-day operations and as an area in which additional training was needed. Over 40 percent of those operators questioned listed alternatives to land filling of sludges as the most critical training need.

A telephone survey was initiated in 1990 to determine the characteristics and operational difficulties which exist at permitted wastewater treatment plants (WWTP) operating in North Carolina. A total of 58 individual operators were questioned. Operators with grades one, two, three, or four certifications were questioned about the following:

1. years of experience;
2. years of education;
3. size of facility (flow);
4. unit processes represented at the treatment facility;
5. sludge management practices utilized at the treatment facility;
6. training needs of individual operators and employees;
7. problems associated with daily operations.

Each factor contributes to the success of a well operated waste treatment facility. Survey results showed:

• Over 60 percent of the operators had 5 years experience operating wastewater treatment facilities and only one had less than one year experience.

• Five operators had not completed high school while twenty-four completed a college degree program. Five operators had post-graduate college training.

• Facility sizes ranged from less than 10,000 gallons per day to over 25,000,000 gallons per day.

• Approximately 90 percent of the facilities required some sludge management practice associated with the wastewater management alternative.

• Most operators relied heavily upon land application as a means to manage sludges produced in the wastewater treatment facility.

• Land filling and land application constituted the major sludge management practices utilized in North Carolina.

• Sludge placed in land fills was used in the top two feet of cover and not in the active land fill cells. Several facilities utilized land filling as a supplement to ongoing land application operations.

• Sludge management was frequently cited as a principle factor in determining the successful operation of a wastewater treatment facility.

Evaluation of 28 soil sites receiving sludge has generally shown increases in concentrations of P, Zn, Cu, Ni, Pb and Cd compared to untreated checks. The increased concentrations have tended to remain in the surface 0.0-1 feet of soil and show little movement to greater depths. However, some exceptions do exist especially for P. Soil concentrations of most heavy metals were not high enough to pose plant toxicity symptoms with the distinct exception of Zn. Extractable Zn concentrations in the soil surface were at levels (>8.5 mg/dm^3) that could cause toxicity problems especially where low soil Ph exists and when using a Zn sensitive crop like peanuts. Fourteen treated areas and 5 untreated areas had extractable Zn levels > 8.5 mg/dm^3.

Eleven of the 28 treated areas had <10 mg/kg NO_3-N at all depths sampled. Nine additional areas had >10 mg/kg NO_3-N between 0.0 and 3.0 feet. The remaining eight treated areas had >10 mg/kg NO_3-N below three feet indicating nitrogen management problem at the site.

The most common soil profile accumulation pattern for nitrate in both treated and untreated areas showed decreasing nitrate concentrations from the surface followed by a concentration increase and subsequent decrease. Eleven untreated and 17 treated areas exhibited this accumulation pattern. The next prevalent pattern showed high nitrate concentrations in the surface with decreasing concentrations thereafter. Twelve of the untreated areas and four of the treated areas had this pattern. The remaining nitrate accumulation patterns were less common.

Twenty-two field sites in 10 municipalities that utilize land application for disposal of sludge were also evaluated using plant tissue analysis. At each field site, plants were also taken from a buffer area or from an untreated adjacent field to serve as a check for comparative purposes.

Results of this assessment suggest that crops being grown on sludge amended soils generally are low or deficient in N and have adequate P for plant growth. Copper levels are generally sufficient but there are some sites that show uptake in excess of crop needs. Nickel and Pb do not appear to be problems and are found in low concentrations in plant tissue. Zinc and Cd, however, have been found at concentrations of concern. Zinc concentrations in plant tissues were considered in excess of plant nutrient needs in 50 % of the treated areas. Tissue concentrations over 220 mg/kg were found at two treated locations in bermudagrass. Concentrations >220 mg/kg Zn were found to be toxic to peanuts (Cox, 1990). Cadmium concentrations in 32 % of the treated samples and 9 % of the untreated sample had concentrations above the 0.5 ppm Cd Maximum Dietary Levels for Livestock. Results of this assessment suggest that cadmium accumulation in plant materials is a major concern for land application of sludge and that managers should be encouraged to utilize plant tissue sampling as an additional monitoring tool.

Approximately 71 % of the treated soils had pH values below agronomically acceptable levels for plant growth. From the results of this assessment there appears to be a general disregard to the importance of soil pH in controlling heavy metal uptake. And in the importance of an optimum soil pH to promote plant growth that subsequently removes nutrients.

RECOMMENDATIONS

More than 25% of the surveyed sites receiving sludge had >10 mg/kg NO_3-N below the root zone (>3'). These results indicate a need for better N management. Nitrogen management should emphasize application rates to meet site specific yield potentials; application timing to coincide with periods of active crop growth to utilize plant available N and optimum spreader patterns to promote uniform fertilization.

The study found Zn and Cd to be the only heavy metals of concern. Half of the treated sites had soil extractable Zn concentrations >8.5 mg/dm^3. Cox (1990) showed concentrations >8.5 mg/dm^3 could cause Zn toxicities in peanuts in the presence of low soil pH. While Cd was not detected at high levels in the soil, 32% of the treated sites had tissue concentrations above the maximum dietary level for livestock which is 0.5 ppm.

These findings indicate that municipalities should continue to seek ways to reduce heavy metal concentrations in sludge and to develop long term soil analysis records for permitted sites. When concentrations of heavy metals approach levels of concern, termination of additional applications should be considered regardless of predetermined site-life values. In addition to soil testing plant tissue analysis should be utilized when forage from sludge treated area is sold. Special attention to tissue Cd concentration is warranted.

Results also indicate a need for research on heavy metal extraction techniques. Correlation of extractable metals to plant uptake and determination of "critical levels" of extractable metals in soils is needed.

Ninety-six percent of treated sites had soil pH values below the required permit level of 6.5. Results indicate that either routine soil tests are not taken at permitted sites or that they are taken and not evaluated. Optimum pH for plant growth and reduction of metal availability is an important management tool that is being neglected.

Operators of land treatment facilities must continue to receive the necessary training concerning the proper operation and required maintenance for all aspects of wastewater and sludge management programs.

The utilization of municipal wastewater treatment plant sludge to support agricultural production will require the continued evaluation of the quality of the materials applied to land.

Comprehensive record keeping and management requirements will dictate that operators maintain all records regarding their land treatment operation and these records must address the quality of sludge applied, application rates, crop quality and yield, soil test results, and, where required, ground water quality data.

Training and certification requirements mandated for NPDES facilities should be extended to better address the specific needs of land treatment facility operators.

INTRODUCTION

An assessment of on going municipal wastewater treatment plant sludge management practices for North Carolina is long overdue. The basic problem appears to be a lack of information regarding the quantity and quality of sludges produced by municipalities as well as insufficient analysis of the effectiveness of existing management practices to adequately treat and renovate those materials. The administrator of the United States Environmental Protection Agency strongly supports the beneficial reuse of wastewater treatment plant residuals or sludges. Options available for managing sludge include: direct land application, land application of composted or chemically stabilized sludges, incineration, monofilling or long term storage. There are several factors which make sludge management decisions increasingly more difficult. The recently proposed sludge management guidelines from the United States Environmental Protection Agency will limit the potential for various sludge management options. While the options available for managing sludges get more and more stringent, increasing volumes of waste are produced at a growing rate. Municipal sludge production in the United States doubled between 1972 and 1985 (EPA,1984). As populations continue to increase, the number of years required for this figure to redouble will again decrease. North Carolina's growth rate is greater than the national average and increasing at a rate equivalent to a city of over 100,000 people per year. With this accelerated growth rate, North Carolina must address and develop strategies for effective waste management.

Annual sludge production in the United States is projected to reach 12 million dry metric tons per year in 2000 (EPA, 1984). North Carolina sludge production in 1990 was estimated to be 200,000 dry tons (Ramsey, 1989). These materials are produced in municipal and industrial wastewater treatment facilities in the primary phase of treatment, the secondary or biological phase of treatment, and, where installed, in the tertiary or final stages of treatment. Increasingly stringent water quality standards are being imposed on municipalities statewide. These standards will contribute to the production of increased volumes of sludge in North Carolina, and by the year 2000 the volume is expected to double.

Wastewater treatment plant sludges are composed of solid and semi-solid material removed from wastewater treatment processes during various operations. Sludges produced in wastewater treatment facilities are subjected to several conditioning phases prior to ultimate disposal for beneficial reuse. All sludges are generally processed to remove liquid, destroy pathogenic micro-organisms, minimize odor potential, and to facilitate the ease of handling.

Historically, the disposal of stabilized sludge has been managed by one of several methods: Ocean disposal, land filling, distribution and marketing, incineration, chemical conditioning, and land application. Of these land filling is the most common. By 1993, the practice of ocean disposal must be eliminated (Environment Reporter, 1988). Further, the North Carolina Solid and Hazard Waste Management Division recently adopted a regulation that prohibits co-disposal of sludge in unlined solid waste landfills. Sludges can be utilized in the top two feet of landfill cover (NCAC 10.0505). Presently, the disposal of sludge in a dedicated landfill or monofill is acceptable. Locating a monofill site is difficult and expensive. There are limited opportunities for marketing products that are produced from containing sludge, such as compost or lime stable product, but these options are gaining popularity and may soon be feasible alternatives for managing a large portion of the sludge produced by municipalities statewide. The most feasible options for managing sludge produced at wastewater treatment facilities in North Carolina today, however, are incineration and land application, with increasing reliance on distribution and marketing.

The United States Environmental Protection Agency has encouraged the beneficial utilization of wastewater treatment plant sludges for many years considering it a viable mechanism for resource recovery (EPA, 1988). For many years, farmers in North Carolina and throughout the world have utilized waste as a soil conditioner and nutrient source. Wastewater treatment plant sludges have been successfully applied to crop land, forest land, and reclamation sites.

The technical and popular literature concerning the various technologies available for sludge management is voluminous. The EPA (1983) prepared a technology transfer publication considered to be the basis for design of sludge land treatment programs. King (1986) reviewed the status of land treatment technology throughout the Southeast. Land treatment literature addresses four major aspects of this technology. These aspects are: overall environmental effects, silvicultural and agricultural benefits, health effects, and social/economic/political factors influencing the acceptance or adoption of land treatment.

A model was developed for predicting the leaching potential of nitrate nitrogen from land treatment facilities (Haith 1983). The factors evaluated in this model include mineralization potential of the sludge, the ammonia volatilization, crop uptake, and existing ground water quality. (Hinsley, et. al. 1984) discussed a ten-year study of the effects of sludge application on land. Quality of runoff water and drainage water were evaluated. Metal uptake by plants, potential vital toxicity, plant germination rates for selected crops, and the effects on livestock from consuming the crops grown on sludge amended soils were evaluated. Overcash and Loehr (1986) evaluated sludges from throughout the United States to determine the presence of toxins and priority pollutants.

The silvicultural and agricultural effects of sludge have been summarized in several publications. A number of studies have indicated that heavy metal loading rates, which were considerably higher than those established by EPA, had no significant adverse effect on plant growth (Heckman, et al. 1987; Payne et al. 1988). Higgins (1984) studied the effects of sludge application on corn and rye and found enhanced crop yields from application programs. Zinc levels were increased slightly above background or control levels in both the soil and vegetation. Coker and Matthews (1983) discussed the potential of heavy metal contamination of soil and the possible effects of metals on plant tissue. Adriano (1986) wrote an excellent text on trace metals that discusses their natural occurrence in soils, their chemical transformations and movement in soils, and their effect on soils, plants, drinking water and food.

The health effects of land treatment have been summarized in several sources. (Brown, et. al. 1985) reviewed sludge application programs and found no significant health risks associated with land treatment of sludge when low application rates are used. Kowal (1986) reviewed potential adverse health effects following land treatment of municipal sludge. Liv (1982) evaluated potential for micro-organism migration into ground water and concluded that there was little danger of contamination following surface application or subsurface injection of sludges.

The social and economic factors influencing sludge application are critical to the overall success of any land treatment program. Pederson and Vallis (1982) indicated that farmers value sludge as a potential nutrient source. This value as a fertilizer source strongly influences their decision to utilize this material. Massey (1983) discussed the federal status of regulations, EPA guidelines, and selected policies directed to the land treatment of wastewaters and sludge. Goldstein (1984) described computer programs that are available for providing assistance in process selection and in operation of land treatment systems. Forster and Southgate (1984) discuss concerns for health risks, environmental factors, nuisance issues, and perceived effects on land values of sludge programs. This survey queried municipal officials nationwide. Boone (1984) discussed management and marketability issues concerning sludge. The Interagency Task Force Report (1984) developed a technology-transfer manual which provides assistance with evaluation of sludge management practices. This technology transfer manual presents an overview of land treatment practices, marketing opportunities for sludge or composts, and sludge management practices utilized nationwide. Goldstein (1985) reviewed the status of land treatment systems across the United States and listed reasons for increased interest in land treatment. Schauer (1986) prepared a state-by-state review of land treatment programs.

Land Application of Sludge in North Carolina

There are over 70,000 acres of land permitted to accept wastewater treatment plant residuals in North Carolina (Ramsey, 1989). The majority of these sites (55 percent) are located in Piedmont counties. The sites currently receiving waste are either agricultural utilization sites or dedicated sludge disposal sites. Agricultural utilization sites are those on which sludges are applied at rates not exceeding the annual nutrient requirements of the crops grown on the site. The primary use of sludge at these agricultural site is to replace or supplement commercial fertilizers. Wastewater treatment plant sludges can supply most of the nitrogen and phosphorus required for commercial crops grown in North Carolina (L.D. King, 1989, personal communication). The cost savings to the average farmer is approximately $50 per acre per year. Many municipalities also supply lime when required for those sites where sludge is applied. This practice amplifies the benefit to farmers who use sludge. Agricultural utilization of wastewater treatment plant sludge is strongly encouraged and benefits both the municipality and the agricultural community.

When sludges are applied at rates higher than agronomic crops need, the site is considered to be a dedicated disposal site. Crops may be grown on dedicated sites and the crop can be harvested for most agricultural purposes, nonetheless, the primary purpose of these sites is disposal. The plant/soil system serves as the primary treatment system. Presently, there are no sites operating in North Carolina that apply at rates higher than the calculated nitrogen loading rate. There are several sites where the phosphorus requirement of the growing crop is exceeded.

The beneficial reuse of sludge for agricultural production and the use of composted and lime stabilized or thermally conditioned sludges will become more common in North Carolina since municipalities no longer have the option of disposing in unlined solid waste landfills. Sludge receiver sites must be operated in accordance with laws and rules promulgated by the North Carolina Division of Environmental Management.(Elmor et. al. 1990) have prepared a decision-making manual to help municipalities determine the sludge management option best suited to meet individual needs. Given the current regulatory framework at both the federal and state level, beneficial reuse of wastewater treatment plant sludge appears to be the most suitable of options for small and large municipalities. Beneficial reuse is the application of sludge at an agronomic rate and those are defined by anticipated crop yield. An agronomic rate is the load required to supply nutrients to the crop at sustainable yield.

