Ilo, Raphael Esione

LAND APPLICATION OF SEWAGE SLUDGE IN AGRICULTURAL LAND
IN NIGERIA WITH SPECIAL REFERENCE TO ENUGU

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RAPHAEL ESIONE ILO

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APPROVED BY:

Gen. W R

James M. Robertson

Mary L. Williams

DISSERTATION COMMITTEE

Do you know what these piles of ordure are, collected at the corners of streets, those carts of mud carried off at night from streets, the frightful barrels of the nightman, and the fetid streams of subterranean mud which the pavement conceals from you? All this is a flowering field, it is green grass, it is mint, thyme, and sage; it is game, it is cattle, it is the satisfying lowing of the heavy kine; at night it is perfumed hay, it is gilded wheat, it is bread on your table, it is warm blood in your veins, it is health, it is joy, it is life.

Victor Hugo, Les Miserables
1862

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CHAPTER I

INTRODUCTION

The rapid growth of Nigerian urban centers has greatly exceeded the ability of most of the cities to provide adequate sanitation in the disposal of human wastes. Therefore, primitive methods of human waste disposals, such as pit and bucket latrines, are still being practiced. In some cities and towns, defication in bushes and direct discharge into rivers, storm drainage and irrigation canals are very common. In the cities where bucket latrines are used, the buckets, when full, are collected by scavengers from individual households and public places of convenience and discharged into rivers and storm drainages or buried in very shallow trenches. This, no doubt, causes serious water pullution due to the untreated wastes.

Since surface water is still the major source of both domestic and drinking water, these practices of disposal causes many public health problems and result in high incidences of endemic waterborne diseases such as dysentery, typhoid, cholera and infectious hepatitis. These contribute to the country's high morbidity and mortality rates and are still the leading causes of death. Also endemic in the country are vector-transmitted diseases such as guinea worms and schistosomiasis. Though these diseases are rarely fatal, they are very debilitating and difficult to cure. Meanwhile, the most modern human waste disposal facilities used in limited houses in large cities are septic tanks. In view of the considerable reduction and possible complete elimination of incidences of waterborne diseases, with subsequent improvement of the health of the people as are obtainable in developed countries, where wastewater treatment plants are in use, there is a great need to collect and treat wastewater in Nigeria.

Even though the Nigerian Federal Government has not passed any legislation mandating municipalities to have modern wastewater treatment facilities, individual cities such as Lagos and Ibadan have become aware of the consequences of unsanitary environmental conditions. Consequently, they are thinking of installing wastewater treatment plants. These cities are now contacting some engineering consulting firms in the United States of America for contracts.

The World Bank has also agreed to finance the construction of wastewater treatment plants in Enugu and Onitsha, the two largest cities in Anambra State, Nigeria. It is hoped that in the near future, the Nigerian Congress will give this a high priority and pass a law compelling large cities to have publicly owned wastewater treatment plants. With the introduction of this modern technology in wastewater management, it will not be very long before many of the Nigerian cities start confronting the problems associated with management of sewage sludges, like the majority of the cities in the developed western countries such as the United States, Britain and Canada have done. It must be emphasized that the problems confronting most of these municipalities stem from inadequate design and planning. Most of these municipalities never thought of the final disposal method and the location for the disposal until after sludge conditioning and handling design were completed. It stands to reason that the difficulties would not have occurred if the final disposal method and actual disposal site had been identified first. In such case, the most cost-effective process for getting the sludge to the best condition to accomodate the mechanism of actual disposal could have been designed. Since such problems are bound to develop, it is necessary to carry out this type of study, hence, this dissertation in part, addresses the problems associated with land application of sewage sludge on agricultural land in Nigeria with particular reference to Enugu and the appropriate ways these problems should be controlled.

The value of sewage sludge as a fertilizer has been well documented. The use of human excreta for fertilizer ranging from "night soil" application to sewage and sludge irrigation is a world-wide practice (Black, 1974). Although such practices are objectionable and considered very unhygenic in the developed western countries, Black (1974) noted that the economy of highly populated countries such as India and China would be wrecked without human manure. In fact, the wastage of the fertilizer content of sewage and sludge by utilization of non-recycling disposal methods such as dumping into the sea has been a subject of many published attacks.

Since sewage sludge has been shown to be a good source of fertilizer, discussed in fertilizing ability of sewage sludge, it seems reasonable to use it as a fertilizer in Nigeria where commercial fertilizer is in high demand and very expensive. A recent report from Nigeria indicated that the Nigerian Federal Government spends millions of dollars annually to purchase commercial fertilizer from foreign countries. The world-wide inflation and renewed emphasis by the Nigerian Federal Government to increase local food production have more than doubled the annual cost of commercial fertilizer purchase. Since Nigeria has limited resources, especially as regards to foreign exchange, it is felt that a study needs to be done to determine (a) if it is cheaper to grow some Nigerian local crops with sewage sludge than with commercial fertilizer and (b) how much of the foreign exchange could be saved by utilizing sewage sludge instead of commercial fertilizer.

Objective and Justification

As mentioned earlier, the Nigerian Federal Government spends an average of 84.72 million dollars annually according to 1977-1980 figures on commercial fertilizer importation from foreign countries (Appendix A). Since sewage sludge can be used as a fertilizer if properly managed to prevent public health hazards, Nigerian cities such as Enugu that have wastewater treatment plants, instead of worrying about the methods of disposing their sewage sludges, should rather make productive use of them by applying them on the farmlands for growing local crops. Therefore, it is the objective of this dissertation to show that it is cheaper to use sewage sludge instead of commercial fertilizer to grow some Nigerian local crops, and that some of the foreign exchange used in commercial fertilizer importation could be saved if sludge were used to grow specific crops. Some problems arise when liquid digested sewage sludge is applied to agricultural lands. It is a secondary objective of this dissertation to show the ways these problems should be controlled in Enugu, Nigeria.

The Layout of this Dissertation

This dissertation consists of five chapters: Chapter I, Introduction, introduces the need to carry out this study and the objectives to be achieved. Chapter II, Literature Review, examines the references on land application of sewage sludge on agricultural lands, evidences of agricultural benefits of sludge as a fertilizer, as well as problems associated with land application of sewage sludge on agricultural lands. Chapter III, Land Application: The Enugu, Nigeria, Situation, covers the existing Nigerian condition, which describes the sanitation, health problems, technological alternative and appropriate ways to control the problems associated with application of sludge on Enugu agricultural lands. Chapter IV, Comparative Cost Analysis of Sewage Sludge and Commerical Fertilizer, demonstrates that sewage sludge can be more cheaply used than commercial fertilizer in Nigeria, and estimates annual savings that could be made by utilizing sewage sludge to grow specific crops. Chapter V, Summary and Conclusion, summarizes and draws a conclusion from the findings of the study.

CHAPTER II

LITERATURE REVIEW

Introduction

The treatment of wastewater for removal of pollutants not only produces clean water, but also a significant quantity of residual materials. Sewage sludge is, therefore, a general term used to describe a variety of materials commonly in suspension containing 1 to 10 per cent solids produced during wastewater treatment (Sommer and Nelson, 1978).

The purpose of this chapter is to give some background information on the works that have been done on land application of sewage sludge. Since wastewater treatment plants are not currently available in Nigeria, the materials and information presented are records of developed countries. The chapter contains the discussions on six aspects of sewage sludge. They are under the following headings: Characteristics of Sewage Sludge; Types of Sewage Sludge; Current Sludge Disposal Alternatives; Land Application of Sludge; Agricultural Benefits of Sludge; and Problems Associated with Land

Application of Sludge.

Characteristics of Sewage Sludge

Sewage sludge is a heterogeneous material which varies in composition from city to city and from day to day in the same city (Sommer and Nelson, 1978). Variations in sludge characteristics have been a subject of comment by many investigators (Culp, 1979; Vesilind, 1979; Kirkham, 1974; Loehr et al., 1979; Sommer and Nelson, 1978; Kelling, 1974; Keeney et al., 1975). Liquid digested sludge is a heterogeneous solid matter in a dilute aqueous salt solution and can be easily transported by pumping (Hinsely et al., 1971; Kirkham, 1979; Kelling, 1974).

Direct comparison between liquid and dried sludge is not very easy to make because of changes that occur during drying. For instance, during drying operations by heat drying, air dry and vacuum filtration, appreciable quantities of ammonia nitrogen (NH_3-N), are lost by volatilization. Kelling (1974) cited cases where 28 per cent and 44 per cent of total Nitrogen (N) present in sludge was lost as NH_3-N during drying. Reduction in total N during air drying of sludge from four Wisconsin communities ranged from 19 to 67 per cent (Kelling, 1974). It has been reported (Hinsely et al., 1971; King and Morris, 1972a) that NH_3-N, Na, K, and P are primarily in liquid phase while heavy metals and organic residues are concentrated in solid phase of sludge. Therefore, dewatering sewage sludge to be applied on land because of its fertilizer contents will lose much of the essential elements.

Sludges resulting from various treatment processes have variable physical and chemical properties depending on the constituents, source of wastewater and level of biological stabilization. Table 1 gives the ranges of various chemical constituents in anaerobic digested sludges from 35 Wisconsin municipalities. Values reported by other investigators fall within the ranges as reported in this table (Loehr et al., 1979; Hinesly et al., 1971; Berrow and Webber, 1972; King and Morris, 1972a; Dotson, 1973; Culp, 1979).

To translate the result of Table 1 into meaningful terms relating to land application, one acre-inch of sludge will supply up to 550 lbs. N, 200 lbs. P, 100 lbs. K, 1,000 lbs. Ca, 100 lbs. Mg and Na, 300 lbs. Cr, 100 lbs. Cu, and Zn, 50 lbs. Pb, 15 lbs. Ni, 2 lbs. Cd, and 0.1 lbs. Hg (Keeney et al., 1975). It is necessary to note that much care must be exercised in the application of sewage sludge to land to avoid the build-up of potential toxic elements.

Sewage sludge from treatment plants that is mainly

TABLE 1

RANGES IN CONCENTRATION OF CHEMICAL CONSTITUENTS
IN ANAEROBIC LIQUID DIGESTED SLUDGE FROM
35 WISCONSIN MUNICIPALITIES

Element	Range	Median	Maximum Amount Applied if Liquid Sludge (5% Solids) is spread (lb/acre-in)
	% of solids		
Total-N (moist)	3.4-9.5	...*	
Total-N (dried)	2.4-3.1	...	352
NH_4-N (moist)	0.8-4.1	...	
NH_4-N (dried)	0.02-0.26	...	29.5
Organic C	25.7-38.5	...	4,370
P	2.7-6.1	...	692
K	1.2-1.9	...	216
Ca	4.2-18.0	...	2,040
Mg	0.8-1.2	...	136
Na	0.6-2.2	...	250
Al	0.36-1.2	...	36
Fe	0.8-7.8	...	885
	mg/kg		
Ag	5-150	20	1.70
As	1-18	7.5	0.204
B	6-1,000	50	11.4
Ba	150-4,000	1,500	45.4

Table 1 (continued)

Element	Range	Median	Maximum Amount...
Cd	1-1,500	12	17.0
Co	2-260	12	2.95
Cr	20-40,615	380	461
Cu	52-11,700	700	133
Hg	0.1-56	3.0	0.636
Mn	60-3,860	400	43.8
Mo	2-1,000	5	11.4
Ni	10-5,300	52	60.2
Pb	15-26,000	480	295
Sn	40-700	120	7.95
Sr	52-7,810	...	88.8
V	20-400	60	4.54
Zn	72-49,000	2,200	556

*Data not available.

Source: Kirkham, M.B., "Sludge Disposal," The Encyclopedia of Soil Science Part 1, Physical, Chemistry, Biology, Fertility and Technology, Dowden, Hutchinson and Ross, Inc., Stroudsbury, Pennsylvania, 1979.

of domestic origin is essentially organic in nature and contains measurable quantities of metals, minerals and other compounds. It may also contain some pathogenic organisms that survived wastewater treatment processes. On the other hand, sludge produced from the combined treatments of both industrial and domestic wastewater has increased potential of containing additional materials of concern, especially heavy metals.

Types of Sewage Sludge

Sludge is produced from all the stages of wastewater treatment operations. This means that there are different types of sewage sludge.

Primary Sludge

Primary sludge also known as raw or undigested sludge, results from the first major treatment in sewageworks, which consists of sedimentation. It is a collection of suspended coarse particles. The coarse and fibrous nature of the particles contribute to the easy dewaterbility of this type of sludge. Clark et al.(1977) described primary sludge as "a gray-coloured, greasy, odorus slurry of settleable solids," which has a typical solid concentration of 6 to 8 per cent.

Waste-Activated Sludge

This is a type of sludge obtained from secondary treatment of wastewater as a result of settling of flocculated bacterial cells that feed on soluble and suspended organic materials in raw or settled sewage. The sludge is usually dark-brown in color and inoffensive when fresh, but turns septic rapidly because of biological activity. It is much finer than primary sludge and has a density similar to that of water. It is more difficult to dewater than primary sludge. Activated sludge has about 0.5 to 2.0 per cent of suspended solids with a volatile fraction of 0.7 to 0.8 (Clark et al., 1977).

Trickling-Filter Humus

This is the sludge produced from the final clarifier of trickling filter treatment plant. Filter humus sludge is dark brown in color and relatively inoffensive when fresh. The suspended solids are fragments of biological growth that slough off the filter rocks (Clark et al., 1977). Filter humus sludge has a solids concentration of 3 to 4 per cent (Vesilind, 1979).

Mixed Digested Sludge

Often the raw primary sludge is mixed with either the filter humus or waste activated sludge before stabilization by either aerobic or anaerobic digestion. Mixed digested sludge, therefore, is the term used to refer to the product of the stabilization process.

Stabilized Sludge

This is a term used to refer to sludge after it is treated by chemical, physical, thermal or biological stabilization process. Anaerobic digestion is the stabilization method most frequently used. EPA (1977) reported that stabilization of sludge results in substantial reduction in volatile organics, odors and pathogenic microorganisms. The United States Environmental Protection Agency (EPA) requires that all sludges to be applied on agricultural land must be stabilized. The reason for this requirement is to reduce the detrimental impacts such as public health hazards and offensive odor conditions (EPA, 1977).

Anaerobic Digested Sludge

Anaerobic Digested Sludge is a dark-colored slurry produced by digestion of sewage sludge by anaerobic bacteria. A well digested sludge dewaters very easily on a sand bed and has an inoffensive odor. The dry solid content of this type of sludge is about 30-60 per cent volatile

(Clark et al., 1977).

Aerobic Digested Sludge

Aerobic digested sludge is a dark-brown flocculent produced by long-term aeration of sludge. Up to 50 per cent of the volatile solids in aerobically digested sludge are converted to gases, and as a result, the sludge is less thick and very expensive to dewater. The review of literature showed that anaerobic digestion process is more commonly used and the majority of sludges applied to agricultural land are either aerobically or anaerobically digested (Sommer and Nelson, 1978).

Sludge after digestion may be further processed to reduce the water content by using such processes as sand dry bed, centrifugation and vacuum filteration. The resulting sludge is referred to as sludge "cake" which contains 30 to 40 per cent solids. In many instances, sludge is applied to land in a liquid form containing 1 to 10 per cent solids because dewatering of sludge not only influences the economics of sludge disposal but also alters the chemical composition and the rate of application (Sommer and Nelson, 1978).

Chemical Sludge

Chemical sludge is sludge produced by chemically coagulating wastewater to precipitate phosphorus and improve other suspended solids removal. Vesilind (1979) has noted that the most commonly used chemicals are iron and aluminum salts and that sludge produced with aluminum sulfate (alum) is known as waste alum sludge. Generally, chemically produced sludges are very difficult to handle and dewater.

Current Sludge Disposal Alternatives

Sewage sludge can be disposed of by other methods such as ocean dumping, incineration, land fill and lagooning. However, review of the literature showed that the environmental impact of these methods has resulted in the enactment of legislation by the United States Congress which has or will phase out these practices (Sabey and Hart, 1975). EPA (1976) reported that ocean dumping would be phased out by the year 1981. Kirkham (1974) reported that the use of ocean dumping, incineration, land fill and lagooning to dispose of sewage sludge only displaces the waste; it does not get rid of it. Sabey and Hart (1975) and Kirkham (1974) reported that the environmental and economical considerations have placed land application of liquid digested sludge as the only viable solution to sewage sludge disposal problems.

Land Application of Sludge

The application of human waste to agricultural land has an ancient history and is still a common practice in different parts of the world. This is due to the recognition of the agricultural value of such waste (Kirkham, 1974; Allan, 1973; Kaplovsky and Genetelli, 1973). In the Orient, "night soil" has been used as crop fertilizer and soil conditioner for centuries (Kirkham, 1974). Some European cities such as Scotland and Edingburgh have been cited by Wolman (1977) and Kirkham (1974) to have operated sewage farms as far back as the middle of the 18th century. Very successful and extensive sewage farms in Paris and Berlin were started around 1850 (Kirkham, 1974; Wolman, 1977). In the United States, sewage effluent has been used for crop irrigation since the early 19th century (Kirkham, 1974). The recycling of sludge to return the concentrated nutrients to the environment has been considered since the development of sewage treatment. In the United States, Lunt (1953; 1959) and Kelling (1974) have reported that such interest in the use of sludge as a fertilizer was initiated in 1927 when a large activated sludge treatment went into operation in Milwaukee, Wisconsin. This was supported by the report (Bryan and Garrett, 1972) that the city of Houston, Texas, processed and marketed sewage sludge as "Hou-Actinite" fertilizer since 1928.

In addition to the use of sewage sludge as a fertilizer and soil conditioner, land application of sludge to agricultural land is now being considered as a viable sludge disposal alternative. Braude et al (1978) noted that the application of sludge to agricultural lands is one solution to the dilemma of ever increasing accumulation of wastewater solids. Zenz et al (1976) reported that land application is now being considered and adopted by many municipalities as a solution to their solid disposal problems. Hillmer (1976) noted that land application is suitable in all the geographical areas of the United States and is only limited by land availability and soil moisture condition. Land application as a disposal alternative has several notable advantages such as recycling of nutrients back to land, improvement of marginal soil with organic matter and economic attractiveness (Kirkham, 1974; Braude et al.,1978; Clark et al., 1977; Zenz et al., 1976).

Kirkham (1974) reported that in a recent survey of nearly 2,000 treatment plants in the United States, 68 per cent stated they are practicing land application. Table 2, shows the land application practice in the United

TABLE 2

LAND SPREADING OF SEWAGE SLUDGE IN THE UNITED STATES

Length of Time (Years)	Sewage Treatment Plants (%)
0-5	46
6-10	22
11-20	26
21-30	3
31-40	2
41-50	1

Source: Kirkham, M.B., "Disposal of Sludge on Land: Effect on Soil, Plant and Ground Water," Compost Science, Vol. 15, No. 2, March-April, 1974, pp. 6-10.

States. The availability of enough agricultural land to utilize the increasing quantities of sludge being generated yearly should not be a problem. EPA (1976) noted that if all the sludge produced in the United States were to be applied to croplands at a rate suitable for nitrogen fertilization, the estimated proportion of total 1970 cropland required to accept the sludge would be less than 1 per cent and would increase to 2 per cent by 1985. In terms of agricultural benefits, EPA (1976), Melsted (1973) and Kirkham (1974) reported that sewage sludge is very valuable as a soil conditioner and as a source of many essential plant nutrients.

Opinions differ regarding the rate or quantities of sludge to be applied to agricultural land to achieve maximum benefits without much environmental impact. Evans (1968) noted that 1-inch field application of liquid sludge produced an amazing growth response in crops. The application of 25 tons per acre of sewage sludge has been reported to have produced growth response equal to that obtainable with commercial fertilizer at conventional rate (Conn, 1970). Corn yield has been reported to have increased to 36 bushels per acre when 2 inches of sludge was applied during tasseling (Conn, 1970). Miller (1978) noted that sufficient nutrients would be supplied to agricultural land if under 10 tons/acre on dry weight basis of sludge were applied annually. EPA (1974) indicated that a 2-inch application of Chicago liquid digested sludge to cropland could supply 200 to 320 pounds of ammonia nitrogen,about the same amount of organic nitrogen, 250 to 400 pounds of phosphorus and 60 pounds of potassium per acre. This was supported by the Berrow and Webber (1972) report that sewage sludge is usually applied at the rate of 10 tons dry matter per acre (25 tons/hectar). It is generally agreed by many investigators that the determination of rate of sewage sludge application should be based on the nitrogen requirements of the crops grown as well as the metal content of sludge (Sommers and Nelson, 1978). EPA (1974) reported that half of the nitrogen and potassium in digested sludge is in the liquid phase, and therefore, dewatering will significantly decrease these nutrients. The application of dewatered sludge not only decreases the nutrient value of sludge but is also very expensive. Corrall et al. (1975) reported that the cost of dewatering and drying liquid sludge can run as much as $55 per ton of solids produced. Although land application of dewatered and dried sludge has been widely practiced in the United States for many years, Corrall et al. (1975) noted that the dewatering operation is expensive, time consuming and often very troublesome. Kirkham (1974) and Corrall et al.(1975) reported that land spreading of liquid sludges eliminates these troublesome aspects and is therefore receiving much attention as an economical means of solving solids disposal problems. In addition, the increasing cost of commercial fertilizer may develop more interest. In terms of cost, Conn (1970) reported that many experts estimate land application as the cheapest sewage sludge disposal method.

Dewatered sludge is generally applied on land by spreading with a tractor and then disked into the soil. Liquid sludge on the other hand has multiple ways of application such as irrigation (sprinkler), spreading by tank truck, ridge and furrow irrigation and subsurface injection. Keeney et al.(1975), White (1978) and Vesilind (1979) indicated that the application method used depends on the size of the community, as well as topographical and seasonal suitability. Although land application of sludge to cropland has some notable benefits, there are, therefore, several problems that can develop from such operations (Kelling, 1974; Vesilind, 1979):

1. Ground and surface water pollution
2. Lack of public acceptance
3. The possibility of disease transmission
4. Offense to senses (mainly odor)
5. Toxic elements (primarily heavy metals),

contamination, food chain accumulation
and phytotoxicity.

EPA (1976) reported that proper operation, maintenance and monitoring of land application sites are very essential to ensure that these adverse environmental impacts do not occur. The review of the literature has shown that there has not been any scientifically confirmed evidence implicating land application of well digested sewage sludge with the spread of pathogenic microorganisms (Miller, 1975; EPA, 1979). Reeves (1959) reported that the only obvious index of the danger of spreading pathogenic organisms lies in the evidence of experiments to determine the existence of these organisms in sludge. The fear of spreading pathogenic microorganisms has led to the recommendation that food crops that are eaten raw should not be grown within three years after the last sludge application.

Land application and land disposal of sludge are often used as if they mean exactly the same thing. It is therefore necessary that a distinction be made between them. Land disposal is used when the primary objective is to dispose of as much sludge as possible in the most convenient and economical manner. The process involves high application rate, as well as putting sludge in a hole and burying it.

Land application, on the other hand, is the utilization of the fertilizer value of sludge as the source of nutrients for agricultural crops. The process has dual advantages of serving as a sludge disposal method and as a means of recycling the nutrient contents of sludge to the soil.

Agricultural Benefits of Sludge

Fertilizing Ability of Sludge

Sewage sludge, when applied to agricultural land under normal conditions, may be as effective as commercial fertilizer in supplying the total plant nutrient requirements. Fraps (1932) found that dried activated sewage sludge is a nitrogenous fertilizer similar to cottonseed meal type commercial fertilizer and has a seventeenth of its value. The investigator concluded that the sludge could be used alone as a fertilizer just like cottonseed meal or used in preparation of mixed fertilizer. Nitrogen in activated sludge passed the chemical test for activity as regards to fertilizing ability (Anderson, 1959). A study by EPA (1974) found that a 2-inch application of liquid digested sludge from Chicago to agricultural land would supply about 200-300 lbs. of ammonia nitrogen, about the same amount of organic nitrogen, 250-400 lbs. of phosphorus and 60 lbs. of potassium per acre. The same study noted that a good corn crop can only utilize 150-250 lbs. of nitrogen. This is a good indication that sewage sludge can provide more than adequate nutrients for agricultural production.

Agricultural yield improvements resulting from the use of sewage sludge have been documented by many investigators (Lunt, 1953; 1959; Anderson, 1955; Coker, 1966a, 1966b, 1966c; Vlamis and Williams, 1961; Kelling, 1974; Evans, 1968; Hyde, 1976; Thompson, 1975). A greenhouse and field trials in Wisconsin in which activated sludge was utilized at the application rate of 500-1,000 lbs. per acre greatly increased the yields of many crops (Anderson, 1955). In another greenhouse test by the same investigator, the number of rose blooms showed an increase of 636 blooms per 1,000 square feet over those of untreated controls. Conn (1970) reported that application of 25 tons per acre of sewage sludge would result in crop growth rate equal to that obtained with commercial inorganic applied at a conventional rate. In one Texas farm sewage sludge was used to grow cotton and corn at the application rates of 500-2,000 lbs. per acre and 1,000 lbs. per acre respectively. Anderson (1955) reported that the lint yield increased to 37-47 lbs. per acre and corn yield increased by 14 per cent. Similar results were reported by Fraps (1932) and Vlamis and Williams (1961).

An outstanding problem with the use of sludge is the large quantities used to produce comparable yields as compared with commercial inorganic fertilizer. According to EPA (1975) it took 168 tons per hectare of sewage sludge to produce a corn yield equal to that obtained with 1.12 tons per hectare of 20-10-10 commercial fertilizer on a sandy soil in Minnesota. Black (1974) reported that application of 3-4 tons per acre of sludge would provide an adequate nitrogen and phosphorus for healthy corn crops. Merz (1959) found that application of liquid sewage sludge at the rate of 22-224 metric tons per hectare of dried solids (3.4 to 34 cm/ha of 6.8 per cent dry solids material) on a sandy soil in Southern California increased the yield of barely up to 112 metric tons per hectare. The investigator concluded that even on a poor sandy soil, sludge loading of 56 metric tons per hectare of dry solids would produce crop growth comparable to that achieved by commercial fertilizer at conventional rate of application. In a field experiment by Kelling (1974) in which anaerobically digested liquid sewage sludge was applied at the rate of 0, 1.25, 2.5, 5 10 and 20 cm. on a sandy loam and silt loam soil to grow rye, sorghum-Sudan and corn, he reported significant yields in the crops up to the 2.5 cm. rate on the silt loam soil and 5 cm. on the sandy soil. This shows that sludge application has an optimum rate after which any subsequent increase in loading rate , instead of increasing the crop yield, would depress it. The optimum rate is influenced by the amount of nutrients (nitrogen, potassium, phosphorus) present in the sludge and in the soil. When these parameters are known, adequate quantities of sludge can be applied to the soil in order to obtain the desired crop yields.

The evidence of the fertilizing value of sludge was highlighted by the experience of some Pennsylvanian farmers who have been applying sewage sludge on their farms as a fertilizer for many years. Evans (1968) reported that "once a farmer begins to use the stuff, he is 'hooked' and can't seem to obtain enough of it thereafter." Six farmers from Saint Mary, a town in Pennsylvania who applied liquid sewage sludge on their farms as fertilizer were interviewed by Evans (1968) and outlined below are some of their responses:

> It is much better than farm manure.
> It is as good or better than commercial fertilizer.
> It is very good for meadow and pasture.
> It is excellent for corn and hay.
> It is good for oats, hay and clover.
> It is almost like a miraole.
> I call it black gold.

All the farmers who used sludge to grow grass reported that their farms produced greater feeds, fiber and more succulent growth. The majority of them complained that their hay grew too thick or dense to be easily cut (Evans, 1968). On comparing two farms, one that received a single sludge application and the other that did not, Evans (1968) reported that the corn growth on the sludge treated soil was very phenominal. Some of the stalks were 12 to 14 feet high and each contained two large ears of corn. If this type of yields could be obtained with the use of sewage sludge, one wonders why farmers would spend much of their hard-earned money to buy commercial fertilizer, especially where liquid sludge can be obtained and applied free of charge and is proven to be free of toxic heavy metals as would be obtainable in Nigeria sludge.

The fertilizing effects of sludge and commercial inorganic fertilizer have been compared by a few investigators. On comparing the growth of barely on plots treated with liquid sewage sludge with those of commercial ammonium phosphate, Merz (1959) observed that 224 tons per hectare of sludge was required to produce growth equal to that obtained with the ammonium phosphate. In a study in which the rate of nitrogen conversion to nitrate in activated sewage sludge and dried blood commercial fertilizer were compared, Barrow (1955) found that the rate of breakdown to nitrate was practically the same in the two materials during the first few days; however, after a week the rate of sludge breakdown decreased to 50 per cent of dried blood, but this was still consistent with plant requirement. The slower conversion has the advantage of maintaining the organic content in the soil for a longer period.

Sewage sludge can be very effectively used to grow mushrooms. The evidence of this was manifested in a study by Barrow (1955). It was observed that when sludge was composted and used as a top soil as compared to dried blood commercial fertilizer, there was 27.5 per cent increase in mushroom yields. The mushrooms produced were found to be of better quality both in color and weight. The outcome of the study resulted in the use of activated sludge or the modified form of it by a greater number of mushroom and cucumber growers in the British Isles (Barrow, 1955). This shows that sludge can be used even in the developed countries to grow edible vegetable crops. Therefore, it will not be improper if it is used in Nigeria, as long as adequate sanitary practices are maintained before the crops are consumed. It should be recommended that vegetables to be eaten raw be thoroughly washed in clean water and then disinfected by any appropriate method.

In a field experiment by Hyde (1976), in which corn was used as a test crop and sludge applied at the rate of 3.3, 6.4 and 11.8 dry tons per acre and commercial fertilizer applied to supply comparable nutrients, the result showed that sludge-treated plots produced a significantly high corn yield up to 20 per cent more than the chemical fertilizer-treated plots, which in turn had a higher yield than the control plots with no sludge application. In a similar study, in which 4 to 32 dry tons per acre sludge application rate was used to grow grass, the result showed that there was a three-to four-fold increase in forage yields in the sludge treated soil compared to the control with no sludge application (Hyde, 1976).

After 10 years of unsatisfactory experience with commercial inorganic fertilizer, Thompson (1975) resorted to the use of sewage sludge as the main source of fertilizer in his farm to grow corn, oats, soyabeans and hay. It was observed that with the application of 7 tons per acre of sludge to supply 150 lbs. of N, 60 lbs. of P and 60 lbs. of K, as were originally used when commercial inorganic fertilizers were being utilized, the corn yield averaged 120 bushels, soyabeans 40-50 bushels and the hay yield was much improved. These yields were equal to those obtained with commercial fertilizer. The farmer noticed that he not only made the same amount of profit as when commercial fertilizer were utilized, but there was a savings of $80 per acre that would have been used to purchase commercial fertilizer. An important observation here is that the farmer, Thompson, had a Masters Degree in Agriculture and was well informed of the two sources of nutrients. It is an added credit to the fertilizering ability of sludge that a person of Thompson's caliber would choose to use sewage sludge over commercial inorganic fertilizer.

