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THE REMOVAL OF NITROGEN FROM WASTEWATER
BY CORN AND RYE: A GREENHOUSE STUDY

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THE REMOVAL OF NITROGEN FROM WASTEWATER
BY CORN AND RYE: A GREENHOUSE STUDY

By

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ABSTRACT

THE REMOVAL OF NITROGEN FROM WASTEWATER
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Nitrate losses to ground water must be minimized in a land application site for sewage effluent. Crop selection is an important consideration in the management of nitrate losses from the application of sewage effluents to the land.

The purpose of this experiment was to study the effect of crop selection on the loss of nitrate in drainage water from the soil profile of a simulated land application system under greenhouse conditions.

There were three crop systems: corn, rye, and corn intercropped with rye. Three rates of simulated effluent were applied: 5 cm/wk, 10 cm/wk, and 15 cm/wk. The simulated effluent contained an average of 6.6 ppm nitrogen, which is the average for the Muskegon County Wastewater Project.

Corn intercropped with rye minimized nitrate losses in drainage water. Rye did nearly as well by itself. Corn was not very effective in controlling nitrate losses.

Generally less total nitrate was lost in all cropping systems when treated with the lowest simulated effluent rate (5 cm/wk), but moisture and nitrogen were probably limiting crop growth. The 15 cm/wk simulated effluent treatment provided the best growth and minimized nitrate loss for rye and corn intercropped with rye. Both of these crops reduced the nitrate nitrogen concentration of the drainage water to less than 0.05 ppm by the end of the experiment.

TO MY WIFE AND CHILDREN

ACKNOWLEDGMENTS

I AM THANKFUL FOR THOSE MEN
AT MICHIGAN STATE WHO
INTRODUCED ME TO AGRICULTURE.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Land treatment and disposal of wastewater in the past decade has risen from the status of "Ancient Practice" to that of a "Scientific Technology". Waste treatment and disposal facilities, both municipal and industrial, must be designed for maximum water renovation with minimum cost. Strict water quality criteria and rising cost of tertiary treatment require the development of cheaper and more efficient methods of waste treatment. Municipal and industrial wastewaters have been successfully renovated by land application.

Many land treatment and disposal facilities use a vegetative cover to remove the nutrients from the wastewater. Forest and grass cover crops have been popular because they require very little maintenance. Federal funding agencies are encouraging land treatment facilities that will become self supporting. One method of reducing costs at a land treatment facility is to harvest the nutrients from the wastewater by growing a crop which can be sold.

The Muskegon County Wastewater Management system irrigates about 2,400 hectares of corn with its sewage effluent. Corn is an attractive crop because of its cash value and ready market. But it is limited by a growing season of about 100 days. Corn actively removes nitrogen from the soil water system for about half this time. It seems unlikely that corn can be effectively used to renovate wastewater at Muskegon because it uses nitrogen at an appreciable rate for only about one third or less of the 145 day wastewater irrigation season.

The soils at the Muskegon project are infertile sands. Water percolates through the soil quickly. The wastewater applied at Muskegon has a nitrogen concentration of about 6.6 ppm nitrogen which is low in comparison to the nitrogen needs of the corn plant. For maximum nitrogen removal the crop should have a dense root growth reaching into a large volume of the soil profile, a high nitrogen requirement and a long growth period. With these conditions the crop could quickly use the nitrogen before it is lost to the ground water.

Many questions must be answered before we can make good decisions concerning each specific use of the land application concept. We need to know how well specific crops can use the nitrogen in wastewater. The diverse contents of wastewaters make experience at one site difficult to use at other sites. The impact of toxic compounds and heavy metals in wastewater spread on the land is far from defined. Each site presents a new set of physical, chemical and biological parameters.

This study seeks to point out some of the limitations of corn as a crop for land treatment and disposal of wastewater.

At Muskegon a cover crop such as rye could be used to compliment corn. If corn were no-till planted into established rye it would extend the nitrogen stripping period because of the different growing seasons of the two crops. This could provide better water renovation for a longer period of time. If the intercropping were managed properly it might be possible to maintain corn yields at a high enough level to reduce land treatment costs.