All municipal and industrial waste applied to land in North Carolina requires a permit from the North Carolina Department of Environment, Health, and Natural Resources, Division of Environmental Management (15A NCAC 2H .0200). All sludge applied to land in North Carolina must be thoroughly tested and found to be non-toxic and non-hazardous. Once a waste determination has been completed and material is deemed suitable for application to land, the Water Quality Section in the division reviews all permit applications to insure that: (1) the site proposed as a receiver for waste is acceptable, (2) the operational strategy for managing the waste is sound, (3) the facility when operational will not adversely impact human health, water quality, or wildlife resources.

Sludge application sites are typically nutrient limited. That is, the level of nutrients, usually nitrogen, contained in the sludge determines the annual application rate to land. Cumulative lifetime heavy metal loadings determine useable site life. These cumulative levels are established by state and federal regulatory agencies for heavy metals such as cadmium, lead, copper, zinc, nickel, mercury, and chromium. King, et al. 1986 lists background heavy metal concentrations for southern soils which have not received applications of sludge.
The longevity of a waste receiver site is dependent upon the concentration of these metals in the waste and the recommended nutrient loading rate. The maximum cumulative loading for these metals has been determined by the U.S. Environmental Protection Agency and there is sufficient margin of safety to allow agricultural and forestry operations after sludge operations have ceased (King and Westerman, 1983).

Each site proposed for sludge application must be evaluated to determine its suitability for treating and renovating waste. Factors that affect the ability of the site to accept liquid and hold nutrients are evaluated. The soil must be examined to a depth of seven feet or to rock. Texture, structure, color, depth, the presence or absence of high water table, seasonal wetness or other restrictive horizons, the hydraulic conductivity, cation exchange capacity, pH, and general soil fertility levels are examined on every waste receiver site. Results of the soil analysis are used to determine the volume of sludge that can be applied to a given site in any year. The soil test results are also used to determine the level of supplemental nutrients and lime required on any waste receiver site.

The permittee is responsible for maintaining all records regarding land application operations. Records must include the time and volume of all sludge application events, the method of application, weather conditions existing on the site, and calculations showing the impact of ongoing land application operations on annual and cumulative lifetime loadings of metals. Once a permit is issued, operators must maintain records of all activities including an annual soils test and sludge analysis. Records of these analyses must be maintained for a minimum of five years. These records are necessary to insure that all wastes are properly managed on permitted sites.

Successful land application operations depend on plant uptake of nutrients, long term storage in the soil system, or filtering of surface active pollutants as a means of preventing surface and ground water impacts. Effective management of vegetation is essential to properly maintain land application operations. All waste loadings onto agricultural or silvicultural lands must be in concert with the nutrient requirements of the vegetation growing or proposed for the site.

The Division of Environmental Management requires that all municipal and domestic wastewater treatment plant sludges that are applied to agricultural or silvicultural land must be processed to significantly reduce pathogens (PSRP). In addition, the Division requires that buffers or set backs are maintained between active application areas and residences or places of public assembly, wells, surface water, and other features of the site that may limit waste application activities. The purpose of these buffers is to minimize the potential for physical contact with waste and to minimize potential off site impacts. In addition to buffer restrictions, once sludge has been applied to land cattle are restricted from grazing for 30 days. Foods used for direct human consumption are restricted from being grown for 18 months, and public awareness and control measures must be taken for 18 months. These site restrictions, use restrictions, and soil restrictions help to insure that sludge can be a source of nutrients which can be utilized beneficially and recycled successfully.

Three components of sludge application programs were evaluated. The first was a survey of operators to assess wastewater treatment plant activities and problem areas. The second consisted of an evaluation of soil from waste receiver sites and from control sites to evaluate impacts of sludge management activities on soils and potential ground water. The third component of this project was to evaluate vegetation grown on receiver sites and control sites to determine the effects of these land application activities on metal and nutrient concentration of plant tissue. These evaluations are necessary because the reliance on land application as a mechanism for sludge management requires assurance that this practice is safe.

ASSESSMENT OF MUNICIPAL RESIDUAL MANAGEMENT PRACTICES IN NORTH CAROLINA

Wastewater Treatment Plant Operator Survey Results.

An evaluation of training needs for wastewater treatment plant operators was conducted in 1988. A total of 808 responses were collected from a mail survey. Inadequate knowledge of sludge management options was listed as a frequent cause of problems in the day-to-day operation of wastewater treatment facilities. Operators did list land application of wastewater and sludge as an area in which additional training was required. Over 40 percent of those operators questioned initially listed alternatives to land filling of sludge as the most critical of their training needs.

A follow-up telephone survey was initiated in 1990 to determine the characteristics and operational difficulties which exist at permitted wastewater treatment plants (WWTP) operating in North Carolina (Appendix I). The survey was a follow-up to a mail survey conducted in 1988. A total of 58 randomly selected certified operators were questioned. All participants agreed to complete a two hour telephone interview. Operators with grades one, two, three or four certifications were questioned concerning the following:

1) Years of experience
2) Years of education
3) Size of facility (flow)
4) Unit processes represented at the treatment facility
5) Sludge management practices utilized at the treatment facility
6) Training needs of individual operators and employees
7) Problems associated with daily operations

Each of these factors contribute to the success of a well operated waste treatment facility.

Years of Experience. There was no well-defined relationship between years of experience and grade or size of operations. There is, however, a suggestion that operators of Class 2 systems have fewer years operating these systems than do operators of larger Class 3 or Class 4 systems. The Class 2 system does appear to be a "training ground" for operators of the more advanced Class 3 and Class 4 systems. Presently, the Operator Certification and Training Commission requires that an operator must be certified at the appropriate level for each plant. For example, a Class 2 plant could be operated by a Class 2, 3, or 4 operator. An operator working at a Class 2 plant with a Class 2 certification could not operate a Class 3 facility until that operator obtains sufficient experience to be reclassified and upgraded and until the operator successfully passed a written examination to be upgraded to a Class 3. In general, operators at the more complex facilities had more years of experience, but that experience was not necessarily at the more complex wastewater treatment plant. The years of experience could be obtained at lower class plants than the operator was currently managing. Operators with many years of experience met permit limits more consistently than operators with fewer years of experience and at the lower classification plants. Years of experience are listed in Table 1.

Table 1. Years experience in wastewater treatment of operators questioned

Less than 1	1
1 to 5	14
6 to 10	18
11 to 15	15
More than 15	10

Years of Education. All operators questioned had at least a ninth grade education. Five had not completed high school, and 24 operators had completed a college degree program. Five of the operators questioned had advanced degrees or post-graduate college educations. The higher the classification of the wastewater treatment facility, the higher the level of educational attainment of the operators.

Facility Size. The operators questioned managed facilities which ranged in size from small minor non-municipal facilities to large, major municipal wastewater treatment facilities treating flows in excess of 25 million gallons per day. The large facilities relied heavily upon best available technology. There was usually a relationship between the size of the facility and the complexity of the operation. The small flows generally had low classifications while the facilities treating large flows had high classifications and required Class 4 operators.

Unit Processes. Operators managed facilities which ranged in treatment complexity from simple systems such as septic tank/sand filter or lagoon systems to more complex systems such as extended aeration facilities with complex wastewater filtration, disinfection, and sludge management technologies. Usually, the larger the flow from the facility, the more complex the operation and generally the more stringent the limits which must be met. Unit processes represented at the 58 facilities are presented in Table 2. Residuals which must be handled in a permitted sludge operation are generated in the lagoons, trickling filters, rotating biological contractors, activated sludge and oxidation ditch portions of these systems. One of the operators questioned had both a trickling filter and activated sludge process present at his facility.

Table 2. Unit Processes Represented at 58 North Carolina Publicly Owned Treatment Works (POTW)

PROCESS	NUMBER
Bar Screen	47
Grit Chamber	40
Trickling Filter *	19
Rotating Biological Contractor *	2
Activated Sludge *	28
Oxidation Ditch *	4
Sequencing Batch Reactor *	1
Chlorination	55
Ultraviolet Disinfection	1
Ozone Disinfection	2
Lagoon *	4

* requires sludge handling

Sludge Management Practices. The primary purpose of the questionnaire was to evaluate sludge management practices utilized by wastewater treatment facilities in North Carolina. Sludge management was often mentioned as a principal factor in determining the successful operation of any wastewater treatment facility.

The sludge management practices at the simple systems such as the septic tank sand filter facilities consisted of utilization of local septage pumpers to remove the solids or septage from septic tanks. Three of the operators questioned stated that septage was removed at least annually from each septic tank in the system. The operators had no knowledge of the fate of the septage once pumped and removed from the septic tank systems.

Operators of lagoon systems indicated that sludge management was generally not a critical issue. The lagoon system operators frequently cited difficulty in meeting permit limits but denied that sludge management contributed to their inability to consistently meet the permitted limits.

The operators of mechanical wastewater treatment facilities frequently cited their inability to properly manage sludge as one of the primary factors in failing to consistently meet permit limits. Thirteen of the 58 operators questioned (or 23 percent) indicated that sludge management was the single factor that most frequently limited their ability to meet permit limits. Forty-three of the 58 operators questioned (or 74 percent) indicated that sludge management was one of the top three critical factors in determining their ability to meet permit limits. Other factors that contributed to program success, in decreasing order of importance, were:

1) The ability to manage industrial waste was cited by 28 percent of the operators as contributing to their inability to meet permit limits.

2) Access to sufficient money and other fiscal resources to operate the facility properly was cited by 26 percent of the operators as a factor.

3) The ability to deal with biological process upsets was cited by 24 percent of the operators as contributing to their inability to meet permit limits.

4) The ability to manage sludge was cited by 23 percent of the operators questioned as contributing significantly to consistently meet permit limits.

Operators were questioned concerning the current sludge management practices at the facility they represented. The survey indicated that there are a variety of sludge management practices ongoing in North Carolina. The sludge management practices utilized by the 58 operators questioned are summarized in Table 3. Land filling and land application constitute the major sludge management practices utilized.

In addition to the phone survey, records of the State Division of Environmental Management were reviewed to establish the number and types of sludge management activities permitted in North Carolina. Results are in Table 3. State records indicate the volume of sludge transported to landfills in 1990. This is somewhat misleading since the Solid Waste Management Division prohibited co-mingling of sludge and municipal solid waste in 1987. This landfill rate is for sludge applied to the top two feet of cover. Some facilities are utilizing landfills only as a supplement to land application, but operators were asked only to describe principal sludge management practice. Those using landfill supplement did not report this practice consistently.

Table 3 - Distribution of Municipal Sludge Management Practices in Operators Study and State-wide (1990)

Activity	Study Result (58 Systems)	State Permit Survey
Land Application	20	214
Composting	2	15
Incineration	3	13
Lagoon/Storage	6	51
Monofill	2	10
Landfill[1]	21	422
No Sludge Management[2]	4	

1 Landfill disposal was outlined in 1987 by the Solid Waste Management Division. This represents the number of facilities permitted to utilize sludge in the top two (2) feet of landfill cover.

2 Lagoon wastewater treatment systems.

Several small municipal wastewater treatment facilities operate under contract to a sludge application contractor who has land permitted for waste sludge from multiple sources. These land areas are divided into subfields and specific subfields are then reserved for sludge from a single source. Presently, there are five private contractors who have land permitted and who provide this service to various municipal sludge generators in North Carolina. Approximately 30 municipalities utilize private contractors for sludge management. These custom contractors apply material onto lands permitted and controlled by the contractor.

The prohibition against co-disposal of municipal wastewater treatment plant sludge in landfills is encouraging industries and municipalities to seek alternatives which promote beneficial utilization of waste sludge. A survey in 1989 conducted by the U.S. Environmental Protection Agency evaluated sludge from numerous municipal wastewater treatment plants. The results of that survey are summarized in a five volume publication, National Sewage Sludge Survey Facility Analytical Results, October 1989. Three municipalities from North Carolina were included in the EPA survey. Sludge from the towns of Whiteville, Rocky Mount, and Warsaw were evaluated. The analysis was intended to examine sludge from various sources to determine the nutrient and metal content of the material and to determine the level of organic constituents present in the municipal wastewater treatment plant sludge. The results from the National Sewage Sludge Survey are currently being compiled and interpreted. In general, the facilities in North Carolina were found to contain valuable concentrations of plant-available nutrients and low concentrations of metals. Toxic organic chemicals were present at low to very low levels.

Training Needs. All operators responded very positively to questions concerning training. Operators indicated that training was essential for them if they are to continue to provide the level of service necessary to adequately protect both water quality and air quality. Operators were asked to respond to specific training needs. Needs and percentage of operators who indicated that these were critical are listed in Table 4.

Table 4. Education and Training Needs of 58 Operators Ranked High to Low

Subject Matter	Percent of Operators Responding to Need
State Enforcement Strategies	71
State and Federal Regulations	67
Process Optimization	50
Effluent Toxicity Testing	48
Land Application of Sludge	41
Biological Nitrification	36
Chlorination/Dechlorination	33
Chemical Phosphorus Removal	31
Biological Phosphorus Removal	31
Sludge Dewatering	31
Sludge Composting	29
Land Application of Wastewater	26
Sludge Incineration	24
Operation of Tertiary Filters	19
Ozone Disinfection	19
Ultraviolet Light Disinfection	19
Chemical Sludge Stabilization	17
Thermal Sludge Stabilization	15

EVALUATION OF LAND APPLICATION SITES

Methods and materials.
This project was designed as a set of case studies to investigate existing conditions at land application sites. Because of the nature of case study evaluations, statistical evaluations and interpretations were not made.

Soil Phosphorus, Zinc, Copper, Nickel, Lead, and Cadmium. Twenty-eight soil sites from fourteen North Carolina municipalities were sampled to assess the effect of land application of municipal treated waste on extractable soil phosphorus and heavy metal concentrations. Municipalities included in this study were Albemarle, Elizabeth City, Eden, Fayetteville, Hillsborough, Graham, Greenville, Jacksonville, New Bern, Carrboro, Reidsville, Tryon, Wilson and Winnabow. The predominant soil type and application histories of the site are listed in Table 5. Element accumulation patterns in the soil profile were plotted by analyzing soils incrementally sampled to a depth of ten feet. At each treated field site, a check sample was taken from an adjacent non-treated area or border to compare against. Soil cores were taken with a Giddons Probe measuring 3 inches in diameter. Three cores were taken per site and composited incrementally by depth. Samples were separated by depth (measured in feet) as follows: 0-0.5, 0.5-1, 1-2, 2-3, 3-4, 4-5, 5-6, 6-7, 7-8, 8-9, 9-10. Samples were dried, ground and analyzed utilizing Mehlich-3 (Mehlich, 1984) extraction currently used by the North Carolina Department of Agriculture (NCDA), Agronomic Division, soil testing laboratory for phosphorus (P), zinc (Zn), copper (Cu), nickel (Ni), lead (Pb) and Cadmium (Cd). Plant tissue samples were also taken from each field site and analyzed for the same elements by the NCDA, Agronomic Division. Results that follow will be reported separately for each municipality. In addition, a summary section will characterize the general accumulation patterns for each element as viewed across all thirty two profiles and discuss the relative impact of these land application programs.

