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Environmental effects of applying feedlot runoff to grassland plots by sprinkler irrigation.

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To the Graduate Council:

I am submitting herewith a dissertation written by Naufal Al-Masri entitled "Environmental effects of applying feedlot runoff to grassland plots by sprinkler irrigation.." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Biosystems Engineering.

D.H. Luttrell, Major Professor

We have read this dissertation and recommend its acceptance:

L.M. Safley Jr, C.H. Shelton, W.L. Parks, H.O. Vaigneur, B.L. Bledsoe

Accepted for the Council:

Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

To the Graduate Council:

I am submitting herewith a dissertation written by Naufal Al-Masri entitled "Environmental Effects of Applying Feedlot Runoff to Grassland Plots by Sprinkler Irrigation." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Agricultural Engineering.

Houston Luttrell
Dr. D. H. Luttrell, Major Professor

We have read this dissertation
and recommend its acceptance:

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Vice Chancellor
Graduate Studies and Research

A

ENVIRONMENTAL EFFECTS OF APPLYING FEEDLOT RUNOFF TO GRASSLAND PLOTS BY SPRINKLER IRRIGATION

A Dissertation
Presented for the
Doctor of Philosophy
Degree
The University of Tennessee, Knoxville

Naufal Al-Masri
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ABSTRACT

Irrigation of grassland with feedlot runoff appears to be a practical solution to the problem of disposal of such material.

The major objectives of this study were: (1) to determine the effects on quality of surface water and groundwater of applying different rates of lagoon effluent on grassland plots, and (2) to determine effects on soil physical properties.

A lagoon effluent irrigation system at The University of Tennessee - USDA Dairy Experiment Station at Lewisburg, Tennessee, served about 200 milk cows on a 8,826 m^2 concrete lot from which runoff was collected into drains and delivered by gravity flow into a 5,550 m^3 lagoon. The lagoon effluent was pumped through 10.16 cm diameter aluminum pipe to fifteen experimental plots and applied to the plots via a sprinkler irrigation system. Each plot area was 40.5 m^2 and had an average slope of 1 to 2 percent. Each plot was equipped with devices for the collection of surface runoff and shallow groundwater samples. Samples were collected following natural or simulated rainfall and analyzed for selected water quality parameters. Eighteen core samples of two types of soil, sandy loam and clay loam, were analyzed to determine the change in permeability and bulk density of soil due to the application of lagoon effluent having 0.0, 0.1, and 0.3 percent solid fibrous material.

The application of 2.54, 5.08, 7.62 and 10.16 cm depth of lagoon effluent to plots resulted in a high ammonia nitrogen concentration in surface runoff and groundwater from the plots which exceeded the maximum standard for raw surface water. The chemical oxygen demand concentration of the surface runoff and groundwater was much higher than that of nearby creek water.

Factors existing at the time of lagoon effluent application which affected water quality parameters measured in surface runoff from the plots were: rainfall amount and intensities, soil moisture of the root zone, delay in time between lagoon effluent application and the occurrence of rainfall, and the rate at which lagoon effluent was applied to the plots.

More reduction in the permeability and bulk density due to application of lagoon effluent occurred in the sandy loam soil than in the clay loam soil. The application of lagoon effluent with high solid fibrous material content caused more reduction in soil permeability and bulk density than lagoon effluent with low solid fibrous material content.

TABLE OF CONTENTS

CHAPTER PAGE

LIST OF TABLES

TABLE PAGE

LIST OF FIGURES

FIGURE PAGE

CHAPTER I

INTRODUCTION

A. IMPORTANCE OF THE STUDY

Agricultural production has increased very rapidly to supply food for world's population growth, and remarkable changes in the efficiency of world agriculture have occurred. This increased efficiency has generated a variety of environmental problems. One of these problems is animal waste, which is considered to be one of the major pollutants to surface water and/or groundwater (Loehr, 1976). In the past, animal wastes were almost totally neglected, often resulting in extensive environmental contamination. Today approximately two billion tons of wet manure are produced annually by domestic animals in the United States (Ross _et al_., 1978). This large quantity of manure has to be disposed of cautiously if tolerable pollution to the environment is to occur.

Land distribution is the simplest and oldest method of manure disposal. This method is not only effective; but it also supplements soil fertility. The rate and frequency of manure application are determined by such factors as temperature, land use, soil type, and the danger of organic and inorganic pollution of the water resource.

Treatment of animal waste is sometimes necessary to avoid land and water pollution. The nature, extent, and cost of a treatment system are determined by several important factors, including:

1. size of livestock unit;
2. location of the unit with respect to other production units, streams, and water courses;
3. the nature and availability of the surrounding land;
4. availability of existing handling, storing, and disposal systems for animal wastes; and
5. chemical and physical properties of the animal waste.

Three degrees of treatment may be appropriate: odor control, partial treatment, and complete treatment. Odor control is commonly required where liquid manure is distributed on land close to urban communities. In the partial treatment system a stabilization of waste products by solid separation is necessary to reduce danger of pollution from waste runoff, and potential leaching of pollutants from manured land. A lagoon system can be used in this system. The complete treatment system includes a complete control system of the nutrient conversion and chemical reaction of the animal waste. This treatment is required when the farm has little or no associated land for spreading.

An understanding of the factors affecting the biological processes occurring in animal waste treatment facilities is essential. Treatment systems may treat liquid or solid waste, may be aerobic or anerobic, and may be within controlled structures or unconfined on the land. Biological treatment processes include oxidation ponds, aerated lagoons, oxidation ditches, anaerobic lagoons, anaerobic digesters, composting, and land disposal. Ponds and lagoons are among the simplest treatment systems and are widely used in animal waste disposal systems. An anaerobic lagoon is a simple treatment process that can achieve solids separation of a waste as well as biological stabilization of a portion of the waste. Such a lagoon can be useful for holding and treating animal wastes by destruction and stabilization of organic matter prior to field application. Lagoons can be used as primary sedimentation units to reduce the load on subsequent treatment units. Solids accumulated in the lagoon are left inside to undergo anaerobic decomposition. The rate of solids accumulation is a function of the loading rate, characteristics of the raw waste, and the rate of solids stabilization. Gradual accumulation of solids usually occurs, and periodic solids removal is necessary. The effluent from an anaerobic lagoon is seldom safe for discharge into a stream. Consequently, in most states the discharge of lagoon effluent into flowing streams is prohibited. Lagoon effluent seldomly meets the BOD, phosphate, nitrogen, or bacterial criteria specified in state standards. One alternative to stream disposal is land application by furrow or sprinkler irrigation. Liquid manure sprinkling onto pasture or waste disposal plots may provide a disposal method for excess liquid.

Temperature is perhaps the variable having the greatest influence on the performance of an anaerobic lagoon. The amount of mixing, pH, salinity, detention time, and type of feed ration will also affect the operation of a lagoon system.

A dairy farm with a lagoon facility is usually operated so that the wastewater and feedlot surface runoff are diverted into a lagoon for storage during cold months and then periodically removed and distributed on land via irrigation during the hotter months of year when the water table level is low. Chopper pumps which can move any material that will flow to the pump are in use. Large nozzles on sprinkler heads will adapt conventional irrigation systems for spreading liquid manure. Such systems can handle liquid manure of less than 5 percent solids concentration. A sprinkler system should be operated so that surface runoff does not occur. Factors affecting the selection of sprinkler system are soil infiltration capacity, field surface slope, vegetative cover, soil moisture condition, and weather. When the application rate is low and vegetative cover is present, liquids are absorbed by the soil and erosion is inhibited. However, surface runoff water might reach a stream and cause a pollution problem. The nature of polluted water might take many forms (Hermanson and Koon, 1973):

1. oxygen depletion and excessive nutrient loads in streams, both of which have reportedly contributed to fish kills;
2. infectious agents that have affected other animals, including man;
3. obnoxious odors that cause human discomfort and economic losses in the community, and might affect animal-product quality;
4. pesticides which might appear in many forms as residues in animal products;
5. unsightly appearance of streams; and
6. toxic gases that might affect livestock and humans.

Predicting the effects of animal waste land application on water sources, soil properties and plant growth requires a knowledge of the composition of the waste material. Only if the concentrations of the constitutents in the waste are known can one estimate such reactions as solute movement in the soil and plant nutrient availability or toxicity. Little research has been done on liquid manure effects on soil physical properties.

B. OBJECTIVES

Techniques have been developed for collecting, storing, and treating manure. A major remaining task and challenge is to determine the limits of our environment to accept, and utilize animal wastes. Guidelines for safe and efficient application of animal waste on land are needed to provide information about application rates and amounts. Such rates and amounts should maintain maximum soil productivity and nutrient recycling, while avoiding surface water and groundwater contamination. The specific objectives of this study are:

1. To determine the effects on surface runoff and shallow groundwater quality of applying different rates of anaerobic lagoon effluent on grassland plots; and
2. To determine changes in soil physical properties due to application of anaerobic lagoon effluent.

CHAPTER II

REVIEW OF LITERATURE

A. POLLUTION CHARACTERISTICS OF ANIMAL WASTE

Selection of effective treatment and/or disposal methods requires an understanding of the characteristics of a waste material. Treatment of liquid waste is appropriate if it contains dissolved organic solids (Loehr, 1977). Ponds and lagoons are among the simplest land treatment systems in current use. Lance (1978) suggests that land treatment systems can be designed and operated to renovate wastewater without producing health hazards due to contaminated air, water, or farm products. He further states that different kinds of systems are needed for different soils, topography, and ground water.

The major types of ponds and lagoons can be classified as faculative, aerobic, and anaerobic. Anaerobic ponds, the type used in this study, are systems in which the concentration of organic wastes applied per unit volume is sufficient to cause complete depletion of dissolved oxygen by limiting photosynthesis, by high biochemical oxygen demands (BOD), or by a combination of both (Loehr, 1977). In these ponds, up to 75 percent of the applied BOD can be accounted for as methane and carbon dioxide released to the atmosphere. (Methane formation is the primary biological process for carbonaceous BOD removal in these units.)

The BOD measurement evaluates the concentration of oxidizable organic material that can be utilized by aerobic bacteria in terms of the amount of oxygen it will require to metabolize this material during a specified time, generally five days at specified temperature, generally 20° C.

Chemical oxygen demand (COD) is another measure of organic and other oxygen-demanding water based on chemical rather than biological oxidation. Humenik (1971) reported that more attention should be directed to the COD and to total organic carbon tests as more reliable measures of the pollutional potential of animal waste. The organic nitrogen compounds can be transformed to ammonium nitrogen and oxidized to nitrite and nitrate nitrogen. The oxidation of ammonia to nitrite and nitrate is thus termed nitrification and occurs under aerobic conditions. Ammonia nitrogen is the main soluble end product in anaerobic units. Denitrification is the process by which nitrate and nitrite nitrogen are reduced to nitrogen gas and gaseous nitrogen oxides under anoxic conditions. This process requires the availability of reducing agents (organic material).

Koelliker and Miner (1971) describe the N transformation within anaerobic lagoons as well as the desorption process by which large amounts of N can be lost. Their data indicate N losses up to 65 percent of the total entering the lagoons annually. Meyer (1973) also found that N losses from dairy waste holding ponds were from 20 to 50 percent.

A primary step in anaerobic treatment is the liquefaction of organic matter and inorganic phosphorus compounds that are released from organic compounds. Microbial transformations of sulfur are similar to those of nitrogen. Both sulfide and ammonia are decomposition products of organic compounds. Both are oxidized by autotrophic bacteria, as are other incompletely oxidized inorganic sulfur and nitrogen compounds. Sulfate and nitrate are reduced by microorganisms under anaerobic conditions. Nye et al. (1971) indicate that, in water-diluted manure, the bacteria reduce the nitrates to nitrogen gas while oxidizing the organic matter, or they reduce the sulfates to sulfides. Both nitrates and sulfates are reduced before methane formation.

Temperature and other climatic conditions are factors which control the chemical and biological activities inside lagoons and holding ponds. Nye et al. (1971) concluded that a definite change in the rate of decomposition of COD and volatile solids seems to occur between 48° F and 56° F.

B. APPLICATION RATES AND AMOUNT

Vaigneur (1972) states that if land on which feed was produced for a particular operation is available for waste disposal, the primary problem would be one of scheduling the disposal operation. Despite public concern, the application of animal waste to soil has been an accepted practice since animals were first domesticated (Menzies, 1976).

Physical and chemical characteristics of liquid waste are factors that limit its application on land. Mutlak et al. (1975) reported that the major factor restricting the application rate of effluent from an anaerobic lagoon would be the increased nitrate content in the grass and soil.

The degree of effluent pollutant reduction required prior to land application is given in the Environmental Protection Agency (EPA) regulations. The first level of regulation that took effect July, 1977 specifies the following: "No discharge of process wastewater is allowed into (process wastewater includes any precipitation which comes into contact with any manure) a navigable water except for runoff which is not contained by facilities designed, constructed and operated to contain all process wastewater in addition to the runoff from the 10-year, 24 hour rainfall event as established by the U. S. Weather Bureau, for the region in which the point source discharge is located." The second level of regulation takes effect July, 1983 and is identical to the first except that the rainfall event is changed to a 25-year, 24 hour event.

Application rates vary according to liquid characteristics, weather of the region, land availability, topography and soil condition. Different quantities have been recommended by different researchers. Bartlett and Marriot (1971) maintained that the optimum rate of liquid manure application is not substantially greater than that which will supply the maximum nitrogen required by the crop produced. Sewell et al. (1975) reported that waste application by slurry irrigation should not exceed crop fertilization rates and should be initiated only where enough land area is available to minimize ground and surface water quality degradation. Manges et al. (1972) found that corn yield could be increased with application of up to 10 inches of beef feedlot runoff application annually. The plots used in the research were on silty clay loam soils. Cummings et al. (1975) found no apparent damage to the crop or soil from applying 22 inches and 24 inches of swine effluent for the first and second year, respectively. Barker and Sewell (1973) report liquid dairy manure slurry application of 5.5 tons of dry matter per acre per month over a two year period. The slurry had an average dry matter content of 4.18 percent, and was applied to pasture, winter wheat and sudan sorghrum hybrid on a four-acre plot. A large sprinkler was used to provide an application rate of 0.5 inch per hour on predominantly clay loam soils having medium to high infiltration rates.

Application rates of liquid manure will differ among regions. Butler _et al_. (1974) advocated initially using a two-inch application of municipal wastewater per week as a general rule for Pennsylvania conditions. McCaskey _et al_. (1971) described irrigation with dairy manure slurry on grassland plots at rates equivalent to twenty-three cows per acre. They also reported that an application rate of approximately twelve tons of solids per acre year applied preferable at one ton per acre per month would permit continuous use of grassland for waste disposal without significant accumulation of manure solids and without impairing runoff water quality beyond standards. In Nebraska Nienaber _et al_. (1973) disposed of wastewater from a 9.3 acre feedlot on a pasture one-half the size of the feedlot. A sprinkler system was used with individual sprinkler discharge rates of 4.2 gallons per minute. Nine different grasses were used, and yields of all grasses were increased due to the wastewater application.

Heavy liquid manure application might effect the nutrient level in the soil profile. McCaskey _et al_. (1971) indicated that the cumulative average of nitrate level in soil at 2 - 12 inch depth was 0.3 milligram per 10 grams of soil for a plot receiving heavy application of liquid dairy manure. This was ten times greater than the nitrate level in the soil not receiving these wastes. Humenik et al. (1975) also found that approximately 85 percent of the wastewater nitrogen was converted to nitrate within the rooting zone (upper 15 cm) for loading rates 2.5 and 5 cm per week with wastewater ranging from COD = 199 mg/l, TKN = 34 mg/l to COD = 650 mg/l, and TKN = 230 mg/l. Average overall removals and conversions of organics and nitrogen were not significantly affected by applying 2.5 or 5 cm of wastewater per week. A mass balance showed no losses in total nitrogen as the wastewater percolated through the soil columns when the initial storage capacity was exhausted after the first eight weeks.

Lagoon and holding pond effluents are commonly applied to land by sprinkler irrigation systems. However, regulations have been imposed on applying wastewater by sprinkler irrigation. A good example of such regulation as described by Porter (1975) is the one in New York State. The Department of Environmental Conservation in New York State and the EPA have taken the position that spray irrigation of wastewater requires a permit. The permit requirement is an attempt to assure that the discharge of wastewater by spray irrigation meets the following conditions:

1. Spray irrigation shall be practiced during the period of May 1 to November 1;

2. Spray irrigation shall be practiced during daylight hours with no spraying during periods of precipitation;
3. No field shall be irrigated on two consecutive days;
4. Surface runoff of irrigated wastewater from the spray field shall not be permitted.

A change in effluent chemical properties might exist from the pond to the land when applied by a sprinkler irrigation system. Koelliker and Miner (1971) reported N losses of 15 to 30 percent between the lagoon and the ground surface during sprinkling.

Many advantages and disadvantages of using a sprinkler irrigation system to dispose of animal waste were given in Barker's (1973) work. The listed advantages are as follows:

1. The labor requirement is low and affected only slightly by increased distance from sources to the sprinkler area.
2. A high water dilution rate can be tolerated without greatly increasing the cost of manure distribution.
3. Pipeline equipment can also be used for conventional irrigation.
4. Pipes and sprinkler equipment may be moved without the necessity for heavy vehicles traveling over land.

The disadvantages were given as follows:

1. The equipment cost is high and increases as delivery distance increases.
2. Blockages in the pump and sprinklers, if frequent, can be troublesome.

3. Manure slurry distribution can be uneven in high winds.
4. Odors created by sprinkler action may be widespread and offensive.

Using irrigation systems in handling liquid manure have been recommended by Swanson et al. (1973). They state that "distributing this wastewater to the disposal area by means of an irrigation system is the most feasible method of disposal." Butchbaker et al. (1971) also recommended using irrigation systems for disposing animal liquid waste. They stated that "in the case of hydraulic handling methods, irrigation offers the possibility for the final step of ultimately disposing of animal waste material on the land."

C. SURFACE RUNOFF QUALITY

Water reaching the soil surface is disposed by: surface runoff, groundwater movement, deep percolation, storage, evaporation and transpiration (Willrich and Smith, 1970).

Surface runoff, groundwater movement, and deep percolation contribute to eutrophication by transporting nutrients to streams and lakes. According to Biggar and Corey (1969), irrigation which involves a recycling of water derived from runoff, seepage, and percolation often increases the amount of nutrients transported to lakes and streams by these waters.

It is generally expected that inorganic nitrogen is transported mainly as nitrate by percolating waters, although the amounts of ammonium and nitrate carried in runoff waters may be highly significant in terms of the receiving water. Similarly, the largest amount of phosphorus is likely transported in particulate form in runoff waters, but the amount of dissolved phosphorus in runoff water might be of equal or greater importance even though lower in quality. Both organic nitrogen and organic phosphorus, as well as inorganic phosphorus, are of low mobility in soil and are likely transported to a large extent in particulate form in runoff wastes (Willrich and Smith, 1970). However, because of the amount of organic nitrogen, quantities of soluble organic nitrogen transported may be significant relative to amounts of inorganic nitrogen. McCaskey et al. (1971) found that the average nitrate nitrogen level in runoff from plots irrigated with liquid manure at rates equivalent to 23 cows per acre was 5.1 milligrams per liter. Sewell et al. (1974) also found that manure slurry apparently infiltrated the shallow groundwater on the downslope side of the test area during periods of high rainfall. All surface runoff nitrate nitrogen median concentrations were within the permissible criteria.

Runoff water from a manured area should be collected and reused as irrigation water. Cross (1975) found the nitrate nitrogen displacement in the runoff water exceeded the allowable limit for water (10 ppm) only during the first 90 minutes of the first irrigation on the heavily manured plots. Under the most pollutional conditions, the maximum contribution to the electrical conductance was only 0.4 millimhos per cm. The water quality standards set a maximum value of electrical conductance of four milliomhos per cm for water suitable for irrigation. Cross found further that the only treatment which produced a statistically significant increase in crop yield was the manure application rate. In contrast, Lund et al. (1975) found that manure did not appreciably affect the NH_4-N content of runoff water. Moreover, the NO_3-N content of the runoff water was essentially unaffected by the manure treatment.

Denitrification might take place during a high precipitation period. Rundall et al. (1975) reported that the low concentration of NO_3-N in soil solution suggested that denitrification reactions may be present during periods of high precipitation, resulting in a loss of NO_3-N and/or slow mineralization of the organic N to inorganic forms.

Rainfall intensity and duration might affect nutrient transport in surface runoff. In a study conducted by Cummings et al. (1975), the rainfall was the major uncontrolled variable influencing swine effluent concentration and soil nutrient movement in the two year period of study. Surface runoff resulting from rainfall, indicated a portion of the nutrients applied was lost by rainfall runoff during the first year.

A delay of time between liquid manure application and rainfall occurrence can also decrease the degree of pollutant in surface runoff. Cross (1975) noted a decrease in NO_3-N concentration in the runoff with elapse of time between manure application and rainfall occurrence. Ross et al. (1978) agreed with Cross's finding in a study conducted in Kentucky. They reported that pollutant concentration in runoff was a function of the concentration in the liquid manure and the total quantity of runoff. Increasing the delay time between application of liquid manure and the simulated rainfall event significantly decreased pollutants in the runoff.

On the other hand, an extended rainfall event might increase the pollutant value in a surface runoff. Miner et al. (1967) found that runoff contamination from an extended rainfall event first increases then decreases to a relatively constant value during the storm. Swanson et al. (1971) reported results similar to those of Miner. They reported that ammonia and nitrate nitrogen contents of runoff decreased on the length of time of precipitation increased indicating leaching of these compounds from feedlot surface.

Bacterial transport in runoff generated by a rainfall event might also occur. Sewell et al. (1975) found that rainfall runoff from the surface of the area receiving slurry irrigation exhibited high bacterial and chloride concentration. Manges et al. (1971) reported that stormwater runoff from cattle feedlot waste disposal plots carried COD concentrations of 150 to 400 milligrams per liter. Swanson et al. (1971) concluded that a high solids loss and a somewhat higher COD value per unit volume of runoff were caused by a very moderate increase in rainfall intensity. Phosphorus removal was closely related to the solids removal and directly affected by rainfall intensity.

Runoff from land treatment systems should not be allowed to reach surface water, since pathogens could survive for some time after entering surface water. Clark et al. (1976) reported that fecal bacteria survived for five to eighteen days in Ohio River water samples held in the laboratory at 20^o C. Enteroviruses survived in Ohio farm pond water as long as 84 days at 20^0 C, and were still present after 91 days at 4^0 C. Thus, pathogens that reach surface water could be a hazard for a long time, particularly in cold weather.

D. GROUNDWATER QUALITY

Willrich and Smith (1970) present some difficulties in establishing standards for prevention of groundwater pollution from agriculturally related products, and these are repeated below.

1. Substances that can become pollutants are numerous and diversified. (Common potential pollutants include animal waste, fertilizers, pesticides and associated chemicals, and inorganic salts.)
2. The environment below ground surface in which agriculture related pollutants might occur is complex and generally not easily determined. (A dry, sandy, clay deposit in a desert might be acceptable for pollutants whereas rocky ground with a near surface water table could be unacceptable.)
3. The distribution of these potential pollutants ranges greatly in space and time. (Wastes from small cow pastures contrast sharply with wastes from large feedlots, and a single pesticide application on a crop contrasts with repeated application on some orchards.)
4. The toxicity and attenuation properties of pollutants range greatly. (Some pesticides in small quantities are known to be harmful to some wildlife. The attenuation of each possible pollutant depends upon complex factors of its environment and on its own inherent characteristics.)

Movement of pollutants into groundwater are controlled by many factors. According to LeGrand (1965), five factors which have to be considered in the movement of pollutants through the ground are: depth to water table, sorption, permeability, water table gradient, and distance to point of water use.

