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EFFECTS OF MUNICIPAL WASTEWATER IRRIGATION ON FOREST SITES IN SOUTHERN MICHIGAN

By

Daniel George Neary

A DISSERTATION

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ABSTRACT

EFFECTS OF MUNICIPAL WASTEWATER IRRIGATION
ON FOREST SITES IN SOUTHERN MICHIGAN

By

Daniel George Neary

This study examined the impact of municipal wastewater irrigation on soil water quality, vegetation growth and nutrient status, soil chemistry, and humus decomposition in a 20-year-old red pine (*Pinus resinosa* Ait.) plantation and a maple-beech (*Acer saccharum* Marsh. and *Fagus grandifolia* Ehrh.) hardwood forest. The pine plantation was spray irrigated with sewage stabilization pond effluent during the summer and early fall of 1972 and 1973. Irrigation treatments consisted of weekly applications of 0, 25, 50, and 88 mm/week. The hardwood forest site received secondary sewage treatment effluent through a trickle irrigation system during the same period. The effects of five irrigation rates (0 mm/week, 50 mm/week of well water, and 25, 50, and 75 mm/week of wastewater) were evaluated in the maple-beech stand.

Soil water samples were collected by means of porous cup suction lysimeters at weekly and bi-weekly

intervals. The lysimeters were placed at depths of 60 and 120 cm in the red pine plantation and 30 and 60 cm in the hardwood stand. Water samples were preserved with 40 mg/l $HgCl_2$ and analyzed for ammonia nitrogen, nitrate nitrogen, total Kjeldahl nitrogen, and total phosphorus.

Renovation of total phosphorus exceeded 99% in the red pine stand and 96% in the hardwood forest throughout both years of the study. In 1972, total nitrogen renovation at the pine site was generally above 90% for all levels of wastewater irrigation. During 1973 total nitrogen renovation remained above 90% for the 25 mm/week treatment but dropped to 81 and 76% for the 50 and 88 mm/week treatments. Reductions in nitrogen renovation resulted from flushing of nitrate nitrogen. In the hardwood forest, total nitrogen renovation fluctuated between 0 and 71% during the two-year period. Ammonia nitrogen renovation was usually above 96%, but no nitrate renovation occurred. Nitrate levels in soil water samples removed from lysimeters in plots irrigated with well water were as high as 10 mg/l and averaged between 1 and 4 mg/l. The nitrate nitrogen leaching was associated with hourly irrigation rates in excess of 50 mm/hour.

Wastewater irrigation produced significant increases in boron, nitrogen, and potassium contents of the red pine foliage. Boron levels in the range of 55-75 ppm were associated with toxicity symptoms (necrosis of needle tips). Nitrogen contents increased from 0.11 to 0.37% and potassium levels increased between 0.05 - 0.07% over the range of irrigation rates. Significant decreases in foliage aluminum contents with increased irrigation were noted. There were no significant changes noted in the nutrient content of the hardwood forest ground cover.

Growth response to wastewater irrigation was most evident in the red pine stand. Needles from the upper one-third of the crown exhibited increases in length of 12 - 36% and increases in dry weight/fascicle of 6 - 55% over the range of irrigation rates.

The most striking soil chemistry change was in pH levels. pH rose from 5.2 to 7.4 at the 15 cm depth in the red pine plantation and increased from 5.7 to 6.8 at the same depth in the hardwood stand with increases in irrigation rates.

Increases in the rate of litter decomposition in the red pine stand were reflected by a 20% decrease in needle litter and fine humus weight and a 1.5 cm decrease in total depth. Considerable numbers of fungal reproductive structures appeared after the second season of irrigation in the red pine stand. Slight decreases in leaf litter weights were also noted in the maple-beech woodlot.

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VITA

DANIEL GEORGE NEARY

Candidate for the degree of

Doctor of Philosophy

FINAL EXAMINATION: September 17, 1974

GUIDANCE COMMITTEE:
Dr. Gary Schneider (Chairman), Department of Forestry
Dr. Donald White, Department of Forestry
Dr. Earl Erickson, Department of Crop and Soil Science
Dr. Dean Urie, U.S. Forest Service

DISSERTATION: Effects of Municipal Wastewater Irrigation on Forest Sites in Southern Michigan

BIOGRAPHICAL ITEMS:
Born October 1, 1946, Chippewa Falls, Wisconsin
Married August 29, 1970, to Vicki Oien

EDUCATION:
University of Wisconsin at Eau Claire, 1964-1967
Michigan State University, B.S., 1969
Michigan State University, M.S., 1972

PROFESSIONAL EXPERIENCE:
September 1973 -- Present
Graduate Assistant, Department of Forestry, Michigan State University
September 1970 -- September 1973
NDEA Fellow, Department of Forestry, Michigan State University
August, 1969 -- May, 1970
Ensign, U.S. Naval Reserve
Summer, 1968
Crew Chief, C.F.I. Project, Plumas National Forest, Quincy, California
Summer, 1967
Field Biologist, Clear Creek Camp, Philmont Scout Ranch, Cimarron, New Mexico

September, 1965 -- June, 1967
Biology Teaching Assistant, University of Wisconsin at Eau Claire, Eau Claire, Wisconsin

ORGANIZATIONS:

Society of American Foresters
Soil Science Society of America
Xi Sigma Pi
Michigan Academy of Science, Arts, and Letters

CHAPTER I

INTRODUCTION

Background

Water is one of man's most important natural resources. The development of civilizations is linked to water abundance and man's ability to exert physical and political control over it. Water utilization in the 20th century has been both varied and extensive. Surface waters are the major source of water supplies in the U.S. (91% in the humid east and 69% in the arid west). Water is used for domestic purposes, crop irrigation, cooling, manufacturing, transportation, and recreation. These uses, coupled with a rapidly growing demand for clean water, have led to deteriorations in the quality of surface water supplies in many regions of the country.

Since the early 1900's, advancements in chemistry and biology have permitted adequate treatment of surface waters. Most cities have been able to deliver unlimited volumes of high quality water which is (1) free from disease hazard, (2) lacking any offensive odors or taste, (3) devoid of color or turbidity, (4) free from harmful minerals, (5) reasonably cool in temperature, and (6) aesthetically acceptable.

In fact, an "Ostrich Philosophy" has developed around the handling of wastewater. The viewpoint is that any problem which is out of sight and therefore out of mind ceases to be of concern. People fail to associate the streams in which they dump their wastes with the water that comes out of their faucets. Thus almost totally raw sewage has been placed into streams and lakes for many years.

While populations were small, streams were able to purify waste loads naturally before reaching another municipality. But as new towns were built and existing cities grew, the loads imposed on many rivers exceeded their capacity to adequately process the wastes. Consequently, surface water quality often reached such low levels that cities had to invest large amounts of capital for water purification prior to its public consumption.

The demand for high quality water in the United States is growing rapidly. It is expected to rise from present amounts of 1.5 billion cubic meters per day (BCMD) (400 billion gallons per day [BGD]) to over 3.8 BCMD (1000 BGD) by the year 2000. With an estimated average daily surface runoff of 2.6 BCMD (700 BGD), extensive re-use of surface water will have to be accomplished to make up for the projected deficit between demand and runoff. Although ground water can provide for some of the deficit, it should not be relied upon to supply all of it. To do so would be a serious threat to ground water supplies. In the Great Lakes Region a similar runoff-demand deficit will occur by the year 2000 in spite of water abundance. In addition, this region is expected to have to handle a municipal sewage load two or three times that of present levels (Todd, 1970).

Water Treatment

With large projected water usages in the Great Lakes drainage basin, steps must now be taken to prevent further surface water deteriorations. Municipalities and industries must begin improving their waste treatment systems, and tertiary treatment will be required.

A complete tertiary wastewater treatment system consists of three stages. The first or primary stage accomplishes the separation of settlable solids. The second stage is designed to satisfy the biological and chemical demand created by the presence of dissolved and suspended organic compounds. It also removes some of the nutrients present in the wastewater. The third stage removes most of the remaining nutrients and produces a high quality effluent effectively free of the materials introduced into the original water.

There are two major methods of achieving tertiary wastewater treatment. The first method is the traditionally used completely mechanical biological-chemical treatment system. Such systems are operational year-round, occupy a minimum of land space, and result in excellent wastewater renovation. However, they are expensive to construct and operate. Another method utilizes the natural waste processing abilities of terrestrial ecosystems in conjunction with some degree of primary or secondary treatment. While this natural system utilizes much more land area and operates at peak efficiency only during the normal growing season, it can provide excellent wastewater renovation with a minimum amount of investment. Such systems have been labelled the "living filter."

The "living filter" concept gained national attention through the Pennsylvania State University wastewater recycling studies. It is by no means a new concept but does differ in that the wastewater is considered a resource rather than a waste. The treatment objective of this natural process is to provide maximum water renovation while maintaining system durability and longevity. Using controlled rates of application, nutrients present as pollutants in wastewater can be removed by microbial degradation and transformation, ion exchange, chemical precipitation, and absorption through soil and plant root systems. Thus polluted water is processed into relatively pure water. Ultimately, this type of wastewater treatment system promotes the maximum re-use of local water resources.

The "living filter" approach operates best with a vegetative cover that can be harvested at frequent intervals. This allows for continuous nutrient removal from the site and thus precludes nutrient buildup which might otherwise result in toxicity conditions or sudden unwanted surges of nutrients into the ground water.

Agricultural food crops meet these restricted requirements since they are harvested annually. Although forests have a longer crop rotation period, they also have properties that make them a desirable terrestrial system for wastewater renovation. In locations such as resort areas, parks, state and national forests, and other similar nonagricultural regions, trees are the only major vegetation type available for processing wastewater. Forest sites are generally adapted to wastewater application since they have high humus levels and high infiltration rates. Furthermore, concerns over disease transmission through the irrigated vegetation are virtually eliminated since no direct human consumption of the vegetational material occurs.

A great deal of information still needs to be obtained about the potential uses of forest lands for renovating wastewater. Long-term effects created by applying wastewater on land sites need further study. The "living filter" concept for wastewater renovation involves a complex matrix of different plants, soils, climate regimes, and effluents whose interactions need more clarification. Evans (1973) identified a whole spectrum of wastewater research topics including long-term effects of wastes on vegetation and soils, quantity and quality of ground water recharge, and the recycling of microorganisms in wastewater recycling.

Study Objectives

The objectives of this study are to evaluate changes in the vegetation, soil physical and chemical properties, and soil water quality resulting from municipal wastewater irrigation in two forest stands in southern Michigan. At the first site, a red pine plantation near Middleville, the study involves monitoring for changes in red pine growth and nutrient content, soil chemistry status, humus development, and nitrogen and phosphorus concentrations of soil water. The second site is a maple-beech hardwood stand near East Lansing which is being evaluated for alterations in herbaceous plant and tree seedling growth and nutrient content, soil chemistry status, soil aeration, litter weights, and soil water nitrogen and phosphorus contents.

CHAPTER II

LITERATURE REVIEW

Historical Perspective

The application of wastewaters to terrestrial ecosystems as an alternative to existing methods of tertiary wastewater treatment has become a subject of great current interest. However, as Thomas (1973) points out, the use of land sites for disposing of wastewaters is nothing new. What is new is the change in attitude towards utilizing land sites for wastewater processing; a shift from one of mere disposal to that of treatment and re-use.

The natural tendency with the disposal approach to sewage effluent is to apply as much waste as possible in a limited area at rates higher than the soil can process (Heukelekian, 1957). With a treatment and re-use approach, wastewaters are applied to the land under proper climatic and soils conditions and sensible management control. Wastewaters need not create nuisance conditions, health hazards, or "poisoned" landscapes. Thus, discarded wastewaters can be renovated by the combined action of plants, microorganisms and soil to a good quality water. Such water can then be safely returned to the ground water reservoir (Kardos, 1970).

The recycling of wastewater has generally been accepted by the public in locations where water shortages have become serious (Hunt, 1954). Buswell (1928) reported that a crop irrigation project was designed to treat wastewaters from Bunslav, Prussia, in 1559 and operated for 300 years. Municipal sewage farms have been operating in England, Germany, France, Italy, and Australia since 1890. The first use of domestic sewage for irrigation in the United States was at Cheyenne, Wyoming, in 1883 (Hunt, 1954). By 1935, 113 localities in 15 western states practiced crop irrigation as a means of renovating and reusing scarce water resources (Hutchins, 1939). Hutchins (1972) recently reported 571 land application wastewater treatment systems in operation in 32 states. Of those, 55% were located in 13 western states.

Not included in Hutchins survey were the approximately 1300 industrial facilities currently utilizing land sites as wastewater treatment systems. The food processing industry is the largest user of land sites, accounting for about 72% of the industrial use of terrestrial wastewater treatment systems. Monson (1958) and Rose (1971) have documented these uses for treating cannery wastes.

Industrial and municipal wastewaters have been applied to land sites by three application modes: overland runoff, rapid infiltration, and spray irrigation. Overland runoff is the controlled application of irrigation wastes onto the land with the path of flow being downslope (Foster, 1965; Bendixen *et al.*, 1969; Gilde, 1971). Rapid infiltration utilizes high rate infiltration and percolation after application by flooding (Parkhurst, 1970; Bouwer, 1968). Spray irrigation utilizes slow rate sprinkler application with the major flow pathway being by infiltration and percolation (Luley, 1963; Law, 1969; Sepp, 1971; Kardos and Sopper, 1973).

Of the three application methods, spray irrigation presents the greatest potential for reliability and longevity, and accounts for about half of the current terrestrial wastewater treatment systems operating in the country (Reed *et al.*, 1972). Deaner (1971) reported that spray irrigation was the dominant wastewater application mode in California. Wastewater treatment systems in Michigan which incorporate spray irrigation on land sites are currently in operation, undergoing pre-operations testing, or are in the planning stage at Middleville, Belding, Harbor Springs, Cassapolis, East Jordan, Fremont, Michigan State University at East Lansing, and Muskegon (Urie, 1971).

Forests and Wastewater Recycling

The use of forest stands for wastewater renovation has thus far been limited. It is undergoing rapid expansion, however, as the technology for renovating wastewaters on forest ecosystems is improved and has been increasingly adopted by recreational developments, municipalities, and industries. One of the earliest reported studies of the use of forested lands for wastewater disposal was by Mather (1953). He documented the use of vegetable processing waste from the Seabrook Farms plant at Bridgeton, New Jersey, in a mixed white and black oak stand (*Quercus alba* L. and *Q. velutina* L.) stand. Little *et al.* (1959) discussed the irrigation effects after the Seabrook Farms system had been operating for seven years.

Rudolph and Dils (1955) and Rudolph (1957) reported on cannery wastewater irrigation at Fremont, Michigan, utilizing box elder (*Acer negundo* L.), cottonwood (*Populus deltoides* Bartr.), willow (*Salix nigra* Marsh.), and balsam poplar (*Populus balsamifera* L.) seedlings. Forested areas have also been used to some extent for treating pulp and paper mill wastes (Voights, 1956; Crawford, 1958; McCormick, 1959; Jorgensen, 1965; Vercher *et al.*, 1965; Flower, 1968). Effects of municipal sewage effluent on a forest site at Detroit Lakes, Minnesota were observed by Larson (1960).

The most intensive investigation of the ability of forests and forest soils to process municipal wastewaters has been done by William E. Sopper and his associates at Pennsylvania State University. Starting in 1966 (Sopper and Sagmuller, 1966) and continuing up through the present (Kardos and Sopper, 1973), these studies have utilized plantations of red pine (*Pinus resinosa* Ait.), white pine (*P. strobus* L.), European larch (*Larix decidua* L.), white spruce (*Picea glauca* Muench. Voss.), Japanese larch (*Larix leptolepis* [Sieb. and Zucc.] Gord.), pitch pine (*Pinus rigida* Mill), as well as a mixed stand of white oak, black oak, red oak (*Quercus rubra* L.) and scarlet oak (*Q. coccinea* Muench).

Urie (1973) discussed the ability of a jack pine (*Pinus banksiana* Lamb.) stand near Cadillac, Michigan, to renovate municipal sewage effluent. The use of a mixed hardwood and conifer forest for the renovation of wastewater from the recreational development at Mount Sunapee State Park in New Hampshire was described by Frost *et al.* (1973). Olson and Johnson (1973) reported that 26 sites in national forest located in 14 states were being considered for land application of wastewaters by spray irrigation or rapid infiltration.

Hydrological Considerations

The primary goal of irrigating wastewater in any terrestrial plant association is one of producing quality water which is free from the nutrients added by man. Thus appropriate monitoring facilities must be available to record changes in ground water quality. Parizek (1973) discusses many of the factors which need to be considered when monitoring unconfined or confined ground water aquifers. Many of these same ground water components are analyzed by Born and Stephenson (1969). Where regional ground waters exist at great depths or adequate funding does not permit the use of monitoring wells, soil water lysimeters allow for a reasonable on-site monitoring of recharge water quality.

Parizek and Lane (1970) described the use of pan and suction lysimeters for monitoring the quality of the irrigation water percolating through the soil at the Penn State project. The porous cup or suction lysimeter has provided an especially direct and simple method of collecting soil water samples (Wood, 1973). The theory of the suction lysimeter was developed by Wallihan (1940), Colman (1946), and Cole (1958). Wagner (1962) reported on the design and use of a suction lysimeter developed by the Soil Moisture Equipment Company, Santa Barbara, California.

Porous cup lysimeters, while providing a simple and direct means of collecting soil water, do have their limitations. Such factors as lysimeter size and depth, porous cup wall thickness, and vacuum system (constant or falling) can affect the amount and nutrient concentration of soil water samples obtained. Physical processes such as sorption, leaching, screening, and plugging which can take place in conjunction with the porous cup also affect sampling (Hansen and Harris, U.S. Forest Service, personal communication, 1974). Nevertheless, porous cup lysimeters are useful tools in instances where direct sampling of an unconfined aquifer is impossible.

Important Nutrients

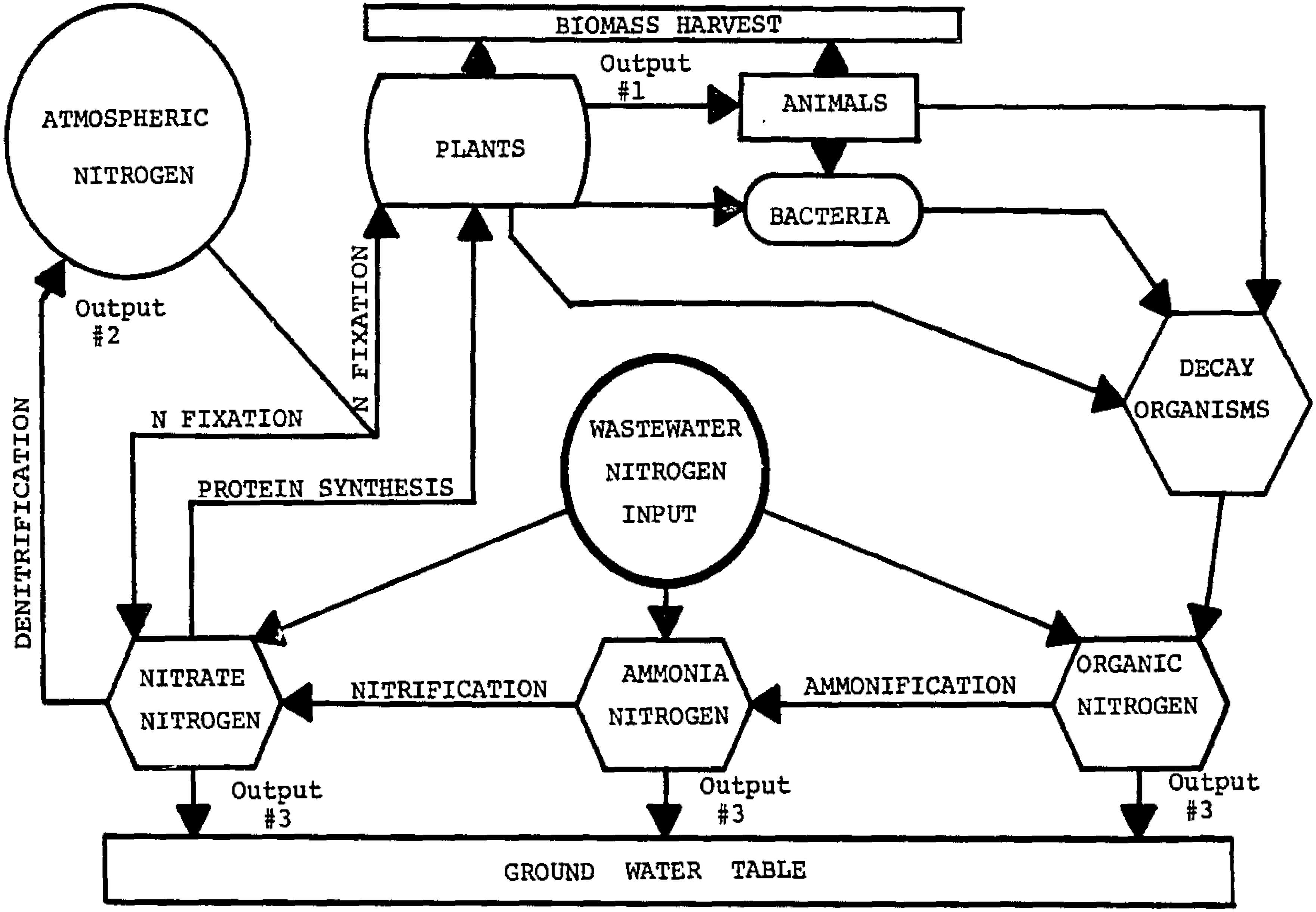
One of the desired goals of terrestrial wastewater irrigation operations is a product water whose quality should approach drinking and irrigation water standards. Reed *et al.* (1972) discussed the parameters of water quality in relation to the amount of uptake needed by the soil-plant-microbe association necessary to produce acceptable water. From the list of chemical and biological constituents of sewage effluent noted by Hunter and Kotalik (1973) it is obvious that sewage has a complex makeup and that water quality can no longer be defined by several parameters. Shuval and Gruener

(1973) have aptly pointed out specific hazardous contaminants entering our water supplies which are not being routinely monitored. Often budgetary, equipment, or manpower restrictions allow only a few water quality parameters to be measured.

Two of the nutrients commonly found in wastewater which play dominant roles in water pollution are nitrogen and phosphorus (Kardos, 1970). Phosphorus occurs predominantly in the inorganic phosphate form. Nitrogen is found as ammonia, nitrate, nitrite, and numerous organic nitrogen forms such as urea, amino acids, and proteins.

The nitrogen cycle in a forest wastewater irrigation site is depicted in Figure 1, with the predominant nitrogen input coming from the wastewater (adapted from Keeney, 1970). The major outputs from the system are: (1) plant uptake and biomass harvest, (2) denitrification, and (3) loss to the ground water table. Proper management of a terrestrial wastewater renovation system would be aimed at maximizing outputs 1 and 2 while minimizing output 3. The major components of the nitrogen cycle consist of ammonification, nitrification, denitrification, and immobilization. Ammonification, as defined by Alexander (1961), is the conversion of organic nitrogen to inorganic nitrogen. It is conducted by numerous heterotrophic microbes under a wide

Figure 1. The nitrogen cycle in a forest wastewater renovation system.


BIOMASS HARVEST
ATMOSPHERIC NITROGEN
PLANTS
Output #1
ANIMALS
BACTERIA
Output #2
N FIXATION
N FIXATION
PROTEIN SYNTHESIS
DENITRIFICATION
DECAY ORGANISMS
WASTEWATER NITROGEN INPUT
NITRATE NITROGEN
NITRIFICATION
AMMONIA NITROGEN
AMMONIFICATION
ORGANIC NITROGEN
Output #3
Output #3
Output #3
GROUND WATER TABLE

range of pH, temperature, and moisture conditions (Bartholomew and Clark, 1965). In nitrification, ammonium is converted to nitrate. Since nitrogen from many secondary treatment plants is in the ammonium form, this is a most important step in wastewater management.

The nitrification process had been reviewed extensively by Quastel and Scholefield (1951), Alexander (1965), Campbell and Lees (1967), Keeney and Gardner (1970), Hunt (1972), and Broadbent (1973). Nitrification, contrary to mineralization, is very sensitive to pH, aeration, temperature, and moisture conditions. Nitrate, the end product of nitrification, is of great concern since it is highly soluble in water and relatively inert in soil chemical reactions. It thus becomes readily available for both plant uptake and loss to the ground water (Corey *et al.*, 1967).

Denitrification is the process of converting nitrate or nitrite to elemental nitrogen and nitrogen oxides (Broadbent, 1973). It is the major pathway whereby nitrogen is returned to the atmosphere. Immobilization completes the nitrogen cycles as it consists of plant or microbial absorption of nitrogen in the nitrate form and subsequent incorporation into cellular material (Bartholomew, 1965).

Phosphorus does not undergo much change in chemical form with cycling throughout the environment.

As a prominent part of nucleic acids and energy transfer compounds, it functions as an essential plant and animal element. In aquatic ecosystems, phosphorus often becomes a limiting factor. Thus the introduction of even modest quantities of phosphorus in sewage effluent often results in lake and stream eutrophication. Fortunately, most terrestrial wastewater disposal sites have high phosphorus renovation capacities. Phosphorus compounds are fairly insoluble in soil, and are made unavailable by iron and aluminum compounds (Lindsay and Moreno, 1960; Woodruff and Kamprath, 1965; and Humphreys and Pritchett, 1971). Plant uptake of phosphorus can also be very significant as indicated by Law (1970), Gilde (1971), and Hook et al. (1973).

The ability of terrestrial wastewater treatment sites to renovate nitrogen and phosphorus-bearing wastewaters has been investigated. Forest sites at Pennsylvania State University which were utilized for spray irrigation have exhibited 99% phosphorus removal and 85% nitrogen removal over seven years. Corn and reed canary grass sites at the same location proved even more effective in removing nitrogen. Bouwer (1973) reported 80% nitrogen and 50% phosphorus renovation levels for the rapid infiltration project at Flushing Meadows, Arizona. The spray irrigation system at Cadillac, Michigan, described by Urie (1973) gave 98% phosphorus removal and greater than 90% nitrogen renovation (except for two months at the end of the irrigation season when nitrate began moving into the ground water). Frost (1973) reported 95% phosphorus removal and only 16% nitrate removal from forest sites irrigated in New Hampshire. An agricultural site at Paris, Texas, irrigated with cannery wastewater achieved 86-93% nitrogen and 50-88% phosphorus renovation (Law et al., 1970). Hill (1972) described a system for irrigating swine waste which was able to achieve 99.5 and 99.8% removal of nitrogen and phosphorus respectively.

The abilities of different terrestrial ecosystems to remove nutrients applied in wastewater are quite marked. A reed canary grass crop at Penn State, irrigated with 50 mm/week of wastewater, removed 457 kg/ha of nitrogen and 63 kg/ha of phosphorus after three harvests during 1970. Under the same conditions a corn silage crop withdrew 180 kg/ha of nitrogen and 47 kg/ha of phosphorus from the irrigation site. In contrast, uptake of nitrogen and phosphorus in an irrigated hardwood forest averaged only 104 and 9 kg/ha respectively (Sopper and Kardos, 1973).

Some investigators have stated that boron is a potential problem in terrestrial wastewater irrigation schemes and requires more study (Richard, 1972, and Baier and Fryer, 1973). Ellis and Knezek (1972) reviewed the absorption mechanisms of boron in soils. Wear and Patterson (1962) showed that plant uptake of water-soluble boron is greatest when the soil is low in pH and coarse in texture. Agronomists have agreed that boron is an essential element for higher plants. However, the critical biochemical role of boron has not yet been isolated. Different hypotheses exist as to what the function of boron in plants is (Price _et al._, 1972). Oertli and Kohl (1961) have substantiated the hypothesis that boron is moved by the transpiration stream and concentrated in the plant extremeties as water is lost through evapotranspiration. This would correlate well with observations by Stone and Baird (1956) that boron toxicity symptoms commonly occur at the top and periphery of the crown in red and white pine.

Soils and Vegetation Considerations

The wastewater renovative capacity of terrestrial ecosystems results from the dynamic processes occurring in soils. A complex interaction of physical, chemical, and biological processes function in removing chemicals from wastewater. Murrmann and Koutz (1972) have discussed the roles of cation exchange, precipitation, adsorption, oxidation-reduction, plant uptake, and microbiological utilization in reclaiming wastewater applied to terrestrial ecosystems. The effects of wastewater on the chemical and physical properties of soils have been investigated by Steel and Berg (1954), Thomas et al. (1966), McGauhey and Krone (1967), and Day et al. (1970). Hajek (1969) and Ellis (1973) have reviewed the chemical interactions which allow the soil to serve as a filtering system for chemicals found in wastewaters. Kardos and Sopper (1973) reported that wastewater irrigation caused significant changes in the principal exchangeable cations of only magnesium and sodium. Distinct increases also occurred in pH, manganese, and extractable chloride.

One key item of concern in the management of a terrestrial wastewater treatment system is the maintenance of the botanical component. Rickard (1972) points out that while plants have a high nutrient absorption capacity, they also are susceptible to nutrient toxicity. Little et al. (1959), Cole et al. (1969), and Baier and Fryer (1973) have cited undesirable plant responses to wastewater irrigation. Sopper and Kardos (1973) discussed the growth and nutrient responses of a variety of agricultural crops and tree species. In general, wastewater irrigation increased the height and diameter of mature forest stands and greatly improved the survival and height growth of tree seedlings. The only exception to this was red pine which initially responded well to irrigation rates of 25 and 50 mm/hour but then exhibited a negative response at 50 mm rate. This they felt was due to boron toxicity which developed in the red pine after six years of wastewater irrigation. Needles on trees containing 33 ppm boron turned yellow. Stone and Baird (1956) observed stepwise needle necrosis of red and white pine fertilized with as little as 11 kg/ha of borax. High correlations existed between the amount of borax applied to the sandy loam soil and the boron content of red pine foliage.

CHAPTER III

STUDY SITES

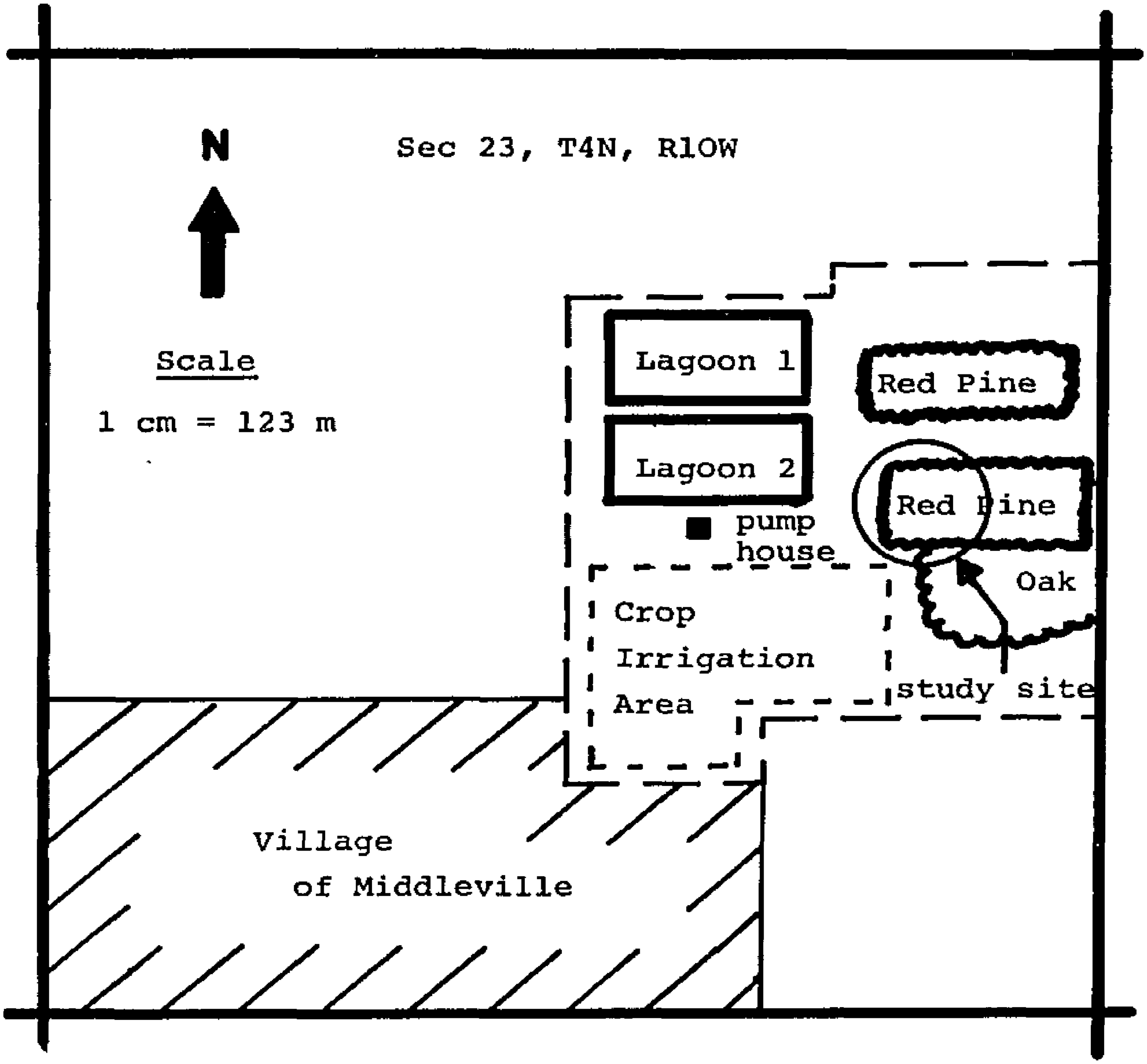
A. Middleville

Geography

Middleville, Michigan has a population of about 2,500 and is located approximately 24 km southeast of Grand Rapids in Barry County. It sits astride the Thornapple River, a tributary of the Grand River. The drainage basin of the Grand River is the dominant watershed in southern Michigan. It drains an area of 12,740 km^2.

In 1971, Middleville constructed a 24 ha sewage treatment facility to the east of town in the NE 1/4 and SE 1/4, Section 23, Township 4 North, Range 10 West, Michigan Meridian. Prior to 1971, all municipal wastewater was given primary treatment and then dumped into the Thornapple River. The new sewage treatment facility consists of two, 4.4 ha, sewage stabilization ponds, a pump house and chlorination chamber, a 14 ha crop irrigation site, and an adjacent 20 ha area of conifer plantations and hardwood stands (Figure 2).

Figure 2. Layout of the wastewater treatment facility at Middleville, Michigan.


N
Sec 23, T4N, R10W
Scale
1 cm = 123 m
Lagoon 1
Lagoon 2
pump house
Red Pine
Red Pine
Oak
Crop Irrigation Area
study site
Village of Middleville

This site was chosen for study because of the availability of sewage effluent for irrigation, and the presence of forest stands on characteristic soils.

Geology

The Middleville sewage stabilization pond facility is located on gentle rolling to hilly topography bordering a recessional moraine. The surface geologic formation consists of unconsolidated glacial drift of the Wisconsinan stage. It is characterized by sorted and unsorted sands and gravels with heterogeneous inclusions of clay till. About 30 m of glacial drift overly the bedrock of Mississippian aged Napolean sandstone (Martin, 1936).

The regional ground water table slopes to the west down to the Thornapple River. It lies from 9 to 18 m below ground surface. Most individual wells utilize this surface aquifer for a water supply.

Soils

The portion of the sewage treatment facility occupied by the red pine plantation is underlain by a Boyer sandy loam. Boyer soils are typic hapludalfs which formed in loamy sand and sandy loam outwash overlying calcareous coarse sand and gravel. Such soils occur on outwash plains, old glacial drainageways, and on moraines. The original vegetation found on them consisted of oak, hickory, and white pine stands, but is predominantly under cultivation for grain and forage crops.

Soils of the Boyer series are well drained and have a moderately rapid permeability of 60 to 250 mm/hr. Surface runoff is slow on gentle slopes and rapid on steep slopes. These soils tend to have a low available moisture capacity and moderately low natural fertility. The pH of the Boyer series ranges from 5.3 to 6.3.

The productivity of trees growing on Boyer soils is medium to high for pine, and low to medium for hardwoods. White pine, red pine, and white spruce are the most desirable plantation species. These species present few management problems when located on Boyer soils. Occasional droughtiness is the only soil limitation of any concern.

A typical soil profile description of a Boyer loamy sand is shown in Figure 3.

Climate

The climate at Middleville alternates between continental and semi-marine. The influence of Lake Michigan to the west results in the marine-like climate during periods of strong wind flow. At other times the continental climate characteristic of interior North America prevails.

Figure 3. Soil Horizon description for the typifying pedon of the Boyer series (Soil Conservation Service, 1966).

Typifying Pedon: Boyer Loamy Sand

SOIL PROFILE:		DESCRIPTION
A_p	00 - 18 cm	Dark grayish brown (10YR4/2) loamy sand; very weak fine granular structure; very friable; numerous roots; slightly acid; abrupt smooth boundary; 15 to 25 cm thick.
A2	18 - 30 cm	Brown (10YR5/3) loamy sand; very weak medium granular structure; very friable; medium acid; clear wavy boundary; 8 to 25 cm thick.
B1	30 - 45 cm	Yellowish brown (10YR5/3) loamy sand; weak fine subangular blocky structure; very friable; 2 to 4% gravel; medium acid; clear wavy boundary; 10 to 30 cm thick.
B21t	45 - 77 cm	Dark brown (7.5 YR4/4) sandy loam; weak coarse subangular blocky structure; firm; few thin clay films; 15% fine and medium gravel; slightly acid; gradual wavy boundary; 20 to 38 cm thick.
B22t	77 - 86 cm	Dark brown (7.5YR4/4) sandy clay loam; weak coarse subangular blocky structure; firm; 15% gravel; common thin and medium clay films; neutral; abrupt irregular boundary; 1 to 15 cm thick.
IIC	86 - 130+cm	Grayish brown (10YR5/2) stratified gravel and coarse sand; single grain; loose; calcareous.

The mean annual temperature for this site is about 8.9°C with the extremes averaging -8.9°C in January and 28.5°C in July. The average length of the growing season is about 160 days.

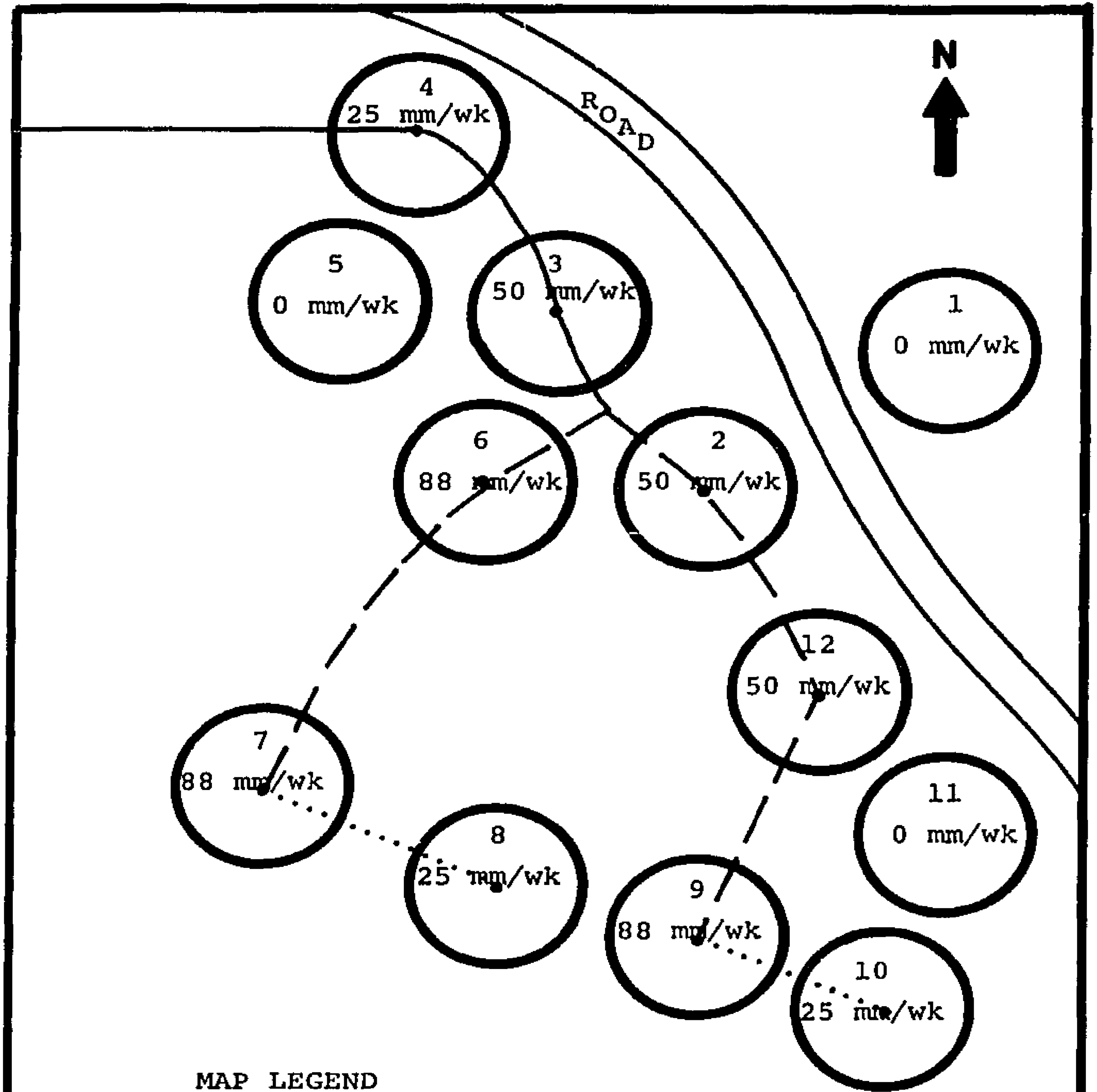
Precipitation is uniformly distributed throughout the year. Annual precipitation averages 820 mm. During the months of April - October, rainfall averages 546 mm, with monthly extremes of 209 and 4 mm having occurred within the past six years. The maximum 24-hour rainfall in the current 30-year period of record was 84 mm in June of 1972.

Measurable precipitation occurs on an average of 140 days each year. About 80% of the days during the year are cloudy or partly cloudy. The relative humidity generally averages about 80% in the morning and 65% during the afternoon (Strommen, 1971).

Study Design

The wastewater irrigation study was established at Middleville in the fall of 1971 and the spring of 1972. Twelve circular 0.02 ha plots were laid out in a 20-year-old red pine plantation (Figure 4). A randomized block design was used to account for slope variations from northwest to southeast across the plots. The design consisted of three replications of four treatments: (1) control (plots 1, 5, and 11),

Figure 4. Wastewater irrigation plots in the 20-year-old red pine plantation at Middleville, Michigan.



MAP LEGEND

———————— 50.8 mm Polyethylene Pipe

—— —— —— 31.8 mm Polyethylene Pipe

. . . . . .18.1 mm Rubberized Hose

Scale: 1 cm = 12 m

(2) 25 mm of wastewater/week (plots 4, 8, and 10), (3) 50 mm/week (plots 2, 3, and 12), and (4) 100 mm/week (plots 6, 7, and 9). The 100 mm/week plots actually turned out to receive 88 mm/week because of insufficient line pressure, and hence are referred to as 88 mm/week treatment plots.

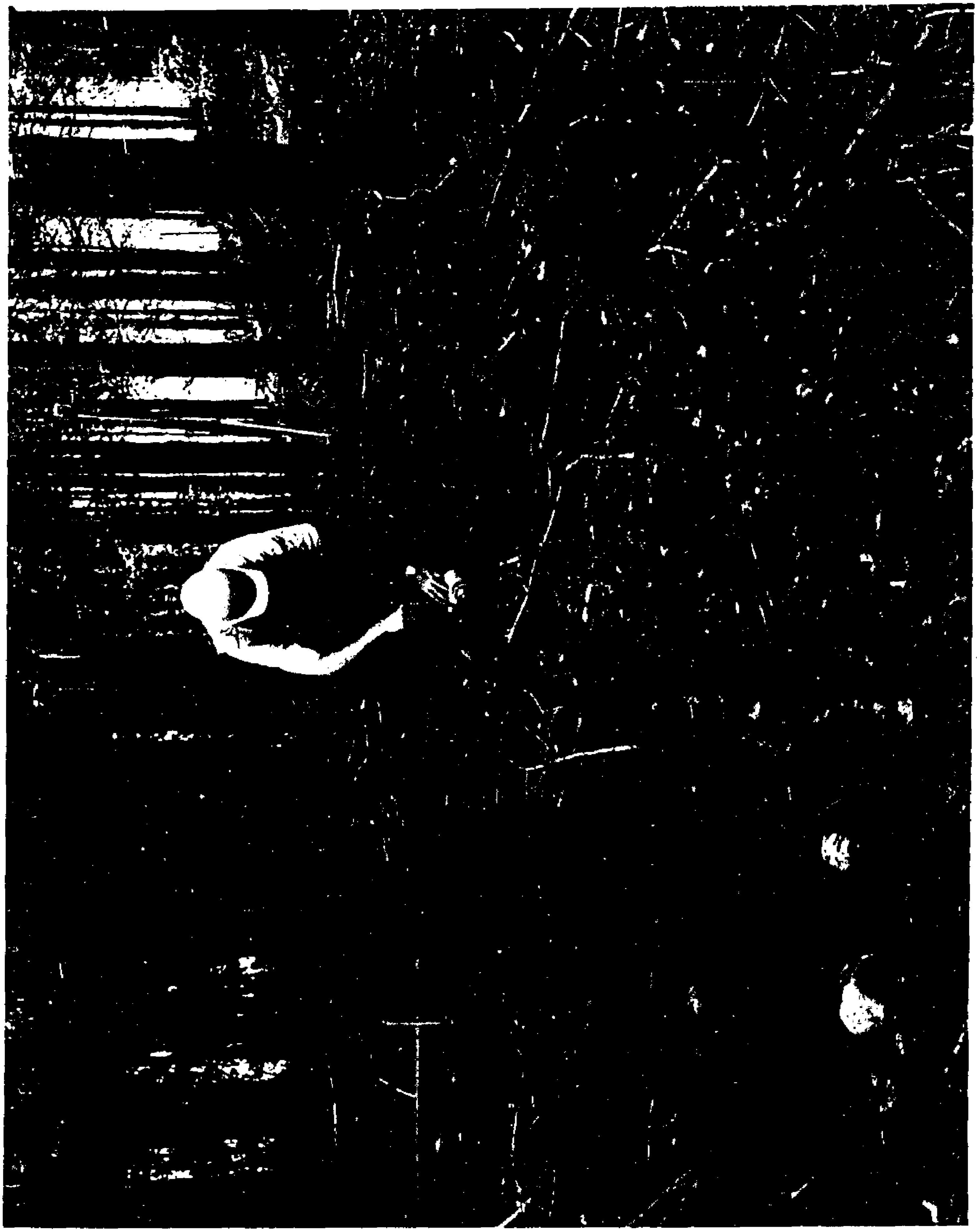
Trees within the 8.02 m plot radius were flagged and pruned to a height of 3 m. A metal post with a plot identity tag was positioned in each plot center. The entire study area was fenced off and posted with warning signs.

Irrigation System

The irrigation system for the study was constructed in the spring of 1972. It is a solid-set, semi-portable, spray irrigation design. A 50.8 mm (2-inch) diameter polyethylene pipeline delivers effluent from the nearest 212.4 mm (6-inch) header in a manhole west of the plantation. From a tee near plot 3, a 31.8 mm (1 1/4-inch) polyethylene pipe and 18.1 mm (3/4-inch) rubberized hose complete the distribution system to the irrigated plots (Figure 5). In the center of each irrigated plot, a post-supported 122 mm (48-inch) riser branches off the distribution line by means of a saddle tee.

The sprinklers, mounted on the galvanized steel risers, are Rainbird single nozzle impact-hammer types.

Figure 5. Polyethylene hose distribution system in the Middleville red pine stand.



The 25 mm/week plots have Rainbird 3-25A-FP-TNT sprinklers with aluminum hammers and 3.2 mm (1/8-inch) Hi-Lo nozzles. The 50 mm and 88 mm/week plots have Rainbird 9-25A-FP-TNT sprinklers with bronze hammers and 4.3 mm (11/64-inch) Hi-Lo nozzles (Figure 6). Two of these sprinklers are tee mounted in the 88 mm/week plots to deliver the designed irrigation rate. Sprinklers were operated at a pressure of 35 to 40 PSI. The Hi-Lo nozzles allowed adjustment to cover all areas within a plot radius. Sprinkler calibration was conducted at the beginning of each irrigation season by a network of rain gage cans located on each plot.

Operation of the irrigation system is designed to be directed through a Buckner electronic control panel in the pump house. In 1972 a separate pumping and control system had to be established to provide wastewater for the tree irrigation project due to the fact that the main irrigation system was not operating. The normal irrigation schedule called for eight hours of irrigation one day/week. Plots were irrigated from late July to mid-October in 1972, and from late May to mid-October in 1973. Irrigation was continued in 1974. However, data from the 1974 irrigation season were not included in the thesis.

Figure 6. Adjusting pressure on a Rainbird 9-25A-FP-TNT impact-hammer sprinkler using pressure gage and control valve.

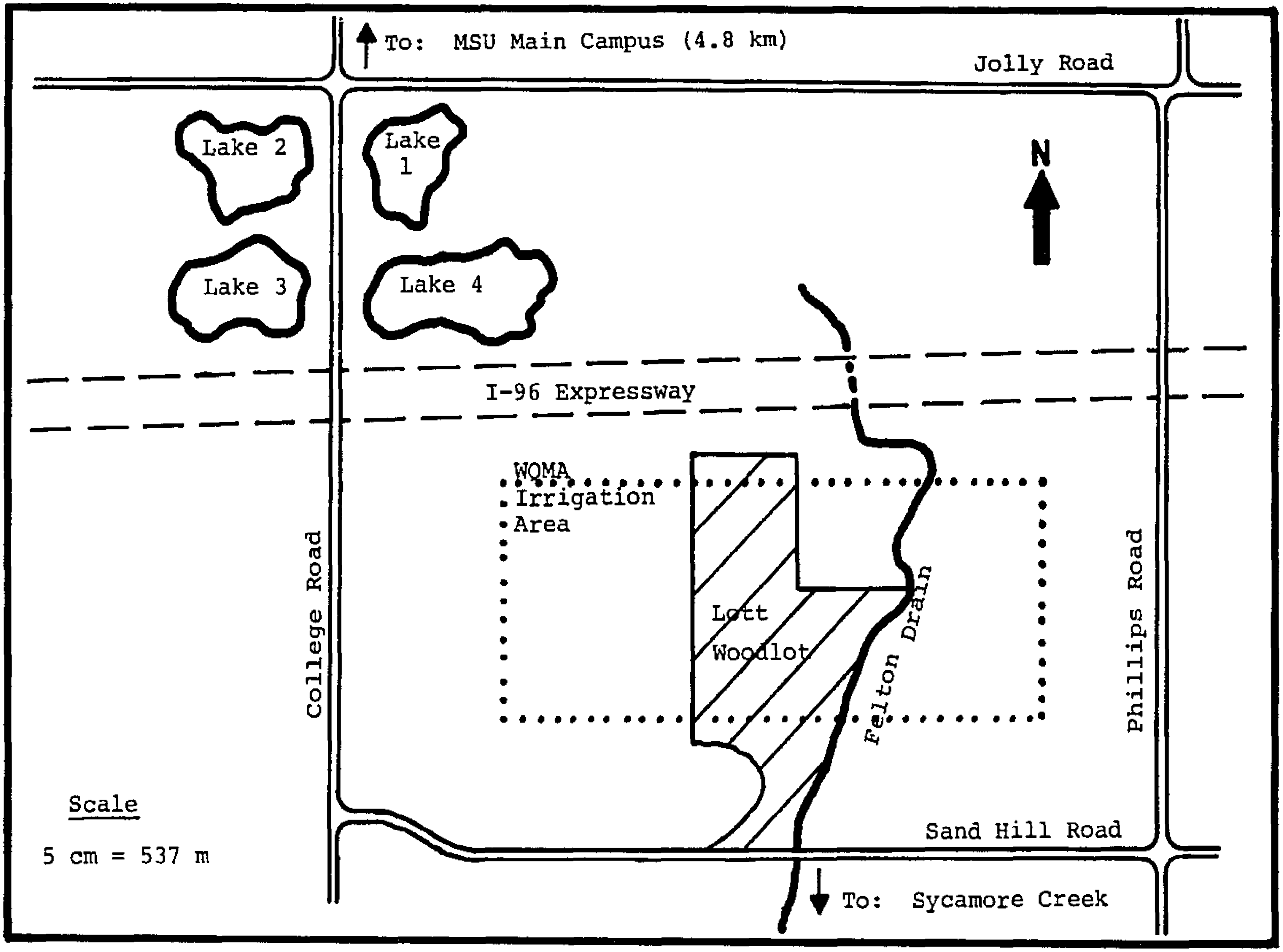
B. Lott Woodlot

Geography

The Lott Woodlot is located on the south edge of the Michigan State University campus in Section 6, Township 3 North, Range 1 West, Michigan Meridian. It is approximately 4.8 km south of the main campus at East Lansing in Ingham County (Figure 7). East Lansing is a major suburban community in the greater Lansing metropolitan area. Michigan State lies within portions of the Sycamore Creek and Red Cedar River watersheds. These two streams empty into the Grand River, which flows through Lansing and westward to Grand Rapids and its junction with the Thornapple River.

The 26 ha Lott Woodlot is part of a 200 ha research area designated as the Michigan State University Water Quality Management Area (WQMA). The Institute of Water Research at Michigan State University plans to conduct long-range studies on the many aspects of using aquatic and terrestrial sites to renovate municipal wastewaters. It is designed to process 7,600 m^3 per day (2mgd) of the approximately 41,800 m^3 per day (11 mgd) of wastewater handled by the East Lansing Sewage Treatment Plant. Effluent for the WQMA will be taken off the secondary treatment final clarifiers in the East Lansing plant and pumped 8 km to a series of

Figure 7. Water Quality Management Area at Michigan State University.