In a study in which liquid sewage sludge was compared with commercial fertilizer, Hinesly et al. (1971) found that applications of one inch and one half inch of liquid sludge, to give 200 lbs. nitrogen, 100 lbs. phosphorus and 100 lbs. potassium as the equivalent of the control commercial fertilizer, gave comparable crop yields as shown in Tables 3, 4 and 5. As indicated in Table 3, the sludge-treated plots produced significantly better soyabean grain and total plant yield than the control commercial fertilizer. Similar results were experienced with Reed Canary grass and grain Sorghum as indicated in Tables 4 and 5 respectively. This is another clear evidence that liquid sewage sludge is as good as commercial fertilizer.

TABLE 3

SOYABEAN YIELD MEANS, IN GRAM DRY WEIGHT FROM

SOUTH FARM LYSIMETER

TREATMENT	WHOLE PLANT	GRAIN	DRY WT/PLANT
Maximum Sludge	288.8**	88.3	14.4**
1/2 Maximum Sludge	253.9**	83.0	12.0**
Control	78.2	24	4.3

** Significantly different from control at the 1% level.

Source: Hinesly, T.D., Braids, O.C., Molina, J.E. "Agricultural Benefits and Environmental Changes Resulting from the use of Digested Sewage Sludge on Field Crops," An Interim Report, U.S. Environmental Protection Agency, Grant No. G 06-EC-00080, EPA-(SW-30d), Washington, D.C., 1971.

TABLE 4

REED CANARY GRASS YIELD MEANS, SOUTH FARM LYSIMETER

TREATMENT	DRY WEIGHT IN GRAMS 7/19/68	9/9/68	5/26/69	9/18/69
Maximum Sludge	190.3**	165.5	239.1	106.3
1/2 Maximum Sludge	132.5**	140.1	231.6	91.4
Control	73.5	143.2	78.0	108.8

** Significantly different from the control at 1% level.

Source: Hinesly, T.D., Braids, O.C., Molina, J.E., "Agricultural Benefits and Environmental Changes Resulting from the Use of Digested Sewage Sludge on Field Crops", An Interim Report, U.S. Environmental Protection Agency, Grant No. G06-EC-00080, EPA-(SW-30b) Washington, D.C., 1971.

TABLE 5

SORGHUM GRAIN (1968) YIELD MEANS,

SOUTH FARM LYSIMETER

TREATMENT	SORGHUM (DRY WEIGHT IN GRAMS)
Maximum Sludge	430.4
1/2 Maximum Sludge	284.9
Control.	354.8

Source: Hinesly, T.D., Braids, O.C., Molina, J.E., "Agricultural Benefits and Environmental Changes Resulting from the use of Digested Sewage Sludge on Field Crops," An Interim Report, U.S. Environmental Protection Agency, Grant No. Go6-EC-00080, EPA-(SW-30d), Washington, D.C., 1971.

In a study by Coker (1966c) in which the yield of barley was compared by using liquid digested sludge containing 89 lbs. Nitrogen, 121 lbs. P_2P_5 and 12 lbs. K_2O dry weight and equivalent commercial inorganic fertilizer and untreated controls, it was found, as shown in Table 6, that though the commercial fertilizer plots had more lodging than the sewage sludge treated plots, there was no difference in the ripeness of the grains. It was also observed that the weights of grain and straw were almost identical in both sludge and commercial fertilizer grown barley. In another similar study in which grass was used as a test crop, Coker (1966a) found that liquid sludge treated grass had as much dry matter as the equivalent commercial fertilizer, as shown in Table 7.

In Illinois, where several crops were grown by application of liquid sewage sludge at the rate of 25 cm. per year, results showed that the yields of corn, grain sorghum, Kenaf and reed canary grass on sludge-treated plots were as high as or significantly improved over the control, treated with commercial fertilizer at relatively high rates of 224-270 Kg N/ha, 110-135 Kg P/ha and 110-185 Kg K/ha (Kelling, 1974; Hinesly and Sosewitz, 1969). In another study in which liquid sludge was compared with commercial inorganic fertilizer, Hinesly et al. (1971) observed that

TABLE 6

HARVEST DATA AND RECORDS ON RIPENING OF BARLEY

	NO. OF TREATMENTS	SLUDGE	FERTILIZER
Lodging record: Mean of categories 1-5*	0.0	0.25	1.75
Ripeness record: Mean of categories 1-5+	4	3.75	3.25
Grain yield (cwt/acre at 14% moisture)	18.7	25.2	25.6
Dry weight of cut straw	8.1	12.1	12.1
Percentage N in dry grain	1.52	1.61	1.91

*Lodging Categories: 1, less than 10% scattered straggle stalks; 2, 10-20 scattered straggled; 3, area of plot entirely lodged below 10% of total; 4, area of plot entirely lodged 10-40% of total; 5, area of plot entirely lodged over 40% of the total.

+Ripeness Categories on August 13, 1960: 1, grain still soft; 2, grain fairly firm; 3, grain firm; 4, grain has not ripened.

Source: Coker, E.G., "The Value of Liquid Digested Sewage Sludge 111. The Results of an Experiment on Barley," Journal of Agricultural Science Camb., Vol. 67, 1966c, pp. 105-107.

TABLE 7

MEAN YIELD OF GRASS (FOR YEARS 1959-1962)

Treatment*	ANNUAL DRY WEIGHT HARVESTED (CUT/ACRE) A Application Rate 63/118 lb/acre	B Application Rate 58-105 lb/acre
None	18.40	16.07
N_1P_1W	26.30	24.15
Sludge 1	26.85	24.73
N_2P_2W	28.35	26.80
Sludge 2	28.82	26.66
N_2P_2	29.10	27.33
KO	24.45	23.47
K_1	26.37	24.60
K_2	26.50	24.80

* None = No manure

Sludge 1 = Single rate of sludge

Sludge 2 = Double rate

N_1P_1W = Inorganic N and P fertilizer and water equivalent to the single sludge application.

N_2P_2 = Inorganic N and P fertilizer with and without

N_2P_2W = Equivalent to double rate of sludge

Table 7 (Continued)

KO = No additional potassium fertilizer

K_1 = 50 lb/acre K_2O

K_2 = 100 lb/acre K_2O

Source: Coker, E.G., "The Value of Liquid Digested Sewage Sludge 1. The Effect of Liquid Sewage Sludge on Growth and Composition of Grass-Clover Swards in South-East England," Journal Agricultural Science Camb., Vol. 67, 1966a, pp. 91-97.

the yields of corn and Kenaf grown with sludge compared favorably with those grown with commercial fertilizer, as shown in Tables 8 and 9. Table 8 shows the average corn yields by year and application rate of digested sludge, while Table 9 shows the yields of three varieties of Kenaf. In terms of yields from the sludge-treated plots, Table 8 indicates that at 1/4 inch sludge application rate, the corn yield increased from 96.2 bushels to 149 bushels per acre, an increase of 52.8 bushels; at 1/2 inch application rate the yield increased from 114.2 to 150.2 bushels per acre, an increase of 38.7 bushels. It appears that the optimum application rate was 1/4 inch. Though the statistics for commercial fertilizer yields were not given, the investigator reported that the yields were comparable to those of sewage sludge. As indicated in Table 9, the yields of kenaf were similar to those shown in Table 8 with sludge-treated plots giving yields comparable to the commercial fertilizer. It appeared in this case that two inches per acre application rate would supply adequate nutrients for the kenaf.

In a greenhouse study in which dried digested sludge was compared with commercial inorganic fertilizer, using barley and Sudan-grass as test crops, Anderson (1955) reported that application of sludge to give

TABLE 8

CORN YIELDS AND DIGESTED SLUDGE APPLICATION ON
BLOUNT SILT LOAM AT N.E. ILLINOIS AGRONOMY
RESEARCH CENTER IN 1968 AND 1969

INCHES OF SLUDGE PER APPLICATION	AVERAGE CORN YIELDS IN BUSHELS PER ACRE 1968	1969
0	66.3	142.8
1/4	96.2	149.0
1/2	114.0	150.2
1	111.0	150.2

Source: Hinesly, T.D., Braids, O.C., Molina, J.E., "Agricultural Benefits and Environmental Changes Resulting from the Use of Digested Sewage Sludge on Field Crops," An Interim Report, U.S. Environmental Protection Agency, Grant No. G06-EC-0080, EPA (SW-30d), Washington, D.C.

TABLE 9

KENAF YIELD IN TONS PER ACRE (ADJUSTED TO 20% MOISTURE)

SLUDGE TREATMENTS*	1968 EVERGLAD 7	VARIETIES CUBA 2032	1969 GUATEMALA 4
0*	2.1	4.99	4.55
2	3.6	4.55	5.12
4	3.7	4.81	5.21
8	3.7	5.28	5.28

*0 = Received only basic application of 200 lb/A of K_2O in 1968 but fertilized with 240-240-200 lb/A in 1969.

2 = Sludge, 1.75 inches 1968 and 2 inches 1969.

4 = Sludge, 3.5 inches 1968 and 4 inches 1969.

8 = Sludge, 7 inches 1968 and 8 inches 1969.

Source: Hinesly, T.D., Braids, O.C., Molina, J.E. "Agricultural Benefits and Environmental Changes Resulting from the Use of Digested Sewage Sludge on Field Crops," An Interim Report, U.S. Environmental Protection Agency, Grant No. G06-EC-00080, EPA-(SW-30d), Washington, D.C., 1971.

45.8 lbs. of P_2O_2, 66.7 lbs. of K_2O and 16-18.7 lbs. of N per acre the equivalent of the commercial fertilizer, resulted in 17.9 per cent increase in yield in sludge-treated plots while the plots treated with commercial inorganic fertilizer had an increase of 56 per cent when compared with the untreated plots. The poor yield from the sludge-fertilized plots may be explained by low nutrient contents of dried digested sludged. That is the reason liquid digested sludge is recommended if sewage sludge should be applied on agricultural land for its fertilizing benefits. This is confirmed by many investigators. For example, Coker (1966) reported that more than half of the nitrogen present in sludge is in liquid form of ammonia and large amounts of this are lost during dewatering of liquid digested sludge to produce dried sludge. Similarly, EPA (1974) reported that almost half of the nitrogen and potassium in digested sewage sludge is in liquid phase; consequently, drying or dewatering would decrease the nutrients. Therefore, the amount of nutrients lost during the drying process seems to be quite sufficient to account for the yield differences that were observed in the example cited above. It may be recalled that dried sludge was mainly used by the earlier investigators; no wonder they concluded that sewage sludge should be regarded as organic manure, comparable to farm yard manure, not as a fertilizer.

In a study by Kelling (1974) in which liquid digested sludge applied at the rate of 2.5, 5, 10, and 15 cm per acre was compared with 365 Kg/ha. N, 108 Kg/ha. P and 101 Kg/ha K commercial inorganic fertilizer, he found that both sludge and commercial fertilizer produced equivalent yields of Sorghum-Sudan at the sludge application rate of 5 cm or more and for corn at 10 cm or more of sludge application rates. When the residual response was tested by growing crops the second year, Kelling (1974) found that the crop yields from the commercial inorganic treated plots could not be differentiated from the untreated control while the plots that were treated with sewage sludge showed improved yields as shown in Tables 10 and 11. Table 10 shows that the first year corn yields produced a significant increase up to 10 cm sludge application rate for the grain and 5 cm rate for the strover. There was no significant difference in the grain yield between the 10 to 15 cm sludge application rate and the commercial fertilizer, but there was significant increase in the strover yields at 10 and 15 cm above the control and commercial fertilizer treatments. The yields of the Sorghum-Sudan for all harvests as shown in Table 11 tend to increase with every increase in sludge application rates.

TABLE 10

CORN YIELD AS AFFECTED BY APPLICATION OF LIQUID DIGESTED SLUDGE MADE BY TANK-TRUCK DURING THE SUMMER AND FALL OF 1971

TREATMENT	GRAIN YIELD Kg/ha	STROVER YIELD Kg/ha
	1st YEAR CORN (1972)	
Control	3,430	2,690
2.5 cm sludge	5,160	3,490
5 cm sludge	5,290	3,900
10 cm sludge	6,310	3,520
15 cm sludge	5,860	3,900
7.5 cm water	6,430	3,160
Fertilizer ‡	6,430	3,850
Bayes LSD* .10	720	850
	2nd YEAR CORN (1973)	
Control	2,310	4,330
2.5 cm sludge	3,310	4,570
5 cm sludge	2,630	4,370
10 cm sludge	2,780	4,910
15 cm sludge	3,030	4,960
7.5 cm sludge	2,835	4,410

Table 10 (Continued)

Fertilizer ‡	1,450	4,320
Bayes LSD* .10	1,120	320

‡ Plot treated with 365 + 108 + 101 Kg N + P + K/ha commercial fertilizer prior to 1972 planting.

* Bayesian multiple comparison test (Waller and Duncan, 1969).

Source: Kelling, K.A., The Effect of Field Application of Liquid Digested Sewage Sludge on Two Soils in South-Central Wisconsin, Unpublished Ph.D. Dissertation, University of Wisconsin, 1974.

TABLE 11

SORGHUM-SUDAN YIELD AS AFFECTED BY APPLICATION OF LIQUID DIGESTED SEWAGE SLUDGE MADE BY TANK-TRUCK DURING THE SUMMER AND FALL OF 1971

TREATMENT	1st CUTTING YIELD Kg/ha	2nd CUTTING YIELD kg/ha
	1st YEAR SORGHUM-SUDAN (1972)	
Control	2,870	1,750
2.5 cm sludge	3,720	2,730
5 cm sludge	3,610	3,160
10 cm sludge	3,360	3,230
15 cm sludge	4,170	3,470
7.5 cm water	3,380	1,900
Fertilizer ‡	3,810	3,740
Bayes LSD* .10	NS	630
	2nd YEAR SORGHUM-SUDAN (1973)	
Control	1,540	2,590
2.5 cm sludge	1,750	3,000
5 cm sludge	1,960	3,100
10 cm sludge	2,100	3,430
15 cm sludge	2,310	3,570
7.5 cm.water	1,490	2,470

Table 11 (Continued)

Fertilizer ‡	1,590	2,430
Bayes LSD* .10	240	460

‡ Plots treated with 365 + 108 + 101 Kg N + P + K/ha commercial fertilizer prior to 1972 planting.

* Bayesian multiple comparison test (Waller and Duncan, 1969).

Severe drought occurred during the summer of 1973.

Source: Kelling, K.A., The Effect of Field Application of Liquid Digested Sewage Sludge on Two Soils in South-Central Wisconsin, Unpublished Ph.D. Dissertation, University of Wisconsin, 1974.

As in corn, the Sorghum-Sudan yields obtained with the commercial fertilizer were similar to those obtained with the higher sludge application rate during the first growing season. These data clearly show the residual benefit that can be obtained with land application of liquid sludge.

The residual benefits of sewage sludge have been reported by other investigators. Coker (1966b) and Anderson (1959) reported that sludge not only has an immediate fertilizing ability, but also its slow release of nutrients due to the nature of organic solids enables it to provide considerable carry-over fertilizing benefits.

It is evident that most of the instances cited above have shown that liquid sewage sludge can produce growth and yield responses comparable with those obtained from the equivalent commercial fertilizer.

Other Agricultural Benefits

In addition to the fertilizing benefit, sewage sludge has some other agricultural values. Sewage sludge is a good soil conditioner. Vlamis and William (1969) and Kirkham (1974) indicated that the addition of liquid sludge to land has a favorable effect on the physical characteristic of the soil. In a sandy soil, it creates chemical reaction sites for nitrate exchanges, improves soil aggregation and makes a good binder to hold the sand from being blown away. Anaerobically digested sludge is outstanding in its ability to increase the humus contents of soils. Kirkham (1974) reported that application of 136 dry tons per acre (309 metric tons per hectare) of anaerobically digested sludge incrementally applied within four years in a farm soil, increased its organic carbon content from 1.2 to 2.4 per cent in the surface 6 inches (15 cm). The humic acid extract from the sludge gave an infrared spectrographic pattern similar to the extracts of the natural organic matter contained in a site farm soil (Kirkham, 1974). The results indicate that the organic matter produced in an anaerobic digestion process has properties similar to those of the natural soil organic matter or humus. Therefore, anaerobically digested sludge can significantly increase the soil organic matter level and can be used as a fertilizer and to bring about a rapid increase in soil humus content.

Evans (1968) reported that although liquid sewage sludge is normally 95 to 97 per cent water, it contains sufficient amounts of nitrogen, phosphorus, potassium, soil conditioning agents and trace minerals that one-inch field application would produce an amazing growth response in crops. Results of studies by Lunt (1953), Black (1974), Evans (1968), and Lavene (1970) showed that sewage sludge has a favorable effect on the soil by increasing the field moisture capacity, non-capillary porosity, cation exchange capacity, organic matter contents and soil aggregation. Sludge is, therefore, a good soil conditioner and promotes increased porosity for better air and water movement in the soil. It provides an increased amount of water in soil available for plant use as well as promotes organic growth and activities. All these factors tend to render the soil more suitable for increased plant growth and agricultural production.

Sewage sludge, according to Erickson (1973), conditions coarse-textured single grained soil and otherwise inert soil by its surface activity and water absorbing activity, thereby improving the soil water properties that are held at any tension. It also increases the soil nutrient sorbtion capabilities of the soil which results in a much more productive soil. In fine textured soils which are capable of developing structure but are, however, low in organic matter, sewage sludge is known to supply the organic matter which is necessary for formation of a stable structure which could increase the infiltration and permeability rates, aeration porosity, decrease the bulk density and improve the productive capacity of the soil (Erickson, 1973). It is generally agreed by both farmers and researchers that sufficient land application of sludge would in the long-run improve both heavy and sandy soils. Manson and Merritt (1975) noted that commercial fertilizers are quite capable of supplying soil nutrient requirements, but sewage sludge has in addition an advantage of containing ready to use humus material which is not easily manufactured. Besides the nutrients in sludge, the addition of liquid sludge to agricultural land may supplement irrigation or precipitation and may sometimes increase plant growth. This is in agreement with Dean's (1971) observation that liquid sewage sludge is liked by many farmers because of its water content. Generally, the agricultural benefits of sewage sludge could be summed up as follows:

1. Increase in humus content of soil.
2. Increase in soil fertility.
3. Increase in water holding capacity of soil.
4. Improvement in soil structure.

Some Observations from the Above Discussions

Although most of the examples cited above were connected with corn, grass, sorghum-Sudan, barley and soyabean, it does not mean that they are the only crops that can be grown on sewage sludge amended soils. It is believed that most crops may do equally well under proper conditions. There is no doubt from the evidence given so far that sewage sludge has fertilizing ability. However, certain reasons can be deduced for the unpopular use of sludge as a fertilizer in the United States of America. One of the prominent reasons is that most of the cities are highly industrialized and the majority of the wastewater treatment plants treat both domestic and industrial wastes, which contain many toxic chemicals and trace elements that have been known or suspected to be harmful to human, animal and plant lives. Another promiment reason is that the quantities of sludge needed as compared to the commercial inorganic fertilizer is too much. While sewage sludge is being applied in tons per acre, commercial fertilizer required to supply equivalent nutrients is applied in pounds per acre. This is in accordance with Dean and Smith's (1973) finding that sewage sludge contains about one-fifth of the nitrogen, phosphorus and potassium found in commercial inorganic fertilizer. Therefore, to get comparable responses of nutrients,about five times as much sludge as the commercial fertilizer must be applied on the agricultural land. The relatively low nutrient content which translates into large quantities of sludge to be used does not permit it to compete effectively with commercial fertilizers. EPA (1975) Kirkham (1974) and Conner (1932) noted that it is believed that the reason sludge is not being used by many American farmers is that they are not willing to purchase and apply the large quantities of sludge required to obtain crop response comparable to that produced by lesser quantities and inexpensive commercial fertilizer. It is not surprising to note that in most of the cases where digested liquid sludges are being used, they are furnished, transported and applied to the farmers' fields free by the municipalities. Another reason given by Anderson (1959) which might help to explain the unpopular use of sludge is that utilization of sewage sludge for its fertilizing value appeals only to limited numbers of people who believe that chemically processed fertilizer should not be applied on the soil that will be used to grow food crops. The last, but not the least, contributing factor for lack of enthusiasm is that the majority of American people have developed an aversion to the use of sludge.

Problems Associated with Land Application of Sludge

Pathogens

The incidence of disease transmission, particularly schistosomiasis associated with "night soil" crop fertilization in China and the epidemics of typhoid fever in the developing countries attributed to the consumption of raw vegetables fertilized with sewage have caused a general aversion to the use of even well treated wastewater sludges in the United States.

Several investigators have addressed the problem of pathogens transmitted by way of land application of sewage sludge (Wolman, 1977; Hyde, 1976; Sopper and Kerr, 1979; Sorber and Sagik, 1978; Tierney et al., 1977; Sagik et al ., 1979). Sorber and Sagik (1978) noted that even though land application of sewage sludge has some obvious advantages, it has the potential of bringing human beings into closer contact with pathogens with possible adverse effect on human health. Corrall et al.(1975) reported that the occurrence and number of human pathogens in domestic sewage is a function of the general health of the area and of the shedding rate of various pathogens by infected people. Figure 1 shows different pathways through which pathogens in sewage sludge can infect man.

Reeves (1959), Dunlop (1968), Martin et al.(1976), Sorber and Sagik (1978), and Corrall et al.(1975) reported that some numbers of each group of pathogens in sewage can

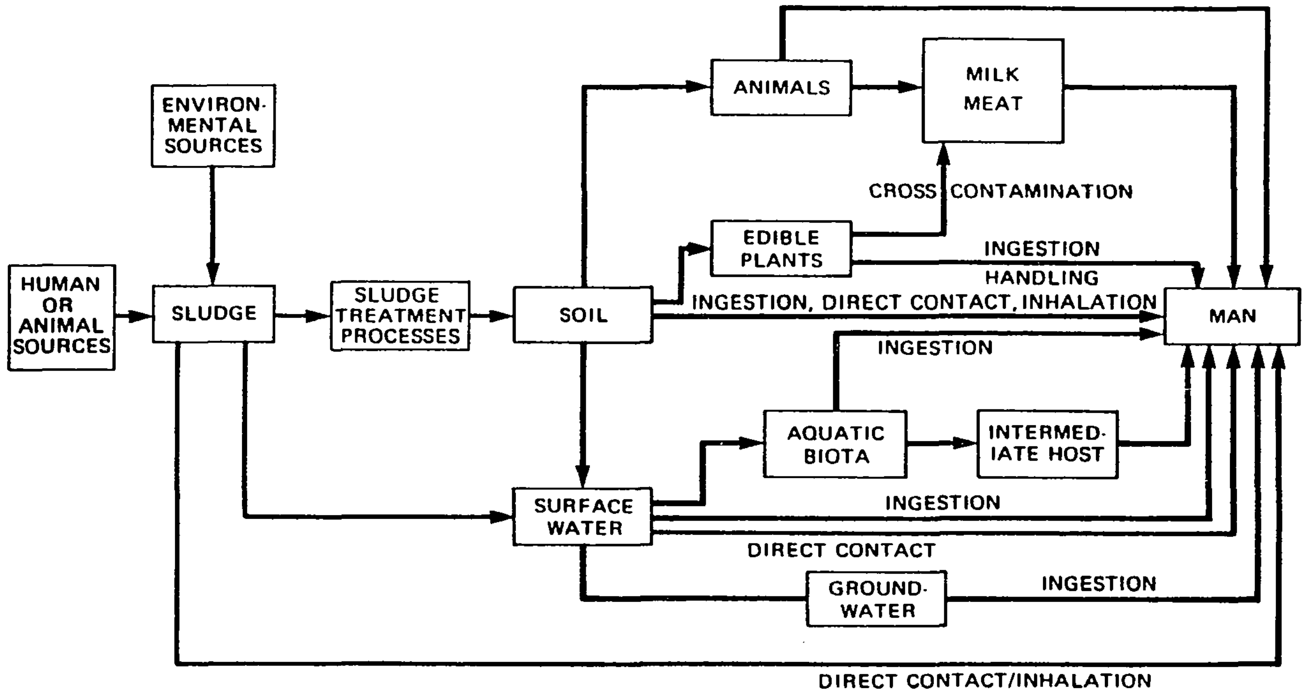

Figure 1: Potential Pathogen Pathways to Man.

Source: U.S. Environmental Protection Agency, Process Design Manual for Sludge Treatment and Disposal, EPA 625/1-79-011, Center for Environmental Research Information Technology Transfer, Cincinnati, Ohio, September, 1979.

survive conventional treatment process, and even though their numbers are reduced, they can be recovered in the receiving soil. Table 12 shows the major organisms of health concern that may be present in sewage.

Hinesly et al.(1971), Corrall et al.(1975), Miller (1977) (1973), Dowdy et al.(1976, and EPA (1974) (1979), reported that anaerobic digestion of sludge appreciably reduces the density of pathogen organisms; however, complete removal cannot be anticipated. Therefore, land application of sludge systems must be operated with consideration to the effect of the microorganisms in the environment. Although conditions in digesters are unfavorable for the multiplication of most pathogenic organisms, they are not lethal; hence , the principal bactericidal effects appears to be related to a natural die-off with time (Dean, 1973; Dotson, 1973; Dowdy et al., 1975). Dotson (1973) reported that some bacteria, viruses and parasites may survive anaerobic digestion and remain viable in digested sludge. Soppar and Kerr (1979) indicated that the level of microbial pathogens ultimately present in sewage sludge depends upon the degree of removal achieved by the treatment employed, therefore, it is not surprising that sludge biomass generated by conventional secondary treatment will contain large portions of microbial population

TABLE 12

HUMAN ENTERIC PATHOGENS OCCURRING IN WASTEWATER AND THE DISEASES ASSOCIATED WITH THE PATHOGENS

	Pathogens	Diseases
BACTERIA	*Vibrio cholerae*	Cholera
	Salmonella typhi	Typhoid and other enteric fevers
	Shigella species	Bacterial dysentery
	Proteus species	Diarrhea
	Coliform species	Diarrhea
	Clostridium species	Botulism
	Pseudomonas species	Local infection
VIRUSES	Infectious hepatitis virus	Hepatitis
	Echoviruses	Enteric and other diseases
	Coxsackie virus	Enteric and other diseases
	Poliovirus	Poliomyletis
	Epidemic gastro-enteritis virus	Gastroenteritis
PARASITES	*Entamoeba histolytica*	Amoebic dysentery
	Balantidium coli	Balantidial dysentery
	Iospora hominis & others	Coccidiosis
	Giardia lamblia	Diarrhea
	Pinworms (eggs)	Ascariasis
	Tapeworms	Tapeworm infestation
	Liver & Intestinal flukes	Liver or intestinal infestation

Source: Love, G.L., Tompkins, E., Galke, W.A., "Potential Health Impacts of Sludge Disposal on the Land," *Proceeding of the 1975 National Conference on Municipal Sludge Management and Disposal*, Anacheim, California, August 18-20, 1975.

in wastewater.

Miller (1977) reported that recycling of liquid sewage sludges on land presents a potential health hazard because of human and animal pathogens they contain. Wolman (1977) reported that evidences from studies for the past 70 years showed that under certain circumstances, there may be real danger of spreading infections by using sewage sludge as fertilizer for growing vegetable crops. Although certain pathogenic organisms such as salmonella typhosa have a relatively brief survival time in wastewater, Soppar and Kerr (1979) reported that other pathogens including mycobacteria, *Ascaris* ova and certain enteric viruses are highly resistant to many environmental stresses caused by conventional wastewater treatment. Complete removal of pathogenic microorganisms by the present wastewater treatment methods is not possible; therefore, pathogens and other microbes may survive waste treatment process and contaminate the food chain via land application of sewage sludge (Braude et al., 1978).

Many pathogens have been shown to survive in soil for a period of time ranging from a few days to several months. Martin et al. (1976) reported that the survival time of a given organisms in soil is generally influenced by: low temperature, high water contents, pH range and organic matter content of soil.

Sewage sludge and effluents have been clearly documented to contain viable pathogens that may pose a threat to animal and human health unless properly handled. These include the bacteria pathogens (*Salmonella*, *Shigella*, *Mycobacterium* and *Vibrio* sp.), the hepatitis, entro and endo viruses, the protozoan *Endomoeba histolytica* and certain pathogenic fungi and fungal allergens (Corrall et al, 1975). Hyde (1976) showed that a significant number of total coliform, fecal coliform, fecal streptococci, Salmonella and Shigella organisms could survive in digested sewage sludge before land application and in soil-sludge medium for as long as 7 months. Hyde (1976) and Sopper and Kerr (1979) reported that they isolated some parasitic helminths of public health significance such as *Ascaris Lumbricoides*, *Strongyloides Sterocoralis* and *Hymanolepsie nana*.

In a recent investigation of the persistence of pathogens in liquid sludge amended soils, Corrall et al. (1975) and Dotson (1973), reported that fecal coliforms were detected after 18 weeks, *Ps Aeruginosa* at 16 weeks and *Salmonella* sp up to 10 weeks. In a study of the hygenic aspects of liquid digested sludge disposal on cropland, Hinesly et al. (1971) showed that liquid digested sludge could harbor a population of fecal Coliform counts in the order of 10^5 cells per milliliter. Reeves, (1959) reported that *Mycobacterium tuberculosis* was isolated from both primary and secondary treatment sewage sludges. The same investigator reported that *Salmonella* typhosa was able to survive for 365 days in activated sewage sludge, and felt that activated sludge should not be considered innocuous.

Kirkham (1974, 1979) reported that after application of sludge on land, the viability of pathogenic organisms varies from a few hours to several months. Spore forming bacteria can remain viable for years in soil and some microorganisms survive almost indefinitely. However, many pathogenic organisms are known to die very rapidly. Corrall et al. (1975) concluded from an extensive literature review that the most common intestinal pathogens which could cause disease by ingestion of contaminated raw vegetables or fruit fertilized with sewage sludge are *Salmonella*, *Eberthella* and *Shigella*.

Dunlop (1968) reported that there was some evidence that significant amounts of enteric viruses such as polioviruses, coxsackie, EHCO and infectious hepatitis viruses might survive sewage treatment and spread diseases through land application practices. Wolman (1977) reported that virus was isolated from the crops and soil treated with raw activated sludge which was innoculated with virus before land application. A recent study by the United States Food and Drug Administration showed that virus prevailed for three weeks in mature lettuce and radish seeds (Wolman, 1977). Soppar and Kerr (1979) reported that one poliovirus type 3 and twenty-four isolates identified as echovirus 7 were recovered after 48 hours on a spray field and 13 days on a sludge drying bed respectively.

Tierney et al.(1977) concluded from the study of the persistence of poliovirus 1 in soil and on vegetables grown in soil previously flooded with innoculated sewage sludge that vegetables can mechanically transmit viruses and warned that the use of sludge to grow crops that would enter the human food chain presents a potential hazard.