The amount of nutrients transported in agricultural drainage is determined in part by the chemical forms of the nutrients and the processes controlling their retention in the soil. In another study, Sewell (1977) found the nitrate-nitrogen and chloride concentration in groundwater near a lagoon rapidly increased during six months immediately following system loading, probably because of the development of effective seals in the lagoon and holding pond. Concentration of NO_3-N for all test wells were less than 10 mg per liter. Fecal coliform and fecal streptococci were ninety colonies per 100 ml sample. The highest concentrations were associated with high liquid levels in the holding pond.

Runoff water carries nutrients in both dissolved and particulate forms, while water percolating through the soil generally carried only dissolved forms. Because inorganic phosphorus is retained more strongly than inorganic nitrogen by soil particles, the forms of nitrogen and phosphorus transported differ appreciably for runoff and percolate waters (Willrich and Smith, 1975). Trout et al. (1976) determined that inorganic nitrogen leaching to groundwater is substantial. It increases with each additional sludge application and will be the first limiting factor for sludge application on a yearly basis. Inorganic nitrogen leaching can be controlled with management techniques involving timing and balancing of nitrogen applications with crop uptake and other factors. The extent to which manure is leached depends mostly on the quality of water percolating through the soil and the degree to which nitrate levels are in excess of plant and microbial need. Data presented by Marriott and Bartlett (1975) indicated manure supplying total nitrogen at the rate of approximately two times the crop requirement will contribute minor amounts of nitrate nitrogen to groundwater supplies. Although ammonium is soluble, the downward movement of ammonium is retarded and conversion of ammonium to nitrate in soils through nitrification is generally quite rapid.

Pathogens and bacterial movement to the groundwater might present pollutional problems, especially with coarser soil profile. Lance (1978) reported that irrigation of crops on coarse sand could allow pathogens to reach the groundwater particularly in areas with shallow water table (less than 150 cm). Chlorinated wastewater should be used on these areas. For the lower hydraulic application associated with spray systems, the presence of 0.5 to 0.7 m of aerated soil appear to be sufficient to prevent intolerable pathogen concentration in soils through soil-water movement to groundwater (Sobsey, 1977). Bitton et al. (1974) concluded that the sieving effect of the soil increased as the soil water content decreased. This indicates that bacterial movement through the soil to groundwater in slow-rate infiltration systems should not be a problem. Since the water is applied in fairly small amounts, the extent to which pollutants are retained depends on the soil through which they move. By ion exchange or some other sorption mechanism clays tend to retain many pollutants better than sands. Lance (1978) reported the movement of pathogens to the groundwater to be the primary concern with high rate systems. Large numbers of both bacteria and viruses can move through coarse sand and gravels to the groundwater. In loamy sand or fine textured soil, only a few bacteria were found to move through 2 m or more soil to groundwater. These appear to be eliminated by around 100 m of lateral travel in groundwater. Since these are general statements, each high-rate system must be considered separately.

E. SOIL PHYSICAL PROPERTIES

One method of waste disposal that is receiving increasing attention is disposal through the soil system (Ogilive and Warkentin, 1973). Soil can be considered as a filter which can trap both solid particles and ions, preventing them from entering either groundwater or surface water as pollutants. But by this process, the soil chemical and physical properties might be altered over a period of time. Most researchers who have measured the effects of animal waste on soil physical properties have found infiltration rates, hydraulic conductivity, bulk density, water holding capacity, and aggregate stability to be improved after applying animal waste (Wallingford et al., 1975). The organic matter contained in the wastes has been credited as being the waste constituent responsible for these improved soil physical properties. Determination of soil physical properties resulting from dispersion of soil colloids has been found less frequently and has been attributed to an imbalance of salts in the soil. Even though some animal wastes, particularly liquid waste, are relatively high in monovalent cations which can cause soil dispersion, the beneficial effects of the organic matter in the waste override the potential negative effects of the salts. Butchbaker et al. (1971) reported that land disposal of animal waste water in large quantities can lead to saline soil conditions and high NO_3-N concentrations in the soil profile. Swanson et al. (1973) also discussed the potential problems of salt and nitrogen accumulations in soil profile, but reported no such accumulation in experimental plots receiving ninety inches of beeflot runoff over a three-year period. Taiganides (1970) indicated that crop production begins to decrease as salt concentration exceed 900 milligram per liter and stops when irrigation water contains more than 5,000 milligrams per liter of salt.

Soil infiltration rate and hydraulic conductivity are two soil physical properties which might be affected by using liquid wastewater. Cross and Fishbach (1973) found that applications of large quantities of feedlot wastewater appreciably changed soil composition and reduced intake rates due to the formation of a microbial barrier in the soil surface layer. Chung and Bechir (1973) have also indicated this problem. They concluded that wastewater can cause soil clogging and greatly reduce infiltration rates. They attribute this clogging to physical, chemical, and biological changes in the soil surface layer. These clogging effects are reduced by intermediate application, allowing the soil surface to dry between applications. Nienaber et al. (1973) also advocated using intermittent wastewater applications to avoid excessive soil clogging. Pile et al. (1974) agreed with the conclusion of Chung and Bechir and

Cross and Fishbach. Pile noticed a layer of fibrous material at the soil surface which restricted slurry intake after an application of dairy manure slurry. Gerba et al. (1975) reported a different results from the above mentioned researcher's results. They reported that bacteria and organic material accumulations on the soil surface increased the filtration properties of the soil. Heavy soil like clay might produce a barrier inside the soil profile, preventing or reducing the infiltration rate. Pile (1974) conducted a test on soil core samples 16 inch in diameter, and his results indicated that water movement through the soil profile was slow due to high clay content of the soil. On the other hand, if solid manure application on land was to be mixed through the upper soil profile, it would cause an increase in the initial intake rate of the soil. Cross et al. (1971) concluded that the initial intake rate of water into soil increased as higher manure loading was applied, and the basic intake rate on any specific manure loaded area increased with time from the date of manure application. Repeated heavy annual applications of manure led to deterioration of soil intake rate.

Permeability is defined as the property of a porous material which permits the passage or seepage of fluids such as water through its interconnecting voids. The permeability of some clays may be many hundreds of times less than that of some sands. Differences of permeability in the horizontal direction although common, are in many cases more gradual than in the vertical direction. The important point is that water and included waste will tend to take preferred paths, following readily through permeable zones, and flowing with difficulty through relatively impermeable materials. The resistance to flow depends upon the type of soil, size and shape of the soil particles, the degree of packing (density of soil) and, thus, upon the size and geometry of the voids. Moreover, the resistance is a function of the temperature of water and organic material. It will present dramatic changes on the liquid waste physical characteristics, and hence it will affect the soil permeability. Azeredo and Stout (1974) considered fiber content of animal manure to be the most important constituent controlling soil permeability after waste application.

Cross et al. (1973) found that, after four months of manure application, hydraulic conductivity of soil was associated with high sodium and potassium content in the percolate as a result of the applied manure. They further concluded that repeated annual applications of heavy rates of manure will lead to deterioration of physical properties of soil, due to large amounts of sodium and potassium in manure.

Soil bulk density might also be effected by animal waste application. Bulk density, which is the weight per unit volume of oven dry soil, was found by Cross et al. (1973) to decrease by 1.01 gm per cm^3 due to application of 260 tons of manure.

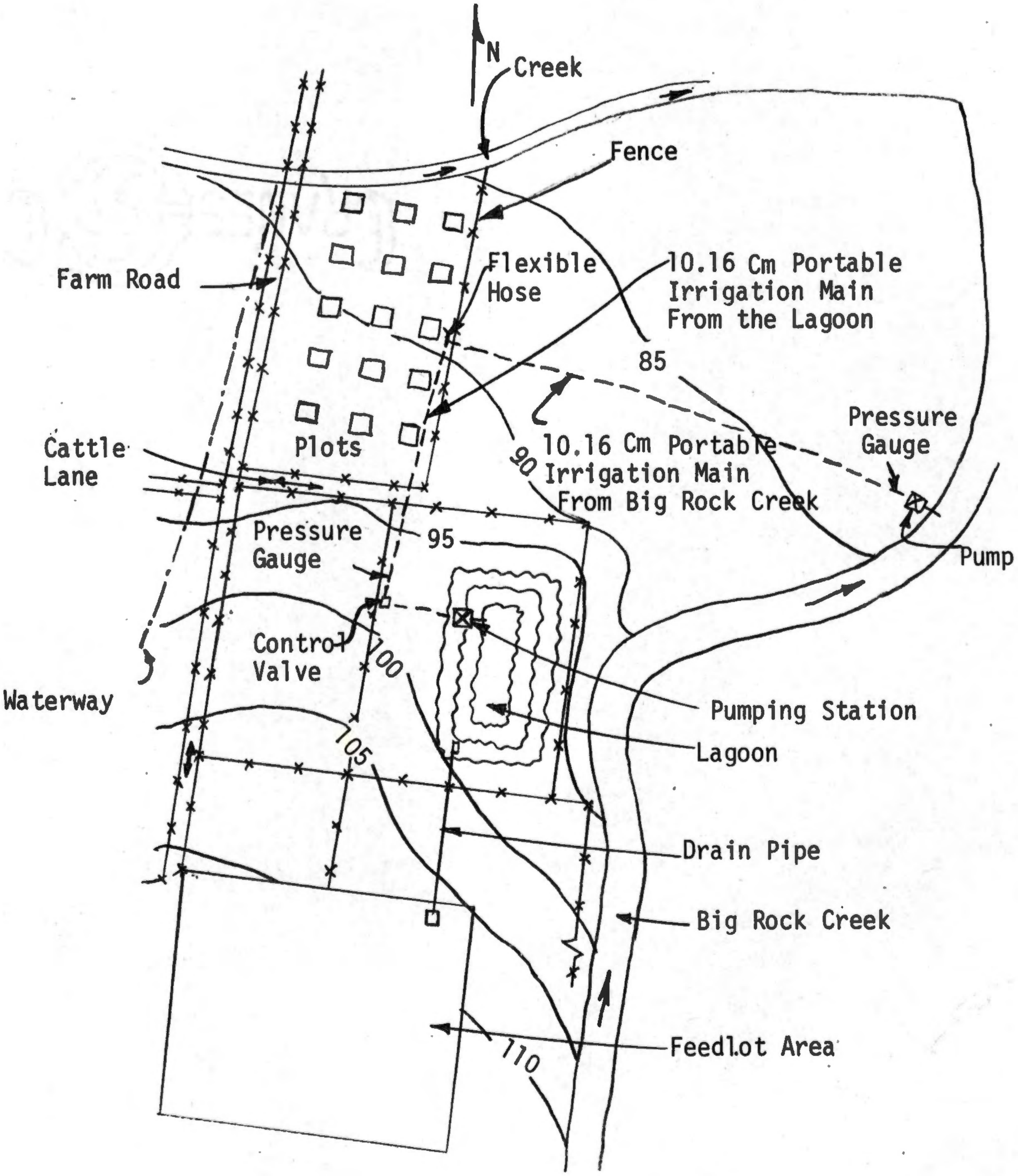
CHAPTER III

RESEARCH METHODS AND FACILITIES

A. FIELD FACILITIES AND PLOTS

This study was conducted at the Dairy Experiment Station at Lewisburg, Tennessee (Figure 1). The feedlot area comprised of 8,826 m^2 of concrete pavement contains the usual complement of feeding, loafing, and milking facilities and houses 200 Jersey milking cows. Rainfall contributes most to the runoff from the area. Wastewater from the milking parlor and calf and maternity barns flows into a main drain and is delivered by gravity flow into a 5,550 m^3 lagoon. The primary purpose for the lagoon is to collect and control disposal of rainfall runoff containing animal wastes, thus preventing its entrance into nearby creeks. An electrically driven pump capable of discharging 0.009 m^3/s at a pressure of 414 kilopascals is located at the lagoon.

Fifteen experimental plots were established in the spring of 1978. Each plot is 40.5 m^2, and has an average slope of 1 to 2 percent. The plots were isolated with elevated borders so that surface runoff samples could be collected. An orchard grass-ladino clover mix was seeded on the plots in the spring of 1978. The plots were divided into three groups, each representing one replication. Five treatments were assigned randomly to the plots in each group. Thus, the experiment was arranged in a randomized block design. The use of five plots in a block



Not to Scale

Figure 1. Layout of a Portion of The University of Tennessee-USDA Dairy Experiment Station Farm at Lewisburg, Tennessee.

(group) was done to minimize the uncontrolled variation from plot to plot within blocks. In this case, soil type and the average slope of the plot are the uncontrolled variation. Figure 2 is a photograph of the experimental plots.

B. SURFACE RUNOFF AND GROUNDWATER SAMPLING FACILITIES

Surface runoff from each plot flowed to one corner of the plot where an outlet device (Figure 3) was located. The runoff was collected in a polyvinyl chloride (PVC) pipe 5.08 cm in diameter and 30.48 cm long. A 5.08 cm ID diameter PVC plate was glued to the bottom of the tubing to form a bucket-like collector. The sample collector was supported vertically inside a 6.72 cm ID PVC pipe, which is located at the bottom portion of the outlet device. The upper portion of the outlet device was covered with a cap to prevent debris from falling into the sample.

A 7.62 cm ID PVC pipe was placed 92.0 cm deep in the center of each plot for collection of groundwater samples. The collection mechanism was a 500 ml polypropylene bottle to which a handle was attached. The pipe was covered with a PVC cap for protection. The groundwater collector is shown in Figure 3. The surface runoff and groundwater collectors were cleaned before each sample collection event.

C. WATER AND LAGOON EFFLUENT IRRIGATION SYSTEM

Liquid manure in the lagoon was pumped through a 10.16 cm steel pipe to a control valve located 6.0 m west of the lagoon. A fine mesh screen was placed around the inlet of the lagoon pump to prevent foreign

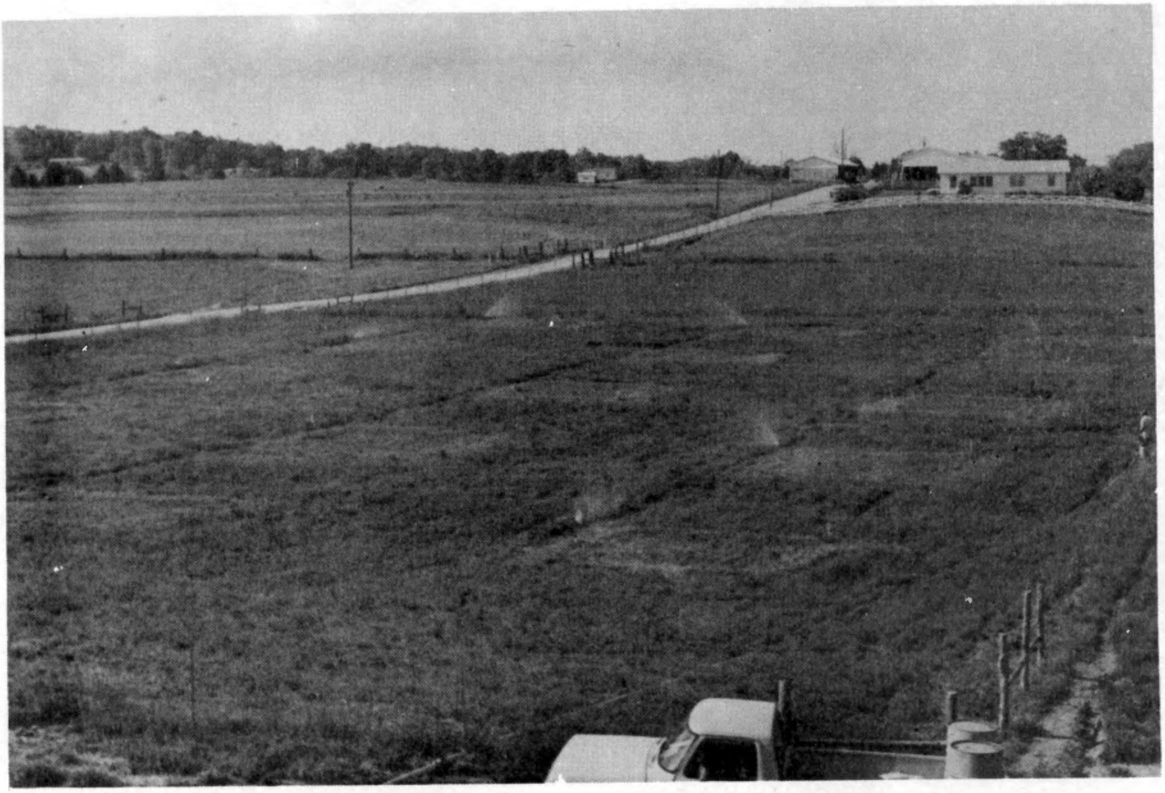


Figure 2. The Experimental Plots.

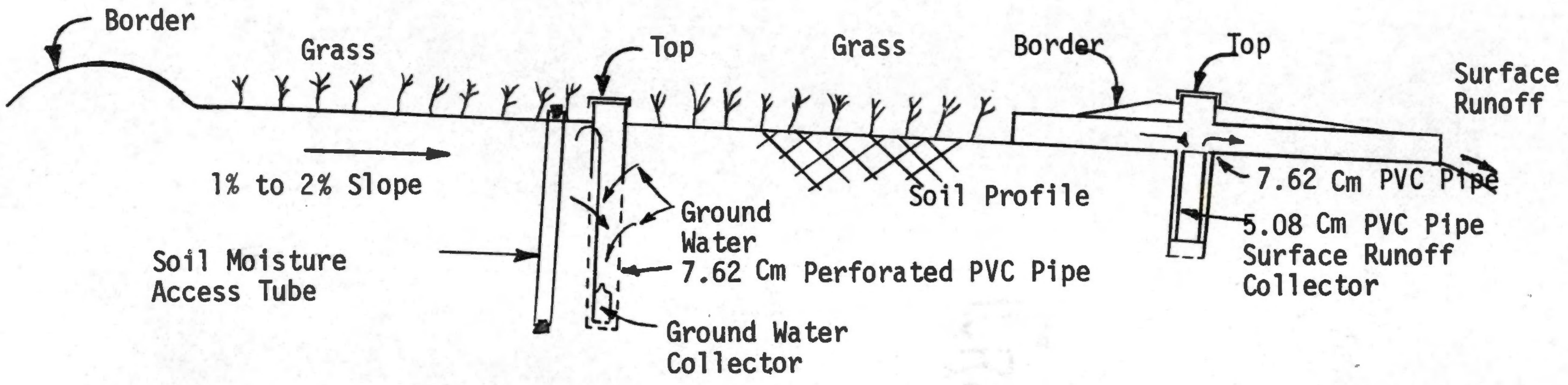


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Figure 3. Schematic of Typical Plot Cross Section and Instrumentation.

material from blocking the nozzles. A sprinkler irrigation system using Rainbird (number 30) sprinklers was used for applying the lagoon effluent on the plots. The system used included three laterals with 61.0 cm risers. The risers were located at the southwest corner of each plot. A 0.635 cm nozzle was used with an average working pressure of 172 kilopascals. The system was designed so that the wetted diameter of each sprinkler covered more than the plot area, and the liquid could be applied with an application rate less than the infiltration capacity of the soil so that surface runoff would not occur. The system used in 1978 (Figure 4) developed leakage problems, and required moving every time the field was moved.

In the spring of 1979 PVC pipe laterals were installed 30 cm underground along the west border of the plots, and a 61.0 cm riser was located at the center of the west side of each plot (Figure 5). A 10.16 cm flexible hose with a fine screen at its end was attached to the inlet of the underground system. The flexible hose was attached to either the line from the creek or the line from the lagoon.

A pressure gage and a drain valve were installed on each lateral. The pressure gage was located on the riser and the drain valve was located at the end of the lateral line. The sprinkler applying lagoon effluent is shown in Figure 6. The clean water applied on the plots and used in performing the simulated rainfall was pumped from Rock Creek by a pump driven by a four cylinder gasoline engine.

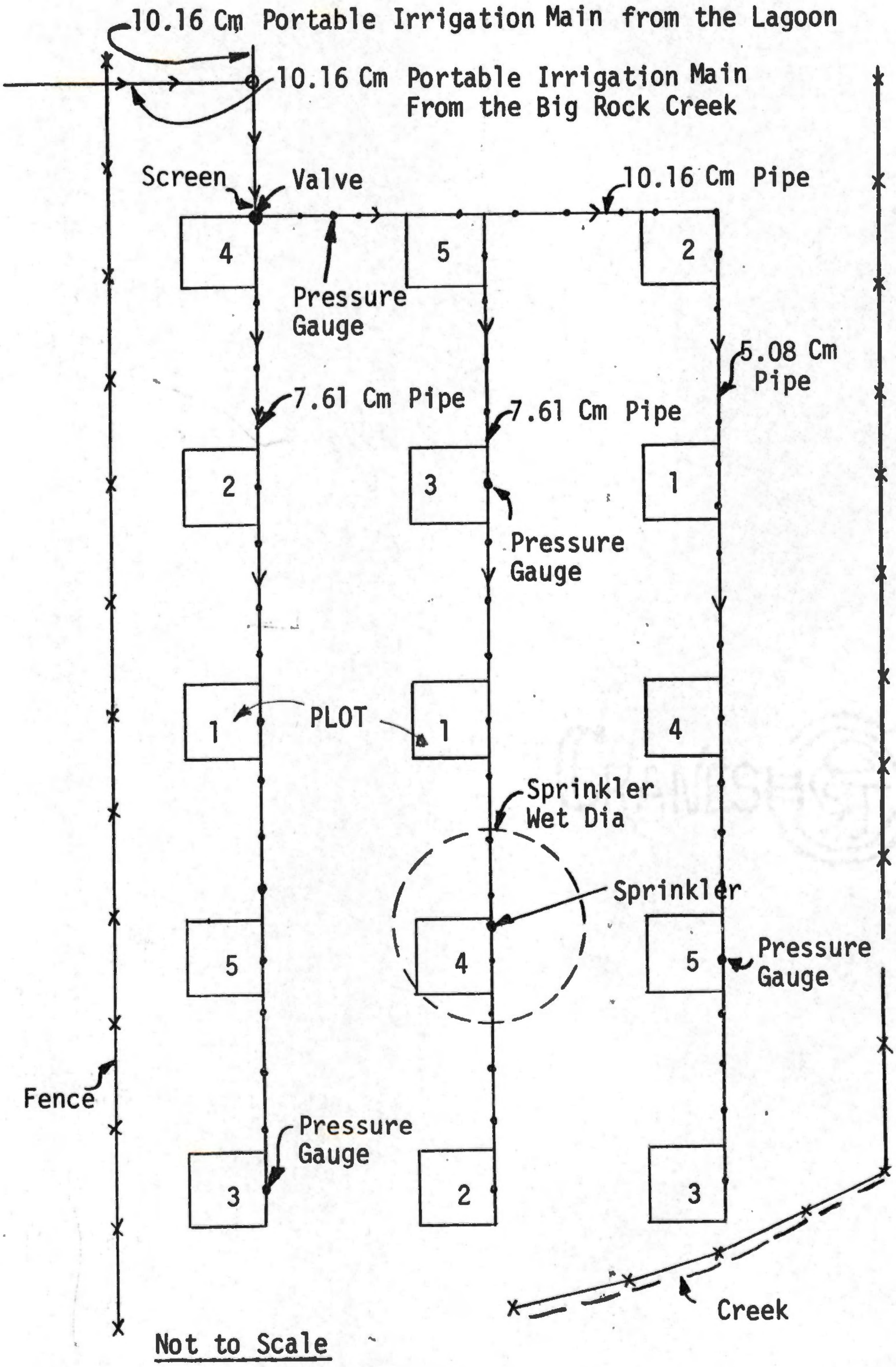

Figure 4. Sprinkler Irrigation System Used in the Summer of 1978.