To: MSU Main Campus (4.8 km)
Jolly Road
Lake 2
Lake 1
Lake 3
Lake 4
N
I-96 Expressway
WQMA Irrigation Area
Lott Woodlot
Felton Drain
College Road
Phillips Road
Scale
5 cm = 537 m
Sand Hill Road
To: Sycamore Creek

four 4.0 ha oxidation ponds. Part of the water from these ponds will then be pumped to a 120 ha irrigation site (Figure 7). The irrigation area consists of abandoned farmland, and the Lott Woodlot, a second growth sugar maple-beech hardwood stand which was heavily cut over by its former owners. Starting operations of the WQMA are expected to commence during the summer of 1974 as construction and equipment testing are completed.

The Lott Woodlot site was chosen for this study to obtain preliminary data on the ability of this particular forest site to renovate municipal wastewater.

Geology

The Lott Woodlot is located on the gently rolling topography of a glacial till plain. The till is unsorted drift, loamy in texture, and of Wisconsinan age. The regional ground water table lies from 3 to 7 m below ground surface. It slopes to the south and east towards Sycamore Creek and Felton Drain. The consolidated bedrock aquifer, located about 15 to 20 m below ground surface, is the Pennsylvanian aged Saginaw sandstone formation (Martin, 1936).

Soils

The study portion of the Lott Woodlot is underlain by Miami loam (typic hapludalf). Soils of the Miami series formed in calcareous loam, silt loam, or light clay loam till. They occur on level to steep morainal areas and on till plains throughout southern Michigan. The original vegetation consisted of sugar maple (Acer saccharum Marsh.), American beech (Fagus grandifolia Ehrh.), American elm (Ulmus americana L.), white oak (Quercus alba L.), red oak (Quercus rubra L.), shagbark hickory (Carya ovata [Mill.] K. Koch), white ash (Fraxinus americana L.), basswood (Tilia americana L.), and green ash (Fraxinus pennsylvanica Marsh.). Much of the area occupied by Miami soils is now utilized for grain crops or pastures.

Miami soils are typically well drained with a moderate permeability of 20 to 63 mm/hour. Permeability may be higher in well-structured soil bodies such as forest areas. Runoff is medium on low slopes and very rapid on steep slopes. Both the available moisture capacity and natural fertility are moderately high due to the fine texture of this soil. The erosion hazard is slight to moderate. Normal soil pH ranges from 6.1 to 6.4.

Soils possessing physical and chemical characteristics similar to that of the Miami have a very high potential productivity for better hardwoods such as black cherry (Prunus serotina L.), tulip poplar (Liriodendron tulipifera L.), basswood, sugar maple, red oak, white oak, and white ash. White spruce, Norway spruce (Picea abies L.), and white pine also have high growth rates and are frequently planted. The only management limitation is weed competition.

A representative soil profile description of a Miami loam soil is presented in Figure 8.

Climate

The Lansing climate is similar to that of Middleville in that it alternates between continental and semi-marine. Despite its location in the middle of the lower peninsula, Lansing is influenced by the proximity of Lake Michigan to the west and Lake Huron to the east. However, the weather tends to be somewhat more continental.

The mean annual temperature for Lansing is about 8.6°C. Yearly extremes average -9.3°C in January and 28.1°C in July. The average growing season is about 154 days.

The annual precipitation of 772 mm is fairly uniformly distributed. During the months of April through October, rainfall averages 514 mm, with monthly extremes of 202 and 4 mm having occurred in the past six years. The maximum 24-hour rainfall in the past 30-year period of record was 110 mm in June of 1963.

Measurable precipitation occurs on an average of 137 days each year. About 79% of the days during

Figure 8. Soil profile description for the typifying pedon of the Miami series (Soil Conservation Service, 1966).

Typifying Pedon: Miami Loam

SOIL PROFILE:		DESCRIPTION
Ap	00 - 20 cm	Dark grayish brown (10YR4/2) loam; weak, medium, and coarse, granular structure; friable; slightly to medium acid; abrupt smooth boundary; 15 to 28 cm thick.
A2	20 - 30 cm	Light yellowish brown (10YR6/4) to brown (10YR5/3) loam; weak, medium, platy to weak, coarse, granular structure; friable; medium to strongly acid; clean wavy boundary; 5 to 15 cm thick.
B1	30 - 38 cm	Yellowish brown (10YR5/4) to dark brown (10YR4/3) loam or clay loam; thin clay coatings on a few ped faces; moderate, fine, subangular blocky structure; friable to firm; medium to strongly acid; clear wavy boundary; 5 to 12 cm thick.
B21t	38 - 60 cm	Dark yellowish brown (10YR4/4) or dark brown (7.5YR4/4) clay loam; clay coatings on many ped faces; moderate to strong, medium and coarse, subangular blocky structure; firm; medium to strongly acid; clear irregular boundary; 18 to 38 cm thick.
B22t	60 - 71 cm	Dark brown (7.5 YR4/4) to (10YR4/3) clay loam; clay coatings on most ped faces; weak to moderate, coarse and very coarse subangular blocky structure; firm; slightly acid to neutral; abrupt irregular boundary; 2.5 to 12.5 cm thick.
C	71 + cm	Light yellowish brown (10YR6/4 - 2.5YR6/4) to brown (10YR5/3) loam or silt loam; massive (structureless) to very weak, very coarse subangular blocky structure; firm; calcareous.

the year are cloudy. Relative humidity averages about 81% in the morning and 66% in the afternoon (Strommen, 1971).

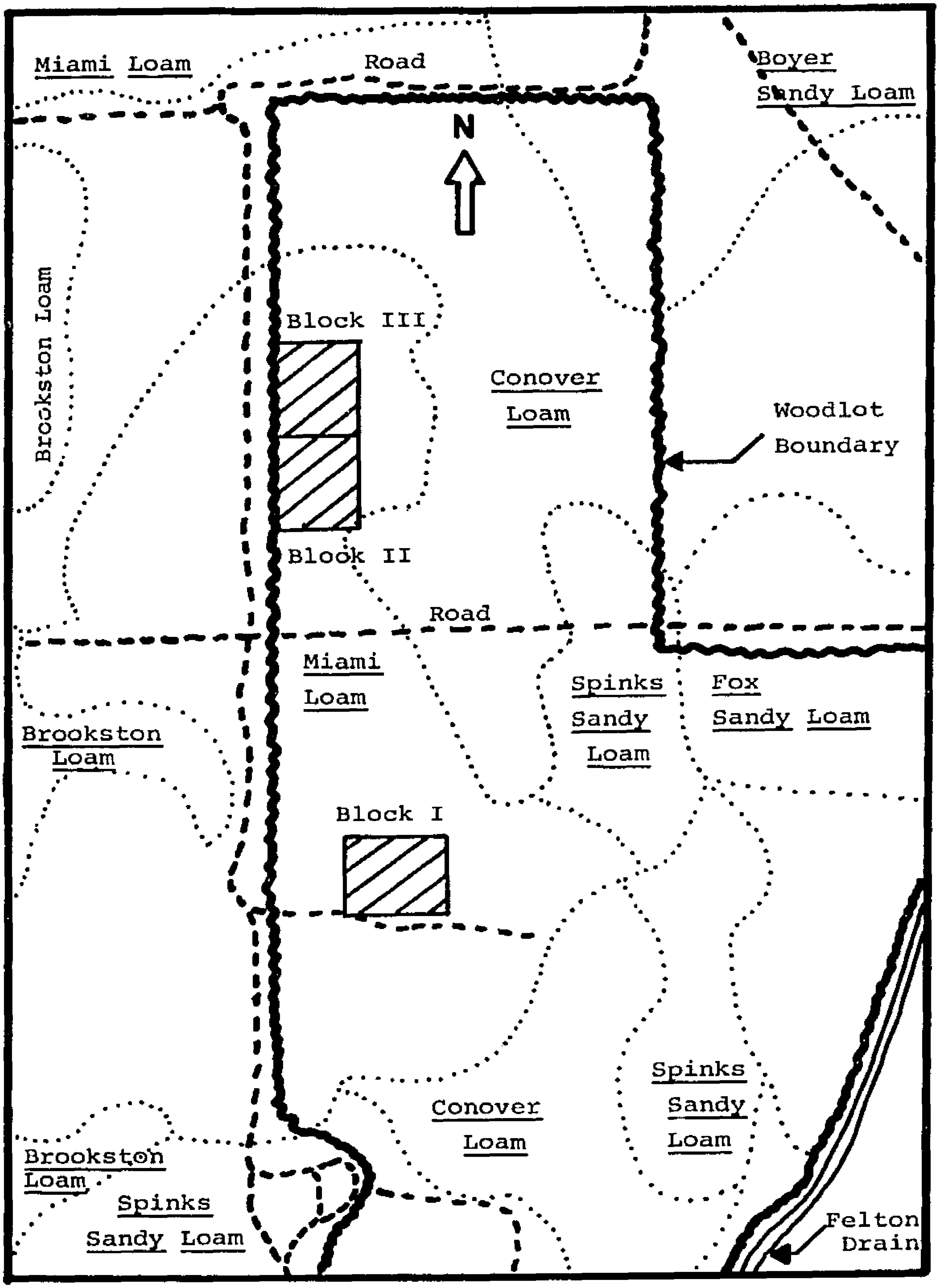
Study Design

The pilot wastewater renovation study in Lott Woodlot was established during the spring and summer of 1972. The design consisted of three replications along the western edge of the woodlot (Figure 9). Each block in the randomized block design consists of five plots with the following treatments: (1) control, (2) 50 mm of well water/week (well water taken from the Michigan State University water system), (3) 25 mm of sewage effluent/week, (4) 50 mm of effluent/week, and (5) 75 mm of effluent/week. Each plot is square, and 0.0004 ha (mil-acre) in size. All plots were on level ground, clear of large trees, and fairly similar in ground cover composition. Each plot was entrenched with 3 mil black plastic to a soil depth of 30 cm to ensure vertical infiltration of the irrigation water.

Irrigation System

The irrigation system in Lott Woodlot was a gravity-feed trickle irrigation type. This was necessitated by the lack of pumped sewage effluent on the irrigation site, and the physical constraints of establishing a portable pumping system for spray irrigation to each plot.

Figure 9. Location of the trickle irrigation plots in the Lott Woodlot.


Miami Loam
Road
Boyer Sandy Loam
N
Brookston Loam
Block III
Conover Loam
Woodlot Boundary
Block II
Road
Miami Loam
Spinks Sandy Loam
Fox Sandy Loam
Brookston Loam
Block I
Spinks Sandy Loam
Conover Loam
Brookston Loam
Spinks Sandy Loam
Felton Drain

The trickle system consisted of metal reservoirs, a control valve, and 12 mm diameter PVC distribution pipe (Figure 10). Combinations of two, four, and five barrels were connected to deliver a given volume of water over the plots. The barrel systems were calibrated in the lab to deliver 101, 202, and 303 liters of water to correspond to the 25, 50, and 75 mm design rates. The PVC pipe was drilled at 15 cm intervals with 2 mm holes to disperse the irrigation water (Figure 11). Water dispersal over the plots, while not as uniform as spray irrigation, was sufficient to wet down the entire plot surface. The control valve had to be kept open to obtain adequate dispersal of the water away from the plastic pipe. This resulted in high hourly application rates of 25 to 50 mm/hour.

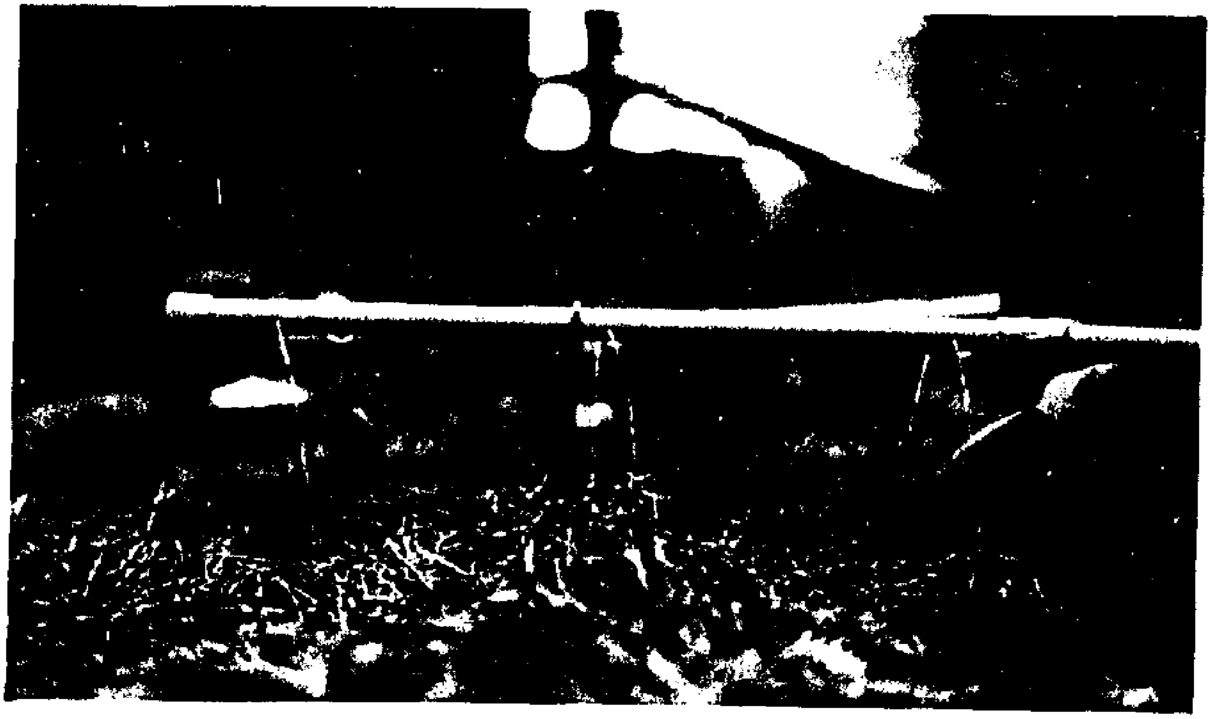
Plots were irrigated one day/week during the growing season. A truck-mounted 2,500 liter tank hauled the chlorinated secondary treatment effluent from the East Lansing Sewage Treatment Plant to the Lott Woodlot (Figure 12). The irrigation reservoirs were pumped full from an access road by aircraft fueling hose. Sewage effluent and well water were delivered by separate hoses and hauling containers to avoid well water contamination.

Irrigation started in July of 1972 and continued to mid-October of that year. In 1973, irrigation was

Figure 10. Trickle irrigation system in the Lott Woodlot. Note storage reservoir and PVC distribution lines.

Figure 11. Water discharge from trickle irrigation system using PVC pipe.

Figure 12. Tank and pump for delivery of wastewater to the Lott Woodlot irrigation site.



started in June and ended in mid-October. This particular project was not continued in 1974. It was designed as a pilot study for research in the period preceding the operation of the main spray-irrigation system in the WQMA. Wastewater was available for irrigation through the main system during the summer of 1974.

CHAPTER IV

METHODS AND MEASUREMENTS

A. Middleville

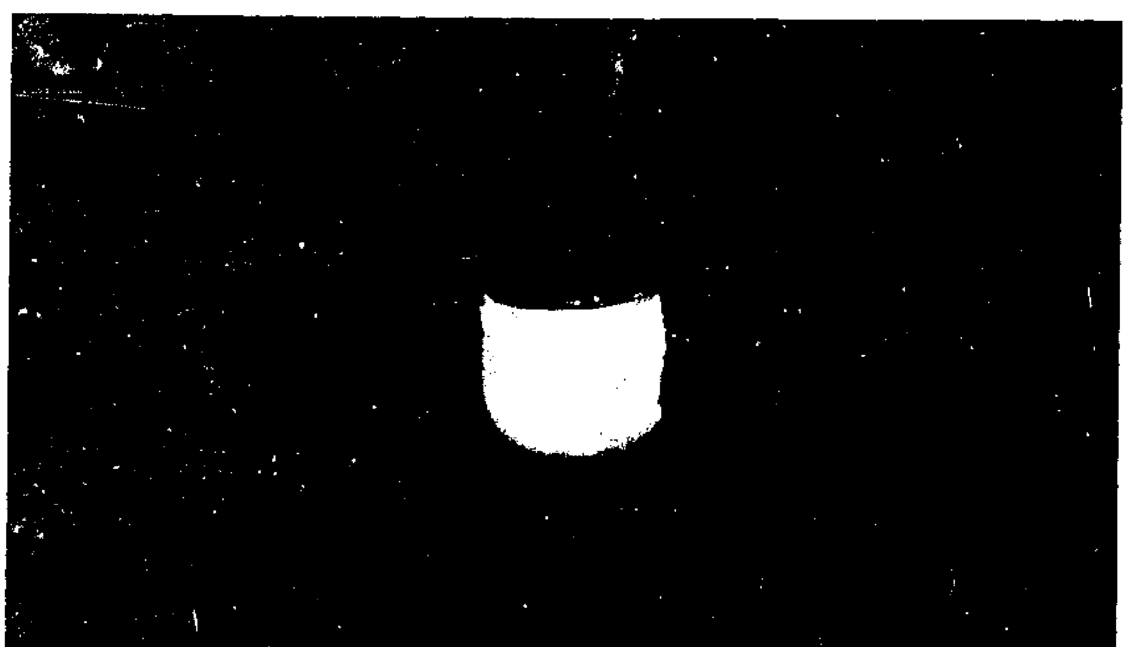
Water Quality Analysis

The objective in utilizing the "living filter" of soil, microorganisms, and plants is to provide a recharge of purified water into the ground water aquifer. Such water, while not pure in the strict sense of the word, is relatively free of the nutrients acquired through use. Porous cup lysimeters were used to sample soil water at Middleville since the ground water table is too far below ground surface for adequate sampling.

The porous cup or suction lysimeter consisted of a 5 cm diameter PVC plastic pipe of two lengths (60 or 120 cm) with a porous clay cup epoxyed to one end. The top end is sealed with a rubber stopper that contains access tubing used for applying a vacuum to withdraw samples (Figure 13).

The lysimeter installation was at 60 and 120 cm depths, 5 m from the sprinkler heads, a comparable

Figure 13. Suction lysimeter: (A) access tubing used to remove water samples and (B) porous cup embedded in soil.



distance from the sprinklers as were the initial calibration cans. A 7.5 cm diameter soil auger was used to dig the holes for the lysimeters. Care was taken to ensure that the cups were properly seated using fine sand. The auger holes were then backfilled with soil corresponding to the original profile. A plastic apron was located around each lysimeter at the soil surface to prevent water seepage down the side. A metal can was also placed over the lysimeter to further reduce possible sideways water flow.

Water samples were obtained with a vacuum of 33 cm of mercury. Sampling procedures involved: (1) putting a vacuum on the lysimeters, (2) irrigated for 8 hours, and (3) removing the samples one week later prior to irrigation (Figure 14). Water collected from the lysimeters was placed in plastic bottles, preserved with 40 mg/l $HgCl_2$, and brought back to Michigan State University. Samples were placed in cold storage until chemical analysis could be completed.

Water samples collected from both lysimeter and lagoon were analyzed for nitrate nitrogen (NO_3-N), ammonia nitrogen (NH_3-N), total Kjeldahl nitrogen (TKN), and total phosphorus (Total P). NO_3-N was determined by the brucine sulfate method, NH_3-N by the phenol hypochlorite method, TKN by micro-Kjeldahl method,

Figure 14. Collecting soil water samples from suction lysimeters at Middleville by means of a hand pump and vacuum flask assembly (center).

and Total P by persulfate digestion using Standard Methods for the Examination of Water and Wastewater, 13th Edition.

Red Pine Growth and Nutrient Status

Additions of water and nutrients from wastewater irrigation would most likely affect tree growth. To document such change, DBH, height, and needle growth, and foliage nutrient level were monitored during 1972 and 1973.

DBH was measured at the end of each growing season. All trees in each plot were measured using a diameter tape. In addition, two trees on each plot were monitored monthly during the 1973 growing season with band dendrometers.

The heights of all trees were measured in 1972 and 1973 using a Haga altimeter. Great difficulty was encountered in locating the tree tops in the thick, closed canopy. An accurate assessment of the height growth response of the trees to the irrigation was therefore not possible. A limited sample of trees with visible tops was selected for measurement of the 1972 and 1973 whorl heights above the ground.

Needle growth was determined by collecting branch samples from the top 2 or 3 whorls on the south side of 4 sample trees in each plot. Sample trees were located at the 4 directional axes of each plot and so marked. The current year's lateral growth was removed, labelled, placed in a plastic bag, and brought back to MSU for analysis. From the basal portion of each sample 100 fascicles were removed, measured for length, and placed in a separate envelope. Remaining needles were stripped off and placed in a paper bag. Foliage was oven dried at 70°C for 24 hours. Terminal bud length of each sample branch was also measured.

Oven-dried needles were ground in a Wiley Mill with a 20 mesh screen for nutrient analysis. Total Kjeldahl nitrogen was determined using the macro-Kjeldahl method. Water extraction and flame spectrophotometry were used for potassium determination. A mass spectrograph was used to determine foliar content of sodium, calcium, magnesium, manganese, cooper, boron, zinc, aluminum, iron, and phosphorus.

Soils

Soil samples were collected in the fall of 1973 to determine changes in soil chemistry. A bucket auger was used to collect soil from the 0-15, 15-30, 45-60, and 105-120 cm depths. Four sampling points were selected in each plot and samples then combined into a plot composite sample. Soil samples were air dried, sieved to pass a 2 mm screen, and analyzed at the MSU soil chemistry lab. Soil pH was determined by glass electrode. Calcium, potassium, and magnesium were measured by atomic absorption analysis after extraction with ammonium acetate. Phosphorus was analyzed by extraction with Bray's P_1 solution and quantitative determination by spectrophotometry. Boron analyses were done by the Wisconsin state soil testing lab using the cucurmin method. Macro-Kjeldahl techniques were used to obtain the total Kjeldahl nitrogen, and soil organic matter was measured using Davies (1974) method for loss-on-ignition, both operations performed in the Department of Forestry soils lab.

Humus

The forest floor (O horizons) beneath a red pine stand consists of organic matter in varying stages of decomposition. This organic matter, called humus, is composed of recently deposited litter such as needles, branches, and cone parts, partially decomposed but still recognizable litter, and organic material in more advance stages of decomposition. The physical, chemical, and biological characteristics of the underlying soil are strongly influenced by the properties of the humus.

A study of the duff mull humus (Trimble and Lull, 1956) in the red pine stand at Middleville was conducted towards the end of the 1973 growing season. Subplots were established on the cardinal axes of each plot at 2, 4, and 6 m distances from the plot center and marked by plastic stakes. A 300 cm^2 core cutter (Figure 15) delineated such plots. Organic material above the Ap horizon was removed and placed in labelled bags. A 50% sand/humus ratio was used as the end point for the lower limit of the forest floor when the boundary was diffuse.

During the actual sampling, several direct measurements were taken. Forest floor depth was measured at six locations around the circumference of the sampling core. Mycelial mat and earthworm counts were used as indicators of decomposition activity of fungi and annelids in relation to wastewater irrigation. These counts are indices and do not represent absolute numbers. Presence or absence of these organisms within the sampling core was recorded simply by means of a "yes" or "no." The index for mycelial mats and earthworms ranged from a minimum value of 0 to a maximum of 12 (based on 12 subplots per plot averaged by treatment).

Samples of the duff mull humus were oven dried at 70°C for 24 hours, and the weight of the woody litter and incorporated mineral soil measured. Woody material was hand separated and weighed. Mineral soil was estimated by sieving the samples through 16 and 32 mesh screens and ashing the material which passed through the sieves. Needle litter and decomposed organic matter weight was determined by subtracting the weights of the mineral soil and woody litter from the total forest floor weight.

Figure 15. The 300 cm^2 core cutter used for collection of forest floor samples.

Fungi Count

A survey of the number of fungal fruiting bodies present in the study plots at Middleville was conducted from mid-August through October of 1973. Representative fruiting bodies were collected for identification but total counts in each plot were combined for all species.

B. MSU Lott Woodlot

Water Quality Analysis

The water sampling and analytical procedures used in the Lott Woodlot were the same as those described for Middleville. Lysimeters, however, were positioned at 30 and 60 cm depths.

Herbaceous Vegetation

Although the herbaceous and tree seedling understory is quite variable throughout the Lott Woodlot, studies were initiated to assess the response of this stratum to wastewater irrigation. Analysis was accomplished through two count surveys and a combination biomass-nutrient study.

A general vegetation survey was conducted in 1971 when permanent vegetation sample plots were established. This survey gives the species composition of the overstory, shrub, and understory components.

In August of 1972 and 1973 a count of the number of individual plant species was conducted on each of the fifteen 0.0004 ha irrigation plots. Spring flora and number of individuals flowering throughout a two-month period was undertaken in the spring of 1973 and 1974.

In May, 1974, the new growth of 10 randomly selected sugar maple seedlings in each plot was collected. The collected samples were weighed, oven dried at 70°C for 24 hours, and reweighed to determine wet weight, dry weight, and percent moisture. The dried samples were then ground up in a Wiley Mill with a 20 mesh screen and subsequently analyzed for nutrient content as described in the section on red pine growth and nutrient status. Comparable data were collected on all herb species found on a 0.25 m^2 area in the northeast quadrant of each plot.

Soil

Soil moisture was monitored throughout the second irrigation season using tensionmeters. Tensionmeters were placed at 30 and 60 cm depths in the control, 25 mm of effluent and 75 mm of effluent treatment plots of Blocks 1 and 2 of the replicated study. Weekly measurements of soil moisture tension were made in centibars. Tensionmeters with broken water columns were assumed to have attained 100 centibars of tension.

Soil samples from the irrigation plots were collected in the spring of 1974. Two sample points per plot at 15, 30, and 60 cm depths constituted a plot composite sample. The soil material was then air dried, sieved to pass a 2 mm mesh screen, and analyzed in the same manner as the Middleville soil samples.

Oxygen diffusion measurements were made during the 1973 irrigation season to determine the affects of irrigation on soil aeration. A Jensen Oxygen Diffusion Ratemeter was used to monitor soil oxygen flux at 10 and 30 cm depths (Lemon and Erickson, 1952). Measurements were made before and after irrigation in mid-July and early August.

Humus

The forest floor in a hardwood forest (01 and 02 horizons) consists mainly of recent leaf and branch litter and partially decomposed litter. Most of the organic matter in advanced stages of decay is incorporated into the A1 horizon by earthworm activity. This type of a forest floor is classified as a coarse mull humus (Trimble and Lull, 1956).

A survey of the humus within the Lott Woodlot wastewater irrigation study was conducted in the fall of 1973 before leaf fall. Four subplots were established in the four quadrants of each plot, midway from the plot center to the respective corners. A 300 cm^2 core cutter was used to define the boundaries of each subplot. Humus within the core was removed and ovendried at 70°C. The dried humus was then separated and weighed by woody and nonwoody components.

CHAPTER V

RESULTS AND DISCUSSION

A. Middleville

Water Quality

Wastewater was applied to the red pine stand at Middleville during the summer and early fall of 1972 and 1973. The 1972 irrigation season began on July 7th and ran to October 31st with a two-week shutdown in the last half of July due to low lagoon levels. During 1972 the red pine irrigation system operated from a separate intake and pumping arrangement which could not draw effluent during low lagoon stages. In 1973 the main Middleville pumping facility was utilized. The 1973 irrigation season was initiated on May 24th and continued to October 14th with another two-week shutdown in mid-July. The halt in the 1973 operations was caused by lightning damage to the pumping electrical system.

Under normal operating conditions, wastewater irrigation in forest stands can begin in late April or early May. At that time most noncapillary pores are open and moisture stress in coarse textured soils begins. In most situations, wastewater irrigation can be resumed earlier and continued longer in forest sites than in cropped fields.

Wastewater Inputs

During both irrigation seasons the lagoon effluent was monitored for concentrations of ammonia nitrogen (NH_3-N), nitrate nitrogen (NO_3-N), organic nitrogen (Organic N), total nitrogen (Total N), and total phosphorus (Total P). Table 1 presents the values of these nutrient forms for each year.

Table 1. Average concentrations of lagoon effluents in the Middleville wastewater.

Year	NH_3-N	NO_3-N	Organic N	Total N	Total P
	-----	-----	mg/l	-----	-----
1972	1.2	0.8	6.4	8.4	3.8
1973	0.7	2.0	4.4	7.1	2.4

Concentrations were variable over the two irrigation seasons. Decreases were noticed in NH_3-N, Organic N, Total N, and Total P while NO^3-N increased. These differences were probably due to changes in the operation of the lagoons. For example, in 1972 the corn irrigation area was not receiving wastewater and all the effluent entered the south lagoon while the north one was being repaired. High levels in NH_3-N, Organic N, Total N, and

Total P would thus be expected due to a lack of any significant nutrient output and further concentration by evaporation. Low NO_3-N levels result with improper water circulation and aeration. In 1973, the entire wastewater treatment facility was operating normally. Thus, NO_3-N levels rose while other nutrient forms decreased. Variability within each year was also noted. For instance, in 1973 NO_3-N fluctuated from a low of 0.10 mg/l to a high of 4.0 mg/l. However, most lagoon determinations for NO_3-N were within ±1.0 mg/l of the mean for the irrigation season. Weekly monitoring of the applied effluent may thus become advisable to obtain a reliable estimate of nutrient loading.

Nutrient Loading

Table 2 shows the water and nutrient loading rates for the two years of irrigation. The addition of the wastewater significantly altered the precipitation regime. It had the effect of increasing precipitation by 40, 80, and 140% in 1972 and by 55, 110, and 190% in 1973 over the yearly precipitation means of 955 and 866 mm respectively. It should be noted that since the wastewater irrigation came during the months of May through July, its impact on precipitation during those months was proportionately greater. The nutrient loadings in kg/ha were determined by using the following equation:

Table 2. Wastewater irrigation and nutrient loading rates at Middleville, 1972 and 1973.

(A) Amount of irrigation and precipitation.

Year	Rainfall	Wastewater Irrigation		
		25	50	88
	---mm---	---------mm----------		
1972	955	375	750	1320
1973	866	475	950	1672

(B) Average nutrient loading rate with different levels of wastewater irrigation.

Nutrient	1972			1973		
	25	50	88	25	50	88
	-------kg/ha-------			-------kg/ha-------		
NH_3-N	4.5	9.0	15.8	3.3	6.6	11.7
NO_3-N	3.0	6.0	10.5	9.5	19.0	33.4
Organic N	24.0	48.0	84.5	20.9	41.8	73.6
Total N	31.5	63.0	110.8	33.7	67.4	118.7
Total P	14.3	28.5	50.2	11.4	22.8	40.1

(Equation 1)

$$N = C \cdot m \cdot v \cdot D \cdot l \cdot a$$

where:

N = nutrient loading in kg/ha

C = effluent concentration in mg/l

m = mass conversion factor (10^{-6} kg/mg)

v = volume conversion factor (10^{-3} l/cm^3)

D = amount of effluent applied in mm/year

l = length conversion factor (10^{-1} cm/mm)

a = area conversion factor (10^{8} cm^2/ha)

Of notable interest is the increase in the NO_3-N loading levels. The rise in 1973 lagoon NO_3-N concentrations coupled with the larger amounts of irrigation water resulted in a three-fold rise in NO_3-N loading. Of the Total N applied to the Middleville site in 1972, 10% was in the NO_3-N form. In 1973, 30% of the Total N loading was in the highly mobile NO_3-N form.

Ground Water Recharge

To interpret the trends in the movement of nitrogen and phosphorus in the soil water beneath the red pine stand at Middleville, it is necessary to compute the water budget utilizing Thornthwaite's Potentital Evapotranspiration Formula (Thornthwaite and Mather, 1957). Table 3 contains computations used to obtain an estimated ground water recharge moving past the

Table 3. Calculation of ground water recharge according to Thornthwaite's Water Budget Method at the 60 cm depth in plots receiving 25 mm/week of wastewater irrigation, 1973.

Water Budget Factor	Month - 1973						
	Apr	May	June	July	Aug	Sept	Oct
Mean monthly Temp. (T_m) - °C	8.6	12.5	21.3	22.6	22.7	17.8	13.2
Heat Index (I)	2.27	4.00	8.97	9.82	9.88	6.84	4.35
Unadjusted Daily Potential Evapotranspiration (PE) - mm	1.1	1.8	3.4	3.7	3.7	2.8	1.9
Latitude Correction Factor (LCF) - 12 hr. units	33.6	37.8	38.4	38.7	36.0	31.2	28.5
Monthly Potential Evapotranspiration (PE) - mm	37	68	131	143	133	87	54
Monthly Rainfall (P_r) - mm	54	38	26	31	60	116	70
Monthly Irrigation (P_i) - mm	0	50	100	50	125	100	50
Total Monthly Precipitation (P_t) - mm	54	88	126	81	185	216	120
Net Precipitation (P_t - PE) - mm	17	20	-5	-62	52	129	66
Accumulated Water Loss (AWL) - mm	0	0	-5	-67	0	0	0
Soil Water Storage (SS) - mm	100	100	95	50	100	100	100
Change in Soil Water Storage (ΔSS) - mm	0	0	-5	-45	+50	0	0
Ground Water Recharge (GWR) - mm	17	20	0	0	2	129	66

60 cm lysimeters beneath the plots receiving 25 mm of wastewater/week in 1973. By knowing the estimated mean monthly temperatures (average of temperatures from Grand Rapids and Hastings) and the latitude for Middleville, the heat index (I), unadjusted daily potential evapotranspiration (pe) and latitude correction factor (LCF) are determined using methods described by Thornthwaite and Mather (1957).

The monthly potential evapotranspiration (PE) is the product of pe and LCF. Total monthly precipitation (Pt) is computed using rainfall (Pr) and irrigation loading (Pi). The difference between Pt and PE produces the net precipitation (Pt - PE). If Pt - PE is negative, an accumulated water loss total (AWL) results and remains so until Pt - PE becomes positive again. Soil water storage (SS) is estimated to be 100 mm for the 60 cm soil profile and 200 mm for the 120 cm soil profile. These figures are based on data which list sandy loam soil as having 150 mm of available water per m of soil (Thornthwaite and Mather, 1957). By interpolating and rounding to the nearest multiple of 50 (i.e. 50, 100, 150, 200, 250, etc.) the figures of 100 and 200 mm for the two depths of soil are obtained. Using tables from Thornthwaite and Mather (1957) which give the soil moisture retained in a given soil after different amounts of potential evaportranspiration have occurred, a SS value is determined. When the SS is a maximum, the ground water recharge (GWR) is assumed to be equal to net precipitation. When P_t - PE is negative, GWR is assumed to be zero. As P_t - PE becomes positive again, the excess precipitation is used to satisfy the soil moisture deficit. Once SS is back up to maximum, any remaining P_t - PE is tabulated as GWR.

Ground water recharge computed for the 1972 and 1973 growing seasons is presented in Tables 4A and 4B. Little ground water recharge occurred during the period of April through October under unirrigated conditions. In 1973, only the 88 mm/week irrigation rate produced ground water recharge each month. Applications of 25, 50, and 88 mm/week of wastewater increased the ground water recharge during the growing season at the 60 cm depth by factors of 5, 9, and 16 in 1972 and 14, 41, and 83 in 1973.

Calculations of Nutrient Renovation

Several methods can be used in evaluating the nitrogen and phosphorus renovation which occurred when wastewater irrigation was applied to the Middleville red pine plantation. The ground water recharge method is fairly accurate since it compares the mass of each nutrient applied to the mass passing through the soil profile. The technique assumes knowledge of: (1) the

Table 4. Estimated ground water recharge at two soil depths and four wastewater irrigation rates on a red pine plantation at Middleville, 1972 and 1973.

(A) 1972	Ground Water Recharge							
	60 cm depth				120 cm depth			
Month	0	25	50	88	0	25	50	88
	---------mm----------				----------mm----------			
April	73	73	73	73	73	73	73	73
May	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0
July	0	0	0	83	0	0	0	81
August	0	94	246	464	0	84	249	464
September	0	137	237	389	0	137	237	389
October	15	121	216	373	0	121	216	373
Total	88	425	772	1382	73	415	775	1382

(B) 1973	Ground Water Recharge							
	60 cm depth				120 cm depth			
Month	0	25	50	88	0	25	50	88
	---------mm----------				----------mm----------			
April	17	17	17	17	17	17	17	17
May	0	20	70	146	0	20	70	146
June	0	0	95	247	0	0	95	247
July	0	0	0	64	0	0	0	64
August	0	2	165	367	0	0	165	367
September	0	129	229	381	0	122	229	381
October	0	66	116	192	0	66	116	192
Total	17	235	692	1414	17	225	692	1414

Table 4. Estimated ground water recharge at two soil depths and four wastewater irrigation rates on a red pine plantation at Middleville, 1972 and 1973.

(A) 1972	Ground Water Recharge							
	60 cm depth				120 cm depth			
Month	0	25	50	88	0	25	50	88
	---------mm----------				---------mm----------			
April	73	73	73	73	73	73	73	73
May	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0
July	0	0	0	83	0	0	0	81
August	0	94	246	464	0	84	249	464
September	0	137	237	389	0	137	237	389
October	15	121	216	373	0	121	216	373
Total	88	425	772	1382	73	415	775	1382

(B) 1973	Ground Water Recharge							
	60 cm depth				120 cm depth			
Month	0	25	50	88	0	25	50	88
	---------mm----------				---------mm----------			
April	17	17	17	17	17	17	17	17
May	0	20	70	146	0	20	70	146
June	0	0	95	247	0	0	95	247
July	0	0	0	64	0	0	0	64
August	0	2	165	367	0	0	165	367
September	0	129	229	381	0	122	229	381
October	0	66	116	192	0	66	116	192
Total	17	235	692	1414	17	225	692	1414

monthly irrigation in mm, (2) the average nutrient concentration of the wastewater in mg/l, (3) the monthly ground water recharge in mm, and (4) the mean monthly concentration of soil percolate in mg/l collected in the lysimeters. Using Equation 1, items 1 and 2 are used to compute (A) the wastewater loading for each nutrient form in kg/ha, and items 3 and 4 are used to compute (B) the amount of nutrient carried in the soil water collected in the lysimeters. The percent renovation (C) is calculated by dividing B by A.

A second and more direct method for calculating nutrient renovation would be to compare the concentration of each nutrient form in the lysimeters (item 4 in the Ground Water Recharge Method) with that of the irrigated wastewater (Item 2 in the Ground Water Recharge Method). The percent renovation for this method is computed by dividing Item 2 by Item 4.

A hypothetical comparison of the use of these two methods in estimating wastewater renovation is presented in Table 5. For periods with low ground water recharge (August) the percent renovation calculated by the direct method is considerably lower than that of the other method. During months with high ground water recharge (September), the direct method produces a higher estimate of renovation. It is believed that the ground water recharge method is the most accurate of the two methods since it accounts for the amount of water percolating through the soil profile. A high NO_3-N content in soil water is of no concern if very little of the irrigated water reaches the ground water table. However a moderate NO_3-N level in soil water is significant if the majority of the applied wastewater moves into the ground water aquifer.

Table 5. Comparative computations of hypothetical NO_3-N renovation using the direct and ground water recharge methods for a 25 mm/week irrigation rate.

Parameter	Item	Units	Month	
			August	September
Irrigation	1	mm	125	100
Wastewater Content	2	mg/l	2.0	2.0
Wastewater Loading	A	kg/ha	2.5	2.0
Ground Water Recharge	3	mm	2	129
Lysimeter Content	4	mg/l	1.0	1.0
Lysimeter Loading	B	kg/ha	0.02	1.29
Ground Water Recharge Method Renovation	C	%	99	35
Direct Method Renovation	D	%	50	50

The nutrient renovations at Middleville during 1972 and 1973 for the two soil depths are presented in Tables 6 and 7. These values are used in discussing changes in water quality monitored by the lysimeters.

Table 6. Percent nutrient renovation using the ground water recharge method at 60 cm depth at Middleville, 1972 and 1973.

Month	Rate mm/week	60 cm depth									
		1972					1973				
		NH_3-N	NO_3-N	Organic N	Total N	Total P	NH_3-N	NO_3-N	Organic N	Total N	Total P
		%					%				
Jun	25	--	--	--	--	--	100	100	100	100	100
	50	--	--	--	--	--	86	95	94	94	99
	88	--	--	--	--	--	96	34	94	75	99
Jul	25	100	100	100	100	100	100	100	100	100	100
	50	100	100	100	100	100	100	100	100	100	100
	88	99	86	96	95	99	97	80	97	93	100
Aug	25	95	90	97	96	100	100	100	99	100	100
	50	90	50	94	90	99	56	96	85	85	99
	88	89	91	95	94	100	52	76	79	75	99
Sep	25	94	91	95	95	99	71	90	64	72	97
	50	87	87	97	95	100	50	60	87	77	99
	88	90	93	94	94	100	88	20	87	69	100
Oct	25	95	75	95	94	97	87	80	68	75	97
	50	79	94	63	68	99	57	70	80	51	99
	88	86	93	93	92	100	92	60	83	78	99
Mean	25	98	90	97	96	99	94	95	88	90	99
	50	88	78	87	87	100	67	85	89	83	100
	88	90	91	94	94	100	81	49	87	76	100

Table 7. Percent nutrient renovation using the ground water recharge method at 120 cm depth at Middleville, 1972 and 1973.

Month	Rate mm/week	120 cm depth									
		1972					1973				
		NH_3-N	NO_3-N	Organic N	Total N	Total P	NH_3-N	NO_3-N	Organic N	Total N	Total P
		%					%				
Jun	25	--	--	--	--	--	100	100	100	100	100
	50	--	--	--	--	--	57	47	95	88	94
	88	--	--	--	--	--	84	87	94	91	98
Jul	25	100	100	100	100	100	100	100	100	100	100
	50	100	100	100	100	100	100	100	100	100	100
	88	90	94	97	97	100	95	89	94	98	100
Aug	25	93	0	91	76	99	100	100	100	100	100
	50	93	25	91	85	97	0	72	89	78	97
	88	91	91	95	94	99	74	62	90	81	99
Sep	25	83	0	84	73	99	57	45	95	93	98
	50	87	12	91	89	93	50	65	77	71	99
	88	93	89	92	92	99	92	6	53	44	99
Oct	25	88	75	89	88	97	0	0	95	92	98
	50	79	81	85	90	86	71	80	70	85	97
	88	93	93	93	93	99	67	74	71	72	98
Mean	25	91	0	90	82	99	87	64	98	97	99
	50	89	47	91	89	93	40	64	87	81	97
	88	92	92	94	94	99	82	59	81	76	99

Nitrogen

60 cm: 25 mm/Week

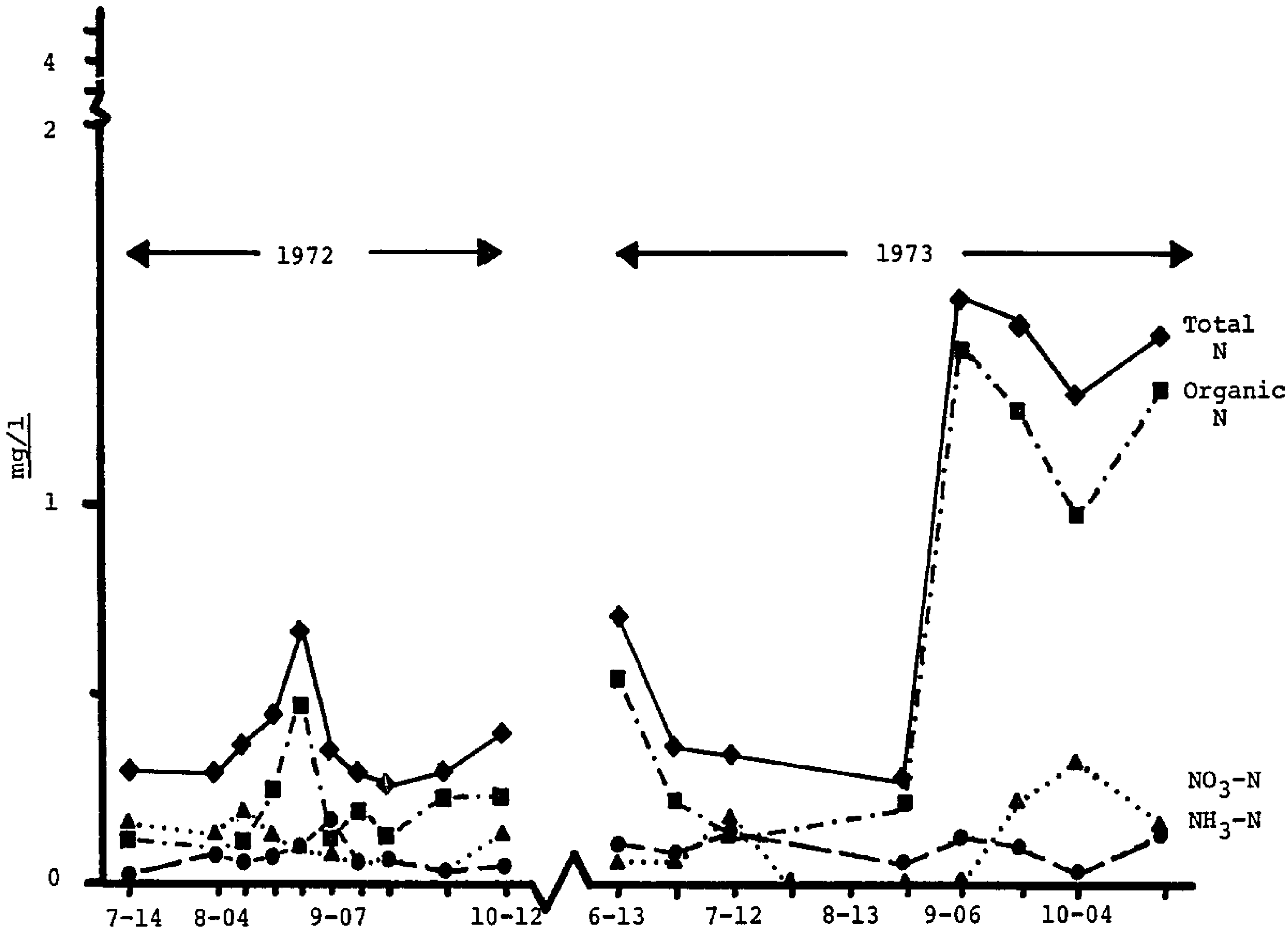
Average concentrations of NH_3-N, NO_3-N, Organic N and Total N at the 60 cm depth for the 25 mm/week treatments are shown in Figure 16. In 1972, both the NH_3-N and NO_3-N forms were relatively stable with average renovations of 98 and 90% respectively. All NO_3-N levels were below 0.2 mg/l. The Organic N concentration rose in late August, but the renovation for the year remained high at 97%. Total N renovation was 96%.

Nitrogen renovations in 1973 were generally lower than in 1972. NH_3-N levels remained stable and very similar to those of the previous year, but renovation dropped slightly to 94%. NO_3-N exhibited the only increase in renovation by rising to 95%. Organic N and Total N showed lower renovations of 88 and 90% respectively. A relatively large peak in Organic N, which occurred in early September, accounted for the lower Total N renovation. The high Organic N levels coincided with the resumption of ground water recharge (Table 4).

60 cm: 50mm/Week

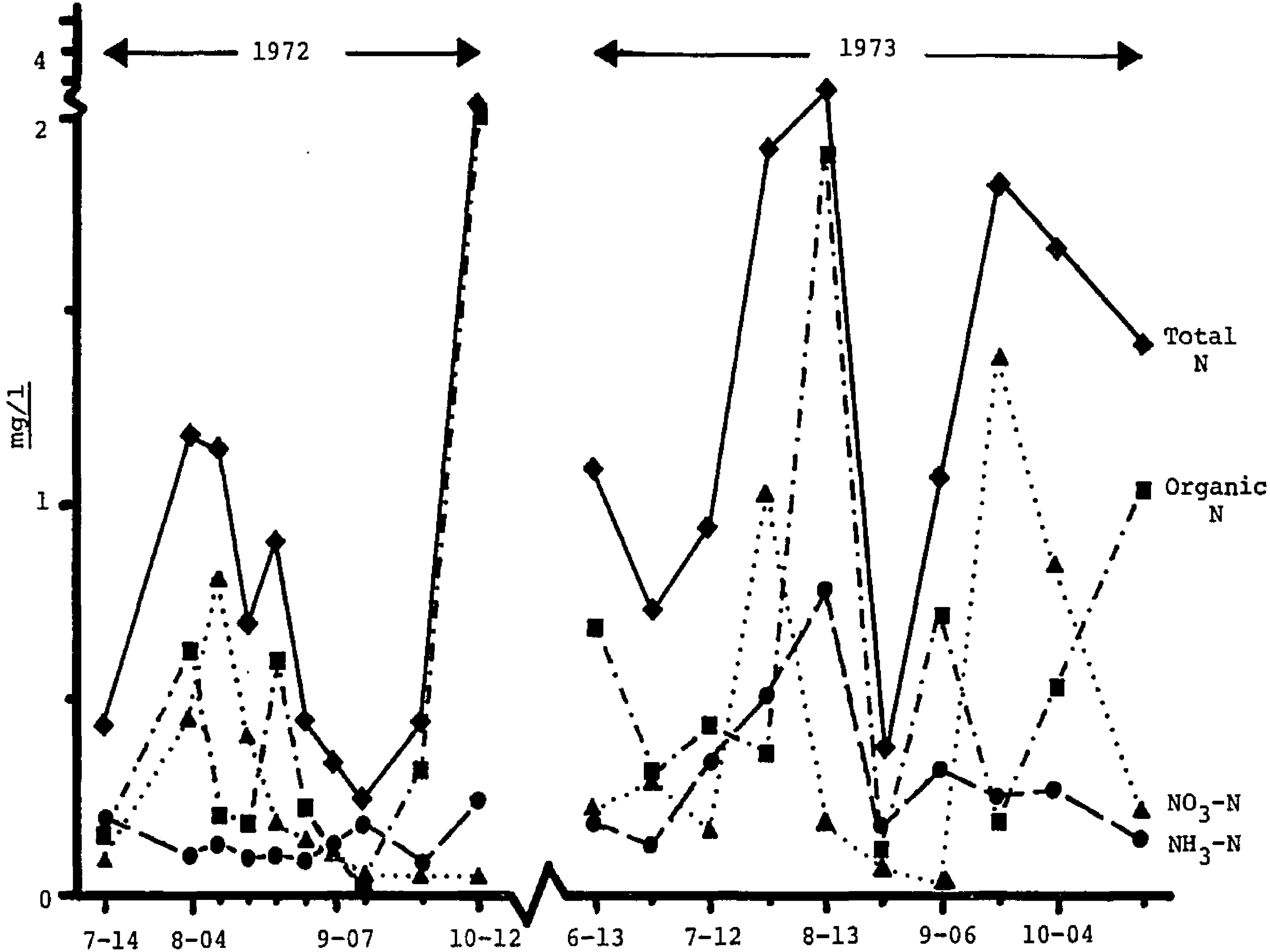
Figure 17 shows the average concentrations of NH_3-N, NO_3-N, Organic N, and Total N in lysimeters at the 60 cm depth for the 50 mm/week irrigation rate.

Figure 16. NH_3-N, NO_3-N, Organic N, and Total N concentrations at the 60 cm depth for the 25 mm/week irrigation rate at Middleville, 1972 and 1973.



4
2
1
0
mg/1
1972
1973
Total N
Organic N
NO3-N
NH3-N
7-14
8-04
9-07
10-12
6-13
7-12
8-13
9-06
10-04

Figure 17. NH_3-N, NO_3-N, Organic N, and Total N concentrations at the 60 cm depth for the 50 mm/week irrigation rate at Middleville, 1972 and 1973.



1972
1973
4
2
1
0
mg/1
Total N
Organic N
NO_3-N
NH_3-N
7-14
8-04
9-07
10-12
6-13
7-12
8-13
9-06
10-04

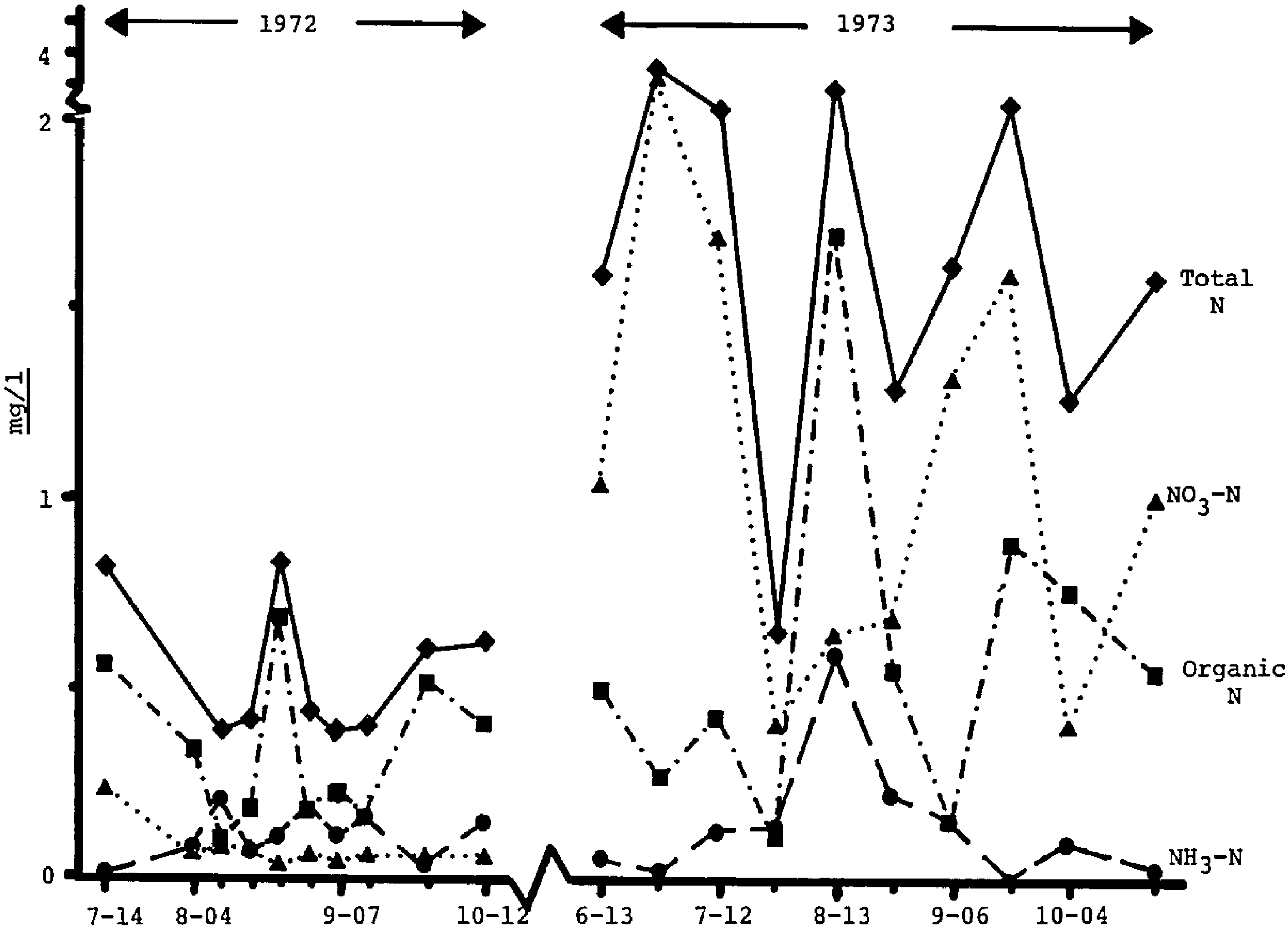
NH_3-N values were relatively uniform throughout 1972. Renovation was at an acceptable level of 88%. NO_3-N renovation during 1972 averaged about 12% lower than the 25 mm/week irrigation rate at 78%. NO_3-N climbed steadily to a peak of about 0.8 mg/l in early August and then declined quite rapidly. Both the Organic N and Total N renovations averaged 87% in 1972. The high Organic N level on October 12th represented an erratic value in one plot. Lysimeters in plots of the other two treatments did not exhibit similarly high values.