Soil nitrate. Subsamples of the composited soil cores were dried, ground and extracted utilizing 20 grams of soil treated with 50 ml of 0.36 N H_2SO_4. The sample was shaken for one hour and left to stand over night. Samples were filtered twice and the extract frozen at -15°C. When enough samples were stored, the extracts were thawed and refiltered prior to analysis. Samples were analyzed for nitrate using an automated Lachate machine which is a colormetric analyzer. Quik Chem® Method No. 12-107-04-1-B was used for NO_3-N analysis. Soil results will be presented in mg/kg NO_3-N throughout this report.

Plant tissue analyses. Plant tissue samples were taken at 10 of the 14 municipality sites that were used in the soils assessment portion of this study. Samples were taken from the predominant plant species that was growing next to the soil boring holes to see if there were correlations between soil and plant concentrations of the different nutrients or heavy metals. Plant tissue samples were analyzed for nitrogen (N), phosphorus (P), copper (Cu), zinc (Zn), nickel (Ni), lead (Pb) and cadmium (Cd) by the Agronomic Division of the North Carolina Department of Agriculture.

Soil pH. Soil pH was determined using a 1:1 soil:water ratio that was stirred for approximately 30 minutes and allowed to settle for 1 hour before analyzing with a pH electrode.

Table 5. Site, Soil and Loading Data Study Receiver Sites

Site	Field	# Acres	Predominant Soils	Crop	Pan	P	Pb	Zn	Cu	Ni	Cd
					- - - - - - - lb/ac/yr - - - - - - -						
Albemarle	1		Badin	Fescue	498	870	4.4	63.9	183	2.3	.2
	2		Badin	Fescue	882	1458	7.0	99.2	246	4.7	.7
Graham	2	15.2	Georgeville	Fescue	63	115	20	118	31	4.5	1.5
	3	12.4	Georgeville	Fescue	121	226	39	137	33	5.6	1.5
	7	6.8	Georgeville	Fescue	242	469	47	142	90	7.4	2.1
	5	8.8	Georgeville	Fescue	118	218	21	81	48	4.6	1.6
	6	10.4	Georgeville	Fescue	115	224	30	83	53	4.3	1.6
	1	12.0	Georgeville	Fescue	142	268	30	86	51	6.6	1.5
	4	9.0	Georgeville	Fescue	249	454	-	-	-	-	-
Eden	2	39	Cecil	Fescue	48	82	3.1	22	29	1.2	.3
		31	Cecil	Fescue	48	82	3.1	22	29	1.2	.3
Reidsville	9		Cecil	Fescue	66	101	1.1	7	7	.8	.1
	9		Cecil	Fescue	66	101	1.1	7	7	.8	.1
New Bern	2	16	Goldsboro	Corn,Sm.gr.	49	164	2.5	22	5	.4	.1
	1	11	Goldsboro	Peanuts	62	167	2.6	24	6	.4	.1
Wilson	1	6	Norfolk	CBG	407	407	43.5	270	64	6.4	1.7
	2	26	Wagram	CBG	355	458	42.7	183	45	5.2	1.2
Jacksonville	10		Norfolk/G.boro	CBG	163	209	13.3	110	36	6.7	.7
Tryon	10		(like) State	Fescue	234	101	1.5	5	12	.8	.1
Greenville	1	46	State	CBG	194	262	3.6	29	13	1.0	.3
	2	100	State	CBG	325	531	4.3	34	16	.8	.4
Fayetteville		190	Norfolk/Wagram	C/smG/CBG	350	180	4.7	22	8	.9	.3
Owasa	2		Georgeville	Fescue	173	CNR	17.5	106	48	3.9	.5
Carrboro	1		Tatum	Fescue	215	CNR	18.2	110	52	4.1	.6
Elizabeth City	900		Bladen Sil	C/smG/Beans	29	9	.2	12	17	.1	.1
	900		Elkton Sil	C/smG/Beans	29	9	.2	12	17	.1	.1
Hillsborough	1	29	Georgeville	Fescue	46	63	.2	11	7	.1	.1
	2	73	Georgeville	Fescue	9	16	.4	2	1	.2	.03
Winnabow	400	73	Torhunta	C/smG	85	135	2.1	25	13	.4	.18

Results by Location

ALBEMARLE. Soil analyses results for P, Zn, Cu, Ni, Pb, Cd and NO_3-N are listed in Table 6 for Albermarle. Analyses showed that P accumulation was primarily restricted to the top 0.5 feet of the soil profile. This pattern is typical of P and is indicative of its low mobility in soils. Phosphorus accumulation was between 15 and 20 mg/dm^3 in the treated field samples compared to 2 and 23 mg/dm^3 for the adjacent untreated areas. These P concentrations are all considered to be insufficient for optimum plant growth. When comparing the concentration of P presumably added to the receiving site (Table 5) to the concentrations found at the site there appears to be a considerable discrepancy.

Copper (Cu), Zinc (Zn) and Lead (Pb) exhibited similar accumulation patterns in the soil profile as P, with greatest accumulation in the surface 0.5 feet. Concentrations of Cu and Zn were adequate for plant growth, in the surface 0.5 feet. Copper showed some additional downward movement in Field 2. This is may be a response to the high surface concentrations. Only one of the treated field samples showed accumulation rates higher than the "check". Nickel and Cd concentrations were very low for all sample depths.

Soil nitrate concentrations were below 10 mg/kg NO_3-N for all depths sampled. Concentrations were highest in the untreated area of Field 1 (5.87 mg/kg NO_3-N). Plant tissue samples were not taken at this location.

CARRBORO. Two sites were sampled in Carrboro. Soil concentrations of all elements in both fields were low in both treated and untreated areas (Table 7). Phosphorus, Zn and Cu levels were low enough to limit plant growth. Nitrate concentrations were very low (< 0.57 NO_3-N) for all soil locations and depths.

The application site consisted of a fescue pasture. The untreated area was taken from a field border containing fescue. Nitrogen concentrations in the plant tissue were within the range that is considered low (1.81 - 2.61 %N) for well managed fescue, with the exception of the untreated sample in F1 which is considered deficient (Table 8). All plant samples had adequate, and not excessive, concentrations of phosphorus (optimum range 0.2-0.6 % P), copper (4-20 ppm) and zinc (15-70 ppm). Low levels of Ni were detected in treated and untreated areas of F1 and only in the untreated area of F2. No detectable concentrations of Pb or Cd were found.

Table 6. Soil concentrations of elements and nitrate by depth from sludge application sites and adjacent untreated areas in Albermarle NC.

Depth ft	P mg/dm^3		ZN mg/dm^3		CU mg/dm^3		Ni mg/dm^3		Pb mg/dm^3		CD mg/dm^3		NO3 mg/kg	
	UT[1]	T[2]	UT	T	UT	T	UT	T	UT	T	UT	T	UT	T
Field 1														
0.5	23	15	1.6	1.1	2.9	1.2	0.40	0.32	4.32	3.04	0.04	0.00	5.87	3.12
1	2	3	0.8	0.6	0.9	0.6	0.28	0.20	2.36	1.24	0.00	0.00	1.97	1.47
2	2	2	0.6	0.5	0.4	0.4	0.36	0.56	2.16	0.88	0.00	0.00	0.91	1.37
3	1	1	0.6	0.5	0.3	0.2	0.32	0.12	2.08	0.88	0.00	0.00	0.66	1.78
4	1	1	0.6	0.6	0.4	0.3	0.48	0.36	1.56	0.56	0.00	0.00	0.62	4.02
5	2	1	0.6	0.5	0.3	0.2	0.20	0.28	1.72	0.12	0.00	0.00	1.03	3.00
Field 2														
0.5	2	20	1.8	2.1	1.1	7.2	0.28	0.40	1.20	2.40	0.00	0.04	0.43	3.12
1	1	6	0.8	1.4	0.6	3.9	0.21	0.32	1.16	1.40	0.00	0.04	0.61	1.47
2	1	2	0.9	1.2	0.4	2.6	0.00	0.28	0.76	1.60	0.00	0.04	0.83	1.37
2.5	1	2	1.0	1.4	0.5	1.4	0.12	0.44	1.88	1.84	0.00	0.00	0.61	1.78

[1]UT = Untreated areas

[2]T = Treated areas

17

Table 7. Soil Concentrations of elements by depth from sludge application sites and adjacent untreated areas in Carrboro NC.

3 Depth ft	P mg/dm^3		Zn mg/dm^3		Cu mg/dm^3		Ni mg/dm^3		Pb mg/dm^3		Cd mg/dm^3		NO^3 mg/kg	
	UT[3]	T[4]	UT	T	UT	T	UT	T	UT	T	UT	T	UT	T
Field 1														
1	4.00	2.00	0.70	0.70	0.20	0.30	0.20	0.24	0.76	2.16	0.00	0.12	0.22	0.57
2	3.00	5.00	0.80	0.60	0.20	0.30	0.16	0.24	1.20	1.60	0.04	0.08	0.18	0.34
3	3.00	5.00	1.40	1.00	0.20	0.30	0.32	0.44	0.72	2.76	0.08	0.08	0.16	0.41
4	5.00	5.00	1.70	1.90	0.30	0.60	0.40	0.80	0.88	2.88	0.08	0.08	0.16	0.28
Field 2														
1	5.00	8.00	0.40	0.60	0.00	0.20	0.36	0.20	0.68	2.16	0.08	0.08	0.34	0.50
2	4.00	6.00	0.80	0.60	0.10	0.20	0.32	0.32	2.76	2.46	0.08	0.08	0.23	0.40
3	2.00	6.00	0.70	0.80	0.00	0.40	0.48	0.32	2.24	1.96	0.08	0.12	0.30	0.25
4	3.00	8.00	0.80	0.80	0.10	0.40	0.44	0.36	2.25	1.64	0.08	0.08	0.30	0.18

---

[3]UT = Untreated areas

[4]T = Treated areas

Table 8. Concentrations of elements in fescue tissue from sludge application sites and adjacent untreated areas in Carrboro NC.				
Element	Field 1		Field 2	
	UT	T	UT	T
	---------- % ----------			
N	1.81	2.61	2.45	2.37
P	.25	.44	.26	.46
	---------- mg/kg ----------			
Zn	16	17.9	22.8	19.9
Cu	5.41	5.52	6.61	5.47
Ni	0.23	1.01	0.3	0
Cd	0	0	0	0
Pb	0	0	0	0

UT = Untreated Areas T = Treated Areas

EDEN. Soil accumulation patterns for P, Zn Cu and Pb were typical for land applied immobile elements (Table 9). Concentrations of these elements were higher in treated than untreated fields. Phosphorus concentrations were in the high soil testing range as designated by NCDA. Zinc concentrations in the surface layer of the treated area of Field 2 (26.8 mg/dm^3) may be high enough to affect a Zn sensitive crop like peanuts (Cox, 1990). Likewise, nickel concentrations in the untreated area (1.64) and Cu in the treated area (38.9 mg/kg) in Field 1 were high enough to approach toxic levels listed in the literature under the conditions of those experiments. Concentrations of Cd and Pb were low.

Nitrate-nitrogen concentrations increased with increasing depth in Field 2 for both treated and untreated areas. Concentrations were greatest at 4 feet in the untreated area (8.37 mg/kg) and at 3 feet in the treated area (20.52 mg/kg). Concentrations decreased at greater depths in both areas in Field 1, but not consistently. Levels >10 mg/kg NO_3-N were found below the root zone in the treated area indicating that application rates may have been too high or that they were not in sequence (time) with crop N needs. Nitrate-nitrogen concentrations in Field 1 did not exceed 10 mg/kg below the root zone. Highest concentrations in Field 1 were in the treated area at 0.0-0.5 feet (30.01 mg/kg NO_3-N).

Plants growing at the Eden sites were not of similar species between the treated and untreated areas. Field 1 had fescue in the treated area and weeds in the untreated area. Field 2 had corn in the treated area and fescue in the untreated area. Plant tissue concentrations of N appeared to be adequate for all areas with the exception of the corn in treated field 2 (Table 10). Phosphorus concentrations were adequate in all plant with the exception of corn from treated F1. Zinc concentrations were in the high range for all plants and areas tested. Tissue concentrations of Cu were on the high end of the sufficiency range for all samples. Untreated areas had higher concentrations of P, Zn, Cu, Ni, and Cd levels than the treated areas. Lead was higher in plants growing in treated F1 than from plants in the corresponding untreated area. Cadmium concentrations were detected in concentrations that exceeded the maximum dietary level for livestock (0.5 ppm Cd) in each sample with the exception of plants in treated F1.