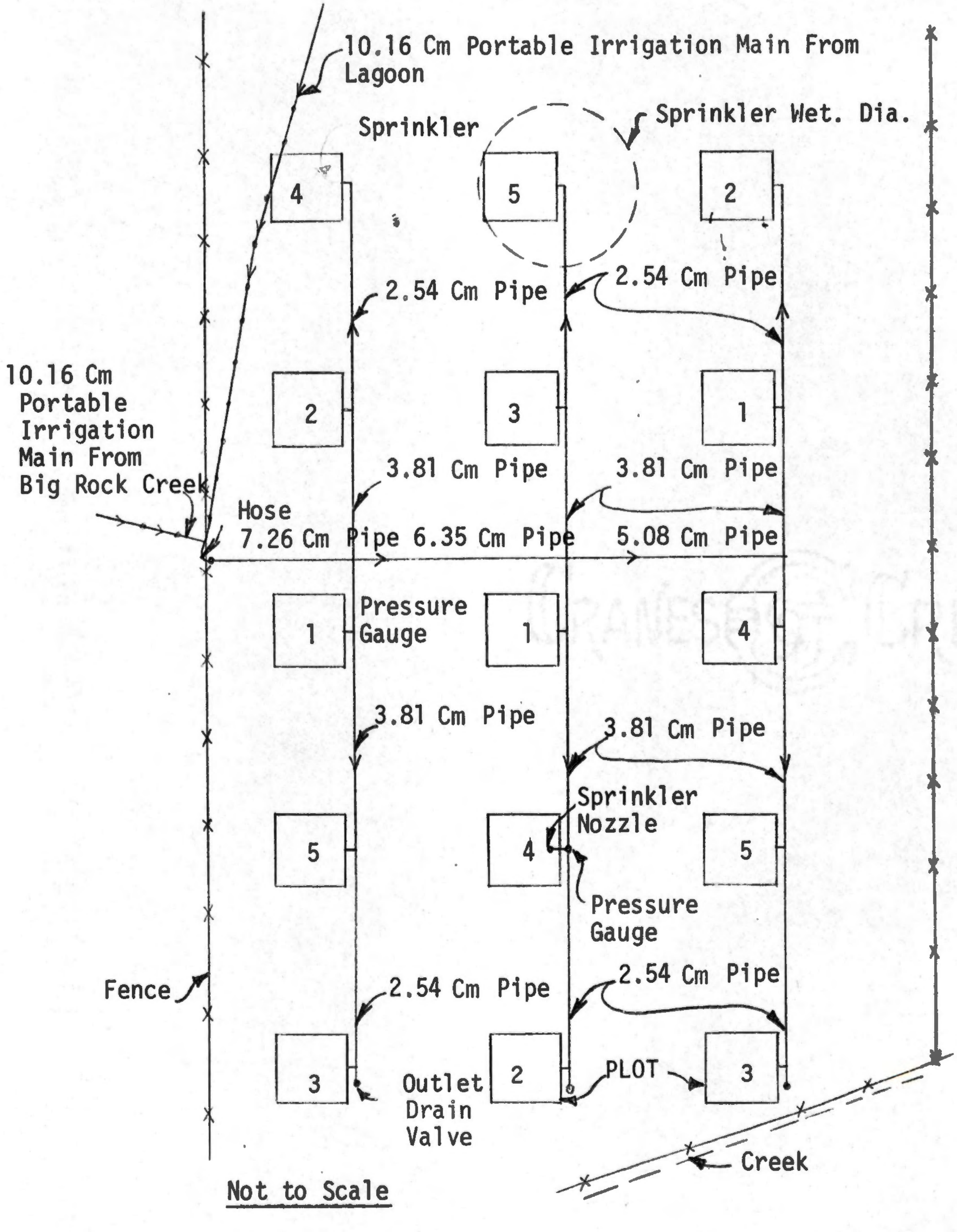

Figure 5. Underground PVC Pipe Irrigation System used in 1979.

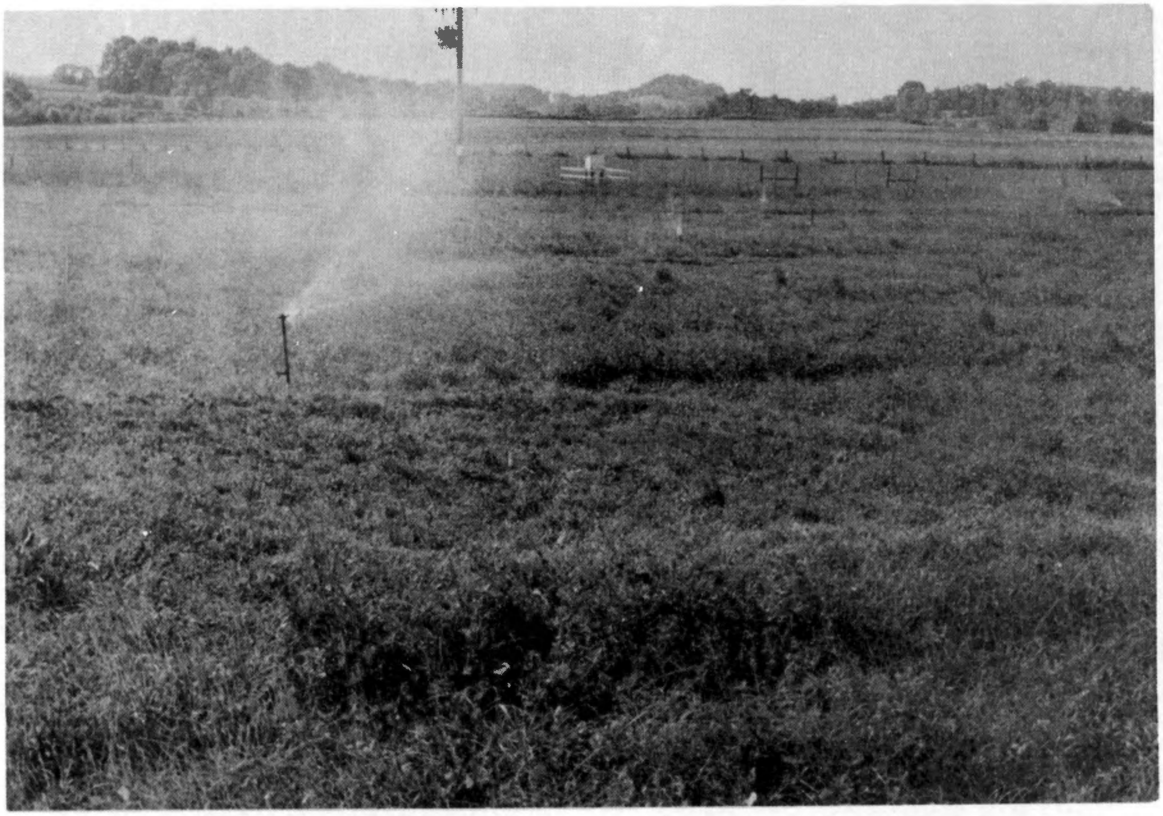

Figure 6. Lagoon Effluent Irrigation Sprinkler.

D. LAGOON EFFLUENT APPLICATION

Lagoon effluent pumped from the lagoon was applied via the portable sprinkler irrigation system from June through October 1978. Treatments consisted of applying 2.54, 5.08, and 7.62 cm of lagoon effluent and 7.62 cm of creek water on four plots biweekly. The fifth plot, which received no application was used as a check. Three replications of each treatment were made and the treatments were assigned randomly to the plots as shown by typical randomized treatments assignment in the data below.

Plot number	1	2	3	4	5
Treatment	no application	2.54 cm Lagoon effluent	5.08 cm Lagoon effluent	7.62 cm Lagoon effluent	7.62 cm Creek Water

Total application per plot was determined by averaging the water depth collected from the sprinkler in four 20.32 cm diameter containers placed randomly inside the plot.

During the summer of 1979 lagoon effluent was applied via the underground sprinkler irrigation system. The treatments consisted of applying 2.54, 5.08, 7.62, and 10.16 cm of lagoon effluent on four plots once a month. One application was made per month in May, June and July. Again, one plot in each replication received no application of lagoon effluent. The treatments were assigned randomly to the plots as shown in the data below:

Plot number	1	1	3	4	5
Treatment (lagoon effluent)	no application	5.08 cm	7.62 cm	10.16 cm	2.54 cm

Total application of lagoon effluent per plot was determined in the same way as in the summer of 1978.

E. SAMPLE COLLECTION AND ANALYSIS

Grab samples of surface runoff and groundwater were collected on six dates between the 19th of June and the 11th of October in 1978. The samples were collected in polypropylene bottles and were frozen until laboratory analysis were made soon thereafter. When practical, samples were collected at or immediately following the initial runoff from each natural rainfall event. Rainfall was measured by a standard rain gage and a recording rain gage located near the lagoon pumping station. No attempt was made to relate quality of runoff to volume of runoff.

Soil moisture was measured prior to lagoon effluent application by using neutron scattering equipment consisting of a subsurface moisture probe and a scaler. Soil moisture access tubes were aluminum pipes 5.08 cm diameter and 92 cm deep. One tube was placed in the center of each plot near the groundwater sampling device (Figure 3, page 28). Soil moisture measurements with the neutron scattering equipment were made at intervals of 15 cm, 30 cm, 60 cm, and 90 cm throughout the soil profile.

Samples of the surface runoff and groundwater were obtained once in May, June, and July of 1979. The collected samples were put into polypropylene bottles and frozen for later laboratory analysis. Sample collections were made after a 0.105 cm per minute simulated rainfall was applied on the plots long enough to obtain all samples. A delay of twelve hours was provided between the time that lagoon effluent application ended and the time of simulated rainfall application.

Samples were analyzed to determine: total phosphorus, ammonia nitrogen, total Kjeldahl nitrogen (TKN), total oxidized nitrogen (TON), chlorides, chemical oxygen demand (COD), pH, electrical conductivity, and total solids. The COD determination was made by the dichromate reflux method outlined in the Standard Methods for the Examination of Water and Wastewater (1976, edition, 14, pp. 550-554). The COD determination is a measure of the oxygen equivalent of that portion of the organic matter in a sample that is susceptible to oxidation by a strong chemical oxidant.

The total phosphorus content of a sample was determined by the Vanodamolybdophosphoric Acid Colorimetric Method after digesting the sample. The phosphorus content of a sample includes all of the orthophosphates and condensed phosphates, both soluble and insoluble, organic and inorganic. The procedure for determining the total phosphorus is described in Standard Methods for the Examination of Water and Wastewater (1976, edition, 14, pp. 550-554).

The forms of nitrogen of greatest interest in water and wastewater are nitrate, nitrite, ammonia, and organic nitrogen. Samples of 5 mg. per liter ammonia-N concentration or less were analyzed by a direct Nesslerization method which includes the addition of the Nessler reagent to the undistilled sample, and then analyzed colorimetrically. For higher ammonia concentrations, a distillation and titration technique was used. The acidimetric method was used for determining the TKN present in the sample. The TON is the sum of nitrate and nitrite nitrogen, and was determined by Devarda's Alloy Reduction Method (Tentative). The procedures for determining ammonia, TKN, and TON are described in Standard Methods for the Examination of Water and Wastewater (1976, edition 14, pp. 410-431).

Chloride was determined by silver nitrate method according to Standard Method for the Examination of Water and Wastewater (1976, edition 14, pp. 306). Conductivity, pH, and total solids were determined according to procedures given in the above source on pages 71-75, 460-465, and 91-92, respectively.

During application of lagoon effluent samples were collected from the lagoon and at the plots surface. During application of creek water a sample of water was obtained for quality parameters analysis.

F. LABORATORY EXPERIMENTAL SETUP

Nine core samples 15.24 cm in diameter were taken from Lewisburg to the Agricultural Engineering Department research laboratory at Knoxville to study the effect of applying lagoon effluent on physical properties of the soil. Mechanical analysis of the clay loam soil determined the following:

Particle size	Sand	Coarser Silt	Silt	Clay
Percent of Total	28.625	18.495	26.240	26.640

Nine core samples were also taken from the Plant and Soil Science Farm at Knoxville. A soil map of the farm indicated that the soil samples were Sequatchie fine sandy loam.

Permeameters were constructed as shown in Figure 7. Acrylic tubing 15.25 cm in diameter and 20.32 cm long was attached to the top of the core samples and held firmly by a rubber band. The core sample was then placed on a sand tray of 2.54 cm depth. A removable PVC tube 20.32 cm in diameter and 15.24 cm long was placed on top of the sand tray and held firmly by a rubber band. The 20.32 cm tubing was used when saturation of the sample was needed. A perforated metal base was placed on the top of the funnel to hold the core sample. The funnel was supported by a board. A 1,000 ml flask was placed on a holder on top of the acrylic tubing. Two capillary pipes were fixed by a rubber stopper at the flask's mouth. One pipe was used for maintaining constant liquid head (air pipe) and the other for adding liquid from the flask to the liquid head above the soil surface. The experimental setup is shown in Figure 8.

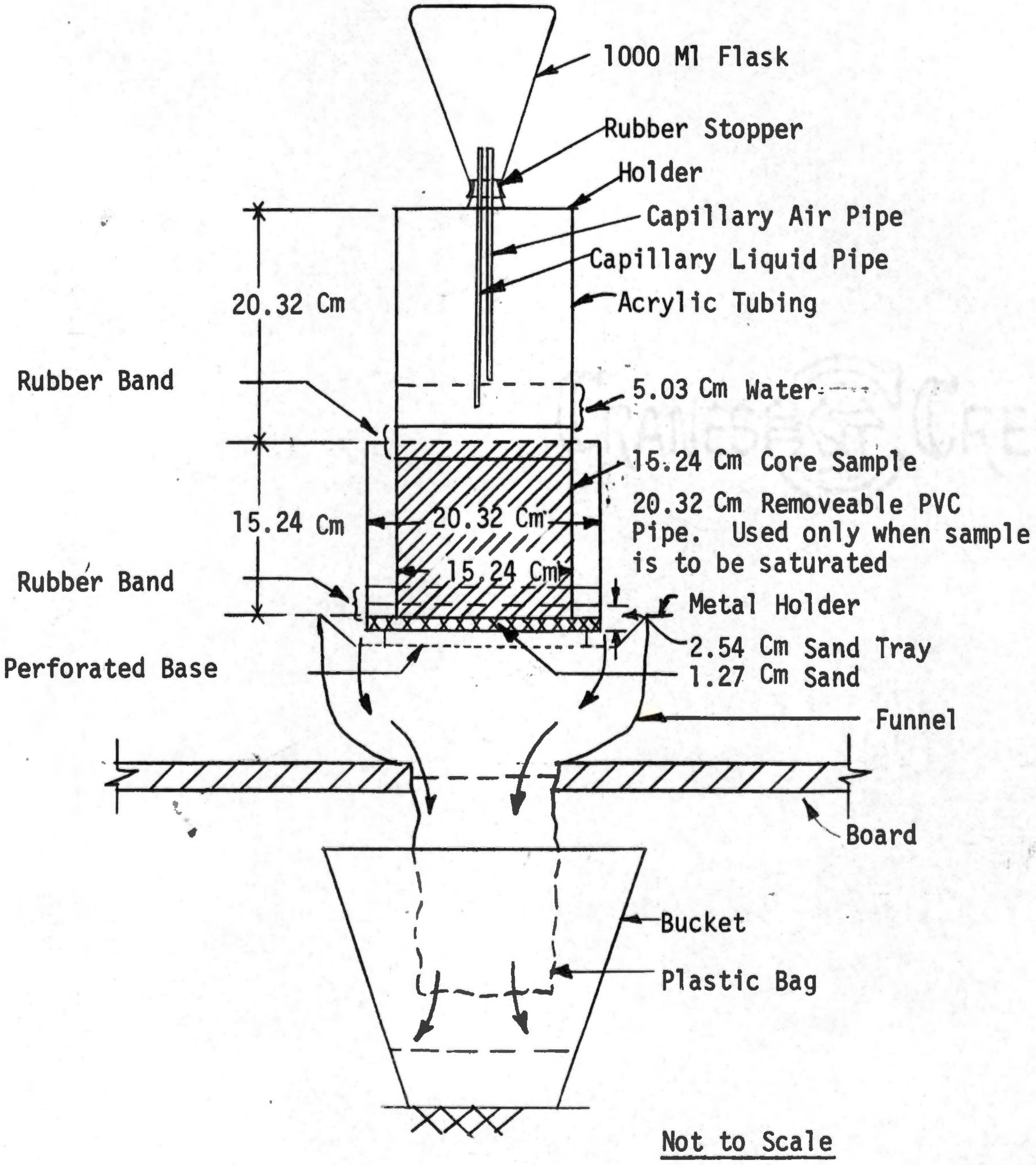

Figure 7. Schematic of Permeameter Construction.

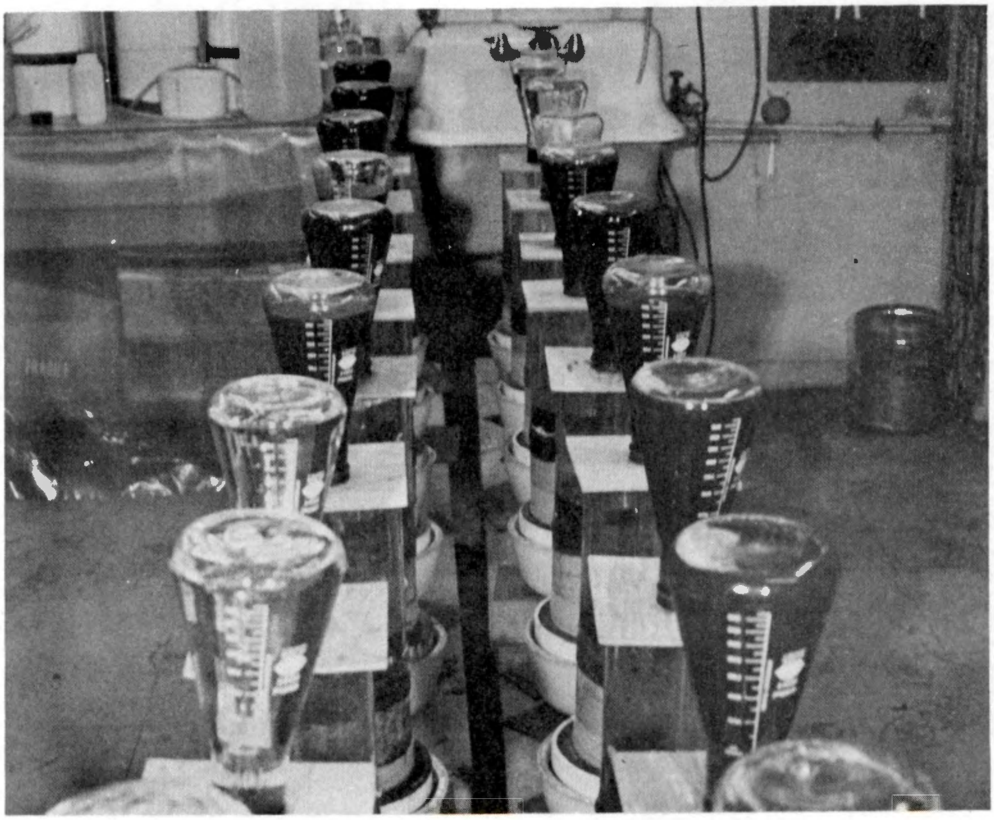

Figure 8. Laboratory Setup for Permeability Measurement.

G. LAGOON EFFLUENT APPLICATION TO CORE SAMPLES

A quantity of lagoon effluent was brought to Knoxville from the Dairy Experiment Station at Lewisburg. The solid content of the lagoon effluent was determined to be equal to approximately 0.1 percent by using the equation:

$$\text{Solid content} = \frac{w_2 - w}{w_1 - w} \text{ ------------------------------------- } (1)$$

where

w_2 = oven dry weight of the material and dish in gm;

w_1 = wet weight of the material and dish in gm; and

w = empty weight of dish in gm.

Dairy solid waste brought from the Dairy Experiment Station at Lewisburg was added to the lagoon effluent in order to bring the mixture solid content to 0.3 percent. Solid waste was added according to the equation:

$$\text{Solid content of mixture} = \frac{TSL - TSM}{TVL + TVM} \text{ --------------------- } (2)$$

where

TSL = total solid in liquid in ml;

TSM = total solid in mixture in ml;

TVL = total volume of liquid in ml; and

TVM = total volume of mixture in ml.

Three treatments of mixed lagoon effluent, lagoon effluent, and distilled water were applied to the core samples. Each treatment, consisting of 15.24 cm of liquid was replicated three times on the two kinds of soils. A total of 183.0 cm of lagoon effluent was applied to some of the core samples in June and July of 1979. The experiment was started by applying distilled water to all core samples to check the permeability measurement and this was repeated after addition of 30.48 cm of lagoon effluent to the samples. Lagoon effluent application is shown in Figure 9.

H. SOIL PHYSICAL PROPERTIES DETERMINATION

Darcy's formula was used for the determination of the coefficient of permeability during the application of lagoon effluent and/or distilled water to the samples. The formula is as follows:

$$K = \frac{-QL}{HAT} \qquad (3)$$

where

K = coefficient of permeability in cm per minute;

Q = volume of liquid passing through the sample in ml;

L = length of core sample in cm;

H = hydraulic head in cm;

A = soil sample cross-sectional area in cm^2; and

T = minute to collect a certain volume of liquid.

Aluminum pipe sections 5.08 cm in diameter and 35.0 cm in length was cut along its longitudinal axis into two halves. The two halves of the pipe were held together with heavy duty tape to form a samplers for soil bunk density determination. At the end of the experiment the

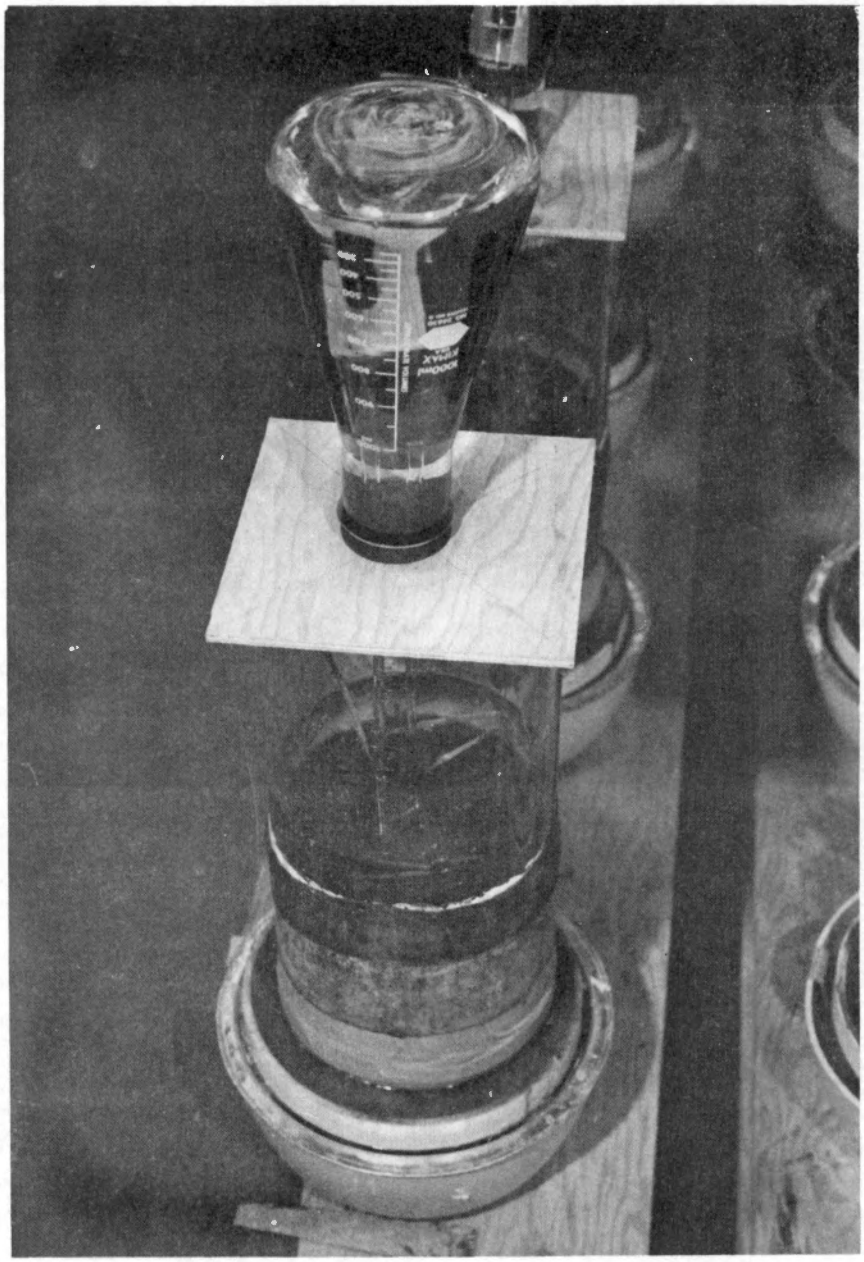

Figure 9. Lagoon Effluent Application to Core Sample.

sampler was pushed into the core samples and a new core sample was obtained for the bulk density determination. In some cases samples less than 15.24 cm long were obtained due to the sampling process and/or the presence of small rocks and gravel in the soil. A total of four samples were taken from every core sample for bulk density determination. Two bulk density samples were cut into 2.54 cm lengths and the other two were cut into 5.08 cm lengths. The cut samples were then placed into weighing dishes and left overnight in a 110° C oven. The dry weight of soil samples was recorded, and bulk density was calculated according to the equation:

$$\text{Bulk density} = \frac{w_a - w_b}{v} \qquad (4)$$

where

w_a = dry weight of soil and dish in gm;
w_b = weight of dish in gm; and
v = volume of sample in cm^3.