The structure of Ascaris eggs and the composition of shell make it possible for the eggs to survive the sewage treatment process; hence, application of sewage sludges may cause some cases of parasitic infestation (Braude et al., 1978). Braude et al.(1978) reported that Ascaris were recovered from seeded radishes and lettuce for 6 days and from soil for 21 days after seeding.

Studies done at the London School of Tropical Medicine in Cairo, Egypt showed that the eggs of Ankylostome and Acaris were frequently recovered in dormant state capable of normal development into an infestive stage in the course of 6 or 8 days from septic tank sludge (Wolman, 1977). Reeves (1959) reported that hookworm ova survived as long as 64 days in digested sewage sludge. Miller (1973) reported that human pathogenic fungi and fungal allergens were isolated from sewage sludge and sludge amended soils.

Fresh vegetables raised on sludge amended soil may transmit pathogenic microorganisms. Tierney et al (1977) reported that animal viruses could penetrate the root system and enter the stem portion of plants thus indicating that it is possible to contaminate both the surface and inner part of plants. Martin et al.(1976) reported that fruits and vegetables, especially root crops, could become surface contaminated by pathogens and if consumed raw, might pose a threat to human health. Tierney et al.(1977) reported that Poliovirus 1 survived for 36 days on lettuce and radishes after spray irrigating the crops with innoculated sewage sludge.

Kirkham (1974) indicated that most intestinal pathogenic bacteria are either destroyed or their population greatly reduced by anaerobic digestion of sludge. The same investigator reported that viruses were not recovered in the feces of piglets fed sludge that was innoculated with virus and digested for 5 days or longer (Kirkham, 1974). Kirkham (1974) then suggested that heating anaerobic digested sludge for 14 days would provide a considerable margin of safety with regards to the destruction of viruses.

Many studies, Miller (1973) and Dowdy et al. (1976), reported that the soil is an excellent disinfectant for pathogens and indicator bacteria that survive wastewater treatment processes. This made Miller (1973) conclude that since there is a rapid die-off of pathogens in the soil matrix, the presence of pathogenic microorganisms should not be a factor limiting application of sewage sludge on farm land.

In spite of evidence of survival of pathogenic microorganisms after wastewater treatment processes, Martin et al (1976) reported that there is little documented evidence that land application of either human or animal waste has caused any significant threat to public health. Corrall et al.(1975) and Kirkham (1974) reported that the most recent incidence of disease transmission in the United States which could be attributed to the consumption of food stuff grown on a sewage farm reportedly occurred in 1919, when eight employees on a sewage farm developed typhoid fever when they ate blackberries or vegatables grown on the farm. What most laymen do not understand according to Kirkham (1974) and Corrall et al (1975) is that most of such outbreaks can be attributed to either the use of raw untreated sewage or unsanitary food preparation and handling practices.

Sorber and Sagik (1978) concluded from their study of the health effect of land application of wastewater and sludge that since there is no evidence of disease transmission from land application of sewage sludges and because it is unrealistic to insist upon pathogen-free waste, land application of treated sewage sludge can be considered an acceptable risk until future studies indicate otherwise.

Dotson (1973) recommended the following methods for destruction of pathogenic microorganisms in sewage sludge:

1. Storing for a long period of time.
2. Pasteurization at 70° for 30 minutes.
3. Addition of lime to raise the pH to 11.5 or higher and maintaining the pH above 11.0 for two hours or more.
4. Using chlorine or other chemicals to stabilize and disinfect sludge.

Sludge pasteurization and high-energy radiation are, according to EPA (1979), the only methods designed specifically to disinfect pathogens in sludge. Long term storage in lagoons has been reported to have the effect of reducing substantially the number of pathogenic organisms in sludge. EPA (1979) reported 99.9 per cent reduction in fecal coliform density after 30 days of storage. The same author, reported that storing anaerobically digested sludge in an anaerobic environment for 24 weeks at 68^{o} F (20^{o} C), no fecal coliform, total coliform and salmonella bacteria could be detected. And on checking the concentration of viruses, it was found that they had been reduced to below detectable limits. This process might be an answer to municipalities that would want a higher degree of pathogen destruction but do not want to utilize pasteurization or high-energy radiation. Significant pathogen reduction can be achieved in sludge that has been lime-treated to pH 12. EPA (1979) reported that pathogenic bacteria were reduced to below detectable levels in sludge treated with lime to pH 12 after 24 hours. Viruses were reported to be inactivated at this pH. However, the Ascaris ova were reported to have survived after the 24 hours.

Chlorine treatment has been mentioned in the literature as another method of chemical disinfection of sludge, but it is not effective in sludge with high solid contents. EPA (1979) indicated that cysts and ova or parasites are very resistant to chlorine. The same author found that addition of 1,000 mg/l doses of chlorine to waste-activated sludge with 0.5 per cent solids concentration reduced the total bacteria count by four to seven logs and coliform bacteria and coliphage to below detection limits.

Though anaerobic digestion can greatly reduce the number of bacteria and viruses levels in sludge, it is less effective with parasitic cysts. However, EPA (1979) has cited a study in which there is substantial reduction in both cysts and helminth ova.

Generally, anaerobic digestion reduces bacterial count by one to four logs and virus count by one to several orders of magnitude (EPA, 1979). Tables 13 and 14 show the pathogenic organisms in raw sludge and mesophilic anaerobic digested sludge. As indicated in Table 14 there is tremendous reduction in the number of pathogens. If such substantial reduction can be achieved by the system, coupled with the other advantages, there will be no justification for additional disinfection of sludge if proper crops selection and adequate sanitary practices are followed to disinfect vegetable crops that are consumed raw. It should be emphasized that the degree of disinfection achieved

TABLE 13

PATHOGENIC ORGANISMS IN SLUDGE

Type	Salmonella (No/100 ml)	Pseudomones aeruginosa (No/100 ml)	Fecal Coliform (No x 10^6/100 ml)
Raw Primary	460	46×10^3	11.4
	62	195	
Trickling Filter	93	110×10^3	11.5
Raw WAS	74	1.1×10^3	2.8
	2,300	24×10^3	2.0
	6	5.5×10^3	26.5
Thickened raw WAS	9,300	2×10^3	20

Source: U.S. Environmental Protection Agency, Sludge Treatment and Disposal, EPA - 625/4-78-012, Environmental Research Information Center, Cincinnati, Ohio, October, 1978.

TABLE 14

PATHOGENIC ORGANISMS IN MESOPHILIC ANAEROBICALLY DIGESTED SLUDGE

Type	Salmonella (No/100 ml)	Pseudomonas aeruginos (No/100 ml)	Fecal Coliform x 10^6 (No/100 ml)
Primary only	29	34	0.29
WAS only	7.3	10^3	0.32
Mixture Primary and WAS	6	42	26

Source: U.S. Environmental Protection Agency, Sludge Treatment and Disposal, EPA-625/4-78-012, Environmental Research Information Center, Cincinnati, Ohio, October, 1978, Vol. 1.

with anaerobic digestion depends on the type digester used. The thermophilic type has been known to achieve more reduction in pathogens than the mesophilic type. EPA (1979) in a study at Los Angeles Hyperian treatment plants, found that there was two-logs greater reduction in virus content of sludge when it was digested in thermophilic digester at a temperature of 121° F (50° C) for 20 days as compared with mesophilic digested sludge at a temperature of 94° F (35° C) for the same time period. On checking the bacteria reduction, it was found that there was two to three logs decrease with thermophilic digestion over the mesophilic digestion. This suggests that if any municipality desires to achieve greater reduction in pathogens, the thermophilic digestion would be the treatment of choice, but this has the disadvantage of high cost of operation, and it is also easily upset.

The Food and Drug Administration has recommended that crops that are to be consumed raw should not be planted within three years after the last land application of sludge (Sorber and Sagik, 1978). The same investigator also reported that because other food and utensils may be contaminated, food that may enter homes or food establishments should not be grown on sludge amended soil unless it has been proven to be free of pathogens.

Heavy Metals

Although heavy metals concentrations obtainable in the industrialized countries is not expected to be a problem in Enugu, Nigeria, because of lack of industries, it is necessary to review briefly the problems resulting from such trace elements, so as to point out what will become of the Nigerian environment if adequate measures are not taken to prevent such environmental impacts as the country enters the industrialization stage.

Heavy metal accumulation in the soil and its subsequent uptake by plants causes a lot of concern whenever land application of sewage sludge is being considered as a disposal option. The effect of this in relation to crop damage and permanent changes in soil properties, especially after several years of sludge application, has been documented by many investigators (Lunt, 1959; Hinesly et al., 1972; King and Morris, 1972b; Dotson, 1973; Walker, 1975; EPA, 1976; Martin et al., 1976; Dowdy et al., 1976). The majority of these studies, as might be expected, showed that sludge application increased the heavy metal content of the amended soil and in some cases the crops grown on them. The quantities of trace elements in sewage sludge are related to the type and amount of industries emptying wastes into the sewer system. Dotson (1973) reported that sludge of high heavy metal concentrations are produced by industrialized cities; however, studies have shown that sludges of domestic origin have concentrations of zinc and copper in excess of those found in soil.

Heavy metal presently of major concern because of its potential phytotoxicity and danger to the animal and human food chain is cadmium. Other heavy metals posing potential problems include: copper, nickel, molybdenum, zinc, lead, chromium and arsenic (Kirkham, 1974; Kelling, 1974; Lunt, 1959; King and Morris, 1972; Wolman, 1977; Hyde, 1976; EPA, 1976; Dowdy et al., 1976; Walker, 1975). Hyde (1976) reported that the effect of heavy metals on "soil-plant-water" ecosystem and the human food chain as the most important obstacle to utilization of sewage sludge on agricultural lands. Certain heavy metals are known to be more toxic than others to specific plants. Kelling (1974), Kirkham (1974, Dotson (1973), for example, reported that Ni is about eight times as toxic to plants as Zn and Cu is twice as toxic as zinc. Kelling (1974) reported that once any soil is contaminated with heavy metals, the problem is a continuous one. Contrarily, Kirkham (1977) reported that sludge is effective in increasing the organic matter content of soil and therefore, would help to reduce the uptake of heavy metals. Since the organic matter in sewage sludge decomposes gradually in the soil and loses its protective effect, heavy metal might intensify with time (Kelling, 1974). LeRiche (1968) reported that high metal concentration was found in the soil as in plants grown on the soil six years after the last sewage sludge application.

Dowdy et al. (1976) reported that if sludge of median metals content is used for their nutrient value, the level added does not become toxic to plants for a number of years and the uptake of sludge-borne metal depends on plant type and soil property.

Of all the heavy metals, cadmium has been reported to be of most concern to the Food and Drug Administration (Kirkham, 1974; Martin et al., 1976; Bingham et al., 1975). Kirkham (1974; 1979) reported that cadmium may be very high in sewage sludge from the industrialized cities and if such sludges are applied in moderate amounts for many years, there might be a high build-up of Od in the soil. The same investigator noted that food obtained from plants grown in such soil could contain concentrations of Cd toxic to both man and animals. Although Cd normally is not present in sludges in quantities that will cause crop injury, it is a possible food chain hazard (Walker, 1975).

Cadmium is a nonessential element and can be a serious hazard to animals and humans if the dietary levels are increased substantially. Bingham et al. (1975) reported that an epidemic of "Itai-Itai" disease in the Jintsu basin of Japan has been associated with the consumption of rice with high cadmium content. The literature on cadmium showed that many crops may contain undesirable concentrations of the element in their vegetable tissue without showing the symptoms of cadmium toxicity (EPA, 1976). Bingham et al (1975) showed that cereals and legumes accumulate less cadmium in their shoots than leafy plants such as lettuce and spinach. EPA (1975) in the appraisal of potential hazards of the heavy metals to plants and animals showed that cadmium concentrations in corn grain are usually 3 to 15 per cent of those in the leaf, whereas in grain of soyabeans, wheat, oats and sorghum, cadmium reaches 30 to 100 per cent of the foliar levels.

Since the greatest detrimental impact of applying sewage sludge to agricultural land is likely to be associated with the cadmium content of sludge, the methods for limiting the entry of the element into the sewage system, removing it from sludge prior to application to soil as well as limiting its accumulation in the food chain should be investigated.

EPA (1976) suggested the following management processes, as the way to limit the cadmium accumulation in food supply:

1. Maintenance of soil pH at or above 6.5.
2. Growing of crops which tend to exclude cadmium from the whole plant or from reproductive tissue.
3. Applying low annual rates of cadmium and use of sludge which has a low cadmium concentration.
4. Growing of nonedible crops.

Braude et al. (1978) in the study of the human health risks of using sludge for growing crops observed the following about heavy metals:

1. That copper, molybdenum and selenium are known to have caused sporadic poisoning of livestock.
2. That nickel is frequently found in sludge in substantial amounts capable of causing phytotoxicity to plants when grown in acid soil.

3. That grazing of animals in land fertilized with sewage sludge may cause some problems due to lead.
4. That cadmium present in significant amounts in municipal sewage sludge can be appreciably absorbed, translocated and accumulated by many food crops as well as accumulate in human kidneys where it can cause severe damage.

Nickel and copper phytotoxicity has been reported in Europe and in Japan; human toxicity resulting from cadmium has been identified (Hyde, 1976). EPA (1976) reported that the only condition in which copper toxicity in animals is expected to occur is when copper toxicity is severe in the plant used as feed. Plant toxicity due to nickel has been known to occur only on acid soil (EPA, 1976). EPA (1976) reported that due to the fact that molybdenum is not toxic to plants, it could accumulate in plants at concentrations sufficient to cause molybdenosis in ruminant animals without prior warning from plant behavior. Copper toxicity may develop in plants when land application of sewage sludge is appreciably high.

Among all the trace elements present in sewage sludge, boron (B) needs special attention in sludge to be applied on agricultural land because of its toxicity to certain crops. Boron is one of the essential mineral elements required in trace amounts for plant growth (Bowen, 1977). However, the amount needed differs among various plants. A boron level that is adequate for one crop, may be too high for more sensitive crops. Though a plant needs a continuous supply of boron throughout its lifetime, excess amounts are toxic to some plants (Bowen, 1977).

Boron does not occur in pure form, but is commonly found as oxides in combination with sodium and calcium. The most common sources in agriculture are borax, sodium tetraborate and solubon used as fertilizer to supply the essential mineral element. Borax is also used as a cleansing agent (detergent). Pure borax contains 11.34 per cent boron and 36.5 per cent boric acid. Concentrations of B in sewage sludge, like other trace elements, such as Cd, Cu, Zn, Ni, Pb, Se, Ba, As, Cr, Co, may be high enough in industrialized areas to cause toxicity to plants when applied in large amounts on agricultural land (EPA, 1976). The same author reported that the concentration of boron in such sludge ranges from 100 to 1,000 ppm. Page (1974) and EPA (1976) reported that substantial amounts of B can be detected in soil in which large amounts of domestic sludge are applied for many years; however, this depends on the community use of boron-containing materials.

Unlike some other trace elements, boron has not been known to pose significant toxicity problems to humans and animals (Bowen, 1977). Toxicity due to B appears first as a yellowing of leaf tips and margins which rapidly increases in severity with eventual death of the tissue (Bowen, 1977). Besides being toxic in high amounts, deficiency of B is a very widespread problem and has great economic importance to farmers (Bowen, 1977; Turner, 1980). Tucker (1981) and EPA (1976) reported that application of sludge that results in B concentration in the soil higher than 1 ppm may damage sensitive crops. Certain crops are more sensitive than others. According to Turner (1980) very sensitive crops such as cotton and soyabean can tolerate 0.5 lbs/acre of boron. Less sensitive crops such as wheat, oat, barley and clover can tolerate up to 1 lb/acre and corn can tolerate up to 2 lbs/acre. More tolerant crops like alfalfa can utilize up to 3 lbs/acre without any sign of toxicity. Ayers (1976) recommended the following as shown in Table 15 as a guideline for interpreting boron

TABLE 15

A GUIDELINE FOR INTERPRETING BORON

ANALYSIS IN WATER AND SOIL

In Water	In Soil	Crop Adaptation
Below 0.5 ppm	Below 0.5 ppm	All crops
0.5 - 1.0	1.0	Sensitive crops show injury
1.0 - 2.0	5.0	Semi-tolerant crops
2.0 - 4.0	10.0	Tolerant crops
Above 4.0	above 10.0	Most crops injured

Source: Ayers, R.S. Irrigation Water Quality in Soil and Plant Tissue Testing in California, H.M. Reisenauer, Editor, Division of Agricultural Science, University of California, Bulletin 1879, 1976.

analysis in water and soil, thus determining the type of crops to be grown. As some crops are tolerant to boron, so is some soil texture. Turner (1980) noted that crops in fine textured soils are more tolerant to B than those in coarse textured soils. The absorption of B in the soil decreases in the soil as alkalinity increases (Bowen, 1977). Therefore, excessive liming of soil amended with sewage sludge high in boron, decreases its availability to plants.

Boron is very soluble and leaches from the soil fairly rapidly (EPA, 1976); this explains why soils in high rainfall areas are frequently deficient in B (Bowen, 1977). EPA (1976) reported that in humid regions, boron in the sludge applied to farmland is diluted to below the threshold toxic concentration and thus presents little hazard. This was confirmed by Tucker (1981) who noted that areas with high annual rainfall like Southern Nigeria, would not have any problems due to boron toxicity, because it would be leached below plants' root levels. Though there are not many industries that may contribute to high B content of sludge produced in Enugu, Nigeria, coupled with the advantage of heavy rainfall especially in the South, it will be necessary for precautionary measures, to do both soil and sludge analyses to determine their boron contents. And depending on the boron levels, the type of crops to be grown would be according to the guideline in Table 15.

Copper poisoning of animals has been associated with the consumption of certain plants such as Heliotropium species grown on sludge-amended soil (EPA, 1976).

Walker (1975) reported that the availability of sludge-borne heavy metals to crops is governed by such factors as soil pH cation exchange capacity, phosphorus, organic matter, reversion in the soil, crop variety, species, organs and age.

Opinions differ widely regarding the hazard of trace element toxicity caused when sludge is used as a fertilizer and soil conditioner. Walker (1975) indicated that trace elements in amounts found in sludge would not cause appreciable plant and animal food chain injury unless they were absorbed into vegetative materials by direct contamination and then ingested by animals in large amounts. Plants vary widely in their tolerance to trace elements. For example, several vegetable crops such as the beet family, turnips and tomatoes are very sensitive, while many general farm crops such as corn, small grains (rice, wheat), and soyabeans are moderately tolerant and most grasses are quite tolerant (Kirkham, 1977; Kelling, 1974; EPA, 1976;

Dowdy et al, 1976; EPA, 1977). The relative sensitivity of many crops to metal toxicity is shown in Table 16.

Kirkham (1974) reported that plants can grow normally and yet contain concentrations of Se, Cd, Mo, and possibly Pb that are toxic to man and animal. Martin et al. (1976) reported that increased metal concentrations in the soil could lead to increased levels in edible plant tissues even though such is not toxic to plants. Such concentrations in plant tissues could create potential health problems either directly by excessive concentrations of non-essential elements toxic to both human and animals or indirectly by causing imbalance of essential elements.

Dowdy et al.(1976) EPA (1977) reported that most of the absorbed metals accumulate in the vegetable tissue, leaving the storage tissue free of metal enrichment. For example, Dowdy and Larson (1975) found that pea vines contained 2 to 3 times as much zinc as the pods and edible tissue. The same investigators reported that application of 450 metric tons per hectare (200 tons/acre) of sewage sludge increased the Cd content of edible corn grain from 0.02 to 0.05 ppm while concentration of the leaf at silking time increased from 0.26 to 1.32 ppm. Potatoes and carrots have been reported to be good crops to be grown in sludge-amended soil

TABLE 16

RELATIVE TOLERANCE TO METAL TOXICITY

Very Sensitive	Beet crops (chard, sugarbeets, red-beet kale, mustard, turnip, tomato.)
Sensitive	Beans, cabbage, collard, other vegetables.
Moderately Tolerant	Many farm crops, i.e., corn, small grains, soybeans.
Tolerant	Most grasses, i.e., fescue, lovegrass, Bermuda grass, perennial rye grass.
Very Tolerant	Ecotypes of grasses.

Source: Walker, J.M., "Sewage Sludges Management Aspects for Land Application," Compost Science, March-April, 1975, pp. 12-21.

because they have been shown to be nonaccumulators of heavy metals (Kirkham, 1977). Contrarily, Lunt (1959) reported that sewage sludge was harmful to growths and yields of potatoes and tobacco. In addition, EPA (1977) reported vegetables such as lettuce, spinach and tobacco are among the highest accumulators of heavy metals.

There is no agreement on the quantities of sludge to be applied on land before plant toxicity results. Lunt (1953) reported that zinc and copper toxicities reduced the growth of beans and oats on an acid soil at the sludge rates above 65 metric tons per hectare. However, King and Morris (1972b) reported that sludge application rate of 224 metric tons per hectare was not harmful to barley. Giordano et al. (1975) reported that application of 100 metric tons per hectare of sewage sludge resulted in increased barley yield with no evidence of toxicity. In a study conducted by the University of Illinois in which 150 tons of digested sewage solids per acre were applied to corn plots, no sign of toxicity was identified (Dotson, 1973). EPA (1975) reported that heavy metal monitoring did not reveal any problems in Great Britain where 20 to 30 communities have practiced land spreading of sewage sludge for several years at application rates of less than 5 tons of dry solids per acre per year. Kirkham (1974; 1979) reported that practices that promote good soil aeration such as structural development and drainage lead to the decrease of trace elements solubility.

The pH of soil receiving sewage sludge is of greater importance, because some heavy metals toxicity problem seem to occur on acid soils. Kelling (1974) reported that soil toxic metal content safe at pH 7 can easily be lethal to most crops at pH 5.5. EPA (1976) and Lunt (1959) reported that maintenance of soil pH above 6.0 prevents plant injuries. The ways of minimizing the impact of trace elements have been suggested by many investigators. Kirkham (1974) indicated that since tissues from different crops and varieties vary widely in their concentration of trace elements, selection of crops provides a way of controlling the entrance of undesirable amounts of trace elements into the food chain. Agriculturists have shown that long term impact of heavy metals could be substantially prevented by growing corn and other selected crops harvested for their edible seeds or fruits instead of the forage or leafy vegetable (Wolman, 1977). Wolman (1977) reported that long experience with heavy metals has shown that a more successful control can be achieved by greatly reducing these objectionable elements at their sources. The factors to minimize heavy metal availability and uptake by plants are summarized in Table 17.

Liming appears to be the primary management practice recommended for alleviation of heavy metal toxicity (Lunt, 1959). Other practices which can be adopted to control the unfavorable effects of heavy metals according to Kelling (1974) include:

1. Application of phosphates if the soil is sufficiently alkaline.
2. Application of iron (Fe) as EDTA chelate.
3. Organic matter treatment of the soil.

Dean (1973) reported that zinc poisoning which was diagnosed in a field that received sludge for many years was corrected by lime treatment. Dean (1973) and Kirkham (1974; 1979) reported that toxic effect of Zn, Cd, Cu, Ni and Pb could be controlled by adequate treatment with lime. This is possible because lime raises the soil pH and converts most toxic metals to the forms which are less soluble and less available to plant roots.

Dowdy and Larson (1975) reported that alkaline soil has amazing capacity to buffer against the extraction of sludge-applied metals by growing plants. Kirkham (1974) noted that because of nitrification reaction and microbial

TABLE 17

FACTORS FOR REDUCING AVAILABILITY OF SLUDGE TRACE ELEMENTS AND THEIR UPTAKE BY PLANTS

Sludge:	Low concentration of trace elements
	Low Cd to Zn ratio
	High P
	High organic matter
	High lime
Soil:	Neutral pH
	High cation exchange capacity
	High organic matter
Crops:	Trace element tolerant variety and species
	Fruits and seed compared with vegetative tissue
	Younger compared with older vegetative tissue

Source: Walker, J.M., "Sewage Sludges Management Aspects for Land Application," Compost Science, March-April, 1975, pp. 12-21.

production of CO_2, sludge can lower the soil pH; therefore, liming is often necessary at land application sites. It is possible to decrease the uptake of one element by supplying another element to the soil. For example, Kirkham (1979) observed that high phosphorus level in soil would often inhibit the uptake of other trace elements. High levels of phosphate have been cited for its ability to reduce zinc availability to plants and thus decrease the stunting injury caused by excessive levels of toxic metals (Kelling, 1974).

Kelling (1974) reported that chelating action of soil organic matter could affect the availability of heavy metals by making the metal less available to harm plants, especially at low pH values. Kirkham (1974; 1979) reported high cation exchange capacities (of a soil) because its ability to hold and immobilize trace elements is effective in controlling the uptake of heavy metals in sludge amended soil. Kirkham (1974) and Dotson (1973) reported that the synergistic and antagonistic interaction between ionic metals species in soil and sludge would affect the absorption of the elements by plant roots and their translocation within plants.

Odor Problem

Land application of sewage sludge to agricultural land poses serious potential offensive odor nuisance if not properly managed. Wasbotten (1978) indicated that sludge odor problem can begin at sludge treatment plant and the potential can extend for a significant period of time even after the actual application of sludge to the land. The importance of odor originating from sewage sludge has been noted by Wasbotten (1978) who recommended that in evaluating the overall impacts of any land application of sewage sludge system, much consideration must be given to the offensive odor nuisance. Dowdy et al.(1976) noted that odor is often mentioned as one of the reasons for public rejection of land application of sludge. Dowdy et al.(1976) reported that odors produced during the normal sludge digestion process tend to dissipate; however, overloading or malfunctioning of the treatment plant results in partially digested sludge which if applied to land has the potential to produce much offensive odor. EPA (1977) reported that odor condition is closely related to the action of anaerobic bacteria on the volatile organic matter in both liquid and solid parts of sludge. Digestion of sludge at 95° F for 10 days in a well designed and carefully operated high-rate anaerobic digestion has been reported to be useful in odor control (EPA, 1977). EPA (1976) reported that odors from poorly managed sludge management systems and perceived odors from anything that has something to do with sewage are the largest single problem limiting land application systems.

Odor nuisance at land application sites can be prevented by utilization of well digested bed-dried sludge (Wasbotten, 1978).

Soils can serve as a deodorizing as well as a disinfecting agent. EPA (1977) and Wasbotton (1978) have indicated that subsurface injection or soil incorporation of liquid sludge would prevent odor problems. Other methods known to be effective in odor control include: compositing, chemical treatment with high concentration of lime and chlorine, heat treatment followed by sludge dewatering and pressure filteration of sludge cake (EPA, 1977; Wasbotten, 1978). Generally, sludge odor problems can be kept to a minimum with proper sludge digestion operation, handling techniques and adequate land management at the application sites (Wasbotten, 1978). Keeney et al.(1975) indicated that the only two practical approaches to controlling offensive odor problems at land application sites are either subsurface injection or location of the sites away from high population areas.

In places like the United States where farms are very close to the residential areas, Dowdy et al (1976) recommended that odor dissipation could be controlled by taking the following steps; locate sludge application sites so that the prevailing winds do not blow across then onto the residential areas. Stop sludge application when the wind is from the wrong direction. Time sludge application operation, with application carried out only when wind is calmest in that locality, which in most cases is during late evening, night or early morning.

It is believed that the same objective can be achieved by construction of hedges around the farms with trees or shrubs to reduce wind speed across the farms. This will also prevent easy sight into the farms for aesthetic reasons, especially if the farms are located along paths or roadways.

Ground and Surface Water Contamination

Page (1974) and Keeney et al.(1975) indicated that the extent to which underground water is contaminated with heavy metals from sludge application site is largely dependent upon the chemical characteristic of sludge, the chemical property of the soil, and the distance the percolating solution must move through the soil to the water table. The potential for contamination will be greatest where a shallow water table occurs beneath sandy soil with low organic matter content. Conversely, the probability of underground water contamination is essentially nill, where water table occurs at a greater distance from the surface.

Underground water contamination by heavy metals is generally considered not to be of much problem on land application sites. EPA (1976) reported that soils readily remove heavy metals from soil solution and prevent them from reaching ground water. Therefore, ground water contamination is not likely to result from sludge-amended soil. In general, heavy metals have been reported to move very little with percolating water and remain at the point of application unless they are transported away on eroded sediment (Kirkham, 1974; 1979). Page (1974) reported that with possible exception of Boron, the contamination of dissolved trace elements is reduced once sludge comes in contact with soil. Kirkham (1974; 1979) reported that the capacity of soil to retain trace elements is limited and Kirkham (1979) noted that because sewage sludge contains certain metal-complexing agents, eventual movement of heavy metals to ground water is possible. Page (1974) indicated that high mobility of Boron in most soils might result in B contamination of underground water in sludge-amended soils.

Heavy metals in sludge-amended soil have been reported to concentrate largely on the erodible surface soils; therefore, run-off and errosion may contribute to heavy metal contamination of surface water (Page, 1974; Keeney et al., 1975). Page (1974) and Keeney et al.(1975) reported that the concentrations of Ag, Cd, Cr, Cu, Hg, Mo, Ni, and Pb as low as 0.01 ug/ml might have serious harmful effects on certain species of aquatic life. Since the tolerance is so low, it is necessary that surface run-off of sediments into surface water be minimized by the use of recommended erosion control practices. Application of sewage sludge to soil surface without incorporation can be transported in run-off water and results in surface water contamination (Miller, 1978). The potential of surface run-off is immensely increased on sloping land, especially in high rainfall regions; therefore, it has been recommended that soils to be used for land application should be restricted to those with less than 6 per cent slopes wherever possible (Miller, 1978).

In a review of the literature dealing with mobility of trace elements in sludge amended soil and the potential for ground water pollution, Kirkham (1977) reported that:

1. With the exception of Boron, the movement of trace elements in soil with sludge is

restricted.

2. Trace elements stay at the depth of tillage.
3. Even though practically all trace elements are fixed in surface layers of soil, any small increase in their solubility with subsequent movement into the water table could result in deterioration of ground water supplies.
4. Increase in the use of subsurface injection rather than surface spreading could result in more leaching of trace elements into ground water.

Leachates from land application sites into the underground water table do not always result in ground water contamination. According to Kirkham (1977), the analysis of ground water receiving leachates from corn plots at Hanover Park, Illinois, after six years of spreading sludge from Chicago, indicated improvement in ground water quality. The analyses showed that there was a decrease in the concentrations of potassium, sodium, calcium, magnesium, zinc, copper, manganese, iron, sulfate, total ammonium nitrogen and alkalinity (Kirkham, 1977).