In 1973, the renovation efficiency for NH_3-N dropped off considerably to 67%. This was due primarily to a rise in NH_3-N levels between July 7th and August 13th. NO_3-N renovation for 1973 (85%) improved over that of 1972 despite two peaks above 1.0 mg/l. The 1973 Organic N renovation improved slightly to 89%. Total N renovation decreased to 83% due to the combined effects of rises in the NH_3-N, NO_3-N, and Organic N forms.

60 cm: 88 mm/Week

Graphs of the levels of NH_3-N, NO_3-N, Organic N, and Total N found soil water taken from lysimeters buried at 60 cm under plots receiving 88 mm/week of wastewater irrigation are shown in Figure 18. During 1972, NH_3-N concentrations were fairly uniform at values less than 0.2 mg/l. Except for the first sampling date, all NO_3-N values were uniformly less than 0.1 mg/l.

Figure 18. NH_3-N, NO_3-N, Organic N, and Total N concentrations at the 60 cm depth for the 88 mm/week irrigation rate at Middleville, 1972 and 1973.


1972
1973
4
2
1
0
mg/1
Total N
NO3-N
Organic N
NH3-N
7-14
8-04
9-07
10-12
6-13
7-12
8-13
9-06
10-04

Renovation of the NH_3-N and NO_3-N forms was quite similar at 90 and 91% respectively. In 1972, Organic N and Total N exhibited trends very similar to those found in the 25 mm/week irrigation rates. Organic N had a high peak of about 0.7 mg/l in late August and accounted for much of the Total N throughout the 1972 irrigation season. However, Organic N renovation averaged 94% for the year. Total N renovation was the same as Organic N.

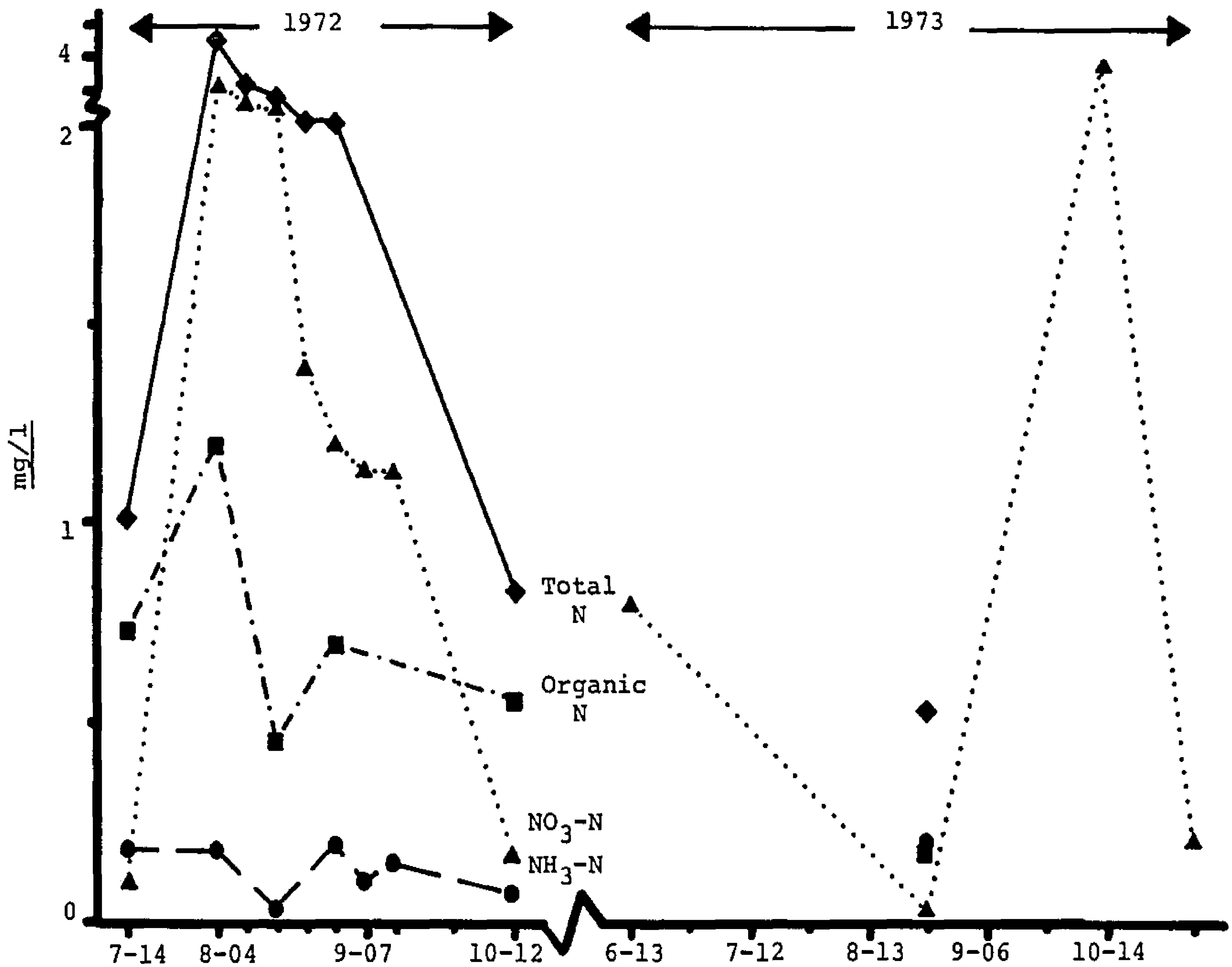
Renovation of the various forms of nitrogen dropped off in 1973 for the 88 mm/week irrigation rate as it did for the other two rates. NH_3-N renovation was 81% in 1973 primarily due to a high level (0.6 mg/l) on August 13th. Organic N renovation fell off 7% to 87%. A high peak (1.7 mg/l) on August 13th coincided with substantial increases in ground water recharge between July and August and probably represented the flushing of wastewater Organic N and litter decay products. The largest drop in renovation was exhibited by NO_3-N. The average NO_3-N renovation in 1973 fell by 42% to a low of 49%. High peaks in the NO_3-N curve in June (over 3 mg/l) and in September (about 1.5 mg/l) accounted for this. These peaks occurred during periods of high ground water recharge (Table 4) and probably represented the flushing of residual NO_3-N through the soil profile. As a result of the reduced renovations in NO_3-N and Organic N, Total N renovation was reduced to 76%. The three distinct Total N peaks in 1973 (Figure 18) were due to pulses of NO_3-N in the first peak, Organic N in the second, and NO_3-N in the third. NO_3-N accounted for nearly 60% (15.1 kg/ha) of the Total N loss (25.5 kg/ha) in the high irrigation rate.

120 cm: 25 mm/Week

Average concentrations of NH_3-N, NO_3-N, Organic N, and Total N at the 120 cm depth for the 25 mm/week irrigation rate are presented in Figure 19. In 1972, NH_3-N levels were relatively stable with renovation averaging 91%. However, NO_3-N was very erratic. Part of this was due to the fact that only one lysimeter produced these data points in 1972. Renovation for NO_3-N in 1972 was zero. While Organic N at the 120 cm depth was more variable than at the 60 cm depth, renovation was still high at 90%. Despite poor NO_3-N renovation, overall removal of Total N was 82%. This was resulted from the fact that NO_3-N loading accounted for a lower proportion of the Total N loading in relation to NH_3-N and Organic N loading.

Since only single data points were available in 1973 for NH_3-N, Organic N, and Total N, rough approximations of the renovations were made using those data points as averages. This procedure was necessitated by the lack of sufficient lysimeter sample volumes

Figure 19. NH_3-N, NO_3-N, Organic N, and Total N concentrations at the 120 cm depth for the 25 mm/week irrigation rate at Middleville, 1972 and 1973.



1972
1973
4
2
1
0
mg/l
Total N
Organic N
NO3-N
NH3-N
7-14
8-04
9-07
10-12
6-13
7-12
8-13
9-06
10-14

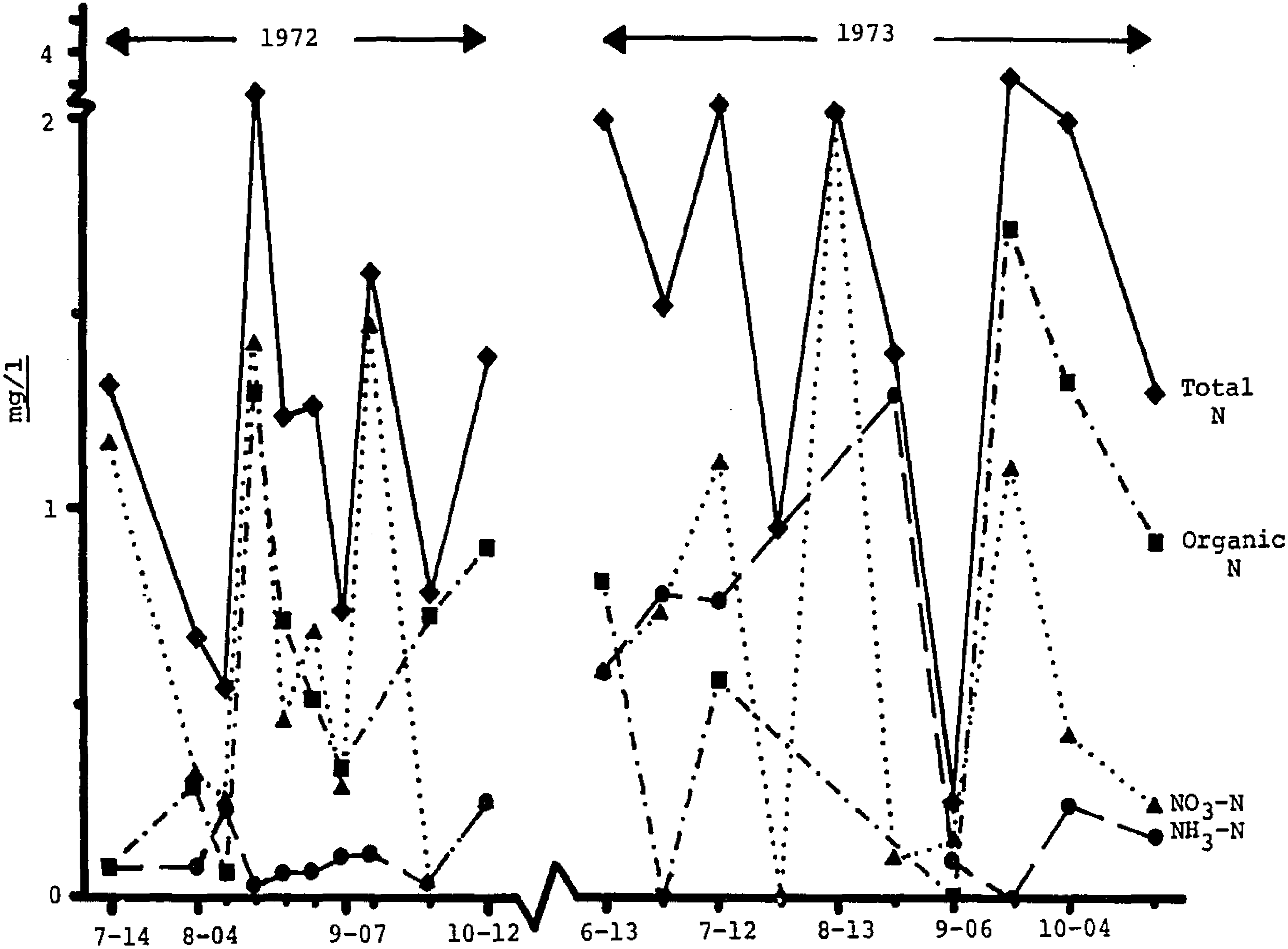
needed to complete the analyses for all nitrogen forms. A more complete picture of the NO_3-N trend was available since sufficient sample volumes were collected on four different dates to test for NO_3-N. Consequently no concise interpretations of the data can be made except to note that NO_3-N did fluctuate considerably from a high of about 3.8 mg/l to a low of 0.02 mg/l.

120 cm: 50 mm/Week

Figure 20 presents the NH_3-N, NO_3-N, Organic N, and Total N trends for the 120 cm depth lysimeters under plots with a 50 mm/week irrigation rate. NH_3-N was relatively stable in 1972 and had an average renovation of 89% for the year. NO_3-N was erratic throughout 1972. A renovation of 47% for NO_3-N was an improvement over that found in plots receiving 25 mm/week, but was less than computed for the same treatment at the 60 cm soil depth. Part of the instability in NO_3-N values was due to the small volumes of samples delivered by one lysimeter out of a replication of three. Organic N levels oscillated quite a bit but overall renovation was good at 91%. The Total N values reflected the peaks in NO_3-N and Organic N, but the renovation was very satisfactory at 89%.

During 1973 the renovation fell off for all nitrogen forms except NO_3-N. NH_3-N exhibited an

Figure 20. NH_3-N, NO_3-N, Organic N, and Total N concentrations at the 120 cm depth for the 50 mm/week irrigation rate at Middleville, 1972 and 1973.



1972
1973
4
2
1
0
mg/1
Total N
Organic N
NO3-N
NH3-N
7-14
8-04
9-07
10-12
6-13
7-12
8-13
9-06
10-04

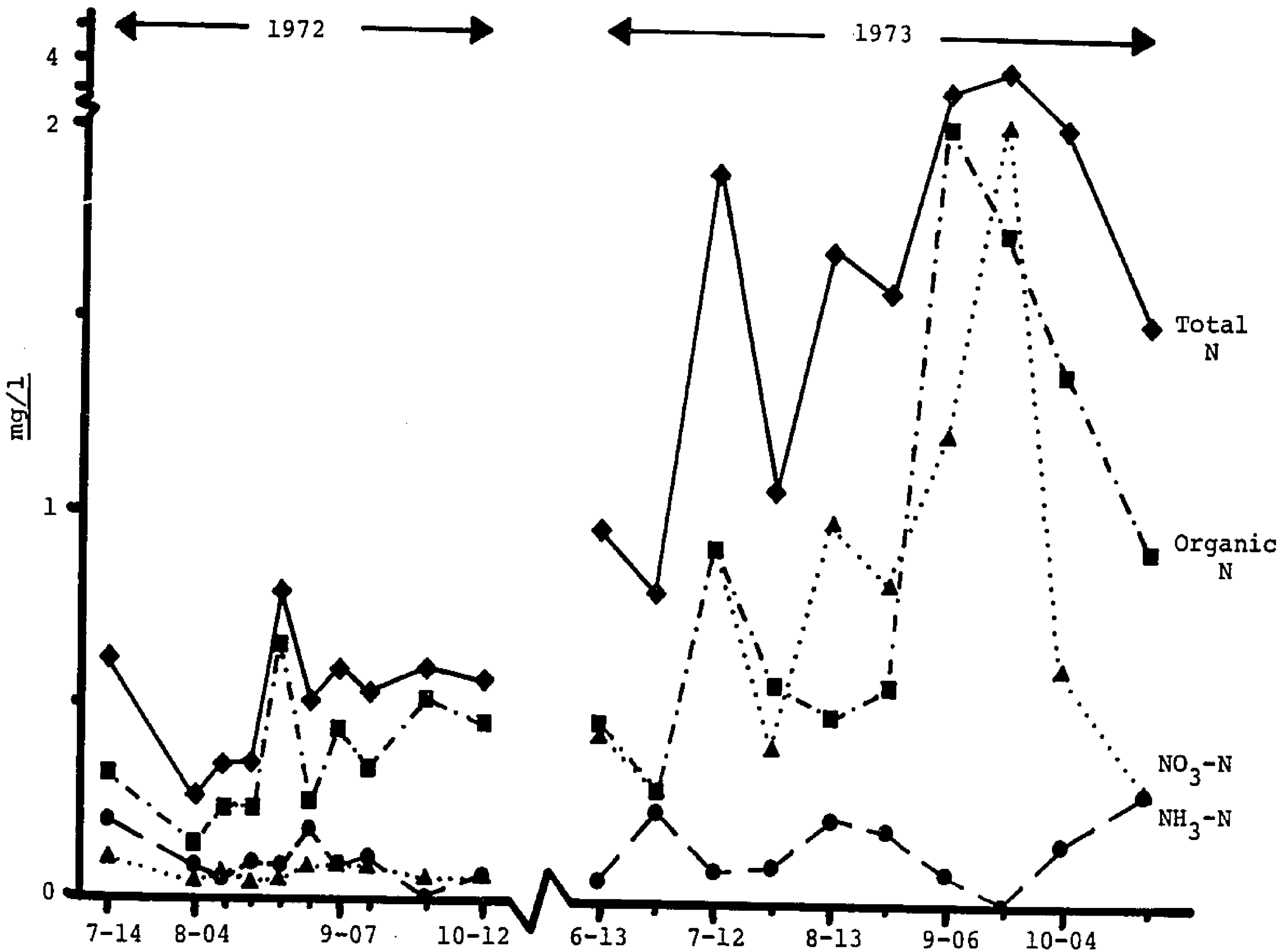
uncharacteristic increase up to 1.3 mg/l in the first part of the irrigation season. Renovation for NH_3-N was low at 40%. NO_3-N continued to show considerable variability (low of 0.0 mg/l and a high of about 2.2 mg/l) but the overall renovation improved by rising to 64%. Organic N renovation remained fairly high at 87%. Total N renovation decreased to 81% as a result of the decreases in Organic N and NH_3-N renovations.

120 cm: 88 mm/Week

The NH_3-N, NO_3-N, Organic N, and Total N renovations for the 120 cm depth and 88 mm/week irrigation rate are presented in Figure 21. NH_3-N and NO_3-N levels in 1972 were stable below 0.2 mg/l with renovations of 92%. Organic N concentrations were higher than either NH_3-N or NO_3-N that same year but the overall renovation for it and Total N was high at 94%.

In 1973 the renovations for all nitrogen forms declined. While NH_3-N levels increased only slightly, the average renovation dropped to 82%. NO_3-N suffered the largest decrease in renovation (92 to 57%). The poor NO_3-N renovation in 1973 resulted from the peak in September which accompanied high ground water recharge. Organic N renovation decreased only slightly to 87% despite high concentrations in September. The lower Total N renovation (76%) reflected the decreases in the other three forms of nitrogen. It is interesting to

Figure 21. NH_3-N, NO_3-N, Organic N, Total N concentrations at the 120 cm depth for the 88 mm/week irrigation rate at Middleville, 1972 and 1973.


1972
1973
4
2
1
0
mg/1
7-14
8-04
9-07
10-12
6-13
7-12
8-13
9-06
10-04
Total N
Organic N
NO3-N
NH3-N

to note that while Organic N applied to the red pine site was twice that of NO_3-N, the nitrogen losses for each form were almost identical.

Nitrogen Summary

From the data presented, the major problem in applying municipal wastewater to the red pine plantation is nitrogen in the form of NO_3-N. This problem may likely be directly related to the hourly rate of irrigation and not the total weekly application. All three weekly levels of wastewater are applied over the same eight-hour time period. Thus the 25, 50, and 88 mm/week irrigation loadings occur at rates of 3, 6, and 11 mm/hour.

An application rate of 11 mm/hour would tend to cause more NO_3-N flushing than one of 3 mm/hour. Water can easily infiltrate into the soil at rates greater than 11 mm/hour (Lull and Reinhart, 1972), but wastewater moving through the soil at such high hourly rates allows very little time for NO_3-N uptake by plants or denitrification by microorganisms before it reaches the lysimeter depths. Therefore it becomes difficult to compare the three irrigation treatments because it is impossible to differentiate whether the reduced NO_3-N renovation for the 88 mm/week irrigation rate, as measured by suction lysimetry, is due to the total amount of nitrogen loading or the hourly rate at which the wastewater is applied.

NH_3-N and Organic N had acceptable renovation levels at all three irrigation rates throughout the study. Improved NO_3-N renovation might be obtained at the high rates of irrigation by limiting the hourly rate to 3 mm/hour.

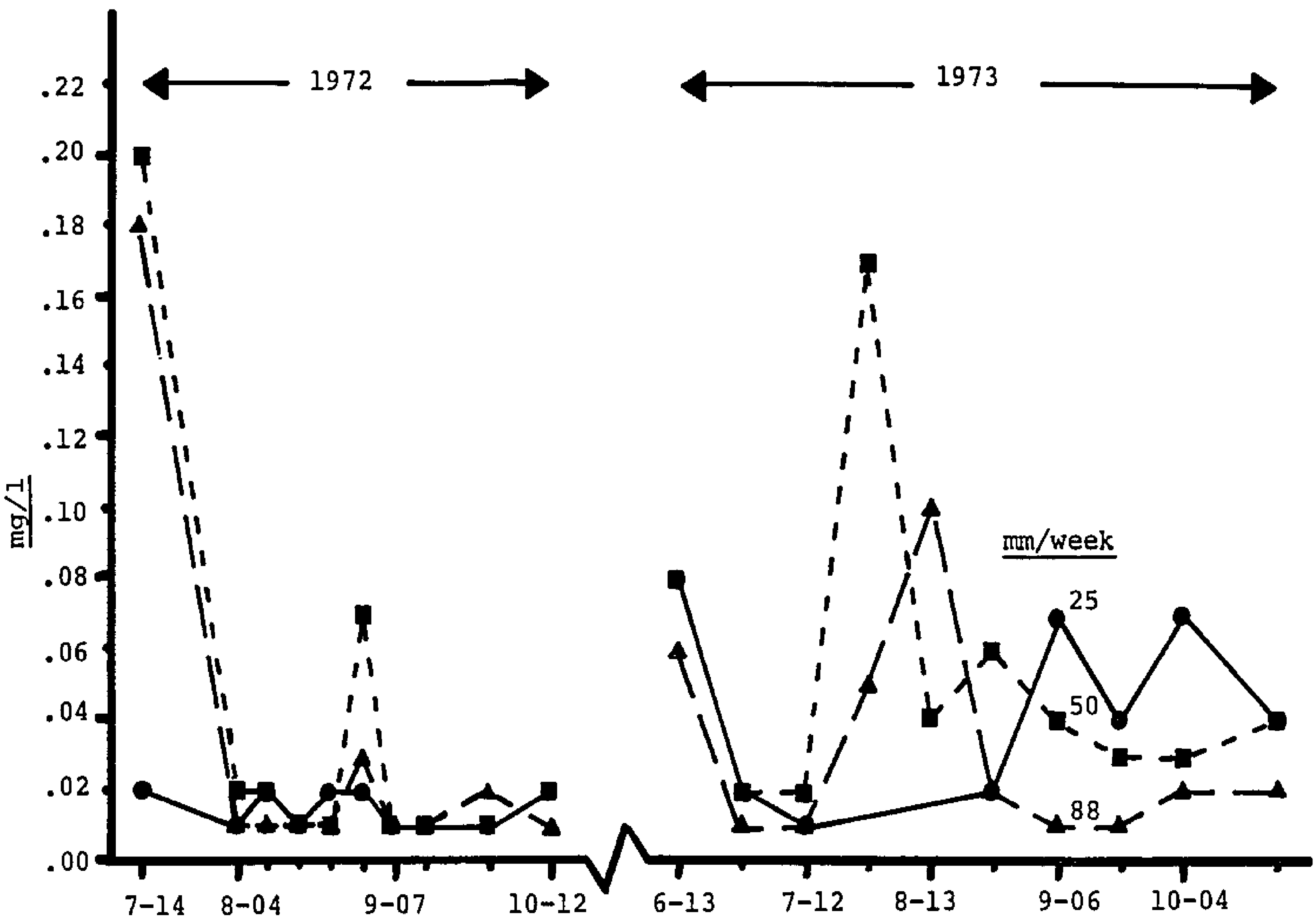
Total Phosphorus

Total P values at the 60 cm depth were variable in 1972 and exhibited several high peaks in 1973 (Figure 22). However, the average Total P renovation was 99, 100, and 100% during 1972 and 1973 for the 25, 50, and 88 mm/week irrigation rates. This represented an excellent Total P renovation. At the 120 cm depth considerable variations in Total P took place (Figure 23), but renovation at this depth during 1972 and 1973 was around 99%.

Red Pine Foliar Nutrients

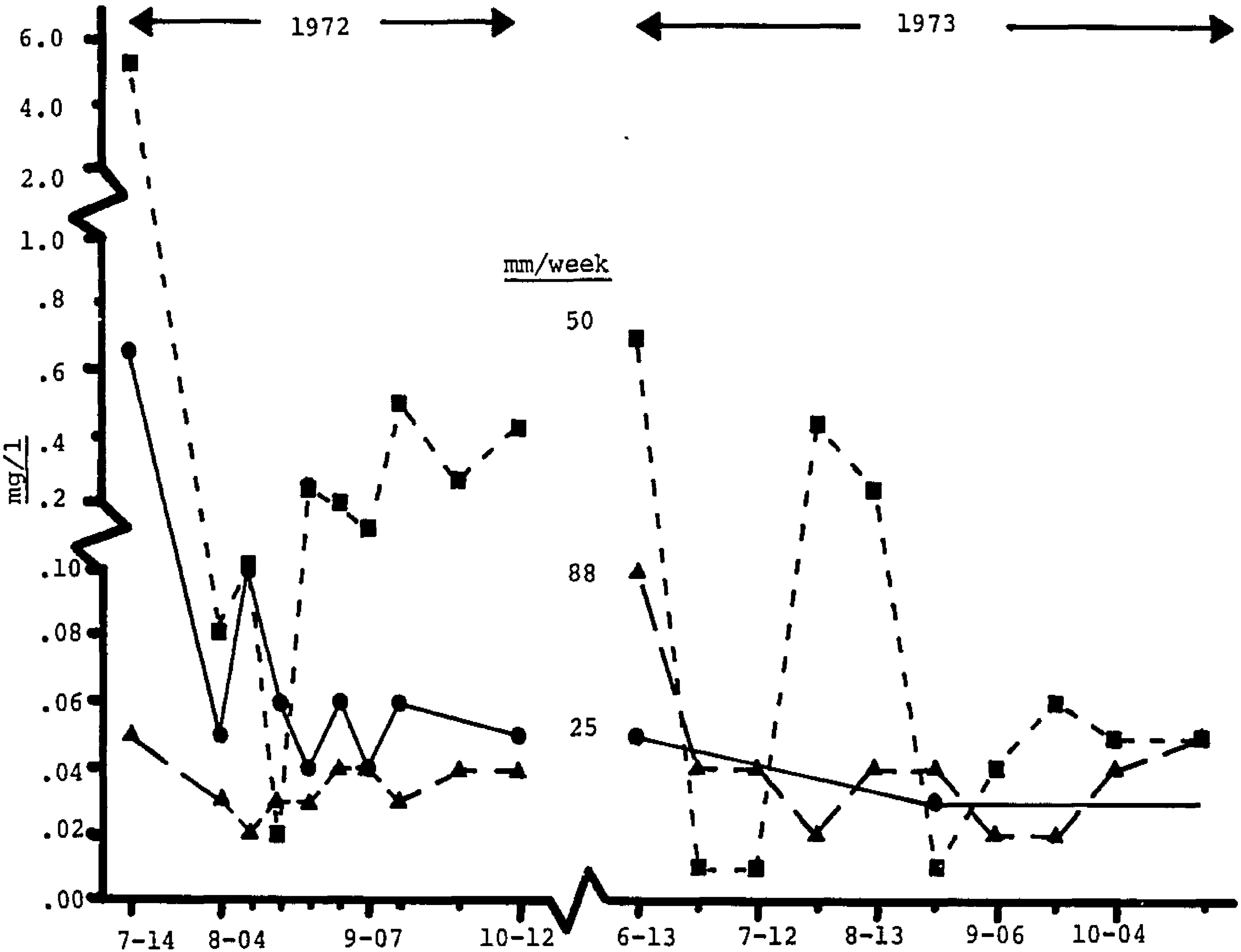
Foliage samples were collected from the upper one-third of the red pine crowns in early December of 1972 and mid-November of 1973 to determine if the different rates of wastewater application were affecting nutrient uptake. When evaluating the nutrient balance of trees, several factors have to be considered. First,

Figure 22. Total P concentrations at the 60 cm depth at Middleville, 1972 and 1973.



1972
1973
mg/l
.22
.20
.18
.16
.14
.12
.10
.08
.06
.04
.02
.00
mm/week
25
50
88
7-14
8-04
9-07
10-12
6-13
7-12
8-13
9-06
10-04

Figure 23. Total P concentrations at the 120 cm depth at Middleville, 1972 and 1973.



1972
1973
mg/1
6.0
4.0
2.0
1.0
.8
.6
.4
.2
.10
.08
.06
.04
.02
.00
mm/week
50
88
25
7-14
8-04
9-07
10-12
6-13
7-12
8-13
9-06
10-04

the nutrient content varies by the tree component, with the concentration per gram of dry weight decreasing in the order of foliage, bark, branches, stem, and root (Nelson *et al.*, 1970). Also, the greatest elemental concentration existing in the foliage occurs in the crown extremities (Young and Guinn, 1966). Thus, needles from the crown top become the most sensitive indicators of changes in nutrient status.

Tree stems accumulate the greatest mass of elements in a forest stand despite their lower percent composition. This is a direct result of their greater stem to foliage ratio. While the annual nutrient return in a coniferous forest is about 3 to 6% of the total amount incorporated, this return is, however, predominantly from the foliage. These nutrients are present in amounts indicating the following descending order of concentrations: nitrogen, calcium, potassium, phosphorus, and sodium (Rodin and Bazilevich, 1967).

A check on the analytical procedures was accomplished by utilizing an internal reference standard of red pine foliage. The reference standard analyses made during 1972 and 1973 are presented in Table 8. The elements which varied to any extent over the two-year period were sodium, calcium, iron, zinc, and aluminum. A change in the calibration curves for the Horticulture Plant Analysis Laboratory mass spectrograph which occurred between the 1972 and 1973 determinations may have accounted for the observed deviations. The calcium levels for the reference standard were about three to eight times lower than normal. No explanation for this phenomenon can be offered. However, calcium percentages for the actual tissue samples were within expected ranges. Data for calcium and the other elements which exhibited variations between the 1972 and 1973 standard analyses can still be used to indicate treatment differences within each study year.

Table 8. Internal reference standards of red pine for nutrient analyses, 1972 and 1973.

Year	N	K	P	Na	Ca	Mg
	%	%	%	ppm	%	%
1972	1.18	0.39	0.14	63.4	0.03	0.10
1973	1.18	0.44	0.14	171.0	0.07	0.09
Year	Mn	Fe	Cu	B	Zn	Al
	ppm	ppm	ppm	ppm	ppm	ppm
1972	158.8	13.2	0.1	10.4	5.8	278
1973	133.0	34.0	0.1	10.3	11.7	152

When comparing the results of independently run nutrient analyses, it should be remembered that element concentrations may vary between different tree components, periods of the year, years, and soil types. The red pine foliage nutrient analyses for 1972 and 1973 are shown in Tables 9 and 10.

Table 9. Nitrogen, potassium, phosphorus, calcium, and magnesium concentrations of red pine foliage for varying rates of wastewater irrigation, Middleville, 1972 and 1973.

Element	Year	Wastewater Irrigation in mm/week			
		0	25	50	88
		----------% of dry weight----------			
N	1972	1.15 a[1]	1.18 a	1.22 a	1.23 a
	1973	1.33 w	1.44 w	1.66 w	1.70 x
K	1972	0.54 a	0.64 a	0.64 a	0.67 a
	1973	0.47 w	0.52 wx	0.52 wx	0.54 x
P	1972	0.18 a	0.19 a	0.19 a	0.18 a
	1973	0.22 w	0.22 w	0.22 w	0.19 w
Ca	1972	0.21 a	0.21 a	0.23 a	0.13 a
	1973	0.21 w	0.23 w	0.21 w	0.19 w
Mg	1972	0.09 a	0.10 a	0.09 a	0.10 a
	1973	0.12 w	0.13 w	0.13 w	0.13 w

[1]Means not followed by the same letter are significantly different at the 5% level (Tukey's test).

Table 10. Sodium, magnesium, iron, copper, boron, zinc, and aluminum concentrations of red pine foliage for varying rates of wastewater irrigation, Middleville, 1972 and 1973.

Element	Year	Wastewater Irrigation in mm/week 0	25	50	88
		ppm of dry weight[2]			
Na	1972	58.3 a[1]	80.6 a	77.8 a	74.7 a
	1973	202.9 w	264.3 w	381.2 w	277.2 w
Mn	1972	480.8 a	474.4 a	465.9 a	450.1 a
	1973	768.8 w	800.1 w	718.5 w	557.7 w
Fe	1972	20.2 a	26.0 a	16.2 a	13.5 a
	1973	78.7 w	59.4 w	58.6 w	54.8 w
Cu	1972	0.1 a	0.1 a	0.1 a	0.1 a
	1973	0.2 w	0.2 w	0.2 w	0.2 w
B	1972	22.1 a	28.1 ab	27.1 ab	33.4 b
	1973	27.0 w	54.9 x	66.4 xy	75.2 y
Zn	1972	11.3 a	11.8 a	11.1 a	9.1 a
	1973	22.8 w	19.5 w	17.2 w	17.2 w
Al	1972	379.6 a	391.5 a	336.2 a	331.9 a
	1973	545.7 w	355.0 x	256.7 xy	106.2 y

[1]Means not followed by the same letter are significantly different at the 5% level (Tukey's test).

[2]ppm = μg/g

In 1972 elements exhibiting concentration increases related to the rate of wastewater application were nitrogen, potassium, and boron. Nitrogen increased from 1.15% at the 0 mm rate to 1.23% for the 88 mm rate. Potassium had an increase from 0.54% to 0.67% over the same range of irrigation rates. None of these differences between irrigation treatments were significant. However, the increase in boron from 22.1 to 33.4 ppm with higher rates of irrigation was significant.

Of the remaining elements, phosphorus, sodium, calcium, magnesium, iron zinc, and aluminum had no distinct trends related to irrigation. Copper was uniform over the four irrigation rates, while manganese exhibited a decreasing concentration with increased wastewater irrigation.

The 1973 nutrient data indicate that many trends established during the 1972 irrigation season continued. Again, phosphorus and calcium showed no distinct patterns. Concentrations of sodium and magnesium, variable in 1972, exhibited clear increases up to 50 mm/week of wastewater irrigation and then decreases with the 88 mm rate. This indicates that an optimum nutrient uptake efficiency probably occurred at 50 mm/week. Decreases in nutrient concentration with increases in wastewater application were evident for manganese, iron, zinc, and aluminum. The copper content of the foliage was constant across the range of irrigation rates. Nitrogen, potassium, and boron continued to increase in concentration with increases in irrigation rate. Significant treatment differences for these elements and aluminum are illustrated in Figure 24.

Boron

The foliar boron content increased dramatically since 1972. While control trees remained fairly constant, varying only 5 ppm from 22 to 27 ppm, the 75.2 ppm boron in needles of trees receiving 88 mm of wastewater/week was 300% greater than that of the controls. All three levels of irrigation produced boron concentrations significantly greater than found in the nonirrigated trees.

Stone and Baird (1956) reported toxicity symptoms in red pine containing more than 45 ppm boron in the foliage. Sopper and Kardos (1973) noticed toxicity problems in red pine after six years of irrigation. They measured boron levels of 23, 28, and 33 ppm in the foliage of trees receiving 0, 25, and 50 mm of wastewater/week. Toxicity symptoms (necrosis of the terminal 1-2 cm of the needles) were first observed in the red pine at Middleville in late May of 1974 (Figure 25). Injury was most evident on needles at

Figure 24. Red pine foliage nutrients exhibiting significant differences between wastewater irrigation rates: (A) boron, (B) potassium, (C) aluminum, and (D) nitrogen.

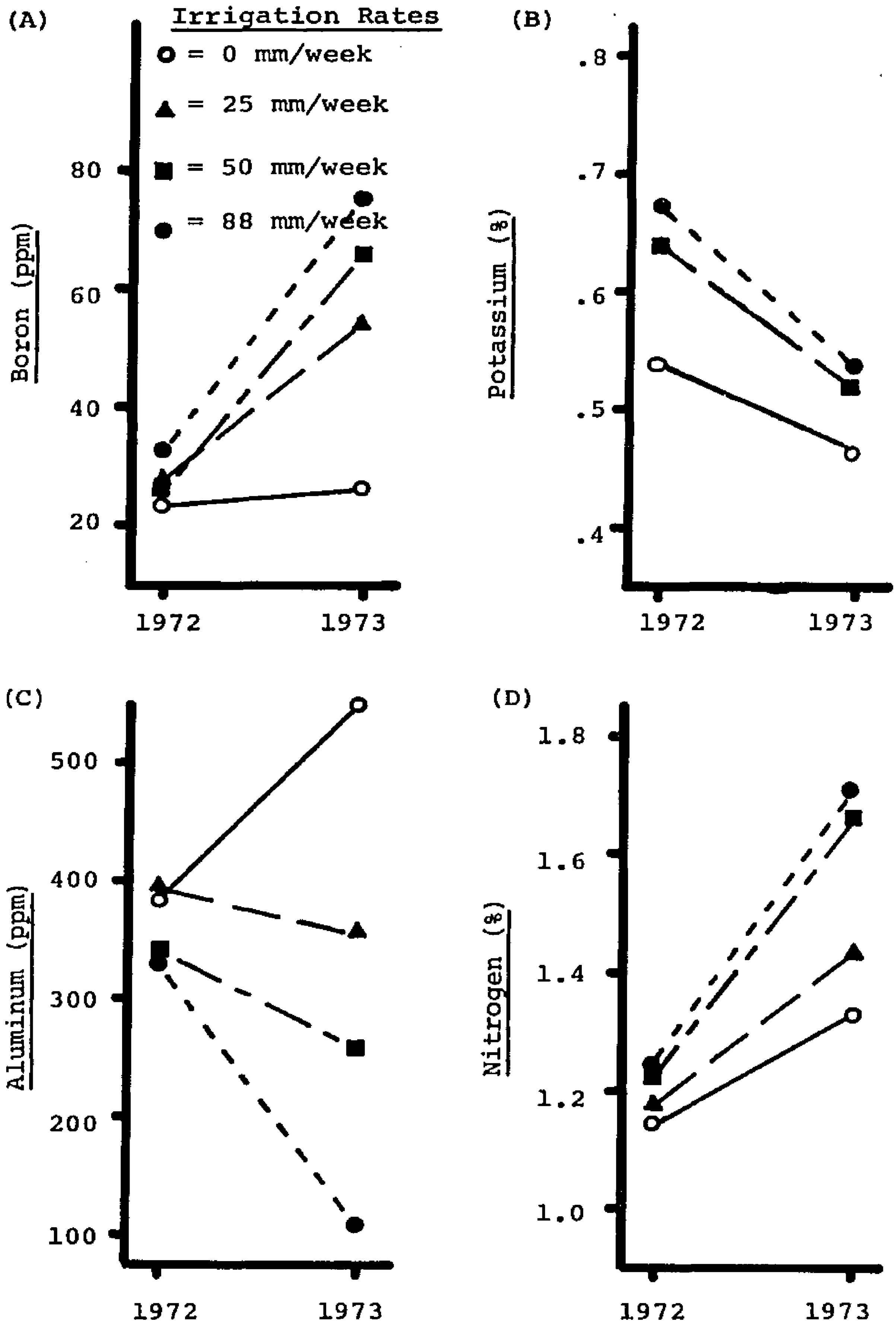
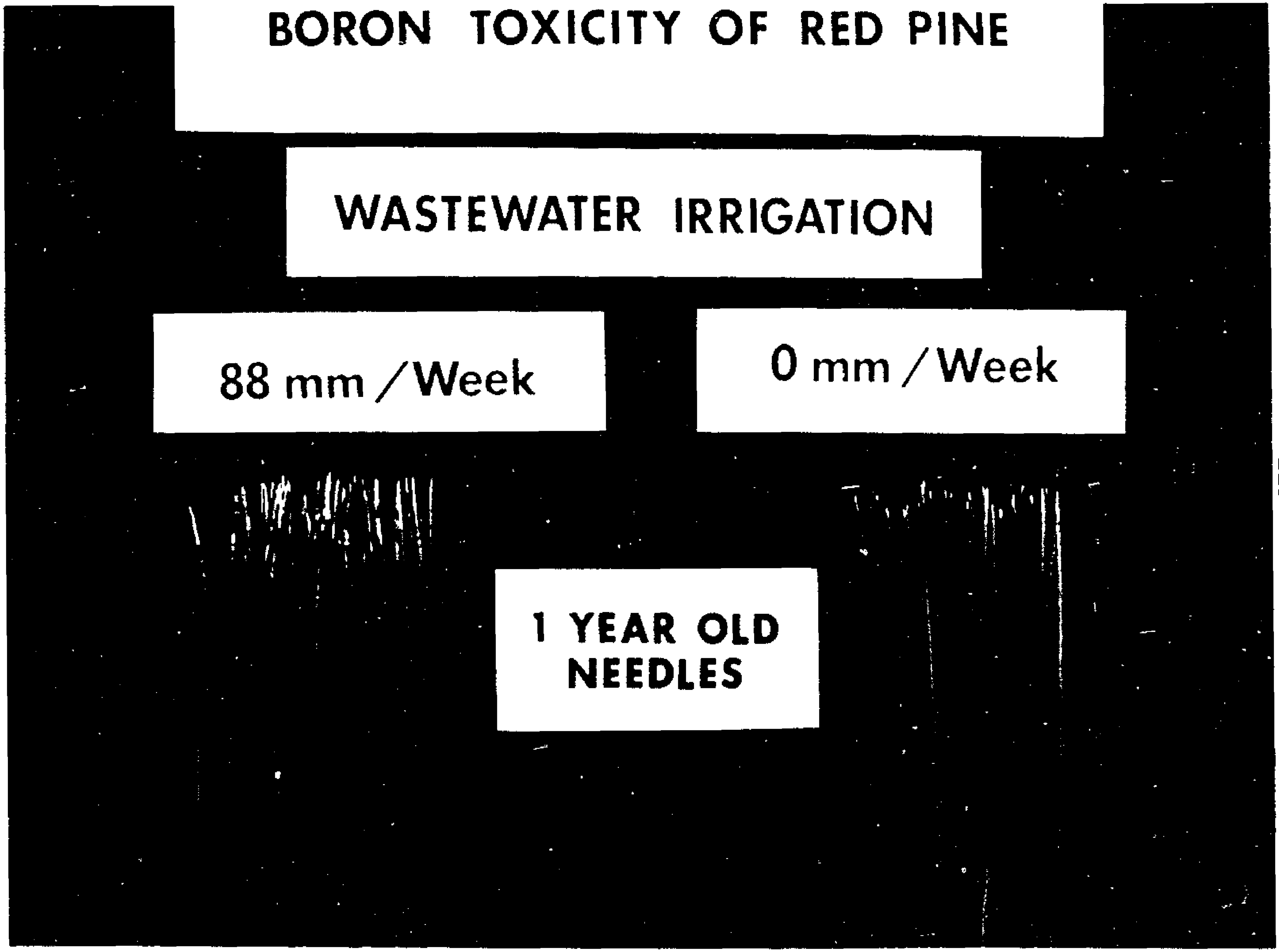

(A)
Irrigation Rates
○ = 0 mm/week
▲ = 25 mm/week
■ = 50 mm/week
● = 88 mm/week
Boron (ppm)
20
40
60
80
1972
1973
(B)
Potassium (%)
.4
.5
.6
.7
.8
1972
1973
(C)
Aluminum (ppm)
100
200
300
400
500
1972
1973
(D)
Nitrogen (%)
1.0
1.2
1.4
1.6
1.8
1972
1973

Figure 25. Necrosis of red pine needles showing boron toxicity induced by wastewater irrigation at Middleville.


BORON TOXICITY OF RED PINE
WASTEWATER IRRIGATION
88 mm / Week
0 mm / Week
1 YEAR OLD NEEDLES

the extremities of the crown. While toxicity symptoms were most acute in needles developed in 1973, they were also noticeable as a slight yellowing on the tips of newly developing needles. It is yet to be determined what physiological effects this will have. Sensitivity to boron toxicity could ultimately eliminate red pine as a tree species suitable to high rates of wastewater irrigation.

Potassium

The potassium content of the red pine foliage decreased in 1973, but was higher in the irrigated plots. The 0.54% potassium found in the 88 mm/week plots was significantly greater than that of control trees at 0.47%. The potassium values in 1972 were somewhat similar, but not significantly so.

Potassium values reported by Sopper and Kardos (1973) for wastewater irrigated red pine differ considerably from those reported here. They found potassium concentration to decrease with increased irrigation. However, the method of application of wastewater also differed. The red pine at Penn State were irrigated from above the crown while those at Middleville were irrigated from below the crown. Thus, the overhead irrigation waters probably leached excess potassium from the needles, thereby reducing foliar concentrations.

Aluminum

The aluminum concentration of the red pine foliage changed radically from 1972 to 1973. While the aluminum content increased in trees receiving no wastewater irrigation, it dropped sharply for those trees receiving 88 mm/week. The 106.2 ppm aluminum in the highest irrigation rate was significantly lower than the 545.7 and 355.0 ppm in the control and 25 mm/week treatments, respectively. All three irrigation treatments produced foliage with aluminum levels lower than that of the controls. This decrease in foliage aluminum is associated with changes in soil pH (see section on soil chemistry). After two years of irrigation soil pH of the upper 30 cm went from 5.5 in the control plots to 6.1, 6.6, and 7.4 in the 25, 50, and 88 mm/week irrigation plots, respectively. Aluminum solubility is highest in acid soils and rapidly approaches zero as soil pH increases to pH 7. Low foliar aluminum levels thus resulted from the insolubility of aluminum brought about by an increase in pH. Sopper and Kardos (1973) experienced similar aluminum decreases at Penn State. The red pine foliage there had 444, 142, and 97 ppm aluminum for the 0, 25, and 50 mm/week irrigation rates, respectively.

Nitrogen

Foliar nitrogen levels exhibited considerable response to wastewater irrigation. Nitrogen concentrations in the foliage of irrigated trees in 1972 were not significantly greater than the control trees. By the end of the 1973 irrigation season the foliage nitrogen levels in the two highest irrigation rates (1.70% and 1.66%) were significantly higher than those of the control and 25 mm/week irrigation rate (1.33% and 1.44%). The red pine thus responded favorably to irrigation by absorbing considerable quantities of nitrogen found in the wastewater. Similar responses by red pine have been reported by Sopper and Kardos (1973).

Red Pine Growth Responses

The 20-year-old un-thinned red pine plantation utilized in this wastewater renovation study had a spacing of 2.4 x 2.4 m, and an average basal area of 7.5 m^2/ ha. Mean tree height and DBH were 11.6 m and 14.8 cm respectively.

Growth responses to weekly irrigation rates during 1972 and 1973 are presented in Table 11.

Needle Length

The average needle length for the red pine stand in 1972 was 144.9 mm with no significant differences between irrigation rates. The late start in the irrigation schedule (July 15) probably accounts for this. Red pine has a determinate growth pattern whereby most of the growth occurs during June and early July (Neary _et al._, 1972). Little foliage growth thus occurred during mid-July to September despite irrigation.

Table 11. Average red pine needle growth with varying wastewater irrigation rates, Middleville, 1972 and 1973.

Parameter	Year	mm of wastewater irrigation/week			
		0	25	50	88
Needle length (mm)	1972	142.6 a[1]	146.0 a	155.0 a	136.2 a
	1973	121.0 w	136.4 wx	154.9 xy	164.4 y
Dry Weight per fascicle (mg)	1972	68.67 a	64.17 a	64.46 a	62.19 a
	1973	68.97 w	74.76 wx	95.23 xy	107.40 y
Terminal Bud Length (mm)	1972	26.6 a	24.0 a	23.7 a	24.2 a
	1973	28.2 w	24.5 x	27.8 w	30.2 w

[1]Means not followed by the same letter are significantly different at the 5% level (Tukey's test).

In 1973, however, there were significant differences in needle growth which related to irrigation rate. Needle lengths increased 12, 28, and 36% over control plots with increasing irrigation levels, going from 121.0 mm for the nonirrigated trees to 164.4 mm for trees receiving the greatest amounts of wastewater. The decrease in needle length for control trees from 1972 to 1973 is attributed to the low rainfall in

June, 1973, (26.9 mm) compared to that of June, 1972, (110.5 mm) which is close to the 30-year mean for June (100 mm).

Branch Buds

Branch terminal bud lengths exhibited no significant variations in 1972 which could be related to irrigation. In 1973, trees receiving 25 mm of wastewater/week had significantly smaller terminal buds. It is unlikely that this was related to amounts of irrigation since similar reductions were not evident at higher irrigation rates. Branch terminal bud length does not appear to be a good indicator of red pine response to irrigation. Main stem terminal bud length, however, has been reported to be a more sensitive indication of irrigation response (Clements, 1970). However this technique is feasible only with small trees.

Dry Weight per Fascicle

Growth trends in the dry weight per fascicle parallel that of needle length. No significant variations from the mean of 64.87 mg/fascicle were evident in 1972. The 1973 data show that the average needle dry weight increased by 8, 38, and 56% over controls with application of 25, 50, and 88 mm of sewage effluent. The significant differences occurred between the two highest irrigation rates and the control. The 88 mm/week plots were also significantly higher than the 25 mm/week plots.

The increase in both needle dry weight and length in trees irrigated with wastewater suggests potential increases in photosynthetic capability and nutrient uptake capacity. This increase in total energy fixation could be expressed in greater height and/or diameter growth which would in turn increase the capacity for red pine to tie up excess wastewater nutrients.

Diameter Increment

The mean DBH increments tabulated from all trees during the 1973 growing season are shown in Table 12. The average height increments of 15 sample trees per treatment are included for reference. No significant trend in DBH increment has yet appeared but may in subsequent years.

Monthly increases of DBH during 1973 by irrigation rate are given in Table 13. Circumference growth was monitored by band dendrometers and it appears that wastewater irrigation prolonged the period of diameter increment. Greatest increment took place in May and June for the controls and July and August for the irrigated plots. Although no statistically significant differences were present in mean circumference growth,

Table 12. Red pine diameter increments and reference height increments for varying rates of wastewater irrigation, Middleville, Fall, 1973.

Irrigation Rate	DBH Increment	Height Increment
----mm/week----	-----mm------	--------m--------
0	3.99 a[1]	0.68
25	4.11 a	0.65
50	4.67 a	0.71
88	4.09 a	0.69

[1]Means not followed by the same letter are significantly different at the 5% level (Tukey's test).

Table 13. Red pine stem circumference as measured by band dendrometers on four sample trees per plot, Middleville, 1973.

Growth Period	Circumference Increment[1]			
	0	25	50	88
	-----------------	mm	-----------------	
May - June	4.95 a	3.30 a	1.70 ab	1.91 b
July - August	2.24 a	3.68 ab	5.00 b	2.84 a
September - October	0.97 a	1.02 a	2.24 a	1.57 a
Total Circumference Increment	8.18 a	7.95 a	8.94 a	6.48 a
(Total DBH Increment)	(2.61)a	(2.53)a	(2.85)a	(2.06)a

[1]Means not followed by the same letter are significantly different at the 5% level (Tukey's test).

the 88 mm/week irrigation treatment produced the lowest increment (6.48 mm). This may be a negative response by red pine to the high irrigation rate. Sopper and Kardos (1973) also noticed that while trees receiving 50 mm of wastewater/week had an average annual diameter increment of 1.52 mm, the controls and 25 mm/week trees had increments of 1.65 and 4.32 mm respectively. Thus, to ensure maximum diameter growth on sandy loam soils similar to Middleville, a maximum irrigation rate of 50 mm/week is required while loamy soils like those at Penn State should receive 25 mm/week.

The DBH increments computed from circumference growth as measured by the band dendrometers were considerably less than those determined by direct DBH measurement. These differences are due to factors inherent in each method. The direct DBH was measured with diameter tape to the nearest 2.5 mm, which is about the magnitude of the variance in the DBH's reported in Tables 12 and 13. These results are most likely an overestimation of the actual increments.

The diameter and foliage growth of red pine resulting from wastewater irrigation are important factors to consider in the renovation efficiency of the water reclamation system. Increases in tree biomass production permits additional nutrients to be absorbed by forest stands that receive irrigated wastewater. To assess the impact of observed growth changes, estimations of total foliage and stem production were made.

Needle biomass produced by the red pine at Middleville during 1972 and 1973 is estimated in Tables 14 and 15.