I. DATA ANALYSES

Concentration of some of the water quality parameters of the lagoon effluent were plotted so that changes in concentrations with time could be discussed.

Analysis of variance was applied to the water quality data collected in the two-year period of study. The data tended to yield a wide range of values. One approach to make the data conform to the usual statistical assumptions is to transform the original data in such a way that the transformed data will meet the conditions specified by the assumptions. (Some of these assumptions include a normal distribution of the population, mean of the treatment is constant throughout the experiment, observation on one unit is unaffected by the observation on the other unit, and the treatment difference is addative.) Therefore a logarithmic transformation was performed on the data, and all statistical analyses employed logarithmic transformation data.

Two kinds of models were used to perform the analyses of variance tests on the quality parameters of the surface runoff and groundwater samples. These models were as follows:

$$Y_{ijkm} = \mu + A_i + B_j + C_k + (A*B)_{ij} + (A*C)_{ik} + E_{ijkm}\text{-------------}(\text{I})$$

$$Y_{ijkm} = \mu + A_i + B_j + C_k + (A*C)_{ik} + E_{ijkm}\text{ ---------------------}(\text{II})$$

where

Y_{ijkm} = the quality parameter of the first or second year data of the $_i$th treatment in the $_j$th replication for the $_k$th sampling date of the $_m$th plot;

μ = the population mean;

A_i = the effect of the $_i$th treatment, $i = 1, 2, ----, 5$;

B_j = the effect of the $_j$th replication, $j = 1, 2, 3$;

C_k = the effect of the $_k$th sampling date, $k = 1, 2, --- 7$ and $k = 1, 2, 3$ for the first and second year of the study, respectively;

$(A*B)_{ij}$ = the interaction between the $_i$th treatment and the $_j$th replication;

$(A*C)_{ik}$ = the interaction between the $_{i}$th treatment and the $_{k}$th sampling date; and

E_{ijkm} = the random error.

The treatment-replication interaction of Model I was used to test the significance of the treatment and replication effects of Model II by using the F-statistic. The residual of Model I was used to test the significance of the sampling date and the treatment-sampling date of Model II. In doing so, the sampling dates were considered to be split among the treatments of the experiment.

A regression analysis was then applied to those treatments which were significant at the 5 percent probability level. The regression analysis was used to determine the correlation between a given water quality parameter and the different levels of treatments. Linear and quadratic models were used in this analysis.

A stepwise regression analysis was conducted on the quality parameters of the surface runoff data for three selected sampling dates in 1978. This analysis was used to find an equation to best predict a water quality parameter. Effects of treatments, amount of rainfall, soil moisture and the delay time between the liquid application and the sample collection were included in this analysis. A graphical representation of the water quality parameters with time was prepared.

Analysis of variance was performed on the permeability data, and the model used in this analysis was:

$$Y_{ijkLm} = \mu + A_i + B_j + (A*B)_{ij} + R\,((A*B)_{ij})_k + C_L + (A*C)_{iL} + (B*C)_{jL} + (A*B*C)_{ijL} + E_{ijkLm} \text{ --------------------------------------- } \quad (III)$$

where,

Y_{ijkLm} = the permeability of the $_i$th treatment in the $_j$th soil for the $_k$th replication in the $_L$th depth of liquid applied of the $_m$th sample;

μ = the population mean;

A_i = the effect of the $_i$th treatment, i = 1, 2, 3;

B_j = the effect of the $_j$th soil, j = 1, 2;

$(A*B)_{ij}$ = the interaction between the $_i$th treatment and the $_j$th soil;

$R((A*B)_{ij})_k$ = the effect of $_k$th replication within the $_i$th treatment and the $_j$th soil;

C_L = the effect of the $_L$th depth of liquid applied, L = 1, 2, 3;

$(A*C)_{iL}$ = the interaction between the $_i$th treatment and the $_L$th depth of liquid applied;

$(B*C)_{jL}$ = the interaction between the $_j$th soil and the $_L$th depth of liquid applied;

$(A*B*C)_{ijk}$ = the interaction between the $_i$th treatment, the $_j$th soil and the $_k$th depth of liquid applied; and

E_{ijkLm} = the random error.

Examining the data showed that a non-linear regression procedure can be used to produce a least-squares estimate of the permeability. Two forms of models for permeability estimation were used for each kind of soil and for different treatments levels.

Analysis of variance was also used to analyze the bulk density data. The model used for this analyses was:

$$Y_{ijkLm} = \mu + A_i + B_j + (A*B)_{ij} + R((A*B)_{ij})_k + C_L + (A*C)_{iL} + (B*C)_{jL} + (A*B*C)_{ijL} + E_{ijkLm} \text{ ------------------------------------ (IV)}$$

where;

Y_{ijkLm} = the bulk density of the $_i$th soil in the $_j$th treatment of the $_k$th replication in the $_L$th soil depth of the $_m$th sample;

μ = the population mean;

A_i = the effect of the $_i$th soil, i = 1, 2;

B_j = the effect of the $_j$th treatment, j = 1, 2, 3;

$(A*B)_{ij}$ = the interaction between the $_i$th soil and the $_j$th treatment;

C_L = the effect of the $_L$th soil depth, L = 1, 2, ---, 5;

$(A*C)_{iL}$ = the interaction between the $_i$th soil and the $_L$th soil depth;

$(B*C)_{jL}$ = the interaction between the $_j$th treatment and the $_L$th soil depth;

$(A*B*C)_{ijL}$ = the interaction between the $_i$th soil, $_j$th treatment and the $_L$th soil depth; and

E_{ijkLm} = the random error.

Graphical representations of bulk density versus soil depth for the two kinds of soil and the different levels of treatment were prepared.

CHAPTER IV

RESULTS AND DISCUSSION

A. PROPERTIES OF DAIRY LAGOON EFFLUENT

Lagoon effluent and water from the Big Rock Creek were analyzed for the water quality parameters (Table 1). Water quality parameters of the lagoon effluent measured six times from June through October of 1978 show that the average TKN and ammonia-N concentrations were 27.0 ppm and 12.2 ppm, respectively. The permissible standards for ammonia-N concentration of raw surface water for public supplies as established by the Federal Water Pollution Control Administration (1972) is 0.5 ppm. The ammonia-N and TKN concentrations of the lagoon effluent were less by 8.4 percent and 7.4 percent, respectively, in the second year of the experiment. The decrease in the nitrogen level in the lagoon was probably due to variation in environmental conditions (temperature, humidity, rainfall, and wind) and loading rate of the lagoon in the two-year period. A similar change in the levels of the other water quality parameters of the lagoon effluent was noticed during the summer of 1979. However, electrical conductivity, total solid, chlorides, TON, pH, and total phosphorus concentrations measured in the lagoon effluent were less than the standards of raw water for public supplies as established by the Federal Water Pollution Control Administration (1972). The average COD level in the lagoon effluent measured during the period of the study

TABLE 1

PROPERTIES OF THE LAGOON EFFLUENT AND BIG ROCK CREEK WATER

Water Quality Parameter	Lagoon Effluent							
	1978		1979				1979	
	at the Lagoon[a]	s.d.[c]	at the Lagoon[b]	s.d.	at the Plots[b]	s.d.	Water from Creek[b]	s.d.
Conductivity[d]	1128	74	949	85	952	82	269	38
Total solids, ppm	0.99	0.02	1.20	0.4	0.98	0.08	0.48	0.3
Chloride, ppm	85.0	10.4	61.0	5.7	59.6	6.5	4.6	1.2
Ammonia-N, ppm	12.20	2.9	11.16	6.9	14.53	3.3	0.48	0.2
TKN, ppm	27.00	5.8	25.00	2.9	23.50	3.6	1.40	0.6
TON, ppm	0.18	0.08	0.33	0.1	0.20	0.1	0.40	0.1
COD, ppm	598	81	395	102	329	52	2	1.6
pH	7.3	0.9	7.5	1.0	7.5	1.0	8.1	1.1
Total phorphorus, ppm	26.25	4.2	19.6	2.1	17.85	2.4	2.1	0.7

[a] Mean value for five observations.

[b] Mean value for three observations

[c] Standard deviation.

[d] Measured in micromhos per cm.

was about 200 times more than that measured in the water from Big Rock Creek.

Variation in concentrations of some water quality parameters in the lagoon effluent with time is shown graphically in Figures 10 and 11 for 1978 and 1979, respectively. The connecting of data points in the figures is not meant to indicate that the data is continous between sampling dates, but it does point out the fluctuation among sampling dates. These graphs show a general decrease in the concentration of water quality parameter during the summer months. This decrease was probably due to the reduction in the discharge rate of the feedlot effluent into the lagoon from the wet winter months to the drier summer season.

A change in the effluent chemical properties from the lagoon to the experimental plots occurred for some water quality parameters (Table 1). Total solid and COD concentrations showed a reduction of 18.6 percent and 16.5 percent, respectively. This reduction may have been due to the screen in the pipe line between the lagoon and the sprinkler nozzles. There was an increase in the ammonia-N concentration in the effluent from the lagoon to the plot surface. This increase may have been due to the mixing of the effluent inside the pipes of the irrigation system. TKN and TON were reduced 6 percent and 40 percent, respectively, from the lagoon to the plots surface. Koelliker and Miner (1971) reported a nitrogen reduction of 15 to 30 percent between the lagoon and the ground surface during sprinkling.

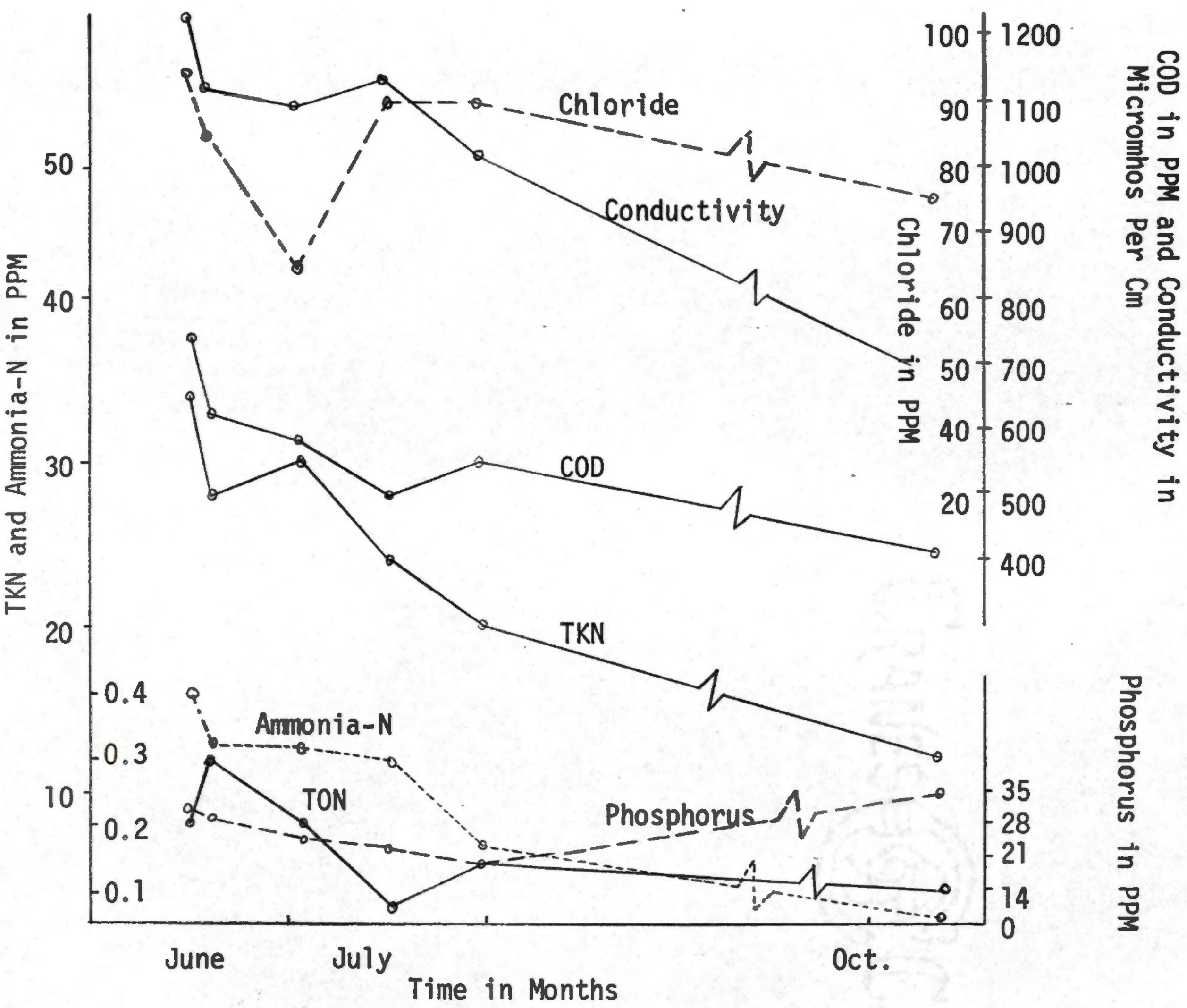

Figure 10. Variation in Concentration of Water Quality Parameters with Time in 1978.

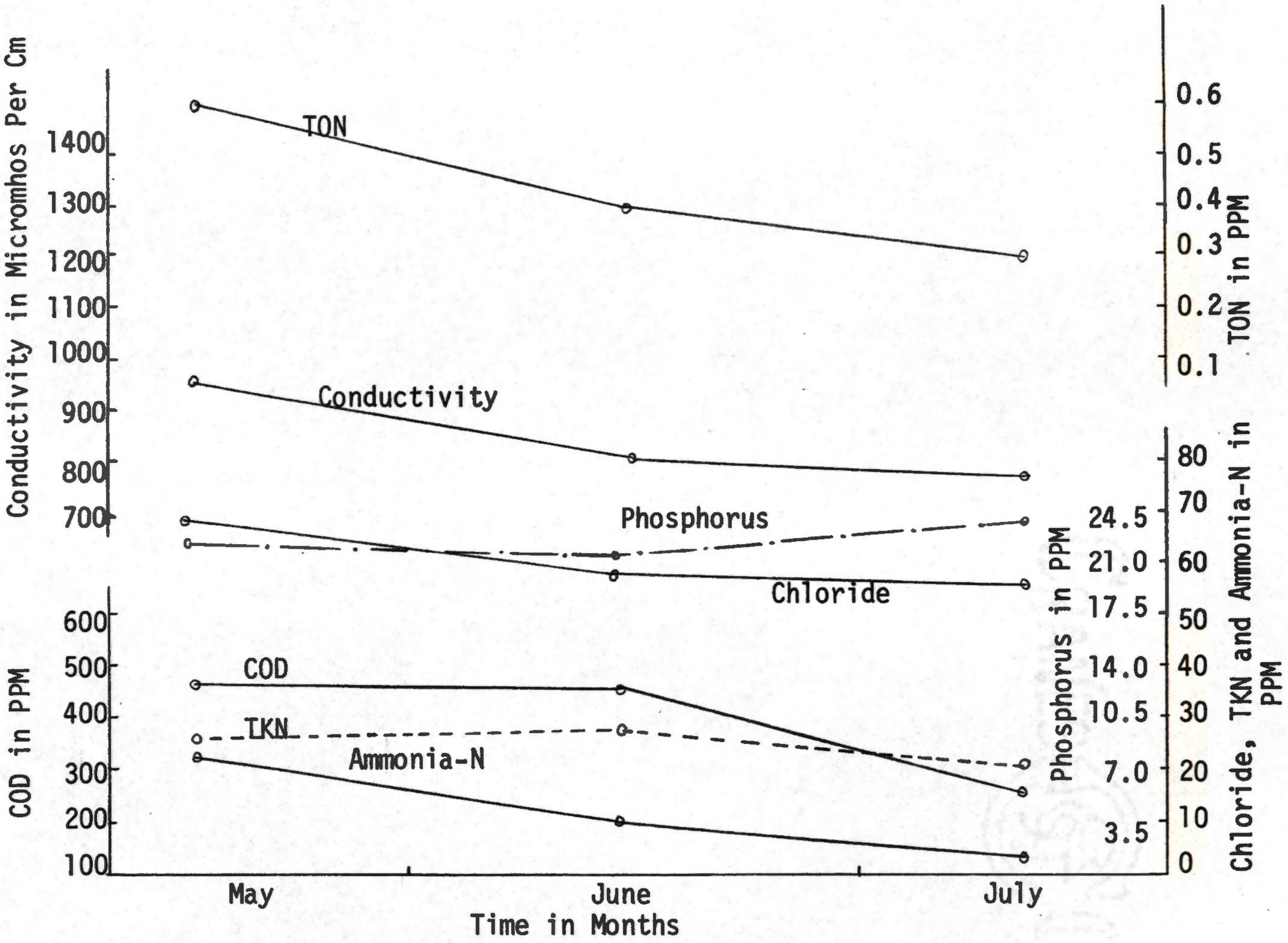

Figure 11. Variation in Concentration of Water Quality Parameters with Time in 1979.

B. WATER QUALITY PARAMETERS OF THE SURFACE RUNOFF WATER

Results of chemical analysis of the surface runoff samples collected in 1978 and 1979 are presented in Tables 2 and 3, respectively. In the 1978 sampling period, runoff samples were taken during each rainfall that produced runoff. However, all sampling locations did not yield runoff on each sampling date. In 1979 simulated rainfall was applied on the plots at a rate of 6.3 cm per hour for sufficient duration to assure that each plot yielded surface runoff.

All treatment levels of the lagoon effluent and the Rock Creek water applied on the plots produced a high level of ammonia-N and TKN in surface runoff samples. The ammonia-N concentration in these samples exceeded the maximum standard of raw surface water for public supplies (0.5 ppm) as established by the Federal Water Pollution Control Administration (1972). The ammonia-N concentration of the surface runoff samples of some plots which received 7.62 cm of the lagoon effluent exceeded the maximum standard of raw surface water by 10 times.

The background levels of ammonia-N and TKN in the soil, and the high concentration of nitrogen in the lagoon effluent, seem to be the reasons for the high nitrogen in the surface runoff. However, the average ammonia-N and TKN concentration measured in the plots' surface runoff were reduced by 45 and 30 percent, respectively from the ammonia-N and TKN concentration measured in the lagoon.

TON concentrations in the surface runoff samples were less than the permissible standard (10 ppm) of raw surface water for public

TABLE 2

RESULTS OF CHEMICAL ANALYSES OF SURFACE RUNOFF SAMPLES COLLECTED IN THE SUMMER OF 1978

Sampling Date	Water Quality Parameter	Plot Treatments in cm of Liquid Applied				
		2.54 L[a]	5.08 L	7.62 L	K[b]	7.62 CW[c]
	Conductivity[d]	141	105	45	68	68
	Total solids, ppm	0.51	1.14	3.00	0.77	0.96
	Chlorides, ppm	6.3	5.0	5.0	5.0	5.0
	Ammonia-N, ppm	0.20	0.55	0.30	0.43	0.40
06-21-78	TKN, ppm	4.00	3.00	2.00	03.00	2.50
	TON, ppm	1.40	0.80	0.10	0.43	0.70
	COD, ppm	70	39	35	74	61
	pH	6.7	6.5	6.4	6.4	6.4
	Total phosphorus, ppm	4.29	1.75	1.40	2.80	0.35
	Number of analyses	(3)	(2)	(1)	(3)	(2)
	Conductivity	71	47	54	62	50
	Total solids, ppm	0.12	0.10	0.16	0.33	0.23
	Chlorides, ppm	8.3	7.5	7.3	5.6	6.6
	Ammonia-N, ppm	1.06	0.90	0.93	1.16	0.83
07-05-78	TKN, ppm	1.50	0.90	1.66	1.66	2.33
	TON, ppm	0.33	0.30	0.26	0.20	0.26
	COD, ppm	29	8	20	29	29
	pH	6.3	6.1	6.3	6.2	6.5
	Total phosphorus, ppm	1.40	8.40	2.80	2.80	7.35
	Number of analyses	(3)	(2)	(3)	(3)	(3)
	Conductivity	87	97	328	69	111
	Total solids, ppm	0.48	0.22	0.66	0.77	0.27
	Chlorides, ppm	5.0	5.0	20.0	5.0	6.0
	Ammonia-N, ppm	1.10	1.30	4.15	0.75	3.20

TABLE 2 (Continued)

Sampling Date	Water Quality Parameter	Plot Treatments in cm of Liquid Applied				
		2.54 L[a]	5.08 L	7.62 L	K[b]	7.62 CW[c]
07-10-78	TKN, ppm	5.00	4.66	7.50	3.00	5.80
	TON, ppm	0.30	3.28	0.30	0.95	0.30
	COD, ppm	59	52	177	81	91
	pH	6.9	6.9	7.2	6.4	6.8
	Total phosphorus, ppm	4.20	4.55	9.45	3.85	4.90
	Number of analyses	(1)	(3)	(2)	(2)	(2)
07-13-78	Conductivity	133	204	248	167	203
	Total solids, ppm	2.39	3.63	1.94	4.11	9.27
	Chlorides, ppm	13.0	22.3	13.3	22.3	12.3
	Ammonia-N, ppm	3.40	2.33	2.60	2.60	2.63
	TKN, ppm	5.70	7.60	7.33	7.60	7.66
	TON, ppm	0.20	0.26	0.23	0.16	0.16
	COD, ppm	243	381	321	290	441
	pH	6.2	6.4	6.4	6.3	6.4
	Total phosphorus, ppm	5.95	3.50	4.20	4.20	3.85
	Number of analyses	(2)	(3)	(3)	(3)	(3)
07-25-78	Conductivity	156	105	235	71	150
	Total solids, ppm	0.66	1.68	3.14	1.23	2.67
	Chlorides, ppm	10.0	7.0	21.0	13.0	10.3
	Ammonia-N, ppm	4.06	3.06	5.13	2.96	3.30
	TKN, ppm	8.60	5.50	9.50	7.66	22.00
	TON, ppm	0.35	0.14	3.33	0.20	1.30
	COD, ppm	215	127	173	200	138
	pH	6.3	6.5	6.5	6.1	6.3
	Total phosphorus, ppm	5.25	6.30	7.35	5.25	---
	Number of analyses	(3)	(3)	(3)	(3)	(3)

TABLE 2 (Continued)

Sampling Date	Water Quality Parameter	Plot Treatments in cm of Liquid Applied				
		2.54 L[a]	5.08 L	7.62 L	K[b]	7.62 CW[c]
07-27-78	Conductivity	86	102	119	86	81
	Total solids, ppm	1.57	2.01	0.90	6.00	7.99
	Chlorides, ppm	8.6	8.3	9.0	5.6	9.0
	Ammonia-N, ppm	0.96	2.00	1.10	2.56	2.50
	TKN, ppm	6.00	10.50	4.20	15.50	11.50
	TON, ppm	0.15	0.06	0.20	0.26	0.02
	COD, ppm	110	243	113	278	136
	pH	6.6	6.9	6.9	6.6	6.7
	Total phosphorus, ppm	2.80	5.25	5.95	1.75	2.80
	Number of analyses	(3)	(3)	(2)	(3)	(2)
10-13-78	Conductivity	62	270	--	--	143
	Total solids, ppm	1.38	0.35	--	--	0.20
	Chlorides, ppm		17.0	--	--	7.0
	Ammonia-N, ppm	1.10	2.30	--	--	1.10
	TKN, ppm	5.00	3.00	--	--	2.00
	TON, ppm	0.20	0.60	--	--	0.10
	COD, ppm	131	144	--	--	66
	pH	6.7	6.6	--	--	7.1
	Total phosphorus, ppm	1.05	9.80	--	--	3.85
	Number of analyses	(1)	(1)			(1)

---

[a] Lagoon effluent.