Table 9. Soil concentrations of elements by depth from sludge application sites and adjacent untreated areas in Eden NC

Depth	P mg/dm^3		Zn mg/dm^3		Cu mg/dm^3		Ni mg/dm^3		Pb mg/dm^3		Cd mg/dm^3		NO^3 mg/kg	
	UT[5]	T[6]	UT	T	UT	T	UT	T	UT	T	UT	T	UT	T
Field 1														
0.5	3	165	2.6	26.8	2.9	38.9	1.64	0.60	4.16	5.64	0.04	0.16	1.02	30.01
1	2	3	1.4	1.2	1.8	0.6	1.08	0.44	2.36	1.00	0.04	0.04	0.66	7.05
2	3	2	1.0	0.8	2.4	0.2	0.76	0.52	2.28	1.08	0.04	0.00	0.84	11.80
3	2	2	0.7	1.0	2.2	0.4	0.60	0.48	2.60	1.60	0.00	0.00	0.45	10.49
4	2	4	0.9	1.1	1.4	1.4	0.56	0.28	1.60	2.24	0.04	0.00	1.82	1.12
5	3	3	1.0	1.3	0.8	0.3	0.40	0.56	1.68	1.40	0.04	0.00	0.20	5.79
6	4	1	1.7	0.9	0.7	0.5	0.36	0.52	1.84	1.44	0.00	0.08	0.13	3.65
7	6	2	1.3	1.0	1.3	0.5	0.72	0.92	1.84	1.20	0.00	0.04	0.36	1.63
Field 2														
0.5	22	99	1.0	4.7	0.6	6.2	0.44	0.32	5.20	5.32	0.00	0.08	0.13	0.30
1	3	4	1.0	1.1	0.4	0.7	0.40	0.84	3.80	4.72	0.00	0.00	0.32	0.18
2	1	2	0.4	0.5	0.2	0.4	0.28	0.44	2.60	2.52	0.00	0.00	0.72	5.97
3	1	1	0.3	0.5	0.1	0.4	0.36	0.44	1.52	2.64	0.00	0.00	3.65	20.52
4	1	1	0.5	0.8	0.2	0.7	0.28	0.72	1.40	3.96	0.00	0.00	8.37	10.44
5	1	1	0.7	1.1	0.2	0.7	0.44	0.88	2.28	2.76	0.00	0.00	5.57	7.51

[5]UT = Area untreated

[6]T = Treated areas

Table 10. Tissue concentrations of elements by field from sludge application sites and adjacent untreated areas in Eden NC.				
Element	Field 1		Field 2	
	UT[1]	T[2]	UT[2]	T[3]
	——— % ———			
N	2.17	2.51	2.26	1.95
P	0.26	0.16	0.26	0.24
	——— mg/kg ———			
Zn	70.6	59.8	63.8	39.8
Cu	10.21	9.45	11.52	7.27
Ni	1.54	0	3.08	0
Cd	0.64	0.43	1.12	0.77
Pb	0	5.92	11.72	8.23

UT = Untreated Areas T = Treated Areas; [1]Weeds, [2]Fescue, [3]Corn

ELIZABETH CITY. Elemental accumulation patterns in soil were erratic at this site, with the exception of P. Phosphorus concentrations consistently decreased with depth (Table 11). Concentrations of P, Cu and Zn greater than 61, 0.5 and 1 mg/dm^3 respectively are considered optimum for plant growth. Accumulation patterns for Zn tended to follow P, with maximum concentrations being found in the top foot. However, treated areas of Field 1 showed a 5.4 mg/dm^3 increase in Zn between 2 and 3 feet. Increases were noted in treated and untreated areas of Field 1 between 2 and 3 feet for Cu, Ni and Pb. Concentrations of Ni appear to be high (1.24 mg/kg) at the three foot level in the treated area of Field 1.

Nitrate-N concentrations in Field 1 were greater in the treated than untreated area. Concentrations in the treated area were highest (11.72 mg/kg NO_3-N) at the greatest depth sampled (3 feet). Concentrations in Field 2 were highest for both treated and untreated areas in the surface 0.0-0.5 feet. Nitrate-N concentrations below this depth never exceeded 5.55 mg/kg NO_3-N.

Plant tissue samples were not taken at this location

FAYETTEVILLE. Elemental concentrations and accumulation patterns in soils at Fayetteville show little difference between the treated and untreated field areas (Table 12). Greatest differences were found in the surface 0.5 foot for P where the untreated area had 94 mg/dm^3 more than the treated field. This may have been due to past fertilization history. Concentrations of P in the treated field are considered to be high while the untreated field is considered to be low for agronomic plant growth (NCDA 1987). Concentrations of Cu are considered medium and Zn medium to high for crop growth. None of the metal concentrations is high enough to raise concerns for potential toxicity. Nitrate concentrations were below 3 mg/kg NO_3-N at all depths and areas sampled.

Plant samples at the Fayetteville site were taken from a bermudagrass pasture that received sludge. The untreated sample was taken from bermudagrass at the field edge. Plant samples from the treated field had low N concentrations while untreated area plants were slightly deficient (Table 13). The optimum range for bermudagrass is 2.5-3.5 % N. Phosphorus concentrations were adequate for all samples. However, the untreated plant sample had higher concentrations than the treated field samples. Copper levels were sufficient for plant growth (optimum range 4-20 ppm Cu) while Zn level were considered deficient (optimum range 15-70 ppm Zn). Plants from the untreated areas had higher concentrations of Zn, Cu and Ni than plants growing in untreated areas. Nickel was not detected in any of the treated field samples but was detected in the untreated plants. Tissue results suggest that the untreated area may have been contaminated at one time. Neither Pb or Cd was detected in any of the plant tissue samples.

Depth ft	P mg/dm^3		Zn mg/dm^3		Cu mg/dm^3		Ni mg/dm^3		Pb mg/dm^3		Cd mg/dm^3		NO^3 mg/kg	
	UT[7]	T[8]	UT	T	UT	T	UT	T	UT	T	UT	T	UT	T
Field 1														
0.5	102	18	3.6	1.7	0.6	0.8	0.52	0.36	2.40	1.72	0.00	0.04	1.38	5.67
1	44	8	2.6	0.8	0.3	0.4	0.44	0.72	2.16	1.92	0.04	0.00	0.34	9.67
2	11	9	2.7	1.3	0.2	0.8	0.52	0.60	1.68	1.84	0.04	0.08	0.21	8.11
3	9	6	1.3	6.7	0.5	1.6	0.64	1.24	2.16	2.08	0.04	0.00	1.18	11.72
Field 2														
0.5	46	99	5.2	5.9	1.0	1.4	0.40	0.60	2.32	2.32	0.04	0.08	24.38	13.38
1	14	55	2.4	3.8	0.3	0.5	0.00	0.36	1.08	2.64	0.04	0.12	5.55	3.01
2	15	36	1.8	3.2	0.6	0.4	0.68	0.40	1.00	1.28	0.04	0.04	2.72	3.41
3	7	16	2.4	3.3	1.5	1.6	0.64	0.80	1.28	1.68	0.04	0.04	2.24	3.09

Table 11. Soil concentrations of elements by depth from sludge application sites and adjacent untreated areas in Elizabeth City NC.

[7]UT = Untreated areas

[8]T = Treated areas

Table 12. Soil concentrations of elements by depth from sludge application sites and adjacent untreated areas in Fayetteville NC.

Depth ft	P mg/dm^3		Zn mg/dm^3		Cu mg/dm^3		Ni mg/dm^3		Pb mg/dm^3		Cd mg/dm^3		NO^3 kg/mg	
	UT[9]	T[10]	UT	T	UT	T	UT	T	UT	T	UT	T	UT	T
0.5	105	11	3.0	4.7	0.8	1.4	0.00	0.00	2.96	3.00	0.04	0.04	2.32	2.60
1	99	2	1.9	0.9	0.5	0.8	0.00	0.00	1.80	1.28	0.04	0.04	0.88	1.09
2	31	1	0.6	0.6	0.3	0.4	0.08	0.00	0.32	0.68	0.00	0.08	0.30	0.50
3	11	18	0.5	1.4	0.2	0.3	0.00	0.24	0.72	0.80	0.04	0.08	0.28	0.12
4	4	7	0.4	0.6	0.2	0.3	0.36	0.04	0.80	0.68	0.00	0.04	0.18	0.38
5	2	8	0.4	0.6	0.2	0.3	1.36	0.08	1.20	0.48	0.00	0.00	0.72	0.20

[9] UT = Untreated areas

[10] T = Treated areas

Table 13. Tissue concentrations of elements from Coastal bermudagrass from sludge application sites and adjacent untreated areas in Fayetteville NC.

Element	UT	T
N	1.71	2.22
P	0.59	0.31
Zn	5.5	3.54
Cu	10.69	6.6
Ni	1.02	0
Cd	0	0
Pb	0	0

UT = Untreated Areas T = Treated Areas

GRAHAM. Seven different fields were surveyed in Graham. Soil P accumulation was primarily in the top foot (Tables 14-17). All treated fields had higher P levels than the adjacent untreated areas. Agronomically, concentrations of P in the surface layer are considered low for treated Fields 4 and 6, medium for Fields 3 and 7, high for Fields 2 and 1 and very high for Field 5 (NCDA, 1987). Like P, concentrations of Zn, Cu, Cd, Ni and Pb tended to be higher in the surface foot of soil than at greater depths. In general, field concentrations of all elements with the exception of Field 2 for Pb, Field 4 for Ni and Field 7 for Zn, Cu, Ni, Pb and Cd had higher concentrations in treated than untreated areas. Zinc levels in the surface 0.5 feet may be high enough to be a concern for a Zn sensitive crop like peanut in the treated area for Fields 1, 2, 3, 5, and 6 and for the untreated area for Field 7 (Cox, 1990). Concentrations of Cu are sufficient but not excessive for crop growth. Concentrations of Cd, Pb and Ni are low.

All untreated areas at Graham showed low soil nitrate concentrations with no change as depth increased. All treated areas had nitrate levels greater than the untreated for all depths sampled. Fields 1, 2, 3, 4, and 5 showed high levels of NO_3-N throughout the profile. Highest concentrations for Fields 1, 2, 3, 4, and 5 were as follows respectively 79.38 (3" depth), 135.94 (2'), 59.52 (3'), 60.33 (5') and 40.20 (3'). Each of these fields had > 10 mg/kg NO_3-N at the greatest depth sampled. Field 6 and 7 while having lower concentrations at greater depths still had concentrations >14 mg/kg NO_3-N at three feet. Concentrations of NO_3-N found in the soil profiles at Graham indicate a problem with N management.

Plant samples from all treated and untreated field areas at Graham were taken from fescue. Nitrogen concentrations in plants growing in the untreated area were lower than in plants grown on the treated soils (Table 18). Most samples had low N concentration. while plants from untreated areas of Fields 1, 2, and 3 were deficient. Phosphorus levels were sufficient for all plant samples. Concentrations of Zn, Cu, Pb, and Cd were higher in plants growing in treated fields than in untreated fields. While no Cd was detected in the check areas, plants taken from the treated areas had concentrations between 0.4 and 1.1 ppm. One sample from the treated area also approached the maximum livestock dietary level for lead (30 ppm). Nickel concentrations were below 2 ppm. The maximum dietary levels are 50 ppm Ni for cattle and sheep and 100 ppm Ni for swine. Differences between the untreated and treated samples were not as clear cut as Zn, Cu, Pb or Cd.

GREENVILLE. Soil P concentrations (Table 19) at all Greenville sites were very high (310 - 1772 mg/dm^3). Agronomically, soil test results with concentrations greater than 84 mg/dm^3 P would not call for additional P fertilization (NCDA, 1987). Concentrations were > 120 mg/dm^3 throughout the soil profile indicating significant mobility. Highest concentrations are, however, in the surface 0.5 feet. Zinc, Cu, Ni, Pb and Cd accumulation patterns were similar to P with the greatest concentrations being in the surface foot. Zinc and copper appeared to have concentration increases to a depth of two feet. While Cd, Ni and Pb showed little movement below the surface 0.5 feet. Zinc concentrations were high enough in both the treated and untreated areas of Field 1 and the treated area of Field 2 to be a potential concern for sensitive crops (Cox, 1990). Copper concentrations were adequate for growth. Concentrations of Cd, Ni, and Pb were below levels of concern for plant toxicities. Soil from treated areas showed an increase in nitrate concentrations compared to untreated areas. Nitrate concentrations never exceeded 8.76 mg/kg NO_3-N at any depth sampled.

Plant tissue was taken from bermudagrass for the treated and untreated field samples. All plant samples had low N concentrations for optimum growth with the exception of the plants from untreated Field 1 which are considered deficient (Table 20). Plants grown on the treated sites had higher concentrations of P, Zn, Cu, Ni, and Cd than those grown on untreated soil. Zinc concentrations in the treated samples from Field 1 were above the range normally considered sufficient for bermudagrass (15-70 ppm). Neither Ni or Cd concentrations in the treated samples were above the maximum dietary levels for livestock.

Table 14. Soil concentrations of elements by depth from sludge application sites and adjacent untreated areas in Graham NC.

Depth ft	P mg/dm3		Zn mg/dm3		Cu mg/dm3		Ni mg/dm3		Pb mg/dm3		Cd mg/dm3		NO^3 mg/kg	
	UT[11]	T[2]	UT	T	UT	T	UT	T	UT	T	UT	T	UT	T
Field 1														
0.5	3	96	2.3	28.5	1.6	9.8	0.32	0.40	1.48	6.12	0.08	0.32	1.10	43.56
1	2	2	0.4	1.0	0.6	0.8	0.32	0.40	0.44	0.30	0.04	0.04	0.56	8.76
2	1	2	0.4	0.5	0.3	0.5	0.40	0.24	0.64	0.88	0.00	0.04	0.61	12.39
3	2	2	0.4	0.3	0.3	0.2	0.12	0.12	0.02	0.60	0.04	0.04	0.35	79.38
4	2	2	0.6	0.7	0.4	0.4	0.08	0.12	0.60	0.48	0.04	0.04	0.42	40.05
5	3	2	0.5	0.4	0.3	0.3	0.24	0.16	0.80	0.44	0.00	0.04	0.34	19.87
6	3	2	0.6	0.4	0.3	0.3	0.16	0.32	0.60	0.48	0.04	0.04	0.37	14.64
7	4	2	0.6	0.5	0.3	0.3	0.44	0.28	0.84	0.40	0.00	0.04	0.27	19.10
8	6	2	0.9	0.4	0.7	0.3	0.28	0.20	0.04	0.40	0.01	0.00	0.04	17.38
9	4	3	0.8	0.6	0.2	0.3	0.12	0.28	0.84	0.32	0.00	0.04	0	15.57

[11]UT = Untreated Areas

[2]T = Treated Areas

Table 15. Soil concentrations of elements by depth from sludge application sites and adjacent untreated areas in Graham NC.

Depth ft	P mg/dm3		Zn mg/dm3		Cu mg/dm3		Ni mg/dm3		Pb mg/dm3		Cd mg/dm3		NO^3 mg/kg	
	UT[3]	T[2]	UT	T	UT	T	UT	T	UT	T	UT	T	UT	T
Field 2														
0.5	3	105	2.1	28.7	1.4	8.6	0.40	0.52	0.80	5.40	0.04	0.28	0.88	45.18
1	1	4	0.3	0.9	0.3	0.8	0.44	0.32	0.24	0.96	0.08	0.04	0.44	28.70
2	1	3	0.4	0.6	0.2	0.5	0.28	0.40	0.40	0.92	0.04	0.04	0.42	135.94
3	1	2	0.6	0.6	0.4	0.3	0.48	0.40	0.48	1.16	0.08	0.04	0.20	112.36
4	2	3	1.3	0.8	0.5	0.3	0.52	0.40	0.64	1.16	0.08	0.00	0.32	44.22
5	2	3	1.2	0.6	0.7	0.2	0.64	0.52	0.28	1.24	0.08	0.04	0.09	20.01
6	2	4	0.8	0.4	0.7	0.2	0.68	0.16	0.52	0.92	0.08	0.04	0.32	15.33
Field 3														
0.5	14	42	3.6	13.2	1.6	4.6	0.24	0.44	3.48	2.76	0.08	0.20	3.47	6.85
1	2	3	0.6	0.4	0.7	0.6	0.24	0.28	0.88	0.12	0.04	0.04	1.08	2.53
2	1	3	0.3	0.4	0.4	0.3	0.20	0.64	0.04	0.00	0.08	0.00	0.53	30.40
3	2	2	0.2	0.3	0.3	0.2	0.40	0.28	0.20	0.00	0.04	0.04	0.91	59.52
4	2	2	0.3	0.3	0.3	0.2	0.28	0.28	0.12	0.00	0.04	0.00	0.32	24.53

[3]UT = Untreated Areas

[2]T = Treated Areas

Table 16. Soil concentrations of elements by depth from sludge application sites and adjacent untreated areas in Graham NC.