Needle Biomass

Estimations of total needle biomass were computed by adapting a method discussed by Brown (1963) for determining crown weights of red pine stands in the Lake States. This method assumes that: (1) the red pine plantation occupies a good site and (2) the stand has a high density (1,000 - 2,500 trees/ha). Total crown weight/tree is first computed by Equation 2:

(Equation 2)

$$L_{TCW} = .9072 + .1087\ D$$

where:

L_{TCW} = Log of the crown weight (pounds, dry weight)

D = DBH in inches

Then the needle biomass/ha on dry weight basis is determined by Equation 3:

Table 14. Estimation of red pine foliage biomass production with varying rates of wastewater irrigation, Middleville, 1972.

Parameter	Units	mm wastewater/week			
		0	25	50	88
DBH	inches	5.76	5.58	6.10	5.89
DBH	cm	14.63	14.17	15.49	14.96
Crown Weight	lb/tree	34.14	32.64	37.18	35.27
Crown Weight	kg/tree	15.49	14.81	16.86	16.00
Trees/ha	#	1780	1780	1780	1780
Total Crown Weight	kg/ha	27,570	26,360	30,010	28,480
Factor for Needle Crown Weight	--	.51	.51	.51	.51
Unadjusted Needle Crown Weight	kg/ha	14,060	13,440	15,300	14,520
1972 Needle Factor	--	.33	.33	.33	.33
1972 Needle Weight	kg/ha	4,600	4,400	5,050	4,790
Dry Weight/Fascicle Adjusted Factor	--	1.00	.93	.94	.91
Actual 1972 Needle Weight	kg/ha	4,600	4,100	4,700	4,400

Table 15. Estimation of red pine foliage biomass production with varying rates of wastewater irrigation, Middleville, 1973.

Parameter	Units	mm wastewater/week			
		0	25	50	88
DBH	inches	5.92	5.75	6.28	6.04
DBH	cm	15.04	14.61	15.95	15.34
Crown Weight	lb/tree	35.49	34.06	38.89	36.62
Crown Weight	kg/tree	16.10	15.45	17.64	16.61
Trees/ha	#	1780	1780	1780	1780
Total Crown Weight	kg/ha	28,660	27,500	31,400	29,570
Factor for Needle Crown Weight	--	.51	.51	.51	.51
Unadjusted Needle Crown Weight	kg/ha	14,610	14,020	16,010	15,080
1973 Needle Factor	--	.33	.33	.33	.33
1973 Needle Weight	kg/ha	4,820	4,630	5,280	4,980
Dry Weight/Fascicle Adjustment Factor	--	1.00	1.08	1.38	1.56
Actual 1973 Needle Weight	kg/ha	4,800	5,000	7,300	7,800

(Equation 3)

$$B_N = TCW \cdot K \cdot D_H \cdot P_N$$

where:

B_N = crown needle biomass in kg/ha

TCW = total crown weight per tree in pounds

D_H = tree density per hectare

P_N = needle percent of total crown weight

K = pounds to kilogram conversion factor (.4536 kg/lb)

The needle biomass computed by Equation 3 is further adjusted by multiplying by a (1) needle factor and (2) dry weight/fascicle factor. The needle factor accounts for the proportion of needles produced in any one year. In this instance a needle factor of 0.33 is assumed. The dry weight/fascicle factor is a ratio of the dry weight/fascicle for the 25, 50, and 88 mm/week irrigation treatments to that of the control treatment for each year. The resultant figure is an estimation of the dry weight needle production during any growing season on a kg/ha basis.

During the 1972 growing season, needle production in red pine on the control plots was 4,600 kg/ha. Production on plots receiving 25, 50, and 88 mm of wastewater/week over the same period was -13, +2, and -6% in contrast to the nonirrigated trees. Needle biomass production in 1973, however, was greatly increased in trees receiving wastewater irrigation. Red pine on the control plots produced a new needle biomass of 4,800 kg/ha, an increase of 200 kg/ha from 1972 to 1973. Meanwhile, needle biomass production for the 25, 50, and 88 mm/week irrigated trees was 4, 51, and 61% greater at 5,000, 7,300, and 7,800 kg/ha.

Stem Biomass

No data on branch growth were collected from the Middleville site in 1972 and 1973. However, the production of stem biomass during this time is presented in Tables 16 and 17.

Stem biomass production was determined by applying wood density and taper factors to a cylinder volume formula and subtracting the biomass computed at the start of the growing season from that determined at the end of the growing season. Stem biomass production was calculated with Equation 3:

(Equation 3)

$$B_S = \pi \cdot r^2 \cdot h \cdot d \cdot T \cdot K_g \cdot D_H$$

where:

B_S = stem biomass production in kg/ha

π = 3.1416

Table 16. Estimation of red pine stem biomass production with varying rates of wastewater irrigation, Middleville, 1972.

Parameter	Unit	mm wastewater/week			
		0	25	50	88
Initial DBH	cm	14.21	13.75	15.07	14.54
Initial Height	m	10.44	10.53	11.35	11.37
DBH Increment	cm	0.42	0.42	0.42	0.42
Final DBH	cm	14.63	14.17	15.49	14.96
Final Height	m	11.12	11.18	12.06	12.08
Biomass Increase per Tree	kg	5.414	5.055	6.289	5.965
Trees/ha	#	1780	1780	1780	1780
Total Stem Biomass Increase	kg/ha	9,600	9,000	11,200	10,600

Table 17. Estimation of red pine stem biomass production with varying rates of wastewater irrigation, Middleville, 1973.

Parameter	Unit	mm wastewater/week			
		0	25	50	88
Initial DBH	cm	14.63	14.17	15.49	14.96
Initial Height	m	11.12	11.18	12.06	12.08
DBH Increment	cm	0.41	0.44	0.46	0.38
Final DBH	cm	15.04	14.61	15.95	15.34
Final Height	m	11.80	11.83	12.77	12.77
Biomass Increase per Tree	kg	5.735	5.578	7.066	5.999
Trees/ha	#	1780	1780	1780	1780
Total Stem Biomass Increase	kg/ha	10,200	9,900	12,600	10,700

r = tree mean radius at DBH

h = mean height in trees in m

d = density of red pine wood (.507 g/cm^3)

T = taper factor (.5)

Kg = grams to kilogram conversion factor (1×10^{-3})

D_H = tree density per hectare

Since data on red pine DBH from the fall of 1971 was unavailable, several assumptions in computation of the 1972 stem biomass production were made. Equivalent DBH increments during 1972 were assumed for all four irrigation rates. The mean diameter increment from the 1973 growing season of .42 cm was also used as the 1972 increment.

In 1972 the nonirrigated red pine stem biomass was estimated at 9,600 kg/ha. The 25, 50, and 88 mm/week irrigated trees had a stem biomass of 9,000, 11,200, and 10,600 kg/ha, respectively. These amounts varied from the control by -6, +17, and +10%. The 1973 stem growth for the nonirrigated red pine was on the order of 10,200 kg/ha. The 25, 50, and 88 mm/week irrigated red pine produced 9,900, 12,600, and 10,700 kg/ha in stem biomass which varied from the control treatment by -3, +22, and +5% respectively.

Soil Chemistry

The chemical balance of any undisturbed pedon is a function of climate and vegetation acting on the parent material over time. The addition of municipal sewage effluents to soil alters the soil chemical status due to the chemical, physical, and biological processes which filter varying chemicals out of the wastewater. Not only do domestic and industrial wastewaters contain diverse amounts of chemicals (Hunter and Kotalik, 1973; Reed et al., 1972), but their addition to land alters precipitation patterns and ultimately affects the natural weathering processes. Soils receiving wastewater at the rates of 25, 50, and 88 mm/week for a 20-week irrigation period would be experiencing 66, 130, and 230% more annual precipitation in Michigan. This inevitably will result in soil chemistry changes.

The effects of wastewater irrigation on pH, phosphorus, potassium, calcium, magnesium, nitrogen, and boron in the Boyer sandy loam are presented in Table 18. Except for nitrogen (which reached a high level with the 25 mm/week rate), the average levels of each parameter increased with higher rates of wastewater irrigation. This indicates that the soil was functioning in wastewater renovation. This action can be analyzed by observing the vertical changes in these chemical parameters in response to irrigation treatments.

Table 18. Average soil chemistry parameters of the Boyer sandy loam for the 0 - 120 cm depth at the Middleville red pine wastewater study, by irrigation rate, 1973.

Parameter	Units	mm wastewater/week			
		0	25	50	88
pH	--	5.9[1] a	6.6 ab	7.0 bc	7.5 c
P	kg/ha	58.0 a	70.3 a	86.4 a	105.8 a
K	kg/ha	60.2 a	68.1 a	83.6 a	111.7 a
Ca	kg/ha	734.2 a	958.7 a	780.8 a	1,258.3 a
Mg	kg/ha	124.8 a	123.9 a	133.6 a	176.0 a
N	kg/ha	395.8 a	530.3 a	470.4 a	425.7 a
B	kg/ha	0.8 a	2.1 b	1.9 ab	2.6 b
Loss on ignition	%	1.3 a	1.5 a	1.3 a	1.3 a

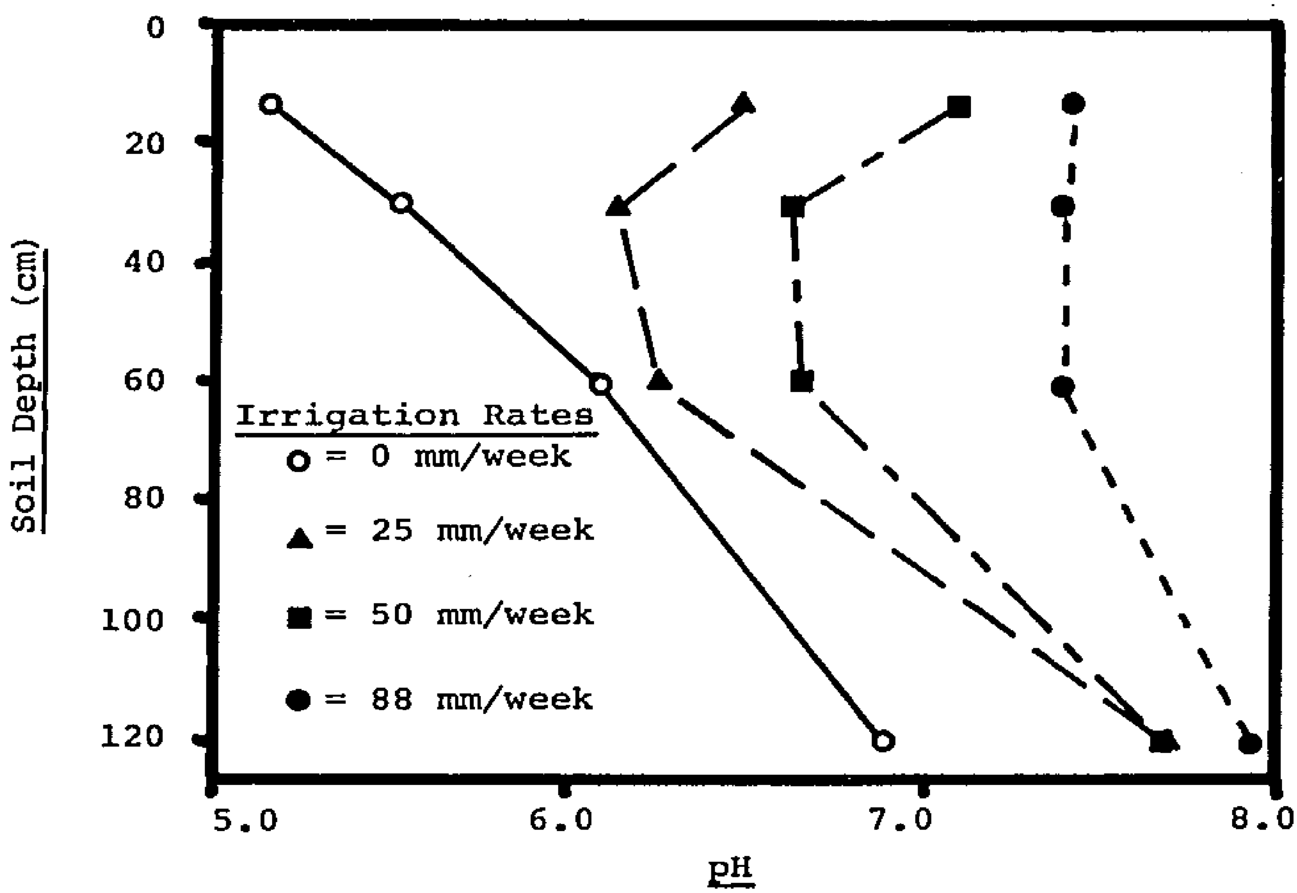
[1]Means not followed by the same letter are significantly different at the 5% level (Tukey's test).

pH

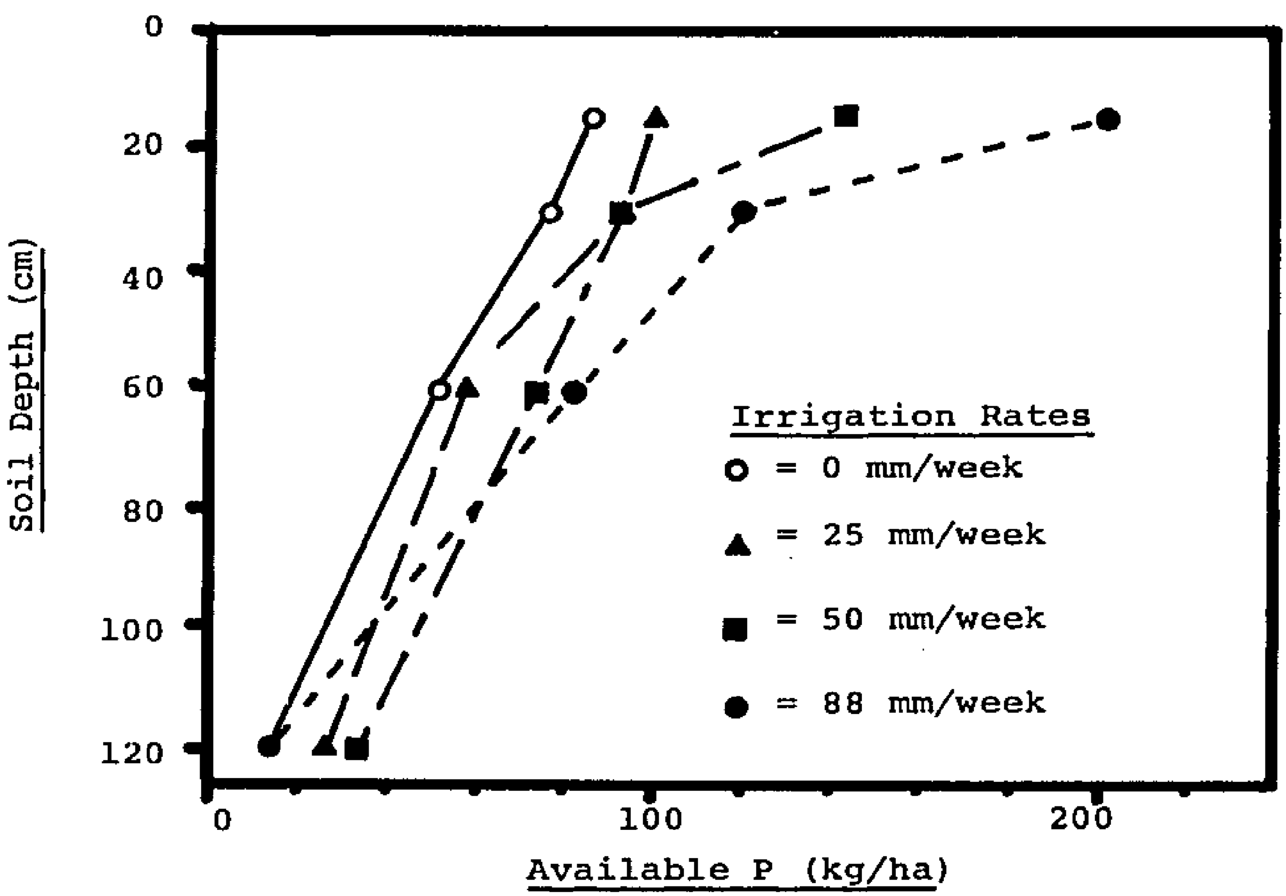
Soil pH, a property expressing the hydrogen ion activity, is an important feature of the soil system since it affects such diverse processes as chemical solubility, ion exchange capacity, plant growth, and microbial activity. The changes in pH throughout the soil profile occurring with wastewater irrigation are illustrated in Figure 26A.

The pH of unirrigated plots increased from 5.2 in the upper 15 cm to 6.9 at the 120 cm depth close to

Figure 26. Changes in (A) pH and (B) available phosphorus with soil depth and wastewater irrigation rates, Middleville, 1973.



Soil Depth (cm)
0
20
40
60
80
100
120
Irrigation Rates
○ = 0 mm/week
▲ = 25 mm/week
■ = 50 mm/week
● = 88 mm/week
5.0
6.0
7.0
8.0
pH



Soil Depth (cm)
0
20
40
60
80
100
120
Irrigation Rates
○ = 0 mm/week
▲ = 25 mm/week
■ = 50 mm/week
● = 88 mm/week
0
100
200
Available P (kg/ha)

the calcareous glacial drift parent material. In soils receiving 88 mm of wastewater/week, pH rose almost to 8.0. At the 15 cm depth the pH of all three irrigation rates (7.4, 7.1, and 6.5 for the 88, 50, and 25 mm irrigation rates respectively) were significantly higher than the control. Among the irrigation treatments, the pH for the 88 mm rate was significantly greater than the 25 mm rate but not of the 50 mm rate. The magnitude of the treatment effects upon pH differences attenuated with depth. The pH of plots receiving the two highest irrigation rates remained significantly greater than the control at 30 cm, but only the soil pH of the 88 mm/week application rate remained significantly higher at 120 cm.

Similar changes in soil acidity have been reported by others. Kardos and Sopper (1973) noted a change in pH from 4.8 to 5.5 in the surface 30 cm of Morrison sandy loam soil beneath a hardwood stand receiving 50 mm of wastewater/week. Little _et al._ (1959) reported a similar pH trend from woodland irrigation of cannery waste at Seabrook Farms in New Jersey. The pH increase at the 15 cm depth between check plots and irrigated plots was from 4.7 to 5.5 over 6 years. Rudolph (1957) cited an increase in pH at the 15 cm depth from 5.2 to 6.8 in an Ottawa loamy sand after one year of irrigation with cannery wastewater. A subsequent decrease from 6.8 to 6.6 was recorded after three years of irrigation.

The addition of municipal wastewater to the soil in this study has resulted in a 100-fold increase in soil pH. This increase will improve total cation exchange capacity by increasing the contribution of organic matter to exchange capacity. A decrease in phosphate solubility is expected (Lindsay and Moreno, 1960), and hence will improve phosphorus renovation. Organic matter decomposition will also improve (see section on litter) as will the establishment of plants normally excluded from the acid soils under red pine.

Phosphorus

The distribution of available phosphorus within the soil profiles receiving the different levels of wastewater irrigation is shown in Figure 26B. Phosphorus concentrations in the control plots decreased significantly from 87.4 kg/ha in the upper 15 cm to 15.3 kg/ha at 120 cm depth. Additions of phosphorus-enriched wastewater have had the greatest impact in the upper 15 cm of soil. At that depth phosphorus concentrations of 88, and 50 mm/week plots (203.2 and 144.2 kg/ha respectively) were significantly greater than the control. The 88 mm/week phosphorus level was also significantly higher than the 25 mm/week wastewater irrigation treatment. However, there was no significant difference in phosphorus levels between the control and 25 mm/week treatment rates.

At the 30 cm depth increases in available phosphorus were evident but were not statistically significant. This trend continued at 60 cm, but at 120 cm phosphorus concentrations were relatively unaffected by the irrigation rate. These data indicate that good phosphorus renovation was taking place, with phosphorus being adsorbed on soil colloids or precipitated as insoluble phosphate compounds in the upper 15 cm of soil. Thus far, little phosphorus has moved below the 60 cm depth.

Hook et al. (1973) reported similar phosphorus trends at Penn State. A deeper phosphorus penetration occurred in a forested sandy loam soil than in a clay loam under corn cultivation. Such deeper phosphorus movement in the forest soil may result from the lack of yearly phosphorus removal via biomass harvesting and lower amounts of iron and aluminum oxides needed to precipitate excess phosphorus. Little et al. (1959) documented similar trends for sandy loam and loamy sand soils. However, the magnitude of the phosphorus increase in the upper 15 cm was only about 5.5 kg/ha (143%) while at Middleville it was 115.7 kg/ha (137%).

The exchangeable potassium, calcium, and magnesium in the soil profiles are presented in Figures 27 (A and B) and 28 (A).

Potassium

Again, the effects of the wastewater irrigation were most pronounced in the upper 15 cm of soil. Potassium increased from 85.1 kg/ha in the control plots to 138.9, 143.4, and 161.3 kg/ha for the 25, 50, and 88 mm/week irrigation rates. Potassium levels for the two higher irrigation rates remained significantly greater down to the 60 cm depth.

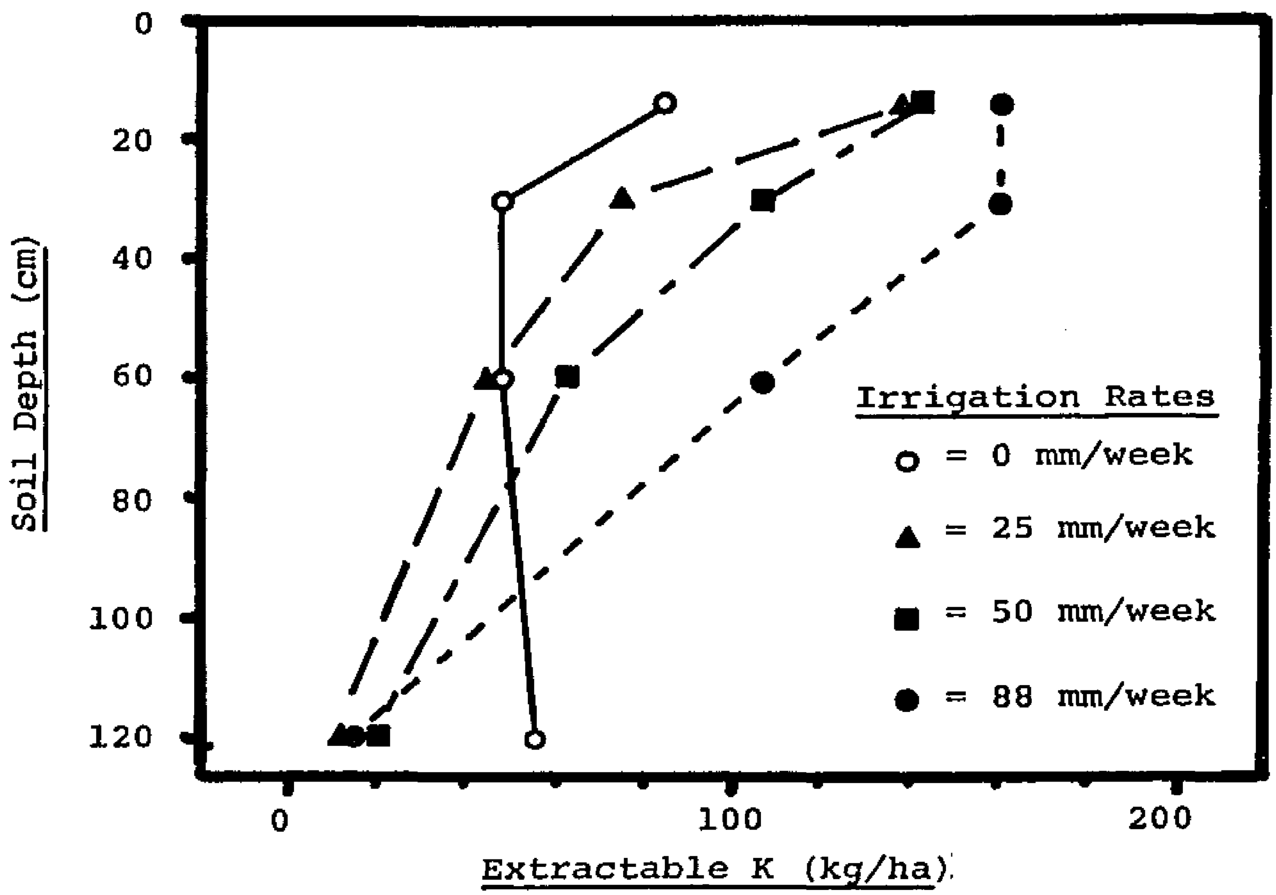
Calcium

Calcium increased considerably in the upper 15 cm, but, despite changes of 300 to 500%, these were judged to be statistically nonsignificant due to high within-treatment variability. The range of calcium levels at 15 cm (242 to 1308 kg/ha for the 0 through 88 mm/week irrigation rates) narrowed at 60 cm to amounts common to the control (290 kg/ha) and then rapidly increased when calcareous till predominated at 120 cm.

Magnesium

The profile distribution curves for magnesium were similar to those of potassium. At 15 cm the magnesium content was 32.5, 219.6, 236.8, and 256.2 kg/ha

Figure 27. Changes in (A) extractable potassium and (B) extractable calcium with soil depth and wastewater irrigation rates, Middleville, 1973.


Soil Depth (cm)
0
20
40
60
80
100
120
0
100
200
Extractable K (kg/ha)
Irrigation Rates
○ = 0 mm/week
▲ = 25 mm/week
■ = 50 mm/week
● = 88 mm/week

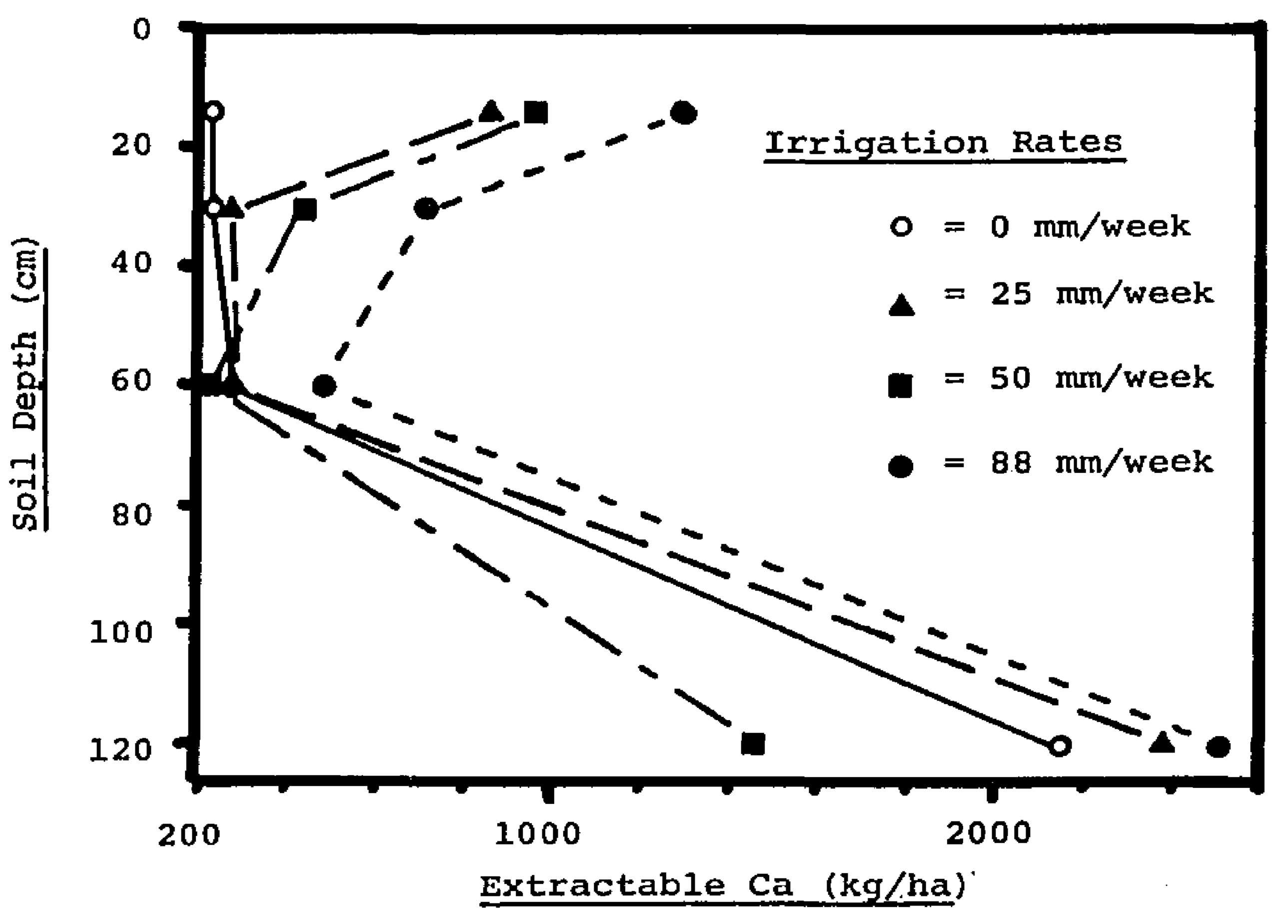
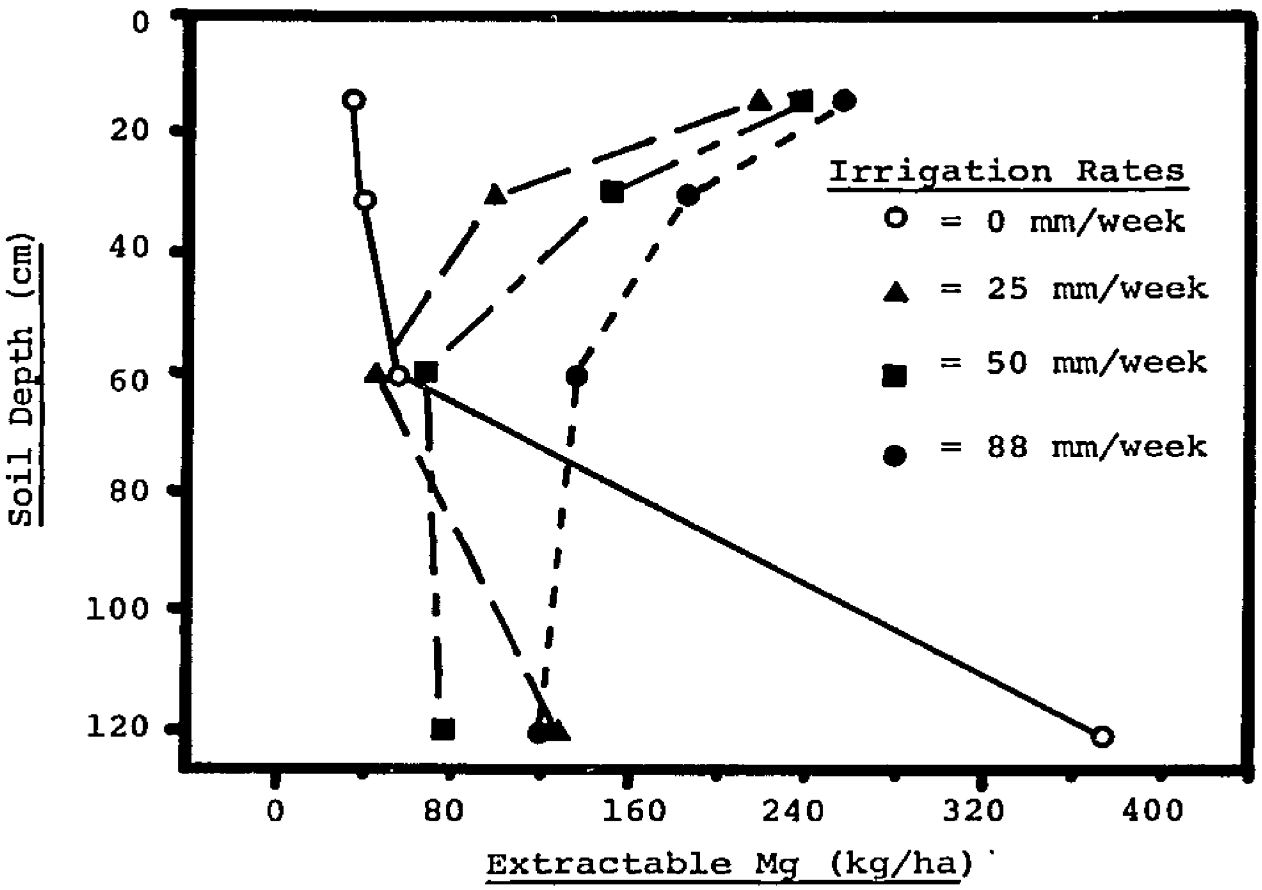
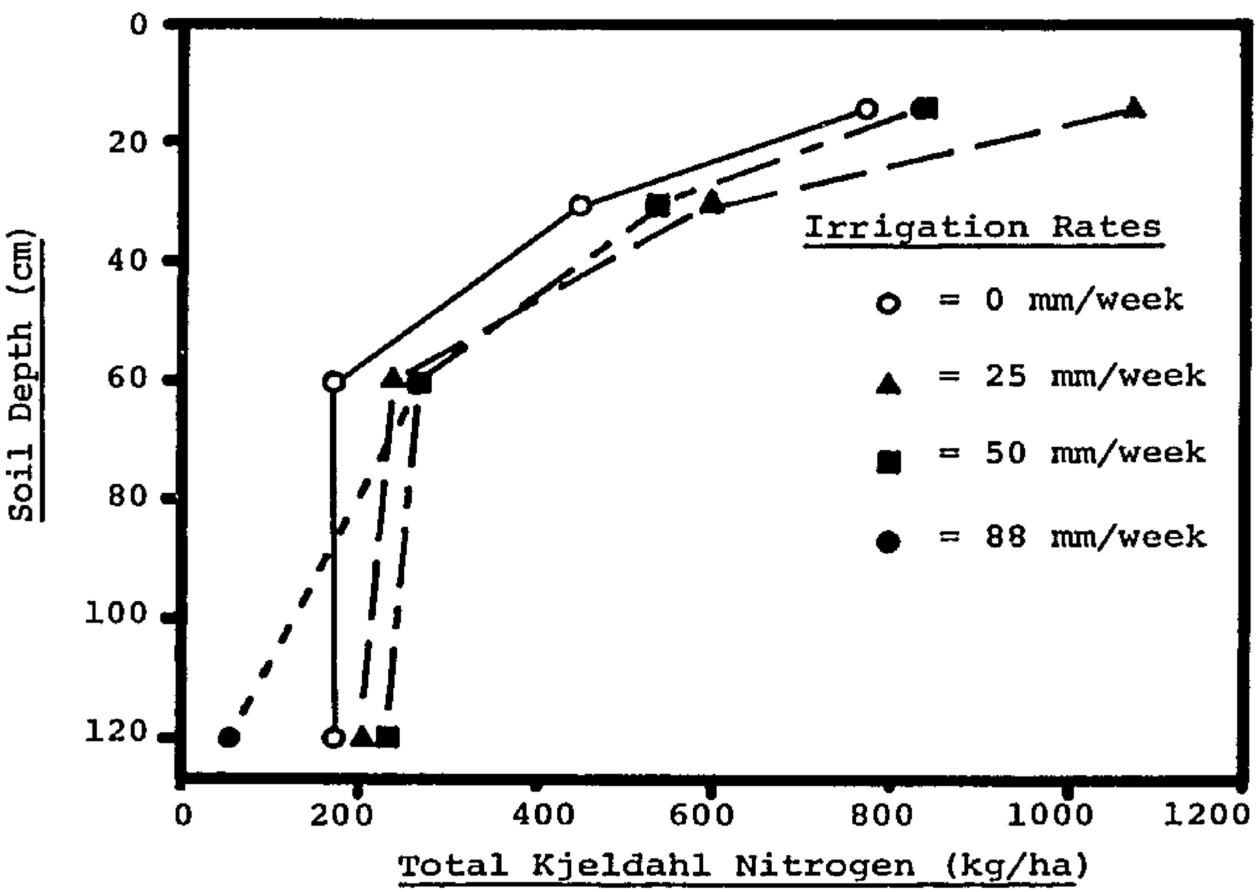

Soil Depth (cm)
0
20
40
60
80
100
120
200
1000
2000
Extractable Ca (kg/ha)
Irrigation Rates
○ = 0 mm/week
▲ = 25 mm/week
■ = 50 mm/week
● = 88 mm/week

Figure 28. Changes in (A) extractable magnesium and (B) total Kjeldahl nitrogen with soil depth and wastewater irrigation rates, Middleville, 1973.



0
20
40
60
80
100
120
Soil Depth (cm)
Irrigation Rates
= 0 mm/week
= 25 mm/week
= 50 mm/week
= 88 mm/week
0
80
160
240
320
400
Extractable Mg (kg/ha)



0
20
40
60
80
100
120
Soil Depth (cm)
Irrigation Rates
= 0 mm/week
= 25 mm/week
= 50 mm/week
= 88 mm/week
0
200
400
600
800
1000
1200
Total Kjeldahl Nitrogen (kg/ha)

for the 0, 25, 50, and 88 mm/week rates. At the 60 cm depth magnesium levels of the two lowest irrigation rates approached those of the control while the high irrigation rate maintained a magnesium level about 100% higher than the rest.

However, at the 120 cm soil depth, the magnesium content of the control plots increased significantly in the proximity of the calcareous glacial till, while the soils receiving the three irrigation rates remained essentially the same to those levels at 60 cm. Potassium reacted in a similar manner with control plots exceeding levels of those at the 25, 50, and 88 mm irrigation rates. Calcium did not respond as such and perhaps a cation displacement occurred from exchange sites at lower soil depths as a result of irrigation. This would cause potassium and magnesium ions to be displaced before calcium.

Little _et_ _al_. (1959) recorded similar findings in the potassium, magnesium, and calcium contents of the upper 60 cm of soils receiving cannery wastes. However, in most cases these cations were at lower concentrations than those at Middleville. Kardos and Sopper (1973) documented apparent reductions in magnesium, calcium, and potassium below controls at depths of 120 cm or more under both hardwood and red pine stands. However, they made no attempt to explain this trend.

Total Kjeldahl Nitrogen

The total Kjeldahl nitrogen content of the soils at Middleville is presented in Figure 28 (B). As expected, nitrogen was highest in the upper soil horizons and dropped off with increased depth. At nearly all depths wastewater irrigation produced high soil nitrogen levels, but differences between irrigation intensities were not statistically significant. Nitrogen remained essentially constant below the 60 cm depth. Sopper (1971) observed similar conditions from soil nitrogen data gathered at the Penn State wastewater renovation study.

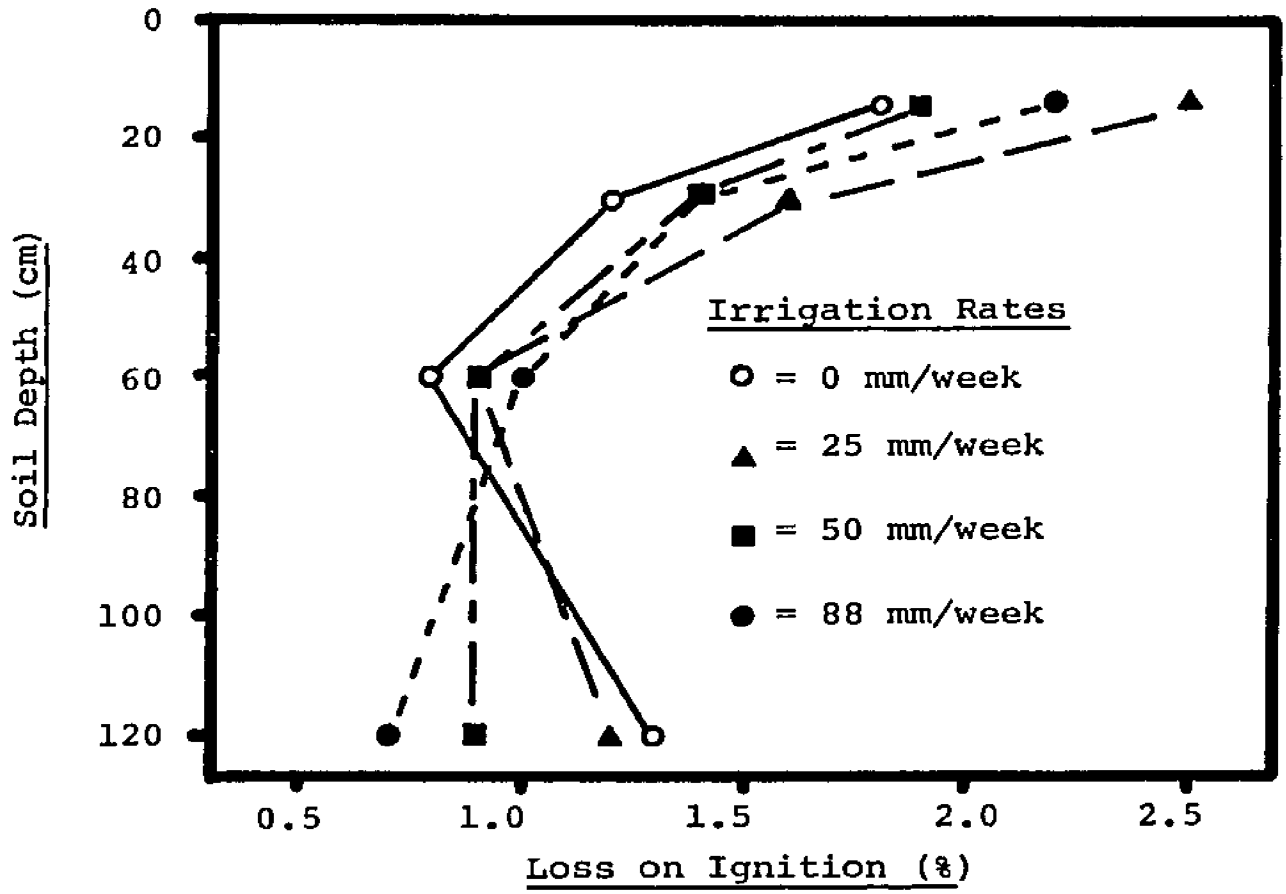
Loss on Ignition

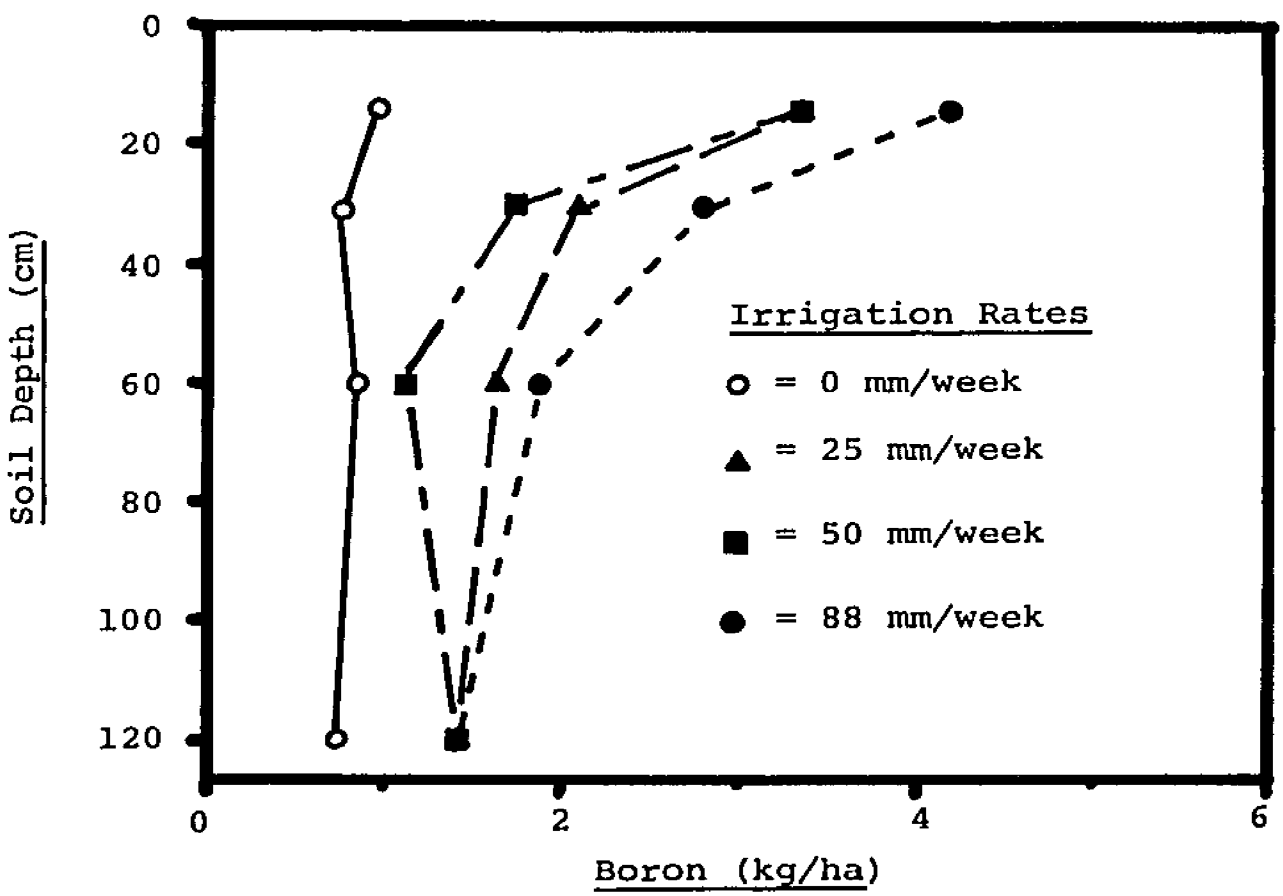
Figure 29 (A) presents loss on ignition values which indirectly estimates soil organic matter. The volatolization of organic matter at 15 cm depth ranged from 1.8% to 2.5% and decreased with depth in a manner similar to total nitrogen. Differences between irrigation rates at the four depths sampled were statistically nonsignificant. At the 120 cm depth, nonsignificant increases in loss on ignition were noted, but were probably due to a breakdown of secondary clay minerals and the decomposition of $CaCO_3$ upon heating.

Boron

Amounts of total boron in the soil at Middleville are presented in Figure 29 (B). The apparent accumulations

Figure 29. Changes in (A) loss on ignition and (B) total boron with soil depth and wastewater irrigation rates, Middleville, 1973.


0
20
40
60
80
100
120
Soil Depth (cm)
Irrigation Rates
= 0 mm/week
= 25 mm/week
= 50 mm/week
= 88 mm/week
0.5
1.0
1.5
2.0
2.5
Loss on Ignition (%)


0
20
40
60
80
100
120
Soil Depth (cm)
Irrigation Rates
= 0 mm/week
= 25 mm/week
= 50 mm/week
= 88 mm/week
0
2
4
6
Boron (kg/ha)

of boron in the red pine foliage paralleled comparable increases in the soil. At 15 cm, the total boron in the plots receiving wastewater irrigation was significantly higher than in unirrigated controls. After two years of irrigation, boron climbed to 3.4, 3.3, and 4.2 kg/ha for the 25, 50, and 88 mm/week irrigation rates compared to 1.0 kg/ha for unirrigated areas. These high boron increases in the upper soil horizons pose a threat to tree species such as red pine which are sensitive to high boron levels. At 30 cm depth, boron contents of the 25 and 88 mm/week irrigation plots were still significantly higher than those of the controls. No statistically significant differences in soil boron content occurred at the 60 and 120 cm depth, but plots receiving irrigation remained about 100% higher than in unirrigated soils. The undisturbed control plots had a uniform boron level throughout the soil profile, varying by no more than 0.2 kg/ha from the 15 to 120 depth.

Boron normally exists in soil solution as either undissociated H_3BO_3 or as an anion. It is adsorbed in soils more strongly than other anions such as the highly mobile chloride or nitrate ions. A major site for adsorption of large quantities of boron is freshly precipitated aluminum hydroxide (Hatcher et al., 1967). Indications that considerable amounts of aluminum hydroxide have been recently precipitated in irrigated plots are evident with the shift in pH and the large reductions in aluminum of red pine needles.

Humus Survey

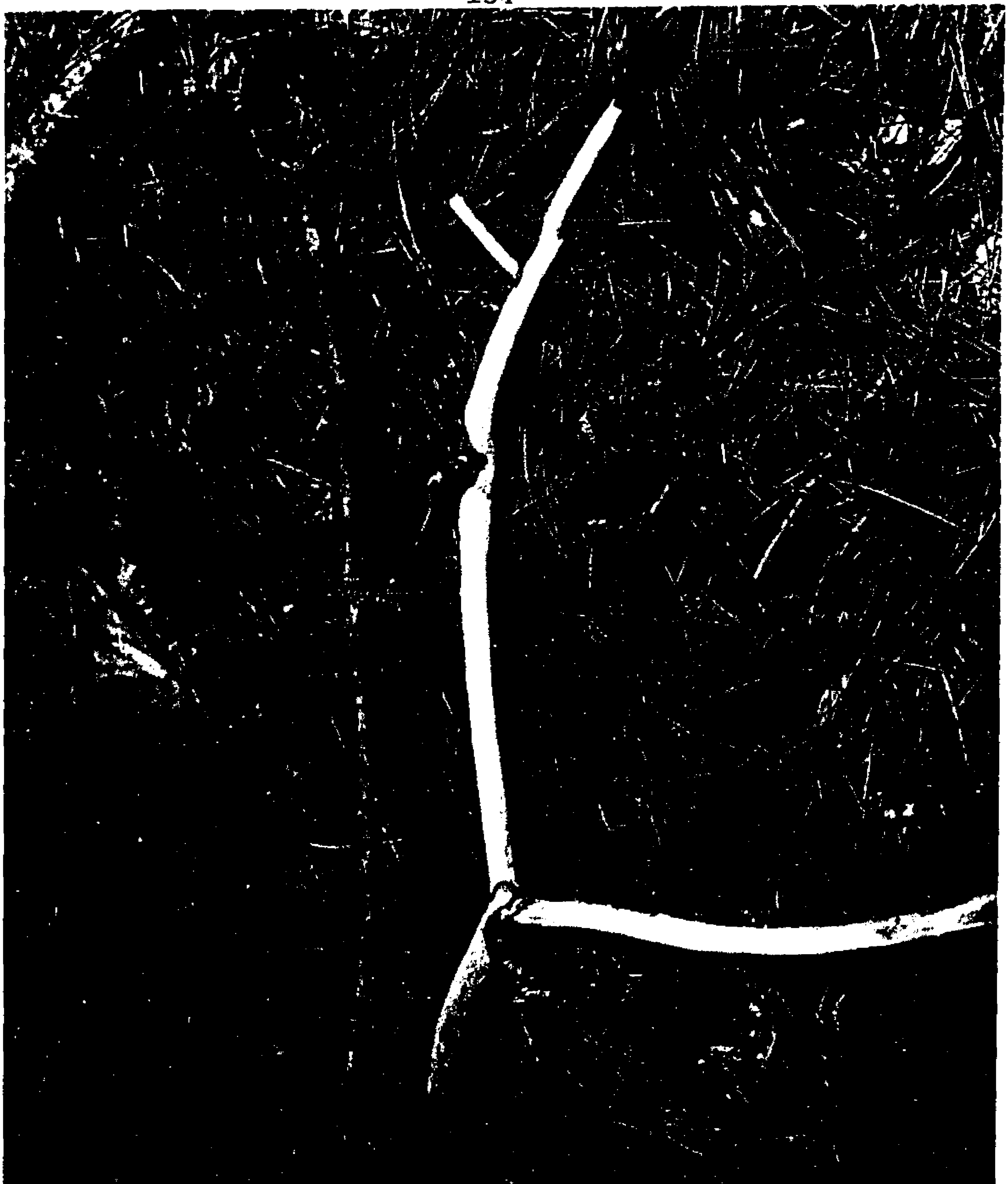
Changes in the red pine duff mull humus were examined in 1973 within the irrigated plots. Alterations from the normal prevailing conditions were: (1) noticeable decreases in humus depth, (2) shifts in humus color from brownish-red to gray-green, and (3) bark removal from branch litter on the soil surface (Figure 30). Survey results are presented in Table 19.

Soil Organisms

The mycelial mat index increased from 2.0 for the control treatment to 4.0 and 3.7 for the 25 and 50 mm/week irrigation treatments, respectively. However, the index for the highest irrigation rate then dropped 50% below control levels. The earthworm index rose from 0.7 for the control plots to 1.7 and 2.0 for the 25 and 50 mm/week application rates. The index for the 88 mm/week rate plots then dropped to less than that of the 25 mm/week rate (index of 1.3).

Wastewater application to the red pine stand apparently stimulated fungi and earthworm activity. The highest indices occurred in plots receiving 50 mm/week. Despite treatment variations of up to 400%,

Figure 30. Comparison between branch litter in unirrigated (top) and irrigated (bottom) red pine plots showing the loss of bark occurring with irrigation, Middleville, 1973.



the mycelial mat and earthworm indices did not produce statistically significant differences related to irrigation rate.

Table 19. Red pine humus survey by wastewater irrigation treatment, Middleville, 1973.

Parameter	Units	mm wastewater/week[1]			
		0	25	50	88
Mycelial Mats	Index	2.0	4.0	3.7	1.0
Earthworms	Index	0.7	1.7	2.0	1.3
Mean Humus Depth	cm	4.23	3.19	2.97	3.40
Total Humus Weight	kg/ha	23,590	23,420	22,340	21,530
Woody Litter	kg/ha	3,240	3,200	2,900	3,480
Mineral Soil	kg/ha	4,310	6,040	5,880	4,940
Fine Humus	kg/ha	16,040	14,190	13,570	13,140

[1]No significant differences with treatment at the 5% level (Tukey's test).