[b] No application of liquid.

[c] Creek water.

TABLE 2 (Continued)

[d] Number of analyses for each treatment on the date indicated.

[e] All conductivities listed in the table are measured in micromhos per cm.

TABLE 3

RESULTS OF CHEMICAL ANALYSES OF SURFACE RUNOFF SAMPLES COLLECTED IN THE SUMMER OF 1979

Sampling Date	Water Quality Parameter	Plot Treatment[a] in cm of Liquid Applied				
		2.54 L[b]	5.08 L	7.62 L	10.16 L	K[c]
05-17-79	Conductivity	406	345	420	390	330
	Total solids, ppm	0.33	0.42	0.42	0.35	0.50
	Chloride, ppm	9.3	6.0	22.6	10.6	3.6
	Ammonia-N, ppm	1.45	0.96	2.76	1.60	1.23
	TKN, ppm	5.00	2.33	6.33	3.33	1.40
	TON, ppm	0.26	0.37	1.03	0.53	0.53
	COD, ppm	84	61	88	70	40
	pH	7.8	7.7	7.5	7.7	7.5
	Total phosphorus, ppm	3.50	2.80	4.20	3.50	1.75
06-14-79	Conductivity	420	358	371	385	338
	Total solids, ppm	0.36	0.18	0.30	0.35	0.25
	Chloride, ppm	7.3	5.0	6.3	6.3	7.6
	Ammonia-N, ppm	0.63	0.40	0.76	0.43	0.13
	TKN, ppm	4.33	5.00	3.33	3.66	3.00
	TON, ppm	0.10	0.53	0.93	1.30	0.31
	COD, ppm	94	102	92	118	81
	pH	7.8	7.7	8.0	7.8	7.7
	Total phosphorus, ppm	3.85	2.80	3.15	3.85	2.10
07-11-79	Conductivity	331	357	360	316	335
	Total solids, ppm	0.23	0.35	0.28	0.24	0.28
	Chloride, ppm	5.0	1.3	6.0	5.6	1.3
	Ammonia-N, ppm	1.30	0.76	0.80	0.13	0.73
	TKN, ppm	2.56	1.34	2.16	1.83	1.50
	TON, ppm	1.23	1.30	1.23	0.60	0.63

TABLE 3 (Continued)

Sampling Date	Water Quality Parameter	Plot Treatment[a] in cm of Liquid Applied				
		2.54 L[b]	5.08 L	7.62 L	10.16 L	K[c]
	COD, ppm	32	23	31	17	22
	pH	7.6	7.9	7.9	7.6	7.8
	Total phosphorus, ppm	2.45	1.40	1.75	2.10	0.70

[a] Three analyses per treatment.

[b] Lagoon effluent.

[c] No application of liquid.

[d] All conductivities listed in the table are measured in Micromhos per cm.

supplies. This agrees with the results of Sewell et al. (1974), who found that all surface runoff nitrate nitrogen concentrations were less the permissible values. In a case of heavily manured plots, Cross (1975) found that the nitrate nitrogen concentration in the surface runoff water exceeded the allowable limit of water (10 ppm) only during the first 90 minutes of the first irrigation. However, his results should not be compared with the results of this study in which lagoon effluent was applied to the plots.

On some occasions the COD concentration in the surface runoff samples was about 130 times higher than the COD concentration measured in the nearby Rock Creek water. Surface runoff water containing high COD levels may cause an oxygen depletion problem if allowed to enter water sources. However, the COD concentration of the surface runoff water was less than that of the lagoon by 98 and 24 percent in the first and second year, respectively.

The maximum electrical conductivity in the surface runoff samples was 420 micromhos per cm, which is below the water quality standard of 750 to 2,000 micromhos per cm for raw public water. Cross (1975) also found that, under the most pollutional conditions, the maximum electrical conductivity was 400 micromhos per cm. The measured pH was within the allowable standard (5 to 9) of surface water used for public supply. Total solids, chloride, and total phosphorus concentrations in the surface runoff samples were below the standards for raw surface water (500 ppm, 250 ppm, and 50 ppm, respectively).

Analysis of variance was performed on the transformed quality data of surface runoff according to the guidelines previously discussed. The routine was part of the computerized Statistical Analysis System (SAS) developed by Barr and Goodnight (1979) and implemented by the University of Tennessee Computing Center.

Table 4 shows that, for 1978, the treatment effects of total phosphorus were significantly different at the 5 percent level of probability. All other water quality parameters, including the TON, did not show a significant difference due to treatment effects in this analysis. Lund et al. (1975) also found that the NO_3-N content of the surface runoff samples was essentially unaffected by the manure treatment.

A regression analysis was applied to the treatment effects of total phosphorus. The treatments included in this analysis were 0.0 cm, 2.54 cm, 5.08 cm, and 7.62 cm applications of the lagoon effluent. Linear and quadratic models were fitted to this data in order to find the equations which best predict total phosphorus concentration in the surface runoff water. The linear model found was:

$$P = 3.0415 + 0.2415\ D$$

and the quadratic model found was:

$$P = 2.9645 + 0.3325\ D - 0.0119\ D^2$$

where:

P = the total phosphorus concentration in ppm, and

D = the depth of lagoon effluent applied on the plot in cm.

The R^2 values and the graph (Figure 12), indicated that the third term

TABLE 4

ANALYSIS OF VARIANCE RESULTS OF THE WATER QUALITY TRANSFORMED DATA FOR SURFACE RUNOFF SAMPLES COLLECTED IN THE SUMMER OF 1978

Source of Variation	Degrees of Freedom	Mean Square								
		Conductivity	Total Solids	Chloride	Ammonia-N	TKN	TON	COD	pH[a]	Phorphorus
Treatment	4	0.33913^{ns}	0.24850^{ns}	0.14331^{ns}	0.08983^{ns}	0.05749^{ns}	0.02682^{ns}	0.16362^{ns}	0.17159^{ns}	0.04383*
Replication	2	0.04861^{ns}	1.07268^{ns}	0.26190^{ns}	0.15649^{ns}	0.71304^{ns}	0.04008^{ns}	0.34772^{ns}	0.02262^{ns}	0.02987^{ns}
Treatment x replication	8	0.35809	0.36726	0.38025	0.06125	0.32042	0.39491	0.41590	0.10658	0.00880
Date	6	1.82404*	2.59815*	1.11658*	1.62043*	0.19133^{ns}	2.80082*	10.46296*	0.54009*	0/04831*
Treatment x date	22[b]	1.77200^{ns}	0.19045^{ns}	0.19334^{ns}	0.13648^{ns}	0.17443^{ns}	0.15814^{ns}	0.26182^{ns}	0.05122^{ns}	0.02750^{ns}
Overall Mean Square		4.63919	0.78549	2.22058	1.00805	1.74090	0.36273	4.59290	6.53417	0.13567
Residual Mean Square		0.14264	0.18837	0.24289	0.12081	0.19283	0.14147	0.21185	0.08116	0.01509

[a] Not transformed data.

[b] Degrees of freedom for chloride is 21.

^{ns}Not significant.

*Significant at 5 percent level of probability.

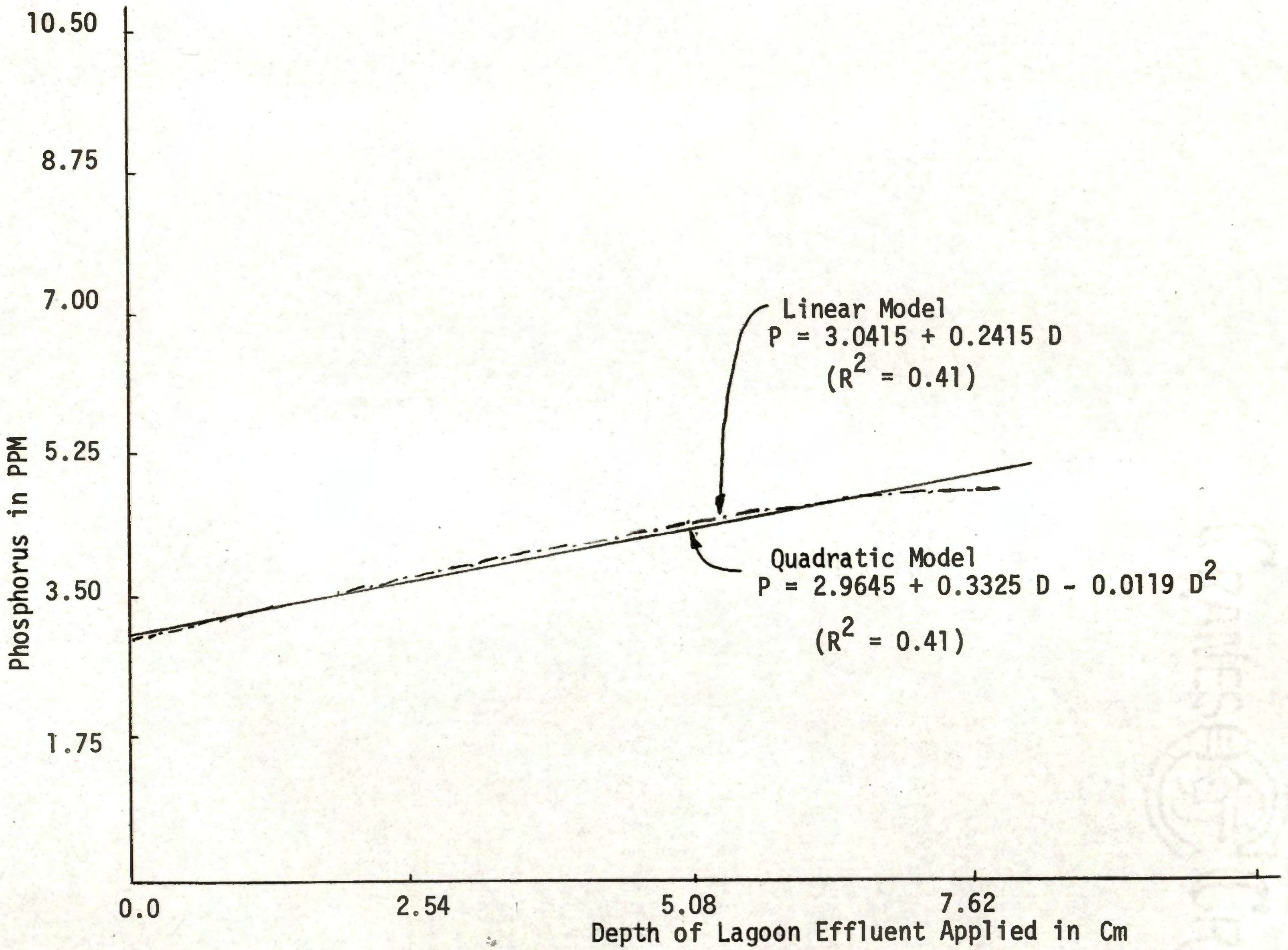

Figure 12. Total Phosphorus at Different Levels of Lagoon Effluent in the Surface Runoff Samples Collected in the Summer of 1978.

of the quadratic model did not significantly contribute in explaining variation of total phosphorus with different levels of treatments. Neither the linear model nor the quadratic model was sufficiently good to predict total phosphorus with various treatment levels. However, data obtained should be useful in arriving at treatment-time relationship. Consequently, table is included to show the minimum, mean and maximum values of phosphorus concentration for each treatment level (Table 5).

An analysis of variance also indicated that, for 1978, all water quality parameters except TKN differed significantly with sampling dates at 5 percent level of probability (Table 4, page 62). The water quality parameters that showed a significant difference with sampling dates were plotted versus time (Figure 13). The results agree with those of Barker (1972), who showed that orthophosphate and nitrate nitrogen were the only water quality parameters which differed significantly among sampling dates.

Table 6 presents the analysis of variance results of the water quality transformed data for surface runoff samples collected in the summer of 1979. No significant difference was found among treatment effects for any parameter in this analysis. However, significant effects of sampling dates were found in ammonia-N, TKN, TON, and COD at 5 percent level of probability. These parameters were plotted versus time as shown in Figure 14. The ammonia-N and the COD concentrations are the water quality parameters that showed a significant difference among sampling dates at the 5 percent level of probability, in the two years.

TABLE 5

PHOSPHORUS MAXIMUM, MEAN AND MINIMUM CONCENTRATION WITH VARIOUS TREATMENT LEVEL

Treatment in cm depth of the lagoon effluent	min	mean*	max
0	0.35	3.85	7.35
2.54	1.05	3.55	5.95
5.08	1.75	5.65	9.80
7.62	1.40	5.20[a]	9.45

*Mean of seven observations.

[a] Mean of six observations.

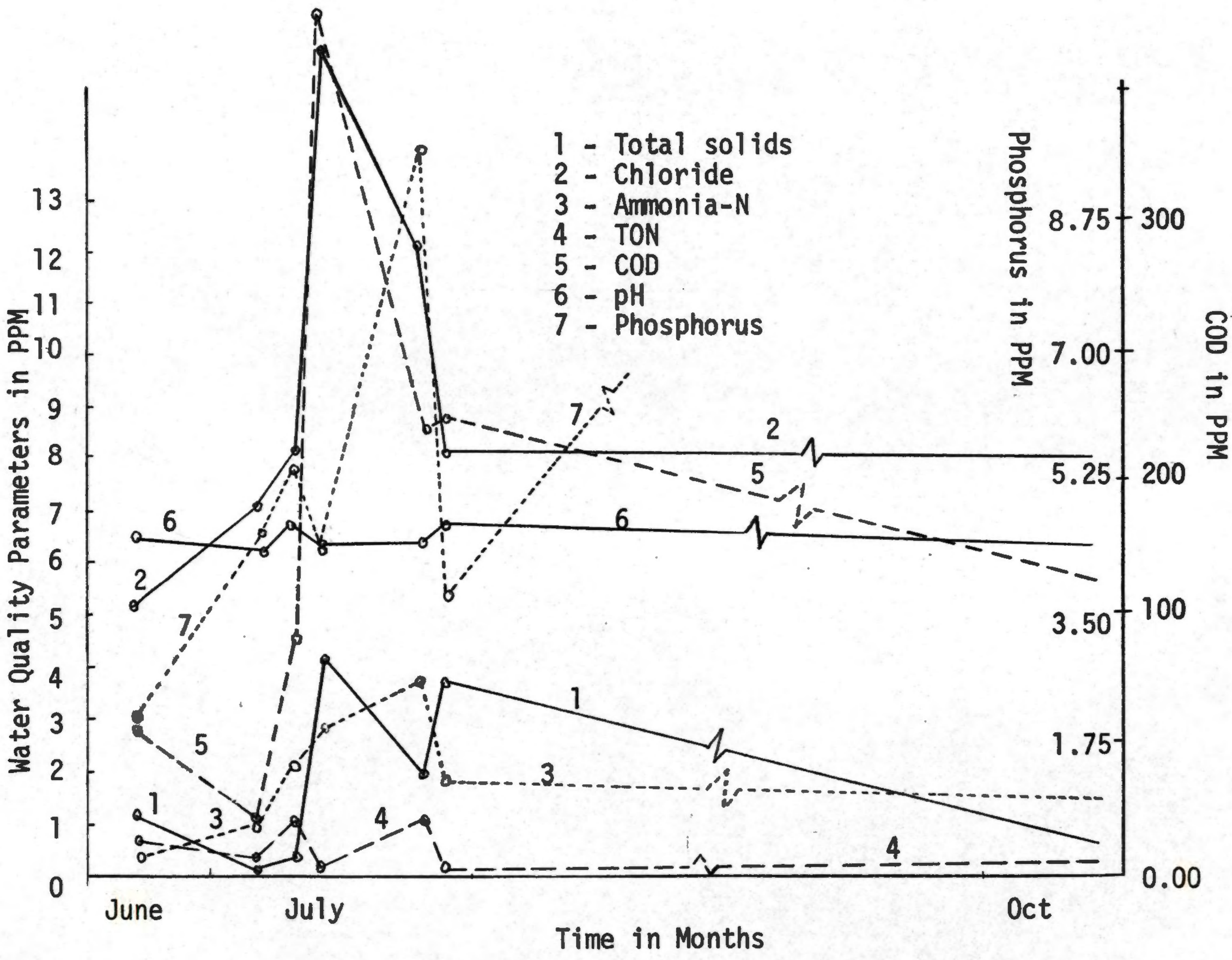

Figure 13. Concentrations of Water Quality Parameters for Surface Runoff Samples Collected in the Summer of 1978.

TABLE 6

ANALYSIS OF VARIANCE RESULTS OF THE WATER QUALITY TRANSFORMED DATA FOR SURFACE RUNOFF SAMPLES COLLECTED IN THE SUMMER OF 1979

Source of Variation	Degrees of Freedom	Mean Square								
		Conductivity	Total Solids	Chloride	Ammonia-N	TKN	TON	COD	pH^{a}	Phosphorus
Treatment	4	0.03559^{ns}	0.00091^{ns}	1.51909^{ns}	0.14785^{ns}	0.29238^{ns}	0.17500^{ns}	0.18789^{ns}	0.07514^{ns}	0.00357^{ns}
Replication	2	0.00199^{ns}	0.00009^{ns}	0.88000^{ns}	0.03776^{ns}	0.05626^{ns}	0.00416^{ns}	0.11229^{ns}	0.22156*	0.00012^{ns}
Treatment x replication	8	0.01530	0.00409	0.63593	0.08346	0.10096	0.18408	0.15571	0.03558	0.00168
Data	2	0,02187^{ns}	0.03106^{ns}	1.77069^{ns}	1.17520*	0.79449*	1.30156*	5.87048*	0.07160^{ns}	0.07164^{ns}
Treatment x data	8	0.01608^{ns}	0.00906^{ns}	0.91218^{ns}	0.06540^{ns}	0.20065^{ns}	0.21806^{ns}	0.07760^{ns}	0.18477^{ns}	0.18477^{ns}
Overall Mean square		5.89948	0.28519	1.81130	0.60837	1.35217	0.61590	3.78662	7.69780	0.07692
Residual Mean square		0.01676	0.00929	0.81627	0.12051	0.15621	0.29830	0.21295	0.09374	0.00073

[a] Not transformed data.

[ns] Not significant.

*Significant at 5 percent level of probability.

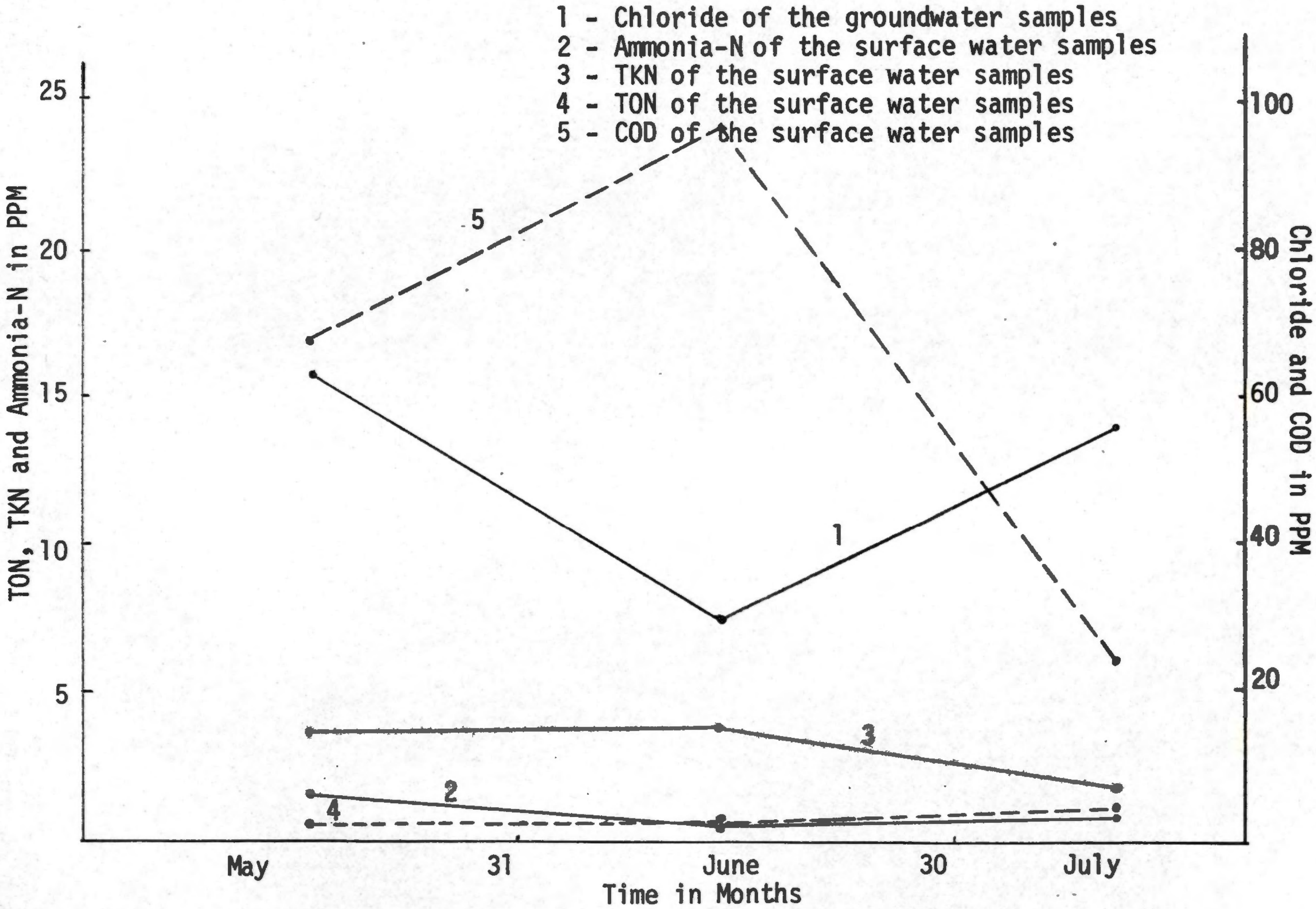

Figure 14. Concentration of Water Quality Parameters of the Surface Runoff and Groundwater Samples for 1979 Sampling Dates.

This indicated that the ammonia-N and the COD are the water quality parameters that are highly effected by the conditions present on sampling dates.