Keeney et al.(1975), EPA (1976) and Miller (1978) reported that application of sewage sludge at the rate supplying nitrogen greater than the amount required by plants on a very permeable soil with water table within a few feet of soil surface can result in ground or surface water contamination with nitrates. It is therefore important that the permeability, the drainage of the soil and the depth of water table or bedrock should be considered when selecting sewage sludge application sites (EPA, 1976). The United States Environmental Protection Agency (EPA) and World Health Organization (WHO) drinking water standard for nitrate-nitrogen is 10 mg/L (EPA, 1974; Keeney et aL, 1975). EPA (1974) and Keeney et al.(1975) reported that high nitrate concentrations in drinking water can cause human and animal health problems. High concentration of nitrate in drinking water has been reported to cause disease in infants known as "blue babies" or methemoglobinemia (Vesilind, 1979). Keeney et al.(1975) reported that surface water contamination with excess nitrate and other nitrogen compounds could hasten the deterioration of streams and lakes by promoting excessive growth of algae and weeds. Miller (1978) reported that high risk of nitrate leachates could be minimized by limiting the application of anaerobically digested sludge to non-legumenous crops to about two inches

(6.6 tons/acre). Keeney et al. (1975) on the other land, observed that the same objective can be achieved by closely observing the recommendation of annual sludge application rate on nitrogen requirement of plants grown. However, EPA (1977) reported that there have been instances where 1 1/2 to 2 times the crops nitrogen fertilizer requirements have been applied without ground water pollution problems. Vesilind (1979) also reported that many farmers have applied two to three times such fertilizers to their crops without any apparent harm.

The outbreaks of diseases associated with the contamination of ground water with pathogenic microorganisms in land application sites have not been well documented. Corrall et al. (1975) reported that the potential for ground water contamination by pathogenic microorganisms is dependent on the ability of pathogen to survive and move through the soil system. In a comprehensive and critical literature review of various aspects which govern the movement of bacteria and viruses through the soil systems, Corrall et al. (1975) indicated that lateral movement of pathogenic microorganisms through granular soil does not normally exceed 30.5 m. Kirkham (1974) and Corrall et al. (1975) reported that pathogenic contamination of ground water poses a serious hazard in granular unfissured rock. Dotson (1973) and Kirkham (1974) reported that contamination of ground water with pathogenic microorganisms can occur, if undisinfected sludge is placed on shallow soil underlaid by porous material or soil that cracks when dry. Kirkham (1974) noted that the presence of cracks and continuous channels which effectively bypass the sorption inactivation of soil can be more important than the physical and chemical factors in the control of movement of pathogens through soil. Kirkham (1974; 1979) reported that surface water contamination with pathogenic microorganisms could be possible if excessive soil erosion occurs at the land application site.

Martin et al. (1976) observed that since fecal coliform rarely penetrate deeper than four feet of unsaturated soil, coupled with the fact that horizontal movement of pathogens through the uniform soil is generally limited to 100 feet, the threat of ground water pollution by pathogenic nicroorganisms has been greatly minimized.

In order to prevent underwater contamination, EPA (1977) indicated that much consideration should be given to the site geology and the soil physical properties. And also farmlands underlaid by highly porous fractured or stratified formation shouldrbe avoided. Manson and Merrit

(1975) reported that application sites could be diked to control run-off. The same author noted that surface water contamination could be controlled by using farmlands isolated from streams and that a distance of at least 200 feet should be given if the farms are on flat terrains. Hall et al.(1978) reported that surface water contamination could be avoided using farmland with closed or modified drainage, instead of the open drainage system. And if natural closed drainage is not available, it can be created artificially by constructing small ridges across the outlet of the drainage basin. The closed drainage system entraps contaminants and excess water. The ponded excess water subsequently infiltrates and evaporates and thus prevents run-off and possible water contamination.

Miller (1978) reported that construction of diversions and earthen barriers may be used to contain run-off where necessary. In addition to the use of farmlands with moderate slopes, Miller(1978) recommended that the following soil conservation practices are necessary to control run-off: strip cropping, terraces, retension of crop residues and reduced tillage.

Public Acceptance

Dowdy et al.(1976) reported that public acceptance is one of the first problems that may be encountered in establishing land application of sewage sludge and can become a major obstacle if handled improperly. Odor production is a factor often associated with public acceptance of land spreading systems, because people associate human waste with unbearable odor, and this is always recalled whenever wastewater treatment plant sludges are mentioned (Dowdy et al., 1976). Corrall et al.(1975) and Conn (1970) have reported that the most frequently stated public objections to land spreading of sewage sludges are related to potential health hazards and "human waste stigma" associated with such operations. However, Corrall et al.(1975) noted that a well planned public information program would effectively overcome these objections. Glover (1978) has noted that health concern is so basic that even the individuals who are otherwise indifferent to normal community affairs are aroused. Public objection due to health concern can be instigated by small groups of opponents of land application by raising founded or unfounded rumors about the operation and its impact on human health (Glover, 1978).

Glover (1978) reported that the acceptance or rejection of land application of sewage sludge by any community is based primarily on the economy and health concern. Many land owners or their neighbors are concerned with any outside factors that might result in negative economic effects such as loss of property values, community tax base and fear of odors (Glover, 1978). Hyde (1976) noted that once the fear of pathogens, odors, nuisances and possible environmental deterioration has been generated in a community, people have great difficulty in accepting the risk of applying wastewater sludges on their agricultural lands. It is, therefore, of paramount importance that the sludge aesthetic characteristic and other matters affecting public health be thoroughly understood and controlled before land application operation is undertaken.

Glover (1978) outlined the following as the factors that would destroy the opportunity for favorable public acceptance of land application of sewage sludge:

1. Implementation of land application of sewage sludge project without presenting the known facts (economic, health or risk of nuisance) to everyone concerned about the system.
2. Any great change in the form or reduction in profit which would result by application of sludge to croplands. For example, in the cornbelt, a change from an intensive corn-soyabeans enterprise to a grassland-beef

enterprise would mean reduced profit; therefore, the economic condition would not be acceptable.

3. Application of a municipality's sludge on lands in other political jurisdictions may present additional problems due to:
    a. The delay in the decision making process because of the indifference in jurisdictions.
    b. Magnified concern about economics, health or risk of nuisances in these jurisdictions, resulting in out right rejection of the project.
4. Localized neighborhood resistance at the site, other than from the land owners, resulting from economic or health reasons.
5. Too great a magnitude of economic disruption and population relocation due to outright purchase of land application sites.
6. Land application sites which are too large and therefore cause much physical and economic control difficulties.

In order to obtain public acceptance to land application systems, Glover (1978) recommended that the municipalities should avoid doing those things that would provoke public resistance. In addition, the same author suggested other steps to be taken so as to gain public acceptance:

1. The municipalities should avoid the panic and negative reactions associated with untimely announcements that many acres of land would be needed for land application system, without determining the public reaction regarding the effects of such an operation.
2. The farmers, neighbors, community elected officials, interest groups and the government officials should be involved right from the beginning in the planning and decisions concerning the land application program.
3. The socio-political neighborhood complaints of nuisances resulting from odors, aesthetics, insects, health and other complaints regarding the program should be prevented by organizing a community mass education and information program.
4. Demonstration farms should be established to show

the farmers and the public what the proposed farms would look like.

Manson and Merritt (1975) reported that public acceptance of land application programs should be gained if sludge is applied in rural areas where the residents are used to handling and disposing of animal wastes on the land, and if the service is offered at no cost to the farmers. Manson and Merritt also indicated that for the program to be accepted, it should be promoted as a way of enriching the soil and the positive aspects of the program should be highlighted.

Seed Germination Inhibition

Limited reports of seed germination inhibition following land application of liquid digested sludge are found in the literature. Toxicity in fresh sewage sludge has been suspected to cause germination inhibition. Hinesly (1968) in a greenhouse experiment with corn seed planted in sandy soil, found that equivalent addition of one-inch of fresh digested sludge totally prevented seed germination, while the application of two inches of old digested sludge (aerated for one week) did not interfere with germination. The same author in 1968 reported that the inhibition factor was caused by ammonium and/or ammonia in liquid digested sludge. Sabey and Hart (1975) in a study on the growth and chemical composition of plants, found that there was severe germination inhibition of sorghum sudan grass and millet when seeded shortly after sludge incorporation into the soil. No germination inhibition occurred at any rate of sludge application when wheat was planted three months later on the same plot. The same authors reported that the inhibition factor was apparently associated with the organic compounds, volatile inorganic or inorganics that were rendered insoluble as oxides. Lunt (1953) reported that sludge could be said to cause delay in seed germination rather than inhibition of germination. Hinesly and Sosewitz (1969) and Hinesly (1968) reported that seed germination inhibition could be controlled by either aerating digested sludge for one week before application or by planting the seeds one week after sludge application.

CHAPTER III

LAND APPLICATION: THE ENUGU, NIGERIA SITUATION

Introduction

The purpose of this chapter is to discuss the ways to control the problems associated with land application of sewage sludge on Enugu, Nigeria, agricultural lands. The approach is first to acquaint the reader with some background knowledge of Nigeria. This chapter covers the geography of the country and the existing unsanitary human waste disposal situation in Enugu, which necessitates the need to install wastewater treatment systems, to help reduce the high morbidity and mortality rates due to waterborne infections. It will be shown that trickling filter system will be more appropriate for the Enugu metropolitan area. The use of sewage treatment will result in the generation of large quantities of sewage sludge which must be disposed of in an acceptable manner with less environmental impacts. The application of the sludge for its fertilizer value on Enugu agricultural land has some problems associated with it which must be controlled.

Geography, Topography, Climate and Population

The Federal Republic of Nigeria is the eastern-most country of West Africa, facing on the Gulf of Guinea. Nigeria is bordered on the north and northeast by the Republics of Niger and Chad respectively, on the west by the Republic of Dahomey and on the east by the Federal Republic of Cameroon as shown on Figure 2. It has an area of 357,000 square miles and is comprised of 19 states, and with the exception of the indentation in the Atlantic Ocean at the southern edge, its boundries almost form a square. The longest east to west distance is almost 700 miles while the north to south longest distance is about 650 miles. The country lies on the tropics between latitude 4^{o} N and 14^{o} N.

Nigeria is marked by some outstanding geographical features. Stretching from east to west across the country along the coast is the belt of low plains. North of this zone is an area of hills and low plateaus. The basin of the Niger and Benue rivers running east and west respectively, and joining at the center, bisects the country into two parts known as Northern and Southern Nigeria. North of the basin, the area as far back as the Northern border is a broad plateau region with an elevation of 1,000 to 4,000 feet.

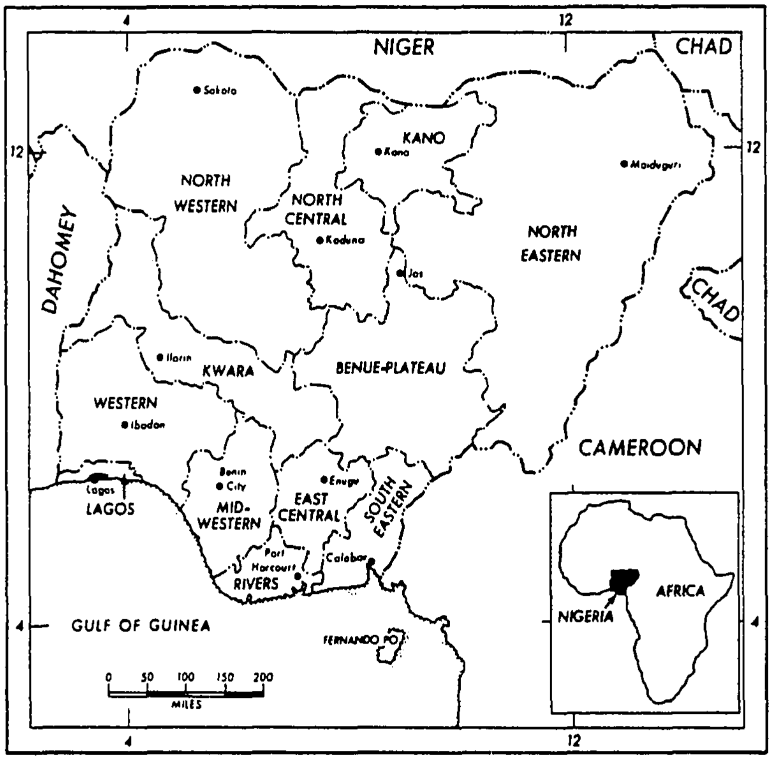

Figure 2. The Federal Republic of Nigeria.

Source: Nelson, H.D., et al, <u>Area Hand Book for Nigeria</u>, United States Government Printing Office, Washington, D.C., 1972.

At the eastern border is a mountainous region with a peak of 6,700 feet. This continues as the Cameroon Mountains.

As a tropical country, Nigeria has a tropical climate which is characterized by heavy rainfall, high temperature, high humidity and low wind. However, marked variations exist between the Northern and Southern States. Basically, there are two seasons: the dry and the rainy seasons which are determined by the movements and interactions of the moist southwest monsoon wind, the dry northeast trade wind (also known as harmattan), and the high equatorial easterlies. Rainfall occurs in all areas during certain periods of the year. In the North, the rainy season is from April to October and the dry season from November to March. The South has two rainy seasons which are from March to July and September to early November. The dry period in the month of August is generally known as the "August Break." The dry season in the South is from mid November to March. The amount of rainfall decreases northwards from the coast. Nelson et al.(1972) described the average annual rainfall in the Niger-Delta and Southeast as over 140 inches. The zone immediately north of this has an average annual rainfall of 80 inches. The city of Enugu is located in this zone and thus has the same average annual rainfall. The average annual rainfall diminishes to between 20 to 30 inches farther north to the border.

The temperature is relatively high throughout the year and rarely falls below 50° F (10° C). The mean maximum temperature is 89° F (31° C) in the South and 95° F (35° C) in the North. The mean minimum temperature in the South is 71° F (21° C) and 66° F (18° C) in the North. Humidity is generally high in the South all year round and ranges from 95 to 99 per cent. It is high in the North only from May to October and very low during the dry season. During harmattan section of the dry season, the weather is so severe that wooden materials exposed on the outside get twisted and crack. It also causes painful drying and cracking of human skin and lips. The amount of rainfall influences vegetation which varies from the rain forest in the South to increasingly drier savanah types in the North. Enugu, the capital of Anambra State, has the same climatic conditions as other Southern cities within the same zone. The city is located in a rich agricultural belt and is surrounded by many agricultural rural communities.

The current estimated population of Nigeria is 85 million people. Since 1911 and up until 1963, national census had been taken in Nigeria almost every ten years. The last comprehensive and accepted census was taken in 1963. The result showed the population at 55.6 million. The most recent census, taken in 1974 by the Federal Military Government in preparation for the return of civilian rule, was rejected because of some political reasons. Therefore, whatever Nigerian population is projected to be now is based on the 1963 census. The population is abitrarily divided into urban and rural categories, based on the size of the community. Towns with a population of 20,000 or more are classified as urban, while individuals classified as rural residents live in communities that range from 5,000 to 20,000 persons. The country is mostly inhabited by native Nigerians. There are more than 200 ethnic groups with accompanying languages and dialects with the major tribes of Ibo, Yoruba and Hausa constituting 58 per cent of the total, while the ethnic groups of Ibibio, Tiv, Edo, Fulani and Ijaw and Kanuri account for 22 per cent. Enugu is mostly inhabited by the Ibos.

Like many other cities in the developing countries, Nigerian cities have experienced marked increases in population growth, especially since the 1960's, due to migration from the rural centers. The growth rate varies from city to city with more concentrations in the cities with geo-political and socio-economic significance. According to Nelson et al. (1972), the city of Kaduna was estimated in 1967 to be growing at the rate of 11 per cent a year and Kano at the rate of 8 per cent. The Greater Lagos City in 1971 was estimated to be growing at the rate of 11 per cent. The City of Enugu in 1981 had an estimated growth rate of 5 per cent (Government of Anambra State, 1981).

Current Excreta Disposal Practices

The environmental sanitation in Enugu and other Nigerian urban centers is very inadequate and unsanitary and lacks all the modern advances that have been made in excreta-collection and disposal methods. The excreta disposal methods currently in use in Enugu include: Pit latrines; bucket latrines; septic tanks and aqua privies. Brief discussions of these systems are given below. These systems, if properly designed, operated and maintained, would give some degree of public health protection but the fact is that they are very unsanitary.

In a recent survey by the World Health Organization on the human waste disposal system in Anambra State, it was estimated that 29 per cent of the population in the urban centers used septic tanks and aqua privies, 13 per cent used pit latrines and 19 per cent used bucket latrines. The survey, however, did not state what types of excreta disposal systems were used by the remaining 39 per cent of the population. It may be assumed that these people defecate indiscriminately on open fields, bushes and possibly into rivers. The statistics seem very unlikely for such a city as Enugu, the capital of Anambra State, and one of Nigeria's most modern cities. The unaccounted population might be due to undercounting resulting from the inability of the survey group to get information concerning the types of systems being used in the houses or apartments. This might be because the majority of tenants, due to certain fears such as increase in taxes, would never volunteer some information to strangers. It might be, on the other hand, that the landlords who were in the position to give such information concerning their properties could not be located.

Bucket Latrine

Bucket system is a practice of defecating into a large metal bucket located under a compartment of wooden or concrete squatting frame. As in the instance of a pit latrine, a small toilet house is constructed around it for privacy, and at the back of this a small opening is provided for easy removal and replacing of the bucket. The collected excreta is periodically removed by the scavengers and disposed of by burying in deep trenches some miles away from the city. The excreta sometimes is dumped in local surface water or street gutters. The bucket is then washed, disinfected and replaced or stored for reuse.

Although the cheapest excreta collection method in terms of capital investment, the bucket latrine has been described by the World Bank (1978) as "an extremely poor form of sanitation, which at best can be considered better than indiscriminate defecation." The operation and maintenance is very high because it is becoming increasingly difficult to recruit scavengers due to the social stigma attached to such a filthy job.

From the public health point of view, the bucket system can be said to offer no remarkable advantages except concentrating excreta at particular locations for disposal. However, it has many disadvantages: the bucket latrine produces much odor, especially during excreta collection. The buckets are rarely washed and disinfected, and when they are washed, it is commonly within the immediate vicinity of the house, with the result that excreta is splashed on the pavements and roads. The sight of piles of collected buckets on roadsides waiting to be picked up by the collecting vehicle is aesthetically very unpleasant. It serves as a breeding place for cockroaches and flies which help to spread excreted infections. The frequent sight of scavengers along the streets carrying leaky buckets with excreta trickling down their bodies is very unpleasant. This particular aspect of the bucket system appears to be common in most developing countries and was confirmed by the World Bank (1978). During strikes by local scavengers, people using bucket latrines suffer lack of places to defecate as well as great odor nuisances resulting from over-filled buckets. The premises are infested with flies and maggots and the community runs the risk of serious epidemic. The uncontrolled spilling of excreta near the latrine and along the road to the disposal site contaminates the soil. In many instances the trenches in which excreta are dumped are left uncovered with surface soil for days and these serve as a feeding ground for flies and domestic and wild animals. In addition, the dumping of excreta on both street gutters and in surface water has increased the risk of waterborne disease, especially after flooding following heavy rainfall. The use of bucket latrines encourages the use of raw "night soil" as a fertilizer to grow some agricultural crops. The practice though prohibited by the local public health department, due to lack of satisfactory supervision at night, has not been successfully checked.

Pit Latrine

Pit latrine is a hand dug hole in the ground over which is placed a concrete squatting slab with a hole and a seat at the center, and around this a small toilet house is built for privacy. It has an average depth of 30 to 40 feet and a diameter of three feet. This depth is necessary to achieve long use life of more than 15 years. In places where enough depth cannot be achieved, due to the presence of rocks or water table being near the ground surface, the land is built up with mud before excavation. Longer use life is possible only if proper cleansing material is used, but it is commonly noticed that people use such cleansing materials as: leaves, corn cobs, sticks, mud balls, stones, and coconut husks which are not readily decomposed, and this helps to shorten the life of the pit. Pit latrines are provided with a lid to prevent the ingress of flies, cockroaches, and mosquitoes. When the pit is filled to within 18 inches of the surface, it is covered with mud and a new pit is dug near it.

Although a pit latrine has the advantage of providing the simplest and cheapest means of excreta disposal when properly maintained, it has some disadvantages such as: it lacks the comfort and convenience of modern life since it is located some distance away from the home, and this makes its use very unpleasant during bad weather. When allowed to fill up to within 18 inches, it produces quite an odor and provides a breeding place for mosquitoes, cockroaches and flies. When the seat or floor is soiled, the users resort to defecating at the nearby bushes and by doing so, contaminate the soil. The fecal material on the other hand, serves as a source of food for flies and domestic and wild animals, and these help in the spread of excreted infections. In the course of time, there will not be any space available to dig new pits. Pit latrines also have a potential to contaminate underground water and nearby wells.

Septic Tank

Septic tanks are currently the most modern and fairly satisfactory excreta disposal system in Enugu and other Nigerian urban centers. These are now being installed in most new buildings. The public health benefits are so remarkable that the city government would hardly approve of the construction of any new building with no plans for installation of the system. The septic tank system consists of a concrete rectangular tank with one or two compartments placed below the ground level and is located very close to the house from which it receives its influence of toilet wastewater and other household liquid waste from bathroom and kitchen. Compared with other methods such as the bucket latrine, it can be considered as an on-the-site method of disposing of excreta, hence, its construction, operation and maintenance are carried out within the confinement of the individual premises.

Generally, the incoming sewage into the tank is held quiescent and retained for a period of one to three days. During this time, the heavier solids settle to the bottom of the tank as sludge where they are digested by anaerobic bacteria and thus reduce their volume tremendously. The lighter solids, including fats and grease remain on the water surface and form scum. After about three to four years of operation, the accumulated sludge is removed. The effluent from the tank is then discharged into a subterranean pipe or trench system which distributes it for percolation into the soil. Wagner and Lanoix (1958) reported that although septic tank effluent has a relatively low biochemical oxygen demand (B O D) it is still offensive in character and from a public health point of view, it is as dangerous as raw sewage because it is laden with pathogens. Therefore, it should not be discharged into surface water without further treatment.

Despite this, septic tank effluent is often seen being discharged either on the ground surface or into the street gutters. These no doubt cause much odor nuisance and potential public health problems. The septic tank has the advantages of being a very neat system and when properly operated and maintained, eliminates flies and odor nuisances. The toilet bowl is installed right inside the home or house, which eliminates the inconvenience of going out during inclement weather. It also offers the comfort and convenience of modern life.

The major disadvantage of the method is the public health hazards that result from discharging the effluent into the street gutters and on the ground surface. The desludged material may produce some odors as well as potential health problems.

Aqua Privy

This is a modified septic tank system, but not as popular. Its use is very limited, and it is employed only by those who like to use water for anal cleansing. Aqua privy consists of a water-tight tank above which a toilet bowl is situated. The bowl has an integral drop-pipe the bottom of which is submerged a few inches below the water level in the tank. Excreta are deposited directly into the tank where they settle at the bottom and undergo anaerobic digestion.

The accumulated sludge is desludged every six to eight years as in a septic tank system.

It is very important that the tank be completely water-tight so as to prevent mosquitoes, flies and odor nuisances. This is achieved by the addition of sufficient water to the tank by the user through the drop-pipe to replace any water losses. But many people find it very hard to use water for anal cleansing and resort to using materials that are not readily decomposed such as leaves, corn cobs, coconut husks and newspapers. These not only result in reduction of water level but also clog the system. The effluent from the tank is passed through a pipe into a trench where it is distributed for absorption into the soil. Like septic tank effluent, it is still laden with pathogens and should not be discharged into street gutters or on the ground surface.

Aqua privy has the advantage of being an inexpensive and simple type of installation which, when properly operated serves as a fairly satisfactory excreta disposal method. However, it has some disadvantages. Since it is located some distance away from the home, its use during inclement weather is very inconvenient. It requires constant maintenance on a daily basis for proper performance. It encourages the breeding of flies and mosquitoes and produces odor nuisance if the water seal level drops. It causes the same type of public health hazards as the septic tank when the effluent is discharged on the ground surface or into the street gutters.

Health Problems with the Current Systems

Human excreta contains wide varieties of pathogenic organisms. Table 18 shows the groups of human excreta pathogenic organisms and the related infections. The current unsanitary excreta disposal methods in Enugu, Nigeria, have resulted in a widespread and serious surface water contamination. Excreted infections can be contacted by ingestion of contaminated water. Enteric diseases such as typhoid, dysentary, cholera and infectious hepatitis have been known to be associated with water contaminated with human excreta. Since surface water is still the major source of both domestic and drinking water in our community, these diseases have not only a very high incidence, but are also endemic. It is not surprising that these diseases are still among the leading causes of morbidity and mortality.

The use of human excreta collected from bucket latrines for crop fertilization in some farms and gardens has resulted in the spread of pathogenic microorganisms endemic in the community to farmers and to the consumers of vegetable crops normally eaten raw. The inadequate

TABLE 18

HUMAN EXCRETED INFECTIONS

Biological Group	Organism	Disease	Reservoir
VIRUSES	Polio virus	Poliomyelitis	Man
	ECHO virus	Various	Man
	Cocksackie virus	Various	Man
	Hepatitis A virus	Infectious hepatitis	Man
	Rotavirus	Gastroenteritis in children	?
BACTERIA	Salmonella typhi	Typhoid fever	Man
	S. paratyphi	Paratyphoid fever	Man
	Other salmonellae	Food poisoning	Man and animals
	Shigella spp.	Bacillary dysentery	Man
	Vibrio cholerae	Cholera	Man
	Other vibrios	Diarrhoea	Man
	Pathogenic E. Coli	Gastroenteritis	Man
	Yersinia spp.	Yersinosis	Animals and Man
	Campylobacter spp.	Diarrhoea in children	Animals and Man
PROTOZOA	Entamoebic histolytica	Amoebic dysentery and liver abscess	Man
	Giardia lamblia	Diarrhoea and malabsorption	Man
	Balantidium coli	Mild diarrhoea	Man and Animals
HELMINTHS	Ascaris lumbricoides	Ascariasis	Man-Soil-Man
	Clonorchis sinensis	Clonorchiasis	Animal or Man-Aquatic Snail-Fish-Man

Table 18 (continued)

HELMINTHS	*Opisthorchis felineus* *O. viverrini*	Opisthorchiasis	Animal - Aquatic snail - fish - man
	Diphyllobothrium latum	Diphyllobothriasis	man or animal - cop-pod - - fish - man
	Enterobius vermicularis	Enterobiasis	Man - man
	Fasciola hepatica	Fascioliasis	Sheep - aquatic snail - aquatic vegetation - man
	Fasciolopsis buski	Fasciolopsiasis	Man or pig - aquatic snail - aquatic vegetation - man
	Gastrodiscoides hominis	Gastrodiscoidiasis	Pig - aquatic snail - aquatic vegetation - man
	Heterophyes heterophyes	Heterophyiasis	Dog or cat - brackish water snail - brackish water fish - man
	Ancylostome duodenale *Necator americanus*	Hookworm	Man - soil - man
	Hymenolepis spp.	Hymenolepiasis	Man or rodent - man
	Metagonimus yokogawai	Metagonimiasis	Dog or cat - aquatic snail - freshwater fish - man
	Paragonimus westermani	Paragonimiasis	Pig, man, dog, cat or other animal - aquatic snail - crab or crayfish - man.

Table 18 (continued)

HELMINTHS	*Schistosoma haematobium*	Schistosomiasis	Man-aquatic snail - man
	S. mansoni	Schistosomiasis	Man-aquatic snail - man
	S. japonicum	Schistosomiasis	Animals and man - snail - man
	Strongyloides stercoralis	Strongyloidiasis	Man - man ?(dog - man)
	Taenia saginata	Taeniasis	Man-cow-man
	Taenia solium	Taeniasis	Man-pig-man or man-man
	Trichuris trichiura	Trichuriasis	Man-soil-man

Source: World Bank, *Appropriate Sanitation Alternatives: A Field Manual*, Energy, Water and Telecommunication Department, Washington, D.C., October, 1978.

sanitation has contributed to widespread schistosomiasis, a disease transmitted by snails that live in ponds, streams and rivers contaminated with human excreta. Also, the contamination of soil due to indiscriminate defecation in nearby bushes and uncontrolled spilling of excreta have resulted in hookworm and ascariasis infestations. The infections caused by these, though rarely fatal, are very hard to cure and have resulted in serious disabilities. The current excreta disposal methods encourage the breeding of flies, cockroaches and mosquitoes. These not only cause many nuisances but also create public health hazards by acting either as mechanical transmitters or as vectors in transmitting excreted pathogens.

Improved health is normally considered one of the principal benefits of improved sanitation. Therefore, as the disposal of excreta improves in our community, so will the health of the people. This observation was supported by what happened in Europe before the installation of waterborne sewage treatment. Godman (1976) reported that the high mortality rate due to cholera and typhoid in many European countries completely stopped with the introduction of sewage treatment plants. Experience in the developed countries has shown that improved sanitation as a result of waterborne excreta collection and disposal by sewage treatment has resulted in cleaner environments. It has prevented the contamination of soil and surface water. It has also rendered potentially hazardous wastes inaccesible to flies, cockroaches and wild and domestic animals and thus prevented the mechanical transmission of excreta-borne diseases to man (Wagner and Lanoix, 1958).

It is evident that the high morbidity and mortality rates in our community due to human excreted infections cannot be controlled without improved environmental sanitation. This can only be achieved by introduction of modern wastewater treatment plants. It is remarkable that the World Bank has realized this, and has agreed to come to our rescue by accepting to finance the construction of wastewater treatment plants at Enugu and Onitsha, the two largest urban centers in Anambra State. It is hoped that the same type of agreements have been reached for other major urban centers in the country.

Alternative Technology

This section deals with the type of wastewater treatment system to be installed in Enugu, Nigeria, based on the required effluent standards (the objectives of the installation) and the capability of the city to operate and maintain the system. The initial objectives of the system should be: The protection of public health through removal of pathogens, thus reducing the high morbidity and mortality rates due to water-borne diseases, as was the case in European countries (Godman, 1976); the prevention of surface and underground water pollutions; the removal of suspended solids; and the removal of biological oxygen demand (B O D) materials. These objectives can be achieved by utilization of trickling filter treatment system. Although waste stabilization pond, because of its lower construction, operation and maintenance costs in comparison to any biological-mechanical wastewater treatment system, is mostly recommended to tropical developing countries, especially where land is available and relatively cheap (Canter and Malina, 1976). This author believes that trickling filter treatment system will be more appropriate for the city of Enugu based on the following reasons: Other waste water treatment systems that are sometimes considered in tropical developing countries include aerated lagoons and oxidation ditches. These however, are designed for small communities. They also have the disadvantages of requiring highly skilled operators, high maintenance and failure to meet the suspended solids and fecal coliform effluent standards without further treatments (Feachem et al., 1977).

Heading the list of the reasons the author thinks that trickling filter treatment system will better serve the sewage treatment needs of Enugu metropolitan area is the availability and cost of land. Land is a very valuable and expensive commodity in Nigeria; therefore, its cost will increase the capital cost of waste stabilization ponds to the extent that installation of trickling filter will be more economical. An acre of land in Enugu at the present time costs $106,575.