This study seeks to determine the limitations of corn as a crop for land treatment and disposal of wastewater. It compares the nitrogen stripping capabilities of corn, rye and corn intercropped with rye, using three simulated effluent application rates.

LITERATURE REVIEW

HISTORY OF LAND APPLICATION OF WASTE

Treatment and disposal of wastewater by land application is not a new concept in waste handling. This simple technology has been employed for at least four hundred years (Thomas, 1973). The applications of waste to the land was the simplest and most logical method of treatment and disposal. As early as 1875 methods such as sedimentation and chemical precipitation had been successfully used to purify wastewater (Egeland, 1973). But land application remained the only widely accepted method of waste treatment until after 1900.

In Germany during the 16th century, wastewater was applied to cropland because it seemed to have some value as a fertilizer or soil amendment (Deturk, 1935). The yield from an early European sewage farm would often be double that from a conventional farm in the same area (Pound and Crites, 1973b). Historically man has had a very narrow concept of land application as simply a method of waste disposal. Recently this concept has enlarged to view land application as a method of water treatment and water recycling (Thomas, 1973). There is also renewed interest in the valuable nutrients contained in these waste materials.

The first "land disposal" operations in the United States began late in the 19th century. Historical data on these facilities can be found in Pound and Crites (1973b).

Land application of wastewater has been practiced for a variety of reasons including economical alternatives to waste treatment, to provide supplemental irrigation water, as a method of disposal in situations lacking suitable receiving waters, and ground water augmentation (Sullivan et al., 1973).

THE IMPORTANCE OF LAND APPLICATION OF WASTE

The Federal Water Pollution Control Act Amendments of 1972 recognized the fact that our nations waters are in a degraded state. These amendments state that as a nation we must "restore and maintain the chemical, physical, and biological integrity of the nations waters" and that "it is the national goal that the discharge of pollutants into navigable waters be eliminated by 1985" (Section 101, Public Law 92-500).

In addition to the "zero discharge" goal, several other portions of the amendments attempt to create a renewed interest in land application of wastewaters. Section 201 of Public Law 92-500 requires that in order to receive federal assistance, a project must study "alternative waste management techniques" and the technique chosen must be the most effective on a cost basis. This is significant in that land application is very economical. Section 212 of Public Law 92-500 also allows that land used in wastewater treatment (such as land application, ponds, etc.) may be purchased with federal money. Section 201 also encourages revenue producing facilities which recycle waste materials into salable agricultural, silvicultural and aquacultural products, and facilities which provide recreational potential.

NITROGEN IN WASTEWATER

In 1972 our nation treated and disposed of 7.5 billion gallons of wastewater per day (National Association of State Universities and Land Grant Colleges, 1973). The approximate concentration of total nitrogen in an average municipal secondary effluent may be 20 - 25 mg/liter (Etzel and Steffan, 1974; Lance, 1972; Pound and Crites, 1973b). Most municipal treatment plants have been discharging their wastewater after secondary treatment. Combining these figures for 1972 we could estimate that 207,000 to 259,000 metric tons of nitrogen were discharged into our water resources by municipal treatment plants. The Hazardous Materials Advisory Committee (1973) has estimated that the wastewater discharged by our nations domestic wastewater treatment plants could contain as much as 840,000 metric tons of nitrogen. Human waste contains about 5.4 kg of nitrogen per person per year. Thus in 1972 about 1,100,000 metric tons of nitrogen entered our sewage and septic systems (Committee on Nitrate Accumulation, 1972).

The quality and content of municipal and industrial wastewaters at various stages of treatment are well documented (Hazardous Materials Advisory Committee, 1973; Pound and Crites, 1973a, 1973c; Reeves, 1972). The composition of municipal wastewater varies greatly and industrial effluents are even more diverse. The characteristics of wastewaters are so different depending on the source that each must be evaluated before good decisions concerning any treatment method can be made.