Analysis of variance of the surface runoff samples, and field observations during the period of study, indicated that the following factors were affecting the concentration of quality parameters in surface runoff:

1. rainfall amount and intensity causing surface runoff;
2. soil moisture condition in the first 15 cm of the soil profile at the time of lagoon effluent application;
3. the delay in time between the lagoon effluent application and the rainfall occurrence;
4. amount of the lagoon effluent applied on the plots (treatment effect);
5. variation in the lagoon concentration with time, which effects the liquid concentration applied on plots;
6. environmental condition, especially the wind and the temperature present at the time of liquid manure application;
7. the homogeneity of the vegetative cover of the plots; and
8. the microtopography of the plots.

However, no data was available to support the last three factors.

All water quality parameters were included in a stepwise regression analysis to determine the model which best fits the data and therefore, best estimates concentration of water quality parameters. The data used in this analysis were adjusted by including the water quality parameters' concentrations in percent of those measured at the lagoon (Table 7). These data were selected from three sampling dates to conduct the stepwise regression analysis, since the selected dates contained all the information needed for the analysis. However, TON was not included in this analysis because its concentration at the plots was higher than that at the lagoon. The following effects were included in these models:

1. Rainfall depth in cm;
2. Soil moisture measured in the upper 15 cm of the soil profile at the time of lagoon effluent application; in percent volume basis;
3. Treatments effects, which consisted of applying 2.54 cm, 5.08 cm and 7.62 cm depth of the lagoon effluent to the plots; and
4. Time delay between lagoon effluent application and rainfall occurrence in days.

The models determined by the stepwise regression analysis, and their R^2 values are presented in Table 8. The ammonia-N concentration in the surface runoff samples was best estimated by including the soil moisture and the treatment effects in the model. This indicates that the degree of ammonia-N concentration in the surface runoff is a function of soil moisture and treatment effects. Ross et al. (1978) also found the concentration of pollutant in surface runoff is a function of the treatment level.

The TON and COD concentration in the surface runoff were a function of soil moisture. The pH of the surface runoff water was a function of

TABLE 7

RELATIONSHIPS OF SELECTED RUNOFF WATER QUALITY PARAMETERS CONCENTRATIONS TO THOSE MEASURED AT THE LAGOON IN PERCENT

Sampling Date	Parameter	Treatments 2.540 cm lag. effluent	5.080 cm lag. effluent	7.620 cm lag. effluent	No Application	7.620 cm. Creek Water	Rainfall in cm	Delay Time in Days	Soil Moisture in percent Volume Basis
6-19-78	Conductivity	11.3	8.4	3.6	5.4	5.4	2.54	5	41
	Total solids	40.3	90.4	23.8	61.1	76.5			
	Chloride	6.6	5.2	5.2	5.2	5.2			
	Ammonia-N	1.2	3.4	1.8	2.6	2.5			
	TKN	11.7	8.8	5.8	8.8	7.3			
	COD	9.4	5.3	4.7	10.0	8.2			
	pH	88.1	86.1	84.2	84.2	84.2			
	Total phosphorus	13.8	6.0	4.3	9.4	1.6			
7-10-78	Conductivity	7.9	8.8	29.8	6.3	10.1	5.08	4	31
	Total solids	55.8	25.5	76.7	90.1	31.3			
	Chloride	7.6	7.6	30.7	7.6	9.2			
	Ammonia-N	8.4	10.0	31.9	5.7	24.6			
	TKN	16.6	15.5	25.0	2.5	19.3			
	COD	10.1	9.0	30.4	13.9	15.6			
	pH	94.5	95.3	99.3	86.6	93.1			
	Total phosphorus	16.2	18.2	36.4	15.5	19.5			
7-25-78	Conductivity	13.6	9.2	20.6	6.2	13.1	6.73	6	12
	Total solids	70.2	100.0*	100.0	100.0	100.0			
	Chloride	11.1	7.7	23.3	14.4	11.4			
	Ammonia-N	33.8	25.5	52.7	24.6	27.5			
	TKN	35.8	22.9	39.5	31.9	91.6			
	COD	43.0	25.4	34.6	40.1	27.7			
	pH	88.1	90.4	90.4	84.7	87.5			
	Total phorphorus	22.9	26.4	30.8	22.9	100.0			

*The 100.0 values in the table mean that the water quality parameter concentration measures at the plot were higher than those at the lagoon.

TABLE 8

REGRESSIONS OF SELECTED VARIABLES ON SOME QUALITY PARAMETERS OF SURFACE RUNOFF IN 1978

Water Quality Parameter	Model	R^2 - Value
Ammonia-N	$37.93 - 1.19M + 2.82T$	0.83
TKN	$42.96 - 0.81M$	0.78
COD	$45.93 - 0.95M$	0.72
pH	$106.20 + 2.03 R - 5.03 D$	0.86
Phosphorus	$-2.48 + 4.59 R$	0.60

M = Soil moisture measured at the upper 15 cm of the soil at the time of lagoon effluent application in percent by volume.

T = Treatments, which consisted of different depths of lagoon effluent in cm.

R = Rainfall depth in cm.

D = Delay time between lagoon effluent application and samples collections in days.

rainfall depth and delay in time, and the total phosphorus concentration was a function of rainfall depth. These results agree with those of Cummings et al. (1975), Ross et al. (1978), Miner et al. (1967), and Swanson et al. (1971).

The uncontrolled effect of the rainfall which occurred in 1978 was adjusted in 1979 by applying a simulated rainfall of known intensity and depth. Similarly, the uncontrolled effect of the delay in time between lagoon effluent application and rainfall occurrence was adjusted by allowing a 12 hour delay in time in the second year of study.

C. QUALITY PARAMETERS OF THE GROUNDWATER

The chemical analyses of the quality parameters of the groundwater samples collected in 1978 and 1979 are presented in Tables 9 and 10, respectively. Groundwater samples were taken after the occurrence of rainfall, been sufficient to produce groundwater samples in the plots. Hence not all sampling locations yielded groundwater on each sampling date of 1978. In the second year of the experiment simulated rainfall was used in order that all plots would yield groundwater samples.

All treatment levels of the lagoon effluent applied on the plots over the two year period produced a high level of ammonia-N and TKN in the groundwater samples. The ammonia-N concentration in these samples exceeded the maximum standard of raw surface water for public supplies (0.5 ppm) as established by the Federal Water Pollution Control Administration (1972). These results agree with the findings of Sewell et al. (1975),

TABLE 9

RESULTS OF CHEMICAL ANALYSES OF GROUNDWATER SAMPLES COLLECTED IN THE SUMMER OF 1978

Sampling Date	Water Quality Parameters	Plot Treatments in cm of Liquid Applied				
		2.54 L^{a}	5.08 L	7.62 L	K^{b}	7.62 CW
06-21-78	Conductivity^{d}	--	600	--	--	140
	Total solids, ppm	--	0.52	--	--	0.34
	Chlorides, ppm	--	42.5	--	--	10.0
	Ammonia-N, ppm	--	1.40	--	--	--
	TKN, ppm	--	1.40	--	--	2.00
	TON, ppm	--	2.10	--	--	0.10
	COD, ppm	--	20	--	--	28
	pH	--	7.0	--	--	7.1
	Total phosphorus, ppm	--	2.80	--	--	5.25
	Number of analyses		(1)			(1)
07-05-78	Conductivity	292	--	210	122	128
	Total solids, ppm	0.42	--	0.31	0.28	0.17
	Chlorides, ppm	43.7	--	8.0	1.0	3.0
	Ammonia-N, ppm	--	--	1.20	0.60	1.00
	TKN, ppm	1.50	--	2.00	1.50	3.00
	TON, ppm	4.25	--	0.80	0.60	2.00
	COD, ppm	15	--	18	11	18
	pH	6.3	--	6.5	6.6	6.7
	Total phosphorus, ppm	4.20	--	3.50	5.60	3.50
	Number of analyses	(2)		(1)	(2)	(1)
	Conductivity	125	--	440	--	175
	Total solids, ppm	0.19	--	0.58	--	0.40
	Chlorides, ppm	7.0	--	40.0	--	8.0
	Ammonia-N, ppm	0.60	--	7.70	--	0.30

TABLE 9 (Continued)

Sampling Date	Water Quality Parameters	Plot Treatments in cm of Liquid Applied				
		2.54 L[a]	5.08 L	7.62 L	K[b]	7.62 CW
07-10-78	TKN, ppm	1.00	--	13.00	--	3.00
	TON, ppm	1.30	--	0.30	--	5.90
	COD, ppm	37	--	208	--	21
	pH	7.0	--	6.8	--	6.8
	Total phosphorus, ppm	7.70	--	13.30	--	2.45
	Number of analyses	(1)		(1)		(1)
	Conductivity	250	480	575	150	267
	Total solids, ppm	0.35	0.47	0.69	0.31	0.42
	Chlorides, ppm	27.0	80.0	86.0	9.0	17.5
	Ammonia-N, ppm	0.70	1.90	3.50	0.30	0.40
07-25-78	TKN, ppm	2.00	2.00	10.50	1.00	1.00
	TON, ppm	0.70	2.50	0.54	1.50	1.25
	COD, ppm	59	187	290	28	39
	pH	7.0	7.3	7.3	7.1	7.3
	Total phosphorus, ppm	2.10	6.30	7.35	1.75	5.25
	Number of analyses	(1)	(1)	(2)	(2)	(2)
	Conductivity	530	385	--	--	650
	Total solids, ppm	0.35	0.46	--	--	0.22
	Chlorides, ppm	70.0	81.0	--	--	25.0
	Ammonia-N, ppm	0.10	0.11	--	--	0.20
10-13-78	TKN, ppm	1.00	2.50	--	--	0.20
	TON, ppm	3.00	1.05	--	--	0.01
	COD, ppm	21	87	--	--	4

TABLE 9 (Continued)

Sampling Date	Water Quality Parameters	Plot Treatments in cm of Liquid Applied				
		2.54 L[a]	5.08 L	7.62 L	K[b]	7.62 CW
	pH	7.0	7.2	--	--	7.9
	Total phosphorus, ppm	2.10	3.15	--	--	2.45
	Number of analyses	(1)	(2)			(1)

---

[a] Lagoon effluent.

[b] No application of liquid.

[c] Creek water.

[d] All conductivities listed in the table are measured in micromhos per cm.

[e] Number of analyses for each treatment on indicated date.

TABLE 10

RESULTS OF CHEMICAL ANALYSES OF GROUNDWATER SAMPLES COLLECTED IN THE SUMMER OF 1979

Sampling Date	Water Quality Parameter	Plot Treatment[a] in cm of Liquid Applied				
		2.54 L[b]	5.08 L	7.62 L	10.16 L	K[c]
	Conductivity[d]	343	366	403	423	200
	Total solids, ppm	0.29	0.22	0.31	0.38	0.52
	Chloride, ppm	13.0	15.6	18.5	26.6	5.2
	Ammonia-N, ppm	1.76	1.90	1.96	2.40	0.23
05-17-79	TKN, ppm	3.02	2.40	4.66	3.00	2.00
	TON, ppm	3.20	0.66	1.23	1.13	1.26
	COD, ppm	37	31	31	54	17
	pH	7.3	7.3	7.5	7.5	7.0
	Total phosphorus, ppm	2.80	2.80	62.16	2.10	1.75
	Conductivity	328	343	423	448	238
	Total solids, ppm	0.32	0.32	0.33	0.38	0.63
	Chloride, ppm	5.0	8.6	5.0	16.6	2.3
	Ammonia-N, ppm	0.50	1.46	1.10	1.23	0.13
6-14-79	TKN, ppm	3.12	2.33	4.33	4.00	3.00
	TON, ppm	3.06	8.40	2.46	3.13	2.36
	COD, ppm	37	24	40	42	58
	pH	7.0	7.2	7.3	7.2	6.6
	Total phosphorus, ppm	2.10	1.40	2.45	3.15	2.10
	Conductivity	335	362[e]	476	440	285
	Total solids, ppm	0.43	0.41	0.66	0.42	0.33
	Chloride, ppm	11.6	15.0	19.6	21.0	3.0
	Ammonia-N, ppm	1.03	1.10	0.65	1.90	1.95

TABLE 10 (Continued)

Sampling Date	Water Quality Parameter	Plot Treatment[a] in cm of Liquid Applied				
		2.54 L[b]	5.08 L	7.62 L	10.16 L	K[c]
07-11-79	TKN, ppm	2.66	2.50	2.66	3.33	4.00
	TON, ppm	4.76	6.30	5.90	6.20	1.46
	COD, ppm	21	20	21	30	22
	pH	6.8	7.1	7.3	7.2	6.9
	Total phosphorus, ppm	3.15	3.50	3.85	3.15	2.80

[a] Three analyses per treatment.

[b] Lagoon effluent.

[c] No application of liquid.

[d] All conductivities listed in the table are measured in micromhos per cm.

[e] Two analyses on indicated date.

who found that the application of manure slurry to a soil during periods of high rainfall contributed greatly to the contamination of shallow groundwater. However, there was no indication that ammonia-N or TKN concentrations differed from that of the surface runoff water.

TON concentration in the groundwater samples was higher than that measured in the surface runoff samples by an average of 10 times. However, this level was still below the allowable standard. The increase in the TON was explained by Bartlett (1975), who found that the conversion of ammonia-N to nitrate in soils through nitrification is generally quite rapid.

Although the level of TON collected at a depth of 90 cm did not exceed the allowable standard, it might exceed the standard if collected at a deeper point in the soil profile. Hence, the TON concentration could be the first limiting factor for the application of lagoon effluent. Trout et al. (1976) also determined that inorganic nitrogen leaching to groundwater was substantial, and that leaching increased with sludge application.

On the average, the COD concentration measured in the groundwater samples was less than that of the surface runoff samples by a factor of about four. This was probably due to the filtering process of the liquid through soil profile.

Electrical conductivity and pH of the groundwater samples were higher than those of the surface runoff samples. This is attributed to salts and other mineral compounds in the soil.

Chloride concentrations in the groundwater samples were higher than those of the surface runoff samples throughout the period of study.

Average of total phosphorus concentrations in the groundwater and surface runoff water samples were the same.

Analysis of variance was performed on the transformed quality data of the groundwater samples according to the guidelines previously discussed, and results from the 1979 samples are presented in Table 11. The analysis of variance for the water quality parameters of the groundwater samples of 1978 was not performed because of the excessive missing data during that year. Table 11 shows that the treatment effects of the electrical conductivity of the groundwater samples were significantly different at the 5 percent level of probability. No other water quality parameters showed any significant effect of treatment in this analysis.

A regression analysis of treatment effects on electrical conductivity was then made. The treatments included in this analysis consisted of applying 0.0 cm, 2.54, 5.08 cm, 7.62 cm, and 10.16 cm of lagoon effluent. Linear and quadratic models which best predict the electrical conductivity readings, were:

$$C = 262.945 + 19.335\ D$$

and

$$C = 244.612 + 33.770\ D - 1.420\ D^2$$

where

C = the electrical conductivity in micromhos per cm, and

D = the depth of lagoon effluent applied in cm.

The R^2 values were 0.84 for the linear model and 0.88 for the quadratic model. The quadratic model in this case gives a better estimation of the electrical conductivity readings. Figure 15 shows the electrical

TABLE 11

ANALYSIS OF VARIANCE RESULTS OF THE WATER QUALITY TRANSFORMED DATA FOR GROUNDWATER SAMPLES COLLECTED IN THE SUMMER OF 1979

Source of Variation	Degrees of Freedom	Mean Square								
		Conductivity	Total Solids	Chloride	Ammonia-N	TKN	TON	COD	PH[a]	Phosphorus
Treatment	4	0.46182*	0.01872[ns]	2.40200[ns]	0.12889[ns]	0.17044[ns]	0.27922[ns]	0.15365[ns]	0.39465[ns]	0.00083[ns]
Replication	2	0.00561[ns]	0.01744[ns]	0.49526[ns]	0.11808[ns]	0.11808[ns]	0.25829[ns]	0.35090[ns]	0.07013[ns]	0.00249[ns]
Treatment x replication	8	0.04757	0.01858	1.46982	0.16600	0.14854	0.38043	0.42538	0.17971	0.00103
Date	2	0.02828[ns]	0.00747[ns]	2.11732*	0.44221[ns]	0.00220[ns]	0.86608[ns]	0.67245[ns]	0.29928[ns]	0.29928[ns]
Treatment x date	7	0.01753[ns]	0.00237[ns]	0.40645[ns]	0.28512[ns]	0.11090[ns]	0.24845[ns]	0.14851[ns]	0.01262[ns]	0.01262[ns]
Overall mean square		5.69630	0.32231	2.08452	0.67661	1.37020	1.07353	3.37226	7.22025	0.07295
Residual mean square		0.01866	0.01095	0.45121	0.24604	0.12814	0.26965	4.51686	0.08583	0.00059

[a] Not transformed data.

[ns] Not significant.

*Significant at 5 percent level of probability.

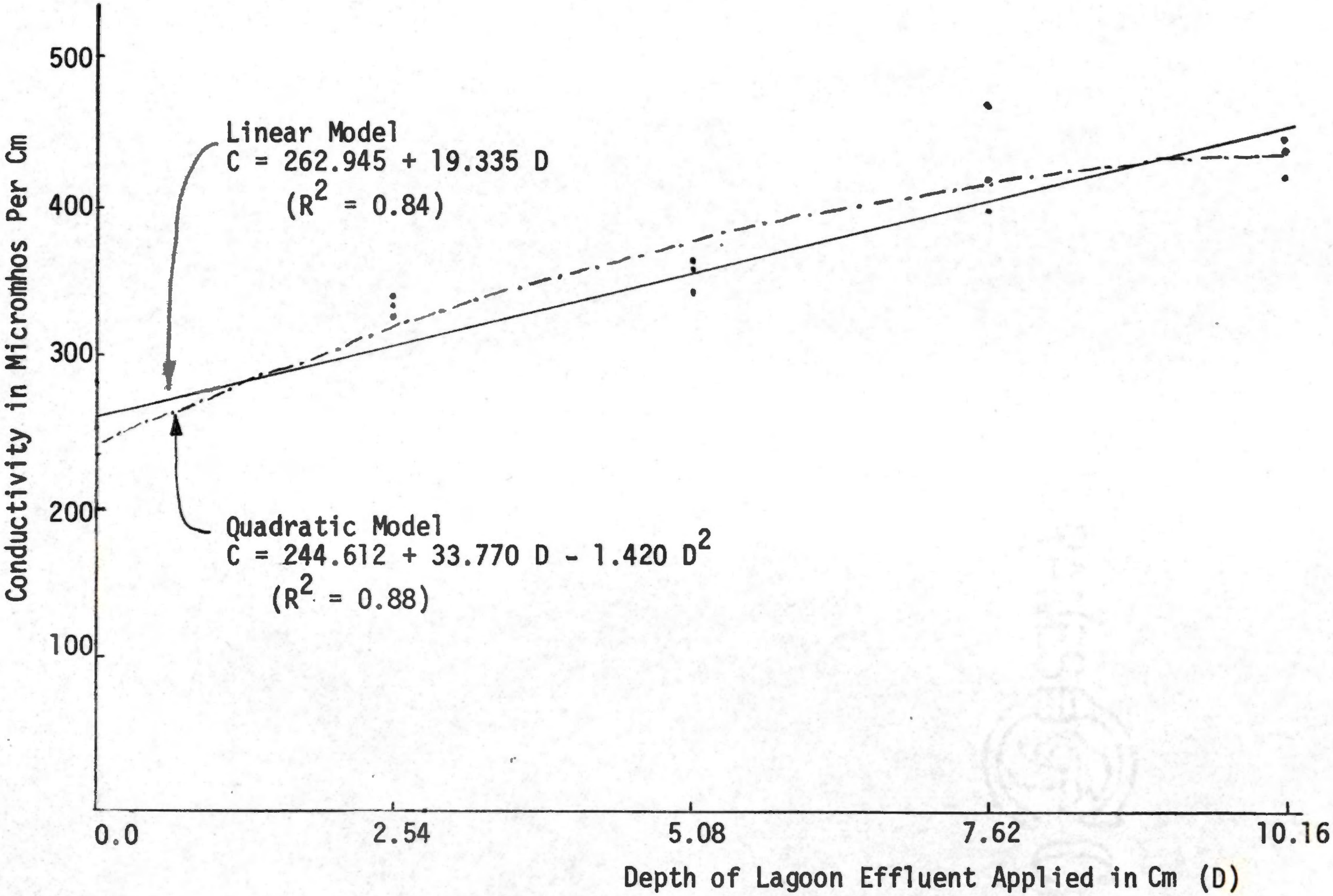

Figure 15. Conductivity at Different Levels of Lagoon Effluent in the Groundwater Samples Collected in the Summer of 1979.

conductivity for different levels of lagoon effluent applied in 1979.

An analysis of variance (Table 11, page 81) indicated that chloride is the only water quality parameter which showed a significant difference due to sampling date. Chloride concentrations were plotted versus time as shown in Figure 14, page 68 for surface runoff. A significant difference due to sampling date was found in most surface runoff samples of the first and second year. This indicates that factors which effect concentration of quality parameters in the surface runoff water did not effect the concentration of parameters in the groundwater.

D. SOIL PHYSICAL PROPERTIES

Permeability

The time for a measured volume of liquid to percolate through the soil core samples was recorded and the permeabilities were determined using Darcy's equation. The results of the permeability determinations are presented in Table 12.

The clay loam core samples appeared to have less reduction in the permeabilities due to the application of lagoon effluent than the sandy loam core samples. At the end of the experiment the percent permeability reduction measured on clay loam soils receiving distilled water, lagoon effluent, and mixed lagoon effluent were 97.82 percent, 98.67 percent and 99.78 percent, respectively. The highest percent reduction in permeability was recorded on the cores that received lagoon effluent of 0.3 percent solid fibrous material. However, the permeability was also reduced

TABLE 12

PERMEABILITY OF CLAY LOAM AND SANDY LOAM SAMPLES IN CM PER HOUR

Application Date	Lagoon Effluent Applied in cm	Clay Loam Samples			Sandy Loam Samples		
		Distilled Water	Lagoon Effluent	Mixed Lagoon Effluent	Distilled Water	Lagoon Effluent	Mixed Lagoon Effluent
06-06-79*	0.00	0.503	10.166	2.836	6.496	14.073	14.090
06-08-79	15.24	0.091	3.174	0.158	7.170	10.672	1.914
06-15-79	30.48	0.004	9.072	0.839	7.564	11.329	2.022
06-19-79*	30.48	0.004	7.888	0.006	6.713	15.925	2.789
06-20-79	45.72	0.004	2.753	0.006	2.522	3.332	1.421
06-21-79	60.96	0.004	2.212	0.006	2.405	1.714	0.474
06-24-79*	60.96	0.004	5.477	0.006	1.673	5.286	1.384
06-25-79	76.20	0.004	1.786	0.006	1.908	1.190	0.454
06-26-79	91.44	0.004	0.596	0.006	2.344	1.074	0.220
06-27-79*	91.44	0.006	0.990	0.000	0.992	1.124	0.290
06-28-79	106.68	0.006	0.799	0.000	0.962	1.508	0.154
06-30-79	121.92	0.006	0.975	0.000	0.999	1.087	0.118
07-02-79*	121.92	0.011	0.725	0.000	1.525	0.840	0.053
07-03-79	137.16	0.011	0.516	0.000	1.133	1.634	0.091
07-04-79	152.40	0.011	0.200	0.000	1.137	0.512	0.129
07-05-79*	152.40	0.011	0.379	0.000	1.482	0.383	0.091
07-07-79	167.67	0.011	0.323	0.000	1.482	0.558	0.000
07-08-79	182.88	0.011	0.102	0.000	1.045	0.382	0.000
07-09-79*	182.88	0.011	0.135	0.000	0.934	0.314	0.000

[a] Mean value for two replications, all other samples values are for three replications.