A study by Canter and Malina (1976) on the sewage treatment in developing countries showed that waste stabilization pond with a capacity of one million gallons per day (MGD) requires 18 acres of land, and the same system with a capacity of 10 MGD requires 180 acres of land. The study also showed that the land requirement for waste stabilization ponds increases as the capacity of the system increases, such that the land requirement for a plant with 100 MGD is 1,800 acres. Similarly, EPA (1974) estimated that trickling filter treatment plant with a capacity of one MGD requires 4 acres of land and the same system with capacities of 10 MGD and 100 MGD require 20 acres and 40 acres of land respectively.

A comparison of the two wastewater treatment systems shows that there is much difference in the land requirements. For example, a comparison of the two systems with capacities of 10 MGD shows that waste stabilization ponds system requires 9 times the land required for trickling filter. In terms of land cost, it is estimated that trickling filter with a capacity of 10 MGD will cost $2,131,500 as compared to $19,183,500 for waste stabilization ponds, a difference of $17.05 million.

A question may be raised as to the advisability of a treatment system that cannot be easily maintained by the local skilled and trained personnel; in other words, trickling filter is not in conformity with the appropriate technology principles. This is not a problem in such cities as Enugu, which has an estimated 1980 population of 317,345 based on 1963 census (Government of Anambra State of Nigeria, 1981). This is in agreement with the findings of Canter and Malina (1976) that in developing countries, cities with population of 100,000 or more can be able to provide the necessary qualified labor force for proper operation of more sophisticated treatment systems. In addition, Nigeria has many college graduates, who, due to lack of appropriate jobs in their areas of specializations, are employed in other types of jobs such as teaching at local secondary and elementary schools just to reduce unemployment. The introduction of such wastewater treatment systems like trickling filter will be a long awaited opportunity for many of these graduates. However, it must be emphasized that the type of wastewater treatment system to be used in each individual city or town in the country should be evaluated on a case by case basis.

As for the appropriate technology in the developing countries, what many authorities feel of such a concept was summarized by Obeng, the director for Africa of the United Nations Environmental Program. Commenting on the project for clean water for all by the year 1990, she said (Tinker, 1980):

> We have spent millions of dollars on wells fitted with pumps, public stand pipes, wind mills, pumps that do not work . . . therefore, whenever it is practicable and feasible, whenever you have the money, use it for pipe water for permanent solutions. Otherwise we have to go back and do the same thing over again.

Translating this to wastewater treatment technology, the rapid growth in population of many Nigerian cities, resulting in part from migration from the rural areas, will result in geographical expansion of the cities. In the case of Enugu, the new developments may encroach on the pond sites. In addition, to the rising cost of land as well as the increasing interest in public health may require that a wastewater treatment system which requires less land space and at the same time is capable of meeting the stringent effluent quality standards be installed. The trickling filter system can satisfy these conditions.

Trickling filter can be easily upgraded at a reasonable cost to meet more stringent effluent quality standards. Although there are not industries at the present time to contribute to industrial wastes, such may be possible in the future. The use of wastewater treatment systems such as waste stabilization ponds, aerated lagoons or oxidation ditches that are more appropriate for domestic waste will mean dismantling them and installing a more sophisticated system. Therefore, the installation of trickling filter right from the very beginning will eliminate such expenses. But, it may require a little inexpensive upgrading. Trickling filter can be upgraded to meet almost any change in municipal wastewater treatment work; for example, the system can be upgraded to meet the increase in industrial loads in excess of those anticipated at the initial design, upgraded to relieve organic and hydraulic overloading, upgraded to increase removal efficiency, and upgraded to remove nutrients such as nitrogen and phosphorous (EPA, 1978).

In addition to the above mentioned points, trickling filter has for the past 40 years been recognized in the developed countries as a very dependable and reliable wastewater treatment system. It has also been credited with much durability and ability to recover from shockloads. Compared with activated sludge and certain physical/chemical processes, the system has the advantage of having a very low power requirement. It also does not require highly skilled operators. Furthermore, trickling filter has successfully provided higher levels of treatment and the majority of the existing plants have been known to meet the current effluent quality standards based on 30 mg/l of BOD_5 and suspended solids (EPA, 1978).

Summing up, if trickling filter can provide satisfactory services in the developed countries, it will under normal circumstances work well in Nigeria. It is clear from the above mentioned information that the city of Enugu, Nigeria, with its present population and tremendous potential for growth and industrial developments will more economically install and maintain such a system.

It is a bad practice according to Mara (1976) that many poor tropical developing countries spend much of their scarce foreign reserves to install modern wastewater treatment systems but do not attempt to recycle the waste. The same author reported that these countries adopt the same policy as the rich industrialized countries in disposing of their sewage effluents and sludges. Obviously, the industrialized countries can afford to wasee the nutrients in sewage sludge, but most tropical developing countries cannot. Therefore, the large volumes of sludge produced by trickling filter can be beneficially applied to the agricultural land as a fertilizer or soil conditioner in Nigeria as a secondary benefit. This program is similar to that in China where more than 90 per cent of the country's "night soil" production is applied to farm lands after treatment, which supplies about one-third of all the nutrients used by the crops (Mara, 1976).

As has been stated before, it is one of the objectives of this study to find out if some of the Nigerian foreign exchange can be saved by utilizing sewage sludge instead of commercial fertilizer to grow local crops. The next chapter deals with this problem.

The use of a wastewater treatment system instead of the current excreta collection and disposal methods in Enugu will not be without some problems. The installation of a trickling filter treatment plant will result in the production of large quantities of sewage sludge which must be adequately disposed of. The application of the sludge on agricultural lands in Enugu, Nigeria, for its fertilizer value will have some problems which must be prevented and controlled. These problems include:

1. Odors and aesthetic nuisances.

2. Transmission of pathogenic organisms.
3. Sociological implications (public acceptance).
4. Surface and underground water contamination.
5. Seed germination inhibition.

Following are discussions on the ways these problems should be controlled.

Control of Problems Associated with Land Application

Odor and Aesthetic Nuisances

To avoid increase in the cost of land application program in Enugu, control of odor problems should be ignored. However, if the municipality insists that odor problems must be controlled, discussed below are the ways of doing so. Odor problems resulting from land application of sewage sludge on farmlands in Enugu can be controlled in two-step processes; in the wastewater treatment plant and by proper sludge handling and management at the application site.

Sludge Treatment: Since odor nuisances are associated with the action of anaerobic bacteria on volatile organic materials in sludge, it is logical that the best place to eliminate most of the odors is at the treatment plant. Care must be taken to make sure that the organic matters in sludge are properly stabilized before land application. Although liquid sludge can be stabilized by chemical treatments with lime or chlorine and aerobic digestion, anaerobic digestion will be more appropriate for the city of Enugu because of its numerous advantages as have been mentioned in the pathogen control section. Therefore, odor nuisances will be controlled by utilizing sludge that has been stabilized in well designed and carefully operated anaerobic digesters. According to EPA (1977), anaerobic digestion of sludge for at least 10 days at 95° F (35° C) will control nuisances resulting from odor.

Management and Handling: At the application sites, odors and aesthetic nuisances should be controlled by immediate incorporation or injection of liquid sludge into the soil. Subsurface incorporation of sludge has been cited by Wasbotten (1978), Kirkham (1979), Walker (1975) and Mitchell (1931), as an effective method of controlling odor nuisances. The incorporation of sludge into the soil can be achieved by the use of plowing or discing equipment. Once sludge is mixed up and covered with surface soil, odor nuisance is automatically controlled. According to Mitchell (1931) there is no better purifier than soil surface.

Further controls should be achieved by taking the following steps:

1. Use the agricultural lands at isolated locations away from residential areas and farms that are not easily accessible to the public. This will not pose any problems

because most of the large farms in our community where sludge can be used are located many miles away from residential areas.

2. Use tank trucks in good working condition in hauling sludge to the application site to avoid sludge spillage, dissemination of odor and unsightly appearance along the roadway.
3. Since winds affect the dispersion of odor, application sites should be located, whenever possible, away from frequent wind direction to avoid wind that has blown across the farms from blowing into the populated areas.
4. For aesthetic considerations, keep the farms as clean as possible and control weeds by constant weeding.
5. Inform and educate the farmers on the nature of land application of sludge operation. Though this will not directly control odor, the impact of the odor will be greatly minimized if they know that the smell is

only temporary and should diffuse and dissipate in the air.

6. Fly breeding problems should be minimized by allowing the sites to dry well after operation before another application is carried out. Insecticides should also be used effectively.

Pathogens

The control of pathogens to minimize health hazards at Enugu, Nigeria, land application sites will be achieved by adoption of pathogen destruction or inactivation operations at the treatment plant, proper crop selection and management techniques. The only two methods designed specifically for sludge disinfection are heat pasteurization and high-energy radiation. Other methods commonly used to achieve substantial destruction of pathogens as well as to stabilize sludge and control odor nuisances in sewage sludge are lime stabilization and anaerobic digestion. These processes are briefly surveyed and anaerobic digestion has been chosen to be more appropriate for the city of Enugu because of the reasons given in the anaerobic digestion discussion.

Pasteurization: Sludge pasteurization is a process of heating all parts of liquid sludge to 158° F (70° C) and holding it at or above that temperature for 30 minutes or heating the sludge to 195° F (91° C) and holding it at or above that temperature for 10 minutes. The process has been found to destroy all pathogenic organisms in sludge just as in pasteurized milk. Although sludge pasteurization is a proven technology in sludge disinfection, the review of literature showed that the process is not currently utilized in the United States. It is used only in West Germany and Switzerland where sewage sludge is applied on pasture during the grazing season.

Pasteurization will not be technologically appropriate for the city of Enugu, Nigeria, because it requires highly skilled manpower which is not yet available in Nigeria. Also, it will not be economically cost effective. EPA (1979) estimated that it would cost a secondary wastewater treatment plant with 10 MGD $33.00 per ton of dry solid to pasteurize sludge.

High-Energy Radiation: This involves the use of either of the two types of energy sources, the Beta or Gamma rays to disinfect liquid sewage sludge. The beta rays are high-energy electrons generated with an accelerator, while gamma rays are high-energy photons emitted from nuclei. Both types of rays induce secondary ionization in sludge as they penetrate, and the secondary ionization so formed directly inactivates pathogens as well as produces reducing compounds which in turn attack pathogenic microorganisms. The technique is an effective sludge disinfection process but at present is only in the pilot study stage. The only known Beta-rays plant in the United States is the pilot study plant at the Deer Island wastewater treatment plant in Boston, Massachusetts. The only known active Gamma-rays plant is the pilot study facility in West Germany.

High-Energy Radiation will not be appropriate for our community, not only because it is not yet a widely used technology, but also like pasteurization, it requires highly skilled labor. Nigeria at the present has not even attained the technological advancement of acquiring nuclear weapons for her defense, let alone disinfecting sewage sludge with the related technique. It is also a very expensive method; EPA (1979) estimated the cost for 0.1 MGD treatment plant utilizing high-energy radiation at $38.50 per ton of dry solids.

Lime Stabilization: Disinfection of sludge with lime is the application of lime to liquid sludge to raise the pH to 12.5 and maintaining it at this level for 30 minutes so that the final pH of 12 or above is achieved. At pH of 12, pathogenic microorganisms are destroyed and inactivated. The annual cost per ton of dry solids of wastewater treatment plants treating 1.0 MGD utilizing land application disposal option was estimated by EPA (1978) at $54.17 for lime stabilization as compared to $99.76 for anaerobic digestion facility handling the same volume of waste.

Sludge disinfection with lime, though it achieves significant pathogen reduction as well as offers low cost and simplicity of operation, will not be recommended for Enugu, Nigeria because in the developed countries where it is being used, it has not proven to be satisfactory by itself on a long time use. According to EPA (1978) lime stabilization is currently used in the United States as a supplement or as a back-up unit to existing facilities such as anaerobic digesters. The addition of lime to sludge increases the quantity of solids to be disposed of; thus it will result in high transportation costs. The process does not cause any reduction in organic matter and once the pH drops to below pH 11, it loses its disinfecting ability and the return of biological decomposition of solids results in noxious odors. Lime treated sludge contains lower plant nutrients such as soluble phosphate, ammonia nitrogen and total Kjeldahl nitrogen. And since the primary objective of adopting land application of sludge in Enugu is to utilize its fertilizing ability, lime treatment will defeat this objective. The availability and cost of lime is another important factor, and since it must be imported, it will result in a greater expenditure of Nigerian foreign exchange.

Anaerobic Digestion: This is a commonly used process which in addition to its stabilizing effect, substantially reduces the number of pathogenic microorganisms in sewage sludge. Anaerobic digestion is a biological decomposition of complex organic materials in sewage sludge in an environment devoid of dissolved oxygen. Theoretically, the process can be said to occur in two stages, in that specific groups of organisms in one stage use the end product of the previous stage. The first stage involves the acid forming bacteria which attack complex organic materials in the sludge and convert them to simple organic acids. In the second stage, the methane forming bacteria which are purely anaerobic in nature convert the organic acid to methane and carbon dioxide. These methane forming bacteria are very sensitive to environmental factors such as temperature and pH and have the optimum pH and temperature of 6.4 to 7.5 and 85 to 95° F (29-35° C) respectively.

Two distinct temperature ranges of digestion are usually recognized; the mesophilic 92 to 98°F or (33-37°C) and the thermophilic 105 to 110^{o} F (40 to 43^{o}C). The thermophilic digestion is not as commonly used as the mesophilic digestion because it is more easily upset and has a high operation cost; however, it has been found to achieve high gas production and pathogen destruction. Anaerobic digestion can be carried out either in one or two digester tanks. In the two tank digester, the first tank, commonly known as the primary digester, is where most of the solids stabilization takes place and requires heating and continuous mixing of sludge. After about 15 days reaction time, the sludge is pumped into the other tank usually known as the secondary digester. Very little biological decomposition occurs in the second digester; however, it provides a quiescent environment which enhances gas collection, supernatant separation and storage for stabilized sludge. Generally, the digestion proceeds for approximately 20 to 30 days (EPA, 1978). It is the digester environmental condition and the long detention time that results in the significant destruction of pathogens.

Discussion

Presently in the United States, most of the municipalities that are applying their sludge to agricultural land utilize anaerobic digestion to reduce the concentration of pathogens as well as stabilize the sludge. And yet, there has not been any scientific, confirmed evidence linking human diseases with land application of sludge (Miller, 1973; EPA, 1979; Dowdy et al., 1976). This suggests that anaerobically digested sludge has been well disinfected enough to be applied to agricultural lands. This was confirmed by Dowdy et al. (1976) who observed that only sewage sludge with pathogenic microorganisms equal to or less than that obtained after anaerobic digestion should be applied to farmlands. Also, Carbertt et al. (1973) indicated that although some pathogens survive anaerobic digestion, they may not cause enough public health hazard to warrant complete disinfection by pasteurization or any other means.

In addition to accomplishing some disinfection function, anaerobic digestion has the following advantages over the other techniques. It produces useful gas of moderate caloric value. The gas produced would yield enough energy that could go a long way in meeting the energy requirements of the wastewater treatment plant. It has a very low operating cost. Well designed and operated anaerobic digester produces odorless sludge, and therefore has a dual advantage of serving as both pathogen and odor control methods. It produces well stabilized sludge with less solid contents.

The lower solid contents results in savings on transportation costs to the farmland. Anaerobic digested sludge contains more plant nutrients which is in conformity with the objective of utilizing the fertilizer content of sludge to grow agricultural crops. The use of any other method with less nutrient value will defeat this aim.

After considering other pathogen destruction or inactivation processes, it is felt that anaerobic digestion will be both technologically and economically more appropriate for the city of Enugu. Therefore, public health hazards resulting from pathogenic organisms in sludge should be controlled at Enugu land application sites by utilizing well stabilized anaerobic digested sludge. However, realizing that pathogens may survive anaerobic digestion process, additional precautionary measures must be taken. It should be recommended that vegetable crops that are consumed raw must not be grown on farms fertilized with sewage sludge. All the crops from the farms must be well washed and thoroughly cooked before they are eaten. On the other hand, if by any chance vegetable crops that are eaten raw are grown they must be thoroughly washed in potable water and disinfected by dipping in chloramine at the concentration of 25 ppm for 5 to 10 minutes or more.

Sociological Implications

For land application of sewage sludge in Enugu, Nigeria,to be successful, it must be accepted by the farmers. It must be acceptable to the majority of them and must be actively supported by enough community leaders so that they can favorably inform and influence those who depend upon them and keep opposition in the minority. The people must be made to feel that land application of sludge is a progressive program which will result in better environmental quality as well as greater yields in local agricultural crops. Also, the feelings of uncertainty and suspicion must be replaced by reliable factual information. They must be informed about why land application of sludge on agricultural land is chosen among other sludge disposal options, as well as all the known facts of such an operation, such as costs, effects on health and agricultural production. The farmers must be educated and assured that the fears of nuisances resulting from odors, insects, aesthetics, pathogens and deterioration of property values are unfounded and that none of these will occur in a well managed and operated land application system. The Enugu municipal officials must therefore devise a means to get the people to think, feel and act more favorably towards land application of sludge. This will be better done by a carefully planned and organized mass education program as will be discussed in the next section.

Having identified what would result in the rejection of a land application program by the people, it is essential that effective actions be taken by the municipal officials to prevent them from developing or occurring. Listed below are some of the things that should be done to insure acceptance:

1. The farmland to be used for application site must be obtained through use-right, instead of out-right purchase, by which the municipality and the farmers (land owners) enter into agreements to apply sludge on the farmers' lands free, with the gaurantee that such operations will not interfere with their objectives of maximizing profits. The farmers will be assured that sludge applications on their farms will be carried out in a manner that will enable them to obtain higher crop yields than have ever been possible. This is because sewage sludge has better fertilizing ability than farmyard manures commonly used and when properly applied, sludge has fertilizing ability comparable to commercial fertilizer. The agreements will

include insurance against anything that will be harmful to the farms and yields lower than what would have been possible without sludge applications. The amounts of coverage by the insurance must be comparable to local cost of land and net agricultural income in the area. Procurement of land application sites by out-right purchase by the municipality will not only remove the farmlands from tax roles, but also has the disadvantage of disrupting the farmers' operations. Glover (1978), Baker and Christensen (1976) reported that out-right purchase is preferred by municipalities in the United States of America because it gives them better control of the farms and enables them to carry out their objective of sludge disposal. Since land application in our community will be primarily adopted in order to utilize the fertilizing ability of sludge, out-right purchase to dispose maximum quantities of sludge will not only provoke resistance by the people but will defeat the objective of higher agricultural crop productions. However, if for any reason the municipality chooses to adopt out-right purchase of farms to be managed as city farms, they must pay taxes on the properties just as would have been paid by the farmers.

2. The municipality will, if use-right is obtained from large farm establishments such as farm cooperatives that have trained technicians and laboratory facilities, agree to supply on request, the application equipment and other materials required to run nutrient tests and other tests they may decide to run on the sludge to ensure maximum crop yields and minimize any harmful sludge effect on the farms.
3. The farmers, especially the farm cooperatives who are well informed, will be allowed much input in the determination of sludge application rates and time of application.
4. The municipality must agree to finance all costs resulting from such an operation and must make sure that the farmers do not incurr expenses more than usual with normal farming operation.

5. Sludge application rate must be in accordance with the nitrogen requirement of the crops to be grown and supplementary commercial fertilizer must be added by the municipality if if needed to maximize crop yields.
6. The farmers and the community leaders (chiefs, town counsellors and clan heads) must be involved right from the beginning in the planning and decision-making concerning the program. This is in keeping with Dunbar's (1973) observation that involvement of people in a project is very effective in winning public acceptance because people tend to understand and support what they create.
7. Demonstration farms will be set up by either contracting with a few farmers or using already municipal-owned land in the farm area to show the people what farms fertilized with sewage sludge look like. The demonstrating farms will also be used to work on minimizing possible detrimental effects and uncertainties before embarking on a large-scale operation by many local farmers. This is very

essential because once the fears of pathogens, odor nuisances and possible environmental deterioration have been generated in a community, people will have great difficulty in accepting the risks of applying sludge on their farms (Hyde, 1976).

8. The municipality must make sure that the farmers (land owners) fully understand the legal agreements between them. On the other hand, the municipal officials must also make sure that they do not go contrary to the agreements.
9. No attempts will be made to change the community farming pattern or reduce profits. For example, if land application of sludge will make farmers who have for many years been growing yams or corn change to growing grass (hay) or any other non-popular crops which will cause change in farming pattern and reduction in profits, it will be rejected by the farmers.
10. Adequate monitoring and safeguard arrangements to protect the public as well as the environment will be made and fully described to the people, and assurance given to them that every

possible action must be taken to protect their health and properties.

11. Carefully planned mass education programs will be carried out so that the farmers can relate what they are doing with land application of sludge. For example, they will be made to see the effect of sludge on the growths and yields of local agricultural crops such as corn, yams, potatoes, and groundnuts.

12. Since people's behavior fluctuates from time to time, continuous appraisals through conversations and town meetings of what the people think and feel of the land application of sludge must be made and adequate action taken to correct any detected problems.

Since our community is made up of different segments of people with different interest levels, understanding, knowledge and concern, for mass education programs to be effective, each of the segments must be approached in different ways. This means that the target audience for the program will determine the contents and methods of communication to be adopted. Thus two different segments of people will be educated for land application of sludge program to be successful in our community. They are the farmers (land owners) and the community leaders (the chiefs, town counsellors and clan heads). The identification of the target audience will make it possible to concentrate on the education program appropriate for each group. It will enable the information to be presented in a manner easy to understand and specific, highlighting the significant issues that they need to know.

The following methods will best be used to communicate with the people.

Radio and Television Programs: Arrangements will be made with these two mass media for a carefully planned education program to be presented during their public service periods. Series of television spots of 30-to 60-second films that dramatize issues that will motivate the people to action, such as the demonstration farms portraying the growth and yields of local crops, will be used. Since these media are owned by the government, getting the time when the majority of the target audience will be reached will not be a problem.

Local newspapers will be used effectively to publish specially prepared articles on the demonstration farms, starting from the time of sludge application to harvesting of crops.

This will help to bring both the operations of the farms and the agricultural benefits of sludge home to the people.

Mails in the form of fact sheets, and pamphlets will be sent to selected members of the target audience, such as the chiefs, town counsellors, clan heads, cooperative farm executives and some prominent farmers.

Personal contact approach will be utilized to educate those individuals whose schedules will not allow the chance to attend town meetings, but whose support is very vital for the success of the program.

Audio visuals in the form of tapes, slides and short movies will be used effectively during different occasions such as during town meetings and personal contacts.

Mobile cinema (movies) will be used to reach those who cannot read and those who do not have access to television. It has successfully been used by the government to inform and educate the public on their programs and achievements.

Town meetings will also be used in the mass education process. It offers a good opportunity to bring all the target audience together.

Mass Education Program

On the basis of winning acceptance for application of sludge on agricultural lands, the Enugu, Nigeria, municipal officials will carry out a mass education program aimed at the two identified target audiences. The program will be designed to achieve the following objectives: Awareness and interest on land application of sludge; acceptance of sludge on their farms; support of the program and minimization of criticism.

The Farmers (Land Owners)

The behavioral changes required from the farmers should be interest in land application and willingness to accept free sludge on their farms. These will be achieved by broadening their knowledge and educating them on the benefits of sewage sludge on agricultural land. They will be made to understand that sludge is better than the farmyard manures and that it will give the same yields as commercial fertilizers.

The estimated comparative cost of using sludge and commercial fertilizer to obtain the same desired yields of local crops will be shown to them. They will be informed of protective measures that will be taken to prevent public health hazards and protect their properties. They will also be assured that a well managed land application of sludge on agricultural land does not result in nuisances due to odors, insects and aesthetics, nor in property deterioration and health problems.

These ideas will be communicated to them by personal contacts, town meetings, mobile cinema, local newspapers, radios and television services. The educated ones among them will be included in the mailing lists.

Community Decision Makers (Chiefs, Town Counsellors and Clan Heads)

The behavioral changes required from this target audience are active support for land application and minimization of criticism. These will be achieved by making them understand what sewage sludge means, and by broadening their knowledge on the advantages and disadvantages of land application of sludge on agrioultural land as compared to other possible sludge disposal alternatives such as landfilling, lagooning and dumping into local rivers and streams.

They will be best educated by personal contacts. The realization that their social and cultural roles in the community have been recognized by city officials will boost their morales.

They can also be educated through the mass media: newspapers, radios and television. They will also be well informed by mailing to them such materials as fact sheets and pamphlets on land application of sludge. This group of individuals will be actively involved in the planning and decisions concerning the program right from the very start, since people have the tendency to support what they help to create.

Surface and Underground Water Contamination

The control of surface and ground water contamination by land application of sewage sludge in Enugu will involve the utilization of proper site and soil selection, adequate soil management techniques, timing of sludge application and soil conservation practices.

Proper Site and Soil Selection

Most of the problems of water pollution can be prevented by careful selection of land application sites and soil that have the characteristics that will not promote either runoff or leaching. To achieve this, the farmlands used for sludge application:

1. Should be isolated from nearby streams, lakes and rivers.
2. Should be within potential flood plains.
3. Should have fairly level surfaces.
4. Should be made up of fine

textured soil, such as sand clay, silt clay, clay loam and silt clay-loam or medium textured soil such as silt loam, sandy clay loam and loam.

The thickness of the soil should be at least three feet without restrictive layer because this will prevent permeability. Medium textured soil is good because not only does it have the advantage of desirable infiltration and permeability rate, but also it has available moisture holding capacity of 15 to 20 per cent and when dry can absorb 9 to 12 inches of water in the upper 60 inches (5 feet) before transmitting water to the underlying aquifer (Hall et al., 1978). The fine textured type soil, because of its ability to transmit water very slowly should be preferred whenever possible, but it must be well prepared by adequate tillage before sludge application to promote infiltration.

Soil Management

Utilization of farmlands that have the above mentioned qualities would prevent runoffs. However, to control further such environmental impact, sludge should be applied in such a manner that the application rate will not be greater than the soil permeability rate. Vesilind (1979) reported that the minimum acceptable soil permeability is 10^{-5} cm/sec (0.015 in/hr) for agricultural lands amended with liquid sludge. The permeability rate should be enhanced by proper tilling of the soil so that the water content of sludge would start to infiltrate as soon as possible after application instead of tending to run off, as would be the case if the soil were hard and unprepared. The method of sludge application is very important in runoff control. Sludge would tend to runoff if it were just spread on top of the soil. This will be prevented by immediate injection and incorporation of sludge into the soil. This also promotes the infiltration rate.

Application of sludge on rainsoaked soil will contribute to runoff. Therefore, it is important to time the period of sludge application. The soil should be prepared and the required quantities of sludge applied during the dry season prior to the rainy season which is also the farming period.

To prevent nitrate contamination of ground water through leaching, the quantity of nitrogen applied into the soil should be calculated to be the exact quantity required for the crops to be grown. This is in conformity with Miller (1973), Dowdy et al.(1976) and Vesilind's (1979) recommendations. The use of proper soil texture as recommended above will also help in preventing ground water pollution. Ground water contamination will not pose much of a problem around Enugu because of the depth of the water table. It should be recalled that pit latrines more than 25 feet deep have been dug around the area without reaching the water table.

Pathogen contamination of ground water should be controlled by using farmlands that are not underlaid by porous material or the type that cracks when dry (Kirkham, 1974) , and by utilization of well stabilized and disinfected anaerobic digested sludge.

Though runoff potential has been controlled by using proper site and soil selections and adequate soil managements, further control precautionary measures should be adopted to guard against flooding and runoff after heavy rainfalls. Some of the measures include soil conservation practices such as construction of terraces, diversions and ponds to act as collection basins. According to McCampbell (1981), places with annual rainfall of more than 35 inches should control erosion by constructing diversions, terraces and grass water filter strips and collection ponds, with grade on the terraces of one foot five inches. The objective of this is to remove excess water instead of conserving it. It should be recalled that the average annual rainfall around Enugu area is 80 inches. Crop residues should be retained on the land surfaces after harvest. These have the advantage of holding the soil surfaces together and preventing runoff and erosion.

Seed Germination Inhibition

Seed germination inhibitions in Enugu land application program should be controlled by application of well anaerobically digested sludge a few weeks before planting season. This is in conformity with Lunt (1953), Hinesly (1968), and Hinesly and Sosewitz' (1969) recommendations. It should be recalled that sludge will be applied on Enugu agricultural lands during the dry season to control runoff potential that may occur, if sludge is applied on the rainsoaked soil. The approach will also control seed germination inhibitions.

CHAPTER IV

COMPARATIVE COST ANALYSIS OF SEWAGE SLUDGE AND COMMERCIAL FERTILIZERS

Introduction

The objective of this chapter is to compare the costs of growing some Nigerian crops with sewage sludge and commercial fertilizer and show that it is less expensive to use sewage sludge. Since it costs the Nigerian Federal Government millions of dollars annually to import commercial fertilizer, it will be shown that some of the foreign exchange could be saved by using sludge to grow specific crops. First, sludge production by trickling filter with anaerobic digestion is estimated; secondly, the annual sludge application rates required to produce certain desired crop yields are calculated; thirdly, the annual costs of commercial fertilizer and sewage sludge production and application are calculated, and this is followed by the discussion of the results.

Material Gathering

Many attempts were made to obtain from Nigeria the necessary data for the estimation of the annual quantity of sludge that would be produced from the proposed Enugu, Nigeria, wastewater treatment plant, the annual application rates of sewage sludge necessary to obtain the desired yields per acre of local crops, the annual cost involved in the sludge production and application, and the annual cost of commercial fertilizer importation by the Nigerian Federal Government. Unfortunately, some of the data were not available due to the inadequate record keeping in Nigeria and the pure reality that the country has not yet obtained the developmental stage at which such data could be available. Therefore, relevant data from other tropical developing countries and the United States were used. The data that were obtained from Nigeria include: estimated population of Enugu, local cost of land per acre, local cost of labor, current interest rate, local cost of power (electricity), and annual cost of importation of commercial fertilizer.

The data relating to the volume of per capita wastewater production and character of such wastewater were taken from published reports for tropical developing countries. The soil test data were obtained from the Oklahoma State

University Agricultural Extension Station for Cleveland County located in Norman, Oklahoma. Sludge transportation cost was obtained from the Norman wastewater treatment plant.

Sludge Production

The general per capita wastewater production in the tropical African countries is within the range of 100 to 200 liters a day (Van der Berg, 1975). Because of low consumption of water in tropical developing countries, the sewage is usually strong and has BOD_5 of 400 to 700 mg/l. The suspended solids for the African country of Kenya is between 550 and 662 mg/l (Mara, 1976). Raw primary sludge typically has the solids concentration of 4 to 8 per cent, while filter humus has solid concentration of 3 to 4 per cent (Vesilind, 1979).