Organic and ammonium nitrogen are the main forms of nitrogen in municipal effluents applied to land (Lance et al., 1976; Adams, 1973; Pound and Crites, 1973b). The ammonium ion may account for 90% of the total nitrogen in secondary effluents. Nitrate and nitrite may also be present. Nitrate concentrations are usually less than 10 mg nitrogen per liter. Nitrite is rapidly oxidized to nitrate under areobic conditions so concentrations above 1 mg/liter are unusual (Pound and Crites, 1973b). Nitrite is generally not a problem in secondary municipal effluents.

The control and removal of nitrogen from wastewater has been extensively studied. Several reviews give good descriptions of methods such as air stripping, ion exchange, biological nitrification-denitrification, and breakpoing chlorination (Atkins and Scherger, 1977; DeRenzo, 1978; Reeves, 1972 and Ripley et al., 1974).

NITROGEN CYCLE

There exists within the soil a very complex network of biochemical and chemical reactions which use and recycle nitrogen. A complete understanding of these mechanisms is essential in attempting to develop a land application system which will maximize nitrogen removal from wastewater. There is an abundance of information available on soil nitrogen (Buckman and Brady, 1969; Bartholomew and Clark, 1965; Lance, 1972; Pound and Crites, 1973b). Several of these references include a detailed diagram illustrating the nitrogen transformations and pathways in the soil.

A mineral soil will normally contain 0.02 - 0.5 percent nitrogen in the "plow layer" (Buckman and Brady, 1969). This is equivalent to about 0.18 to 4.5 metric tons of nitrogen per acre furrow slice. Nitrogen occurs in the soil mainly in the organic form. Nitrogen also occurs as ammonium fixed by the soils exchange complex and as soluble ammonium and nitrate.

Organic nitrogen suspended in wastewater is physically filtered out as it is applied to the soil. This organic nitrogen is subject to mineralization (microbial decomposition) to ammonium. Many microorganisums are capable of mineralizing organic nitrogen. Mineralization is favored by well drained and aerated soil conditions. Soil temperature, pH, and concentration of soluble mineral nitrogen also affect the rate and occurrence of nitrogen mineralization (Harmsen and Kolenbrander, 1965). It may be possible to predict nitrogen mineralization rate as the soil moisture conditions change (Stanford and Epstein, 1974).

Ammonium nitrogen, the major inorganic form of nitrogen in wastewater, may be volitalized, immobilized, adsorbed or absorbed by soil, or nitrified as wastewater is applied to land.

Harmsen and Kolenbrander (1965) have reviewed the study of ammonia losses from soil. Several factors which can increase ammonia volitalization from soil are pH above 7.0, increased aeration, and ammonia concentrations which exceed the capacity of the soil to "sorb" ammonia. Ammonia losses from the wastewater before it comes into contact with the soil can be significant if the wastewater has a pH of 8.0 or greater and if adequate air-water contact is maintained such as in a spray irrigation system (Lance, 1972; Lance et al., 1977).

Nitrogen immobilization is best described as the "tying-up" of inorganic forms of nitrogen in microbial cell tissue during the decomposition of organic residues that contain nitrogen. Ammonium nitrogen is more readily used by most soil microbes. In a land application system the amount of wastewater nitrogen immobilized is dependent on the carbon to nitrogen ratio of the wastewater (Lance, 1972; Lance et al., 1977). Low temperatures slow down the immobilization process. Aerobic conditions promote greater immobilization than anerobic conditions. Immobilization rate varies with soil depth due to differences in moisture, temperature, pH, and oxygen availability (Bartholomew, 1965). Nitrogen is fairly stable after it is immobilized in the soil.