Depth ft	P mg/dm3		Zn mg/dm3		Cu mg/dm3		Ni mg/dm3		Pb mg/dm3		Cd mg/dm3		NO^3 mg/kg	
	UT[3]	T[2]	UT	T	UT	T	UT	T	UT	T	UT	T	UT	T
Field 4														
0.5	3	30	1.0	4.4	1.0	2.5	0.44	0.40	1.84	2.16	0.04	0.12	1.37	20.02
1	3	58	1.0	11.1	1.0	4.7	0.36	0.36	4.40	4.48	0.04	0.16	0.44	4.76
2	4	14	0.6	3.4	0.8	1.3	0.44	0.48	1.28	2.16	0.04	0.08	0.52	2.33
3	2	2	0.4	0.4	0.4	0.3	0.24	0.36	0.64	0.60	0.04	0.04	1.14	5.74
4	2	2	0.3	0.3	0.4	0.2	0.40	0.24	0.96	0.04	0.04	0.04	0.63	14.18
5	2	2	0.3	0.3	0.3	0.2	0.36	0.36	0.92	0.20	0.04	0.04	0.58	60.33
Field 5														
0.5	24	136	4.5	13.7	2.2	6.1	0.08	0.48	0.60	0.80	0.12	0.16	3.52	27.59
1	4	4	0.6	0.5	0.6	0.7	0.00	0.24	0.72	4.24	0.04	0.04	1.94	9.44
2	2	2	0.4	0.8	0.2	0.3	0.08	0.24	0.84	0.24	0.08	0.04	3.40	36.22
3	2	4	0.6	1.3	0.2	0.7	0.20	0.28	4.40	0.00	0.00	0.00	5.81	40.20

[3]UT = Untreated Areas

[2]T = Treated Areas

Table 17. Soil concentrations of elements by depth from sludge application sites and adjacent untreated areas in Graham NC.

Dept	P		Zn		Cu		Ni		Pb		Cd		NO^3	
	UT[3]	T[2]	UT	T	UT	T	UT	T	UT	T	UT	T	UT	T
Field 6														
0.5	2	27	0.6	11.7	0.8	3.1	0.08	0.20	0.28	4.40	0.04	0.16	0.79	15.43
1	3	3	1.6	0.4	0.8	0.6	0.04	0.08	1.16	1.72	0.00	0.04	0.69	4.88
2	3	2	1.0	0.2	0.5	0.2	0.00	0.08	1.40	1.80	0.04	0.04	0.94	5.00
3	3	2	0.7	0.2	1.2	0.1	0.23	0.08	1.28	0.88	0.08	0.08	0.98	14.70
4	2	2	0.2	0.4	0.2	0.1	0.16	0.08	0.24	0.60	0.04	0.04	0.74	7.39
5	2	2	0.4	4.4	0.2	0.2	0.08	0.00	0.60	0.52	0.04	0.04	0.97	7.04
Field 7														
0.5	37	47	35.3	5.1	3.7	2.1	0.44	0.04	5.80	2.48	0.20	0.08	1.06	14.48
1	4	6	3.0	2.4	1.0	0.5	0.24	0.20	1.56	1.36	0.04	0.08	0.91	30.74
2	2	2	2.0	0.3	0.4	0.3	0.00	0.16	0.96	1.12	0.00	0.04	0.99	50.23
3	1	1	0.4	0.2	0.2	0.1	0.04	0.04	1.00	1.12	0.00	0.04	0.64	17.47
4	1	1	0.4	0.3	0.3	0.2	0.00	0.20	1.28	1.20	0.00	0.04	0.48	3.20
5	2	2	0.5	0.4	0.3	0.2	0.04	0.20	1.16	2.12	0.04	0.00	0.30	1.82

[3]UT = Untreated Areas

[2]T = Treated Areas

Table 18. Tissue concentrations of elements in Coastal bermudagrass by field from sludge application sites and adjacent untreated areas in Graham NC.

	Field 1		Field 2		Field 3		Field 4		Field 5		Field 6		Field 7	
Element	UT	T	UT	T	UT	T	UT	T	UT	T	UT	T	UT	T
---------- % ----------														
N	1.39	3.52	1.86	2.94	1.47	2.69	2.59	3.19	2.52	3.1	2.71	3.29	2	3.02
P	.27	.31	.58	.33	.41	.34	.29	.32	.51	.45	.73	.33	.59	.37
---------- mg/kg ----------														
Zn	28.6	65.6	20.8	72.7	22.1	68.7	31.4	89.7	34.3	132.7	62.6	90.2	24.99	43.77
Cu	5.83	28.88	7.73	15.01	6.41	25.37	9.1	44.61	9.17	69.99	24	90.7	8.62	38
Ni	0.47	0.99	0	0.76	1.02	0.82	1.22	1.05	0	1.98	1.41	1.24	0	1.35
Cd	0	0.4	0	0.44	0	0.58	0	0.43	0	1.11	0	0.78	0	0.53
Pb	0	9.69	0	2.59	5.81	8.16	2.51	15.55	0	29.16	13.61	16.74	4.68	11.29

UT = Untreated Areas T = Treated Areas

Table 19. Soil concentrations of elements by depth from sludge application sites and adjacent untreated areas in Greenville NC.

Depth ft	P mg/dm^3		Zn mg/dm^3		Cu mg/dm^3		Ni mg/dm^3		Pb mg/dm^3		Cd mg/dm^3		NO^3 kg/mg	
	UT[3]	T[4]	UT	T	UT	T	UT	T	UT	T	UT	T	UT	T
Field 1														
0.5	1442	959	25.3	14	5.3	4.4	0.40	0.72	3.88	2.08	0.10	0.12	2.54	5.28
1	268	569	1.2	5.0	0.5	1.2	0.28	0.24	1.72	0.80	0.04	0.08	0.21	1.08
2	102	721	1.0	4.9	0.4	1.1	0.24	0.40	0.24	3.04	0.04	0.08	0.13	2.68
3	171	357	1.9	1.4	0.6	0.7	0.00	0.36	0.56	0.64	0.04	0.04	0.05	0.59
4	117	159	1.2	0.4	0.4	0.4	0.08	0.40	0.00	0.12	0.04	0.04	0.12	0.10
5	237	200	0.5	0.7	0.4	0.4	0.00	0.00	0.48	0.48	0.04	0.04	0.20	0.83
6	328	171	2.2	0.4	0.5	0.4	0.16	0.24	0.64	0.00	0.04	0.04	0.11	1.89
7	284	177	0.3	0.9	0.3	0.5	0.36	0.00	0.48	0.64	0.04	0.04	0.08	0.84
8	244	171	0.2	0.2	0.3	0.3	0.12	0.12	0.64	0.30	0.04	0.04	0.05	0.83
Field 2														
0.5	310	1772	1.8	26.8	1.0	8.4	0.44	0.84	0.44	0.40	0.04	0.24	0.56	8.76
1	149	824	0.8	3.6	0.5	2.2	0.32	0.04	0.20	2.08	0.08	0.12	0.76	2.87
2	120	347	0.4	0.7	0.4	1.0	0.12	0.44	0.00	0.60	0.04	0.08	0.12	2.76
3	124	192	0.6	2.0	0.4	0.7	0.08	0.20	0.16	0.24	0.04	0.04	0.07	3.61
4	144	171	0.5	1.8	0.3	0.7	0.28	0.20	0.00	1.08	0.00	0.04	0.15	2.57
5	229	184	0.2	0.4	0.2	0.6	0.28	0.28	0.24	0.72	0.00	0.04	0.13	1.99

[3]UT = Untreated areas

[4]T = Treated areas

Table 20. Coastal bermudagrass tissue concentrations of elements from sludge application sites and adjacent untreated areas in Greenville NC.

	Field 1		Field 2	
Element	UT	T	UT	T
---------- % ----------				
N	1.69	2.4	2.65	2.57
P	.27	.29	.27	3200
---------- mg/kg ----------				
Zn	39.7	93	62.5	69.3
Cu	5.64	7.68	10.21	13.18
Ni	0.79	1.36	1.31	1.3
Cd	0	0.35	0	0.41
Pb	0	0	0	0

UT = Untreated Areas T = Treated Areas

HILLSBOROUGH. Soil accumulation patterns for P, Zn, Cu, Pb and Ni show the greatest concentrations in the surface 0.5 feet (Table 21). Soil samples from fields amended with sludge did not differ in elemental concentration of Cu, Zn or Cd at any depth, from the untreated comparison. Differences between treated and untreated areas do appear to exist for Ni and Pb for the surface 0.5 feet, with the treated areas having higher levels of these metals. Concentrations of Zn in both treated and untreated areas may be enough to affect the growth of a Zn sensitive crop like peanuts if the pH is not maintained above 6.5 (Cox, 1990). Phosphorus concentrations in both fields would require additional P for optimum growth according to NCDA recommendations. Cadmium concentrations were low for all sites and depths.

Soil nitrate concentration in the surface 0-0.5 feet of soil exceeded 10 mg/kg NO_3-N for all fields. Field areas treated with sludge, however, had higher concentration (39.6 F1 and 21.1 F2 mg/kg NO_3-N) than the untreated area (10.2 mg/kg NO_3-N). Nitrate concentrations in the treated area of Field 1 decreased to almost the same levels as the untreated check at 2-3 feet then increased to 12 mg/kg NO_3-N at 3-4 feet and decreased again to 7.67 mg/kg NO_3-N at 5 feet. Concentrations decreased from the surface in Field 2 until levels nearly equalled the untreated soil.

The Hillsborough sites consisted of three fescue pastures. Plants from treated and untreated areas were either deficient or low in N (Table 22). Phosphorus, Zn and Cu were sufficient for all plant samples. There were no detectable concentration of Ni, Cd or Pb in any of the samples

JACKSONVILLE. Accumulation patterns for soil P, Zn, Cu, Cd, Ni and Pb at the Jacksonville site showed higher concentrations in the top 0.5 to 1 foot samples than in soil at greater depths in the treated field areas (Table 23). Lead concentrations in the untreated area was also higher in the surface 1 foot than deeper samples. Concentrations of all elements in the untreated areas were consistently low, yet surface concentrations were always higher than greater depths. Nickel concentrations were similar to or higher than the untreated field at all depths except at one foot.

Agronomically, the P concentration in the surface 0.5 feet of the treated area is considered very high and would not require additional fertilizer for plant growth. Zinc concentration (0-0.5 feet) in the treated area is potentially toxic to sensitive crops (Cox, 1990). Copper concentrations (0-0.5 feet) is adequate for plant growth in both the treated and untreated ares. Concentrations of Ni, Pb and Cd were low and should not pose any plant growth problems.

Nitrate concentrations in sludge treated soil was higher than the untreated areas for all depths sampled. Concentrations in the 0.5-1 foot sample were fairly low, 1.30 mg/kg NO_3-N. Highest NO_3-N concentration in treated area was found at 0.5 - 1 foot (28.7 mg/kg NO_3-N). Nitrate concentrations decreased down to 4 feet then increased again. Concentrations at six feet were 9.38 mg/kg NO_3-N.

Plant samples were taken from a bermudagrass field. Plant N concentration in samples from the treated field was deficient, while N concentration in tissue from the untreated area was sufficient (Table 24). Phosphorus concentrations were sufficient for all samples as was copper. Zinc concentrations were considered deficient. Concentrations of all elements where higher in plants growing in untreated areas. No detectable concentrations of Ni, Cd or Pb were found in any of the samples.

Table 21. Soil concentrations of elements by depth from sludge application sites and adjacent untreated areas in Hillsborough NC.

	P mg/dm3		ZN mg/dm3		Cu mg/dm3		Ni mg/dm3		Pb mg/dm3		Cd mg/dm3		NO3 mg/kg	
Depth	UT[5]	T[2]	UT	T	UT	T	UT	T	UT	T	UT	T	UT	T
Field 1														
0.5	8	57	8.7	10.2	1.2	1.8	0.20	0.48	4.28	5.60	0.08	0.08	10.27	39.6
1	2	4	0.8	1.4	0.5	0.5	0.32	0.28	2.40	2.56	0.00	0.00	1.86	4.64
2	4	1	0.3	0.3	0.4	0.3	0.00	0.04	1.24	1.56	0.04	0.00	1.30	1.85
3	3	1	0.3	0.2	0.2	0.2	0.16	0.12	1.08	1.60	0.00	0.00	0.54	1.67
4	1	1	0.3	0.6	0.2	0.2	0.12	0.00	0.60	1.32	0.04	0.00	1.66	12.0
5	2	1	0.2	0.8	0.2	0.3	0.16	0.12	0.36	1.76	0.00	0.00	0.30	7.67
Field 2														
0.5	8	17	8.7	8.3	1.2	1.8	0.20	0.52	4.28	7.12	0.08	0.08	10.27	21.1
1	2	1	0.8	0.7	0.5	0.6	0.32	0.28	2.40	2.32	0.00	0.00	1.86	6.00
2	4	1	0.3	0.2	0.4	0.4	0.00	0.00	1.24	0.36	0.04	0.00	1.30	0.39
3	3	2	0.3	0.3	0.2	0.4	0.16	0.00	1.08	0.68	0.00	0.00	0.54	0.48
4	1	1	0.3	0.2	0.2	0.3	0.12	0.12	0.60	1.32	0.04	0.00	1.66	1.04

[5] UT = Untreated areas

[2] T = Treated areas 2

Table 22. Tissue concentrations of elements in fescue tissue from sludge application sites and adjacent untreated areas in Hillsborough NC.

Element	Field 1		Field 2	
	UT	T	UT	T
---------- % ----------				
N	2.15	1.64	1.69	1.8
P	0.43	0.45	0.41	0.52
---------- mg/kg ----------				
Zn	22.6	22.3	26.1	22.5
Cu	7.99	7.28	7.22	9.19
Ni	0	0	0	0
Cd	0	0	0	0
Pb	0	0	0	0

UT = Untreated Areas T = Treated Areas

Table 23. Soil Concentrations of elements by depth from sludge application sites and adjacent untreated areas in Jacksonville NC.