It was assumed that the proposed Enugu wastewater treatment plant would start initial operation with 50 per cent of the population sewered and would attain 70 per cent sewerage within 11 years of operation. Table 19 shows the estimated population of Enugu from 1980-1990. The 1981-1990 population was projected by using the 1977 to 1980 population estimated data that was based on the 1963 census (Appendix B) at the annual growth rate of 5 per cent (Anambra State Government, 1981).

TABLE 19

ESTIMATED POPULATION OF ENUGU 1980-1990

Year	Estimated Population
1980	317,345
1981	333,212
1982	349,872
1983	376,365
1984	385,733
1985	405,019
1986	425,269
1987	446,532
1988	468,858
1989	492,300
1990	516,915

By using the estimated population, the per cent sewered, the volume of wastewater to be produced per capita per day, the million gallons per day (MGD) flow rate into the trickling filter treatment plant was calculated for each of the 11 years. Using the MGD and other pertinent parameters **peculiar** to trickling filter treatment plants and necessary assumptions, sewage sludge that would be produced was calculated as shown in the sample calculation below. Since the exact values of the data obtained were not known, it was decided that whenever the data available were in ranges, the mid-range value would be used for the calculations.

Sample Calculation of Sludge Production

Estimation of the quantity of sludge to be produced by the proposed Enugu trickling filter treatment plants with anaerobic digestion at the 6.3 MGD flow rate of municipal wastewater, that is predominately domestic in nature. Assuming the influent BOD of 550 mg/L, suspended solids (SS) of 606 mg/L. And that the raw primary and filter humus sludges have the solid contents of 6 per cent and 3.5 per cent respectively. The following symbols are used:

S_o = influent BOD lb/day (5-day 20^o C)

X_o = influent suspended solids (SS), lb/day

h = fraction of BOD not removed in primary clarifier

i = fraction of BOD not removed in aeration of trickling filter

X_f = plant effluent (SS) lb/day

K = fraction of X_o removed in primary clarifier (efficiency of primary clarifier)

j = fraction of solids not destroyed in digester

ΔX = net solids produced by biological action, lb/day

Y = yield = $\Delta X/\Delta S$, where $\Delta S = hs_o - ihs_o$

According to Vesilind (1979) the following values can be assumed to be **constants** in trickling filter treatment plants: treating domestic wastewater.

$h = 0.7$

$K = 0.6$

$j = 0.8$ (assuming no supernantant withdrawal)

$i = 0.2$

$y = 0.2$

By using the following equations, Vesilind (1979), sludge production by the proposed Enugu, trickling filter treatment plant can be estimated.

1. Raw Primary Sludge:

$$KX_o \qquad (4\text{-}1)$$

2. Filter Humus:

(a) BOD Removed:

$$\triangle S = hs_o - ihs_o \qquad (4\text{-}2)$$

(b) The net solids production:

$$\triangle X = (\triangle S)y \qquad (4\text{-}3)$$

(c) Total filter humus:

$$(1\text{-}k)X_o - X_f + \triangle X \qquad (4\text{-}4)$$

Procedure:

1. Raw Primary Sludge.

Step 1:

(a) Determine total solids in influent, X_o;

for SS of 606 mg/L at 6.3 MGD flow rate:

606 mg/L x 6.3 MGD x 8.34 (conversion factor)

= 31,840.4 lb/day

(The 6.3 MGD was calculated by taking the product of population estimate, per cent sewered and the volume of wastewater produced per capita per day and dividing by 3.78 (conversion factor, U.S. gallon) . . .

= 317,345 x 0.5 x 150 L ÷ 3.78

(b) Calculate raw primary sludge, using

equation (4.1) KX_o

Where:

K = fraction of suspended solids (SS) removed in primary clarifier, the efficiency of primary clarifier.

X_o = influent suspended solids.

Data: $K = 0.6$, $X_o = 31,840.4$ lb/day.

$KX_o = 0.6 \times 31,840.4 = 19,104.2$ lb/day

(c) Estimate the volume of sludge produced, assuming raw primary sludge is 6 per cent solids.

Volume of sludge produced:

$$= \frac{19,104.2}{0.06} \times \frac{1 \text{ gal.}}{8.34 \text{ lb.}} = 38,177.8 \text{ gal/day}$$

2. Filter Humus (Sludge from the final clarifier).

Step 2

Determine the BOD removed, S, using equation (4.2),

$$\Delta S = hs_o - ihs_o$$

Where:

h = fraction of BOD not removed in primary clarifier

S_o = influent BOD

i = fraction of BOD not removed in aeration of trickling filter

Data: $h = 0.7$, $S_o = 550$ mg/L, $i = 0.2$

$$\Delta S = hs_o - ihs_o = (0.7 \times 550 \text{ mg/L}) - (0.2 \times 0.7 \times 550 \text{ mg/L})$$

$= 308$ mg/L

$= 308$ mg/L x 8.34 x 6.3 MGD

$= 16{,}182.9$ lb/day

Step 3

Determine the net solids production by biological action, ΔX by using equation (4.3), $\Delta X = (\Delta S)Y$.

Where:

ΔX = net solids production

ΔS = BOD removed

Y = sludge yield per lb BOD

Data: $\Delta S = 16{,}182.9$ lb/day, $Y = 0.2$

$\Delta X = (\Delta S)\,Y$

$= 16{,}182.9$ lb/day x 0.2

$= 3{,}236.6$ lb/day

Step 4

Estimated total filter humus, using equation (4.4)

$(1-K)\,X_o - X_f + \Delta X$

Where:

K = fraction of (SS) removed in primary clarifier.

X_o = influent suspended solids (SS).

X_f = plant effluent (SS)

Data: $K = 0.6$, $X_o = 31{,}840.4$ lb/day, $X_f = 20$ mg/L

(the amount of solids escaping the plant).

$(1\text{-}K)\ X_o - X_f + \Delta X$

$= (0.4 \times 31{,}840.4 \text{ lb/day}) - (20 \text{ mg/L} \times 6.3 \text{ MGD} \times 8.34) + 3{,}236.6$

$= 12{,}736.2 - 4.287.4$

$= 8{,}448.8$ lb/day

Step 5

Estimate volume of filter humus produced, assuming filter humus is 3.5 per cent solids.

Volume of filter humus:

$$= \frac{8{,}448.8 \text{ lb/day}}{0.035} \times \frac{1 \text{ gal.}}{8.34 \text{ lb.}}$$

$= 28{,}944.1$ gal/day

3. Mixed Digested Sludge:

Step 6

Total influent to digester was obtained by adding the raw primary sludge and total filter humus.

$19{,}104.2 + 8{,}448.8 = 27{,}553$ lb/day

Mixed Digested Sludge:

The mixed digested sludge was obtained by taking the product of total influent to digester and the fraction of solids not destroyed in the digester (j), where j is equal to 0.8.

$0.8 \times 27{,}533 \text{ lb/day} = 22{,}042.4 \text{ lb/day}$

Step 7

Annual mixed sludge production:

$$365 \times 22{,}042.4 \text{ lb/day} = \frac{8{,}045{,}476}{2{,}000} \text{ lb/year}$$

$$= 4{,}022.7 \text{ tons/year}$$

Annual Sewage Sludge Application Rates

In order to ensure that the environment is properly protected from contaminants such as heavy metals and nitrates in sewage sludge, it should be applied to agricultural lands at a certain desired rate per acre. The application rate of sewage sludge that is predominately domestic in nature should be consistent with the nitrogen requirement of the crops to be grown so as to prevent nitrate pollution of ground water. On the other hand, the rate of application of sewage sludge that is contaminated with heavy metals should be based on heavy metal contents with Cadmium, Nickel, Lead and Copper as the metals of primary concern. The annual sludge application of heavy metal contaminated sludge should be such that cadmium is not greater than 2 lb/acre (Sommers and Nelson, 1978). This is to prevent the uptake of Cadmium on food chain crops and potential adverse effects on human health.

In other words, municipal sewage sludge with no heavy metal contents could be used as a nitrogen fertilizer material,and thus the annual application rate should be limited by nitrogenous substances. Furthermore the application rates should provide total plant available nitrogen equivalent to the nitrogen fertilizer requirement of the crops to be grown. Sludge that contains high concentrations of heavy metals such as cadmium could only be used as a supplementary nitrogen source and not as a fertilizer material.

Plant available nitrogen includes that mineralized from the soil, the inorganic sludge nitrogen in the form of ammonia and nitrate mineralized the first growing season following sludge application and the per cent mineralized residuals for three subsequent growing seasons. After sludge application to soils, it slowly decomposes and results in the release of nitrogen available for plant growth.

According to Sommers and Nelson (1978), 20 per cent of the organic nitrogen in sewage sludge is converted to plant available form the first year of sludge application and 3 per cent of the remaining organic nitrogen is released each year for three subsequent years. Table 20 shows the release of residual nitrogen during decomposition in the soil. The sludge application rates are, therefore, based on the quantity of readily available nitrogen (ammonia and nitrate) in sludge and on the amount of nitrogen released during decomposition

TABLE 20

RELEASE OF RESIDUAL NITROGEN IN SOIL WITH SEWAGE SLUDGE

Years After Sludge Application	Organic N Content of Sludge, %						
	2.0	2.5	3.0	3.5	4.0	4.5	5.0
	Lbs. N Released per Ton Sludge Added						
1.	1.0	1.2	1.4	1.7	1.9	2.2	2.4
2.	0.9	1.2	1.4	1.6	1.8	2.1	2.3
3.	0.9	1.1	1.3	1.5	1.7	2.0	2.2

Source: Sommers, L.E., and Nelson, D.W., "Analysis and their Interpretation for Sludge Application to Agricultural Land:" Application of Sludges and Wastewaters on Agricultural Land; A Planning and Educational Guide EPA-MCD 35, U.S. Environmental Protection Agency, Washington, D.C., March, 1978, pp. 3-6.

in soil (Sommers and Nelson, 1978). It should be pointed out that plant available nitrogen added to soils in sludge is greatly influenced by the application method utilized. If liquid sludge is applied on soil surface and allowed to dry, approximately 50 per cent of NH_4-N applied is lost to the atmosphere as ammonia (NH_3) and this results in increased application rate to meet the crop's nitrogen requirement. On the other hand, if liquid sludge is incorporated or injected immediately into the soil,no ammonia is lost to the atmosphere and, therefore, the available nitrogen applied equals the fertilizer nitrogen requirement (Sommers and Nelson, 1978).

Generally, when sewage sludge is applied to soils at nitrogen utilization rates, the quantity of phosphorus added is more than the quantity required for the crops' desired yield. Also enough potassium is added,but in cases where there is not enough potassium,it should be supplemented with potassium fertilizer to ensure optimum crop yields. It is advisable, since sewage sludge contains low percentage of potassium, to add potassium to sludge to be used as fertilizer on a routine basis.

It is assumed that sewage sludge to be produced by the Enugu treatment plant would contain no heavy metal because of lack of industries. Therefore, nitrogen was used as the base for calculating sludge application rate. Also in order to maximize the utilization of plant available nitrogen, incorporation method of sludge application was used.

The information required to calculate annual sludge application rate based on plant available nitrogen include:

1. Total and inorganic nitrogen content of sludge
2. Nitrogen, phosphorus and potassium requirement of crops to be grown
3. Soil test for nitrogen, phosphorus and potassium
4. Crops to be grown
5. Soil pH, cation exchange capacity and lime requirement to adjust the soil to pH 6.5

Table 21 shows the range of nitrogen, phosphorus and potassium contents typically found in anaerobically digested sludge. Table 22 shows some local Nigerian crops that can be grown with sewage sludge. It must be pointed out that the growing of such crops as tomatoes and onions will not pose any public health hazards because almost all the Nigerian agricultural crops are cooked before they are eaten. Tomatoes and onions are not eaten raw in vegetable salad in the Nigerian diet. Table 23 shows the nitrogen, phosphorus and potassium requirements of the crops to be grown. Table 24

TABLE 21

COMPOSITION OF REPRESENTATIVE ANAEROBIC SEWAGE SLUDGE

Component	Ranges*,%	Lb/Ton**
Organic nitrogen	1-5	20-100
Ammonia nitrogen	1-3	20-60
Total phosphorus	1.5-5	30-100
Total potassium	0.2-0.8	4-16

* Per cent of Oven-dry solids

** Lb/ton dry sludge

Source: Sommers, L.E., and Nelson, D.W., "Analyses and their Interpretation for Sludge Application to Agricultural Land," Application of Sludges and Wastewaters on Agricultural Land: A Planning and Educational Guide, EPA-MCD-35, U.S. Environmental Protection Agency, Washington, D.C., March 1978, p. 3.

TABLE 22

SOME NIGERIAN CROPS THAT CAN BE GROWN WITH SEWAGE SLUDGE

1. Corn (Grain)
2. Potatoes Sweet (Yams)
3. Rice
4. Sorghum grain (Millate)
5. Sugar Beets
6. Tomatoes
7. Snap Beans
8. Peanuts (Groundnuts)
9. Onions
10. Cotton

TABLE 23

FERTILIZER REQUIREMENTS FOR SPECIFIC YIELDS

Crops	Lb. per Acre			
	Yield	N	P_2O_5	K_2O
Corn (Grain)	150 bushels	240	85	195
Potatoes, Sweet (Yam)	500 bushels	115	35	175
Rice	45 cwt.	110	45	110
Sorghum Grain (Millate)	60 bushels	115	45	110
Sugar Beets	25 tons	190	71	212
Tomatoes	30 tons	250	80	480
* Snap Beans	5 tons	27	4	112
Peanuts (nuts)	1.25 tons	90	10	15
Onions	10 tons	122	27	136
Cotton	1.5 bales	105	45	65

Source: Willcox, L.A., The Answers, a Handbook of Agri-Business Facts, Formulas. General Guidelines, Willcox Enterprise, Inc.; City National Bank Tower, Oklahoma City, 1972.

* U.S. Environmental Protection Agency, Sludge Treatment and Disposal, Vol. 2, EPA-625/4-78-012, Cincinnati, Ohio, October, 1978.

shows the soil test result. By utilizing the data in Tables 20 through 24 and the procedure recommended by Sommers and Nelson (1978), the annual sludge application rates for the first, second, third, fourth and fifth years were calculated for the crops. Given below is a sample calculation of sludge application rate using corn as an example. Sample Calculation to determine sludge application rate on Enugu agricultural land assuming the following requirements:

1. Sludge Analysis:

   NH_4-N: 2%

   Organic N: 3%

   P: 3.25%

   K: .54%

2. Soil Test Results:

   Soil pH: 5.7

   Available P: 30.5

   Available K: 163

3. Previous application: None

4. Crop to be grown: Corn

5. Yield expected: 150 bushels/acre

6. Fertilizer requirements in Lbs/acre: N, 240; P_2O_5, 85; K_2O, 195.

TABLE 24

1978 SOIL TEST RESULTS FOR CLEVELAND COUNTY*

Test	Ranges
Soil pH	5.5 - 5.9
Surface Nitrate (Lbs. N/acre)	21 - 40
Subsurface Nitrate (Lbs. N/acre)	41 - 60
Available Phosphorus (Lb. P/acre)	21 - 40
Exchangeable Potassium (Lbs. K/acre)	126-200

* Soil type: silt loam soil.

Source: O.S.U. Agricultural Extension Station, Norman, Oklahoma.

7. P and K recommendation in Lbs/acre based on soil test. P_2O_5, 15.16; K_2O, 0.

Calculation of Annual Rate of Sludge Application Based on N:

Step 1:

Calculate tons of sludge needed to meet the crop's N requirement:

It should be noted that according to Sommers and Nelson (1978) 20 per cent of organic N in sludge is mineralized the first year of application if sludge is incorporated into the soil.

(a) The sludge available nitrogen was calculated by using the formula:

$$\text{lb. } NH_4\text{-N/ton} = \frac{\%NH_4\text{-N in sludge}}{100} \times \frac{2{,}000 \text{ lb.}}{\text{ton}}$$

$$= \%\ NH_4\text{-N} \times 20 \qquad (4.5)$$

$$\text{lb. Plant Organic N/ton} = \frac{\%\text{ organic N}}{100} \times \frac{2000 \text{ lb.}}{\text{ton}}$$

$$\times\ 0.2 = \%\text{ organic N} \times 4 \qquad (4.6)$$

(b) Using sludge incorporation method, lb. available N/ton sludge was calculated with the formula:

$$\text{Incorporated sludge lb available N/ton sludge} = (\%\text{ organic N} \times 4) + (\%NH_4^{-N} \times 20) \quad \ldots \quad (4\text{-}7)$$

Data: % organic N = 3%, %NH_4-N = 2%

= (3% x 4) + (2% x 20)

= 12 + 40

= 52 lb. N/ton sludge.

(c) Annual Sludge Application Rate for 150 bushels of corn grain per acre was calculated by the formula:

$$\text{Tons Sludge/acre} = \frac{\text{crop N requirement - residual N}}{\text{lb. available N/ton sludge}} \quad (4.8)$$

Where:

Crop N requirements = the quantity of nitrogen required for the desired crop yield per acre.

Residual N = the quantity of plant available N within 3 years following the first year of sludge application.

lb. available N/ton sludge = the quantity of plant available N per ton of sludge.

Data: crop N requirement for 150 bushels of corn is 240 lbs; residual N is 0 (because there has not been sludge application in the previous years), lb. available N/ton of sludge is 52 lb.

$$\text{Tons sludge/acre} = \frac{\text{240 lb. N - 0}}{\text{52 lb. N/tons sludge}}$$

$$= 4.61 \text{ tons/acre}$$

Step 2

The amounts of P and K added in sludge were calculated by using the formulae:

lb of P added = tons of sludge x %P in sludge x 20 (4.9)

lb of K added = tons of sludge x %K in sludge x 20 (4.10)

Data: %P and K in sludge are 3.25% and 0.54% respectively.

(a) lb of P added = 4.61 tons/acre x 3.25% P x 20

= 299.65 lb P/acre

= 299.65 x 2.29 (conversion factor to P_2O_5)

= 686.19 P_2O_5/acre

If the quantity of P in sludge is less than that required for the desired crop yield, the amount of P fertilizer to be added is calculated by using the formula:

lb P fertilizer needed = (lb P required for crop) - (lb P in sludge) (4-11)

Based on the soil test, it was recommended that 15.16 lb/acre of P fertilizer should be added in order to produce the desired corn yield of 150 bushels per acre. But since the lb/acre of P in sludge was found to be more than the fertilizer recommendation, no P_2O_5 fertilizer should be added.

(b) lb of K added was obtained by using equation (4-10).

$$\text{lb of K added} = \text{Tons of sludge} \times \%\text{ K in sludge} \times 20.$$

$$= 4.61 \text{ tons/acre} \times 0.54\ \%\text{ K} \times 20$$

$$= 49.79 \text{ lb K/acre}$$

$$= 49.79 \times 1.2 \text{ (conversion factor to } K_2O)$$

$$= 59.75 \text{ lb } K_2O\text{/acre}$$

The quantity of K fertilizer to be added when necessary is calculated by the formula:

$$\text{lb K fertilizer needed} = (\text{lb K required for crop}) - (\text{lb K in sludge}) \qquad (4\text{-}12)$$

Based on the soil test, no K fertilizer was recommended to be added to the soil in order to produce the desired corn yield. This was because the soil contained more than the required quantity of K in addition to the quantity in the sludge application.

<u>Step 3</u>

By using formula (4-8) and the data on Table 20 for 3 per cent organic N, the annual sludge application rates for the desired corn yields for the second, third, fourth and fifth years following the first year of sludge application were calculated. This is also known as the residual effect of sludge.

Second year sludge application =

$$\frac{\text{Crop N requirement - Residual N}}{\text{lb available N/ton sludge}}$$

Where:

Crop N requirement = the quantity of nitrogen required for the desired crop yield per acre

Residual N = tons/acre added the first year x lb N/ton released one year after the first year of sludge application as shown in Table 20.

lb available N/ton sludge = the quantity of plant available N per ton of sludge

Data: crop N requirement for 150 bushels of corn per acre is 240 lb., residual N is equal to (4.61 tons/acre x 1.4 lb N/ton of sludge) and lb available N/ton of sludge is 52 lb.

Sludge application rate =

$$\frac{240 \text{ lb N} - (4.61 \text{ tons/acre} \times 1.4 \text{ lb N/ton})}{52 \text{ lb available N/ton sludge}}$$

= 4.49 tons/acre

Third Year:

$$\frac{240 \text{ lb N} - (4.61 \text{ tons/acre} \times 1.4 \text{ lb N/ton}) - (4.49 \text{ tons/acre} \times 1.4 \text{ lb N/tons})}{52 \text{ lb. available N/ton sludge}}$$

= 4.37 tons/acre

Note: The residual was obtained by subtracting the product of tons/acre added the second year and lb N/ton released the first year from the product of tons/acre added the first and lb N/ton released the second year as shown in Table 20. The residuals for the fourth and fifth years were similarly obtained.

Fourth Year:

$$\frac{240 - (4.61 \times 1.3) - (4.49 \times 1.4) - (4.37 \times 1.4)}{52}$$

= 4.28 tons/acre.

Fifth Year:

$$\frac{240 - (4.49 \times 1.4) - (4.37 \times 1.3) - (4.28 \times 1.4)}{52}$$

= 4.27 tons/acre

Annual Cost of Commercial Fertilizer

The annual cost of commercial fertilizer was determined by taking the average total cost of commercial fertilizer imported into Nigeria for three consecutive years: 1977/78, 1978/79 and 1979/80. Table 25 shows the cost of commercial fertilizer imported into Nigeria. The average annual cost of commercial fertilizer as shown in Table 25 is \$84,718,021.

$$\text{Cost per ton} = \frac{\$84{,}718{,}021}{281{,}913.33 \text{ tons}}$$

$$= \$300.51/\text{ton}$$

$$\text{Cost per lb.} = \frac{\$300.51}{2{,}000}$$

$$= \$0.15/\text{lb}$$

It is necessary to note that the given annual cost is not a true representation of the current cost of commercial fertilizer in Nigeria. The figures might be true prior to the change of administration from Military to Civilian government in October, 1979. With the change in administration there has been much emphasis in agriculture, hence the promulgation of the famous "Green Revolution," for the current five years development plan to increase local food production and minimize food importation from foreign countries. The increase in the agricultural budget has more than doubled and so has the annual cost of commercial fertilizer importation. Since the current cost data were not available, the average cost of the three available years was used.

Cost Estimation for Sludge Treatment and Disposal:

TABLE 25

COSTS OF IMPORTATION OF COMMERCIAL FERTILIZER

1977/78, 1978/79, 1979/80

Year	Quantity(tons)	Amount(Niara ₦)	Amount(dollar $)*
1977/78	298,200	52,872,485	92,526,849
1978/79	234,400	40,478,999	70,838,248
1979/80	313,140	51,879,409	90,788,966
Total	845,740	145,230,993	254,154,063
Average	281,913.33	48,410,331	84,718,021

* Conversion factor, from Niara to dollar = 1.75

Basically there are two methods which can be used to estimate the cost related to wastewater treatment plant construction and operation. These are:

1. The deductive method: This is a method by which cost is constructed from costs data reported from existing wastewater treatment plants.
2. The inductive method: This is a method by which the cost is projected by calculating the unit costs for each item or process within the system, adding the appropriate add-on costs to obtain the total cost.

The preferred method for this study was the deductive approach because of its nature and the difficulties involved in obtaining the cost of data of the inductive method. The major task of the deductive method of cost estimation is the collection of cost data from existing plants. The method of procuring the cost information is to scan the published reports and literatures. Therefore, numerous government research reports and publications, especially the EPA, were scanned for appropriate cost information.

The base cost data for this study were obtained from EPA report, Table 26, which is a profile sheet for trickling

TABLE 26

TRICKLING FILTER PROCESS PROFILE SHEET, STRATEGY 4 AT A FLOW RATE OF 10 MGD DISCHARGE TO LAND

	LIQUID TREATMENT					ORGANIC SLUDGE TREATMENT OPTIONS							
	PRIMARY	SECONDARY	TERTIARY	LIQUID DISPOSAL	UNIT OPERATION	1	2	3	4	5	6	7	8
					THICKENING:	GRAVITY		GRAVITY	GRAVITY	GRAVITY		GRAVITY	GRAVITY
					CONDITIONING:	CHEMICAL	CHEMICAL	PORTEOUS	DIGESTION	DIGESTION	DIGESTION	DIGESTION	DIGESTION
					DEWATERING:	VACUUM FILTRATION	CENTRIFUGE	VACUUM FILTRATION	SAND DRYING			VACUUM FILTRATION	VACUUM FILTRATION
		Trickling Filter		Land	DISPOSAL:	INCINERATION LANDFILL	INCINERATION LANDFILL	INCINERATION LANDFILL	LANDFILL	LAND SPREADING	OCEAN DUMPING	LANDFILL	OCEAN DUMPING
INPUTS - ENERGY (UNITS/DAY)	1270 kwh	1774 kwh		4600 kwh		670 kwh 60×10^6 Btu	560 kwh 70×10^6 Btu	600 kwh 25×10^9 Btu	30 kwh	30 kwh	Not Practical	250 kwh	250 kwh
CONCRETE (CU YDS)	756	1160		252		27	26	30	775	775		780	780
STEEL (TONS)	75	108		66.7		48	45	58	79	78		83	83
CHEMICALS (LBS/DAY)				Chlorine 840		30-170	35-70					50-180	50-180
LAND (ACRES)		20		1290		2.7-3.7	2.6-3.6	1.9-2.5	5.4-7.2	40-170		2.2-3	.17-.23
LABOR (MAN YRS/YR)	3.2	3		10		4.3-5.8	3.6-4.8	4.1-4.5	2.25-11.5	9.6-12.9		2.6-3.5	3.4-4.6
OUTPUTS - BOD (MG/L)	130	30-50		.6-1.0									
(LBS/DAY)	10,400	2500-4170		50-83									
SUSPENDED SOLIDS (MG/L)	80	40-60		1.4-4									
(LBS/DAY)	6400	3370-5000		21-52									
NUTRIENTS: P (MG/L)	14.3	10		.1									
(LBS/DAY)	1140	840		8		250-400	250-400	250-400	250-400	250-400		250-400	250-400
N (MG/L)	32	24		3.6									
(LBS/DAY)	2560	2010		302					400-700	400-700		400-700	400-700
HEAVY METALS (LBS/DAY)		30-630		2-32		9-159	9-159	9-159	10-160	10-160		10-160	10-160
ATMOSPHERIC EMISSIONS (LBS/DAY)						Metals=.7-1 NO_x=5.0-7.8	SO_2=.7-1 Particulates = 22-33	HCl=3.5-6					
SLUDGES-% SOLIDS	5	7.5				100	100	100	25-50	7.5		20-30	20-30
TOTAL DRY WT. (LBS/DAY)	10,800	3200				4500	4500	3150	9300	9300		9300	9300
SOLID WASTE (CU FT/YR)						19-112	23-46					33-118	33-118
NUISANCE - ODOR	Potential	Potential				None	None	None	Potential	Potential		Potential	None
NOISE							Above Average						
TRAFFIC				.02		.11	.11	.08	.23	.23		.23	Negligible
SAFETY (INJURIES/10^6 MAN-HRS)		28.5		Pathogens Last 1 mo									
COSTS - CAPITAL ($\$ \times 10^6$)	2.21	1.6-1.7		3.9-5.7		.94-1.3	.65-.88	.73-.98	.46-.47	.24-.32		.40-.64	.84-1.1
RUNNING TOTAL CAPITAL ($\$ \times 10^6$)	2.21	3.81-3.9		7.71-9.61		8.65-10.9	8.36-10.5	8.44-10.6	8.17-10.1	7.95-9.93		8.11-10.2	8.55-10.7
LAND ($)		20,000		1.29×10^6		2700-3700	2600-3600	1900-2500	5400-7200	$.4-1.7 \times 10^5$		2200-3000	170-230
RUNNING GRAND TOTAL ($\$ \times 10^6$)	2.21	3.83-3.9		9.02-10.9		9.96-12.2	9.67-11.8	9.75-11.9	9.49-11.4	9.3-11.4		9.42-11.5	9.86-12.0
OPERATING (¢/1000 GAL)	4	2		5 —9		3.2-3.8	2.9-4.3	2.4-3.2	1.7-2.3	.91-1.15		1.6-3.3	1.2-3
10% AMORTIZED (¢/1000 GAL)	7.1	5.2-5.5		16.7-22.5		3.0-4.2	2.1-2.8	2.3-3.2	1.5	.9-1.6		1.3-2.0	2.7-3.5
TOTAL OPERATING (¢/1000 GAL)	11.1	7.2-7.5		21.7-31.5		6.2-8.0	5.0-7.1	4.7-6.4	3.2-3.8	1.8-2.8		2.9-5.3	3.9-6.5
RUNNING TOTAL (¢/1000 GAL)	11.1	18.3-18.6		40.0-50.1		46.2-58.1	45.0-57.2	44.7-56.5	43.2-53.9	41.8-52.9		42.9-55.4	43.9-56.6

Source: U.S. Environmental Protection Agency, Evaluation of Municipal Sewage Treatment Alternatives, Final Report, Contract EQC 316, Washington, D.C., February, 1974.

a filter treatment plant with a flow rate of 10 MGD with land disposal option. From this, cost for sludge treatment and disposal for the desired flow rate could be determined by using appropriate updating and adjustments as discussed below. The costs from the profile sheet, Table 26, do not reflect sludge treatment cost for any particular region of the United States of America. They rather reflect the average national cost which can be updated to get the actual cost for any particular region in the nation.

Capital Cost

The base total capital cost from Table 26 was adjusted to correct for difference in flow rate, national cost factor, local multiplier and land cost. Cost change due to variation in plant size can be approximated through the use of exponential rule. That is, if plant size changes by a factor of X, the cost will change by a factor of X^N, where N varies from 0-1. The exponential factor N has been found to average 0.6 for wastewater treatment facilities and equipment designed for plants with 100 MGD flow rate or less (EPA, 1974).

In order to update the capital cost, the national cost factor was used. The national cost factor refers to change in the overall price structure due to economic trends such as recession and inflation. These factors are frequently updated and published in Engineering News Records as the ENR cost index. Cost estimates can be updated by multiplying the base cost by the ratio of the current ENR index to the index that prevailed when the cost was formulated. The EPA also published a Sewage Treatment Plant Construction Cost Index (STPCCI). Because EPA Treatment Plant Construction Cost Index is based on information peculiar to wastewater treatment plants construction, its usefulness for evaluating the cost relating to wastewater treatment plant is much greater than the ENR cost index. Therefore, in this study, the STPCCI index was used to update the sludge treatment cost data.