Humus Depth

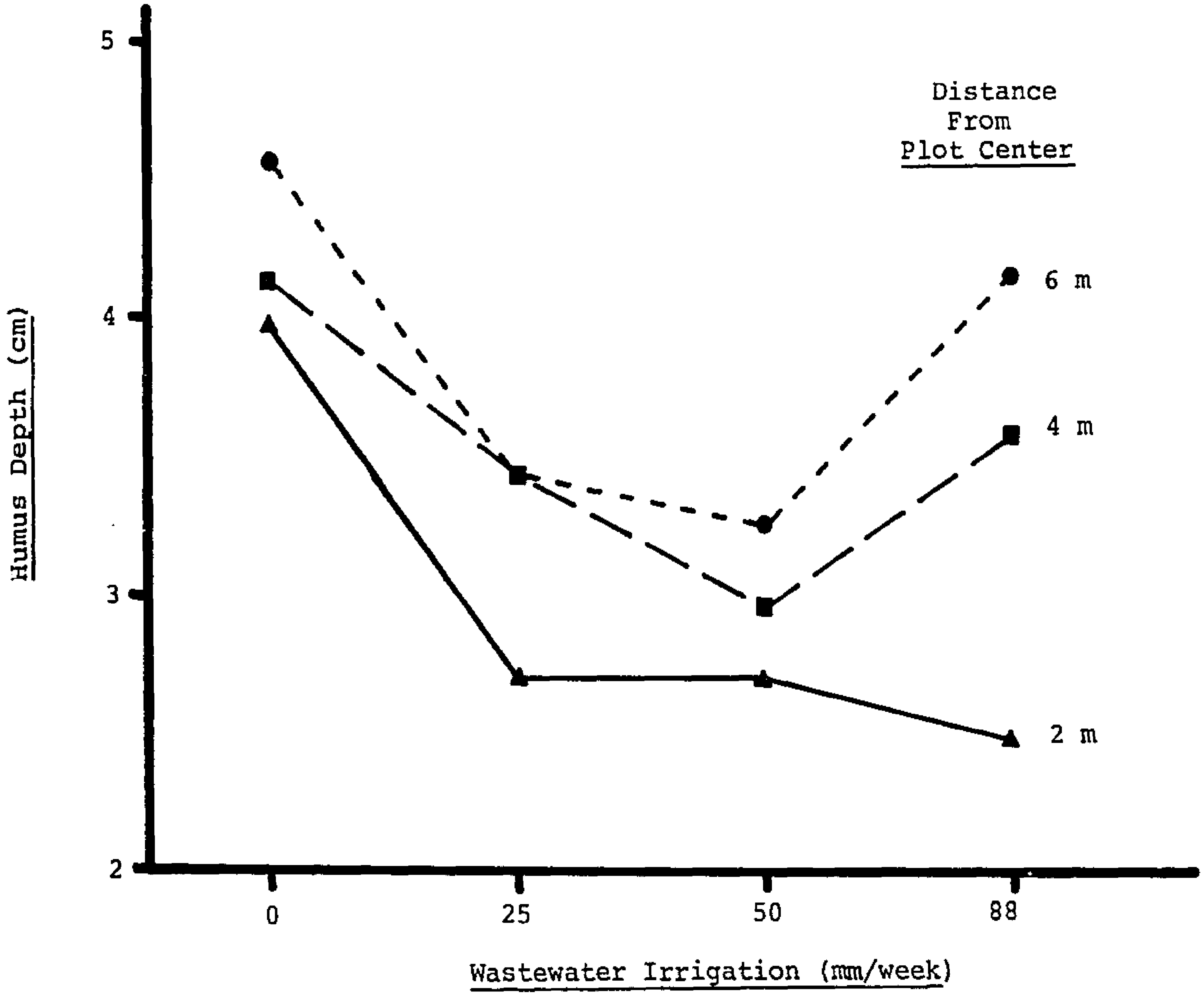
Average forest floor depth varied from a maximum 4.23 cm in unirrigated plots to 2.97 cm in plots receiving 50 mm of wastewater/week. Plots receiving 88 mm/week had an average depth of 3.4 cm. Depth for the control plots agreed with those reported by Stutzbach _et al_. (1972) for a 37-year-old red pine plantation in New York. Humus depths of 4.52 and 3.15 cm were recorded for good (site index 64) and poor (site index 47) sites respectively.

Based on the biological activity index, the major amount of decomposition occurred in the 50 mm/week treatment. However, analysis of the wastewater application rate and sampling point interactions indicated that the forest floor depths for each level of wastewater application were affected by distance of the sampling point from the plot center (Figure 31). Those depths measured at distances of 2, 4, and 6 m from plot center differed because of variations in total irrigation across the plot. For example, the humus depth at the 2-m sampling point decreased with increased amounts of irrigation. Total humus depth was about 4 cm on plots receiving no irrigation and 2.5 cm in plots irrigated with 88 mm of wastewater/week. The biggest change in forest floor depth, 1.28 cm, occurred in the interval between the control and 25 mm/week treatments. Mean depths measured at the 4 and 6 m locations approximately paralleled those of the 2-m location. The humus depths at the 2-m sampling point clearly reveal that wastewater irrigation has decreased forest floor thickness. This decrease was probably due to both a physical compaction by the weight of the applied water as well as by actual decomposition.

Total Humus Weight

The extent of organic matter decomposition on the forest floor as a result of wastewater irrigation

Figure 31. Mean humus depth in red pine at Middleville by irrigation rate and distance from plot center, 1973.


Distance
From
Plot Center
6 m
4 m
2 m
5
4
3
2
Humus Depth (cm)
0
25
50
88
Wastewater Irrigation (mm/week)

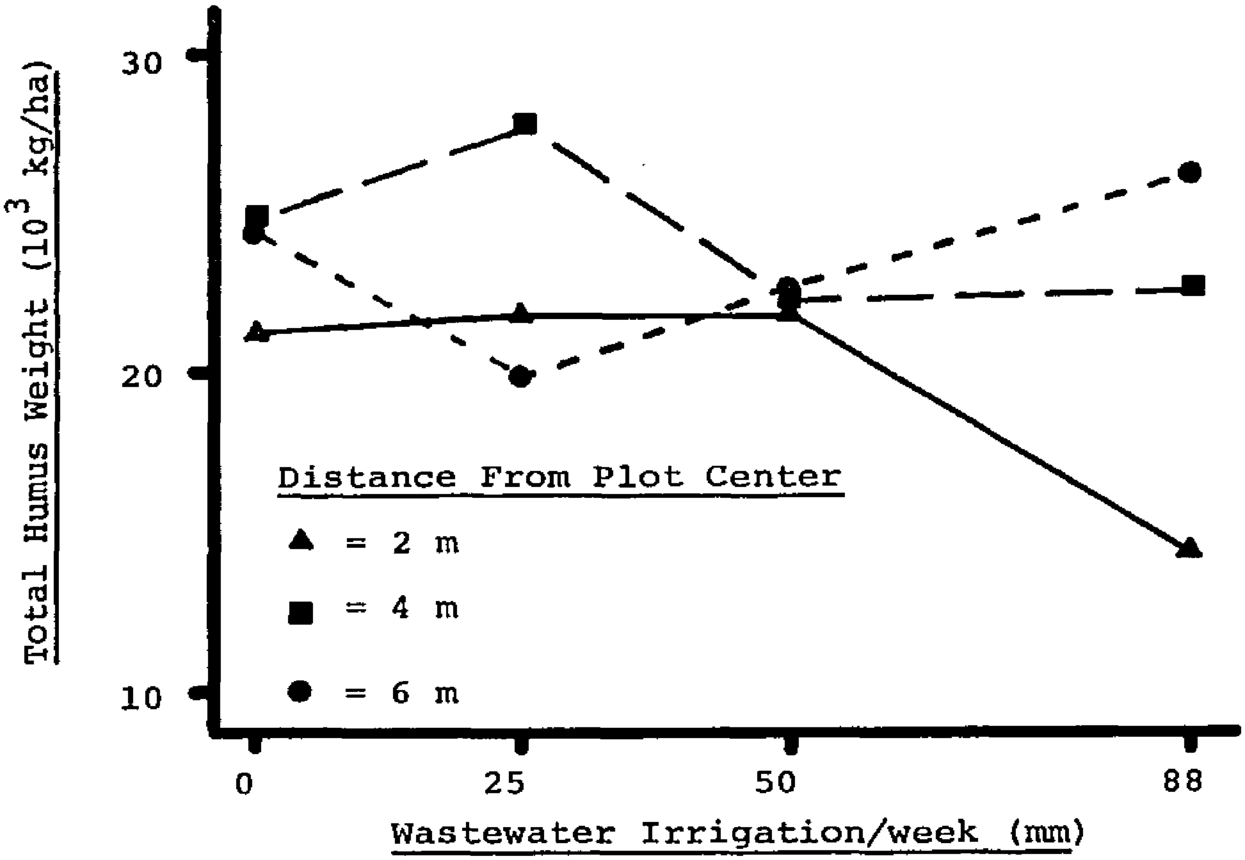
can be estimated by examining the forest floor weight components (Table 19). Total humus weights decreased consistently with increases in irrigation rates. The oven-dry weight of 23,590 kg/ha for the control plots was within the weight range of 30,610 to 22,370 kg/ha reported by Stutzbach _et_ _al_. (1972) for good and poor red pine sites respectively. Total humus weights measured at the 4-m and 6-m sampling points at Middleville were variable (Figure 32A). Those determined at the 2-m location were more uniform (21,740 330 kg/ha at the lower irrigation treatments, but dropped sharply to 14,840 kg/ha for the 88 mm/week rate).

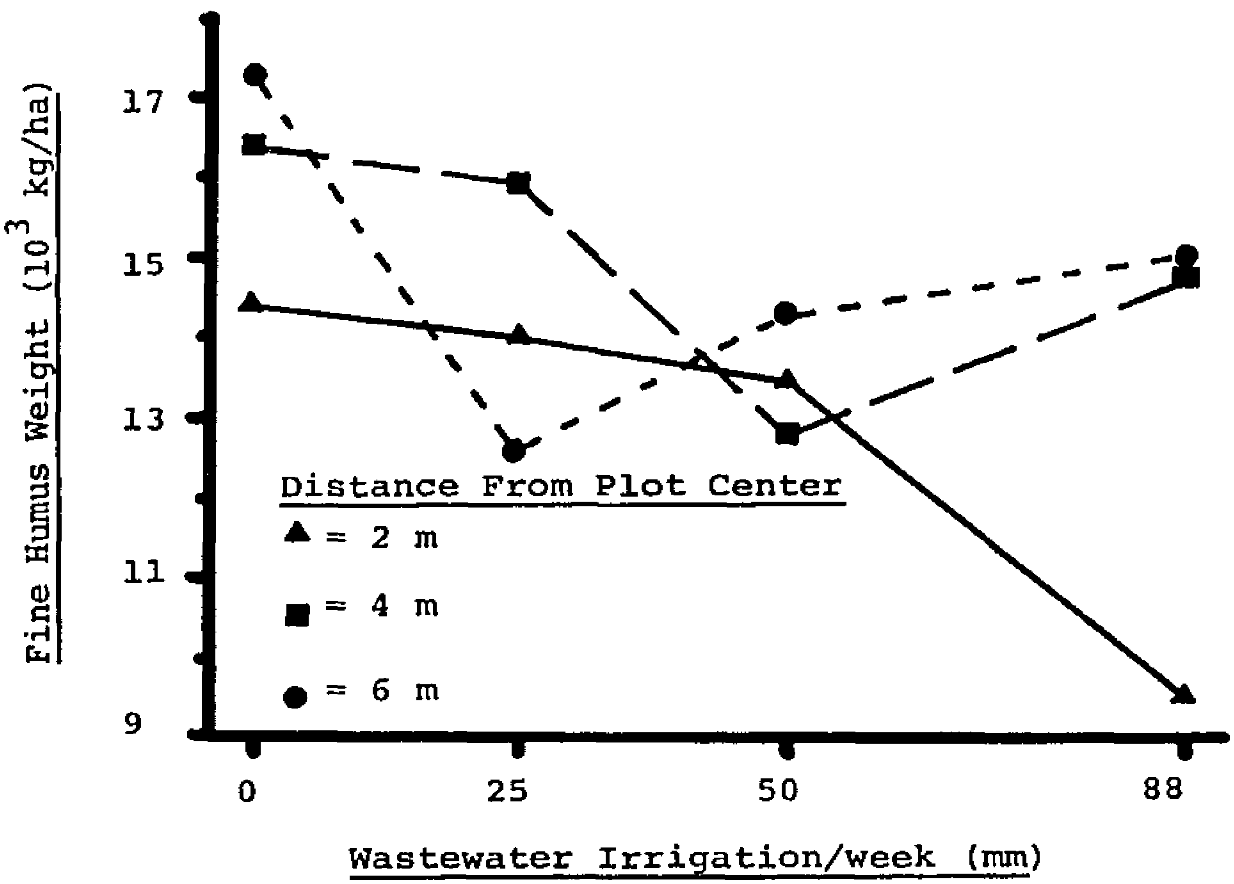
Fine Humus

Fine humus (needle litter and other organic matter) dry weights corresponded in a similar manner, with gradual decreases of 16,040 to 13,140 kg/ha occurring over the range of irrigation treatments (Figure 32B). These weights varied considerably at the 4 and 6 m sampling point. Humus weights at the 2-m locations decreased uniformly from 14,490 to 13,500 kg/ha between the 0 and 50 mm/week treatments, and then dropped more rapidly at the 88 mm/week rate to 9,630 kg/ha.

Although all decreases in the duff mull humus weights and depth were not statistically significant, distinct trends were present. If these trends continue,

Figure 32. Interaction effects of wastewater irrigation rate and distance from plot center on (A) total humus weight and (B) fine humus weight.


30
20
10
Total Humus Weight (10^3 kg/ha)
0
25
50
88
Wastewater Irrigation/week (mm)
Distance From Plot Center
= 2 m
= 4 m
= 6 m

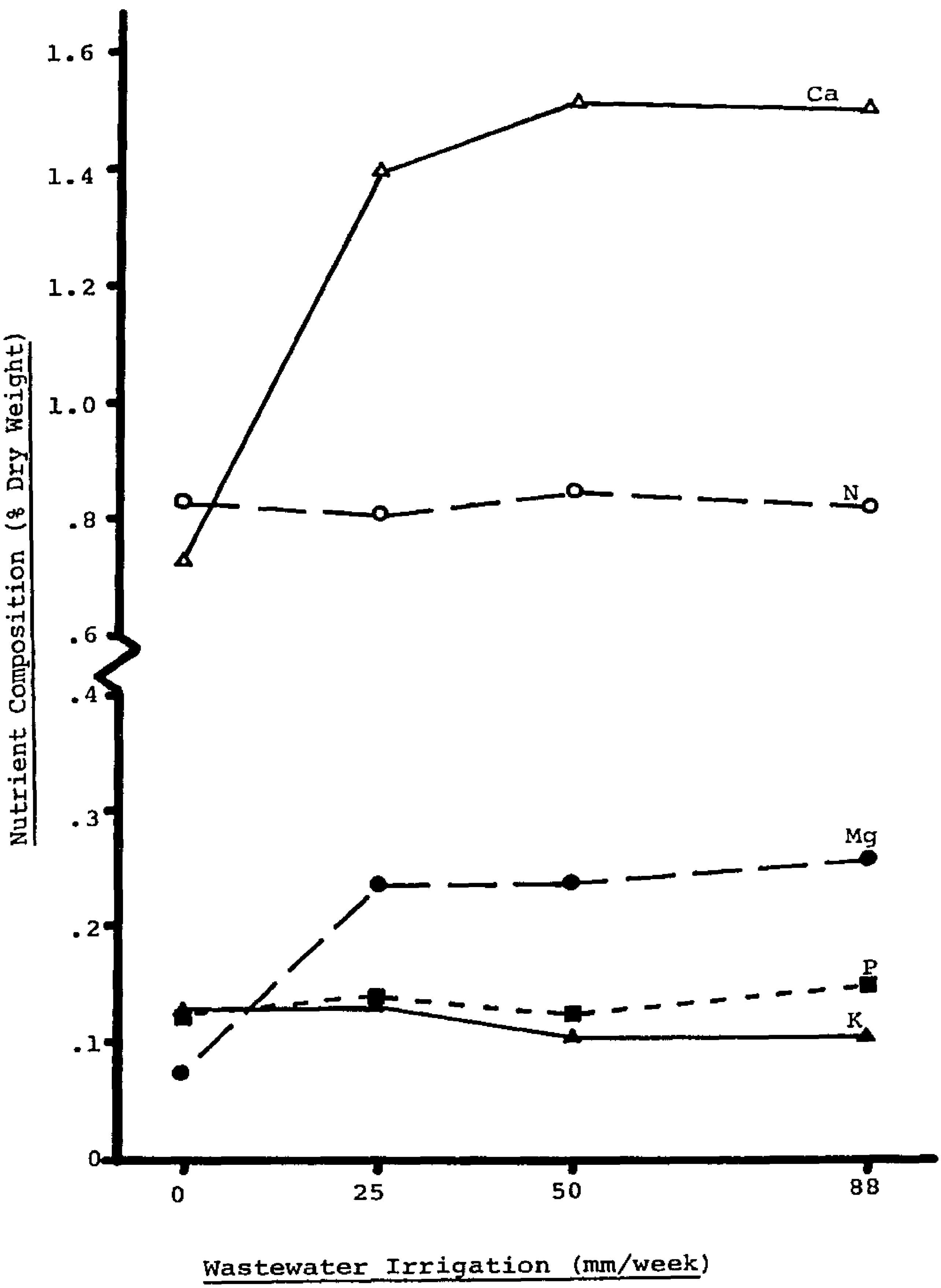

17
15
13
11
9
Fine Humus Weight (10^3 kg/ha)
0
25
50
88
Wastewater Irrigation/week (mm)
Distance From Plot Center
= 2 m
= 4 m
= 6 m

considerable changes in the forest floor will occur. Further decomposition and amelioration of the acidic red pine needle litter will probably hasten successional changes to a hardwood understory. In addition, the continued litter breakdown will affect the wastewater renovation capacity of the site. Litter decomposition will lead to an increase in organic matter of the soil surface and improve the cation exchange capacity. However, organic matter breakdown will also create problems by mobilizing additional nutrients, such as nitrogen, which may adversely influence the site's wastewater renovation efficiency.

Nutrients

A nutrient analysis of the red pine fine humus was made to relate its chemical status with wastewater irrigation. The effects of increased rates of wastewater irrigation on the calcium, nitrogen, magnesium, phosphorus, and potassium contents of fresh and partially decomposed needle litter is shown in Figure 33. Nitrogen and potassium were relatively uniform for all irrigation treatments with averages of .83 and .12% respectively. Phosphorus showed a moderate increase between the 25 and 88 mm/week treatments with the .15% phosphorus level for the higher rate being significantly greater than the other two treatments. The largest increases were

Figure 33. Amounts of calcium, magnesium, nitrogen, phosphorus, and potassium in red pine fine humus at Middleville, 1973.



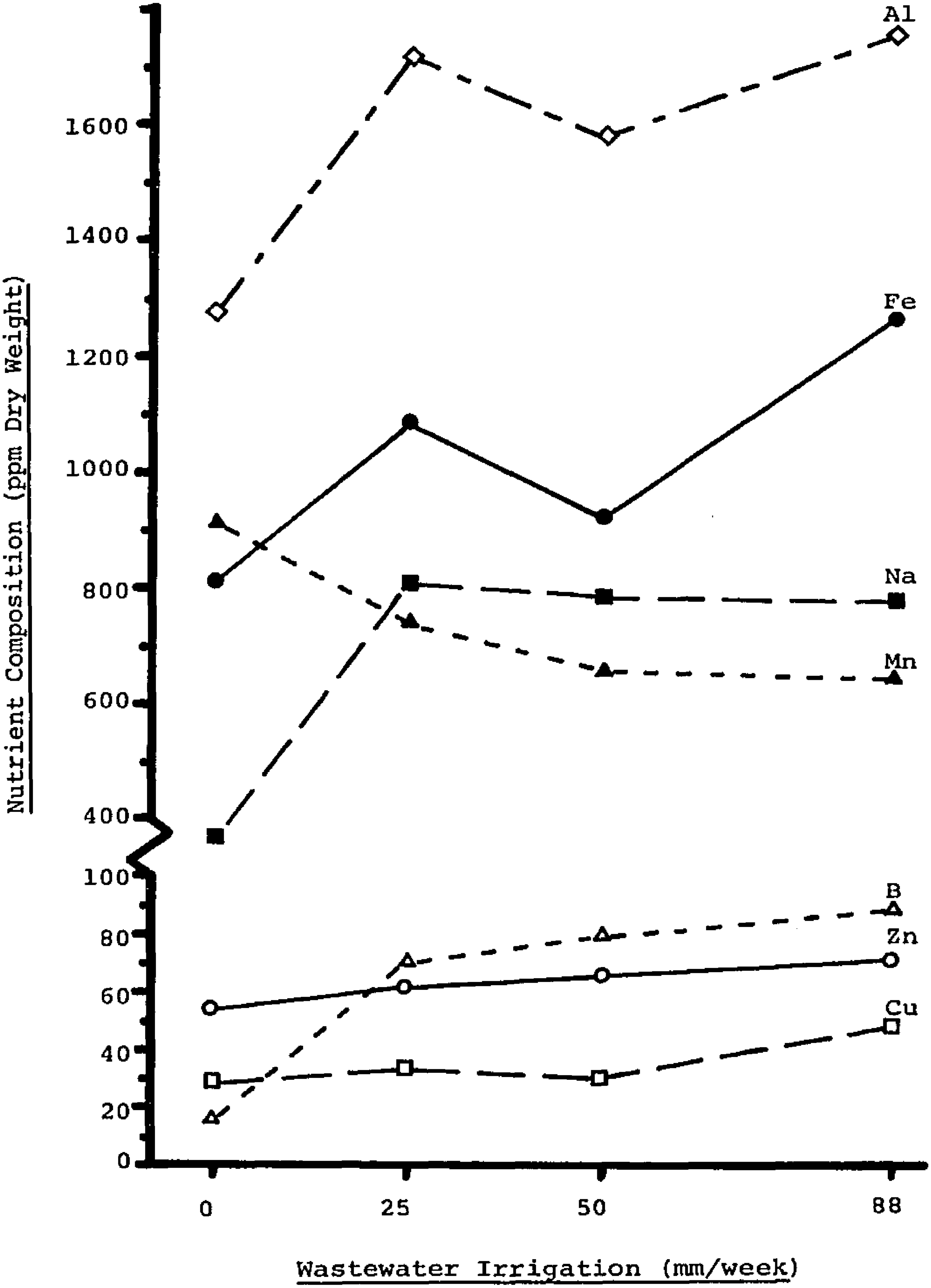
1.6
1.4
1.2
1.0
.8
.6
.4
.3
.2
.1
0
Nutrient Composition (% Dry Weight)
Ca
N
Mg
P
K
0
25
50
88
Wastewater Irrigation (mm/week)

recorded for magnesium and calcium. Magnesium made a significant jump from .07% for the 0 mm/week rate to .24, .24, and .26% for the 25, 50, and 88 mm/week rates respectively. Calcium significantly increased from .73% in the control plots to 1.40, 1.56, and 1.50% for the 25, 50, and 88 mm/week rates respectively.

Calcium and magnesium increases were due to absorption of those cations on organic cation exchange sites in the humus. Leaching induced by irrigation water, probably kept potassium levels near normal. No significant irrigation rate sampling point interactions were noted.

Fluctuations in the levels of aluminum, boron, copper, iron, manganese, sodium, and zinc in the fine humus at Middleville are presented in Figure 34. With the exception of manganese, nutrient increases were noted in all irrigated plots in comparison to unirrigated plots. Manganese exhibited a nonsignificant decrease from 923.0 ppm for the control treatment to 644.6 ppm for that of the highest irrigation rate. Of the other nutrients, only copper had a nonsignificant increase over the range of irrigation rates. Zinc levels gradually increased from 55.1 to 74.0 ppm, with low and high rates of irrigation being significantly different. Iron followed a similar pattern, but aluminum was more variable, with a general increase

Figure 34. Aluminum, boron, copper, iron, manganese, sodium, and zinc contents of fine humus in the red pine plantation at Middleville, 1973.


Al
Fe
Na
Mn
B
Zn
Cu
1600
1400
1200
1000
800
600
400
100
80
60
40
20
0
Nutrient Composition (ppm Dry Weight)
0
25
50
88
Wastewater Irrigation (mm/week)

in concentration with increased irrigation. Sodium levels in the red pine fine humus rose significantly from 373.3 ppm in plots receiving no irrigation to 809.6 ppm in the 25 mm/week irrigation rate where they reached a plateau. Boron exhibited a 440% increase from the nonirrigated plots of 16.2 ppm to 71.5 ppm for the 25 mm/week rate, and then continued to climb to 90.0 ppm for the 88 mm/week irrigation rate. For boron, all three rates of wastewater application produced significantly greater levels (at 5%) than controls. In addition, the 88 mm/week treatment was significantly higher than that of the 25 mm/week rate.

Stutzbach _et al_. (1972) reported maximum and minimum nitrogen, phosphorus, potassium, calcium, and magnesium concentrations in the forest floor layers of a 37-year-old red pine stand in New York. The nitrogen and phosphorus levels at Middleville were within those concentration ranges for all four wastewater treatments. However, different trends were evident in the potassium, calcium, and magnesium contents. The calcium concentration in control plots was well within the range found in the New York stand, but, in the wastewater irrigation plots, the calcium level was 59 to 70% higher than the maximum value reported by Stutzbach. Potassium and magnesium values in the fine humus of all four wastewater irrigation treatments at Middleville exceeded the maximums in the New York red pine stand.

The application of municipal wastewater to the red pine stand at Middleville has resulted in considerable changes in the chemical balance of the forest floor. Except for nitrogen, potassium, and manganese, the levels of the monitored elements all increased. Nitrogen remained unaltered while potassium and manganese decreased in concentration. While no apparent nitrogen decreases have occurred, the decomposition documented in the study has the potential of contributing up to 133 kg/ha (8 kg/100 kg of fine humus) of total nitrogen to the soil or ground water systems. This additional nitrogen flow must be considered when analyzing the nitrogen pathways in a terrestrial wastewater disposal system.

Fungal Fruiting Survey

An additional visible indication that wastewater irrigation induced litter decomposition was the occurrence of fungal fruiting structures. Normally the fungi produce a burst of reproductive structures in September or October corresponding to the fall rainy season.

In 1972 the fruiting activity was of such a short duration that it could not be documented. However, it did show early evidence of a fruiting body number--irrigation rate interaction.

During the 1973 irrigation season count of the total numbers of fungal reproductive structures on each plot was initiated on September 6th. A scattering of fruiting structures of the genus *Lycoperdon* spp. (Figure 35A) were noted within several of the irrigated plots. They remained visible throughout the entire fungal body survey. Fruiting structures emerging later in October were basidiomycetes of the *Agaricus* spp. and *Amanita* spp. (Figure 35B) or unidentified Fungi Imperfecti.

With the first appearance of the fungal fruiting structures in early September, the normal late summer dry spell dominated the weather picture. At that time, fruiting structures were found only in irrigated plots. Rainfall increased by late September and on October 12th fungal reproductive structures occupied a large percentage of the forest floor area within and outside the irrigated plots.

Wastewater irrigation treatment effects on numbers of fungal reproductive structures in the fall of 1973 are presented in Table 20 and Figure 36. From September 6th to September 27th, wastewater irrigation stimulated fungal fruiting. Litter within irrigated plots stayed moist throughout the week while litter in

Figure 35. Typical fungi reproductive structures in the red pine stand at Middleville, 1973: (A) basidiomycete of the genus Lycoperdon and (B) basidiomycete of the genus Agaricus.

(A)

(B)

the unirrigated control plots was dry. The peak fruiting date for plots receiving wastewater was October 4th. Fungi in the unirrigated plots reached their peak one week later. Total numbers of fungi were declining by October 23, the last day of the survey. However, numbers in the irrigated plots were higher than in control plots and declining at a slower rate.

Table 20. Mean number of fungal fruiting structures/ 0.02 ha plot by irrigation rate, Middleville, September to October, 1973.

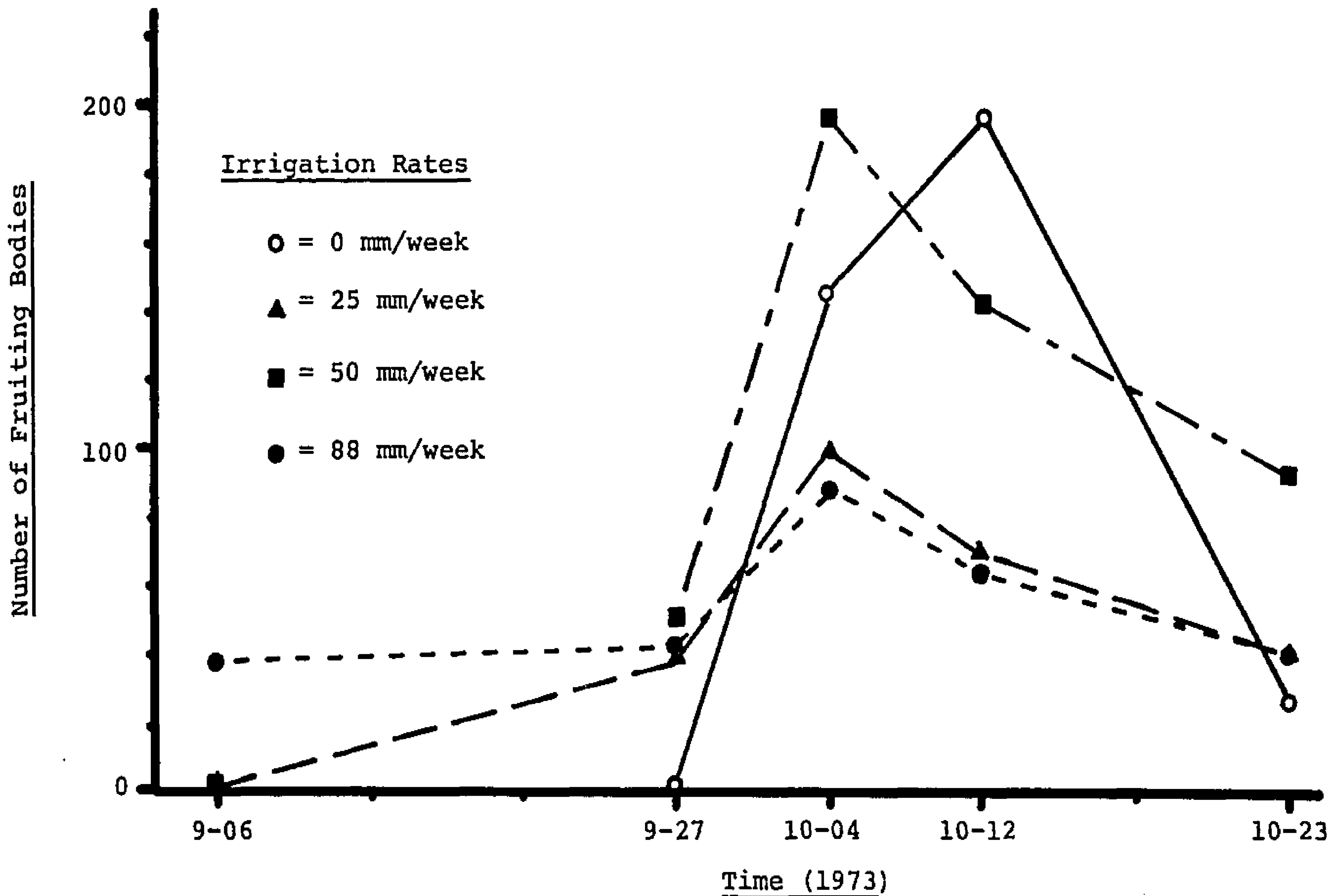
Date	mm wastewater/week							
	0		25		50		88	
	$\bar{x}$[1]	s[2]	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
	number							
9/06	0.0	0.0	1.7	1.5	2.7	1.5	38.0	57.4
9/27	1.7	1.5	38.7	28.1	51.3	69.2	43.0	57.4
10/04	145.0	44.5	100.7	54.9	197.7	149.1	88.0	56.3
10/12	197.0	20.0	70.7	51.5	142.0	156.7	62.3	47.0
10/23	27.0	7.9	40.7	25.4	93.3	119.3	38.0	35.4

[1]$\bar{x}$ = mean

[2]s = standard deviation

The data depicted in Figure 36 do not reveal the impact of the wastewater on the fungi reproduction in some of the plots. Large variations occurred within each treatment and this is indicated by the high standard deviations listed in Table 20. By selecting the one plot

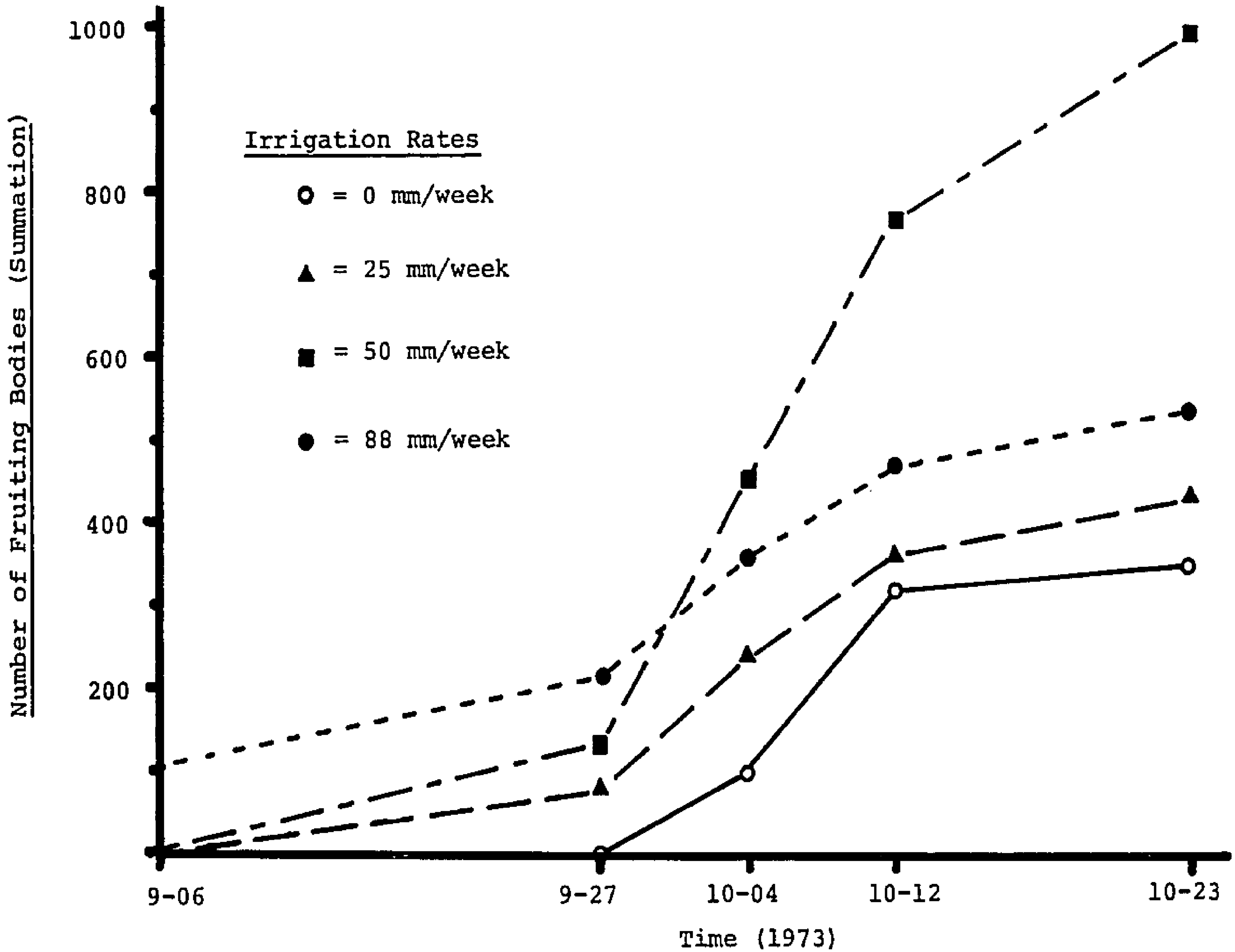
Figure 36. Mean number of fungal fruiting structures/0.02 ha plot by irrigation rate, Middleville, September to October, 1973.


Irrigation Rates
= 0 mm/week
= 25 mm/week
= 50 mm/week
= 88 mm/week
Number of Fruiting Bodies
200
100
0
9-06
9-27
10-04
10-12
10-23
Time (1973)

in each treatment that produced the highest fungal fruiting body counts, a different picture arises. Figure 37 presents the total counts on plots 11, 4, 3, and 9 as representing the 0, 25, 50, and 88 mm/week irrigation rates. The values are summations of the individual counts on each of the five sampling dates. Several distinct trends are noticeable in Figure 37. All three wastewater irrigation treatments stimulated fungi fruiting. Production of the fungal fruiting structures was most rapid for all treatments between September 27th and October 12th. The plots receiving wastewater maintained their maximum fruiting body production rates over the entire period while the control plot did so only during the last week of that period.

No significant interactions between irrigation rate and fungal fruiting body production were noted. There was also little correspondence between the fruiting body count and the mycelial mat count in the litter survey. It was evident that wastewater irrigation increased the time over which fruiting occurred. While this is a minor indication that wastewater irrigation stimulated litter decomposition, it nevertheless is a supportive one. A clearer picture of the effects of the wastewater on fungal fruiting could probably be obtained by counting species of the *Lycoperdon* genus separate from all others. These fungi dominated the

Figure 37. Summation on plots with highest individual fungal fruiting body counts, Middleville, September to October, 1973.



Irrigation Rates
○ = 0 mm/week
▲ = 25 mm/week
■ = 50 mm/week
● = 88 mm/week
Number of Fruiting Bodies (Summation)
1000
800
600
400
200
9-06
9-27
10-04
10-12
10-23
Time (1973)

early September counts, were most prolific in plots irrigated with wastewater, and occurred infrequently in the unirrigated control plots. This genus thus appears to be of value as an indicator species.

Nutrient Budget

A focal point of this study has been the effects of wastewater irrigation on the nutrient status of the red pine ecosystem. Discussions have included soil water quality, soil chemistry, foliage nutrient levels, and elemental constituents of the litter. Tables 21 and 22 summarize individual observations of these components into a nutrient budget of the red pine system.

Table 21 contains the total nitrogen budget of the system. The budget assumes that: inputs - outputs = changes in storage. No attempt is made to account for nitrogen already present in the system. Therefore, the primary concern is only with the fate of the nitrogen added via wastewater irrigation. Other nitrogen inputs such as rainfall and bacterial fixation are disregarded since no measurements of these sources were made.

The main items in the nitrogen budget include wastewater loading, needle litter decomposition, loss to the water table, foliage uptake, stem uptake, soil increase, and the net balance. The wastewater loading item (1) constitutes the input quantity and has been discussed in the section on water quality. Needle

Table 21. Estimation of total nitrogen budget in the red pine stand at Middleville, 1972 and 1973.

Budget Items	Budget Relationship	Wastewater Irrigation (mm/week) 25	50	88
		-------------kg/ha	-------------	
1. Wastewater loading	Input	- 61.8	-123.4	-217.0
2. Needle Litter Decomposition	Storage Δ	- 15.0	- 21.2	- 23.8
3. Loss to Water Table	Output	4.2	18.8	32.7
4. Foliage Uptake				
a) 1972 foliage uptake	Storage Δ	+ 1.2	+ 4.4	+ 3.5
b) 1973 foliage uptake	Storage Δ	+ 8.2	+ 57.3	+ 68.8
5. Stem uptake				
a) 1972 stem uptake	Storage Δ	0.0	+ 5.6	+ 3.5
b) 1973 stem uptake	Storage Δ	0.0	+ 8.4	+ 1.7
6. Soil Increase (0-60 cm)				
a) Estimated (sum of 1-5)	Storage Δ	+ 63.2	+ 50.1	+130.6
b) Measured	Storage	+612.4	+328.6	+328.6
7. Net		+549.2	+278.5	+198.0

Table 22. Estimation of phosphorus budget in the red pine plantation at Middleville, 1972 and 1973.

Budget Item	Budget Relationship	Wastewater Irrigation (mm/week) 25	50	88
		------------	kg/ha	------------
1. Wastewater Input	Input	-24.5	- 48.9	- 86.0
2. Needle Litter Decomposition	Storage Δ	- 2.6	- 3.2	- 3.2
3. Loss to Water Table	Output	+ 0.1	+ 0.1	+ 0.3
4. Foliage Uptake				
a) 1972 foliage uptake	Storage Δ	+ 0.4	+ 0.5	0.0
b) 1973 foliage uptake	Storage Δ	+ 0.4	+ 5.5	+ 5.7
5. Stem Uptake				
a) 1972 stem uptake	Storage Δ	0.0	+ 0.1	+ 0.1
b) 1973 stem uptake	Storage Δ	0.0	0.3	+ 0.1
6. Soil increase (0-60 cm)				
a) Estimated (sum of 1-5)	Storage Δ	+26.2	+ 45.6	+ 83.0
b) Measured	Storage Δ	+49.5	+113.3	+229.5
7. Net		+23.3	+ 67.7	+146.5

litter decomposition (2) is a storage item which is negative if decomposition exceeds accumulation and positive if the reverse is true. Loss to the ground water table (3), the output quantity, is discussed in the water quality section. The foliage uptake items (4a and 4b) are storage changes computed by a two-step summation process using data from previously described sections on red pine growth and foliar nutrients. The first step determines the amount of nitrogen generated by the irrigated red pine over that of the unirrigated control trees. The second step computes the mass of nitrogen accumulated in the new growth due to increases in needle nitrogen content. Nitrogen values are assumed to be zero if biomass production and percent nitrogen contents are below that of the control. Stem uptake (5a and 5b) is calculated in a similar manner except that a constant nitrogen level of 0.35% is assumed for the stem (Neary, 1972). The estimated soil nitrogen increase (6a) is a derived value indicating the amount of soil nitrogen needed to balance the budget equation (assuming all other terms to be valid). Measured soil nitrogen increase (6b) is computed by summing the soil nitrogen differences between the control and irrigation treatments at 15 cm intervals from the 0-to-60 cm depth.

A brief look at the net nitrogen values in Table 21 reveals considerable "noise" in this budget equation. The 25, 50, and 88 mm/week treatments produced a net nitrogen gain of about 5, 27, and 19 kg/ha. The values are considerably higher than the estimated soil increases needed to balance the budget. One possible source of additional nitrogen is through bacterial fixation. However, it is unlikely that such large soil nitrogen increases resulted from fixation alone. Another possible source of discrepancy lies in the measurement of soil nitrogen. Nitrogen levels in the irrigated plots while consistently higher than in control plots were not significantly so.

Table 22 estimates the phosphorus budget and consists of the same items as for nitrogen in Table 21. Phosphorus contents used in the stem calculations are from Rickard (1972). The phosphorus budget comes closer to being balanced than did the nitrogen budget. As in the nitrogen budget, soil increases throw the budget onto the additive side. The soil represents only available phosphorus and thus does not include the entire phosphorus content. However, the higher available phosphorus levels at the higher irrigation rates are more readily explained. As was indicated in the section on soil chemistry, the pH in the Boyer soil at Middleville rose from 5.9 to 7.5 with wastewater irrigation. This would indicate conditions where phosphorus tied up as insoluble precipitates would again go into solution.

B. Lott Woodlot

Water Quality

Wastewater Inputs

Wastewater from the East Lansing Sewage Treatment Plant and well water from the Michigan State University water system were applied to plots within Lott Woodlot during the summer and early fall of 1972 and 1973. The 1972 irrigation was from August 1 through October 10 and in 1973 from June 8 to October 19.

Average concentrations of the ammonia nitrogen (NH_3-N), nitrate nitrogen (NO_3-N), organic nitrogen (Organic N), total nitrogen (Total N), and total phosphorus (Total P) found in the sewage effluent and well water are presented in Table 23. Each wastewater nutrient parameter exhibited some variability over the two-year period. NO_3-N showed the most variation, going from 5.2 mg/l in 1972 to 0.8 mg/l in 1973. However, nearly all nutrient values were within expected ranges for secondary effluent from the East Lansing sewage treatment plant (D'Itri, 1973). Total P was slightly below the minimum values for secondary effluent. Nutrient values of the irrigated well water agreed with results reported by D'Itri (1973).

Table 23. Average concentrations of sewage effluent and well water used in Lott Woodlot, 1972 and 1973.

Year	NH_3-N	NO_3-N	Organic N	Total N	Total P
	mg/l				
(A) Sewage Effluent					
1972	4.8	5.2	1.5	11.5	1.0
1973	6.5	0.8	0.7	8.0	0.7
(B) Well Water					
1972	0.04	0.04	0.02	0.10	< 0.01
1973	0.04	0.04	0.02	0.10	< 0.01

Nutrient Loading

The irrigation and nutrient loadings achieved in Lott Woodlot during 1972 and 1973 are presented in Table 24. The 1973 irrigation was the most effective since it was applied over a longer period of time. Irrigation during 1973 at the rates of 25, 50, and 75 mm/week increased the annual effective precipitation by 62, 124, and 186%, respectively. An interesting nutrient loading trend resulting from fluctuations in the sewage effluent nutrient concentrations involved the NH_3-N/NO_3-N ratio. During 1972, when the NH_3-N/NO_3-N ratio was 0.75, the NH_3-N fraction accounted for 38% of the total nitrogen load. In 1973 this ratio abruptly changed to 8.13 with NH_3-N accounting for a significant 81% of the nitrogen load.

Table 24. Wastewater irrigation and nutrient loading rates for Lott Woodlot, 1972 and 1973.

(A) Depth of irrigation and precipitation

Year	Rainfall	Wastewater Irrigation			Well Water
		25	50	75	50
	mm	mm			mm
1972	949	250	500	750	500
1973	808	500	1000	1500	1000

(B) Average nutrient loading rate with different levels of well water and wastewater irrigation

Nutrient	1972				1973			
	25 s	50 s	75 s	50 w	25 s	50 s	75 s	50 w
	kg/ha				kg/ha			
NH_3-N	12.0	24.0	36.0	0.2	32.5	65.0	97.5	0.4
NO_3-N	16.0	32.0	48.0	0.2	4.0	8.0	12.0	0.4
Organic N	3.8	7.6	11.4	0.1	3.5	7.0	10.5	0.2
Total N	31.8	63.6	95.4	0.5	40.0	80.0	120.0	0.5
Total P	2.5	5.0	7.5	<0.1	3.5	7.0	10.5	<0.1

Ground Water Recharge

Ground water recharge totals for Lott Woodlot during April through October of 1972 and 1973 are shown in Table 25. At the 60 cm depth, applications of 25, 50, and 75 mm of wastewater/week increased the ground water recharge by factors of 3, 6, and 9 in 1972 and 6, 15, and 26 in 1973. Ground water recharge totals during April through October at Lott Woodlot were lower than at Middleville in 1972 due to a later starting date, but higher in 1973 because irrigation at Middleville was suspended in July during the height of the evapotranspirative demand period due to equipment failure. Ground water recharge computed for Lott Woodlot indicated no periods of soil moisture deficit in 1973 in plots receiving 25 or 50 mm of water/week. In 1973 at Middleville, periods of soil moisture deficit occurred at both the 25 and 50 mm/week plots.

Nutrient renovations at Lott Woodlot during 1972 and 1973 as measured with lysimeters buried at 30 and 60 cm depths are presented in Tables 26 and 27. The calculation of these renovations is approached from the point-of-view of total impact of the wastewater on soil water quality. An alternative approach is to compute renovation on the basis of wastewater additions minus well water additions in order to separate the effects of wastewater nutrients from the water itself.

Table 25. Estimated ground water recharge calculated at two soil depths and four irrigation rates, Lott Woodlot, 1972 and 1973.

Month	Ground Water Recharge							
	0		25		50		75	
	30	60	30	60	30	60	30	60
	mm							
(A) 1972								
April	86	86	86	86	86	86	86	86
May	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0
August	0	0	17	0	152	120	277	245
September	0	0	142	127	242	242	342	342
October	16	0	68	68	93	93	118	118
Total	102	86	313	281	573	541	823	791
(B) 1973								
April	23	23	23	23	23	23	23	23
May	32	32	32	32	32	32	32	32
June	0	0	33	33	108	108	183	183
July	0	0	36	36	161	161	286	286
August	0	0	42	42	167	167	292	292
September	0	0	101	101	201	201	301	301
October	0	0	88	88	163	163	338	338
Total	55	55	355	355	855	855	1455	1455

Table 26. Percent renovation for 1972 and 1973 using the ground water recharge method at the 30 cm depth in the Lott Woodlot.

Month	Rate mm/week	1972					1973				
		NH_3-N	NO_3-N	Org. N	Total N	Total P	NH_3-N	NO_3-N	Org. N	Total N	Total P
		%					%				
June	50 w	--	--	--	--	--	0	0	0	0	50
	25 s	--	--	--	--	--	98	0	96	78	99
	50 s	--	--	--	--	--	98	0	0	57	98
	75 s	--	--	--	--	--	98	0	0	4	96
Jul	50 w	--	--	--	--	--	0	0	0	0	0
	25 s	--	--	--	--	--	98	70	93	95	99
	50 s	--	--	--	--	--	98	0	61	79	98
	75 s	--	--	--	--	--	97	0	38	65	96
Aug	50 w	0	0	0	0	0	0	0	0	0	0
	25 s	99	78	98	90	99	98	0	97	73	99
	50 s	97	5	58	51	96	96	45	0	59	98
	75 s	98	0	93	26	99	97	0	31	43	96
Sep	50 w	0	0	0	0	0	0	0	0	0	0
	25 s	98	0	73	0	97	94	0	14	0	93
	50 s	98	0	60	0	97	94	0	29	52	96
	75 s	93	0	44	19	97	96	0	10	0	96
Oct	50 w	0	0	0	0	0	0	0	0	0	0
	25 s	83	0	0	0	98	98	0	80	0	92
	50 s	92	0	75	0	84	97	0	0	59	92
	75 s	92	0	55	0	94	97	0	0	19	94
Mean	50 w	0	0	0	0	0	0	0	0	0	0
	25 s	97	0	76	24	98	97	0	77	14	97
	50 s	97	0	61	13	96	96	0	77	63	97
	75 s	96	0	70	9	98	97	0	15	28	96

Table 27. Percent renovation for 1972 and 1973 using the ground water recharge method at the 60 cm depth in the Lott Woodlot.

Month	Rate mm/week	1972 NH$_3$-N	1972 NO$_3$-N	1972 Org. N	1972 Total N	1972 Total P	1973 NH$_3$-N	1973 NO$_3$-N	1973 Org. N.	1973 Total N	1973 Total P
		%					%				
June	50 w	--	--	--	--	--	0	0	0	0	0
	25 s	--	--	--	--	--	99	0	60	80	99
	50 s	--	--	--	--	--	99	0	36	69	96
	75 s	--	--	--	--	--	99	0	25	36	97
July	50 w	--	--	--	--	--	0	0	0	0	0
	25 s	--	--	--	--	--	99	97	89	98	99
	50 s	--	--	--	--	--	98	0	72	76	97
	75 s	--	--	--	--	--	98	0	27	78	98
Aug	50 w	0	0	0	0	0	0	0	0	0	0
	25 s	100	100	100	100	100	99	0	44	45	99
	50 s	99	13	55	55	98	98	0	50	66	98
	75 s	99	0	91	34	99	98	0	38	0	97
Sep	50 w	0	0	0	0	0	0	0	0	0	0
	25 s	98	0	60	29	97	95	0	71	0	99
	50 s	99	0	33	0	97	98	87	0	86	99
	75 s	86	0	73	0	98	98	0	0	0	96
Oct	50 w	0	0	0	0	0	0	0	0	0	0
	25 s	95	0	25	0	98	98	0	96	0	96
	50 s	99	0	0	0	96	98	0	9	55	93
	75 s	98	0	82	0	97	96	0	0	29	94
Mean	50 w	0	0	0	0	0	0	0	0	0	0
	25 s	99	22	76	52	99	98	0	71	10	98
	50 s	99	0	38	8	98	98	0	44	71	97
	75 s	97	0	83	0	99	98	0	7	26	96

However, such an approach is unrealistic since irrigation alone can alter the quality of the ground water aquifer by the flushing of nutrients normally present in the soil. Thus the total impact of wastewater nutrient constituents and irrigation water must be considered in determining the effect upon ground water quality.