Depth ft	P mg/dm^3		Zn mg/dm^3		Cu mg/dm^3		Ni mg/dm^3		Pb mg/dm^3		Cd mg/dm^3		NO3 mg/kg	
	UT[3]	T[4]	UT	T	UT	T	UT	T	UT	T	UT	T	UT	T
0.5	14	159	2.4	19.6	0.4	2.0	0.32	0.36	4.36	3.36	0.04	0.12	0.23	1.30
1	15	42	0.5	1.9	0.2	0.7	0.04	0.32	2.72	2.60	0.00	0.08	0.21	28.7
2	2	4	0.4	0.9	0.2	0.3	0.16	0.10	1.52	1.36	0.04	0.00	0.24	7.84
3	1	2	0.3	0.5	0.2	0.2	0.24	0.12	1.08	1.08	0.00	0.00	0.17	0.37
4	1	11	0.4	1.2	0.2	0.5	0.20	0.08	1.68	1.24	0.00	0.00	0.17	0.37
5	1	2	0.4	0.5	0.4	0.2	0.52	0.00	1.64	1.24	0.00	0.00	0.02	2.74
6	1	2	0.4	0.9	0.5	0.4	0.16	0.24	1.54	2.64	0.04	0.04	0.16	9.38

[3] UT = Untreated Soils

[4] T = Treated areas

Table 24. Concentrations of elements in Coastal bermudagrass from sludge application sites and adjacent untreated areas in Jacksonville NC.

Element	UT	T
---------- % ----------		
N	3.28	1.25
P	3400	2800
---------- mg/kg ----------		
Zn	10.31	2.87
Cu	15.46	5.96
Ni	0	0
Cd	0	0
Pb	0	0

UT = Untreated Areas T = Treated Areas

NEW BERN. Soil accumulation patterns for P and Cu were similar with highest concentrations in surface 0.5 feet of soil and decreasing to a constant level at three feet (Table 25). Treated samples had higher concentrations of P and Cu, 377 and 7 mg/dm^3, than untreated, 237 and 1.6 mg/dm^3 at 0.5 feet. Zinc concentrations were consistently higher at all depths in the treated field than in the untreated area. This was the first location that maintained a difference for all depths sampled. The accumulation patterns between the treated and untreated areas were quite similar in spite of the concentration differences. Zinc concentrations in the treated area were high enough to cause potential toxicity problems for sensitive crops to a depth of three feet. This was the first site that has potentially toxic levels below 1 foot. Cadmium levels were higher in the surface layer in the treated areas with no evidence of downward movement. Nickel concentration were low at all depths with an erratic accumulation pattern. Lead concentrations in the surface 0.5 feet were higher in both treated and untreated areas compared to greater depths. There is some movement of Pb to 1 foot in the treated area.

Nitrate concentrations were very low (<4 mg/kg NO_3-N) at all soil depths at the New Bern locations. Concentrations at all depths were similar for treated and untreated areas. Concentrations in the surface 0-0.5 foot layer maybe too low (<1.54 mg/kg NO_3-N) to sufficiently support a non-leguminous crop.

Peanuts were sampled in the sludge amended field and bermudagrass was used as the untreated check. Nitrogen concentrations were sufficient in the peanut plant, which produces its own N (Table 26). The bermudagrass, however, was deficient in N. Phosphorus levels in the treated peanuts were just below the sufficiency range, The bermudagrass check had sufficient concentrations of P. Peanuts are very sensitive to zinc especially if the soil pH is low. Peanuts from the treated fields had very high concentrations in the plant tissue (>160 ppm) well above the sufficiency range and approaching toxicity levels. Concentrations in the bermudagrass check were considered within the sufficient range. All samples had sufficient concentrations of copper. There were no detectable concentrations of Ni, Cd or Pb.

REIDSVILLE. Two field sites were sampled at Reidsville. Soil accumulation patterns of P, Zn, Cu, Pb, Cd and Ni showed increased concentrations in the surface foot of soil in both treated fields compared to the untreated (Table 27). From two to ten feet no differences were found in concentration patterns between treated and untreated fields. Phosphorus concentrations in the treated fields were agronomically very high, while the untreated areas were deficient for optimum plant growth. Zinc concentration in the surface foot of the treated area in Field 1 was high enough to cause potential toxicity to sensitive crops under low pH conditions (Cox, 1990). No downward movement of elements were noted below 1 foot.

Concentrations of nitrate in the untreated soils never exceeded 2.47 mg/kg NO_3-N at any depth. Both treated fields, however, had evidence of excessive nitrate movement below the root zone. Field 1 showed a nitrate accumulation pattern that peaked at 49 mg/kg NO_3-N at 1-2 feet then decreased with depth thereafter to 9.59 mg/kg NO_3-N at 4.5 feet. Field 2 showed increasing concentrations of nitrate with depth to a maximum concentration of 52.4 mg/kg NO_3-N at 3 feet. Concentrations decreased slightly, but remained above 10 mg/kg NO_3-N down to 7 feet. Nitrate concentrations were dramatically reduced from 8-9 feet (0.30 mg/kg NO_3-N) possibly as a result of denitrification or lateral transport. Similar findings were reported by Gilliam (1988) and Gambrell et al. (1975) in other North Carolina soils.

Plant samples were taken from a wheat field in both the sludge amended portion of the field and in the untreated area. Nitrogen concentrations in the plant tissue were deficient in all samples for optimum plant growth (Table 28). Highest concentrations were found in the untreated samples. Phosphorus concentration were optimal only in the untreated samples. Unlike the N and P levels, the treated fields had excessive concentrations of zinc. Plants from the untreated area had concentration within the sufficiency range recommended for wheat (15-70 ppm Zn). Copper concentrations were all within the sufficient range of 5-25 ppm with the exception of one from the untreated area in F1. There were no detectable levels of Ni, Cd, or Pb in any of the samples.

Table 25. Soil concentrations of elements by depth from sludge application sites and adjacent untreated areas in New Bern NC.

Depth ft	P mg/dm^3		Zn mg/dm^3		Cu mg/dm^3		Ni mg/dm^3		Pb mg/dm^3		Cd mg/dm^3		NO3 mg/kg	
	UT[5]	T[6]	UT	T	UT	T	UT	T	UT	T	UT	T	UT	T
0.5	237	377	4.4	18.6	1.6	7	0.04	0.4	4.04	7.6	0.08	0.24	0.17	1.54
1	94	140	2	7.9	0.6	1.4	0.24	0	1.68	3	0.08	0.08	0.16	0.12
2	18	30	3.3	8.7	0.3	0.5	0	0.16	1.32	1.36	0.08	0.04	0.39	0.26
3	6	7	3.7	9.7	0.2	0.3	0.16	0.16	2.2	2.76	0.08	0.04	3.53	1.66
4	6	9	2.8	7.2	0.2	0.3	0	0.2	2.12	2.76	0.04	0.04	1.55	3.49
5	6	6	1.8	5.7	0.2	0.3	0.12	0.52	1.4	1.68	0.04	0.04	1.85	3.77

[5]UT = Untreated areas

[6]T = Treated areas

Table 26. Tissue concentrations of elements from sludge application sites and adjacent untreated areas in New Bern NC.		
Element	UT[1]	T[2]
---------- % ----------		
N	1.42	3.69
P	0.36	0.18
---------- mg/kg ----------		
Zn	44.6	160.3
Cu	5.64	5.39
Ni	0	0
Cd	0	0
Pb	0	0

UT = Untreated Areas T = Treated Areas
[1]Peanut, [2]Bermudagrass

Table 27. Soil concentrations of elements by depth from sludge application sites and adjacent untreated areas in Reidsville NC.

Depth ft	P mg/dm^3		Zn mg/dm^3		Cu mg/dm^3		Ni mg/dm^3		Pb mg/dm^3		Cd mg/dm^3		NO3 mg/kg^3	
	UT[7]	T[8]	UT	T	UT	T	UT	T	UT	T	UT	T	UT	T
Field 1														
0.5	7	177	1.4	12.0	1.7	8.1	0.00	0.08	2.84	4.44	0.00	0.12	1.07	4.11
1	2	3	0.5	0.5	0.4	0.2	0.00	0.00	2.08	2.12	0.00	0.00	0.57	9.26
2	2	2	0.5	0.4	0.2	0.2	0.00	0.00	2.72	2.52	0.00	0.00	0.66	49.02
3	3	1	0.4	0.5	0.3	0.2	0.12	0.00	2.88	2.24	0.00	0.00	2.47	28.24
4	6	4	0.4	0.9	0.3	0.4	0.00	0.00	2.60	2.60	0.00	0.00	1.89	16.68
4.5	6	2	0.2	1.1	0.2	0.2	0.08	0.00	2.12	2.84	0.00	0.00	1.74	9.59
Field 2														
0.5	8	124	2.6	7.0	1.5	7.9	0.36	0.52	3.88	4.64	0.00	0.08	0.10	1.82
1	1	3	0.6	0.5	0.4	0.3	0.12	0.00	2.00	2.28	0.04	0.00	0.40	0.98
2	1	3	0.4	0.4	0.2	0.2	0.08	0.04	2.24	1.92	0.00	0.04	0.37	14.39
3	1	3	0.4	0.5	0.3	0.2	0.04	0.00	2.64	2.52	0.00	0.00	0.23	52.45
4	1	8	0.5	1.0	0.3	0.6	0.08	0.08	2.48	3.32	0.00	0.04	0.30	43.05
5	3	4	0.6	0.6	0.2	0.3	0.16	0.08	2.24	2.80	0.00	0.00	0.27	15.38
6	3	2	0.8	1.8	0.4	0.5	0.08	0.16	1.60	3.00	0.00	0.00	0.20	31.34
7	3	4	0.7	0.6	0.2	0.3	0.08	0.00	1.85	3.48	0.00	0.00	0.13	14.37
8	3	4	0.8	1.0	0.2	0.3	0.12	0.00	1.92	2.88	0.04	0.00	0.15	2.93
9	2	4	1.3	0.7	0.4	0.3	0.28	0.00	3.08	2.84	0.00	0.00	0.19	0.30

[7] UT = Untreated areas

[8] T = Treated areas

Table 28. Concentrations of elements in wheat tissue from sludge application sites and untreated areas in Reidsville NC.

	Field 1		Field 2	
Element	UT	T	UT	T
---------- % ----------				
N	1.59	1.25	1.84	1.3
P	0.23	0.13	0.21	0.14
---------- mg/kg ----------				
Zn	35.4	83.9	26	87.8
Cu	4.7	5.92	7.54	6.67
Ni	0	0	0	0
Cd	0	0	0	0
Pb	0	0	0	0

UT = Untreated Areas T = Treated Areas

TRYON. Small differences were detected between the treated and untreated soils for Zn, Cu, Pb, Cd and Ni (Table 29). Phosphorus concentrations in the treated field were higher than the untreated at 0.5 and 1 foot, but showed no differences at greater depths. Agronomically, concentrations of P were adequate for plant growth in both the treated and untreated areas. Concentrations of Cu and Zn were also adequate for plant growth. Concentrations of other heavy metals were low and should not pose plant growth problems.

Nitrate concentrations in soil at the Tryon site were below 10 mg/kg NO_3-N for all field areas and sampling depths. Soil concentrations were greatest in the surface 0-1 foot and decreased with increasing depths. Concentrations in the surface foot were slightly higher in treated than in the untreated areas but no differences occurred at greater depths.

Plants were not sampled at the Tryon site.

WILSON. Soil concentrations of all elements, with the exception of Cd, were highest in the surface 0.5 feet of soil (Table 30).Phosphorus concentrations in the soil surface were higher in both untreated areas than the sludge amended soils and showed mobility to a much greater depth. This is probably a result of fertilization programs from previous cropping systems. Zinc concentrations were higher in the surface 0.5 feet of treated fields but showed no differences at greater depths. Concentrations in both the treated and untreated areas of Field 1 and the treated area of Field 2 were high enough to pose a potential toxicity problem to Zn sensitive crops.

Nitrate analysis of soil samples from 0-1 foot were missing for all fields at the Wilson site. The remaining samples showed low nitrate concentrations throughout the profile in Field 2. Field 1 had concentrations around 10 mg/kg NO_3-N at two and three feet in the untreated area but decreased to 1.64 mg/kg NO_3-N at four feet.

Both the treated and untreated plant samples were bermudagrass. Nitrogen concentrations in the plant tissue were low or deficient for all samples (Table 31). Phosphorus levels were at the low end of the sufficiency range. Zinc concentrations were very high in all the treated field samples with values between 220.2 and 311.5 mg/kg Zn. The maximum dietary concentration for sheep is 300 ppm Zn. Also, these plant accumulation levels would be considered toxic for peanut. Concentrations in the untreated samples were within the Zn sufficiency range for bermudagrass. All plant samples had sufficient concentrations of copper. Nickel concentrations were lowest in samples from untreated areas. Lead was not detected in any of the plant samples. Cadmium concentrations in both treated field samples were all over 0.5 ppm Cd which is the maximum allowable dietary levels for livestock.

WINNABOW. Soil elemental accumulation patterns were very similar for P, Zn, Cu, Cd and Pb with increased concentrations in the treated soil being limited to the surface 0.5 -1 feet (Table 32). Agronomically, P levels were medium and Zn and Cu levels adequate for plant growth. Zinc concentrations, while not high enough to be toxic, are approaching concern levels. Nickel concentrations showed no definable pattern with depth.

Soil concentrations of NO_3-N exceeded 10 mg/kg in the treated and untreated field areas at 0-0.5 feet and for the untreated area 0.5-1 feet. Nitrate concentrations below two feet were lower for the treated area. Concentrations in the untreated area remained between 5-8 mg.kg NO_3-N throughout the remainder of the profile to the maximum depth sampled at 6.5 feet.

Plants were not sampled at the winnabow site.

Table 29. Soil concentrations of elements by depth from sludge application sites and adjacent untreated areas in Tryon NC.