Since the cost data from the profile sheet, Table 26, from which the base capital cost was taken, was formulated in 1973, the ratio of the 1973 STPCCI index of 175 and 1981 STPCCI index of 334.9 was used to multiply the base capital cost to update it to the first quarter of 1981 value which is the most current STPCCI index available. The index used was that of Birmingham, Alabama, and was arbitrarily chosen. Appendix C shows the sewage treatment construction cost index.

To account for possible regional differences for cost updating, the local multiplier of 0.75 for the Birmingham region was employed to adjust the national average cost to figures reflecting the price structure likely to prevail in the Birmingham area. The local multiplier index is also shown in Appendix C.

Operation and Maintenance Costs

As in the capital cost estimate, the base operation and maintenance data were obtained from the profile sheet, Table 26, and then adjusted to the level applicable to sludge produced by 15 MGD flow rate.

Adjustment factors vary with the parameters of concern. An exponential rule has been approximated for operation and maintenance costs. The quantity requirement estimation for sludge treatment and disposal at a level other than the level shown in Table 26 can be made by taking the ratio of the desired rate to that in the profile sheet to a standard exponential; EPA (1974) reported that the exponential values for labor and supervision, and for electrical and chemical requirements are 0.58, 0.55 and 1.0 respectively for up to 100 MGD flow rate, and that fuel and transportation costs are directly related to sludge volume and thus can be considered to have a quantity multiplier exponential close to one. Also transportation cost is dependent on the distance travelled.

The appropriate exponentials were then used to adjust the values from the profile sheet, and the obtained values were then multiplied by the local cost of electrical power, labor and sludge transportation. The obtained individual costs were summed up to get the total operation and maintenance cost.

After updating the capital cost and amortization to get the capital annual cost, the total annual cost was calculated by adding the amortized capital cost to the operation and maintenance costs. Shown below is a sample calculation on cost estimation of sewage sludge production of trickling filter treatment plant with anaerobic digestion and land application of sludge.

Assumption for sample calculation:

1.	Flow rate	15 MGD
2.	Local land cost	$106,575
3.	Local cost of labor	$1.20/hour
4.	Transportation distance for sludge	10 miles (round trip)
5.	Local multiplier	0.75
6.	Local cost of power (electricity)	$0.11/kw hr
7.	Transportation cost of sludge	$0.42/ton-mile
8.	Amortization years	20 years

9.	Interest rate	9%
10.	Capital recovery factor (CRF)	0.109
11.	Prevailing construction cost index - STPCCI	334.9

Capital Cost:

1. Take the total capital cost from option number 5 column of Table 26. Base capital cost = $28,000. This was obtained by taking the mid-range of the difference of the total capital cost from option number 5 column of sludge treatment.
2. Determine the multiplier to account for flow change by taking the ratio of the new flow rate 15 MGD to the old flow rate 10 MGD to the 0.6 exponential rule.

   Flow change multiplier = $\frac{(15)}{(10)}$ x 0.6 = 1.27
3. Adjusted base cost = 1.27 x 28,000 = $35,560
4. The cost adjustment due to change in national cost structure was determined by first calculating the national cost factor as the ratio of the prevailing STPCCI index (334.9 and base STPCCI index (175) employed by EPA in 1973

during the profile sheet study.

National Cost Factor = $\frac{334.9}{175}$ = 1.91

5. Price index adjusted cost:

   1.91 x $35,560 = $67,919.6

6. Variation in price due to local considerations was determined by taking the product of local multiplier, 0.75 and the price index adjusted cost:

   Total Adjusted Cost = 0.75 x $67,919.6 = $50,939.7

7. The base land requirement was obtained by taking the mid-range of land requirement of option 5, Table 26.

   Base Land Requirement = 105 acres

8. Land requirement multiplier was obtained in the same manner as in number 2 above and is the same.

9. The adjusted land requirement was determined by taking the product of base land requirement and the land requirement multiplier.

   Adjusted Land Requirement:

   1.27 x 105 = 133.35 acres.

10. Adjusted land cost = 0

    (This is because the farmlands are owned by individual farmers and they would opt not to sell their farms to the City but would accept the sludge because of the fertilizer content.)

11. Total capital expenditures = \$50,939.7 + 0

    = \$50,939.7

12. Amortization or annual capital cost was calculated by taking the product of total capital (cost) expenditures and capital recovery factor (CRF) 0.109.

$$AC = P \times (CRF) \tag{4-13}$$

Where:

AC = Annual cost

P = Capital cost

CRF = Capital recovery factor

$AC = P \times (CRF)$

$= \$50,939.7 \times 0.109$

$= \$5,552.43$

Operation and Maintenance Costs:

1. The base labor requirement was determined from Table 26, option 5, by taking the mid-range of the listed base labor requirements.

   Base Labor Requirement = 11.25 man-years.

2. The labor multiplier was calculated by taking the ratio of desired flow and the base flow to

the 0.58 power.

$\frac{(15)}{(10)}$ x 0.58 = 1.26

3. The adjusted labor requirements:

   1.26 x 11.25 = 14.17 man-years.

4. The daily labor cost was calculated by taking the product of adjusted labor requirement and local labor cost of \$1.20/hour and conversion factor of 8 man-hour per man-day.

   14.17 x \$1.2 x 8 = \$136.03/day

5. The base electrical requirement was determined from Table 26, option 5, as the energy requirement for sludge treatment.

   Base Electrical Requirement = 30 kw hr/day

6. The electrical multiplier was determined by taking the ratio of the desired flow and the base flow to the 0.55 power.

   $\frac{(15)}{(10)}^{0.55} = 1.25$

7. The Adjusted Electrical Requirement:

   1.25 x 30 = 37.5 kw hr/day

8. The daily electrical cost was calculated by taking the product of electrical requirement and local cost of power, of \$0.11.

$37.5 \times \$0.11 = \$4.12/day$

9. Quantity of sludge requiring transportation, from sludge production calculation:

   11.02 tons/day.

10. The daily sludge transportation cost was calculated by taking the product of quantity of sludge, transportation distance for sludge of 10 miles and transportation cost for sludge of \$0.42.

    $11.02 \times 10 \times \$0.42 = \$46.28/day$

11. Total operation and maintenance costs:

    $\$136.03 + \$4.12 + \$46.26 = \$186.43$

12. Total annual cost:

    $\$5,552.43 + \$186.43 = \$5,738.86$

13. Total annual sludge production:

    4,022.7 tons

14. Cost per ton of sludge:

    $$\frac{\$5,738.86}{4,022.7 \text{ tons}} = \$1.43/ton$$

Discussion of Results

Table 27 shows the annual sewage sludge production at different percentages of population sewered. It shows for example, that 4,022.7 tons of sludge is produced at 50 per

TABLE 27

ANNUAL ESTIMATED SEWAGE SLUDGE PRODUCTION IN

ENUGU PROPOSED TRICKLING FILTER PLANT

Year	Estimated Population	% of Population Sewered	Dry Solids Wts in tons
1980	317,345	50	4,022.7
1981	333,212	52	4,405.9
1982	349,872	54	4,789.0
1983	367,365	56	5,235.9
1984	385,733	58	5,682.9
1985	405,019	60	6,129.9
1986	425,269	62	6,704.6
1987	446,532	64	7,215.4
1988	468,858	66	7,853.9
1989	492,300	68	8,492.4
1990	516,915	70	9,131.0

cent sewarage, and at 70 per cent 9,131 tons of sludge are produced.

Table 28 shows the specific number of pounds of nitrogen, phosphorus and potassium fertilizers contained in the quantities of commercial fertilizer and sludge applied for the desired yields per acre of different agricultural crops. Table 28 also shows that with the exception of peanuts (groundnuts) the lb/acre of K_2O contained in the tons per acre of sludge application is not enough to meet the potassium requirements for the crops. In cases where the soil available potassium as indicated by soil test does not make up the difference, supplementary commercial K_2O fertilizer should be added in order to optimize crop yields. The soil test result utilized in this study indicates that the soil has enough available potassium. Therefore, no supplementary commercial potassium fertilizer is needed. It is advisable, however, for precautionary measures to add K fertilizer in sludge that would be applied on agricultural land on a routine basis since sewage sludge typically is low in K, relative to its N and P contents.

The average annual cost of commercial fertilizer in Nigeria was found to be $84,718,021.00 for 281,913.33 tons of fertilizer. The cost per a ton was calculated to be

TABLE 28

THE SPECIFIC POUNDS OF NITROGEN, PHOSPHORUS AND POTASSIUM FERTILIZER CONTAINED IN SEWAGE SLUDGE AND COMMERCIAL FERTILIZER APPLIED PER ACRE

Crops	Yields per acre	Commercial Fertilizer Quantities Used lb/acre	Commercial Fertilizer Specific Fertilizer Content lb/acre			Sewage Sludge Quantities Used Ton/acre	Sewage Sludge Specific Fertilizer Content lb/acre		
			N	P_2O_5	K_2O		N	P_2O_5	K_2O
Corn (Grain)	150 bu.	520	240	85	195	4.61	240	686.19	59.75
Sweet Potatoes (Yams)	500 bu.	325	115	35	175	2.21	115	328.96	28.64
Rice	45 cwt	265	110	45	110	2.11	110	314.07	27.25
Sorghum (Grain) (Millate)	60 bu.	270	115	45	110	2.21	115	328.96	56.96
Sugar Beets	25 tons	473	190	71	212	3.65	190	453.30	47.30
Tomatoes	30 tons	810	250	80	480	4.8	250	714.48	62.21
Snap Beans	5 tons	143	27	4	112	0.52	27	77.4	6.74
Peanuts (nuts)	1.25 tons	115	90	10	15	1.73	90	257.51	22.42
Onions	10 tons	285	122	27	136	2.34	122	348.30	30.32
Cotton	1.5 bales	215	105	75	65	2.02	105	300.68	26.18

$300.51, and since commercial fertilizer is usually applied in lb/acre, the cost per pound was calculated to be $0.15. On the other hand, the annual cost of sludge production and application at 50 per cent sewerage was estimate to be $5,738.86. The cost per ton was found to be $1.43. Similarly, the annual cost of sludge production and application at 70 per cent sewerage was estimated to be $5,797.58. The cost per ton was estimated to be $0.63.

Table 29 shows how much it costs per acre to produce specific agricultural crops at certain desired yields per acre using sludge produced at 50 per cent population sewerage. It shows that 520 lb/acre of commercial fertilizer are needed to produce 150 bushels per acre of corn grain at the cost of $78.00. On the other hand, Table 29 shows that the same number of bushels of corn per acre can be produced with 4.61 tons of sewage sludge at the cost of $6.59. The production of 500 bushels per acre of potatoes (yams) will require 325 lb/acre of commercial fertilizer at a cost of $48.75 per acre. The same quantities of potatoes (yams) per acre can be produced with sludge application rate of 2.21 tons/acre at a cost of $3.16. Table 29 also indicates that if 45 cwt/acre of rice were desired to be produced, it would take 265 lb/acre of commercial fertilizer which would cost

TABLE 29

COST PER ACRE OF COMMERCIAL FERTILIZER AND SEWAGE SLUDGE PRODUCED AT 50% POPULATION SEWERAGE FOR SPECIFIC CROPS, FIRST YEAR OF APPLICATION

Crops	(A) Quantities of Commercial Fertilizer in lb/acre	(B) Cost of Commercial Fertilizer per acre in dollars ($)	(C) Quantities of sewage Sludge in tons/acre	(D) Cost of Sewage Sludge per acre in ($)	(E) Crop Yields
Corn (grain)	520	78	4.61	6.59	150 bu.
Sweet Potatoes (Yams)	325	48.75	2.21	3.16	500 bu.
Rice	265	39.75	2.11	3.02	45 cwt
Grain Sorghum	270	40.5	2.21	3.16	60 bu.
Sugar Beets	473	70.95	3.65	5.22	25 tons
Tomatoes	810	121.5	4.8	6.86	30 tons
Snap Beans	143	21.45	0.52	0.74	5 tons
Peanuts (nuts)	115	17.25	1.73	2.47	1.25 tons
Onions	285	42.75	2.34	3.34	10 tons
Cotton	215	32.25	2.02	2.89	1.5 bales

(A) The quantities of commercial fertilizer were obtained by summing the number of lbs. of N, P_2O_5, K_2O, fertilizer required to give the desired crop yield as shown in Table 23.

(B) The cost of commercial fertilizer was obtained by multiplying the quantities of commercial fertilizer required for desired crop yields by $0.15, which is the cost per lb. ot commercial fertilizer.

(C) The quantities ot sewage sludge in tons/acre required to give desired crop yields.

(D) The cost of sewage sludge was obtained by multiplying the quantities of sewage sludge required for desired crop yields by $1.43, which is the cost per ton of sewage sludge produced at 50% population sewerage.

(E) The desired crop yields per acre as shown in Table 23.

$39.75 per acre. Similarly, 2.11 tons/acre of sludge at a cost of $3.02 per acre would be required to produce the same quantity of rice.

Table 30 shows how much it costs per acre the first year of application by using sludge produced at 60 per cent population sewerage. The table shows that it costs $2.08 per acre to produce 60 bushels of grain sorghum (millate) as compared to $40.50 for using commercial fertilizer to produce the same number of bushels of grain sorghum. Table 30 also indicates that the production of 30 tons/acre of tomatoes which costs $121.50 with commercial fertilizer costs $4.51 with sewage sludge. Table 30 shows that if 25 tons/acre of sugar beets were desired to be produced, it would cost $70.95 by using commercial fertilizer. On the other hand, the same number of tons of sugar beets per acre could be produced at a cost of $3.43 by utilizing sewage sludge.

Table 31 shows how much it costs per acre the first year of application by using sludge produced at 70 per cent population sewerage. Table 31 indicates that it costs $21.45 to produce 5 tons/acre of snap beans with commercial fertilizer, as compared to $0.33 with sewage sludge to produce the number of tons of snap beans. Table 31 also indicates that if 1.5 bales of cotton per acre were desired to be

TABLE 30

COST PER ACRE OF COMMERCIAL FERTILIZER AND SEWAGE SLUDGE PRODUCED AT 60% POPULATION SEWERAGE FOR SPECIFIC CROPS, FIRST YEAR OF APPLICATION

Crops	Quantities of Commercial Fertilizer in lb/acre	Cost of Commercial Fertilizer per acre in dollars ($)	Quantities of Sewage Sludge in tons/acre	Cost of Sewage Sludge per acre in ($)	Crop Yields
Corn (grain)	520	78	4.61	4.33	150 bu.
Sweet Potatoes (Yams)	325	48.75	2.21	2.08	500 bu.
Rice	265	39.75	2.11	1.98	45 cwt
Grain Sorghum	270	40.5	2.21	2.08	60 bu
Sugar Beets	473	70.95	3.65	3.43	25 tons
Tomatoes	810	121.5	4.8	4.51	30 tons
Snap Beans	143	21.45	0.52	0.49	5 tons
Peanuts (nuts)	115	17.25	1.73	1.62	1.25 tons
Onions	285	42.75	2.34	2.20	10 tons
Cotton	215	32.25	2.02	1.90	1.5 bales

TABLE 31

COST PER ACRE OF COMMERCIAL FERTILIZER AND SEWAGE SLUDGE PRODUCED AT 70% POPULATION SEWERAGE FOR SPECIFIC CROPS, FIRST YEAR OF APPLICATION

Crops	Quantities of Commercial Fertilizer lb/acre	Cost of Commercial Fertilizer per acre in dollars ($)	Quantities of Sewage Sludge in tons/acre	Cost of Sewage Sludge per acre in dollars ($)	Crop Yields
Corn (grain)	520	78.00	4.61	2.90	150 bu.
Sweet Potatoes (Yams)	325	48.75	2.21	1.39	500 bu.
Rice	265	39.75	2.11	1.33	45 cwt
Grain Sorghum	270	40.50	2.21	1.39	60 bu.
Sugar Beets	473	70.95	3.65	2.30	25 tons
Tomatoes	810	121.50	4.8	3.02	30 tons
Snap Beans	143	21.45	0.52	0.33	5 tons
Peanuts (nuts)	115	17.25	1.73	1.09	1.25 tons
Onions	285	42.75	2.34	1.47	10 tons
Cotton	215	32.25	2.02	1.27	1.5 bales

produced, it would cost $32.25 by using commercial fertilizer. Similarly, the same 1.5 bales of cotton per acre could be produced at a cost of $1.27 by utilizing sludge.

Observation of Table 29 through 31 show that the costs per acre of crops production with sludge decrease progressively as the percentages of population sewered increase. The economic advantage of sludge over commercial fertilizer also can be realized by observing Table 29 through Table 31. An observation of Table 29 shows that on the average, commercial fertilizer is 14 times more expensive than sludge. Similarly, Table 31 indicates that on the average sludge is 33 times cheaper than commercial fertilizer. It must be emphasized that despite the fact that the annual cost of commercial fertilizer utilized for this analysis is an underestimate of the current annual cost of commercial fertilizer coupled with both the transportation costs to the farm as well as other operation costs such as labor are not included, it is still more economical to use sewage sludge instead of commercial fertilizer. The application of sludge in tons/acre as compared to sludge application in lb/acre does not shift the economic advantage in favor of commercial fertilizer.

Tables 32, 33, and 34 show the costs and the quantities of yields expected if the same types of agricultural

TABLE 32

COST PER ACRE OF COMMERCIAL FERTILIZER AND SEWAGE SLUDGE PRODUCED AT 50% POPULATION SEWERAGE FOR SPECIFIC CROPS SECOND YEAR OF APPLICATION

Crops	Quantities of Commercial Fertilizer in lb/acre	Cost of Commercial Fertilizer per acre in dollars ($)	Quantities of Sewage Sludge in tons/acre	Cost of Sewage Sludge per acre in ($)	Crop Yields
Corn (grain)	520	78.00	4.49	5.84	150 bushels
Sweet Potatoes (Yams)	325	48.75	2.15	2.79	500 bushels
Rice	265	39.75	2.06	2.68	45 cwt
Grain Sorghum	270	40.50	2.15	2.79	60 bushels
Sugar Beets	473	70.95	3.55	4.61	25 tons
Tomatoes	810	121.50	4.68	6.08	30 tons
Snap Beans	143	21.45	0.5	0.65	5 tons
Peanuts (nuts)	115	17.25	1.68	2.18	1.25 tons
Onions	285	42.75	2.28	2.96	10 tons
Cotton	215	32.25	1.96	2.55	1.5 bushels

TABLE 33

COST PER ACRE OF COMMERCIAL FERTILIZER AND SEWAGE SLUDGE PRODUCED AT 50% POPULATION SEWERAGE FOR SPECIFIC CROPS, THIRD YEAR OF APPLICATION

Crops	Quantities of Commercial Fertilizer in lb/acre	Cost of Commercial Fertilizer per acre in dollars ($)	Quantities of Sewage Sludge in tons/acre	Cost of Sewage Sludge per acre in ($)	Crop Yields
Corn (grain)	520	78.00	4.37	5.24	150 bushels
Sweet Potatoes (Yams)	325	48.75	2.09	2.51	500 bushels
Rice	265	39.75	2.00	2.40	45 cwt
Grain Sorghum	270	40.50	2.09	2.51	60 bushels
Sugar Beets	473	70.95	3.46	4.15	25 tons
Tomatoes	810	121.50	4.55	5.46	30 tons
Snap Beans	143	21.45	0.49	0.59	5 tons
Peanuts (nuts)	115	17.25	1.64	1.97	1.25 tons
Onions	285	42.75	2.22	2.66	10 tons
Cotton	215	32.25	1.86	2.04	1.5 bales

TABLE 34

COST PER ACRE OF COMMERCIAL FERTILIZER AND SEWAGE SLUDGE PRODUCED AT 50% POPULATION SEWERAGE FOR SPECIFIC CROPS, FOURTH YEAR OF APPLICATION

Crops	Quantities of Commercial Fertilizer in lb/acre	Cost of Commercial Fertilizer per acre in dollars ($)	Quantities of Sewage Sludge in tons/acre	Cost of Sewage Sludge per acre in ($)	Crop Yields
Corn (grain)	520	78.00	4.28	4.71	150 bushels
Sweet Potatoes (Yams)	325	48.75	2.04	2.24	500 bushesl
Rice	265	39.75	1.95	2.14	45 cwt
Grain Sorghum	270	40.50	2.04	2.24	60 bushels
Sugar Beets	473	70.95	3.37	3.71	25 tons
Tomatoes	810	121.50	4.44	4.88	30 tons
Snap Beans	143	21.45	0.48	0.53	5 tons
Peanuts (nuts)	115	17.25	1.60	1.76	1.25 tons
Onions	285	42.75	2.16	2.37	10 tons
Cotton	215	32.25	1.86	2.04	1.5 bales

crops were grown the second, third and fourth years respectively following the first year of sludge application. In other words, the tables show the residual effect of sewage sludge. Table 32 through Table 34 indicate that the quantities of sludge for all the specific crops decrease continuously each subsequent year and then level off after the fourth year as shown in the sample calculation. Thus corresponding to the end of decomposition of organic nitrogen in sludge. Similarly, there are decrease in the cost per acre for most of the crops. As in the quantities of sludge application the costs decrease each year of application and level off after the fourth year.

Tables 32 through Table 34 show that both the application rates and costs of commercial fertilizer remain constant all the time due to the fact that commercial fertilizer has no residual effect. An important advantage of the residual effect of sludge is that, with the decrease in the quantities of sludge required per acre for the desired crop yields, more acres of agricultural land will be incorporated into the program. This means more agricultural crops production.

Tables 35, 36, and 37 show the estimated annual yields and savings that are possible when the annual sewage sludge produced at 50%, 60% and 70% population sewerage are

TABLE 35

ESTIMATED ANNUAL SAVINGS AND CROP YIELDS POSSIBLE WITH UTILIZATION OF SEWAGE SLUDGE PRODUCED AT 50% POPULATION SEWERAGE

Crops	Number of Acres Fertilized with Sludge	Estimated Savings in dollars ($)	Annual Yields
Corn (grain)	872.60	62,312.36	130,890 bushels
Sweet Potatoes (Yams)	1,820.23	82,984.29	910,115 bushels
Rice	1,906.49	70,025.38	4,289.60 tons
Grain Sorghum (Millate)	1,820.23	67,967.39	109,213.80 bushels
Sugar Beets	1,102.11	72,441.69	27,552.75 tons
Tomatoes	838.06	96,075.20	25,141.8 tons
Snap Beans	7,735.96	160,211.73	38,679.8 tons
Peanuts (nuts)	2,325.26	34,367.34	2,906.57 tons
Onions	1,919.10	75,420.63	19,191.0 tons
Cotton	1,991.43	58,468.38	2,987.14 bales

TABLE 36

ESTIMATED ANNUAL SAVINGS AND CROP YIELDS POSSIBLE WITH UTILIZATION OF SEWAGE SLUDGE PRODUCED AT 60% POPULATION SEWERAGE

Crops	Number of Acres Fertilized with Sludge	Estimated Savings in Dollars ($)	Annual Yields
Corn (grain)	1,329.69	97,958.26	199,453.5 bu.
Sweet Potatoes (Yams)	2,773.71	129,449.05	138,685.5 bu.
Rice	2,905.16	109,727.89	6,536.61 tons
Sorghum grain (Millate)	2,773.71	106,565.94	166,422.6 bu.
Sugar Beets	1,679.42	113,394.44	41,985.5 tons
Tomatoes	1,277.06	149,403.25	38,311.8 tons
Snap Beans	11,788.27	247,082.14	58,941.35 tons
Peanuts (nuts)	3,543.29	55,381.62	4,429.11 tons
Onions	2,619.61	106,225.19	26,196.1 tons
Cotton	3,034.60	92,100.11	4,551.9 bales

TABLE 37

ESTIMATED ANNUAL SAVINGS AND CROP YIELDS POSSIBLE WITH UTILIZATION OF SEWAGE SLUDGE PRODUCED AT 70% POPULATION SEWERAGE

Crops	Number of Acres Fertilized with Sludge	Estimated Savings in Dollars ($)	Annual Yields
Corn (grain)	1,980.69	148,749.82	297,103.5 bu.
Sweet Potatoes	4,131.67	195,675.89	2,065,335 bu.
Rice	4,327.47	166,262.17	9,736.85 tons
Grain Sorghum	4,131.67	161,589.61	247,900.2 bu.
Sugar Beets	2,501.64	171,737.59	62,541 tons
Tomatoes	1,902.29	225,383.32	57,060 tons
Snap Beans	17,559.61	370,858.96	87,798.05 tons
Peanuts (nuts)	5,278.03	85,292.96	6,597.54 tons
Onions	3,902.13	161,079.93	39,021.3 tons
Cotton	4,520.30	140,038.89	6,780.45 bales

used to grow only one specific crop. The estimated savings were obtained by taking the difference of costs per acre of commercial fertilizer and sewage sludge for each of the crops and multiplying by the number of acres fertilized with the sludge produced at each percentage of population sewered. The annual yields were obtained by taking the product of the desired yields per acre and the number of acres fertilized with sludge.

Table 35 shows that if all the 4,022.7 tons of sludge were used to grow only corn grain, 130,890 bushels of corn would be produced with an estimated annual savings of $62,312.36. This amount is what would have been spent to purchase commercial fertilizer. However, if snap beans were to be grown instead, the same Table 35 shows that 38,679.8 tons of beans would be produced with an annual savings of $160,211.73. Table 36 shows for instance, if all the 6,129.9 tons of sludge were used to grow only sweet potatoes (yams), 1,386,855 bushels of yams would be produced and $129,449.05 annual savings would be made. On the other hand, the growth of rice as the crop of choice would give an annual yield of 4,289.6 tons of rice, and an annual savings of $109,727.89 would be made. Similarly, Table 37 shows that if all the 9,131 tons of sludge were used to grow only tomatoes, 57,060 tons of tomatoes would be produced and $225,383.32 annual savings would be made. However, the production of only cotton as the preferred crop would result in annual yields of 6,780.45 bales of cotton and an annual savings of $140,038.89. The estimated annual savings and yields for other percentages of population sewered are shown in Appendix D. Observation of Table 35 through Table 37 show that no matter which of the ten crops are grown, an annual savings of not less than $34,367.34 will be made.

Table 35 through Table 37 show that the greatest benefit in terms of crop yields would be made if only sweet potatoes (yams), corn, grain sorghum (millate) or snap beans were grown. It is interesting to note that these crops happen toobe among Nigerian staple food stuffs. It is, therefore, expected that farmers will welcome the opportunity to maximize the yields of these crops on their farms, because they are crops that are in high demand and, thus, there will be much cash profit. In terms of savings, Table 35 through Table 37 indicate that much savings would be made if sludge were used to grow only snap beans, tomatoes, or sweet potatoes (yams). The data in Tables 35, 36, and 37 have shown that sewage sludge is not only a good fertilizer for agricultural crops, but also an excellent fertilizer for most Nigerian staple food crops.

The data in Tables 29 through Tables 37 show that not only can sludge be effectively used to produce the same desired yields of agricultural crops, but it is cheaper than commercial fertilizer and its utilization will result in much savings of Nigerian foreign exchange.

Let us consider for example a local farmer who produces 30 tons of tomatoes per acre by mere acceptance of free application of sludge on his farm, which has not been possible by usual utilization of farmyard manure. The production of 30 tons of tomatoes under normal commercial fertilizer application rate will cost him $121.50 per acre. On the other hand, if he instead chooses to produce 150 bushels/acre of corn, it would cost him $78.00 per acre. By using sludge which is supplied free by the municipality, the farmer will not only make a savings of $121.50 or $78.00 per acre depending on the crop grown but, will have more than enough for his family consumption and still have some surplus to sell for cash money. However, it must be noted that the saving to the farmers may disappear when the municipality stops subsidizing the land application program and starts selling the sludge to the farmers.

Consideration of the cost of land filling of the same quantity of sludge after drying on sand beds, which is one of the most common methods of sludge disposal, shows that it will cost the City of Enugu the sum of $102,486.14 as shown in Appendix E. This amount of money should be regarded as a complete loss, since there is no economic benefits to be derived from such a practice as compared to $5,738.86 of land application on agricultural land. Land application as shown on Table 35 results in an estimated annual saving of between $34,367.34 and $160,211.73, depending on the type of crop grown. The estimated savings is the amount of Nigerian foreign exchange that would have been used in importation of commercial fertilizer. Summing up, land application of liquid sludge on agricultural land in Nigeria can be said to have the following advantages;

1. It saves some Nigerian foreign exchange which would have been used in commercial fertilizer importation.
2. It enhances much production of local agricultural crops.
3. It saves municipalities thousands of dollars that would have been spent if other sludge disposal options such as landfilling were adopted.

The use of sewage sludge to grow many agricultural crops is not very popular in the United States, principally because most American farmers do not give adequate credit to the fertilizing ability of sludge. This is due to the fact that at present commercial fertilizers are relatively cheap. However, this attitude will not last for a long time. Manson and Merritt (1975) and Kirkham (1974) have observed that in the future, the increase in the cost of commercial fertilizers, especially the nitrogen fertilizer, because of large quantities of energy used to manufacture them, may force farmers to turn to sewage sludge as the source of fertilizer. The uneconomical consideration of sludge as compared to commercial fertilizers may be appropriate in the industrialized countries such as the United States. However, this is not the case in many developing countries such as Nigeria where millions of dollars are being spent annually to import commercial fertilizer. Recent reports from the Nigerian Federal Ministry of Agriculture showed that the Nigerian Federal Government spent $92.5 million in 1978, $70.8 million in 1979 and $90.8 million in 1980 on importation of commercial fertilizer alone (Nigeria Federal Ministry of Agriculture, 1981). It should be realized that in a situation where a traditional commercial inorganic fertilizer industry ceases to exist due to high operation costs, a sewage treatment facility is kept in business by the community that depends on its service of treating wastewater from which sludge is generated as a mere waste product which must be disposed of adequately.

Land application of liquid digested sludge is one of the most cost effective methods of sludge disposal because it eliminates many expensive sludge treatment processes. EPA (1979) estimated that by the year 1990, between 100 and 500 million dollars would be saved in the United States if land application of liquid digested sludge would be increased to about 50 per cent. It was also estimated by the same author that such increase would result by 1980 in the recovery of about 50 million dollars worth of plant nutrients and organic matter which could be utilized for growing crops and improving soil structure.

Utilization of digested liquid sludge on agricultural land as a fertilizer will be very much welcomed by the majority of Nigerian farmers who depend solely on the small quantities of farmyard manures generated within their households for their fertilizer needs. The search for fertile agricultural lands has in many instances resulted in clearing of virgin forests. The lands are then cultivated continuously for several years until they are devoid of plant nutrients. Lack of adequate plant nutrients in the soil have necessitated allowing some farmlands to grow fallow for three to five years. The vegetation is then cleared and the leaves allowed to decay in order to supply plant nutrients which are in many cases not enough. These practices result in very poor crop yields, hence, the inability of the farmers to produce enough food to feed the people and the subsequent importation of certain food stuffs from other countries.