Nitrogen

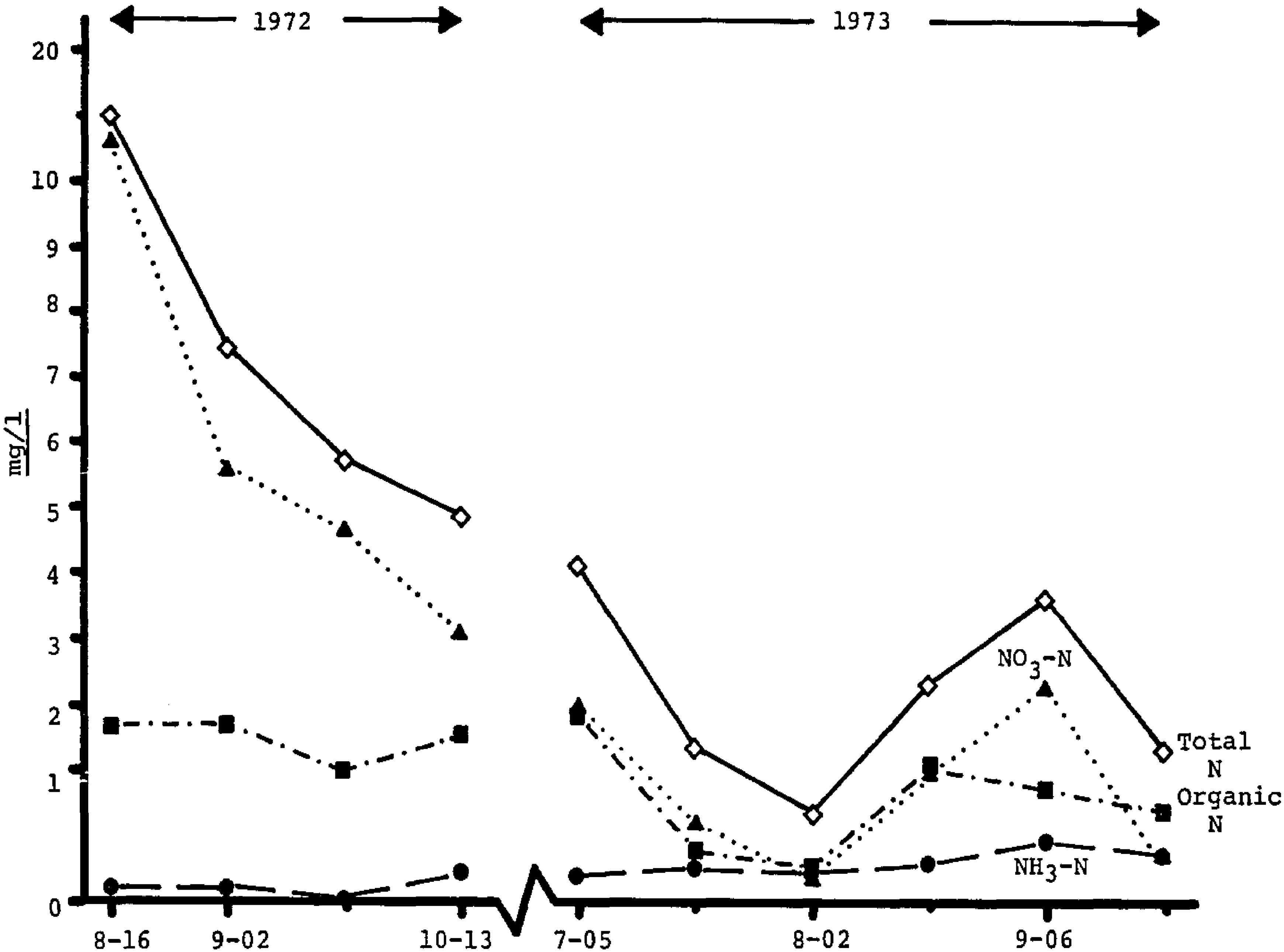
30 cm: 50 mm/week of Well Water

The average concentrations of NH_3-N, NO_3-N, Organic N, and Total N in the soil solution sampled at 30 cm are shown in Figure 38. These values and those determined for the 60 cm depth (Figure 42) indicate the amount of flushing which has taken place. In every instance, the concentrations of all four forms of nitrogen found in the soil water exceeds that in the well water used for irrigation.

In 1972, NH_3-N levels were very stable at concentrations less than 0.25 mg/l. Organic N was also relatively uniform between 1.0 and 2.0 mg/l. NO_3-N showed the most variability. It started out quite high at about 13 mg/l and then gradually receded throughout the remainder of the irrigation season. Most of the Total N content in the lysimeter samples was NO_3-N.

In 1973, NO_3-N continued the recession curve established in 1972 until it reached its low point in

Figure 38. NH_3-N, NO_3-N, Organic N, and Total N concentrations at the 30 cm depth for the 50 mm/week of well water irrigation rate, Lott Woodlot, 1972 and 1973.


1972
1973
20
10
9
8
7
6
5
4
3
2
1
0
mg/l
8-16
9-02
10-13
7-05
8-02
9-06
NO_3-N
Total
N
Organic
N
NH_3-N

early August. However, even at that low level (0.35 mg/l), NO_3-N was still much higher than that found in the well water (0.04 mg/l). NH_3-N levels rose somewhat in 1973 but remained less than 0.5 mg/l. Organic N accounted for a larger proportion of the Total N concentrations. Total N levels were lower in 1973 due to less NO_3-N flushing.

30 cm: 25 mm/week of Wastewater

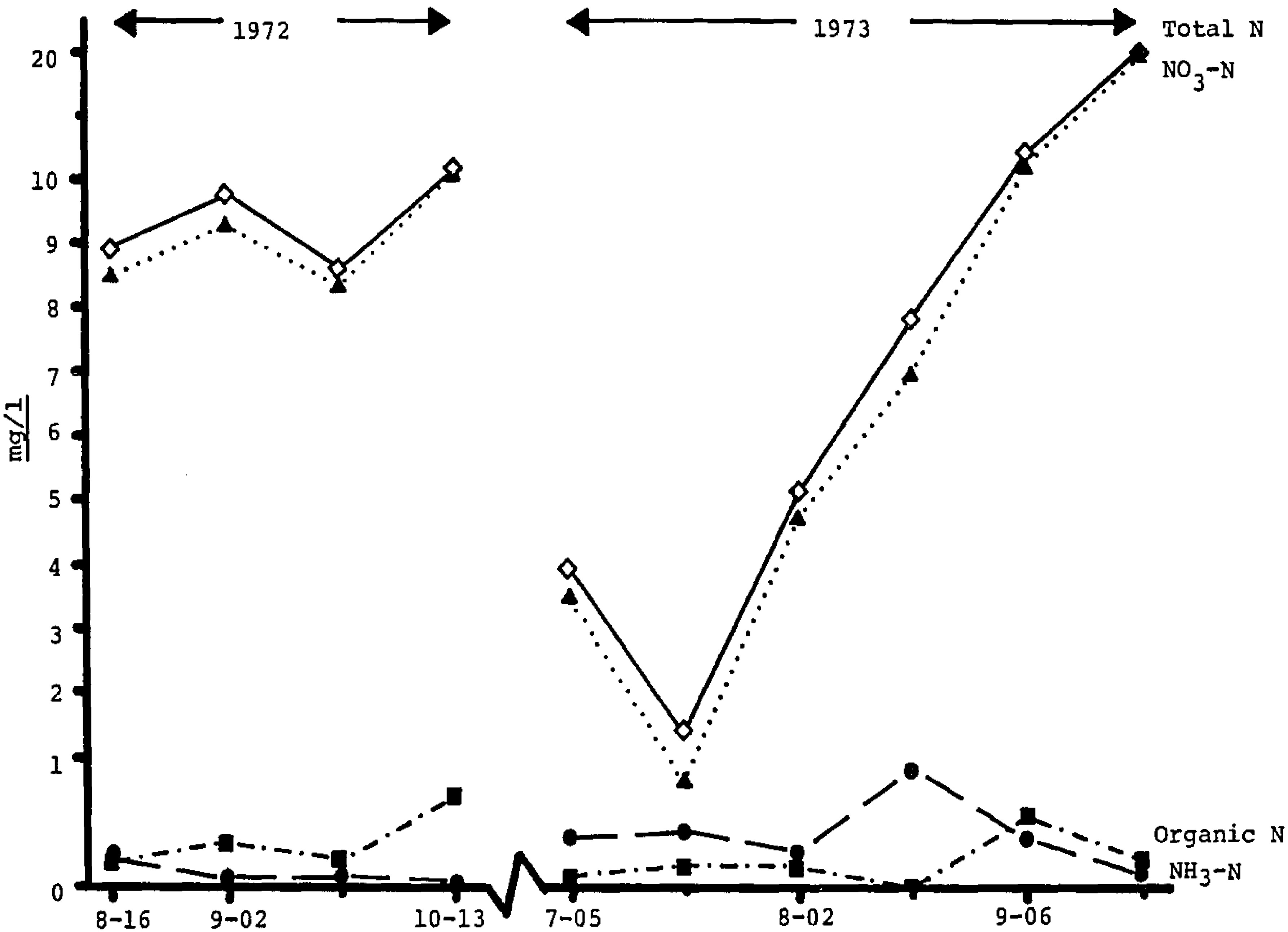
The renovation of nitrogen in plots irrigated with 25 mm/week of wastewater was strongly influenced by NO_3-N (Figure 39). In 1972, Total N renovation was 24% due to the lack of NO_3-N renovation. Removal of NH_3-N and Organic N was 97 and 76% respectively. NO_3-N levels were consistently between 8.0 and 11.0 mg/l throughout 1972.

During 1973, NO_3-N concentrations dropped somewhat in July but then rose to well above the 10 mg/l maximum limit allowed by the Public Health Service for water supplies. NH_3-N and Organic N levels were similar to those in 1972. Renovations were 97 and 77% for those two forms of nitrogen. As in 1972, the Total N contents of the soil solution were largely due to NO_3-N. Total N renovation was low at 14%.

30 cm: 50 mm/week of Wastewater

The 1972 NH_3-N, NO_3-N, Organic N, and Total N levels in the soil solution collected in plots

Figure 39. NH_3-N, NO_3-N, Organic N, and Total N concentrations at the 30 cm depth for the 25 mm/week of wastewater irrigation rate, Lott Woodlot, 1972 and 1973.


1972
1973
Total N
NO_3-N
Organic N
NH_3-N
mg/l
20
10
9
8
7
6
5
4
3
2
1
0
8-16
9-02
10-13
7-05
8-02
9-06

irrigated with 50 mm/week of wastewater were quite similar to those in plots receiving 25 mm/week of wastewater (Figure 40). NH_3-N levels were very stable and renovation was excellent (97%). Organic N tapered off during the irrigation season. Renovation was 61%. Total N contents of the soil water again were strongly affected by NO_3-N. Renovation was poor at 13%.

In 1973, Total N renovation improved to 63% as NO_3-N levels fell to less than 5.0 mg/l. NO_3-N renovation managed to increase to 45% in August, but averaged 0% for the irrigation season. NH_3-N and Organic N renovations were good at 97 and 77%. Some Organic N flushing occurred in late August along with NO_3-N flushing.

30 cm: 75 mm/week of Wastewater

The levels of the four forms of nitrogen during 1972 resembled those found in the 25 and 50 mm/week of wastewater irrigation treatments (Figure 41). NO_3-N was high (greater than 7.0 mg/l) and accounted for much of the Total N content in the lysimeters. Renovation for NH_3-N (96%) and Organic N (70%) was similar to that of the other wastewater treatment plots at the same depth. Again, Total N renovation was low at 9%.

In 1973, NO_3-N exhibited several distinct flushing pulses at approximately monthly intervals. Total N renovation improved somewhat to 28%. NH_3-N

Figure 40. NH_3-N, NO_3-N, Organic N, and Total N concentrations at the 30 cm depth for the 50 mm/week of wastewater irrigation rate, Lott Woodlot, 1972 and 1973.

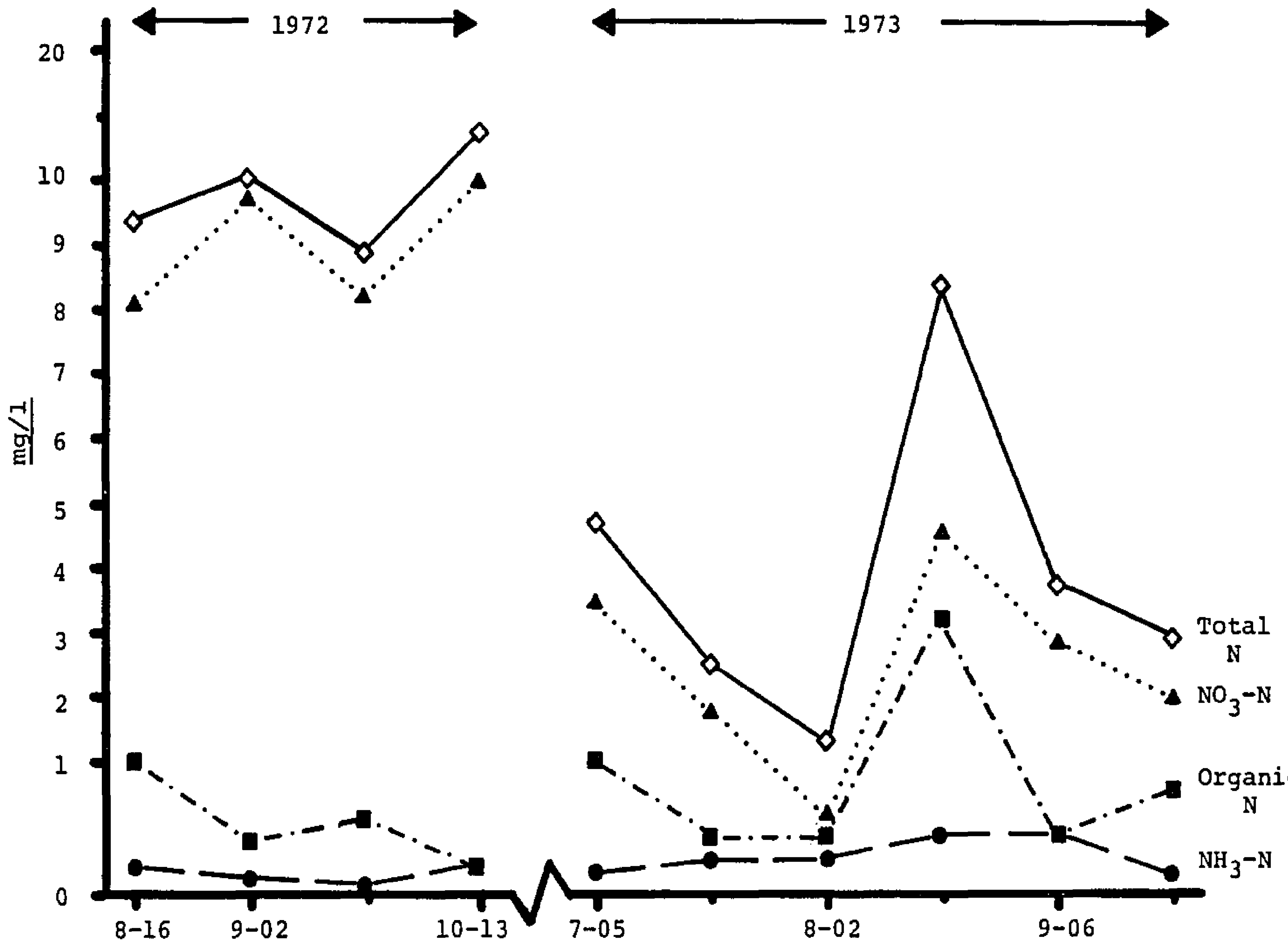
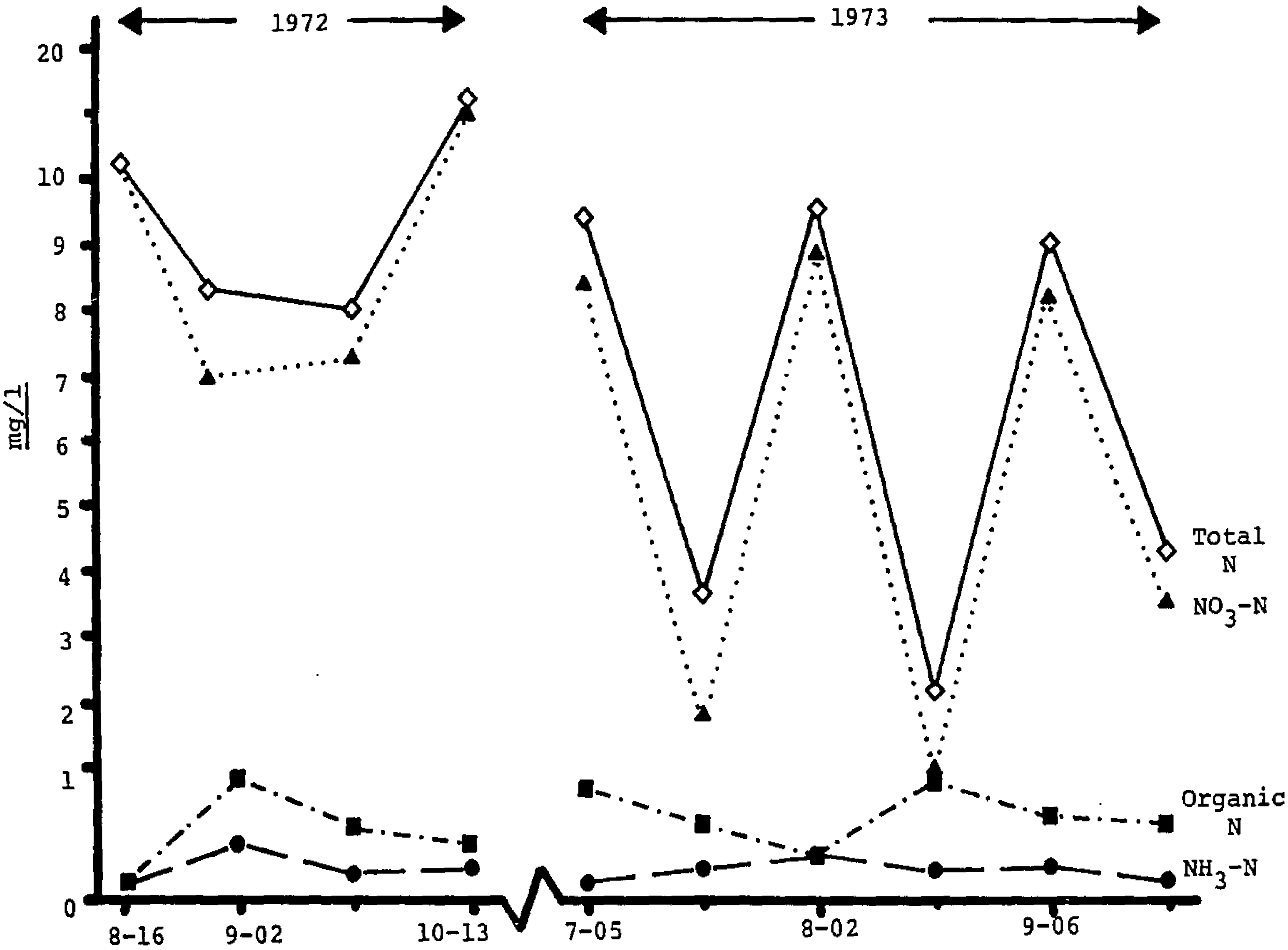

1972
1973
mg/1
20
10
9
8
7
6
5
4
3
2
1
0
8-16
9-02
10-13
7-05
8-02
9-06
Total N
NO_3-N
Organic N
NH_3-N

Figure 41. NH_3-N, NO_3-N, Organic N, and Total N concentrations at the 30 cm depth for the 75 mm/week of wastewater irrigation rate, Lott Woodlot, 1972 and 1973.



1972
1973
mg/1
20
10
9
8
7
6
5
4
3
2
1
0
8-16
9-02
10-13
7-05
8-02
9-06
Total N
NO_3-N
Organic N
NH_3-N

levels continued very stable (97% renovation). While Organic N concentrations were up only slightly above 1972 levels, renovation decreased to 15% as a result of lower Organic N in the wastewater.

60 cm: 50 mm/week of Well Water

Average concentrations of NH_3-N, NO_3-N, Organic N, and Total N found in soil solution of plots irrigated with 50 mm/week of well water are illustrated in Figure 42. All values during 1972 and 1973 represent the amount of flushing of each nitrogen form that occurred with irrigation. In 1972 NO_3-N made up a greater proportion of the Total N concentration. However, in 1973 Organic N accounted for more of the Total N value than did NO_3-N. NH_3-N stayed fairly uniform over the two-year period while NO_3-N levels declined and Organic N levels increased somewhat.

60 cm: 25 mm/week of Wastewater

Figure 43 presents the average values of NH_3-N, NO_3-N, Organic N, and Total N for the 25 mm/week of wastewater plots at 60 cm depth. Most of the values during 1972 and 1973 were quite similar to those at the 30 cm depth (Figure 39). Renovations were 99, 22, 76, and 52% in 1972 and 98, 0, 71, and 10% in 1973 for the NH_3-N, NO_3-N, Organic N, and Total N forms respectively.

Figure 42. NH_3-N, NO_3-N, Organic N, and Total N concentrations at the 60 cm depth for the 50 mm/week of well water irrigation rate, Lott Woodlot, 1972 and 1973.

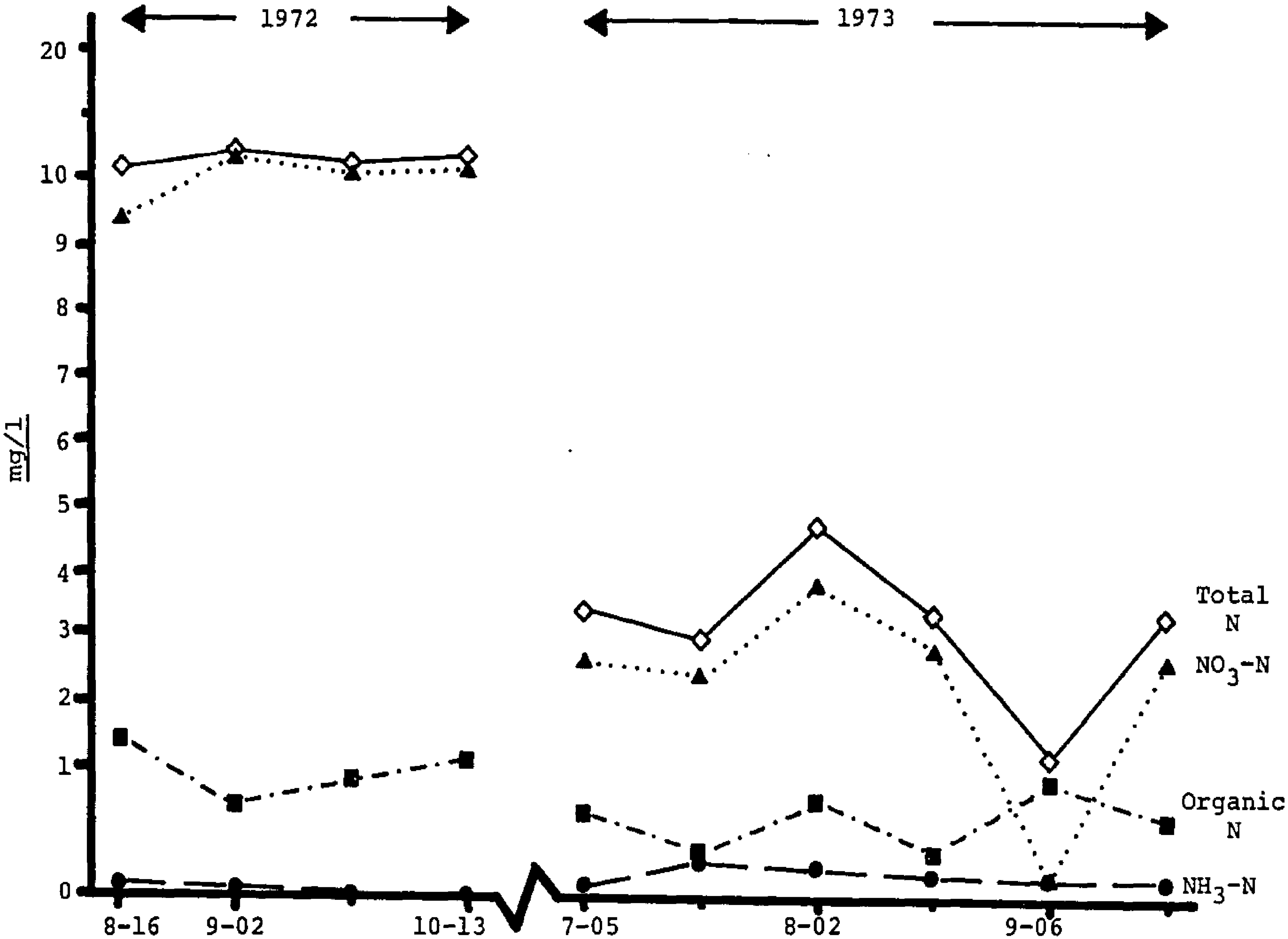
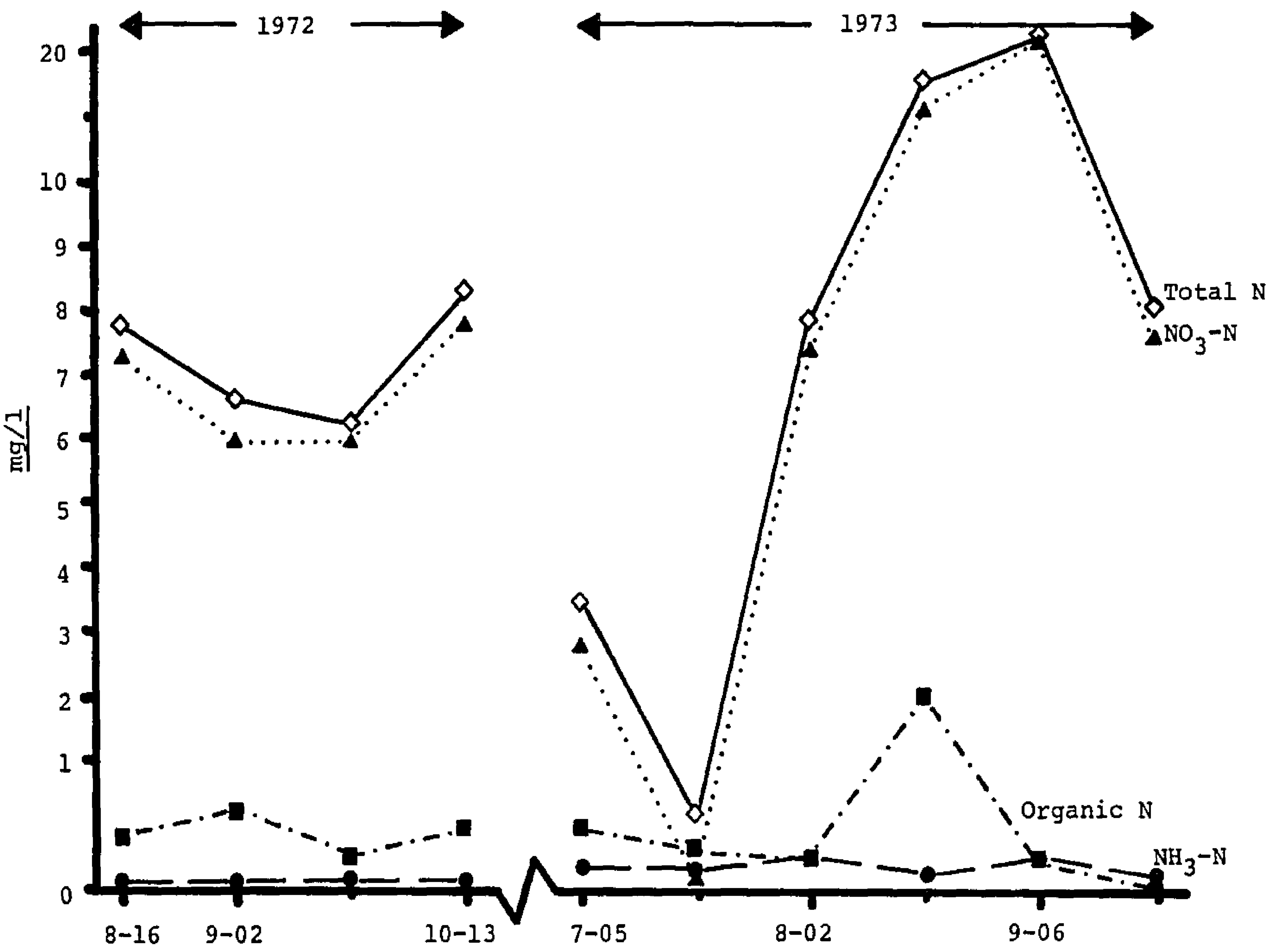

1972
1973
20
10
9
8
7
6
5
4
3
2
1
0
mg/l
8-16
9-02
10-13
7-05
8-02
9-06
Total N
NO_3-N
Organic N
NH_3-N

Figure 43. NH_3-N, NO_3-N, Organic N, and Total N concentrations at the 60 cm depth for the 25 mm/week of wastewater irrigation rate, Lott Woodlot, 1972 and 1973.


1972
1973
20
10
9
8
7
6
5
4
3
2
1
0
mg/l
Total N
NO_3-N
Organic N
NH_3-N
8-16
9-02
10-13
7-05
8-02
9-06

Higher renovation values in 1972 were due to the lack of ground water recharge in August. Thus, the renovations for that month were all 100%.

60 cm: 50 mm/week of Wastewater

Figure 44 illustrates the changes in NH_3-N, NO_3-N, Organic N, and Total N at 60 cm with 50 mm/week of wastewater irrigation. The 1972 NO_3-N values were typically high and accounted for much of the Total N in the soil solution. Renovations were 99, 0, 38, and 8% for the NH_3-N, NO_3-N, Organic N, and Total N forms respectively.

In 1973 the NO_3-N levels dropped considerably but still accounted for a large percentage of Total N. However, Total N renovation improved considerably rising to 71%. Renovation for the other three nitrogen forms held fairly constant.

60 cm: 75 mm/week of Wastewater

Flushing of NO_3-N was very pronounced at the 75 mm/week irrigation rate during 1972 and 1973 (Figure 45). In 1972, NO_3-N values were consistently above 10 mg/l. As has been quite evident in many of the other rates and at both lysimeter depths, NH_3-N and Organic N concentrations were fairly low. Percent renovations were 97 and 83% for the NH_3-N and Organic N forms, but 0% for the other two forms.

Figure 44. NH_3-N, NO_3-N, Organic N, and Total N concentrations at the 60 cm depth for the 50 mm/week of wastewater irrigation rate, Lott Woodlot, 1972 and 1973.

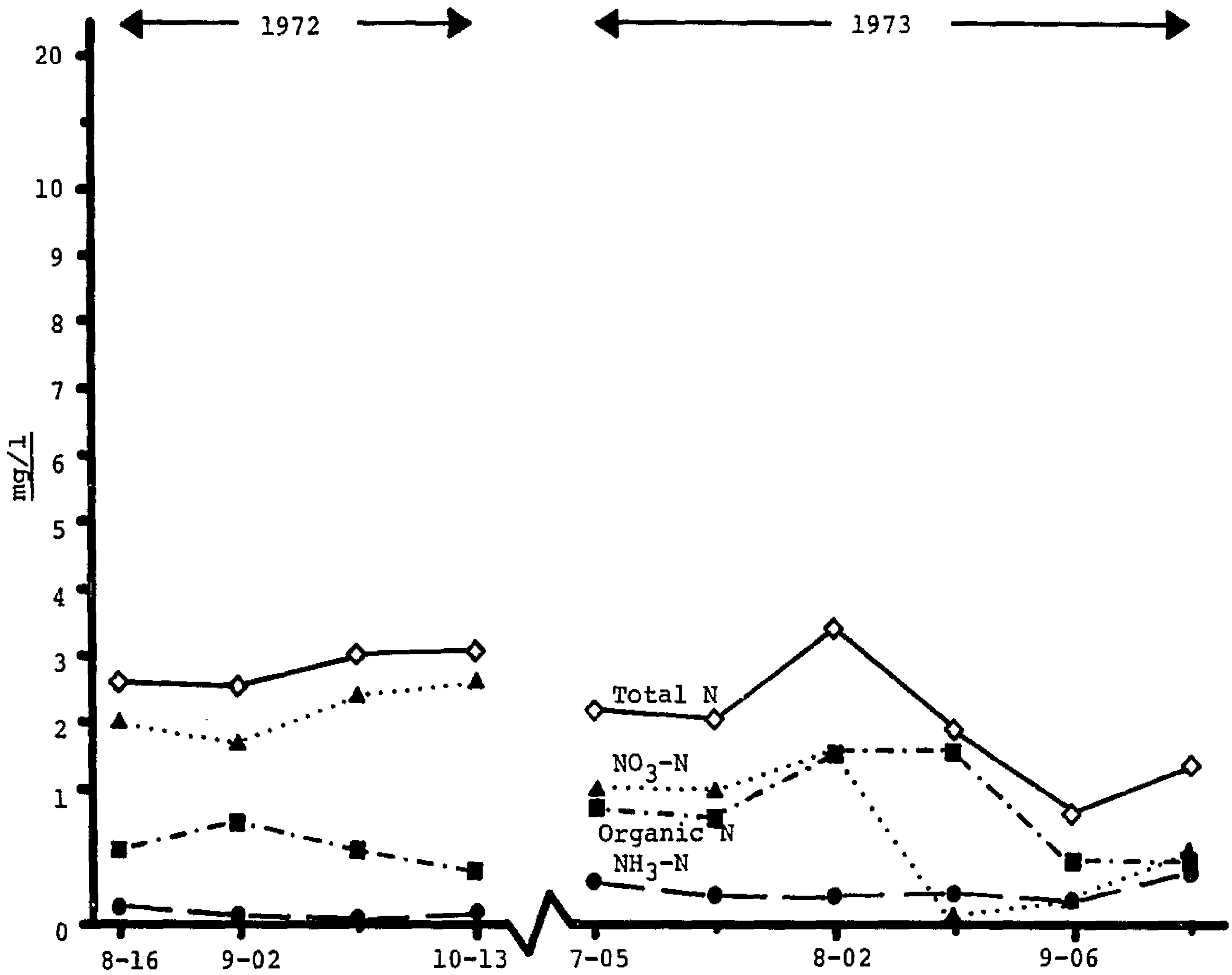
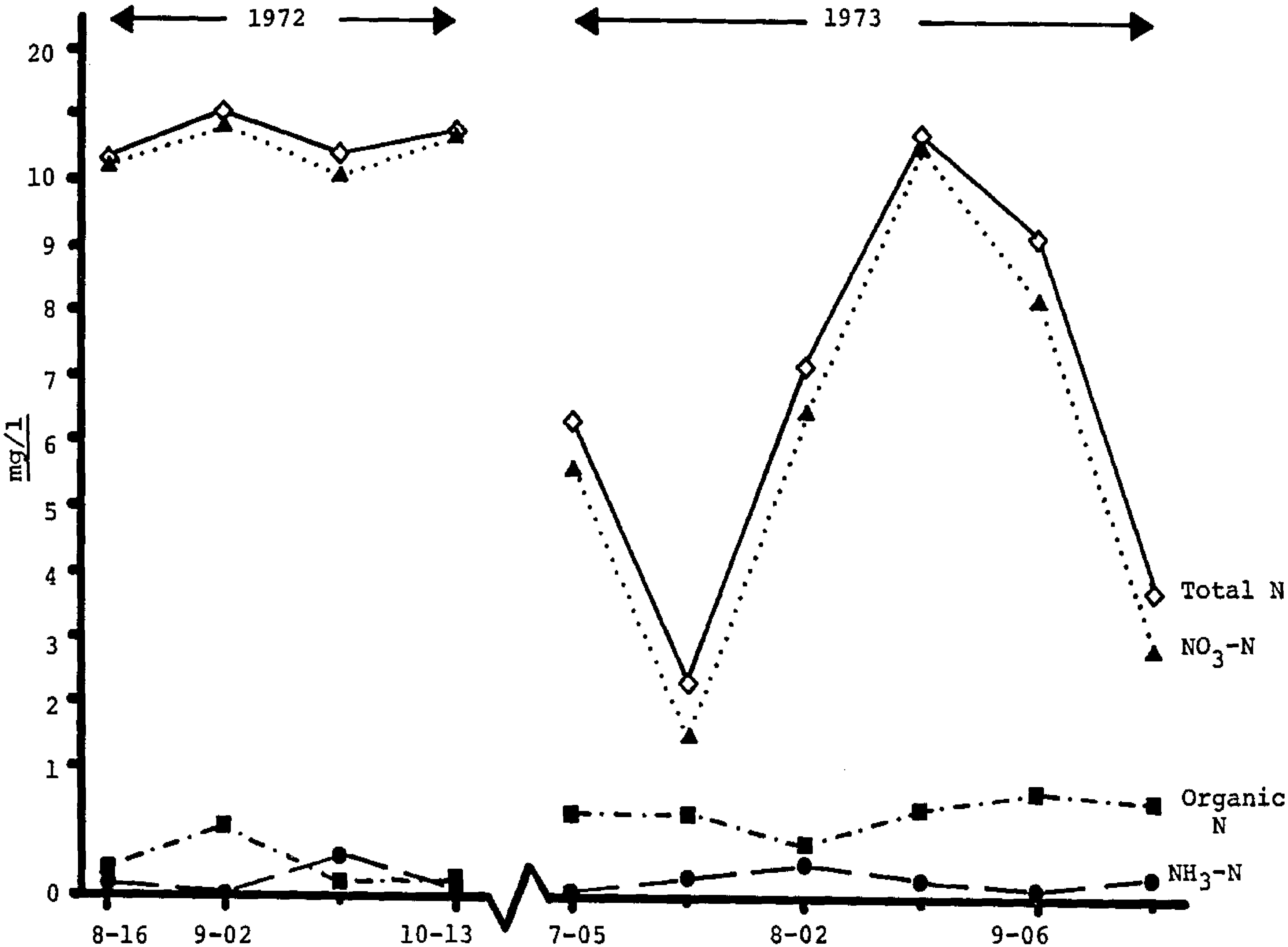

1972
1973
mg/l
20
10
9
8
7
6
5
4
3
2
1
0
Total N
NO_3-N
Organic N
NH_3-N
8-16
9-02
10-13
7-05
8-02
9-06

Figure 45. NH_3-N, NO_3-N, Organic N, and Total N concentrations at the 60 cm depth for the 75 mm/week of wastewater irrigation rate, Lott Woodlot, 1972 and 1973.


1972
1973
20
10
9
8
7
6
5
4
3
2
1
0
mg/1
Total N
NO_3-N
Organic N
NH_3-N
8-16
9-02
10-13
7-05
8-02
9-06

In 1973, the NO_3-N flushing continued but was not as uniform across the irrigation season. Organic N concentrations increased despite lower Organic N inputs (Table 24). NH_3-N levels changed very little during the 1973 irrigation season. Renovations were 98, 0, 7, and 26% for the NH_3-N, NO_3-N, Organic N, and Total N forms respectively.

Nitrogen Summary

The dominant trend in the Lott Woodlot water quality data has been the NO_3-N flushing. A perfect example of the overall flushing process can be seen in the data for the 75 mm/week of wastewater irrigation rate at 60 cm lysimeter depth during 1973. About 81% (97.5 kg/ha) of the nitrogen applied by irrigation was in the NH_3-N form. However, 87% (76.9 kg/ha) of the Total N reaching the lysimeters was in the form of NO_3-N. Since total NO_3-N loading for that rate in 1973 was only 12.0 kg/ha, 64.9 kg/ha of the NO_3-N had to therefore come from NH_3-N which was oxidized in normal soil nitrogen transformations. While the Lott Woodlot soil-plant filtering system produced a 96% renovation on the bulk of the nitrogen applied in the wastewater (NH_3-N), much of this was later lost as NO_3-N. Nitrogen losses as NO_3-N accounted for 64% of the Total N loading of 120.0 kg/ha.

The major factor contributing to the loss of nitrogen as NO_3-N in Lott Woodlot is attributed to the hourly rate at which wastewater was applied. The gravity-feed irrigation system used in the Lott Woodlot required that the valves on the reservoirs be operated in the "wide-open" position to insure adequate spread of irrigation water. Attempts to reduce the flow produced minimum lateral dispersion from the PVC pipe distribution system. In the "wide-open" valve position, wastewater was distributed on the plots at a rate of 50 mm/hour.

Most well-structured and drained forest soils can infiltrate precipitation at rates much greater than 50 mm/hour (Lull and Reinhart, 1972), however, such high infiltration rates also promote NO_3-N flushing. NO_3-N is a very mobile form of nitrogen and moves quite easily with any pulse of infiltrating water. Thus lysimeters in Lott Woodlot were sampling soil water containing NO_3-N that was both originally present in the wastewater and flushed out of the soil.

Total Phosphorus

Despite some initial variability in 1972, Total P was generally stable at both the 30 and 60 cm soil depths (Figures 46 and 47). Renovation was greater than 96% for all treatments except with the 50 mm of

Figure 46. Total P concentrations at the 30 cm depth, Lott Woodlot, 1972 and 1973.

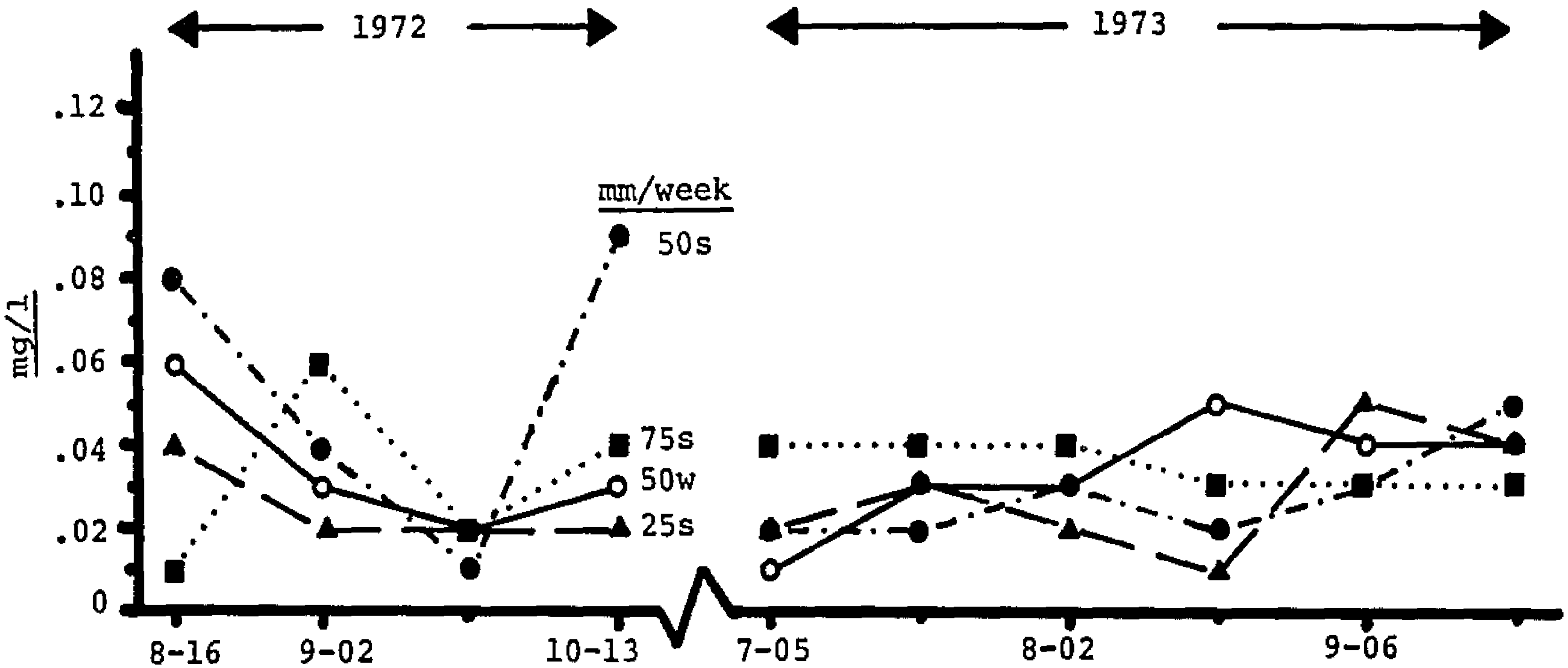
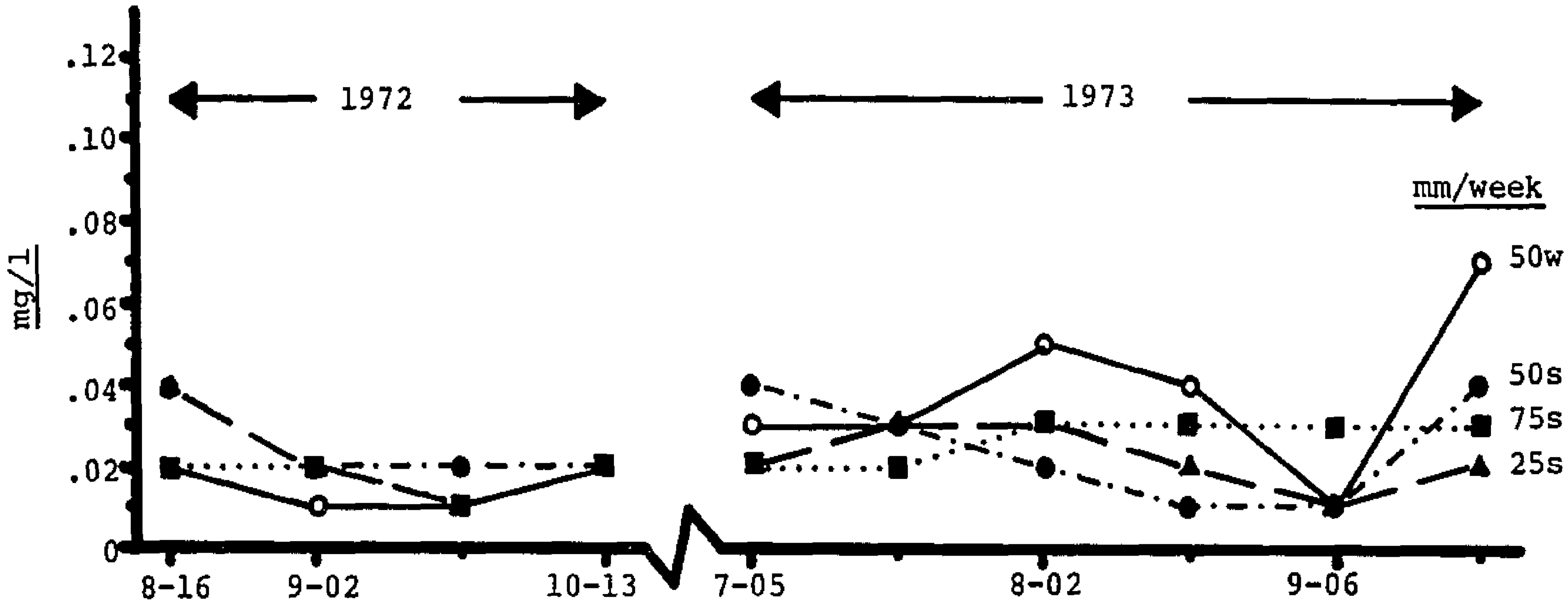

1972
1973
mg/l
.12
.10
.08
.06
.04
.02
0
mm/week
50s
75s
50w
25s
8-16
9-02
10-13
7-05
8-02
9-06

Figure 47. Total P concentrations at the 60 cm depth, Lott Woodlot, 1972 and 1973.


mg/l
.12
.10
.08
.06
.04
.02
0
1972
1973
mm/week
50w
50s
75s
25s
8-16
9-02
10-13
7-05
8-02
9-06

well water. That particular treatment exhibited a flushing effect here with Total P as it did with the other four nutrient parameters.

Vegetation

The Lott Woodlot is a typical second growth hardwood stand found on many southern Michigan farms. It is dominated by sugar maple (*Acer saccharum* Marsh.), slippery elm (*Ulmus rubra* Muhl), prickly ash (*Zanthoxylum americanum* Mill.), American beech (*Fagus grandifolia* Ehrh.), hophornbeam (*Ostrya virginiana* [Mill.] K. Kosch), black cherry (*Prunus serotina* Ehrh.) and black maple (*Acer nigrum* Michx. F.) which make up 72% of the stand. High-graded by its former owners, the woodlot contains numerous over-mature hardwoods of low quality and a dense understory of small diameter trees. In this pilot study, analysis of plant response to wastewater irrigation was limited to tree seedlings and herbaceous plants found on the treatment plots.

Summer Flora

The herbaceous plants and tree seedlings occupying the wastewater irrigation plots were surveyed in August of 1972 and 1973 (Table 28). The 15 plots located on Miami loam were dominated by hairy blue violet (*Viola sororia* Willd.), sugar maple, stinging nettle (*Urtica dioica* L.), Virginia creeper (*Parthenocissus*

Table 28. Vegetative abundance for 15 irrigated plots on Miami loam, Lott Woodlot, 1972 and 1973.

	Species	Number/0.006 ha[1]			Number/ha		
		1972	1973	Change	1972	1973	Change
1.	*Acer saccharum*	95	361	+ 266	15,865	60,287	+44,422
2.	*Carex pennsylvanica*	114	135	+ 21	19,038	22,545	+ 3,507
3.	*Carya ovata*	11	10	- 1	1,837	1,670	- 167
4.	*Daucus carota*	9	9	0	1,503	1,503	0
5.	*Euonymus spp.*	19	19	0	3,173	3,173	0
6.	*Fagus grandifolia*	5	9	+ 4	835	1,503	+ 668
7.	*Fraxinus americana*	17	20	+ 3	2,839	3,340	+ 501
8.	*Ostrya virginiana*	2	2	0	334	334	0
9.	*Parthenocissus quinquefolia*	60	119	+ 59	10,020	19,873	+ 9,853
10.	*Podophyllum peltatum*	44	72	+ 28	7,348	12,024	+ 4,676
11.	*Prunus pennsylvanica*	1	1	0	167	167	0
12.	*P. serotina*	9	3	- 6	1,503	501	- 1,002
13.	*P. virginiana*	2	1	- 1	334	167	- 167
14.	*Quercus alba*	1	2	+ 1	167	334	+ 167
15.	*Q. rubra*	1	2	+ 1	167	334	+ 167
16.	*Ribes cynosbati*	10	26	+ 16	1,670	4,342	+ 2,672
17.	*Sambucus canadensis*	3	3	0	501	501	0
18.	*Sanguinaria canadensis*	13	31	+ 18	2,171	5,177	+ 3,006
19.	*Senecio plattensis*	4	4	0	668	668	0
20.	*Smilacina stellata*	8	5	- 3	1,336	835	- 501
21.	*Thallictrum dioicum*	33	9	- 24	5,511	1,503	- 4,008
22.	*Tilia americana*	2	2	0	334	334	0
23.	*Toxicodendron radicans*	43	48	+ 5	7,181	8,016	+ 835
24.	*Ulmus americana*	44	39	- 5	7,348	6,513	- 835
25.	*Urtica dioica*	112	147	+ 35	18,704	24,549	+ 5,845
26.	*Viola canadensis*	14	17	+ 3	2,338	2,839	+ 501
27.	*V. eriocarpa*	31	18	- 13	5,177	3,006	- 2,171
28.	*V. sororia*	347	505	+ 158	57,949	84,335	+26,386
29.	*Xanthaxylum americanum*	2	0	- 2	334	0	- 334
	Totals	1,056	1,619	+ 563	176,352	270,373	+94,021

[1]Each plot is 0.0004 ha (1 milacre).

quinquefolia [L.] Planch.), May apple (*Podophyllum peltatus* L.), poison ivy (*Toxicodendron radicans* L.), and bloodroot (*Sanguinaria canadensis* L.).

Changes in occurrence and percent frequency have taken place with irrigation over the two-year period (Table 29). The largest change in percent frequency occurred in the following species: hairy blue violet, sugar maple, sedge (*Carex pennsylvanica* Lam.), American elm (*Ulmus Americana* L.), Virginia creeper, white ash (*Fraxinus Americana* L.), and smooth yellow violet (*Viola eriocarpa* Schwein.).

A statistical analysis of these seven species was conducted to determine significance of wastewater irrigation upon species abundance (Table 30). While distinct increases and decreases in species numbers were noted in certain treatments, such differences were not statistically significant.

As wastewater irrigation treatments are continued, shifts in species composition may occur. Several visible plant responses to wastewater irrigation have been noted which may eventually lead to significant changes in the plant composition, biomass, or distribution. During the droughty period of July and August, most herbaceous plants outside of the irrigated plots consistently wilted by mid-afternoon whereas plants within the irrigated plots remained turgid.

Table 29. Frequency and occurrence of vegetative cover for the 15 plots on Miami loam, Lott Woodlot, 1972 and 1973.

Species	Occurrence[1]			% Frequency		
	1972	1973	Change	1972	1973	Change
1. *Acer saccharum*	10	10	0	67	67	0
2. *Carex pennsylvanica*	12	10	- 2	80	67	-13
3. *Carya ovata*	4	3	- 1	27	20	- 7
4. *Daucus carota*	2	2	0	13	13	0
5. *Euonymus spp.*	1	1	0	7	7	0
6. *Fagus grandifolia*	3	4	+ 1	20	27	+ 7
7. *Fraxinus americana*	5	8	+ 3	33	53	+20
8. *Ostrya virginiana*	1	1	0	7	7	0
9. *Parthenocissus quinquefolia*	10	9	- 1	67	60	- 7
10. *Podophyllum peltatum*	3	5	+ 2	20	33	+13
11. *Prunus pennsylvanica*	1	1	0	7	7	0
12. *P. serotina*	3	2	- 1	20	13	- 7
13. *P. virginiana*	1	1	0	7	7	0
14. *Quercus alba*	1	1	0	7	7	0
15. *Q. rubra*	1	2	+ 1	7	13	+ 6
16. *Ribes cynosbati*	3	5	+ 2	20	33	+13
17. *Sambucus canadensis*	1	1	0	7	7	0
18. *Sanguinaria canadensis*	3	3	0	20	20	0
19. *Senecio plattensis*	1	1	0	7	7	0
20. *Smilacina stellata*	2	2	0	13	13	0
21. *Thallictrum dioicum*	5	4	- 1	33	27	- 6
22. *Tilia americana*	2	2	0	13	13	0
23. *Toxicodendron radicans*	3	2	- 1	20	13	- 7
24. *Ulmus americana*	10	10	0	67	67	0
25. *Urtica dioica*	3	2	- 1	20	13	- 7
26. *Viola canadensis*	4	4	0	27	27	0
27. *V. eriocarpa*	9	6	+ 3	60	40	-20
28. *V. sororia*	12	12	0	80	80	0
29. *Xanthoxylum americanum*	1	1	0	7	7	0

[1]Each plot is .0004 ha. (1 milacre).

Table 30. Influence of irrigation on actual vegetative count for the most commonly occurring ground cover species, Lott Woodlot, 1972 and 1973.[1]

Species	Year	mm Irrigation per Week				
		0	50 w	25 s	50 s	75 s
1. Acer saccharum	1972	7.0	4.6	5.3	5.7	9.0
	1973	21.3	10.3	6.0	24.3	58.3
2. Carex pennsylvanica	1972	16.7	6.7	10.7	10.7	3.3
	1973	16.7	7.0	6.0	10.7	4.7
3. Fraxinus americana	1972	0.7	0.7	1.7	2.7	0.0
	1973	0.7	0.7	1.3	3.0	1.0
4. Parthenocissus quinquefolia	1972	6.0	0.3	1.3	3.0	9.3
	1973	12.3	0.3	4.0	1.7	21.3
5. Ulmus americana	1972	5.7	5.3	0.7	1.7	1.7
	1973	3.7	5.3	0.7	2.3	1.3
6. Viola eriocarpa	1972	3.0	1.3	4.3	0.7	1.0
	1973	0.7	0.7	3.3	0.7	0.7
7. V. sororia	1972	10.7	1.3	38.0	36.7	29.0
	1973	19.7	18.7	52.0	47.7	30.3

[1]No significance at the 5% level (Tukey's test) with treatment.