Depth ft	P mg/dm^3		Zn mg/dm^3		Cu mg/dm^3		Ni mg/dm^3		Pb mg/dm^3		Cd mg/dm^3		NO^3 mg/kg	
	UT[9]	T[10]	UT	T	UT	T	UT	T	UT	T	UT	T	UT	T
0.5	60	149	1.8	2.9	2.4	3.3	0.00	0.08	3.92	3.60	0.04	0.04	3.66	6.87
1	89	52	2.4	1.2	5.0	1.9	0.00	0.12	4.08	3.76	0.00	0.00	5.31	8.12
2	5	10	1.0	0.6	1.1	1.0	0.00	0.08	2.16	2.52	0.00	0.00	1.91	2.69
3	8	2	0.6	0.5	1.2	0.4	0.12	0.12	1.92	2.08	0.00	0.00	1.15	0.71
5	5	4	0.6	0.5	2.3	0.5	0.04	0.00	1.52	2.76	0.00	0.00	1.26	0.25

[9] UT = Untreated areas

[10] T = Treated areas

Table 30. Soil concentrations of elements by depth from sludge application sites and adjacent untreated areas in Wilson NC.														
Depth	P		Zn		Cu		Ni		Pb		Cd		NO^3	
	UT[11]	T[12]	UT	T	UT	T	UT	T	UT	T	UT	T	UT	T
Field 1														
0.5	432	192	18.0	38.4	3.1	3.4	0.40	0.48	8.64	5.20	0.12	0.16	Lost	Lost
1	301	94	4.5	4.4	0.6	0.8	0.28	0.08	1.64	2.12	0.64	0.08	Lost	Lost
2	94	4	3.2	0.5	0.5	0.4	0.16	0.00	0.32	0.52	0.04	0.00	11.10	3.74
3	80	3	2.8	0.8	0.4	0.5	0.52	0.20	0.36	1.16	0.00	0.04	10.78	0.18
4	43	9	0.8	1.0	0.3	0.4	0.00	0.28	0.12	0.44	0.00	0.04	1.64	0.05
Field 2														
0.5	312	192	3.3	31.2	0.4	3.9	0.08	0.44	3.28	5.28	0.04	0.16	Lost	Lost
1	200	17	1.2	2.1	0.6	0.6	0.24	0.24	1.08	0.72	0.04	0.04	Lost	Lost
2	17	6	0.5	0.5	0.3	0.4	0.00	0.24	0.28	0.46	0.00	0.00	1.13	0.72
3	3	3	0.3	0.8	0.2	0.4	0.08	0.04	0.96	0.72	0.00	0.00	0.54	0.39
4	2	9	0.3	1.5	0.4	0.4	0.48	0.04	1.32	0.24	0.00	0.00	0.45	0.08
5	3	18	0.3	1.3	0.4	0.5	0.24	0.08	0.96	0.32	0.00	0.00	Lost	0.85

[11]UT = Untreated areas

[12]T = Treated areas

Table 31. concentrations of elements in Coastal bermudagrass sites and adjacent untreated areas in Wilson NC.				
Element	Field 1		Field 2	
	UT	T	UT	T
---------- % ----------				
N	2.72	1.96	1.93	2.19
P	2100	2200	2300	2300
---------- mg/kg ----------				
Zn	61.4	311.5	86.8	220.2
Cu	7.49	8.24	3.94	8.16
Ni	0.57	1.12	0.5	0.6
Cd	0	0.94	0	0.5
Pb	0	0	0	0

Table 32. Soil Concentrations of elements by depth from Municipal Waste Treatment sites and adjacent untreated areas in Winnabow NC.

Depth ft	P mg/dm^3		Zn mg/dm^3		Cu mg/dm^3		Ni mg/dm^3		Pb mg/dm^3		Cd mg/dm^3		NO_3 mg/kg	
	UT[13]	T[14]	UT	T	UT	T	UT	T	UT	T	UT	T	UT	T
0.5	37	47	4.8	6.6	1.4	1.7	0.68	0.56	3.84	6.12	0.08	0.12	48.43	18.57
1	4	27	0.8	2.8	0.3	1.0	0.52	0.96	1.80	3.12	0.04	0.04	12.44	3.97
2	2	4	0.6	0.5	0.2	0.3	0.68	0.48	1.80	1.72	0.04	0.04	6.70	0.27
3	2	2	0.5	0.5	0.3	0.2	0.56	0.64	2.04	1.80	0.04	0.08	8.46	1.40
4	1	1	0.4	0.4	0.3	0.3	0.48	0.72	2.00	1.92	0.04	0.04	5.16	1.21
5	1	1	0.4	0.5	0.2	0.4	0.56	0.80	2.24	2.08	0.04	0.00	5.67	0.44
6	3	2	0.5	0.4	0.3	0.5	0.68	0.20	1.52	1.88	0.04	0.04	6.81	0.35
6.5	4	2	0.6	0.5	0.5	0.5	0.52	0.32	2.52	2.08	0.00	0.08	6.64	0.05

[13] UT = Untreated areas

[14] T = Treated areas

Results by Element

Soils were analyzed at twenty-eight field sites treated with municipal sludge in fourteen North Carolina municipalities. Soil analyses from treated fields were compared against soils from adjacent areas that were untreated. Accumulation patterns for P, Zn, Cu, Ni, Cd and Pb were determined to a depth of ten feet at most sites. General statements concerning the effect of the land application programs on soil concentrations of individual elements will follow.

Twenty-two field sites in 10 municipalities that utilize land application for disposal of sludge were evaluated using plant tissue analysis. At each field site, plants were also taken from a buffer area or from an untreated adjacent field for comparative purposes.

Phosphorus (P) is relatively immobile in soils and usually moves less than an inch from where it is placed. Soluble phosphorus reacts the iron and aluminum compounds found in clay minerals and is converted to less available forms. Because of its relative immobility, P accumulates in the soil surface where it is applied and/or incorporated. A typical phosphorus accumulation pattern will show highest concentrations in the surface with rapidly decreasing concentrations at greater depths. This accumulation pattern would look similar regardless of the P source.

Results from 28 field sites in North Carolina show typical P accumulation patterns with soil depth. Twenty-one of the sites had higher P concentrations in the surface foot of soil from treated fields than untreated fields. The remaining sites probably reflect past fertilization practices prior to the land application programs. Phosphorus concentrations in treated areas at Albermarle, Eden (Field 2), Elizabeth city (Field 1), Graham (Fields 1, 2, 3, 5, 6, 7) Hillsborough, Jacksonville, Riedsville and Winnabow showed higher concentrations in the surface 0.0-1 feet of soil than at greater depths. Evidence of P movement to 2 feet was found at treated sites at Eden (Field 1), Graham (Field 4), New Bern, Fayetteville and Wilson, and in untreated areas at Elizabeth City (Fields 1, 2), New Bern and Wilson (Field 2). Phosphorus movement was found below 3 feet at Elizabeth City (Field 2, treated), below 4 feet in untreated areas for Fayetteville and Wilson and below 5 feet for treated and untreated areas in both fields at Greenville.

Phosphorus concentrations in plant tissue were as high as 0.7% P. Only four plant samples from the treated areas had deficient concentrations of P for plant growth. None of the plants growing in the untreated areas had P deficiencies. When comparing plant P concentrations from treated and untreated areas, 13 of the 22 field comparisons had higher P concentrations in the untreated areas.

Heavy metals, like phosphorus, are relatively immobile in soils. Research by Giordano and Mortvedt (1976), Boswell (1975) and King and Morris (1972) showed little movement of metals below 30 cm. Soil profile accumulation patterns for most of the metals, therefore, should be similar in appearance to P.

Zinc concentrations were greater in treated than untreated areas at 22 of the sites. Accumulation patterns of all treated and treated areas (56 areas) showed only 5 areas with evidence of movement below 1 foot. Three of these were from untreated areas and two from treated areas. Zinc concentrations below 1 mg/dm^3 are considered to be insufficient for plant growth when found in the soil surface 0-0.5 feet (NCDA,1987). Twenty-three of the untreated and 14 of the treated areas had these concentrations. Concentrations between 8.5 and 17 mg/dm^3 have been shown to cause zinc toxicity in peanuts when soil pH is below 4.5 (Cox, 1990). Two untreated and six treated areas were within this range. Zinc concentrations >17 mg/dm^3 were found to be toxic to peanuts even when the soil pH was 6.0 (Cox,1990). Concentrations above 17 mg/dm^3 were found in three untreated areas: Fields (F) located at Graham F7 (35.3 mg/dm^3), Greenville F1 (25.3 mg/dm^3), and Wilson F1 (18.0 mg/dm^3). Eight treated areas had Zn concentrations over 17 mg/dm^3. These were located at Eden F2 (26.8 mg/dm^3), Graham F1 (28.5 mg/dm^3), Graham F2 (28.7 mg/dm^3), Greenville F2 (26.8 mg/dm^3), Jacksonville (19.6), New Bern (18.6), Wilson F1 (38.4 mg/dm^3) and Wilson F2 (31.2 mg/dm^3). Only the New Bern location showed movement of Zn concentrations >8.5 mg/dm^3 below the 0.5 feet were it was found to a depth of three feet.

Most of the plants (73 %) growing in untreated areas were within the recommended range for crop growth for zinc (15-75 ppm Zn). Two plants samples were deficient and two had concentrations in excess of crop needs from the untreated areas. Only 41 % of the plants growing in sludge amended soil were within the sufficient range (15-70 ppm Zn). Half the samples were in excess of plant Zn needs and an additional 9 % were considered deficient.

Copper concentrations followed the expected accumulation pattern for non-mobile nutrients. Copper concentrations were primarily located in the top 1 foot of the soil profile with no further evidence of movement at 27 of the 28 untreated areas and at 20 of the treated areas. Of the remaining areas, movement was detected only to two feet and not further. None of the treated or untreated areas had concentrations of Cu that exceeded 20 mg/dm^3. The highest concentration found was at Graham F1 at 9.8 mg/dm^3. Walsh et al (1972) showed a significant reduction in snap bean growth when extractable Cu by HCl or DPTA methods exceeded 20 ppm. The critical level decreased to 15 ppm Cu using EDTA extractant. Additional studies by Lexmond and de Haan (1980) suggested that Cu may become phytotoxic when 20 - 30 ppm of HNO_3 extractable Cu is present for each 1% of organic matter. Delas (1980) noted that the threshold of soil Cu phytotoxicity was 25 ppm of NH_4-extractable Cu for sandy soils and 100 ppm in clay soils. Drouineau and Mazayer (1962) reported Cu phytotoxicity at 50 ppm NH_4-exchangeable Cu in soils with pH 5 and 100 ppm in soils with pH 6-7. While the research is diverse in the extractant used, soil types and pH levels, it appears that a concentration of around 20 mg/dm^3 extractable Cu is a reasonable guideline to begin questioning potential phytotoxicities. While this level is probably reasonably safe for most conditions and crops, there is sufficient evidence to suggest that under certain environmental conditions and with certain Cu sensitive species, phytotoxicity may be possible.

Copper concentrations in plants grown on untreated soils were mostly (95%) within the general range recommended for crop production of 4-20 ppm Cu. Only plants from untreated fields were deficient in Cu, and none had excessive concentrations. In the treated areas, 73% of the samples were within the recommended Cu sufficiency range. The remaining 27% of the samples had Cu concentrations in excess of the sufficiency range. From this assessment, it appears that copper build-up is less of a concern with land application of municipal sludge than zinc. However, it should be noted that there were still 7 samples with excessive copper levels in the plant tissue.

Lead accumulation patterns were again typical of non-mobile elements. With the exception of three untreated and two treated areas, all areas sampled had little evidence of Pb movement below one foot. Of the sites that showed possible movement, both treated areas and one untreated had indications of movement only to two feet. Untreated areas at Graham F5 and Hillsborough F1 showed evidence of further movement to three feet. The highest concentration of Pb was found in the surface 0.5 feet in the untreated area of Field 1 at Wilson (8.64 mg/dm^3). Research published on extractable soil Pb concentrations that may cause phytotoxicity is limited. Davis et al. (1978) found 25 ppm Pb added into a sand culture solution caused phytotoxicity in barley. Hooper (1937) similarly reported phytotoxicity with > 30 ppm Pb for beans. Because of the limited research on what level of soil extractable Pb is considered phytotoxic, it is more difficult to confidently define a concentration or range of concentrations that could be used as guidelines to begin questioning if additional land application might induce phytotoxicities. For our study, we assumed that 25 - 30 mg/dm^3 of soil-extractable Pb is high enough to question additional Pb applications.

Lead concentrations in plant tissue were fairly low for most locations. Fifty-nine percent of all sites had no detectable concentrations of Pb in plant tissue. Thirty percent of the plant samples growing on treated areas had higher Pb concentration than plants from untreated areas. While only one sample from an untreated area had higher concentrations. No samples were above the Maximum Dietary Level of 30 ppm Pb for livestock.

Nickel concentrations at all sites were fairly low. The highest concentration was found at 0.5 - 1 feet at Winnabow (0.96 mg/dm^3). Because of the low concentrations, distribution patterns were difficult to discern in either treated or untreated areas. This may not be unusual since several countries have indicated that for nonpolluted soils, there were no discernable patterns in the distribution of Ni in the soil Profile (Adriano, 1986). Research on phytotoxic concentrations of soil-extractable Ni are difficult to find. Khalid and Tinsley (1980) noted no yield depressions and the absence of chlorotic symptoms in rye grass until about 90 ppm Ni level in a noncalcareous (pH 4.7) soil. Mishra and Kar (1974) reported that in nutrient solution Ni may be toxic to plants at levels as low as < 1 ppm to levels as high as 300 ppm.

Nickel concentrations were below 3.08 mg/kg for all plant samples. When using the Maximum Dietary Guidelines for Livestock of 50 ppm for cattle and sheep and 100 ppm for swine, it appears that Ni is of little concern. When comparing plants grown in sludge treated soils to those grown in untreated soils, 8 treated sites were higher and one was the same.

Forty-one percent of the sites had no detectable Ni in any of the plant samples.

Cadmium concentrations were low for all treated and untreated areas. The highest concentration found was at Graham F1 (0.32 mg/dm^3) at 0.0 -0.5 feet. Movement of Cd below one foot was evident only at the treated area in Greenville Field 1, where it appears Cd moved to three feet. While these levels of Cd appear low there is little soils research to support this contention. Haghiri (1973) induced phytotoxicity on soybean and wheat at pH 6.7 with soil applied Cd rates of 2.5 ppm. Bingham and Page (1975) reported phytotoxic concentrations of > 4 ppm for spinach and >640 ppm for paddy rice. Adriano (1986) stated that Cd is known to be more toxic to plants at much lower concentrations than other metals like Zn, Pb, Cu, etc. While the soil levels detected in our research appear to be low and should not pose phytotoxic concerns for plants, the real concern is the degree of uptake in plants that may be toxic to mammals.

Eighty- six percent of plants sampled from untreated areas and 36% of the treated area plants had no detectable Cd in their tissue. An additional 32% of the treated samples and 9% of the untreated sample had concentrations above the 0.5 ppm Cd Maximum Dietary Levels for Livestock. Results of this assessment suggest that cadmium accumulation in plant materials is a major concern for land application of sludge and that managers should be encouraged to utilize plant tissue sampling as an additional monitoring tool.

Nitrogen Twenty-three of the 28 untreated areas had soil concentrations < 10 mg/kg NO_3-N at all depths sampled. Four additional areas had concentrations >10 mg/kg NO_3-N at depths between 0.0 and 3.0 feet. Nitrate at this depth is in the root zone of most agronomic crops and should not be a problem. Only one untreated area (Eden F1) had nitrate concentrations >10 mg/kg NO_3-N at depths below three feet. Nitrate >10 mg/kg NO_3-N below the root zone is a potential pollutant to ground or surface waters. Examination of concentration magnitude and change with increasing depth below the root zone is a good indicator of the potential ground water risk from nitrate at an individual site.