*Measurements of permeability were made using distilled water.

on the core samples which received distilled water. This indicates that the percent permeability reduction was due not only to the presence of fibrous materials in the lagoon effluent, but also to the application of liquid. Moreover, the surface tension of the lagoon effluent is less than that of the distilled water, which caused more liquid to enter into samples that received lagoon effluent.

For the purpose of data analysis the percent reduction in the permeability of core samples which received distilled water was subtracted from the percent permeability reduction of the core samples which received lagoon effluent. The application of lagoon effluent containing 0.1 percent solid fibrous material reduced the permeability of the clay loam core samples by 0.85 percent, and the application of mixed lagoon effluent containing 0.3 percent solid fibrous material reduced the permeability of the clay loam core samples by 1.96 percent. The application of mixed lagoon effluent of 0.3 percent solid fibrous material caused the clay loam core samples to clog after applying 60.96 cm depth of the liquid. A layer of microbial and fibrous material 1.3 cm thick was observed on the soil surface at the end of the experiment. The percent permeability reduction in the sandy loam samples was 85.62 percent, 97.96 percent, and 99.35 percent for the core samples receiving distilled water, lagoon effluent, and mixed lagoon effluent, respectively. Therefore, the application of lagoon effluent containing 0.1 percent solid fibrous material, caused a reduction of 12.14 percent in the permeability of sandy loam core samples. Moreover, the application of mixed lagoon effluent containing 0.3 percent solid fibrous material caused a reduction of 13.73 percent in the permeability of sandy loam core samples. However, the application of mixed lagoon effluent of 0.3 percent solid fibrous material caused the sandy loam core samples to clog after applying 152.40 cm of the lagoon effluent. A layer of microbial and fibrous material 2.5 cm thick was observed on the soil surface at the end of the experiment.

From the previous discussion it is clear that the reduction in the permeability due to the application of lagoon effluent was greater in the sandy loam soil than that in the clay loam soil. Since the sandy loam soil contained larger voids than the clay loam soil, more solid material entered the larger voids. Researchers like Cross and Fishbach (1973), Chung and Bechir (1973), Nienaber et al. (1973), Pile et al. (1975) also found a reduction in the permeability of soil after applying a large quantities of lagoon effluent. However, Gerba et al. (1975) found that bacteria and organic material accumulated on the soil surface increased the filtration properties of soil.

The analysis of variance conducted on the permeability is presented in Table 13. The treatment effects show a significant difference at 5 percent level of probability. This indicates that the percent solid fibrous material present in the lagoon effluent greatly effects the permeability of the soil. This agrees with Azeredo and Stout (1974), who reported that the fiber content of animal manure is the most important constituent controlling soil permeability after waste application.

TABLE 13

ANALYSIS OF VARIANCE FOR PERMEABILITY DETERMINATION

Source of Variation	Degrees of Freedom	Mean Squares	F-Value
Treatment	2	124.20441	30.49*
Soil	3	128.99200	31.77*
Treatment x soil	2	4.72762	1.16^{ns}
Replication (treatment x soil)	12	9.14881	2.25*
Depth of liquid applied	6	146.03391	35.97*
Depth of liquid applied x treatment	12	29.92480	7.37*
Depth of liquid applied x soil	6	30.11422	7.42*
Depth of liquid applied x treatment x soil	12	3.88810	0.96^{ns}
Experimental error	66	267.95741	
Total	119	2227.24561	

^{ns}Not Significant

*Significant at 5 percent level of probability.

Different types of soil also show a significant difference at 5 percent level of probability.

A significant difference of 5 percent in the treatment-soil interaction within replication was also found. Replications had a wide range of permeability, since each core sample of a specific type of soil had a different soil-core interface condition (i.e. different vegetative cover and different degrees of compaction).

The analysis of variance also indicated a significant difference at the 5 percent level of probability of liquid depth applied, liquid depth applied with different soils, and liquid depth applied with treatment effects. These results indicate that the amount of lagoon effluent applied on the core samples highly affects permeability, and the more liquid added, the more reduction in the permeability of the soil. Permeability of the soil decreased as the percentage of solid content in the lagoon effluent increased. The depth of lagoon effluent added to soils effected the permeability on different types of soils by different amounts. Soils of different void sizes will take different amounts of liquid to fill these voids with fine solid particles. In this study it was found that 60.96 cm of mixed lagoon effluent was required to clog the voids of clay loam, while 152.40 cm was required to clog the voids of sandy loam. Graphical presentations of the permeability versus depth of lagoon effluent are shown in Figures 16 through 21 for the three levels of treatment and the two types of soil. The forms of models were used in attempt to describe the permeability decrease with lagoon effluent application. One model was of the form:

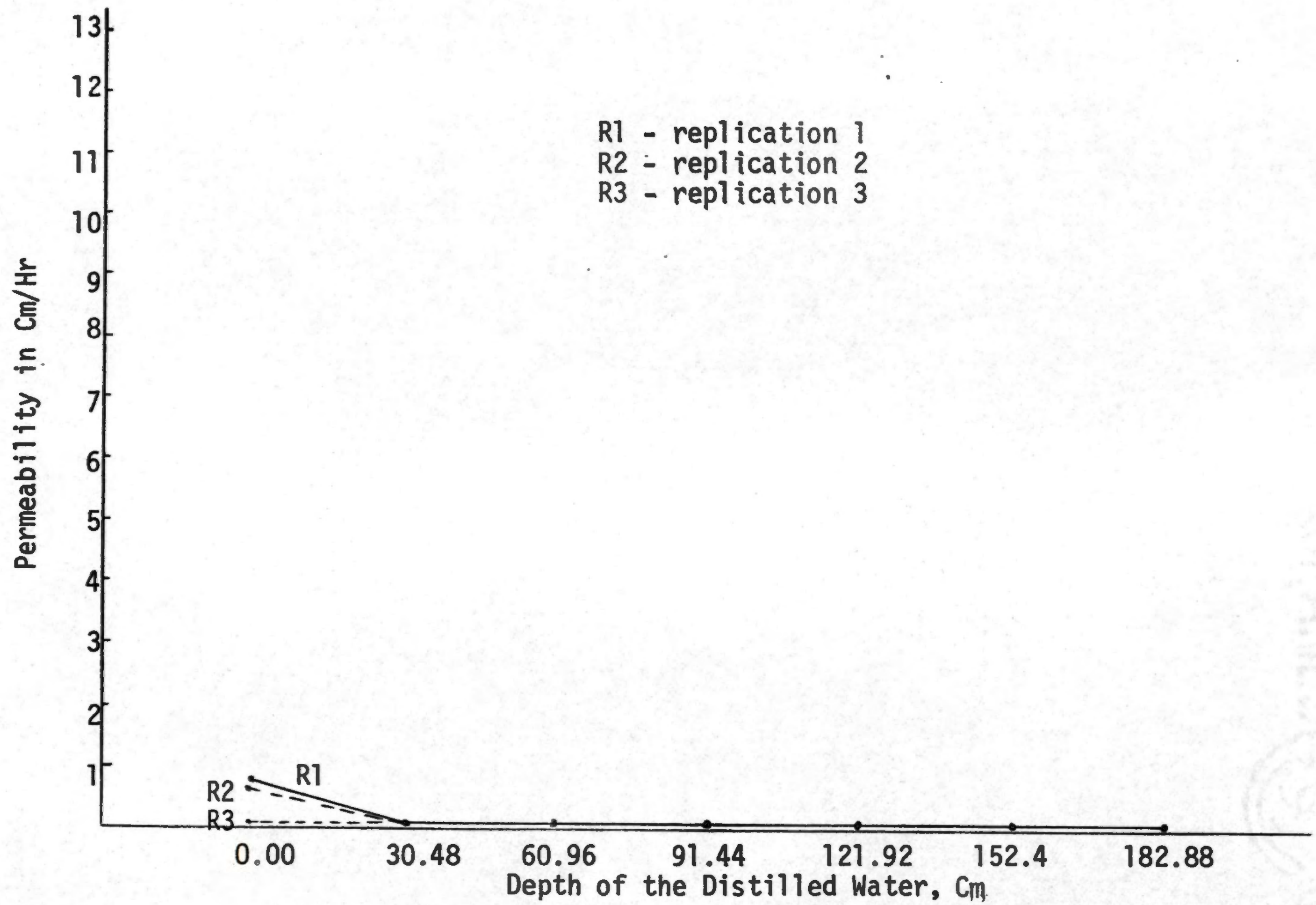

Figure 16. Effect of Applications of Distilled Water on Permeability of Clay Loam Samples.

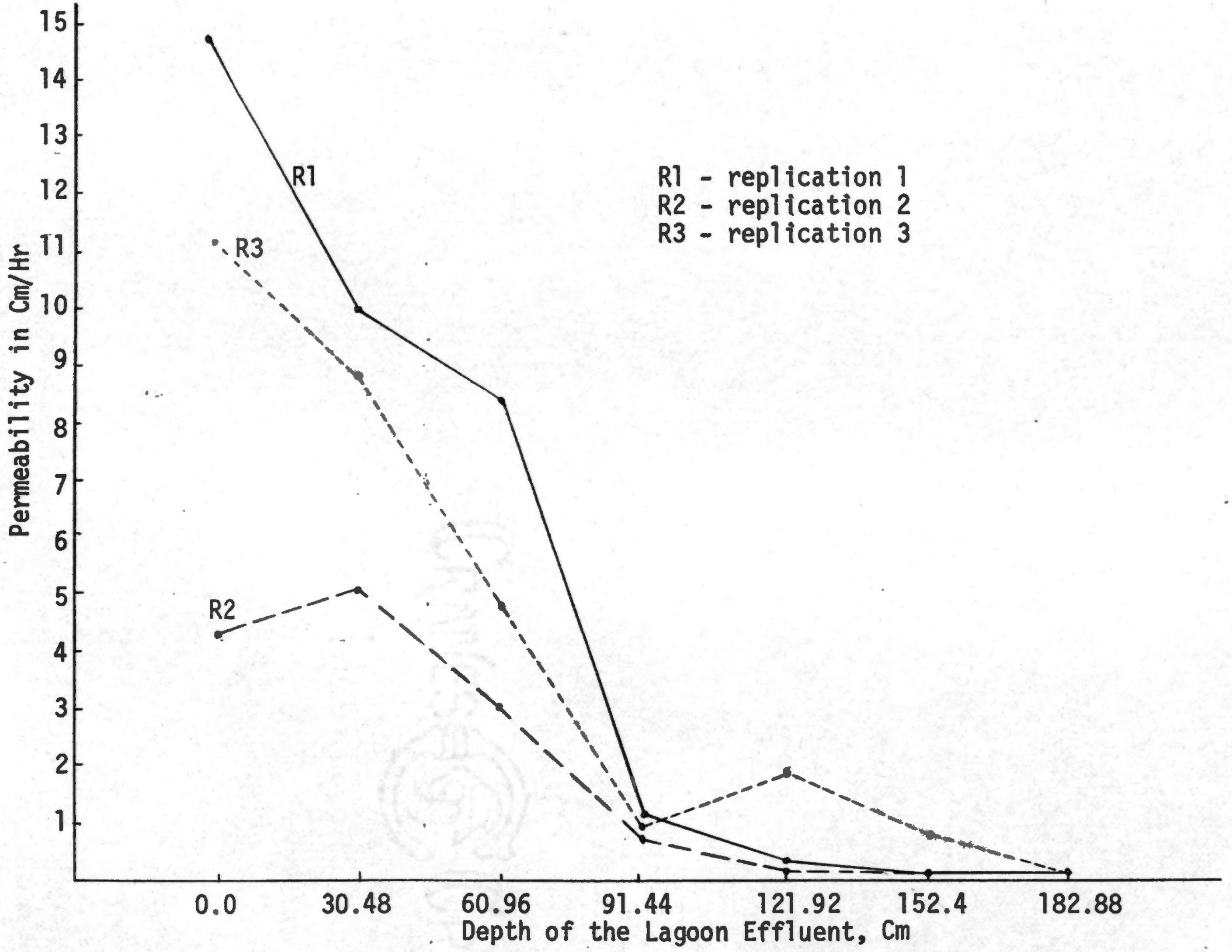

Figure 17. Effects of Application of Lagoon Effluent on Permeability of Clay Loam Samples.

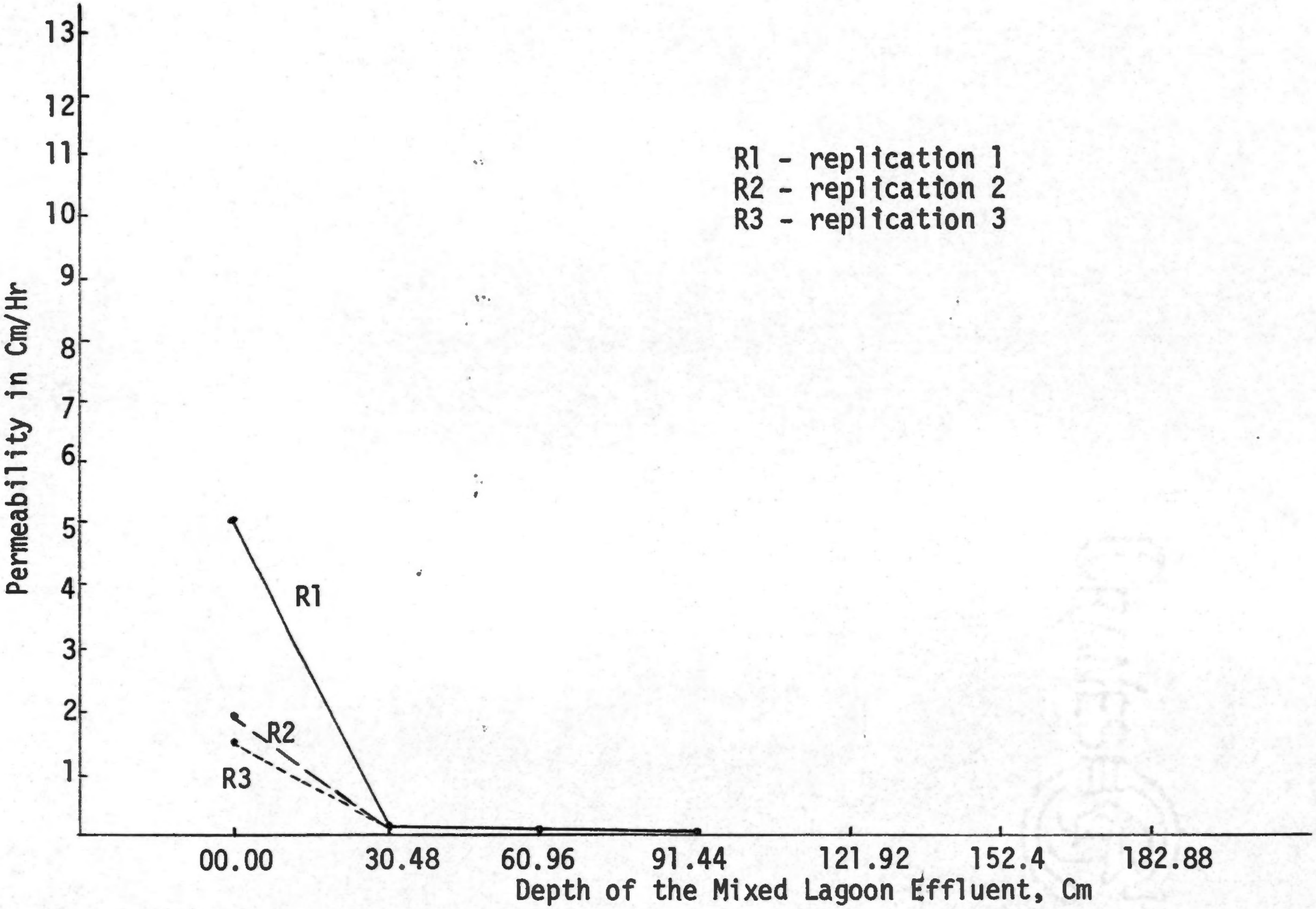

Figure 18. Effects of Application of Lagoon Mixed Lagoon Effluent on Permeability of Clay Loam Samples.

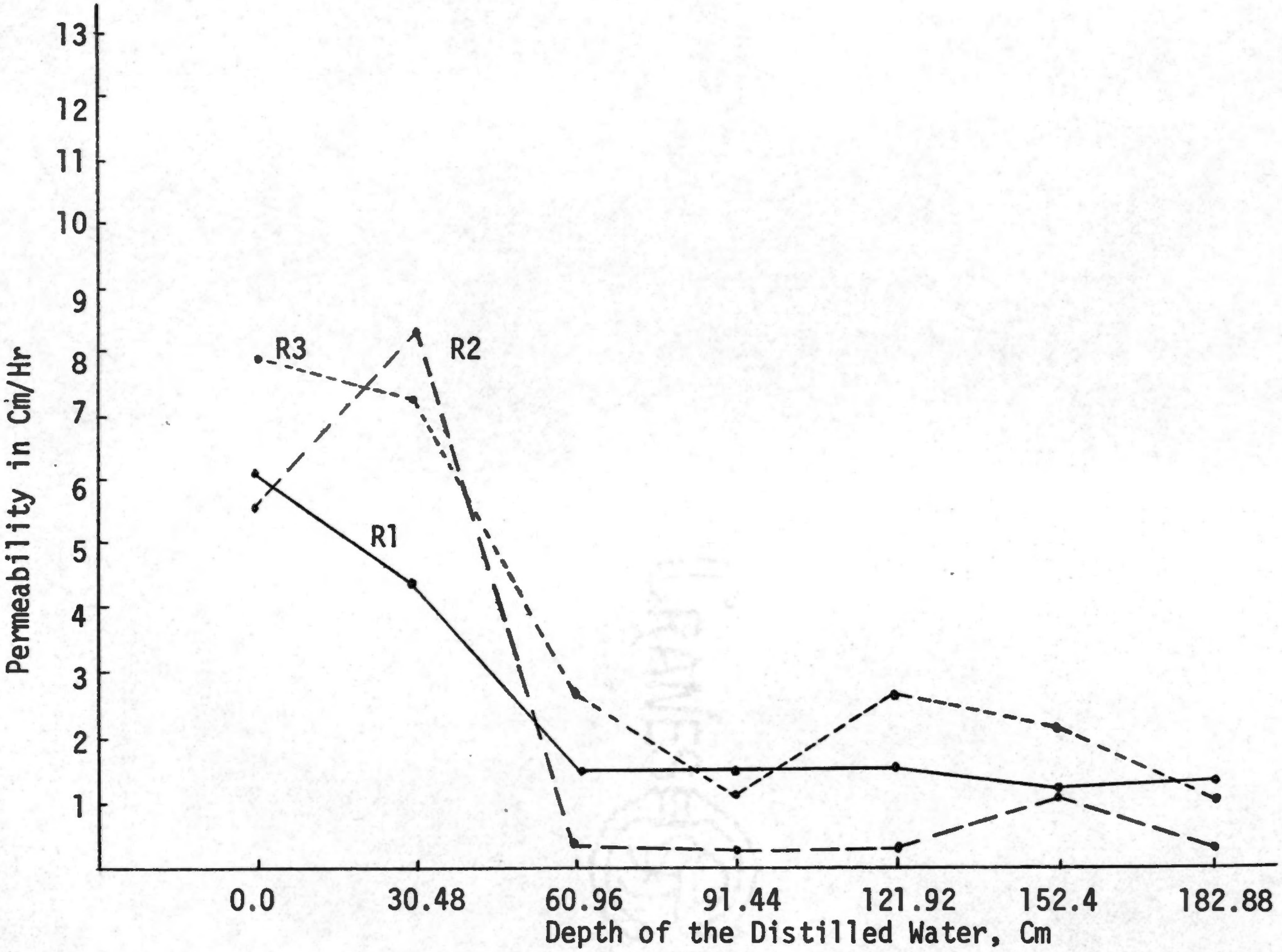

Figure 19. Effects of Application of Distilled Water on Permeability of Sandy Loam Samples.

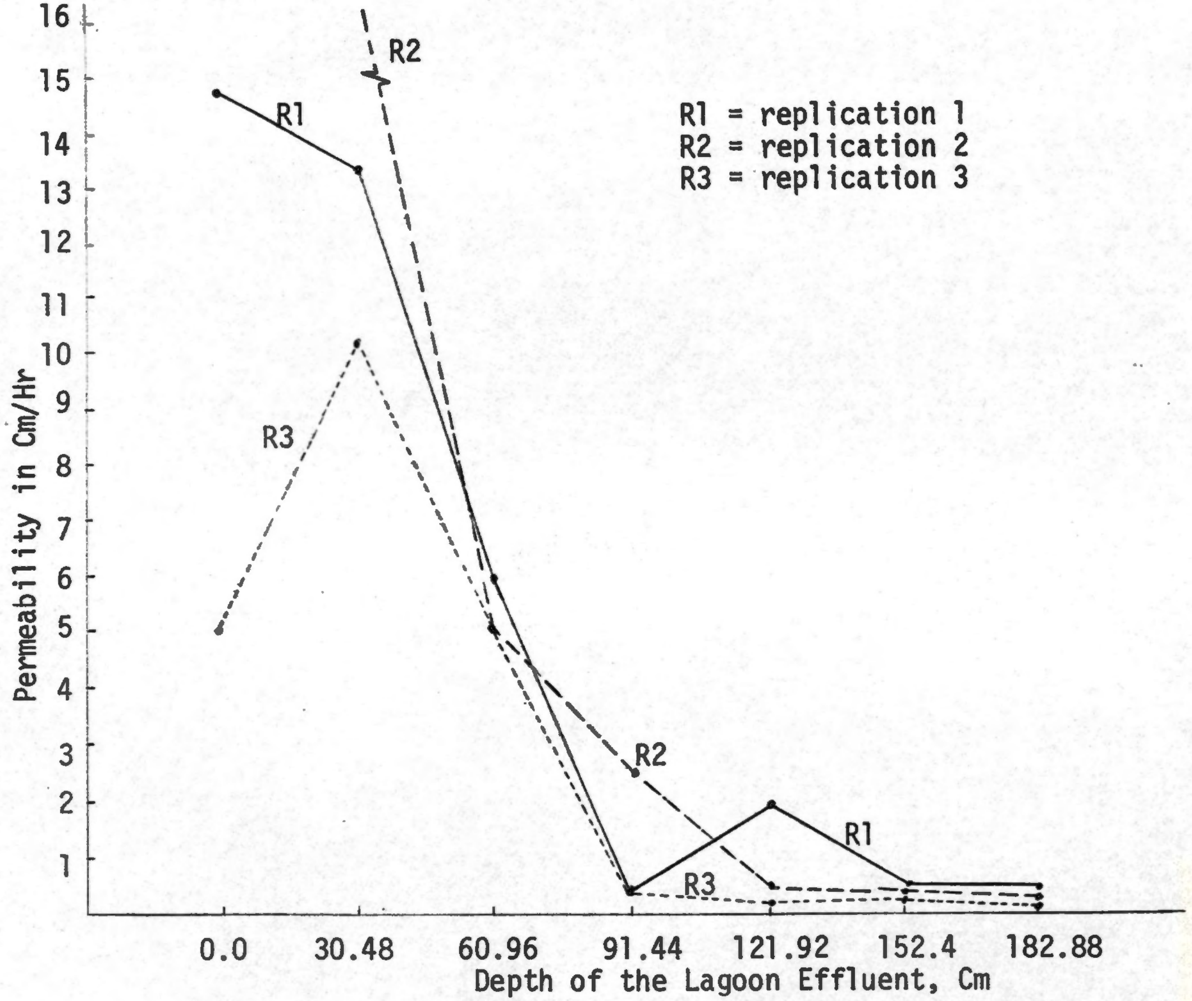

Figure 20. Effects of Application of Lagoon Effluent on Permeability of Sandy Loam Samples.