It is necessary to emphasize that most of the commercial fertilizers used in Nigeria are being used by the few government farms, institutions such as schools and colleges and very few cooperative farms that do not contribute much to the market food supplies. The majority of market food supplies comes from local farmers who are too illiterate to understand the instructions on how to use commercial fertilizers, and therefore, are very hard to convince to invest some of their small capital on commercial fertilizers which they do not have any faith in. Experience has shown that these farmers refuse to use the fertilizer even when it is supplied free.

The author believes that the farmers' attitudes towards the use of digested liquid sludge will be different because the municipality will supply and apply the sludge at the required rates free. It has been demonstrated that a supply of adequate fertilizer by sludge will result in an increase of crop yields, hence, the production of enough food to feed the people and less dependence on imported foods. In addition to being an adequate organic fertilizer for many agricultural crops, digested liquid sludge provides soil conditioning and residual benefits which are not possible with commercial fertilizers. The author, therefore, believes very strongly that sludge will adequately supply some Nigerian farmers with their fertilizer requirements and save some of the foreign exchange that would have otherwise been used to purchase commercial fertilizer.

CHAPTER V

SUMMARY AND CONCLUSION

Introduction

This chapter is intended to give a summary of a number of issues discussed in this dissertation. One issue that motivated this author to work in this area is the enormous sum of money spent annually by Nigerian Federal Government on commercial fertilizer purchase. It is reported that the government spends an average of 84.72 million dollars annually to import commercial fertilizer (Nigerian Federal Ministry of Agriculture, 1981). The amount of money spent becomes larger when the quantity of commercial fertilizer needed to be purchased to support the "Green Revolution" included in the current five year development plan, which was started in January, 1980, is considered. The objective of this is to produce more local agricultural crops and minimize importation of food from foreign countries. To reduce this alarming expenditure, it is felt that it is reasonable for Nigerian cities that have wastewater treatment plants to utilize sewage sludge as fertilizer. Furthermore, there are not many industries to contribute to industrial wastes that may contain trace elements hazardous to animal, human and plant lives. It is the opinion of this author that this study is a contribution to the efforts being made in the developed countries to encourage application of sewage sludge on agricultural land as a fertilizer, especially in poor developing countries that spend much of their scanty foreign reserves to import commercial fertilizers.

Summary

The literature review demonstrates that application of sewage sludge to give equivalent plant nutrients as commercial fertilizer gives the same quantity of crop yields. The only difference is in the quantities required. While commercial fertilizer is applied in lbs/acre, sewage sludge is applied in tons/acre to give comparable crop yields. Sewage sludge is not very popular in the United States because of the following reasons:

1. The quantity of sewage sludge needed to achieve desired yields when compared to commercial fertilizer is too much.
2. The majority of American people have developed

an aversion to the use of sludge.

3. Most of the sewage sludges contain some toxic chemicals and trace elements that have been known or suspected to be harmful to human, animal, and plant lives.

4. Fear of transmission of pathogenic organisms.

In addition to the fertilizing benefit, sewage sludge has the additional agricultural benefits of increasing the humus content, increasing the water holding capacity of the soil and improving the soil structure.

Application of sewage sludge on agricultural land has some problems associated with it such as:

1. Odor and aesthetic nuisances.
2. Possibility of transmission of pathogenic organisms.
3. Sociological implications (public acceptance).
4. Surface and underground water pollution.
5. And seed germination inhibition.

These problems can be controlled if appropriate measures are taken. To control such problems in Enugu, Nigeria, this author recommends that the following measures be adopted:

Pathogens:

1. Public health hazards resulting from pathogenic organisms in sewage sludge should be controlled by utilizing sludge that has been digested in well designed and operated anaerobic digester at 92 to 98^{o} F (33 to 37^{o} C) for 30 days.
2. Crops to be grown should be properly selected and vegetable crops normally consumed raw should be avoided. The crops should be thoroughly washed and cooked before eating. If by chance vegetable crops are grown, they must be thoroughly washed with potable water and disinfected by dipping in 25 ppm chloramine for 5 to 10 minutes or more.

Sociological Implication

To achieve acceptance of application of sewage sludge on agricultural land by the farmers, the Enugu city officials should:

1. Obtain the farms by use-right instead of by out-right purchase and supply and apply the sludge free to the farmers.
2. Set up demonstration farms to show the people what farms fertilized with sewage sludge look like.
3. Agree to finance all the cost resulting from such operation and make sure that the farmers do not incurr sewage expenses more than usual with normal farming operation.
4. Employ sludge application rates in accordance with the nitrogen requirement of crops to be grown and add supplementary commercial fertilizer if needed to maximize crop yields.
5. Involve the farmers, chiefs, town councilors, and clan heads right

from the beginning in the planning and decision making concerning the program.

6. Make no attempts to change the community farming pattern or reduce profits. For example, introducing growing of hay in place of corn and yams (sweet potatoes) would drastically reduce profits.
7. Carry out well planned mass education programs so that the people can relate what they are doing with land application of sludge.
8. Explain to the people measures taken to monitor and safeguard the environment and public health.
9. Make continuous appraisal through conversations and town meetings of what the people think and feel of the land application of sludge, and take adequate actions to correct any

detected problems.

Surface and underground water pollution should be controlled by proper site and soil selection, adequate soil management techniques, timing of sludge application and adoption of soil conservation practices. Finally seed germination inhibition should be controlled by application of sludge a few weeks before planting the seeds.

On comparing the cost of producing some Nigerian local agricultural crops by using sewage sludge and commercial fertilizer, it was estimated that the production of say, for example, 150 bushels/acre of corn grain required 520 lbs/acre of commercial fertilizer at the cost of $78.00 while the production of the same quantity of corn/acre with sewage sludge required 4.61 tons of sludge at a cost of $6.59. Similarly, the production of 5 tons/acre of snap beans required 143 lbs/acre of commercial fertilizer at a cost of $21.45, while comparable yields of snap beans were produced with 0/48 tons/acre of sludge at a cost of $0.53. The use of sewage sludge was estimated to be on the average of 14 times cheaper than commercial fertilizer.

On comparing the residual effects of growing the same type of crops the second, third, and fourth years following the first year of sludge application, it was observed that both the sludge application rates and the costs/acre decreased progressively each year and levelled off after the fourth year. However the costs/acre and application rates of commercial fertilizer remained constant all through the years. This demonstrates that commercial fertilizer has no residual effect. When the annual savings that could be made by using sewage sludge instead of commercial fertilizer was considered, it was found that, depending on the specific crop produced, estimated annual savings of $34,367.34 to $160,211.73 could be made by using sludge produced at 50% population sewerage and $85,292.96 to $370,858.96 by using sludge produced at 70% sewerage. In terms of crop yields, it was found that the greatest benefit would be made if only sweet potatoes (yams), corn, grain sorghum (millate) or snap beans were grown. Similarly, much savings would be made if only snap beans, tomatoes or yams were grown.

Conclusion

The following conclusions can be drawn from this study:

1. Sewage sludge, if properly utilized, can be a good source of fertilizer to Nigerian farmers. It can be cheaply used to produce the same desired crop yields as commercial fertilizer.

2. The recycling of sewage sludge into the farmland could save some of the Nigerian foreign exchange used in commercial fertilizer purchased from foreign countries.
3. The utilization of free sewage sludge as fertilizer would enhance much production of local agricultural crops by the illiterate farmers who under normal circumstances depend on insufficient farmyard manures for their fertilizer needs.
4. Land application of sewage sludge on agricultural land would save the municipalities thousands of dollars that would have been spent by adopting other sludge disposal alternatives such as landfill.
5. The long-term residual benefit of sewage sludge, coupled with the high cost of commercial fertilizer, makes application of liquid sludge on agricultural land as fertilizer a very attractive sludge disposal method.
6. The problems associated with sewage sludge application on agricultural land would not be experienced by Nigerian municipalities if they

would learn from the mistakes of some of the cities in developed countries and take some time to plan land application programs and hence adopt the recommended measures to control the problems.

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APPENDIX A

COST OF IMPORTATION OF COMMERCIAL FERTILIZER, 1977-1980

FERTILIZER PROCUREMENT AND DISTRIBUTION UNIT

NIGERIA FEDERAL MINISTRY OF AGRICULTURE:

COST OF IMPORTATION OF FERTILIZER,

1977/78, 1978/79, 1979/80

Year	Quantity (tons)	Amount Niara (₦)
1977/78	298,200	52,872,485
1978/79	234,400	40,478,999
1979/80	313,140	51,879,409

Source: Fertilizer Procurement and Distribution Unit, Nigerian Federal Ministry of Agriculture, Lagos, Nigeria, 1980.

APPENDIX B

PROJECTED POPULATION OF ENUGU BASED ON 1963 CENSUS

PROJECTED POPULATION OF ENUGU BASED

ON 1963 CENSUS

Year	Population
1963	138,457
1977	274,135
1978	287,842
1979	302,234
1980	317,345

Source: Government of Anambra State of Nigeria, Anambra State Population Estimates by Local Government Areas, Statistics Division, Ministry of Economic Development and Planning, Enugu, Nigeria, Fourth Edition, 1980.

APPENDIX C

SEWAGE TREATMENT PLANT CONSTRUCTION COST INDEX AND AREA MULTIPLIERS

SEWAGE TREATMENT PLANT AND SEWER CONSTRUCTION COST INDEX

(1957 - 1959 = 100)

1ST QUARTER 1981

Cities	Values Mar. 1981	% Change Mar. 1980	% Change Dec. 1980
Atlanta	335.9	4.6	2.8
Baltimore	347.7	5.8	2.6
Birmingham	334.9	5.6	4.1
Boston	379.7	4.9	2.4
Chicago	380.2	4.4	2.1
Cincinnati	372.7	5.3	2.2
Cleveland	403.8	6.4	2.4
Dallas	352.4	5.9	1.4
Denver	361.7	4.4	0.6
Detroit	392.7	6.5	1.6
Kansas City	370.1	6.3	1.5
Los Angeles	412.1	7.3	2.6
Minneapolis	373.5	5.6	2.0
New Orleans	343.3	5.5	1.8
New York	428.1	10.0	1.5
Philadelphia	374.2	5.6	0.9
Pittsburgh	394.0	5.5	3.5
St. Louis	385.9	8.2	1.8
San Francisco	431.0	6.8	2.9
Seattle	408.9	5.9	0.3
NATIONAL INDEX VALUES	379.1	6.0	2.0

Based on a 1.0-MGD High Rate Trickling Filter Plant with Aeration.
Source: U.S. EPA, Construction Cost Indexes, 1981.

AREA MULTIPLIERS WASTEWATER TREATMENT PLANT CONSTRUCTION

1.	Albany, NY	1.17	36.	Milwaukee, WI	1.04
2.	Albuquerque, NM	0.85	37.	Minneapolis, MN	1.12
3.	Appleton, WI	1.04	38.	Mobile, AL	0.78
4.	Atlanta, GA	0.83	39.	New Orleans, LA	0.93
5.	Baltimore, MD	1.03	40.	New York, NY	1.35
6.	Binghamton, NY	1.10	41.	Philadelphia, PA	1.18
7.	Birmingham, AL	0.75	42.	Pittsburgh, PA	1.04
8.	Boston, MA	1.22	43.	Portland, ME	1.21
9.	Buffalo, NY	1.14	44.	Portland, OR	0.95
10.	Chicago, IL	1.31	45.	Providence, RI	1.21
11.	Charlotte, NC	0.77	46.	Rochester, NY	1.12
12.	Cincinnati, OH	1.12	47.	St. Louis, MO	1.07
13.	Cleveland, OH	1.15	48.	San Diego, CA	0.98
14.	Columbia, MO	0.71	49.	San Francisco, CA	1.32
15.	Dallas, TX	0.79	50.	Seattle, WA	1.05
16.	Davenport, IA	0.83	51.	Springfield, MA	1.19
17.	Denver, CO	0.93	52.	Springfield, MO	0.76
18.	Des Moines, IA	0.84	53.	Syracuse, NY	1.13
19.	Detroit, MI	1.12	54.	Wheeling, WV	1.04
20.	Duluth, MN	1.34	55.	Wilkes-Barre, PA	0.95
21.	Evansville, IN	0.95			
22.	Grand Rapids, MI	0.96			
23.	Harrisburg, PA	1.19			
24.	Houston, TX	0.87			
25.	Huntington, WV	0.84			
26.	Indianapolis, IN	1.23			
27.	Kansas City, MO	1.00			
28.	Lafeyette, LA	0.67			
29.	Lafayette, IN	1.20			
30.	Lake Charles, LA	0.89			
31.	Lansing, MI	1.06			
32.	Los Angeles, CA	1.06			
33.	Louisville, KY	0.77			
34.	Lynchburg, VA	0.89			
35.	Miami, FL	0.88			

STATE AND TERRITORIAL MULTIPLIERS

Alaska	2.74
Guam	1.40
Hawaii	1.71
Puerto Rico	0.98
Trust Territories	1.40

Source: U.S. EPA, <u>Construction Costs for Municipal Wastewater Treatment Plants 1973-1978</u>, April, 1980.

APPENDIX D

ESTIMATED ANNUAL SAVINGS AND CROP YIELDS POSSIBLE WITH UTILIZATION OF SEWAGE SLUDGE PRODUCED AT OTHER PERCENTAGES OF POPULATION SEWERAGE

TABLE 1

ESTIMATED ANNUAL SAVINGS AND CROP YIELDS POSSIBLE WITH UTILIZATION OF SEWAGE SLUDGE PRODUCED AT 52% POPULATION SEWERAGE

Crops	Number of Acres Fertilized with Sludge	Estimated Savings in Dollars ($)	Annual Yields
Corn (grain)	955.73	68,812.56	143,359.5 bushels
Sweet Potatoes (Yams)	1,993.62	89,752.77	996,810 bushels
Rice	2,088.10	77,280.58	4,698.22 tons
Sorghum grain (Millate)	1,993.62	75,019.92	119,617.2 bushels
Sugar Beets	1,207.09	79,921.43	30,177.25 tons
Tomatoes	917.89	105,796.00	27,536.7 tons
Snap Beans	8,472.88	175,981.72	42,364.4 tons
Peanuts (nuts)	2,546.76	38,201.40	3,183.45 tons
Onions	1,882.86	74,768.37	18,828.6 tons
Cotton	2,181.14	64,627.18	3,271.71 bales

TABLE 2

ESTIMATED ANNUAL SAVINGS AND CROP YIELDS POSSIBLE WITH UTILIZATION OF SEWAGE SLUDGE PRODUCED AT 54% POPULATION SEWERAGE

Crops	Number of Acres Fertilized with Sludge	Estimated Savings in Dollars ($)	Annual Yields
Corn (grain)	1,038.83	74,130.91	155,824.5 bushels
Sweet Potatoes (Yams)	2,166.97	99,897.32	1,083,485 bushels
Rice	2,269.67	84,477.12	5,106.76 tons
Sorghum grain (Millate)	2,166.97	82,019.81	130,018.2 bushels
Sugar Beets	1,312.05	87,343.17	32,801.25 tons
Tomatoes	997.71	115,474.96	29,931.3 tons
Snap Beans	9,209.61	191,836.18	46,048.05 tons
Peanuts (nuts)	2,768.21	42,021.43	3,460.26 tons
Onions	2,046.58	81,740.4	20,465.8 tons
Cotton	2,370.79	70,720.66	3,556.18 bales

TABLE 3

ESTIMATED ANNUAL SAVINGS AND CROP YIELDS POSSIBLE WITH UTILIZATION OF SEWAGE SLUDGE PRODUCED AT 56% POPULATION SEWERAGE

Crops	Number of Acres Fertilized with Sludge	Estimated Savings in Dollars ($)	Annual Yields
Corn (grain)	1,135.77	82,831.70	170,365.5 bushels
Sweet Potatoes (Yams)	2,369.18	107,963.53	1,184,590 bushels
Rice	2,481.47	92,881.42	5,583.3 tons
Sorghum Grain (Millate)	2,369.18	90,194.68	142,150.8 bushels
Sugar Beets	1,434.49	90,024.76	35,862.25 tons
Tomatoes	1,090.81	126,773.94	32,724.3 tons
Snap Beans	10,069.04	210,241.56	50,345.2 tons
Peanuts (nuts)	3,026.53	46,457.23	3,783.16 tons
Onions	2,237.76	89,913.20	22,377.6 tons
Cotton	2,592.03	77,838.66	3,888.04 bales

TABLE 4

ESTIMATED ANNUAL SAVINGS AND CROP YIELDS POSSIBLE WITH UTILIZATION OF SEWAGE SLUDGE PRODUCED AT 58% POPULATION SEWERAGE

Crops	Number of Acres Fertilized with Sludge	Estimated Savings in Dollars ($)	Annual Yields
Corn (grain)	1,232.73	90,420.74	184,909.5 bushels
Sweet Potatoes (Yams)	2,571.45	119,623.85	1,285,725 bushels
Rice	2,693.32	101,322.70	6,059.97 tons
Sorghum Grain (Millate)	2,571.45	98,409.39	154,287 bushels
Sugar Beets	1,556.96	104,736.7	38,924 tons
Tomatoes	1,183.94	138,106.6	35,518.2 tons
Snap Beans	10,928.65	228,736.64	54,643.25 tons
Peanuts (nuts)	3,284.91	50,916.10	4,106.14 tons
Onions	2,428.59	98,066.46	24,285.9 tons
Cotton	2,813.31	84,990.09	4,219.96 bales

TABLE 5

ESTIMATED ANNUAL SAVINGS AND CROP YIELDS POSSIBLE WITH UTILIZATION OF SEWAGE SLUDGE PRODUCED AT 62% POPULATION SEWERAGE

Crops	Number of Acres Fertilized with Sludge	Estimated Savings in Dollars ($)	Annual Yields
Corn (grain)	1,454.36	107,680.81	218,154 bushels
Sweet Potatoes (Yams)	3,033.75	142,131.19	1,516,875 bushels
Rice	3,177.53	120,555.49	7,149.44 tons
Sorghum (Grain) (Millate)	3,033.75	117,102.75	182,025 bushels
Sugar Beets	1,836.87	124,558.15	45,921.75 tons
Tomatoes	1,396.79	163,941.24	41,903.7 tons
Snap beans	12,893.46	270,762.66	64,467.3 tons
Peanuts (nuts)	3,875.49	61,077.72	4,844.36 tons
Onions	2,865.21	116,728.66	28,652.1 tons
Cotton	3,319.11	101,266.05	4,978.66 bales

TABLE 6

ESTIMATED ANNUAL SAVINGS AND CROP YIELDS POSSIBLE WITH UTILIZATION OF SEWAGE SLUDGE PRODUCED AT 64% POPULATION SEWERAGE

Crops	Number of Acres Fertilized with Sludge	Estimated Savings in Dollars ($)	Annual Yields
Corn (grain)	1,565.16	116,307.04	234,774 bushels
Sweet Potatoes (yams)	3,264.88	153,384.06	163,244 bushels
Rice	3,419.62	130,150.74	7,694.14 tons
Grain Sorghum (Millage)	3,264.88	126,446.48	195,892.8 bushels
Sugar Beets	1,976.82	134,483.06	49,420.5 tons
Tomatoes	1,503.12	176,857.1	45,093.6 tons
Snap Beans	13,875.77	291,946.2	69,378.85 tons
Peanuts (nuts)	4,170.75	66,189.80	5,213.44 tons
Onions	3,083.50	126,053.48	30,835 tons
Cotton	3,571.98	109,445.47	5,357.97 bales

TABLE 7

ESTIMATED ANNUAL SAVINGS AND CROP YIELDS POSSIBLE WITH UTILIZATION OF SEWAGE SLUDGE PRODUCED AT 66% POPULATION SEWERAGE

Crops	Number of Acres Fertilized with Sludge	Estimated Savings in Dollars ($)	Annual Yields
Corn (grain)	1,703.66	127.076.00	255,549 bushels
Sweet Potatoes (Yams)	3,553.80	167.455.06	17,776,900 bushels
Rice	3,722.23	142,151.96	8,375.02 tons
Grain Sorghum (Millate)	3,553.80	138,136.21	213,228 bushels
Sugar Beets	2,151.75	146,856.94	53,793.75 tons
Tomatoes	1,636.23	192,993.33	49,086.9 tons
Snap Beans	15,103.65	318,233.91	75,518.25 tons
Peanuts (nuts)	4,539.82	72,500.92	5,674.77 tons
Onions	3,356.37	137,678.3	33,563.7 tons
Cotton	3,888.07	119,597.03	5,832.10 bales

TABLE 8

ESTIMATED ANNUAL SAVINGS AND CROP YIELDS POSSIBLE WITH UTILIZATION OF SEWAGE SLUDGE PRODUCED AT 68% POPULATION SEWERAGE

Crops	Number of Acres Fertilized with Sludge	Estimated Savings in Dollars ($)	Annual Yields
Corn (grain)	1,842.17	137,923.27	276,325.5 bushels
Sweet Potatoes (Yams)	3,842.71	181,568.05	1,921,355 bushels
Rice	4,024.83	154,231.49	9,055.87 tons
Grain Sorghum (Millate)	3,842.71	149,865.69	230,562.6 bushels
Sugar Beets	2,326.68	159,307.78	58,167 tons
Tomatoes	1,769.25	209,196.12	53,077.5 tons
Snap Beans	16,331.54	344,595.49	81,657.7 tons
Peanuts (nuts)	4,908.90	78,935.11	6,136.12 tons
Onions	3,629.23	149,379.11	36,292.3 tons
Cotton	4,204.16	129,824.46	6,306.24 bales

APPENDIX E

COST OF DISPOSAL OF SLUDGE BY SAND DRYING AND LANDFILL

COST OF DISPOSAL OF SLUDGE BY SAND DRYING AND LANDFILL

Capital Cost

1. The base capital cost = \$47,500. This was obtained by taking the mid-range of the difference of total capital cost of liquid disposal from the liquid treatment and total capital cost from option 4 column of sludge treatment which is the anaerobic digested, sand drying and landfill of sludge column.

2. Determine the multiplier to account for flow change by taking the ratio of the new flow rate 15 MGD to the old flow rate 10 MGD to the 0.6 exponential rule. Flow change multiplier = $\left(\frac{15}{10}\right)^{0.6} = 1.27$

3. Adjusted base cost = 1.27 x \$47,500 = \$60,325

4. The cost adjustment due to change in National Cost Structure was determined by first calculating the National Cost factor as the ratio of the prevailing STPCCI index (334.9) and base STPCCI index (175) employed by EPA in 1973 during the profit sheet study.

   National Cost Factor = $\frac{334.9}{175} = 1.91$

5. Price index adjusted cost: 1.91 x $60,325

   = $115,220.75

6. Variation in price due to local considerations was determined by taking the product of local multiplier, 0.75 and the price index adjusted cost:

   Total adjusted cost = 0.75 x $115,220.75

   = $86,415.56

7. The base land required was obtained by taking the mid-range of land requirement of option 4, Table 26.

   Base land requirement = 6.3 acres.

8. Land requirement multiplier = 1.27

9. The adjusted land requirement was determined by taking the product of base land requirement and the land requirement multiplier.

   Adjusted land requirement = 1.27 x 6.3 = 8 acres

10. Adjusted land cost = 8 acres x $106,575

    = $852,600

11. Total capital expenditure = $86,415.56 + $852,600

    = $939,015.56

12. Amortization on annual capital cost was calculated by taking the product of total capital (cost) expenditure and capital recovery factor (CRF) 0.109

    A.C. = P x (CRF)

Where:

A.C. = Annual cost

P = Capital cost

CRF = Capital recovery factor

A.C. = P x (CRF) = $939,015.56 x 0.109 = $102,352.7.

Operation and Maintenance Costs

1. The base labor requirement was determined from Table 26, option 4, by taking the mid-range of the listed base labor requirement.

   Base labor requirement = 6.87 man-years

2. The labor multiplier was calculated by taking the ratio of desired flow and the base flow to the 0.58 power $\left(\frac{15}{10}\right)^{0.58} = 1.26$

3. The adjusted labor requirements: 1.26 x 6.87 = 8.65 man-years

4. The daily labor cost was calculated by taking the product of adjusted labor requirement and local cost of $1.20/hour and conversion factor of 8 man-hour per man-day: 8.65 x $1.20 x 8 = $83.04 day

5. The base electrical requirement was determined from Table 26, option 4, as the energy requirement for sludge treatment.

Base electrical requirement = 30 Kw hr/day

6. The electrical multiplier was determined by taking the ratio of the desired flow and the base flow to the 0.55 power. $\frac{(15)}{(10)}^{0.55} = 1.25$

7. The adjusted electrical requirement:

   1.25 x 30 = 37.5 Kw hr/day

8. The daily electrical cost was calculated by taking the product of electrical requirement and local cost of power of \$0.11.

   37.5 x \$0.11 = \$4.12/day

9. Quantity of sludge requiring transportation, from sludge production calculation: 11.02 tons/day

10. The daily sludge transportation cost was calculated by taking the product of quantity of sludge, transportation distance for sludge of 10 miles and transportation cost for sludge of \$0.42.

    11.02 x 10 x \$0.42 = \$46.28/day

11. Total operation and maintenance costs:

    \$83.04 + \$4.12 + \$46.28 = \$133.44

12. Total annual cost: \$133.44 + \$102,352.70

    = \$102.486.14

APPENDIX F

GUIDELINES

GUIDELINES

The following are some guidelines for safe operation of land application of sewage sludge on agricultural land in Nigeria:

1. Sewage sludge to be applied on agricultural land should be well stabilized by anaerobic digestion to reduce public health hazard and prevent nuisance odor condition.
2. Sludge conveyance to the application sites should be with leak-proof tank trucks to prevent possiblity of spillage, dissemination of odors along the roadways.
3. Since sludge characteristics vary from day to day, it is necessary to carry out periodic sludge analysis instead of relying on a one-time test result to determine sludge properties such as: pH, total solids, volatile solids, nitrogen, phosphorus, potassium and trace elements.
4. Equipment should be maintained in good working condition at all times and should be cleaned on a regular basis.
5. Soil for sludge application should be

properly tested to gain full knowledge of such soil data as: phosphorus, potassium, nitrogen, pH, trace elements and cation exchange capacity.

6. Sludge application rate should be based on the nitrogen requirements of the crops to be grown. Sub-surface injection application method should be adopted. Where necessary, as determined by soil test, supplementary commercial fertilizer should be added to maximize crop yields.
7. Crops that are usually consumed raw should not be grown on farms fertilized with sewage sludge.
8. Sludge should not be sprinkled over or brought in direct contact with growing or matured vegetables. Therefore, sludge should be applied on the land a few weeks before planting the seeds.
9. Records of the whole operation should be kept and should include such things as the location of the farms and the quantities of sludge applied.

10. The farm selected for sludge application should not be susceptible to flooding, should be remote from surface water supplies and isolated from residential areas. Maximum distance between the farms and surface water should be determined by the land slope, as shown in Table 1.

11. As the country becomes industrialized, industries must be forced to pre-treat their wastes before discharging into the municipal waste-water treatment plant, to reduce to a safe level or when possible remove completely toxic trace elements, such as Cd, Cu, Zn, Ni, B, and Pb.

12. With metal contaminated sludge, the recommended upper limits for metal addition into the soil to prevent human, animal or plant injuries should be in accordance with Table 2.
Under no circumstances should the annual sludge application result in more than 2 lbs. of Cd/ acre. Soil pH of greater than 6.5 must be maintained on the farms for years to reduce trace element solubility and plant uptake of

TABLE 1

MAXIMUM DISTANCE TO WATER COURSES UNDER VARIOUS MAXIMUM SUSTAINED SLOPES ON FROST FREE SOILS

Slopes %	Minimum Distance to Water Course (M)
0 to 3	61 (200 feet)
3 to 6	122 (400 feet)
6 to 9	184 (603 feet)

Source: Dowdy, R.H., et al., "Sewage Sludge and Effluent Use in Agriculture," Presented at Soil Conservation Society of America Conference on Land Application of Waste Material, Des Moines, Iowa, March 15-18, 1976.

TABLE 2

TOTAL AMOUNT OF SLUDGE METAL ALLOWED ON AGRICULTURAL LAND

	Soil Cation Exchange Capacity(meg/100g)*		
Metal	0-5	5-15	15
	Maximum Amount of Metal (lb/acre)		
Pb	500	1,000	2,000
Zn	250	500	1,000
Cu	125	250	500
Ni	50	100	200
Cd	5	10	20

* Determined by pH 7 ammonium acetate procedure.

Source: Sommer, L.E., and Nelson, D.W., "Analyses and Their Interpretation for Sludge Application to Agricultural Land," Application of Sludge and Wastewaters on Agricultural Land: A Planning and Educational Guide, EPA-MCD-35, U.S. Environmental Protection Agency, Washington, D.C., March, 1978, p. 3.5.

the potential toxic trace elements.

13. Ground water table, should not be less than three feet from the surface soil with moderate permeability and not less than five feet from the surface soil with high permeability.

APPENDIX G

NIGERIA CURRENT INTEREST RATES, AND LAND COST

UNION BANK
UNION BANK OF NIGERIA LIMITED

 UNION BANK OF NIGERIA LIMITED
Okpara Avenue, P.M. Bag 1119, Enugu
Telephone 3117, 2840 (Manager)
Telegrams Barkpara

6, JULY 1981

PRIVATE & CONFIDENTIAL

Mr. R. E. Ilo
119W, Constitution
Norman, Oklahoma 73069

Dear Sir

LONG-TERM LOAN ON PUBLIC CONSTRUCTION

Construction of buildings and other public utilities by the Government falls under the above Sector. With our present lending guidelines advances or lendings under this heading attract an interest rate of 9%. However construction of pure residential buildings is classified under the preferred Sector - and lendings under this sector attract interest rate of 6% as it is geared towards encouraging Nigerians to set up residential properties of their own to boost the Housing Scheme of the present Federal Government.

Yours faithfully

I. C. UJUAGU
ACCOUNTANT

GOVERNMENT OF ANAMBRA STATE OF NIGERIA

Telegrams : PERMLANDS

Telephone :

Your ref..

Our ref...MLSTP/TPD/Vol.II/186...

(*All replies to be addressed to the Permanent Secretary.*)

MINISTRY OF LANDS, SURVEY AND TOWN PLANNING

Land DIVISION

P.M.B. 1078

ENUGU

2nd November 1981

Dear Mr. R. E. Ilo.,

REQUEST FOR INFORMATION REGARDING THE COST OF LAND IN ENUGU

I am writing in reply to your inquiry concerning the cost of land in Enugu, metropolitan area. Land cost around the city, varies depending on whom you are buying it from. However, I will give you the official government price. The Government of Anambra State, stipulates that a plot of land, 50ft. by 100 ft. should cost ₦7000.00 and an acre ₦60900.00. It must be stressed that any person who plans to buy land from an individual must be prepared to spend a little bit more money. If you have any further questions concerning this, do not hesitate to contact me.

Thank you.

Yours faithfully,

D. A. Okoli,
for: Permanent Secretary,
Ministry of Economic Development and Planning.