Eleven of the 28 treated areas had <10 mg/kg NO_3-N at all depths sampled. Nine treated areas had >10 mg/kg NO_3-N between 0.0 and 3.0 feet. Two of these areas (Graham Field 5 and Jacksonville), however, had either extremely high nitrate levels at three feet and that was the maximum depth sample at that site or accumulation patterns were showing evidence of an increase with depth but did not exceed 10 mg/kg NO_3-N at the maximum depth sampled. The remaining eight treated areas had >10 mg/kg NO_3-N below three feet indicating a nitrogen management problem at the site. These areas were located at Eden Field 1, Graham Field 1, Field 2, Field 3, Field 4, Hillsborough Field 1, Reidsville Field 1 and Field 2.

Nitrate accumulation patterns can give additional insight on the potential risk of an area to ground water contamination. Gambrell et al (1975) and Gilliam (1988) have shown varying degrees of oxidation-reduction potentials through out soil profiles that can affect denitrification. In addition, some profile changes in nitrate concentration with depth have also been attributed to lateral flow caused by an aquatard.

Nitrate accumulations from the 28 treated and untreated areas seemed to fall into six different patterns. At some sites it was more difficult to determine the pattern because the maximum depth sampled was four feet or less and did not provide a full enough "view". The predominant pattern for both treated and untreated areas showed decreasing nitrate concentrations from the surface followed by a concentration increase and subsequent decrease. Eleven untreated and 17 treated areas exhibited this accumulation pattern. The next prevalent accumulation pattern showed high nitrate concentrations in the surface with decreasing concentrations thereafter. Twelve of the untreated areas and four of the treated areas had this pattern. The remaining accumulation patterns were less common. Two treated and three untreated areas had nitrate concentrations that decreased from the surface to a point then increased with depth. Two treated sites had erratic concentrations changes with depth and two untreated areas had uniform concentrations with depth. The remaining area and accumulation pattern showed a nitrate concentration decrease from the surface followed by a concentration increase, decrease and increase.

Nitrogen concentrations in plant tissue never exceeded 3.52% except where peanuts were planted. When comparing treated to untreated areas, 13 sites had lower N concentrations in plants growing in untreated areas. Eight treated and 11 untreated plant sample were considered deficient in N. Results from this assessment showed 28% of the sludge-receiving crops were deficient and 65% had low concentrations of N in their tissue at time of sampling. These low concentrations could be the result of the stage of growth the samples were harvested at or the degree of management the site received. Optimum plant growth is desirable to extract the most nutrients from each site.

SOIL pH

Soil pH was determined from the surface six inch layer from 28 land application sites in 14 municipalities (Table 33). Samples were taken from land that was treated with sludge and from adjacent soils that were not treated. While the EPA guidelines require a soil pH of 6.5 on land treated with municipal sludge, only one treated field met that criteria. When treated soils were grouped in pH units of 0.5, 7% of the samples had pH values between 4.0-4.5, 32% between 4.6-5.0, 38% between 5.1-5.5, 18% between 5.6-6.0, 7% between 6.0-6.5, and 4% above a pH of 6.5.

Approximately 71% of the treated soils had pH values below agronomically acceptable levels for plant growth. From the results of this assessment there appears to be a general disregard to the importance of soil pH in controlling heavy metal uptake. And in the importance of an optimum soil pH to promote plant growth that subsequently removes nutrients.

Table 33. Soil pH of Sludge Treated and Untreated Areas (0.0 - 0.5 ').

Location	Field	pH		Location	Field	pH		Location	Field	pH	
		UT	T			UT	T			UT	T
Albermarle	1	4.77	5.47	Graham	1	5.64	5.28	Hillsborough	1	4.93	5.37
	2	4.55	5.22		2	5.45	6.02		2	4.93	5.69
Carrboro	1	4.57	4.30		3	5.01	5.49	Jacksonville	1	4.92	5.17
	2	4.59	4.39		4	5.62	5.38	New Bern	1	5.09	5.04
Eden	1	3.99	5.45		5	6.31	5.72	Reidsville	1	5.34	4.84
	2	5.70	6.26		6	5.26	6.32		2	5.01	5.59
					7	6.59	4.74	Tryon		4.98	5.29
Elizabeth City	1	4.89	4.89	Greenville	1	7.19	4.74	Wilson	1	4.49	5.01
	2	4.51	4.88		2	5.17	6.63		2	4.75	5.09
Fayetteville		4.56	5.95					Winnabow	1	4.14	5.06

REFERENCES

Adriano, C. D. 1986. Trace Elements in the Terrestrial Environment, Springer-Verlag, New York, Berlin, Heidelberg, Tokyo. 1986. 533 pp.

Bingham, F.T. and A.L. Page. 1975. In.Proc Int'l Conf. on Heavy metals in the Environment. pp 433 - 441. Toronto Ontario, Canada.

Boone, T. 1984. The Trick to Selling Sludge As Fertilizer. Water Engineering Management 131(13):28.

Boswell, F.C. 1975. Municipal Sewage Sludge and Selected Element Application to Soils: Effect on soil and Fescue. J. Environ. Qual. 4; 267 - 273.

Brown, R., T. Logan, R. Dorn, V. Hamparian and A.C. Otolenghi. 1985. Demonstration of Acceptable Systems for Land Disposal of Sludge. EPA 600/S2-85/062, USEPA, Cincinnati, OH.

Coker, E.G. and P.J. Matthews. 1983. Metals in Sewage Sludge and Their Potential Effects on Agriculture. Water Science and Technology, Vol. 15, p. 209.

Cox, F.R. 1990. A Note on the Effect of Soil Reaction and Zinc Concentration on Peanut Tissue Zinc. Peanut Science 1990, 17:15-17

Davis, R.D., P. H. T. Beckett and E. Wollan. 1978. Critical Levels of Twenty Potentially Toxic Elements in Young Spring Barley. Plant Soil 49:395-408.

Delas, J. 1980. In Problems Encountered with Copper. Europ. Econ. Comm. Workshop. Bordeaux, France. Oct 8 - 10.

Drouineau, G. and R. Mazayer. 1962. Contribution a L'Étude de la Toxicitie du Cuivre dans les Sols. Ann. Agron. Paris 13: 31 - 53.

Elmor, Tom, S. Stevens, and W. Eaker. 1990. Sludge Management Decision Making Guide for Local Goveerments. Land-of-Sky Regional Council, Asheville, North Carolina

Environmental Protection Agency To Ban Ocean Dumping. Environment Reporter; 1988. Bureau of National Affairs; Volume 19, pg 2544; Washington, D.C.

EPA. 1983. Process Design Manual. Land Application of Sludge. EPA-623/1-83-016.

EPA. 1984. Environmental Regulations and Technology Use and Disposal of Municipal Wastewater Sludge. EPA 625/10-84-003.

EPA. 1988. Draft Guidance for Writing Case-by-Case Permit Requirements for Municipal Sewage Sludge. Washington, D.C.

Forster, D.L. and D.D. Southgate. 1984. Social Institutions Influencing Land Application of Wastewater and Sludge. J. Water Pollution Control Federation. 56(5):399.

Gambrell, R.P., J.W. Gilliam and S. B. Weed. 1975. Denitrification in Subsoils of the North Carolina coastal Plain as Affected by Soil Drainage. J Environ. Qual. 4 (3): 311- 316.

Gilliam, J.W. 1988. Nitrate in North Carolina Ground Water. Soil Sci. Soc. NC XXXI Proc. 70 - 78.

Giordano, P. M. and J.J. Mortvedt. 1976. Nitrogen Effects on Mobility and Plant Uptake of Heavy Metals. J. Environ. Qual. 5: 165 - 168.

Goldstein, N. 1984. Sludge Management in the Electronic Age. Bio Cycle 25(4):18.

Goldstein, N. 1985. Sewage Sludge Composting Facilities on the Rise. Bio Cycle 26(8):19.

Haghiri, F. 1973. Cadmium Uptake by Plants. J. Environ. Qual. 2:93-96.

Haith, D.A. 1983. Planning Model for Land Application of Sludge. J. Environmental Engineering Division, American Society Civil Engineers, 109(66).

Heckman, J.R., J.S. Angle, and R.L. Chaney. 1987. Sludge effects of sewage sludge on soybean: I.Accumulation of heavy metals. J.Environ.Qual.16:113-117.

Higgins, A.J. 1984. Land Application of Sewage Sludge with Regard to Cropping System and Pollution Potential. J. Environmental Quality, Vol. 13, p. 441.

Hinsley, T.D. L.G. Hansen, and G. K. Dotson. 1984. Effects of Using Sewage Sludge on Agricultural and Disturbed Land. EPA 600/S2-83-113, USEPA, Cincinnati, OH.

Hooper, M.C. 1937. An Investigation on the Effect of Lead on Plants. Ann. Appl. Biol. 24:690 - 695.

Interagency Task Force on Sludge. 1984. Environmental Regulations and Technology, Use and Disposal of Municipal Sludge. EPA/625/10-84-003, USEPA, Washington, D.C.

Jensen, R., 1988. Sludge Management Activities in Texas. Biocycle. 29, (3): 40-43.

Khlaid, B.Y. and J. Tinsley. 1980. Some Effects of Nickel Toxicity on Rye Grass. Plant Soil 55: 139 - 144.

King, L. D. and H. D. Morris. 1972. Land Disposal of Liquid Sewage Sludge II. The Effect on Soil pH, Manganese, Zinc and Growth and Chemical Composition of Rye (Secale cereale L.) J. Environ. Qual. 1: 425 - 429.

King, L.D. and P.W. Westerman, 1983. General Guidelines for Land Treatment of Sludge. Land Treatment Series, Report No. 3. Water Resources Research Institute of the University of North Carolina, Raleigh, N.C.

King, L.D. 1986. Agricultural Use of Municipal and Industrial Sludges in the Southern United States. Southern Coop. Series Bull. 314. NC State University, Raleigh NC.

Kowal, N.E. 1986. Health Effects of Land Application of Municipal Sludge. EPA-600/S1-85/015, USEPA, Health Effects Research Lab, RTP, NC.

Lexmond, T.M. and F. H. M. de Haan. 1980. In J.K.R. Gasser ed. Effluents from livestock. 410 - 419. Applied Sci.

Liv, D. 1982. The Effects of Sewage Sludge Land Disposal on the Microbiological Quality of Groundwater. Water Res. (G.B) Vol. 16, p. 957.

Massey, D. T.. 1983. Features of Federal Law that Encourage Land Application of Waste. J. Water Resources Planning Division. American Socirty of Civil Engineers. 109 (121) 1983.

Mays, D.A. and P.M. Giordano, 1988. Land Spreading in the Tennessee Valley. Biocycle. Vol. 29, No. 8, p. 41-43.

Mehlich, A. 1984. Mehlich-3 soil test extractant: A modification of Mehlich-2 extractant. Comm. Soil Sci. Plant Anal. 15:1409-1406.

Mishra, D. and M. Kar. 1974. Nickel in Plant Growth and Metabolism. Bot. Rev. 40:395 - 452.

N.C. Administrative Code, Title 10, Department of Human Resources. Chapter 10. Division of Health Services, Subchapter 10 G, Solid Waste Management Rules, Section .0505, 1988.

N.C. Administrative Code, Title 15, Department of Natural Resources and Community Development. Chapter 2, Division of Environmental Management, Subchapter 2H, Procedures for Permits: Approvals, Section .0200, 1988.

NCDA. 1987. Crop Fertilization Based on NC Soil Tests. M.R. Tucker and R.Rhodes. NC Dept. of Agric. Agronomic Div.

Overcash, M.R., J. B. Weber, and W. Tucker. 1986. Toxic and Priority Organics in Municipal Sludge Land Treatment Systems. EPA 600/S2-86/010, USEPA, Water Res. Lab.

Overcash, M.R., and Loehr R.1986. Toxic and Priority Organics in Municipal Sludge Land Treatment Systems. EPA 600/100 USEPA, Washington, D.C. 1986.

Payne, G. G., D .C. Martens, C. Winarko, and N.F. Perera. 1988. Form and availability of copper and zinc following long-term copper sulfate and zinc sulfate applications. J.Environ. Qual. 17:707-711.

Pederson, T. A. and R. Vallis. 1982. Farmer Attitude Toward Sludge. Bio Cycle 23(1):34.

Schauer, D, 1986. Nationwide Survey of Land Application Practies. Bio Cycle, 27(9):24.

Ramsey, 1989, General Permit Requirements for Land Treatments of Sludge; Proceedings North Carolina/South Carolina Environmental School; Charlotte, North Carolina; Sept.

Walsh, L.M., W.H. Erhardt and H.d. Siebel. 1972. Copper Toxicity in Soybeans (Phaseolas Vulgaris L.) J. Environ. Qual. 1:197 - 200.

APPENDIX

I. OPERATORS QUESTIONNAIRE

1. Are you, the operator, in responsible charge for a municipal wastewater treatment facility?

2. What grade certification do you currently hold?

3. How many years have you worked in the wastewater treatment field?

4. How many years of formal school have you completed?

5. Do you hold any degrees beyond a high school diploma?

6. What is the design flow of the facility you operate?

7. Does the facility you operate discharge directly to surface water?

8. List the unit processes represented in the facility you operate:
   a. bar screen
   b. pre-aeration
   c. pre-chlorination
   d. flow equalization
   e. grit chamber
   f. primary settling tanks
   g. trickling filter
   h. rotating biological contractor(s)
   i. activated sludge (specify type and modifications)
      1. extended aeration
      2. step feed
      3. conventional
      4. two stage with nitrification
      5. conventional with nitrification
      6. contact stabilization
      7. pure oxygen
      8. other

9. List the various alternatives used at the facility you operate to manage sludges or residuals.
    a. land application at agronomic rates
    b. land application at non-agronomic rates
    c. composting
    d. incineration
    e. lagoon storage (residuals stored for 2 years or more)
    f. monofill
    g. landfill
    h. no residuals management plan

10. Do you feel that continuing education credits or units should be required of all wastewater treatment facility operators in order to maintain certification?

11. List the areas in which you feel additional training is required
    a. chemical phosphorus control
    b. biological phosphorus control
    c. biological nitrification
    d. effluent toxicity and toxicity testing
    e. incineration
    f. land application of sludge _______ of wastewater _______
    g. composting
    h. dewatering and thickening
    i. process optimization and troubleshooting
    j. tertiary filter operation
    k. chlorination/dechlorination
    l. UV disinfection
    m. ozone disinfection
    n. state enforcement strategies
    o. state and federal regulations
    p. thermal conditioning to achieve a PFRP
    q. chemical conditioning (lime stabilization) to achieve a PFRP

12. As operator in responsible charge, which of the following causes you the most consistent problems in the day-to-day operation of the facility you operate? (rank the top 5 with a 1 being the biggest problem and a 5 the least critical)
    a. industrial waste
    b. lack of certified operators to fill in when required
    c. changes to state regulations
    d. operator turn-over
    e. money
    f. lack of training opportunities for your staff
    g. personnel
    h. sludge or residuals management
    i. upsets to biological processes
    j. laboratory operations
    k. toxicity testing
    l. other

Thank you for participating in this survey of your operation. Do you have any additional comments?