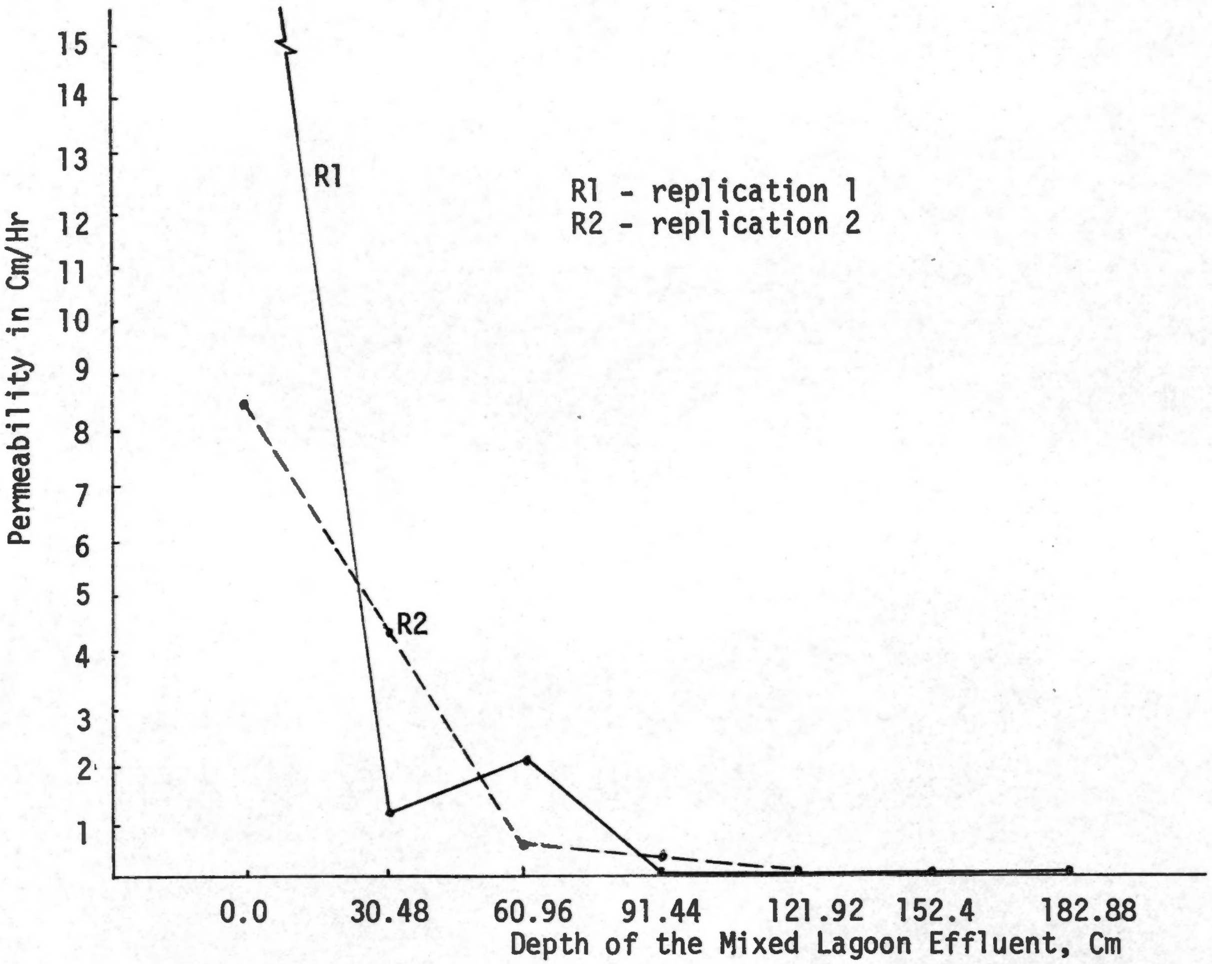

Figure 21. Effects of Application of Mixed Lagoon Effluent on Permeability of Sandy Loam Samples.

$$H = A + B\ e^{KD}$$

and

the other model was of the form:

$$H = A\ (1\ -Be)^{kd\ (1/1-m)}$$

where:

H = the inverse of permeability in hr per cm;

D = the depth of lagoon effluent applied in cm, and;

A, B, K and m are coefficients.

However, none of these models was found to efficiently describe the permeability decrease with lagoon effluent application.

Bulk Density

Bulk density of the core samples was determined using equation 4, and the results, presented in Table 14, show that bulk density increased with depth. This is logical because the upper soil contained both more roots and a higher percentage of sandy soil than the deeper soil. Hence, core samples of different treatment levels must have, on the average, the same rate of bulk density increase with depth. A graphical presentation of bulk density increase in percent of the bulk density value at the first 2.54 cm of the soil profile versus depth is shown in Figures 22 and 23. These graphs show differences in the three core samples of each of the two soils and indicate that the addition of lagoon effluent with different levels of solid fibrous material changes the bulk density, especially in the first 2.54 cm of the soil.

TABLE 14

BULK DENSITY OF CLAY LOAM AND SANDY LOAM SAMPLES IN GM PER CM^3

Increment Depth of Soil in cm	Clay Loam Samples*			Sandy Loam Samples*		
	Distilled Water	Lagoon Effluent	Mixed Lagoon Effluent	Distilled Water	Lagoon Effluent	Mixed Lagoon Effluent
First 2.54	1.129	1.183	0.950	0.853	0.787	0.295
Second 2.54	1.245	1.335	1.309	1.043	1.117	0.965
Third 2.54	1.318	1.416	1.360	1.240	1.205	1.171
Fourth 2.54	1.404	1.501	1.570	1.195	1.280	1.299
Fifth 2.54	1.501	1.548	1.581	1.370	1.453	1.291
Sixth 2.54	--	--	--	--	--	1.473

*The bulk density values in the table are the means for six replications.

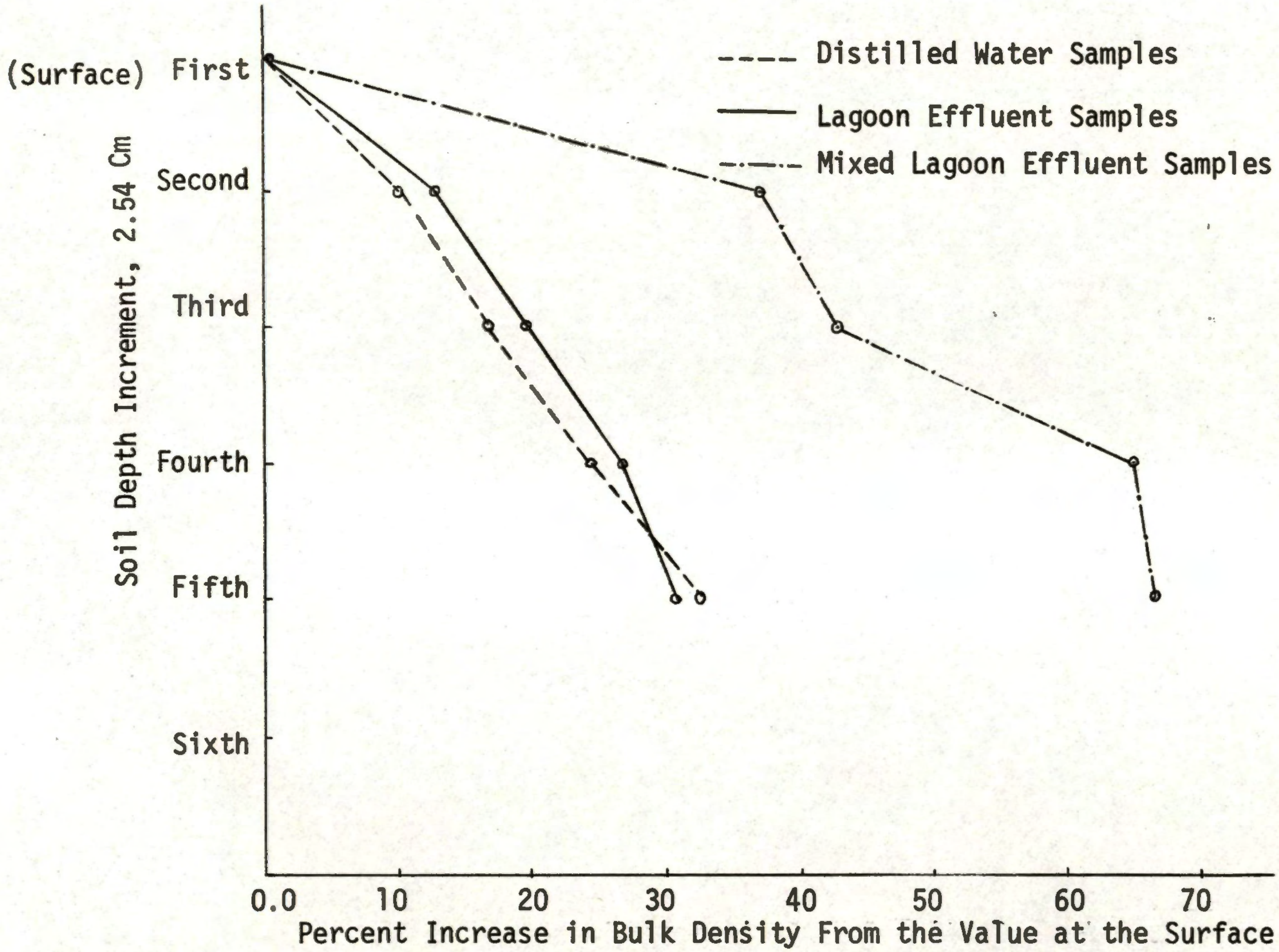

Figure 22. Percent Increase in Bulk Density with Depth of Clay Loam Soil.

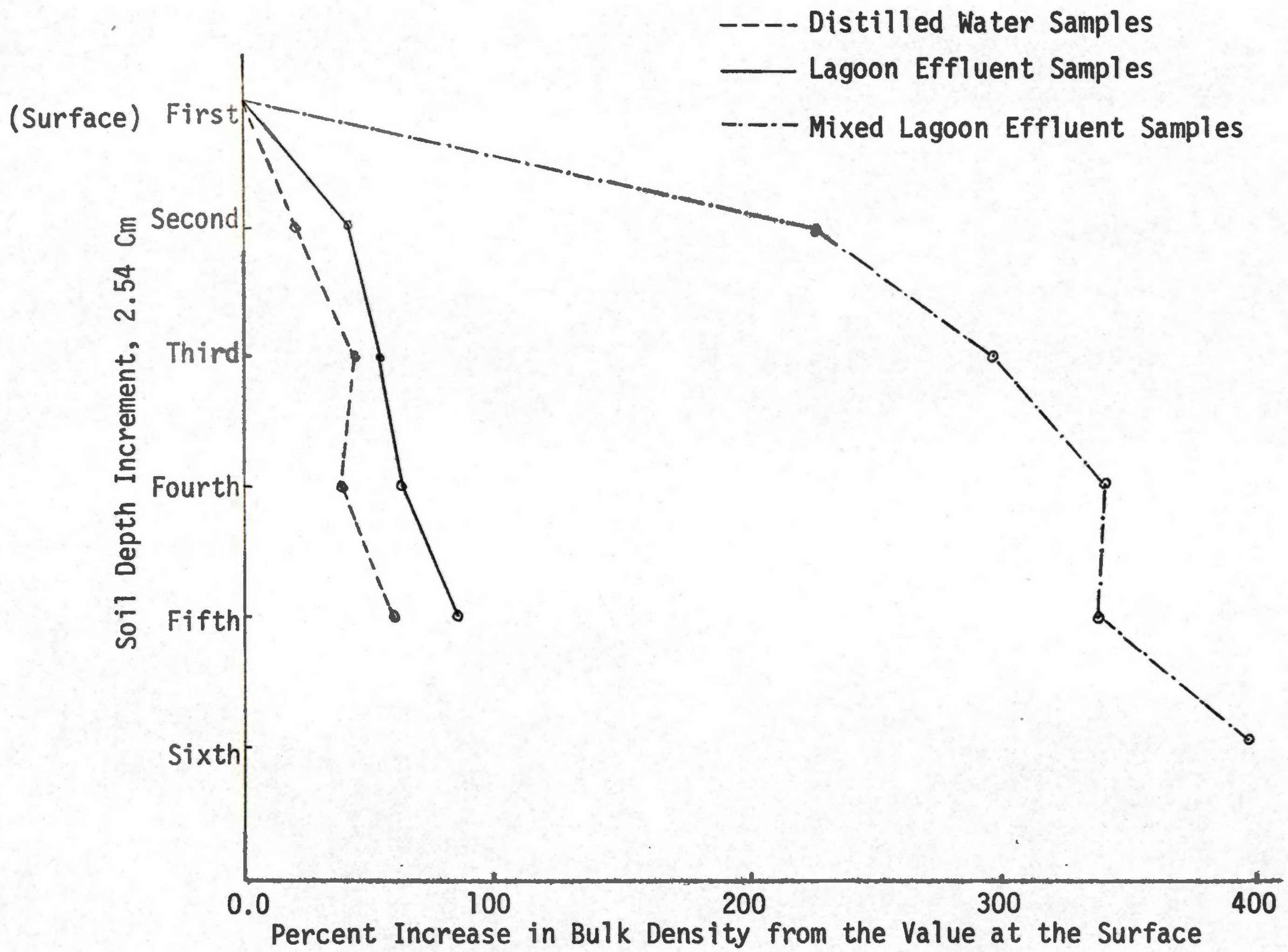

Figure 23. Percent Increase in Bulk Density with Depth of Sandy Loam Soil.

Figure 22, page 97 shows graphs of bulk density increase with depth with respect to the bulk density at the first 2.54 cm of the clay loam samples. The bulk density reduction, of the first 2.54 cm depth with respect to the second 2.54 cm depth, of the core samples were 10 percent, 13 percent, and 37 percent for distilled water, lagoon effluent and mixed lagoon effluent application, respectively. If we consider the core sample which received distilled water as a background sample, a reduction of 3 percent in the bulk density of the first 2.54 cm depth with respect to the second 2.54 cm was found due to the application of 182.8 cm depth of lagoon effluent containing 0.1 percent solid fibrous material. A reduction of 27 percent in the bulk density of the first 2.54 cm depth with respect to the second 2.54 cm was due to the application of 60.92 cm depth of mixed lagoon effluent containing 0.3 percent of solid fibrous material. Similarly a reduction in the bulk density of the second 2.54 cm with respect to the third 2.54 cm, was 2.5 percent and 26.5 percent due to the addition of 182.8 cm depth of the lagoon effluent and 60.92 cm depth of the mixed lagoon effluent, respectively. It is clear from Figure 22, page 97 that the top three depth increments are most effected by the application of lagoon effluent.

Figure 23, page 98 shows graphs of bulk density increase with respect to the bulk density at the first 2.54 cm with soil depth for the sandy loam samples. A reduction of 20 percent in the bulk density of the first 2.54 cm depth with respect to the second 2.54 cm was due to the application of 182.8 cm of lagoon effluent containing 0.1 percent solid fibrous material. A reduction of 204 percent in the bulk density of the first 2.54 cm depth with respect to the second 2.5 cm was due to the application of 152.4 cm depth of a mixed lagoon effluent containing 0.3 percent solid fibrous material. The reduction in the bulk density of the third 2.54 cm depth with respect to the second 2.54 cm depth was 8 percent and 250 percent due to the application of 182.8 cm depth of the lagoon effluent and 152.4 cm depth of the mixed lagoon effluent, respectively. The application of 182.8 cm depth of the lagoon effluent appeared to effect the bulk density of sandy loam samples much more than that of the clay loam samples, especially at the first two 2.54 cm increments of depth. Since the sandy loam soil has larger voids than the clay loam soil, larger quantities of the solids in the liquid effluent penetrated into the sandy loam samples, and more change to the bulk density was produced.

The application of 60.92 cm depth and 152.4 cm depth of the mixed lagoon effluent to the clay loam, and sandy loam samples, respectively, cause the core samples to clog. An accumulation of 1.3 cm and 2.5 cm of the fibrous material was found on the surface of the clay loam and sandy loam soils, respectively, at the end of the experiment. The accumulation of the fibrous material on the soil surface, and penetration of the fine solid content of the lagoon effluent into the soil, caused a dramatic decrease in the bulk density of the soil. However, the decrease in the bulk density of the sandy loam samples was greater than that of the clay loam samples due to the application of larger quantities of the mixed lagoon effluent in the case of sandy loam samples.

The analysis of variance results of the bulk density data are presented in Table 15. A significant difference in bulk density was found at the 5 percent level of probability with the treatments, soil type, and depth of soil. This indicates a difference in the bulk density due to the distilled water, lagoon effluent, and mixed lagoon effluent application on the core sample. The same is true with the clay loam soil, the sandy loam soil, and the five depths in soil column at which the bulk density was measured.

The interaction between the soil type and the treatment effect was significantly different with the bulk density measure at the 5 percent level of probability. This indicates that the bulk density was different due to the treatment effects for both the clay loam soil and the sandy loam soil. A similar difference was found between soil type with soil depth and the treatment with soil depth. The analysis of variance indicates that the bulk density was different for different levels of treatment, soil type, and depth of soil, and, therefore, the graphical representation of these effects must be dissimilar (Figures 22 and 23, page 97 and 98.

TABLE 15

ANALYSIS OF VARIANCE FOR BULK DENSITY DENSINATION

Source of Variation	Degrees of Freedom	Mean Squares	F-Value
Soil type	1	1.28922	142.71*
Treatment	2	0.09101	10.08*
Soil type x treatment	2	0.09000	9.97*
Replication (soil type x treatment	12	0.01021	1.13[ns]
Depth of soil	4	0.98641	109.19*
Soil type x depth of soil	4	0.06350	7.03*
Depth of soil x treatment	8	0.06040	6.69*
Soil type x depth of soil x treatment	8	0.01290	1.43[ns]
Experimental error	48	0.43361	
Total	89	6.99471	

*Significant at 5 percent level of probability.

[ns] Not significant.

CHAPTER V

SUMMARY AND CONCLUSIONS

A. SUMMARY

Confined animal enterprises have increased the possibility of runoff containing heavy concentrations of animal wastes. This feedlot runoff must be managed by lagooning or spreading onto the ground in such a manner that the bacterial action can occur and water quality will not be adversely affected. Irrigation of pastures with feedlot runoff appears to be a practical approach to the problem of disposing the feedlot runoff. A lagoon effluent irrigation system was established at The University of Tennessee-USDA Dairy Experiment Station at Lewisburg, Tennessee, to study the environmental effects of applying lagoon effluent on grassland plots.

The major objectives of this study were to determine the effects of applying different rates of lagoon effluent on the surface runoff and groundwater quality of grassland plots, and to detect changes in the soil physical properties.

The rainfall/manure runoff from 8,826 m^2 of concrete pavement was collected into a drain and delivered by gravity flow into a 5,550 m^3 lagoon. Fifteen plots, each with an area of 40.5 m^2 and an average slope of 1 to 2 percent were established. The lagoon effluent was pumped to the experimental plots through 10.16 cm aluminum pipe and discharged through a sprinkler irrigation system onto the plots. Water from Big Rock Creek was pumped to the field to provide simulated rainfall on the plots.

Lagoon effluent was applied to the plots in 1978 at depths of 2.54 cm, 5.08, 7.62 cm and creek water was applied to the fourth plot at depth of 7.62 cm. In 1979, the treatments consisted of applying 2.54, 5.08, 7.62, and 10.16 cm depth of lagoon effluent on the plots. A fifth plot treatment received no application of liquid in either year. Three replications of each treatment were used.

Collection of surface runoff and groundwater samples was made after the occurrence of natural rainfall in the first year and after simulated rainfall in the second year. Water quality parameters analyzed included COD total phosphorus, ammonia-N, TKN, TON, chlorides, pH, electrical conductivity, and total solids.

Eighteen core samples of 15.24 cm of clay loam and sandy loam soils were taken to the laboratory to determine changes in permeability and bulk density of soil after the addition of lagoon effluent.

Constant head permeameters were constructed, and three treatments were applied to the samples, with three replications of each treatment. These treatments consisted of distilled water, lagoon effluent, and mixed lagoon effluent having 0.0, 0.1 and 0.3 percent solid fibrous material, respectively. Bulk density was determined on soil samples of 5.08 cm diameter for six depth increments at the end of the experiment.

B. CONCLUSIONS

Results of the study indicate the conclusions given below.

1. Application of 2.54, 5.08, and 7.62 cm of lagoon effluent and 10.16 cm of a creek water in 1978; and 2.54, 5.08, and 7.62 cm of lagoon effluent in 1979 on experimental plots resulted in the following conclusions:

    a. The average ammonia nitrogen and total Kjeldahl nitrogen concentrations in the plots' surface runoff were 45 and 30 percent, respectively, less than those in the lagoon. However, the concentration of ammonia nitrogen and total Kjeldahl nitrogen concentrations in surface runoff and groundwater exceeded the standard of raw water for public supplies as established by the Federal Water Pollution Control Administration in 1972.

    b. Chemical Oxygen Demand concentration in the plots' surface runoff and groundwater reached, in some cases, 130 and 30 times, respectively, of that measured in nearby creek water. However, chemical oxygen demand concentration of the groundwater was about 4 times lower than that of the surface runoff.

    c. The concentrations of total oxidized nitrogen, electrical conductivity, pH, total solid, chloride and total phosphorus measured in the plots' surface runoff water and groundwater were within the standard of raw water for public supplies. However, the total oxidized nitrogen concentration measured in the groundwater of some plots was about 10 times higher than that measured in the plots' surface runoff. Electrical conductivity, pH, and chloride concentration of the plots' groundwater were higher, on the average, than those measured in the plots' surface runoff water.

2. Statistical analysis of the data showed that different application rates of lagoon effluent were significantly different with total phosphorus and electrical conductivity in the plots' surface runoff of 1978 and the plots' groundwater of 1979, respectively.

3. The following factors affected the concentrations of water quality parameters measured in the plots' surface runoff:

a. rainfall amount and intensity;
b. soil moisture in the root zone at the time of lagoon effluent application;
c. delay in time between the occurrence of rainfall and lagoon effluent application; and
d. concentration and amount of the lagoon effluent applied on the plots.

Ammonia nitrogen and chemical oxygen demand concentration in the plots' surface runoff water appeared to be the water quality parameters effected most by these factors. However, these factors did not appear to affect the plots' groundwater quality parameters.

4. The application of lagoon effluent causes more permeability reduction in sandy loam soils than in clay loam soils.

5. Application of lagoon effluent containing 0.3 percent solid fibrous material caused higher reduction in the soil permeability and bulk density than that containing 0.1 solid fibrous material.

6. The clay loam soils and the sandy loam soils were clogged after applying 60.96 cm depth and 152.4 cm, respectively, of lagoon effluent containing 0.3 percent solid fibrous material.

7. Applications of 183 cm of lagoon effluent caused higher reductions in bulk densities of sandy loam soils than those of clay loam soils.

C. RECOMMENDATION FOR FURTHER STUDY

This study should be continued over a period of several years to determine the long term effects of continuous lagoon effluent application on plots. Higher application rates of lagoon effluent are required, since most of water quality parameters of the plots' surface runoff water were within the permissible standards for raw water. All factors effecting the concentration of the water quality parameters must be monitored or held constant while applying lagoon effluent onto plots. These factors include soil moisture prior to lagoon effluent application, and delay in time between effluent application and rainfall occurrence. Varying the delay in time prior to sample collection would provide better information on the peak pollution of the surface runoff water and groundwater quality.

The permeability determination should be made on a larger number of core samples, because a wide range of permeabilities existed between core samples of same soils. Also, more than three replications of each treatment are necessary. Determination of the soil organic matter would support the information obtained on the penetration of the organic material in the lagoon effluent into the soil. Finally, determination of soil water holding capacity would supplement the information about the change in soil physical properties due to the application of lagoon effluent.

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He was married to Huda Ismail in September, 1976 and their daughter, Huwayda, was born in the summer of 1978. He plans to return to Iraq after graduation to teach and conduct research at Iraqi universities.