Irrigation also appeared to extend the growing season in species such as *Podophyllum peltatus* and *Viola sororia*. While most plants in unirrigated plots die back by October 10th, such plants in irrigated plots were still vigorous.

Spring Flora

Dominant spring plants on the study area in Lott Woodlot are: spring beauty (*Claytonia virginica* L.), *Anemone* spp., Dutchman's breeches (*Dicentra cucullaria* [L.] Vernh.), toothwart (*Dentaria* spp.), violets (*Viola* spp.), yellow adder's-tongue (*Erythronium americanum* Ker.), bedstraw (*Galium* spp.), and sugar maple seedlings. To determine the extent to which wastewater irrigation affected vegetative growth and nutrient content, a 0.25 m^2 sample was taken of ground cover plants occupying the study plots in the spring of 1974.

The data gathered in this sampling indicated that the irrigation treatments thus far had negligable effect on biomass production (Tables 31 and 32). Leaf biomass for the sugar maple was somewhat lower in irrigated plots, but the reductions were not significant. The 50 and 75 mm of wastewater/week treatments produced slightly higher herbaceous plant biomass but again not significantly.

Nutrient contents of the plants sampled for biomass determinations are shown in Tables 33 and 34. As

Table 31. Composite biomass of spring herbaceous species by wastewater irrigation rate, Lott Woodlot, 1974.[1]

Irrigation Rate	Irrigation Type	Wet Weight Biomass	Dry Weight Biomass	% Moisture
mm/week		--------------g/m^2	----------	%-----
0	None	328.7	78.1	396
50	Well water	204.0	37.6	479
25	Wastewater	287.3	51.7	469
50	Wastewater	455.9	99.1	435
75	Wastewater	451.6	91.2	428

Table 32. Leaf biomass of 10 randomly chosen sugar maple seedlings in each plot of the Lott Woodlot wastewater irrigation study, 1974.[1]

Irrigation Rate	Irrigation Type	Wet Weight Biomass	Dry Weight Biomass	% Moisture
mm/week		----------g	----------------	%-----
0	None	11.9	4.0	196
50	Well water	8.9	3.0	203
25	Wastewater	9.7	3.2	196
50	Wastewater	11.8	3.8	201
75	Wastewater	9.5	3.1	198

[1]No significant difference with treatment at the 5% level (Tukey's test).

Table 33. Foliar nutrient content of composite sample of 10 sugar maple seedlings by irrigation rate, Lott Woodlot, 1974.[1]

Parameter	Unit	mm Irrigation/week				
		Control	Well Water	Wastewater		
		0	50	25	50	75
N	%[2]	2.29	2.17	2.37	2.15	2.28
K	%	0.99	0.98	1.04	1.03	1.00
P	%	0.15	0.15	0.18	0.16	0.15
Na	ppm[3]	450.7	602.3	496.3	462.7	422.3
Ca	%	0.48	0.58	0.50	0.49	0.45
Mg	%	0.17	0.18	0.18	0.17	0.19
Mn	ppm	130.3	108.0	234.0	212.0	58.0
Fe	ppm	90.0	81.0	105.0	98.0	78.0
Cu	ppm	4.8	4.5	7.5	6.5	2.3
B	ppm	16.5	17.7	17.9	19.8	19.8
Zn	ppm	19.3	21.3	20.0	21.7	11.3
Al	ppm	1.0	1.0	1.0	1.0	1.0

[1]No significant difference with treatment at the 5% level (Tukey's test).

[2]Percent of dry weight.

[3]ppm = μg/g.

Table 34. Composite nutrient content of spring herbaceous species by irrigation rate, Lott Woodlot, 1974.[1]

Parameter	Unit	mm of Irrigation Per Week				
		Control	Well Water	Wastewater		
		0	50	25	50	75
N	%[2]	2.23	2.39	1.87	2.01	2.18
K	%	2.01	2.48	2.36	2.27	2.47
P	%	0.14	0.13	0.13	0.13	0.15
Na	ppm[3]	648.0	646.3	735.0	685.0	714.3
Ca	%	0.89	1.27	0.94	0.88	1.08
Mg	%	0.27	0.40	0.44	0.42	0.36
Mn	ppm	92.0	56.0	94.3	75.0	72.0
Fe	ppm	680.0	290.7	785.3	424.7	584.0
Cu	ppm	16.1	8.3	46.9	8.9	26.1
B	ppm	16.8	14.9	17.1	15.2	16.1
Zn	ppm	45.0	67.7	71.3	46.7	58.3
Al	ppm	886.0	253.3	940.0	428.7	613.0

[1]No significant difference with treatment at the 5% level (Tukey's test).

[2]Percent of dry weight.

[3]ppm = μg/g.

for biomass, no significant treatment-related differences were noticeable. The sugar maple leaves had higher manganese and boron levels and lower potassium, sodium, calcium, magnesium, iron, copper, zinc, and aluminum levels than the herbaceous species. Nitrogen and phosphorus levels were comparable in both sugar maple and the composite of all the herbaceous species.

Tree seedlings and herbaceous vegetation can exhibit considerable response to wastewater irrigation (Little *et al.*, 1959, and Sopper and Kardos, 1973). Such significant differences have not as yet been detected in the Lott Woodlot study. This may be due to either (1) an insufficient length of irrigation or (2) the mode of applying the wastewater.

Soil Chemistry

The effects of two years of wastewater irrigation on pH, available phosphorus, total Kjeldahl nitrogen, loss on ignition, and exchangeable potassium, calcium, and magnesium are shown in Table 35. Considerable variability exists in the Lott Woodlot soil chemistry data and the detection of existing trends thus becomes difficult. Part of this variability is undoubtably associated with the method of wastewater application. Spray irrigation distributes water much more uniformly than does trickle irrigation and does so over a more prolonged period of time.

Table 35. Average soil chemistry parameters of Miami loam for 0-60 cm depth, Lott Woodlot, after two years of irrigation treatments.

Parameter	Units	Irrigation (mm/week)				
		Control	Wellwater	Wastewater		
		0	50	25	50	75
pH	--	5.7 a	6.1 ab	6.2 ab	6.4 b	6.7 b
P	kg/ha	14.9 a	13.3 a	10.0 a	12.7 a	16.8 a
K	kg/ha	94.1 a	170.2 b	97.1 a	110.5 a	105.3 a
Ca	kg/ha	1458.0 a	2046.8 a	1668.9 a	1546.0 a	2002.8 a
Mg	kg/ha	139.7 a	355.2 b	224.1 ab	230.8 ab	278.9 b
N	kg/ha	2151.0 a	1852.2 a	1802.4 a	1493.7 a	1453.9 a
Loss on Ignition	%	3.4 a	3.7 a	3.4 a	2.8 a	3.1 a

[1]Means not followed by the same letter are significantly different at the 5% level (Tukey's test).

pH

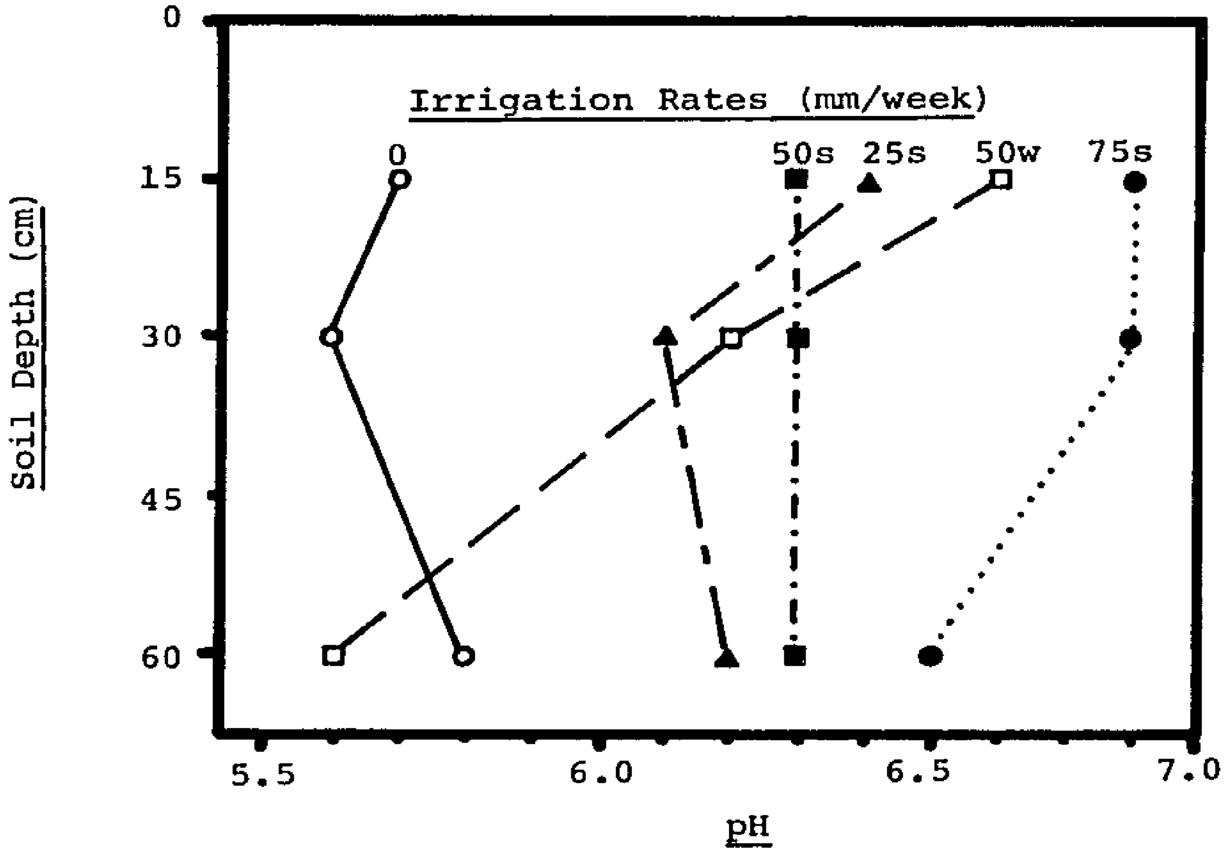
Application of municipal wastewater to the Miami loam soil in the Lott Woodlot altered the pH of the upper 60 cm of soil (Figure 48A). In the unirrigated plots the pH was uniform, varying from 5.7 in the upper 15 cm to 5.8 at 60 cm. With irrigation rates of 25, 50, and 75 mm/week, the pH at 15 cm increased to 6.4, 6.3, and 6.8 respectively. The plots with 50 mm/week of well water had a pH of 6.6. The magnitude of the increase in pH with irrigation decreased with increased soil depth for all four irrigation rates. However, the 50 mm/week of well water rate decreased the most with depth, and at 60 cm was lower than in the unirrigated control plots. None of the five treatments exhibited significant variations associated with soil depth. At 15 cm, irrigated plots were significantly higher in pH than were the control. But at 60 cm only the highest two wastewater irrigation rates had a pH significantly greater than the controls.

Phosphorus

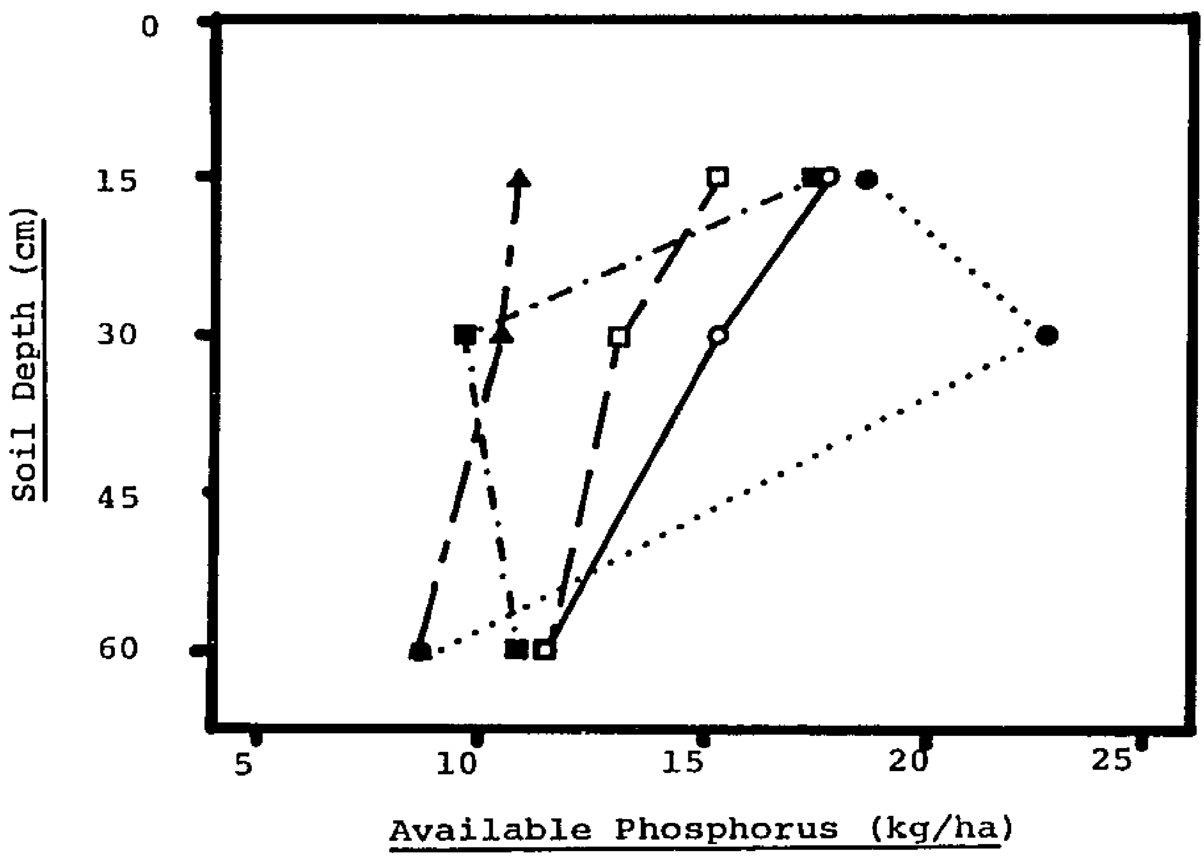
The distribution of available phosphorus within the upper 60 cm of soil in Lott Woodlot is illustrated in Figure 48B. No significant differences were noted between treatment of soil depth. The low available phosphorus levels, while unusual for this soil texture

Figure 48. Changes in (A) pH and (B) available phosphorus with soil depth and irrigation rates, Lott Woodlot, 1973.

(A)


Irrigation Rates (mm/week)
0
50s
25s
50w
75s
Soil Depth (cm)
0
15
30
45
60
5.5
6.0
6.5
7.0
pH

(B)


Soil Depth (cm)
0
15
30
45
60
5
10
15
20
25
Available Phosphorus (kg/ha)

and pH, are typical of forest stands which occupy sites with no previous history of cultivation. Under such conditions humic phosphorus normally cannot be extracted with Bray's P1 solution, although it is still available to plants.

Potassium

The extractable potassium content of the Miami loam soil in Lott Woodlot showed significant differences related to soil depth (Figure 49A). Plots with 25 mm/week of wastewater irrigation, 50 mm/week of well water irrigation, and nonirrigated controls were significantly higher in potassium at 15 cm depth than at 30 cm depth. The remaining treatments did not show any significant differences due to soil depth.

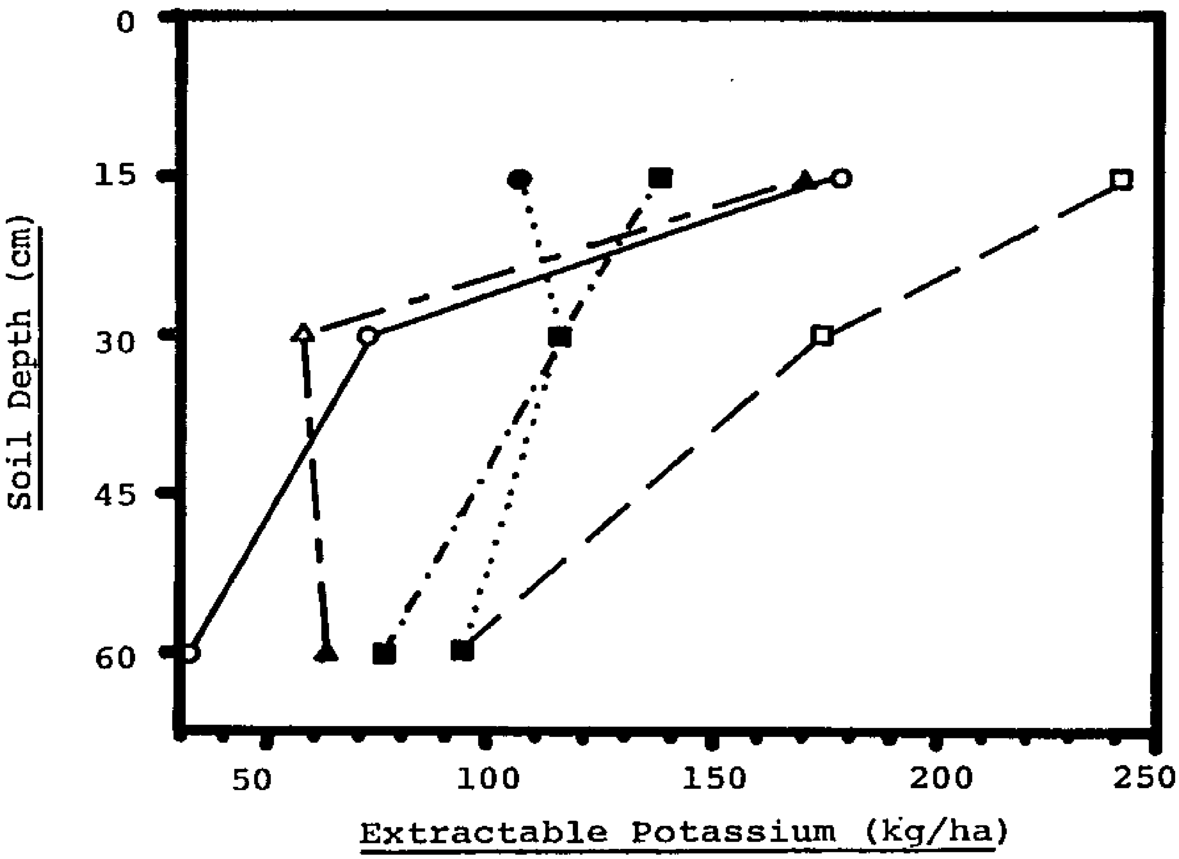
No obvious treatment patterns were observed for potassium content. At 15 cm, the control, 50 mm/week of well water, and 25 mm/week of wastewater treatments were significantly higher (179.2, 241.9, and 170.2 kg/ha respectively) than the 75 mm/week of wastewater rate (107.5 kg/ha).

Calcium

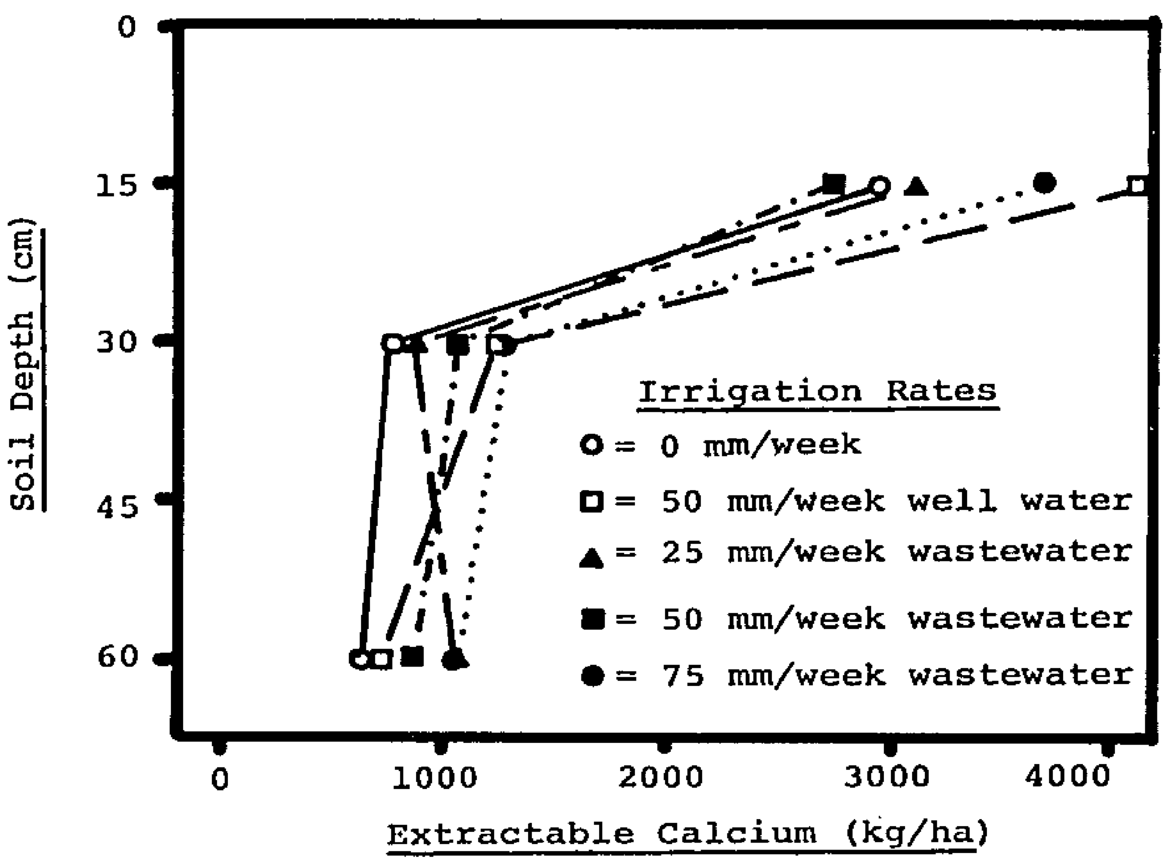
The levels of extractable calcium in the soil in Lott Woodlot ranged from 4190.0 to 2740.6 kg/ha at the 15 cm depth but were not affected by wastewater irrigation. Significant differences within treatments,

Figure 49. Changes in (A) extractable potassium and (B) extractable calcium with soil depth and irrigation rates, Lott Woodlot, 1973.

(A)


0
15
30
45
60
Soil Depth (cm)
50
100
150
200
250
Extractable Potassium (kg/ha)

(B)


0
15
30
45
60
Soil Depth (cm)
Irrigation Rates
= 0 mm/week
= 50 mm/week well water
= 25 mm/week wastewater
= 50 mm/week wastewater
= 75 mm/week wastewater
0
1000
2000
3000
4000
Extractable Calcium (kg/ha)

however, were noted with depth. Calcium content was considerably higher at the 15 cm depth than at the 30 or 60 cm depths (Figure 49B).

Magnesium

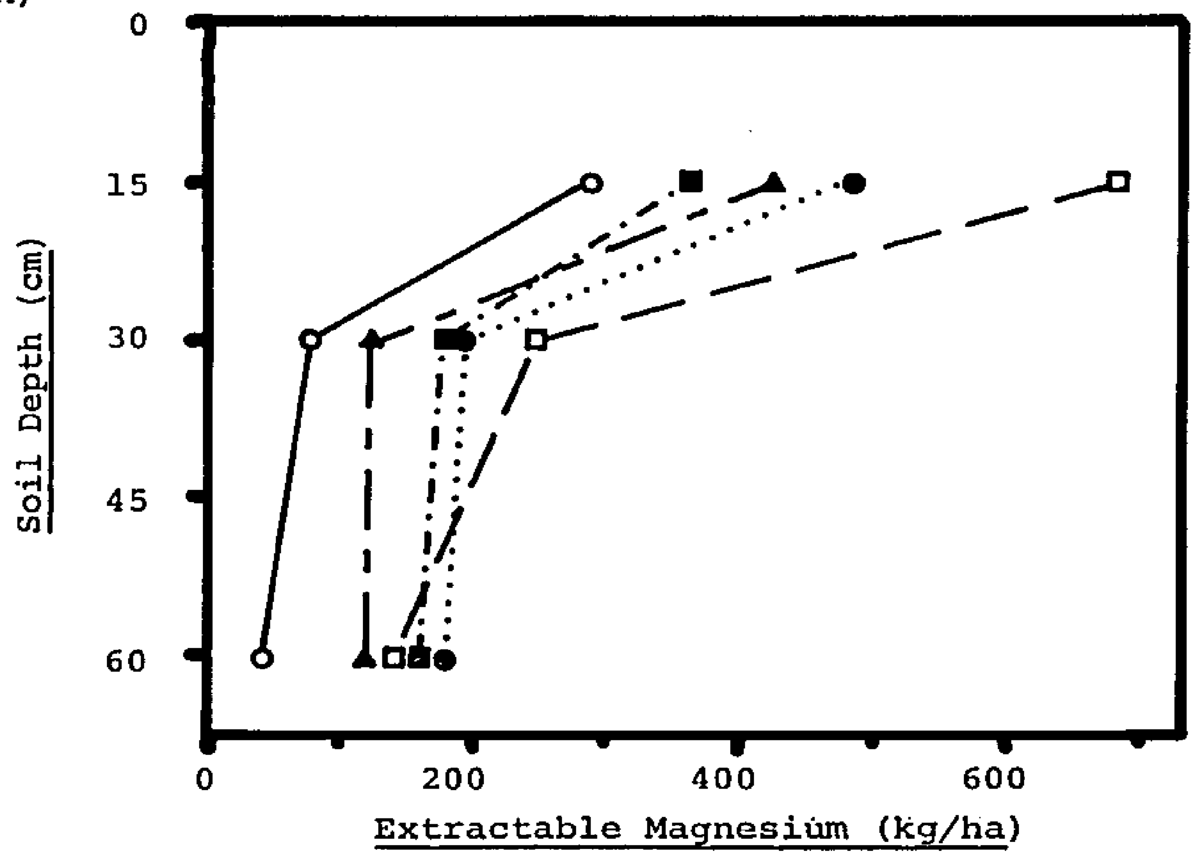
Changes were evident in the exchangeable magnesium contents of the Miami loam soil which reflected the application of irrigation waters (Figure 50A). At 15 cm magnesium levels in the soils of all four irrigation treatments (678.8, 419.6, 362.9, and 482.2 kg/ha) were higher than the control (243.1 kg/ha). Magnesium in the 75 mm/week of wastewater and 50 mm/week of well water plots were significantly higher than that of the control. At 30 cm only the well water treatment was significantly higher in exchangeable magnesium than the control. At 60 cm the four irrigated plots were still higher than the control but not significantly. The higher magnesium levels associated with the well water treatment, for both the 15 and 30 cm soil depth, when compared to the lower levels related to the wastewater treatments is unexplained.

Nitrogen

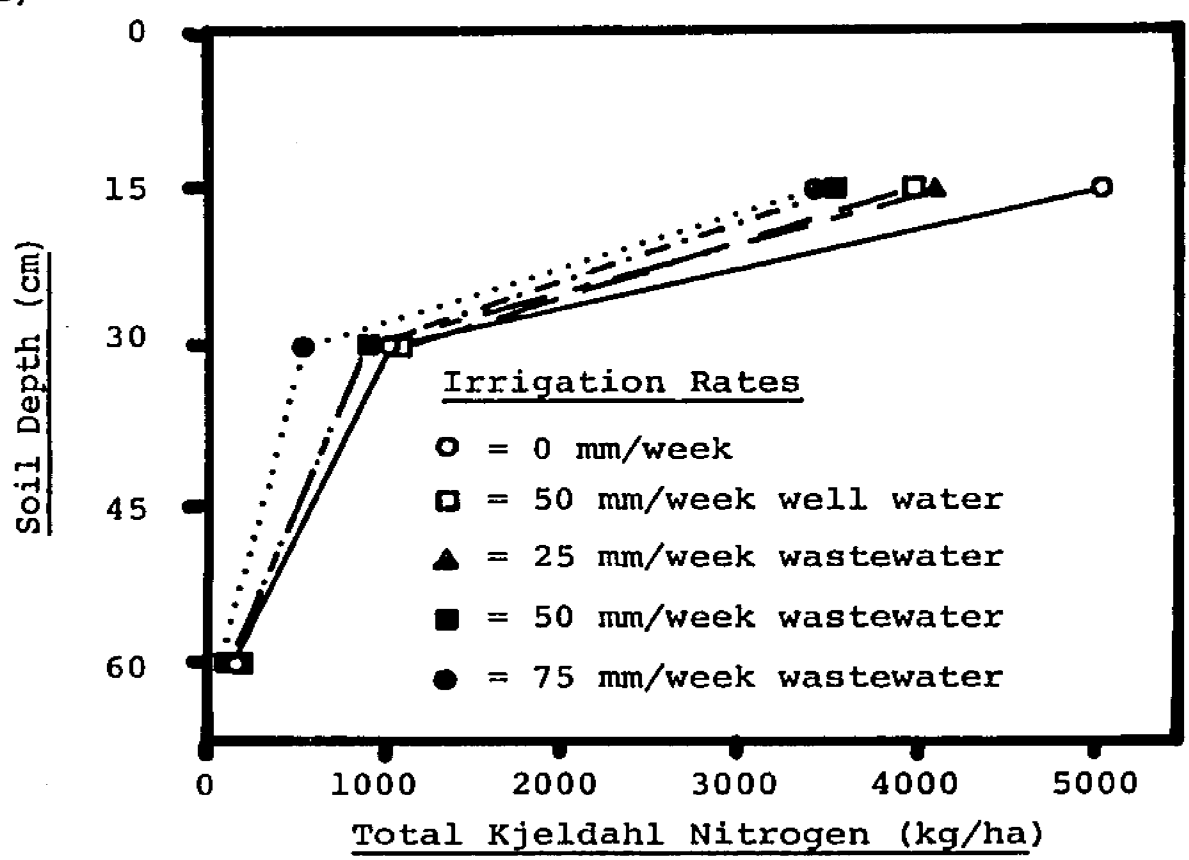
Total Kjeldahl nitrogen exhibited considerable decrease with increased depth (Figure 50B). The nitrogen content showed a gradual decline with irrigation (5108.6 kg/ha in control plots to 3465.5 kg/ha in the

Figure 50. Changes in (A) extractable magnesium and (B) total Kjeldahl nitrogen with soil depth and irrigation rates, Lott Woodlot, 1973.

(A)


0
15
30
45
60
Soil Depth (cm)
0
200
400
600
Extractable Magnesium (kg/ha)

(B)


0
15
30
45
60
Soil Depth (cm)
Irrigation Rates
○ = 0 mm/week
□ = 50 mm/week well water
▲ = 25 mm/week wastewater
■ = 50 mm/week wastewater
● = 75 mm/week wastewater
0
1000
2000
3000
4000
5000
Total Kjeldahl Nitrogen (kg/ha)

75 mm/week irrigation rate plots) at the 15 cm depth but these differences were not statistically significant. This trend continued at 60 cm except in the case of the 50 mm/week of well water treatment. If the premise that nitrogen variability in forested loam soils will approach that indicated in Figure 50B, then the 200 kg/ha added by wastewater irrigation seems small by comparison. The two-year duration of this study was, however, insufficient to detect any significant soil nitrogen changes.

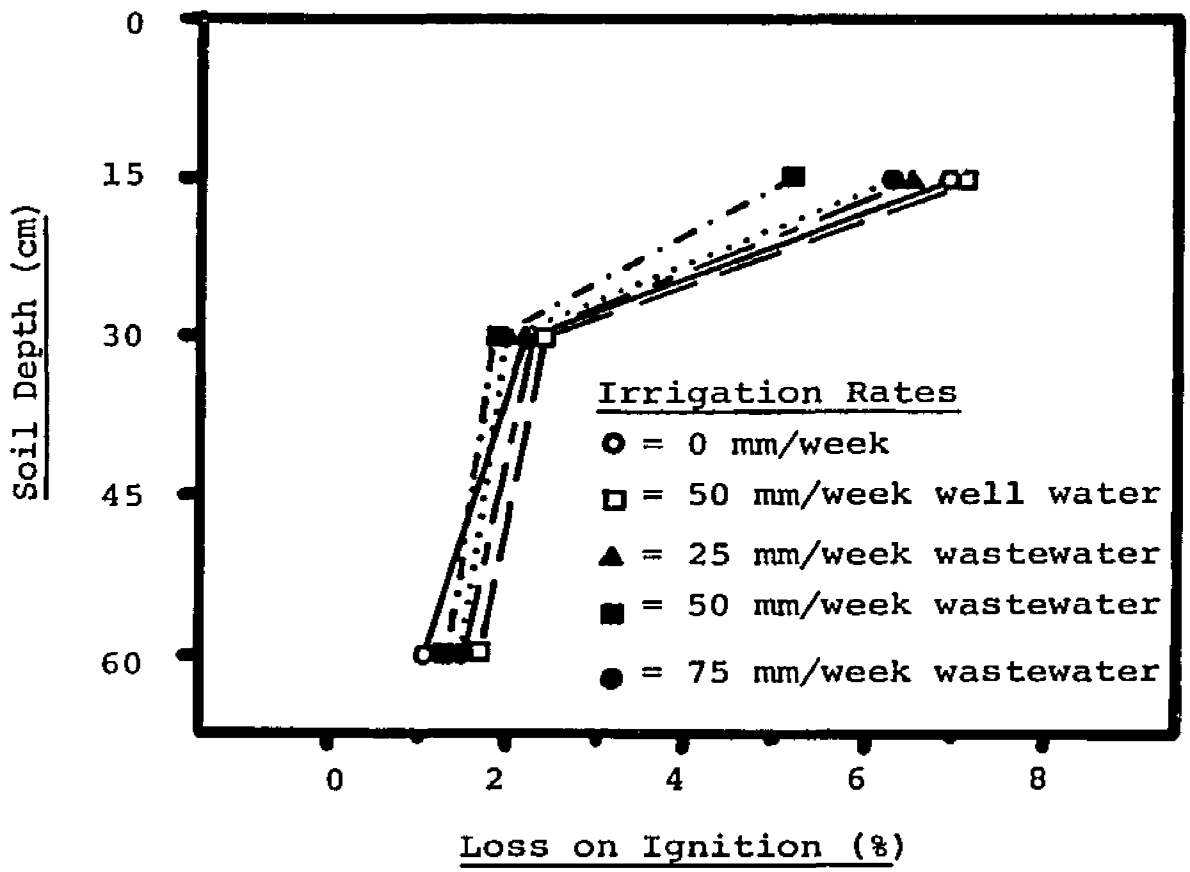
Loss on Ignition

The loss on ignition in the Miami loam in the Lott Woodlot paralleled that of soil nitrogen (Figure 51). Significant differences were noted within each treatment between the 15 and 30 cm depth. Otherwise, no significant differences existed between individual loss on ignition values. At 15 cm a trend of decreasing loss with increasing irrigation rate was observed. The percent loss went from 7.1% for the control treatment to 5.8% for the high rate of wastewater irrigation. Although these decreasing levels were not significant, such values, if valid, would serve as an indicator of increasing organic matter decomposition.

Soil Moisture

The application of wastewater to forest ecosystems is capable of altering moisture regime to a

Figure 51. Changes in percent loss on ignition with soil depth and irrigation rates, Lott Woodlot, 1973.



0
15
30
45
60
Soil Depth (cm)
Irrigation Rates
○ = 0 mm/week
□ = 50 mm/week well water
▲ = 25 mm/week wastewater
■ = 50 mm/week wastewater
● = 75 mm/week wastewater
0
2
4
6
8
Loss on Ignition (%)

considerable extent. The fluctuations in soil moisture tension in Lott Woodlot, as measured by tensionmeters, is shown in Figure 52.

Soil moisture tension in the control plots rose steadily after July 4th, peaking in early September. Similar rises were not exhibited in the 25 and 75 mm/week of wastewater treatments until August. Soil moisture tension in the unirrigated plots remained above 50 centibars for 91 days beginning July 23 and ending October 23. The 25 and 75 mm/week treatments exceeded the 50 centibar mark for only 24 and 12 days, respectively. During July 18 to August 24, and September 15 to November 4, soil moisture tension in one or both of the irrigated treatments was significantly lower than that of the control treatment.

These data indicate that wastewater irrigation will have a considerable effect on the vegetative evapotranspirational processes in Lott Woodlot.

Oxygen Diffusion

Soil oxygen diffusion rates were periodically measured in the Lott Woodlot wastewater plots during the 1973 irrigation season (Table 36). These measurements were taken to determine if the weekly application of irrigation water was adversely affecting soil aeration.

Figure 52. Soil moisture tension for 0, 25, and 75 mm/week wastewater irrigation rates, Lott Woodlot, 1973.

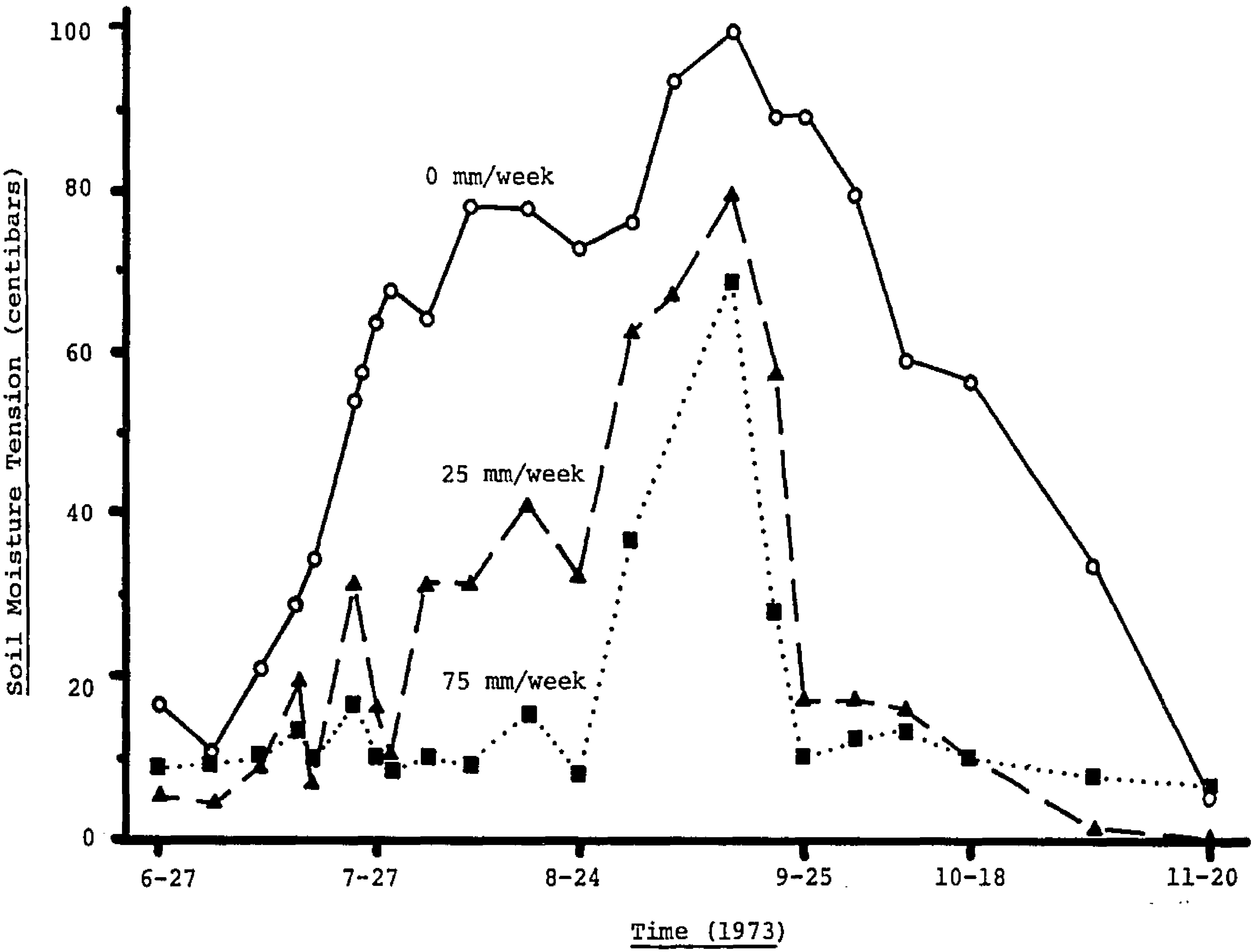

0 mm/week
25 mm/week
75 mm/week
Soil Moisture Tension (centibars)
100
80
60
40
20
0
6-27
7-27
8-24
9-25
10-18
11-20
Time (1973)

Table 36. Soil oxygen diffusion in Miami loam, Lott Woodlot, 1973.

Date	Irrigation in mm/week				
	Control	Well Water	Wastewater		
	0	50	25	50	75
	micrograms/cm^2/minute				
7/26	0.136 a[1]	0.236 ab	0.236 ab	0.382 b	0.350 b
8/02	0.112 a	0.168 ab	0.327 bc	0.267 abc	0.479 c
10/9	0.183 a	0.294 ab	0.495 c	0.430 bc	0.534 c

[1]Means not followed by the same letter are significantly different at the 5% level (Tukey's test).

The flux of oxygen was never lower in the irrigated plots than in the unirrigated plots. In all but one instance, the oxygen diffusion in soils receiving 75 mm/week of wastewater was significantly higher than in all other treatments. This is the reverse of what would normally be expected. Such readings are inherent in the platinum electrode method itself.

The low oxygen diffusion in the control plots resulted from the high soil moixture tension. Platinum electrodes respond only to that portion of their surface covered with water since the transfer of electrons occurs through water. Therefore, the oxygen diffusion rates are underestimated in dry soil (VanDoren and Erickson, 1966).

The oxygen diffusion rates in the irrigated plots are within acceptable limits for the texture of soil. Thus, additions of wastewater to the Miami loam has thus far not altered its drainage properties to any detectable extent.

Humus

The forest floor under the Lott Woodlot maple-beech stand is a coarse mull humus. By late fall it consists of a 2-10 cm layer of recently fallen hardwood leaves and woody material in various stages of decay. At the end of the following summer much of the leaf layer is incorporated into the A1 soil horizon by earthworms and other soil fauna. The activity of these organisms produces a highly porous, crumb-structured soil horizon.

Plots in the wastewater renovation study were surveyed to determine irrigation effects on litter decomposition. Considerable variation occurred in the coarse mull humus (Table 37) but treatment results were in all cases nonsignificant. Total humus varied from a high of 4,900 kg/ha in the 25 mm/week wastewater rate to a low of 2,470 kg/ha in the 50 mm/week treatment. Much of this variability was due to the woody litter component, that accounted for as much as 50% (25 mm/week of wastewater rate) and as little as 15% (50 mm/week of well water rate) of the total humus. Leaf litter contributed the largest portion of the total litter in all treatments.

Table 37. Humus accumulations by irrigation rate, Lott Woodlot, August, 1973.[1]

Irrigation Rate	Irrigation Type	Total Humus	Woody Litter	Leaf Litter
mm/week		kg/ha		
0	control	3,270	940	2,330
50	well water	3,630	570	3,060
25	wastewater	4,900	2,360	2,540
50	wastewater	2,470	830	1,640
75	wastewater	2,843	1,163	1,680

[1]No significant difference with treatment at the 5% level (Tukey's test).

Leaf litter exhibited a general trend of decreasing mass with increasing levels of wastewater irrigation but differences were not statistically significant. The highest leaf litter weight was noted in plots receiving 50 mm/week of well water irrigation.

To date it is difficult to say whether continued irrigation will affect the coarse mull humus. So far, no significant trends have been established but a tendency does exist for wastewater irrigation to hasten the decomposition process as noted in the duff mull litter at Middleville. Certainly, irrigation does establish ideal conditions for decay organisms to operate.

Nutrient Budget

A detailed nutrient budget could not be computed for Lott Woodlot due to a lack of sufficient data to characterize the storage components. However, Table 38 contains, in general terms, the input and output data for total nitrogen and total phosphorus as determined by suction lysimeters.

Table 38. Estimation of total nitrogen and total phosphorus budget, Lott Woodlot, 1972 through 1973.

Budget Item	Budget Relationship	Irrigation Rate (mm/week)			
		Well Water	Wastewater		
		50	25	50	75
		kg/ha			
Nitrogen:					
Wastewater Loading	Input	1.6	68.8	137.6	206.2
Loss to Water Table	Output	26.8	50.0	76.0	180.7
Phosphorus:					
Wastewater Loading	Input	0.1	6.2	12.0	18.1
Loss to Water Table	Output	0.3	< 0.1	0.2	0.4

Evidence of the nitrogen flushing that has gone on in Lott Woodlot is quite apparent from the well water irrigation levels. While 1.6 kg/ha of nitrogen was added by well water irrigation, a significant amount (26.8 kg/ha) was flushed through the soil. This quantity is in close agreement to the average of 28 kg/ha estimated to be lost from harvested crop land in the United States (Lipman and Conybeare, 1936). The 25 mm/week of wastewater irrigation treatment lost 50 kg/ha of the 68.8 kg/ha of total nitrogen applied. The 50 mm/week wastewater treatment had the least percentage loss of nitrogen but still lost 33% more than the 25 mm/week rate. The highest irrigation rate had as an output 180.7 kg/ha of the 206.2 kg/ha applied.

The total phosphorus budget indicates that a greater output over input value occurred only for the well water treatment. For the wastewater treatments, outputs exceeded inputs by only 1.6, 1.6, and 2.2%.

CHAPTER VI

SUMMARY AND RECOMMENDATIONS

A. Middleville

Effluent from sewage stabilization ponds at Middleville was spray irrigated only a 20-year-old red pine plantation during the summer and early fall of 1972 and 1973. The wastewater typically contained from 7.1 to 8.4 mg/l total nitrogen and 2.4 to 3.8 mg/l total phosphorus. Irrigation during the two years delivered a total application of 61.8, 123.4, and 217.0 kg/ha of nitrogen and 24.5, 48.9, and 86.0 kg/ha of phosphorus for the 25, 50, and 88 mm/week irrigation rates, respectively.

The ability of the red pine plantation site to renovate the nitrogen and phosphorus applied by irrigation was monitored by porous cup soil moisture samplers at depths of 60 and 120 cm. Renovation of phosphorus generally exceeded 99% for all irrigation rates at both depths during the years of irrigation. Total nitrogen renovation was 96, 87, and 94% at 60 cm and 82, 89, and 94% at 120 cm in 1972 for the 25, 50, and 88 mm/week irrigation rates, respectively. In 1973, total nitrogen renovation decreased for the two highest irrigation rates to 83, and 76% at 60 cm and 81 and 76% at 120 cm. Much of the reduction in renovation was due to leaching of NO_3-N. The hourly rates of irrigation (3, 6, and 11 mm/hour for the 25, 50, and 88 mm/week loading rates, respectively) probably contributed to the leaching differences between treatments.

The red pine foliar nutrient concentrations of boron, aluminum, potassium, and nitrogen have undergone significant changes. Boron levels have risen from about 27 ppm in unirrigated trees to 55, 66, and 75 ppm for the 25, 50, and 88 mm/week irrigation rates, respectively. These increases in foliage boron resulted in the appearance of toxicity symptoms. Aluminum levels have dropped by a factor of five from 545.7 ppm in unirrigated trees to 106.2 ppm in trees receiving the greatest amount of wastewater application. Wastewater irrigation has resulted in potassium increases of 0.07% over the range of irrigation rates. The nitrogen content of the red pine needles increased in both years. In 1973, the nitrogen levels were 1.33, 1.44, 1.66, and 1.70% for the 0, 25, 50, and 88 mm/week rates, respectively.

The wastewater irrigation had its most pronounced effect on red pine growth in 1973. Needles from the upper one-third of the crown increased in length from an average of 121.0 mm in unirrigated trees to 136.4, 154.9, and 164.4 mm for the 25, 50, and 88 mm/week irrigation rates. Dry weights/needle fascicle increased in a similar fashion, rising from 68.97 mg to 107.40 mg over the range of irrigation rates. Diameter and height growth have not as yet responded significantly to the wastewater.

The Boyer sandy loam soil underlying the red pine plantation at Middleville underwent significant changes in pH and boron content during the two years of wastewater irrigation. The pH in the upper 120 cm of soil climbed significantly from 5.9 in unirrigated plots to 6.6, 7.0, and 7.5 for the 25, 50, and 88 mm/week irrigation rates. Boron concentrations increased from 0.8 to 2.6 kg/ha over the range of irrigation rates. Available phosphorus and exchangeable potassium and magnesium contents of the soil showed significant increases in the 0 to 15 cm depth. Calcium, nitrogen, and percent loss on ignition values were not significantly different between irrigation rates.

Wastewater irrigation has enhanced decomposition of the humus layer in the red pine plantation. A 20% decrease in humus weight and a 1.5 cm reduction in humus depth have resulted from irrigation. Changes in the activity of soil microorganisms were reflected by increases in their number and duration of appearance.

B. Lott Woodlot

Wastewater from the East Lansing secondary treatment plant has been trickle irrigated onto plots within a maple-beech hardwood forest during the summer and early fall of 1972 and 1973. Concentrations of total nitrogen and phosphorus in the sewage effluent ranged from 8.0 to 11.5 mg/l for nitrogen and 0.7 to 1.0 mg/l for phosphorus. Well water applied on a control treatment contained 0.10 mg/l total nitrogen and less than 0.01 mg/l total phosphorus. Total nitrogen loadings over the two-year period were 1.0, 71.8, 143.6, and 215.4 kg/ha for the 50 mm/week well, water, 25, 50, and 75 mm/week of wastewater treatments, respectively. Total phosphorus loadings for the same treatments were 0.01, 6.0, 12.0, and 18.0 kg/ha.

Renovation of the nitrogen and phosphorus applied via wastewater irrigation was ascertained by porous cup soil moisture samplers at depths of 30 and 60 cm. Total phosphorus renovation averaged above 96% at both depths for all treatments over the two years. Total nitrogen renovation was quite variable and generally less than 50% for all treatments, depths, and years. This was primarily due to the NO_3-N renovation (the most common form of nitrogen sampled in the soil solution) being generally 0%. As at Middleville, the leaching of NO_3-N most likely resulted from the high hourly application rate (in excess of 50 mm/hour). NH_3-N (the most commonly applied form of nitrogen) renovation was above 96% in all instances.

Ground cover vegetation response to wastewater irrigation was inconclusive. No apparent growth, survival, or nutrient uptake response was detected. However, there was a noticeable lack of wilting during dry weather and a delay of leaf senescence in the fall.

A general decrease in leaf litter with increasing rates of wastewater irrigation was noted, although none of the differences in treatment were statistically significant. Leaf litter weight was highest in plots receiving 50 mm/week of well water irrigation (3,060 kg/ha) and lowest in plots receiving the same amount of wastewater (1,640 kg/ha). Woody litter varied from 570 to 2,360 kg/ha across the range of treatments.

Soil chemistry data for Lott Woodlot was inconclusive. Significant increases in pH and extractable magnesium were recorded. However, no differences between the well water and wastewater irrigation were noted. Irrigation water *per se* tended to be the prevailing factor rather than the wastewater constituents. Wastewater irrigation significantly reduced soil moisture tension and improved soil water relations throughout the summer.

Recommendations

Data gathered during this research project and others of a similar nature have indicated that forest ecosystems are readily able to renovate municipal wastewater. However, it must be remembered that terrestrial ecosystems, like aquatic ones, have physical limits to their wastewater processing ability. Thus, the following recommendations are made for wastewater irrigation in forest stands in Michigan similar to those discussed here:

1. Application rates should be kept below 3 mm/hour. Low hourly rates produce high wastewater renovations and simplify operation of irrigation equipment.

2. Weekly wastewater loadings up to 50 mm are acceptable in coarse textured forest soils as long as renovation standards are met.

3. The management objectives of a wastewater irrigation system will definitely affect the amount of vegetative growth. While maximization of tree growth does not necessarily have to be an objective, the tree cover must be maintained in a viable condition; and this in turn will determine the allowable amounts of irrigation per unit area.

4. Some tree species, such as red pine and white pine, are highly sensitive to boron and will exhibit toxicity symptoms with normal levels of boron in wastewater (1 ppm). If such toxicity conditions persist and produce stand deterioration, irrigation should be discontinued.

This and similar studies have shown that forest ecosystems are capable of removing nutrients from municipal wastewater. However, wastewater disposal by spray irrigation should not be approached with the idea of disposing of the maximum amount of water on the least area of land. It should be handled in relation to the ultimate goal of removing the highest amount of nitrogen and phosphorus while maintaining site longevity and renovation efficiency.

APPENDIX

Table 39. Mean monthly air temperature for Middleville using data from Grand Rapids and Hastings.

Month	Mean monthly temperature (°C)					
	Grand Rapids		Hastings		Middleville (mean)	
	1972	1973	1972	1973	1972	1973
January	-6.3	-2.6	-5.0	-2.1	-5.7	-2.4
February	-5.7	-5.2	-4.3	-3.8	-5.0	-4.5
March	-1.3	5.5	-0.2	6.1	-0.8	5.8
April	5.8	8.3	6.8	9.0	6.3	8.6
May	15.3	12.2	15.6	12.8	15.4	12.5
June	17.6	21.2	18.6	21.4	18.1	21.3
July	21.4	22.6	21.8	22.7	21.6	22.6
August	20.6	22.8	21.1	22.6	20.8	22.7
September	16.8	17.6	19.9	17.9	18.4	17.8
October	7.9	12.9	8.8	13.4	8.4	13.2
November	2.2	4.4	3.0	5.2	2.6	4.8
December	-3.0	-3.2	-2.4	-2.6	-2.8	-2.9

Table 40. Mean monthly ammonia nitrogen at 60 and 120 cm at Middleville, 1972 and 1973.

Month	Mean lysimeter values					
	25 mm/week		50 mm/week		88 mm/week	
	60 cm	120 cm	60 cm	120 cm	60 cm	120 cm
	ppm (mg/l)					
(1972)						
Jun	--	--	--	--	--	--
Jul	0.02	0.19	0.20	0.08	0.02	0.20
Aug	0.09	0.14	0.11	0.10	0.13	0.10
Sep	0.05	0.13	0.13	0.12	0.10	0.07
Oct	0.05	0.08	0.25	0.25	0.15	0.07
(1973)						
Jun	0.10	0.21*	0.16	0.68	0.04	0.15
Jul	0.14	0.21*	0.44	0.76	0.14	0.09
Aug	0.06	0.21	0.49	1.30	0.41	0.21
Sep	0.12	0.21*	0.30	0.30	0.08	0.04
Oct	0.08	0.21*	0.22	0.20	0.07	0.23

*Due to missing data, the mean value for the irrigation season was used.

Table 41. Mean monthly nitrate nitrogen at 60 and 120 cm at Middleville, 1972 and 1973.

Month	Mean lysimeter values					
	25 mm/week		50 mm/week		88 mm/week	
	60 cm	120 cm	60 cm	120 cm	60 cm	120 cm
	ppm (mg/l)					
(1972)						
Jun	--	--	--	--	--	--
Jul	0.16	0.10	0.08	1.17	0.24	0.10
Aug	0.12	2.15	0.40	0.62	0.06	0.06
Sep	0.05	1.13	0.07	0.60	0.05	0.08
Oct	0.13	0.18	0.05	0.24	0.06	0.06
(1973)						
Jun	0.06	0.80	0.26	0.66	2.15	0.36
Jul	0.18	0.93*	0.61	0.56	1.04	0.66
Aug	0.00	0.03	0.12	1.18	0.58	0.90
Sep	0.12	0.93	0.71	0.63	1.46	1.72
Oct	0.24	2.00	0.54	0.32	0.71	0.46

*Due to missing data, the mean value for the irrigation season was used.

Table 42. Mean monthly organic nitrogen at 60 and 120 cm at Middleville, 1972 and 1973.

Month	Mean lysimeter values					
	25 mm/week		50 mm/week		88 mm/week	
	60 cm	120 cm	60 cm	120 cm	60 cm	120 cm
	ppm (mg/l)					
(1972)						
Jun	--	--	--	--	--	--
Jul	0.12	0.73	0.16	0.07	0.56	0.32
Aug	0.21	0.78	0.37	0.57	0.32	0.30
Sep	0.19	0.75*	0.15	0.52	0.36	0.43
Oct	0.22	0.56	2.16	0.90	0.41	0.44
(1973)						
Jun	0.38	0.19*	0.50	0.41	0.38	0.38
Jul	0.12	0.19*	0.40	0.56	0.27	0.75
Aug	0.21	0.19	1.01	0.74*	1.13	0.52
Sep	1.28	0.19*	0.46	0.86	0.52	1.91
Oct	1.06	0.19*	0.80	1.12	0.66	1.14

*Due to missing values, the mean value for the irrigation season was used.

Table 43. Mean monthly total nitrogen at 60 and 120 cm at Middleville, 1972 and 1973.

Month	Mean lysimeter values					
	25 mm/week		50 mm/week		88 mm/week	
	60 cm	120 cm	60 cm	120 cm	60 cm	120 cm
	ppm (mg/l)					
(1972)						
Jun	--	--	--	--	--	--
Jul	0.30	1.02	0.44	1.32	0.82	0.62
Aug	0.42	2.96	0.88	1.29	0.51	0.45
Sep	0.28	1.60	0.35	0.75	0.46	0.58
Oct	0.40	0.82	2.46	1.39	0.62	0.57
(1973)						
Jun	0.53	0.43*	0.92	1.76	2.57	0.88
Jul	0.34	0.43*	1.44	1.70	1.45	1.48
Aug	0.27	0.43	1.63	1.72*	2.12	1.64
Sep	1.52	0.43*	1.46	1.79	2.06	3.67
Oct	1.38	0.43*	1.55	1.64	1.43	1.83

*Due to missing data, the mean value for the irrigation season was used.

Table 44. Mean monthly total phosphorus at 60 and 120 cm at Middleville, 1972 and 1973.

Month	Mean lysimeter values					
	25 mm/week		50 mm/week		88 mm/week	
	60 cm	120 cm	60 cm	120 cm	60 cm	120 cm
	ppm (mg/l)					
(1972)						
Jun	--	--	--	--	--	--
Jul	0.02	0.67	0.20	5.32	0.18	0.05
Aug	0.02	0.06	0.03	0.13	0.01	0.03
Sep	0.01	0.05	0.01	0.31	0.01	0.04
Oct	0.02	0.05	0.02	0.43	0.01	0.04
(1973)						
Jun	0.05	0.05	0.05	0.36	0.04	0.07
Jul	0.01	0.04*	0.10	0.23	0.03	0.03
Aug	0.02	0.03	0.05	0.13	0.03	0.04
Sep	0.05	0.04*	0.03	0.05	0.01	0.02
Oct	0.05	0.04*	0.03	0.05	0.02	0.04

*Due to missing data, the mean value for the irrigation season was used.

Table 45. Total nitrogen and total phosphorus renovation at the 60 cm depth at Middleville computed by the ground water recharge method, 1972.

Nutrient Form	Month	60 cm depth								
		Amount Applied			Lysimeter Content			Renovation		
		25	50	88	25	50	88	25	50	88
		-------kg/ha-------			-------kg/ha------			-------%-------		
Total Nitrogen	Jun	--	--	--	--	--	--	--	--	--
	Jul	4.2	8.4	14.8	0.0	0.0	0.7	100	100	95
	Aug	10.5	21.0	37.0	0.4	2.2	2.4	96	90	94
	Sep	8.4	16.8	29.5	0.4	0.9	1.8	95	95	94
	Oct	8.4	16.8	29.5	0.5	5.3	2.3	94	68	92
	sum/mean	31.5	63.0	110.8	1.3	8.4	7.2	96	87	94
Total Phosphorus	Jun	--	--	--	--	--	--	--	--	--
	Jul	1.9	3.8	6.7	0.0	0.0	0.1	100	100	99
	Aug	4.8	9.5	16.7	<0.1	<0.1	<0.1	100	99	100
	Sep	3.8	7.6	13.4	<0.1	<0.1	<0.1	99	100	100
	Oct	3.8	7.6	13.4	0.1	<0.1	<0.1	97	99	100
	sum/mean	14.3	28.5	50.2	0.1	<0.1	0.1	99	100	100

Table 46. Ammonia nitrogen, nitrate nitrogen, and organic nitrogen renovation at the 60 cm depth at Middleville computed by the ground water recharge method, 1972.

Nutrient Form	Month	60 cm depth: Amount Applied 25	50	88	Lysimeter Content 25	50	88	Renovation 25	50	88
		---kg/ha---			---kg/ha---			---%---		
Ammonia Nitrogen	Jun	--	--	--	--	--	--	--	--	--
	Jul	0.6	1.2	2.0	0.0	0.0	< 0.1	100	100	99
	Aug	1.5	3.0	5.3	< 0.1	0.3	0.6	95	90	89
	Sep	1.2	2.4	4.2	< 0.1	0.3	0.4	94	87	90
	Oct	1.2	2.4	4.2	< 0.1	0.5	0.6	95	79	86
	sum/mean	4.5	9.0	15.8	< 0.1	1.1	1.6	98	88	90
Nitrate Nitrogen	Jun	--	--	--	--	--	--	--	--	--
	Jul	0.4	0.8	1.4	0.0	0.0	0.2	100	100	86
	Aug	1.0	2.0	3.5	0.1	1.0	0.3	90	50	91
	Sep	0.8	1.6	2.8	< 0.1	0.2	0.2	91	87	93
	Oct	0.8	1.6	2.8	0.2	0.1	0.2	75	94	93
	sum/mean	3.0	6.0	10.5	0.3	1.3	0.9	90	78	91
Organic Nitrogen	Jun	--	--	--	--	--	--	--	--	--
	Jul	3.2	6.4	11.3	0.0	0.0	0.5	100	100	96
	Aug	8.0	16.0	28.2	0.2	0.9	1.5	97	94	95
	Sep	6.4	12.8	22.5	0.3	0.4	1.4	95	97	94
	Oct	6.4	12.8	22.5	0.3	4.7	1.5	95	63	93
	sum/mean	24.0	48.0	84.5	0.8	6.0	4.9	97	87	94

Table 47. Total nitrogen and total phosphorus renovation at the 120 cm depth at Middleville computed by the ground water recharge method, 1972.

Nutrient Form	Month	120 cm depth								
		Amount Applied			Lysimeter Content			Renovation		
		25	50	88	25	50	88	25	50	88
		-------kg/ha-------			-------kg/ha------			--------%--------		
Total Nitrogen	Jun	--	--	--	--	--	--	--	--	--
	Jul	4.2	8.2	14.8	0.0	0.0	0.5	100	100	97
	Aug	10.5	21.0	37.0	2.5	3.2	2.1	76	85	94
	Sep	8.4	16.8	29.5	2.2	1.8	2.3	73	89	92
	Oct	8.4	16.8	29.5	1.0	1.7	2.1	88	90	93
	sum/mean	31.5	63.0	110.8	5.7	6.7	7.0	82	89	94
Total Phosphorus	Jun	--	--	--	--	--	--	--	--	--
	Jul	1.9	3.8	6.7	0.0	0.0	< 0.1	100	100	99
	Aug	4.8	9.5	16.7	<0.1	0.3	0.1	99	97	99
	Sep	3.8	7.6	13.4	<0.1	0.7	0.2	98	91	99
	Oct	3.8	7.6	13.4	< 0.1	0.9	0.1	98	88	99
	sum/mean	14.3	28.5	50.2	< 0.1	1.9	0.4	99	93	99

Table 48. Ammonia nitrogen, nitrate nitrogen, and organic nitrogen renovation at the 120 cm depth at Middleville computed by the ground water recharge method, 1972.

		120 cm depth								
		Amount Applied			Lysimeter Content			Renovation		
Nutrient Form	Month	25	50	88	25	50	88	25	50	88
		-------kg/ha--------			-------kg/ha-------			--------%--------		
Ammonia Nitrogen	Jun	--	--	--	--	--	--	--	--	--
	Jul	0.6	1.2	2.1	0.0	0.0	0.2	100	100	90
	Aug	1.5	3.0	5.3	0.1	0.2	0.5	93	93	91
	Sep	1.2	2.4	4.2	0.2	0.3	0.3	83	87	93
	Oct	1.2	2.4	4.2	0.1	0.5	0.3	88	79	93
	sum/mean	4.5	9.0	15.8	0.4	1.0	1.3	91	89	92
Nitrate Nitrogen	Jun	--	--	--	--	--	--	--	--	--
	Jul	0.4	0.8	1.4	0.0	0.0	< 0.1	100	100	94
	Aug	1.0	2.0	3.5	1.8	1.5	0.3	0	25	91
	Sep	0.8	1.6	2.8	1.5	1.4	0.3	0	12	89
	Oct	0.8	1.6	2.8	0.2	0.3	0.2	75	81	93
	sum/mean	3.0	6.0	10.5	3.5	3.2	0.8	0	47	92
Organic Nitrogen	Jun	--	--	--	--	--	--	--	--	--
	Jul	3.2	6.4	11.3	0.0	0.0	0.3	100	100	97
	Aug	8.0	16.0	28.2	0.7	1.4	1.4	91	91	95
	Sep	6.4	12.8	22.5	1.0	1.2	1.7	84	91	92
	Oct	6.4	12.8	22.5	0.7	1.9	1.6	89	85	93
	sum/mean	24.0	48.0	84.5	2.4	4.5	5.0	90	91	94

Table 49. Total nitrogen and total phosphorus renovation at the 60 cm depth at Middleville computed by the ground water recharge method, 1973.

Nutrient Form	Month	60 cm Lysimeter Depth								
		Amount Applied[1]			Lysimeter Content			Renovation		
		25	50	88	25	50	88	25	50	88
		kg/ha			kg/ha			%		
Total Nitrogen	Jun	7.1	14.2	25.0	0.0	0.9	6.3	100	94	75
	Jul	3.6	7.1	12.5	0.0	0.0	0.9	100	100	93
	Aug	8.9	17.8	31.2	< 0.1	2.7	7.8	100	85	75
	Sep	7.1	14.2	25.0	2.0	3.3	7.8	72	77	69
	Oct	3.6	7.1	12.5	0.9	3.5	2.7	75	51	78
	sum/mean	30.3	60.4	106.2	2.9	10.4	25.5	90	83	76
Total Phosphorus	Jun	2.4	4.8	8.4	0.0	< 0.1	0.1	100	99	99
	Jul	1.2	2.4	4.2	0.0	0.0	< 0.1	100	100	100
	Aug	3.0	6.0	10.6	< 0.1	< 0.1	0.1	100	99	99
	Sep	2.4	4.8	8.4	< 0.1	< 0.1	< 0.1	97	99	100
	Oct	1.2	2.4	4.2	< 0.1	< 0.1	< 0.1	97	99	99
	sum/mean	10.2	20.4	35.8	< 0.1	< 0.1	0.2	99	100	100

[1]Sum for the amount applied does not include that applied in May.

Table 50. Ammonia nitrogen, nitrate nitrogen, and organic nitrogen renovation at the 60 cm depth at Middleville computed by the ground water recharge method, 1973.

Nutrient Form	Month	60 cm lysimeter depth								
		Amount Applied[1]			Lysimeter Content			Renovation		
		25	50	88	25	50	88	25	50	88
		--------kg/ha--------			--------kg/ha--------			--------%---------		
Ammonia Nitrogen	Jun	0.7	1.4	2.5	0.0	0.2	0.1	100	86	96
	Jul	0.4	0.7	1.2	0.0	0.0	< 0.1	100	100	97
	Aug	0.9	1.8	3.1	< 0.1	0.8	1.5	100	56	52
	Sep	0.7	1.4	2.5	0.2	0.7	0.3	71	50	88
	Oct	0.4	0.7	1.2	< 0.1	0.3	0.1	87	57	92
	sum/mean	3.1	6.0	10.5	0.2	2.0	2.0	94	67	81
Nitrate Nitrogen	Jun	2.0	4.0	7.0	0.0	0.2	5.3	100	95	34
	Jul	1.0	2.0	3.5	0.0	0.0	0.7	100	100	80
	Aug	2.5	5.0	8.8	0.0	0.2	2.1	100	96	76
	Sep	2.0	4.0	7.0	0.2	1.6	5.6	90	60	20
	Oct	1.0	2.0	3.5	0.2	0.6	1.4	80	70	60
	sum/mean	8.5	17.0	29.8	0.4	2.6	15.1	95	85	49
Organic Nitrogen	Jun	4.4	8.8	15.5	0.0	0.5	0.9	100	94	94
	Jul	2.2	4.4	7.7	0.0	0.0	0.2	100	100	97
	Aug	5.5	11.0	19.4	< 0.1	1.7	4.1	99	85	79
	Sep	4.4	8.8	15.5	1.6	1.1	2.0	64	87	87
	Oct	2.2	4.4	7.7	0.7	0.9	1.3	68	80	83
	sum/mean	18.7	37.4	65.8	2.3	4.2	8.5	88	89	87

[1] Sum for the amount applied does not include that applied in May.

Table 51. Total nitrogen and total phosphorus renovation at the 120 cm depth at Middleville computed by the ground water recharge method, 1973.

Nutrient Form	Month	120 cm depth								
		Amount Applied[1]			Lysimeter Content			Renovation		
		25	50	88	25	50	88	25	50	88
		kg/ha			kg/ha			%		
Total Nitrogen	Jun	7.1	14.2	25.0	0.0	1.7	2.2	100	88	91
	Jul	3.6	7.1	12.5	0.0	0.0	0.3	100	100	98
	Aug	8.9	17.8	31.2	0.0	3.9	6.0	100	78	81
	Sep	7.6	14.2	25.0	0.5	4.1	14.0	93	71	44
	Oct	3.6	7.1	12.5	0.3	1.9	3.5	92	85	72
	sum/mean	30.3	60.4	106.2	0.8	11.6	26.0	97	81	76
Total Phosphorus	Jun	2.4	4.8	8.4	0.0	0.3	0.2	100	94	98
	Jul	1.2	2.4	4.2	0.0	0.0	< 0.1	100	100	100
	Aug	3.0	6.0	10.6	0.0	0.2	0.1	100	97	99
	Sep	2.4	4.8	8.4	< 0.1	0.1	< 0.1	98	99	99
	Oct	1.2	2.4	4.2	< 0.1	< 0.1	< 0.1	98	97	98
	sum/mean	10.2	20.4	35.8	< 0.2	< 0.7	< 0.6	99	97	99

[1]Sum for the amount applied does not include that applied in May.

Table 52. Ammonia nitrogen, nitrate nitrogen, and organic nitrogen renovation at the 120 cm depth at Middleville computed by the ground water recharge method, 1973.

		120 cm depth								
		Amount Applied[1]			Lysimeter Content			Renovation		
Nutrient Form	Month	25	50	88	25	50	88	25	50	88
		-------kg/ha--------			-------kg/ha-------			--------%--------		
Ammonia Nitrogen	Jun	0.7	1.4	2.5	0.0	0.6	0.4	100	57	84
	Jul	0.4	0.7	1.2	0.0	0.0	< 0.1	100	100	95
	Aug	0.9	1.8	3.1	0.0	2.1	0.8	100	0	74
	Sep	0.7	1.4	2.5	0.3	0.7	0.2	57	50	92
	Oct	0.4	0.7	1.2	0.1	0.2	0.4	75	71	67
	sum/mean	3.1	6.0	10.5	0.4	3.6	1.9	87	40	82
Nitrate Nitrogen	Jun	2.0	4.0	7.0	0.0	2.5	0.9	100	47	87
	Jul	1.0	2.0	3.5	0.0	0.0	0.4	100	100	89
	Aug	2.5	5.0	8.8	0.0	1.9	3.3	100	72	62
	Sep	2.0	4.0	7.0	1.1	1.4	6.6	45	65	6
	Oct	1.0	2.0	3.5	2.0	0.4	0.9	0	80	74
	sum/mean	8.5	17.0	29.8	3.1	6.2	12.1	64	64	59
Organic Nitrogen	Jun	4.4	8.8	15.5	0.0	0.4	0.9	100	95	94
	Jul	2.2	4.4	7.7	0.0	0.0	0.5	100	100	94
	Aug	5.5	11.0	19.4	0.0	1.2	1.9	100	89	90
	Sep	4.4	8.8	15.5	0.2	2.0	7.3	95	77	53
	Oct	2.2	4.4	7.7	0.1	1.3	2.2	95	70	71
	sum/mean	18.7	37.4	65.8	0.3	4.9	12.8	98	87	81

[1]Sum for the amount applied does not include that applied in May.

Table 53. Changes in (A) pH and (B) available phosphorus with soil depth and wastewater irrigation rates, Middleville, 1973.

Irrigation Rate	Soil Depth (cm)[1]			
	15	30	60	120
mm/week	pH units			
(A) pH				
0	5.2 aw	5.5 abw	6.1 bcw	6.9 cw
25	6.5 ax	6.1 awx	6.3 aw	7.7 bwx
50	7.1 abxy	6.6 axy	6.7 awx	7.7 bwx
88	7.4 ay	7.4 ay	7.4 ax	7.9 ax
(B) Available phosphorus				
	kg/ha			
0	87.4 aw	76.9 aw	52.3 abw	15.3 bw
25	101.6 awx	93.7 aw	59.0 abw	26.9 bw
50	144.2 ax	92.6 bw	74.3 bcw	34.7 cw
88	203.2 ay	121.7 bw	83.3 bw	14.9 cw

[1]Means within the same column (w, x, y, and z) or line (a, b, c, and d) not followed by the same letter are significantly different at the 5% level (Tukey's test).

Table 54. Changes in (A) extractable potassium and (B) extractable calcium with soil depth and wastewater irrigation rates, Middleville, 1973.

Irrigation Rate	Soil Depth (cm)[1]			
	15	30	60	120
mm/week	----------kg/ha----------			
(A) Extractable Potassium				
0	85.1 aw	49.3 aw	49.3 aw	57.1 aw
25	138.9 awx	76.2 bwx	44.8 bcw	12.3 cw
50	143.4 ax	107.6 abxy	62.7 bcwx	20.5 cw
88	161.3 ax	161.3 ay	107.6 ax	16.4 bw
(B) Extractable Calcium				
0	242.4 aw	242.0 aw	290.5 aw	2161.8 aw
25	872.0 aw	290.2 aw	290.2 aw	2382.5 aw
50	968.7 aw	435.8 aw	242.4 aw	1476.2 aw
88	1308.1 aw	726.7 aw	484.3 aw	2514.0 aw

[1]Means within the same column (w, x, y, and z) or line (a, b, c, and d) not followed by the same letter are significantly different at the 5% level (Tukey's test).

Table 55. Changes in (A) extractable magnesium and (B) total Kjeldahl nitrogen with soil depth and wastewater irrigation rates, Middleville, 1973.

Irrigation Rate	Soil Depth (cm)[1]			
	15	30	60	120
mm/week	kg/ha			
(A) Extractable Magnesium				
0	32.5 aw	39.6 aw	54.2 aw	373.1 bw
25	219.6 ax	100.4 aw	46.3 bw	129.2 ax
50	236.8 ax	150.5 aw	68.3 aw	78.8 ax
88	256.2 ax	186.3 aw	139.7 aw	121.7 ax
(B) Total Kjeldahl Nitrogen				
0	776.7 aw	448.1 bw	179.2 bw	179.2 bw
25	1075.5 aw	597.5 bw	239.0 bw	209.1 bw
50	836.5 aw	537.7 abw	268.9 bw	239.0 bw
88	836.5 aw	537.7 abw	268.9 bw	59.8 bcw

[1]Means within the same column (w, x, y, and z) or line (a, b, c, and d) not followed by the same letter are significantly different at the 5% level (Tukey's test).

Table 56. Changes in (A) loss on ignition and (B) boron with soil depth and wastewater irrigation rates, Middleville, 1973.

Irrigation Rate	Soil Depth (cm)[1]			
	15	30	60	120
mm/week	%			
(A) Loss on Ignition				
0	1.8 aw	1.2 abw	0.8 bw	1.3 abw
25	2.5 aw	1.6 bw	0.9 bw	1.2 bw
50	1.9 aw	1.4 bw	0.9 bw	0.9 bw
88	2.2 aw	1.4 bw	1.0 bw	0.7 bw
(B) Boron				
	kg/ha			
0	1.0 aw	0.8 aw	0.9 aw	0.8 aw
25	3.4 ax	2.1 bx	1.6 bw	1.4 bw
50	3.3 ax	1.8 bwx	1.1 bw	1.4 bw
88	4.2 ax	2.8 abx	1.9 bcw	1.4 cw

[1]Means with the same column (w, x, y, and z) or line (a, b, c, and d) not followed by the same letter are significantly different at the 5% level (Tukey's test).

Table 57. Changes in (A) mean humus depth, (B) fine humus dry weight, and (C) total humus dry weight in red pine by irrigation rate and distance from plot center, Middleville, 1973.

mm wastewater/week	Sample Point Distance from Plot Center 2-m	4-m	6-m
	--------cm--------		
(A) Mean Humus Depth			
0	3.98 aw[1]	4.16 aw	4.56 aw
25	2.71 aw	3.43 aw	3.42 aw
50	2.71 aw	2.96 aw	3.24 aw
88	2.48 aw	3.57 aw	4.16 aw
(B) Fine Humus Dry Weight			
	--------kg/ha--------		
0	14,490 aw	16,390 aw	17,250 aw
25	13,990 aw	15,990 aw	12,590 aw
50	13,500 aw	12,880 aw	14,320 aw
88	9,630 aw	14,750 aw	15,060 aw
(C) Total Humus Dry Weight			
0	21,310 aw	24,780 aw	24,690 aw
25	21,830 aw	27,850 aw	19,730 aw
50	22,070 aw	22,260 aw	22,680 aw
88	14,840 aw	23,100 aw	26,740 aw

[1]Means within the same line (a, b, c, and d) or column (w, x, y, and z) not followed by the same letter are significantly different at the 5% level (Tukey's test).

Table 58. Nutrient content of the litter layer in red pine, Middleville, 1973.

Element	Units	mm wastewater/week[1]			
		0	25	50	88
N	%	.83 a	.81 a	.86 a	.82 a
K	%	.13 a	.13 a	.11 a	.11 a
P	%	.13 a	.14 a	.13 a	.15 b
Na	ppm	373.3 a	809.6 b	789.1 b	785.2 b
Ca	%	.73 a	1.40 b	1.56 b	1.50 b
Mg	%	.07 a	.24 b	.24 b	.26 b
Mn	ppm	923.0 a	742.4 a	664.3 a	644.6 a
Fe	ppm	815.9 a	1090.9 ab	936.3 ab	1273.1 b
Cu	ppm	29.8 a	35.0 a	31.2 a	50.6 a
B	ppm	16.2 a	71.5 b	80.1 bc	90.0 c
Zn	ppm	55.1 a	63.9 ab	67.7 ab	74.0 b
Al	ppm	1280.3 a	1714.8 b	1581.9 ab	1761.3 b

[1]Means not followed by the same letter are significantly different at the 5% level (Tukey's test).

Table 59. Mean monthly temperatures in East Lansing and total monthly precipitation at the Michigan State University Tree Research Center, 1972 and 1973.

Month	East Lansing Temp. 1972	East Lansing Temp. 1973	Tree Research Center Precipitation 1972	Tree Research Center Precipitation 1973
	--------°C--------		--------mm--------	
January	-6.0	-2.5	22	29
February	-5.7	-6.0	16	29
March	-1.3	4.4	55	112
April	5.4	8.0	60	56
May	14.7	11.7	96	85
June	16.6	20.0	81	81
July	20.2	21.3	43	43
August	19.7	23.0	54	54
September	15.6	16.8	82	82
October	7.2	12.5	64	64
November	1.8	4.4	67	138
December	-3.1	-3.0	94	88

Table 60. Mean monthly ammonia nitrogen at 30 and 60 cm depth, Lott Woodlot, 1972 and 1973.

Month	Mean Lysimeter Values							
	Well Water		Wastewater					
	50 mm/week		25 mm/week		50 mm/week		75 mm/week	
	30 cm	60 cm	30 cm	60 cm	30 cm	60 cm	30 cm	60 cm
	mg/l							
(1972)								
Jun	--	--	--	--	--	--	--	--
Jul	--	--	--	--	--	--	--	--
Aug	0.12	0.12	0.24	0.08	0.20	0.10	0.11	0.10
Sep	0.08	0.06	0.08	0.08	0.10	0.06	0.30	0.18
Oct	0.23	0.07	0.06	0.09	0.23	0.02	0.24	0.06
(1973)								
Jun	0.20	0.31	0.38	0.20	0.18	0.10	0.14	0.08
Jul	0.26	0.23	0.44	0.19	0.25	0.27	0.24	0.17
Aug	0.27	0.23	0.59	0.20	0.37	0.20	0.27	0.21
Sep	0.47	0.17	0.38	0.26	0.40	0.12	0.25	0.09
Oct	0.25	0.38	0.09	0.13	0.16	0.12	0.15	0.17

Table 61. Mean monthly nitrate nitrogen at 30 and 60 cm depth, Lott Woodlot, 1972 and 1973.

Month	Mean Lysimeter Values							
	Well Water		Wastewater					
	50 mm/week		25 mm/week		50 mm/week		75 mm/week	
	30 cm	60 cm	30 cm	60 cm	30 cm	60 cm	30 cm	60 cm
	mg/l							
(1972)								
Jun	--	--	--	--	--	--	--	--
Jul	--	--	--	--	--	--	--	--
Aug	13.02	1.93	8.48	7.31	8.08	9.42	11.20	11.36
Sep	5.16	2.08	8.81	5.91	8.99	11.03	7.15	13.24
Oct	3.10	2.60	10.12	7.78	10.15	10.95	15.40	13.50
(1973)								
Jun	2.07	1.04	3.52	2.82	3.50	2.65	8.42	5.60
Jul	0.67	1.05	0.79	0.09	1.83	2.37	2.83	1.47
Aug	0.59	0.84	5.86	11.79	2.63	3.28	4.99	9.66
Sep	2.29	0.19	11.10	21.40	2.87	0.12	8.20	8.20
Oct	0.45	0.53	20.00	8.10	2.02	2.60	3.55	2.85

Table 62. Mean monthly organic nitrogen at 30 and 50 cm depth, Lott Woodlot, 1972 and 1973.

Month	Mean Lysimeter Values							
	Well Water		Wastewater					
	50 mm/week		25 mm/week		50 mm/week		75 mm/week	
	30 cm	60 cm	30 cm	60 cm	30 cm	60 cm	30 cm	60 cm
	mg/l							
(1972)								
Jun	--	--	--	--	--	--	--	--
Jul	--	--	--	--	--	--	--	--
Aug	1.66	0.57	0.19	0.41	1.08	1.40	0.13	0.19
Sep	1.35	0.66	0.28	0.45	0.49	0.82	0.72	0.34
Oct	1.56	0.39	0.68	0.48	3.19	1.12	0.43	0.15
(1973)								
Jun	1.89	0.86	0.07	0.49	1.08	0.66	0.87	0.66
Jul	0.43	0.80	0.17	0.32	0.44	0.34	0.58	0.65
Aug	0.67	1.60	0.07	1.13	1.87	0.54	0.62	0.56
Sep	0.86	0.48	0.55	0.22	0.49	0.89	0.62	0.83
Oct	0.70	0.47	0.12	0.02	0.81	0.60	0.59	0.76

Table 63. Mean monthly total nitrogen at 30 and 60 cm depth, Lott Woodlot, 1972 and 1973.

Month	Mean Lysimeter Values							
	Well Water		Wastewater					
	50 mm/week		25 mm/week		50 mm/week		75 mm/week	
	30 cm	60 cm	30 cm	60 cm	30 cm	60 cm	30 cm	60 cm
	mg/l							
(1972)								
Jun	--	--	--	--	--	--	--	--
Jul	--	--	--	--	--	--	--	--
Aug	14.80	2.62	8.91	7.80	9.36	10.92	11.44	11.65
Sep	6.59	2.79	9.18	6.45	9.58	11.90	8.18	13.76
Oct	4.89	3.06	10.86	8.35	13.57	12.09	16.07	13.71
(1973)								
Jun	4.16	2.21	3.97	3.51	4.76	3.41	9.43	6.34
Jul	1.36	2.08	1.40	0.60	2.52	2.98	3.65	2.29
Aug	1.53	2.67	6.52	13.11	4.87	4.02	5.88	10.43
Sep	3.62	0.84	12.03	21.88	3.76	1.13	9.07	9.12
Oct	1.30	1.38	20.21	8.12	2.99	3.32	4.29	3.78

Table 64. Mean monthly total phosphorus at 30 and 60 cm depth, Lott Woodlot, 1972 and 1973.

Month	Mean Lysimeter Values							
	Well Water		Wastewater					
	50 mm/week		25 mm/week		50 mm/week		75 mm/week	
	30 cm	60 cm	30 cm	60 cm	30 cm	60 cm	30 cm	60 cm
	mg/l							
(1972)								
Jun	--	--	--	--	--	--	--	--
Jul	--	--	--	--	--	--	--	--
Aug	0.06	0.02	0.04	0.04	0.08	0.04	0.01	0.02
Sep	0.02	0.01	0.02	0.02	0.02	0.02	0.04	0.02
Oct	0.03	0.02	0.02	0.02	0.09	0.02	0.04	0.02
(1973)								
Jun	0.01	0.03	0.02	0.02	0.02	0.04	0.04	0.02
Jul	0.03	0.03	0.03	0.03	0.02	0.03	0.04	0.02
Aug	0.04	0.04	0.02	0.02	0.02	0.02	0.04	0.03
Sep	0.04	0.01	0.05	0.01	0.03	0.01	0.03	0.03
Oct	0.04	0.07	0.04	0.02	0.05	0.04	0.03	0.03

Table 65. Total nitrogen and total phosphorus renovations at 30 cm depth, Lott Woodlot, computed by the ground water recharge method, 1972.

Nutrient Form	Month	30 cm Depth											
		Amount Applied				Lysimeter Content				Renovation			
		50 w	25 s	50 s	75 s	50 w	25 s	50 s	75 s	50 w	25 s	50 s	75 s
		kg/ha				kg/ha				%			
Total Nitrogen	Jun	--	--	--	--	--	--	--	--	--	--	--	--
	Jul	--	--	--	--	--	--	--	--	--	--	--	--
	Aug	0.2	14.4	28.8	43.1	22.5	1.5	14.2	31.7	0	90	51	26
	Sep	0.2	11.5	23.0	34.5	15.9	13.0	23.2	28.0	0	0	0	19
	Oct	< 0.1	2.9	5.8	8.6	4.5	7.4	12.6	19.0	0	0	0	0
	sum/mean	0.4	28.8	57.6	86.2	42.9	21.9	50.0	78.7	0	24	13	9
Total Phosphorus	Jun	--	--	--	--	--	--	--	--	--	--	--	--
	Jul	--	--	--	--	--	--	--	--	--	--	--	--
	Aug	< 0.1	1.2	2.5	3.8	< 0.1	< 0.1	0.1	< 0.1	0	99	96	99
	Sep	< 0.1	1.0	2.0	3.0	< 0.1	< 0.1	< 0.1	0.1	0	97	97	97
	Oct	< 0.1	0.5	0.5	0.8	< 0.1	< 0.1	< 0.1	< 0.1	0	98	84	94
	sum/mean	< 0.1	2.7	5.0	7.6	0.2	< 0.1	0.2	0.1	0	98	96	98

Table 66. Ammonia nitrogen, nitrate nitrogen, and organic nitrogen renovations at 30 cm depth, Lott Woodlot, computed by the ground water recharge method, 1972.

Nutrient Form	Month	30 cm depth											
		Amount Applied				Lysimeter Content				Renovation			
		50 w	25 s	50 s	75 s	50 w	25 s	50 s	75 s	50 w	25 s	50 s	75 s
		----------kg/ha----------				----------kg/ha----------				----------%----------			
Ammonia Nitrogen	Jun	--	--	--	--	--	--	--	--	--	--	--	--
	Jul	--	--	--	--	--	--	--	--	--	--	--	--
	Aug	0.1	6.0	12.0	18.0	0.2	< 0.1	0.3	0.3	0	99	97	98
	Sep	< 0.1	4.8	9.6	14.4	0.2	0.1	0.2	1.0	0	98	98	93
	Oct	< 0.1	1.2	2.4	3.6	0.2	0.2	0.2	0.3	0	83	92	92
	sum/mean	0.2	12.0	24.0	36.0	0.6	0.3	0.7	1.6	0	97	97	96
Nitrate Nitrogen	Jun	--	--	--	--	--	--	--	--	--	--	--	--
	Jul	--	--	--	--	--	--	--	--	--	--	--	--
	Aug	0.1	6.5	13.0	19.5	19.8	1.4	12.3	31.0	0	78	5	0
	Sep	< 0.1	5.2	10.4	15.6	12.5	12.5	21.8	24.4	0	0	0	0
	Oct	< 0.1	4.8	2.6	2.9	2.9	6.9	9.4	18.2	0	0	0	0
	sum/mean	0.2	16.5	26.0	39.0	35.2	20.8	43.5	73.6	0	0	0	0
Organic Nitrogen	Jun	--	--	--	--	--	--	--	--	--	--	--	--
	Jul	--	--	--	--	--	--	--	--	--	--	--	--
	Aug	< 0.1	1.9	3.8	5.6	2.5	< 0.1	1.6	0.4	0	98	58	93
	Sep	< 0.1	1.5	3.0	4.5	3.3	0.4	1.2	2.5	0	73	60	44
	Oct	< 0.1	0.4	0.8	1.1	1.4	0.5	3.0	0.5	0	0	75	55
	sum/mean	0.1	3.8	7.6	11.2	7.2	0.9	5.8	3.4	0	76	61	70

Table 67. Total nitrogen and total phosphorus renovations at 30 cm depth, Lott Woodlot, computed by the ground water recharge method, 1973.

Nutrient Form	Month	30 cm Depth											
		Amount Applied				Lysimeter Content				Renovation			
		50 w	25 s	50 s	75 s	50 w	25 s	50 s	75 s	50 w	25 s	50 s	75 s
		kg/ha				kg/ha				%			
Total Nitrogen	Jun	0.2	6.0	12.0	18.0	4.5	1.3	5.1	17.3	0	78	57	4
	Jul	0.3	10.0	20.0	30.0	2.2	0.5	4.2	10.4	0	95	79	65
	Aug	0.3	10.0	20.0	30.0	2.6	2.7	8.1	17.2	0	73	59	43
	Sep	0.2	8.0	16.0	24.0	7.3	12.2	7.6	27.3	0	0	52	0
	Oct	0.2	6.0	12.0	18.0	2.1	17.8	4.9	14.5	0	0	59	19
	sum/mean	1.2	40.0	80.0	120.0	18.7	34.5	29.9	86.7	0	14	63	28
Total Phosphorus	Jun	< 0.1	0.5	1.0	1.6	< 0.1	< 0.1	< 0.1	< 0.1	50	99	98	96
	Jul	< 0.1	0.9	1.8	2.6	< 0.1	< 0.1	< 0.1	0.1	0	99	98	96
	Aug	< 0.1	0.9	1.8	2.6	< 0.1	< 0.1	< 0.1	0.1	0	99	98	96
	Sep	< 0.1	0.7	1.4	2.1	< 0.1	< 0.1	< 0.1	< 0.1	0	93	96	96
	Oct	< 0.1	0.5	1.0	1.6	< 0.1	< 0.1	< 0.1	0.1	0	92	92	94
	sum/mean	0.1	3.5	7.0	10.5	0.3	0.1	0.2	0.4	0	97	97	96

Table 68. Ammonia nitrogen, nitrate nitrogen, and organic nitrogen renovations at depth, Lott Woodlot, computed by the ground water recharge method, 1973.

Nutrient Form	Month	30 cm Depth											
		Amount Applied				Lysimeter Content				Renovation			
		50 w	25 s	50 s	75 s	50 w	25 s	50 s	75 s	50 w	25 s	50 s	75 s
		kg/ha				kg/ha				%			
Ammonia Nitrogen	Jun	< 0.1	4.9	9.8	14.6	0.2	0.1	0.2	0.3	0	98	98	98
	Jul	0.1	8.1	16.2	24.4	0.4	0.2	0.4	0.7	0	98	98	97
	Aug	0.1	8.1	16.2	24.4	0.4	0.2	0.6	0.8	0	98	96	97
	Sep	< 0.1	6.5	13.0	19.5	0.9	0.4	0.8	0.8	0	94	94	96
	Oct	< 0.1	4.9	9.8	14.6	0.4	< 0.1	0.3	0.5	0	98	97	97
	sum/mean	0.4	32.5	65.0	97.5	2.3	1.0	2.3	3.1	0	97	96	97
Nitrate Nitrogen	Jun	< 0.1	0.6	1.2	1.8	2.2	1.2	3.8	15.4	0	0	0	0
	Jul	0.1	1.0	2.0	3.0	1.1	0.3	2.9	8.1	0	70	0	0
	Aug	0.1	1.0	2.0	3.0	0.9	2.5	4.4	14.6	0	0	45	0
	Sep	< 0.1	0.8	1.6	2.4	4.6	11.2	5.8	24.7	0	0	0	0
	Oct	< 0.1	0.6	1.2	1.8	0.6	17.6	3.3	12.0	0	0	0	0
	sum/mean	0.4	4.0	8.0	12.0	9.4	32.8	20.2	74.8	0	0	0	0
Organic Nitrogen	Jun	< 0.1	0.5	1.1	1.6	2.0	< 0.1	1.2	1.6	0	96	0	0
	Jul	< 0.1	0.9	1.8	2.6	0.7	< 0.1	0.7	1.6	0	93	61	38
	Aug	< 0.1	0.9	1.8	2.6	1.1	< 0.1	3.1	1.8	0	97	0	31
	Sep	< 0.1	0.7	1.4	2.1	1.7	0.6	1.0	1.9	0	14	29	10
	Oct	< 0.1	0.5	1.1	1.6	1.1	0.1	1.3	2.0	0	80	0	0
	sum/mean	0.2	3.5	7.2	10.5	6.6	0.8	7.3	8.9	0	77	0	15

Table 69. Total nitrogen and total phosphorus renovations at 60 cm depth, Lott Woodlot, computed by the ground water recharge method, 1972.

Nutrient Form	Month	60 cm Depth													
		Amount Applied				Lysimeter Content				Renovation					
		50 w	25 s	50 s	75 s	50 w	25 s	50 s	75 s	50 w	25 s	50 s	75 s		
		kg/ha				kg/ha				%					
Total Nitrogen	Jun	--	--	--	--	--	--	--	--	--	--	--	--		
	Jul	--	--	--	--	--	--	--	--	--	--	--	--		
	Aug	0.2	14.4	28.8	43.1	3.1	0.0	13.1	28.5	0	100	55	34		
	Sep	0.2	11.5	23.0	34.5	6.8	8.2	28.8	47.1	0	29	0	0		
	Oct	< 0.1	2.9	5.8	8.6	2.8	5.7	11.2	16.2	0	0	0	0		
	sum/mean	0.4	28.8	57.6	86.2	12.7	13.9	53.1	91.8	0	52	8	0		
Total Phosphorus	Jun	--	--	--	--	--	--	--	--	--	--	--	--		
	Jul	--	--	--	--	--	--	--	--	--	--	--	--		
	Aug	< 0.1	1.2	2.5	3.8	< 0.1	0.0	< 0.1	< 0.1	0	100	98	99		
	Sep	< 0.1	1.0	2.0	3.0	< 0.1	< 0.1	< 0.1	< 0.1	0	97	97	98		
	Oct	< 0.1	0.5	0.5	0.8	< 0.1	< 0.1	< 0.1	< 0.1	0	98	96	97		
	sum/mean	< 0.1	2.7	5.0	7.6	< 0.1	< 0.1	< 0.1	< 0.1	0	99	98	99		

Table 70. Ammonia nitrogen, nitrate nitrogen, and organic nitrogen renovations at 60 cm depth, Lott Woodlot, computed by the ground water recharge method, 1972.

Nutrient Form	Month	60 cm depth: Amount Applied 50 w	25 s	50 s	75 s	Lysimeter Content 50 w	25 s	50 s	75 s	Renovation 50 w	25 s	50 s	75 s
		kg/ha				kg/ha				%			
Ammonia Nitrogen	Jun	--	--	--	--	--	--	--	--	--	--	--	--
	Jul	--	--	--	--	--	--	--	--	--	--	--	--
	Aug	0.1	6.0	12.0	18.0	0.1	0.0	0.1	0.2	0	100	99	99
	Sep	< 0.1	4.8	9.6	4.4	0.2	0.1	0.1	0.6	0	98	99	86
	Oct	< 0.1	1.2	2.4	3.6	< 0.1	< 0.1	< 0.1	< 0.1	0	95	99	98
	sum/mean	0.2	12.0	24.0	36.0	0.4	0.1	0.2	0.9	0	99	99	97
Nitrate Nitrogen	Jun	--	--	--	--	--	--	--	--	--	--	--	--
	Jul	--	--	--	--	--	--	--	--	--	--	--	--
	Aug	0.1	6.5	13.0	19.5	2.3	0.0	11.3	27.8	0	100	13	0
	Sep	< 0.1	5.2	10.4	15.6	5.0	7.5	26.7	45.3	0	0	0	0
	Oct	< 0.1	4.8	2.6	3.9	2.4	5.3	10.2	15.9	0	0	0	0
	sum/mean	0.2	16.5	26.0	39.0	9.7	12.8	48.2	89.0	0	22	0	0
Organic Nitrogen	Jun	--	--	--	--	--	--	--	--	--	--	--	--
	Jul	--	--	--	--	--	--	--	--	--	--	--	--
	Aug	< 0.1	1.9	3.8	5.6	0.7	0.0	1.7	0.5	0	100	55	91
	Sep	< 0.1	1.5	3.0	4.5	1.6	0.6	2.0	1.2	0	60	33	73
	Oct	< 0.1	0.4	0.8	1.1	0.4	0.3	1.0	0.2	0	25	0	82
	sum/mean	0.1	3.8	7.6	11.2	2.7	0.9	4.7	1.9	0	76	38	83

Table 71. Total nitrogen and total phosphorus renovations at 60 cm depth, Lott Woodlot, computed by the ground water recharge method, 1973.

Nutrient Form	Month	60 cm depth											
		Amount Applied				Lysimeter Content				Renovation			
		50 w	25 s	50 s	75 s	50 w	25 s	50 s	75 s	50 w	25 s	50 s	75 s
		kg/ha				kg/ha				%			
Total Nitrogen	Jun	0.2	6.0	12.0	18.0	2.4	1.2	3.7	11.6	0	80	69	36
	Jul	0.3	10.0	20.0	30.0	3.3	0.2	4.8	6.5	0	98	76	78
	Aug	0.3	10.0	20.0	30.0	4.5	5.5	6.7	30.5	0	45	66	0
	Sep	0.2	8.0	16.0	24.0	1.7	22.1	2.3	27.5	0	0	86	0
	Oct	0.2	6.0	12.0	18.0	2.2	7.1	5.4	12.8	0	0	55	29
	sum/mean	1.2	40.0	80.0	120.0	14.1	36.1	22.9	88.9	0	10	71	26
Total Phosphorus	Jun	< 0.1	0.5	1.0	1.6	< 0.1	< 0.1	< 0.1	< 0.1	0	99	96	97
	Jul	< 0.1	0.9	1.8	2.6	< 0.1	< 0.1	< 0.1	< 0.1	0	99	98	97
	Aug	< 0.1	0.9	1.8	2.6	< 0.1	< 0.1	< 0.1	< 0.1	0	99	98	97
	Sep	< 0.1	0.7	1.4	2.1	< 0.1	< 0.1	< 0.1	< 0.1	0	99	99	96
	Oct	< 0.1	0.5	1.0	1.6	0.1	< 0.1	< 0.1	0.1	0	96	93	94
	sum/mean	0.1	3.5	7.0	10.5	0.3	< 0.1	0.2	0.4	0	98	97	96

Table 72. Ammonia nitrogen, nitrate nitrogen, and organic nitrogen renovations at 60 cm depth, Lott Woodlot, computed by the ground water recharge method, 1973.

Nutrient Form	Month	60 cm Depth: Amount Applied 50 w	25 s	50 s	75 s	Lysimeter Content 50 w	25 s	50 s	75 s	Renovation 50 w	25 s	50 s	75 s
		kg/ha				kg/ha				%			
Ammonia Nitrogen	Jun	< 0.1	4.9	9.8	14.6	0.3	< 0.1	0.1	0.1	0	99	99	99
	Jul	0.1	8.1	16.2	24.4	0.4	< 0.1	0.4	0.5	0	99	98	98
	Aug	0.1	8.1	16.2	24.4	0.4	< 0.1	0.3	0.6	0	99	98	98
	Sep	< 0.1	6.5	13.0	19.5	0.3	0.3	0.2	0.3	0	95	98	98
	Oct	< 0.1	4.9	9.8	14.6	0.6	0.1	0.2	0.6	0	98	98	96
	sum/mean	0.4	32.5	65.0	97.5	2.0	0.6	1.2	2.1	0	98	98	98
Nitrate Nitrogen	Jun	< 0.1	0.6	1.2	1.8	1.1	0.9	2.9	10.2	0	0	0	0
	Jul	0.1	1.0	2.0	3.0	1.7	< 0.1	3.8	4.2	0	97	0	0
	Aug	0.1	1.0	2.0	3.0	1.4	5.0	5.5	28.2	0	0	0	0
	Sep	< 0.1	0.8	1.6	2.4	0.4	21.6	0.2	24.7	0	0	87	0
	Oct	< 0.1	0.6	1.2	1.8	0.9	7.1	4.2	9.6	0	0	0	0
	sum/mean	0.4	4.0	8.0	12.0	5.5	34.6	16.6	76.9	0	0	0	0
Organic Nitrogen	Jun	< 0.1	0.5	1.1	1.6	0.9	0.2	0.7	1.2	0	60	36	25
	Jul	< 0.1	0.9	1.8	2.6	1.3	0.1	0.5	1.9	0	89	72	27
	Aug	< 0.1	0.9	1.8	2.6	2.7	0.5	0.9	1.6	0	44	50	38
	Sep	< 0.1	0.7	1.4	2.1	1.0	0.2	1.8	2.5	0	71	0	0
	Oct	< 0.1	0.5	1.1	1.6	0.8	< 0.1	1.0	2.6	0	96	9	0
	sum/mean	0.2	3.5	7.2	10.5	6.7	1.0	4.0	9.8	0	71	44	7

Table 73. Changes in (A) pH and (B) available phosphorus with soil depth and wastewater irrigation rates, Lott Woodlot, 1973.

Irrigation Rate	Soil Depth (cm) 15	30	60
mm/week	----------pH----------		
(A) pH			
0	5.7 ax[1]	5.6 ax	5.8 axy
50 w[2]	6.6 ay	6.2 axy	5.6 ax
25 s	6.4 ay	6.1 axy	6.2 axyz
50 s	6.3 ay	6.3 ayz	6.3 ayz
75 s	6.8 ay	6.8 az	6.5 az
(B) Available Phosphorus			
	----------kg/ha----------		
0	17.9[3]	15.3	11.6
50 w	15.3	13.1	11.6
25 s	10.8	10.5	8.6
50 s	17.5	9.7	10.8
75 s	18.7	22.8	8.9

[1]Means within the same line (a, b, c, and d) or column (x, y, and z) not followed by the same letter are significantly different at the 5% level (Tukey's test).

[2]w = well water; s = wastewater.

[3]No significant difference with treatment at 5% level (Tukey's test).

Table 74. Changes in (A) extractable potassium and (B) extractable calcium with soil depth and wastewater irrigation rates, Lott Woodlot, 1973.

Irrigation Rate	Soil Depth (cm) 15	30	60
mm/week	kg/ha		
(A) Extractable Potassium			
0	179.2 ax[1]	71.7 bx	31.4 bx
50 w[2]	241.9 az	174.7 by	94.1 cy
25 s	170.2 ay	58.3 bx	62.7 bxy
50 s	138.9 ayx	116.5 axy	76.2 axy
75 s	107.5 ax	114.2 ax	94.1 ay
(B) Extractable Calcium			
0	2951.2 ax[1]	790.3 bx	632.4 bx
50 w[2]	4190.0 ax	1212.2 bx	738.1 bx
25 s	3109.5 ax	843.4 bx	1053.9 bx
50 s	2740.6 ax	1053.9 bx	843.4 bx
75 s	3716.2 ax	1264.5 bx	1027.6 bx

[1]Means within the same line (a, b, c, and d) or column (x, y, and z) not followed by the same letter are significantly different at the 5% level (Tukey's test).

[2]w = well water; s = wastewater.

Table 75. Changes in (A) extractable magnesium and (B) total Kjeldahl nitrogen with soil depth and wastewater irrigation rates, Lott Woodlot, 1973.

Irrigation Rate	Soil Depth (cm) 15	30	60
mm/week	kg/ha		
(A) Extractable Magnesium			
0	293.1 ax[1]	77.3 bx	48.9 bx
50 w[2]	678.0 az	248.3 bx	138.5 bx
25 s	419.6 axy	126.6 bxy	126.6 bx
50 s	362.9 axy	171.0 bxy	158.6 bx
75 s	482.2 ay	183.7 bxy	170.8 bx
(B) Total Kjeldahl Nitrogen			
0	5108.6 ax[1]	1045.6 bx	298.7 bx
50 w[2]	3973.3 ax	1195.0 bx	388.4 bx
25 s	4212.3 ax	866.4 bx	328.6 bx
50 s	3555.1 ax	806.6 bx	119.5 bx
75 s	3465.5 ax	657.2 bx	239.0 bx

[1]Means within the same line (a, b, c, and d) or column (x, y, and z) not followed by the same letter are significantly different at the 5% level (Tukey's test).

[2]w = well water; s = wastewater.

Table 76. Changes in loss on ignition with soil depth and wastewater irrigation rates, Lott Woodlot, 1973.

Irrigation Rate	Soil Depth (cm)		
	15	30	60
mm/week	%		
0	7.1 ax[1]	2.2 bx	1.1 bx
50 w[2]	6.9 ax	2.4 bx	1.7 bx
25 s	6.5 ax	2.2 bx	1.6 bx
50 s	5.2 ax	1.9 bx	1.4 bx
75 s	5.8 ax	2.0 bx	1.5 bx

[1]Means within the same line (a, b, c, and d) or column (x, y, and z) not followed by the same letter are significantly different at the 5% level (Tukey's test).

[2]w = well water; s = wastewater.

Table 77. Soil moisture tension in the 30-60 cm depth of Miami loam, Lott Woodlot, June 27 to August 17, 1973.

Date	mm of wastewater/week		
	0	24	75
	------------centibars-----------		
6/27	16.8 a[1]	6.5 a	9.0 a
7/04	11.0 a	4.5 a	9.5 a
7/11	21.2 a	8.8 a	10.0 a
7/16	29.0 a	19.8 a	13.5 a
7/18	34.2 a	7.0 b	9.5 b
7/24	54.0 a	31.8 a	17.0 a
7/27	63.8 a	16.2 b	10.2 b
7/29	67.3 a	10.5 b	8.5 b
8/03	64.5 a	31.5 a	10.0 a
8/10	78.0 a	30.5 ab	10.8 b
8/17	78.0 a	41.3 ab	15.5 b

[1]Means not followed by the same letter are significantly different at the 5% level (Tukey's test).

Table 78. Soil moisture tension in the 30-60 cm depth of Miami loam, Lott Woodlot, August 24 to November 20, 1973.

Date	mm of wastewater/week		
	0	25	75
	------------centibars------------		
8/24	73.0 a[1]	32.5 ab	8.0 b
8/31	76.2 a	62.2 a	37.0 a
9/06	93.8 a	67.3 a	50.5 a
9/15	100.0 a	80.0 ab	69.0 b
8/21	89.5 a	57.5 ab	28.5 b
9/25	89.5 a	17.5 a	10.2 a
10/02	79.8 a	17.2 b	12.5 b
10/10	62.8 a	2.0 b	8.5 b
10/18	56.8 a	10.0 b	10.0 b
11/04	34.0 a	2.0 b	8.0 b
11/20	6.0 a	0.0 a	7.0 a

[1]Means not followed by the same letter are significantly different at the 5% level (Tukey's test).

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