Negatively charged mineral and organic fractions or colloids of the soil can adsorb ammonium nitrogen (Lance 1972; Pound and Crites, 1973b; Scarsbrook, 1965; Stevenson, 1965; Tilstra et al., 1972). The amount of nitrogen adsorbed depends on the cation exchange capacity of the soil and the concentration of other cations in the soil. It is possible to estimate the amount of nitrogen adsorbed in this way (Lance, 1972). Ammonium nitrogen which is adsorbed on the exchange complex is generally unstable. It is subject to microbial oxidation (nitrification), leaching, immobilization, and plant uptake if the environmental conditions are favorable. Ammonium adsorbed in an anaerobic zone is relatively stable except when conditions favoring displacement from the exchange complex and leaching are in effect (Avnimelech and Raveh, 1976; Lance, 1972; Pound and Crites, 1973b).

Ammonium nitrogen can be fixed by clay and organic fractions in the soil so that it is very stable compared to the ammonium nitrogen adsorbed on the exchange complex. The forces which hold this nitrogen are much stronger than those which hold ammonium in its readily available state on the soils exchange complex. The fixation of ammonium by certain clays involves the incorporation of the ammonium ion into their crystal lattice (Lance, 1972; Buckman and Brady, 1969). There are several detailed discussions of this complex subject and those factors which affect it (Mortland and Wolcott, 1965; Nommik, 1965). The organic fixation of ammonium is not well understood. Compounds resulting from these soil reactions are fairly stable. The proposed nature and significance of this form of ammonium fixation have been reviewed by Lance (1972), Mortland and Wolcott (1965), and Nommik (1965).

The soluble and readily available fractions of ammonium nitrogen in the soil may be biologically oxidized to nitrate nitrogen under aerobic conditions. This microbial conversion of ammonium nitrogen occurs rapidly in soils when aeration, acidity and temperature are favorable to plant growth (Committee on Nitrate Accumulation, 1972). Nitrification has been thoroughly studied and is very well understood (Bear, 1953; Buckman and Brady, 1969; Alexander, 1965).

Nitrate nitrogen accumulation in soils is a major ecological concern because nitrate is so easily leached to the ground water. Nitrate nitrogen is a substantial contributor to the eutrophication of our surface waters and the contamination of our ground waters.

The United States Department of Health, Education and Welfare has set 10 mg N/l as the maximum concentration of nitrate allowed in water for human consumption. Nitrate in excess of this level may cause methemoglobinemia, a blood disorder which affects infants less than three months old. Nitrate consumed in the water is reduced to nitrite in the infants stomach. Nitrites then enter the bloodstream and oxidize hemoglobin to methemoglobin, which does not function properly as an oxygen carrier (Bailey and Thomas, 1975; DeRenzo, 1978; Lehninger, 1970; Steel, 1960). In the soil nitrites are very unstable. They are denitrified under anerobic conditions or oxidized to nitrate in the presence of oxygen and the appropriate microbes.

Many studies have been conducted on denitrification (Ardakani et al., 1975; Lance et al., 1976; Volz et al., 1975). Denitrification or the microbial reduction of nitrate to nitrogen gas and its oxides requires an environment which provides reducing substrates (Lance and Gerba, 1977) and anerobic conditions. Many kinds of microorganisms can serve as denitrifiers so the presence of the proper microflora is seldom limiting to denitrification (Buckman and Brady, 1969). Environmental factors affecting denitrification have been reviewed by Bear (1953) and Harmsen and Kolenbrander (1965). In well aerated soils, such as those used for crop irrigation with sewage effluents, denitrification may occur in anerobic microenvironments (Nommik, 1965; Volz, 1975). Denitrification and nitrification can occur in the same system by alternate flooding and drying cycles (Bouwer et al., 1974; Lance and Whisler, 1972). Nitrogen gas or nitrogen oxides evolved from the denitrification process are completely removed from the soil system. This makes denitrification an important factor in the removal of nitrogen from wastes with land application. Denitrification may also occur as the result of a chemical reaction between soil organic matter and nitrate. This reaction generally does not remove a significant amount of nitrogen from the soil system (Pound and Crites, 1973b).

CROP REMOVAL OF NITROGEN

A crops need for nitrogen is tremendous. More atoms of nitrogen are needed than any other nutrient supplied by soil or fertilizers (Viets, 1965). Knowledge of this fact makes cropping a prime candidate for nitrogen removal in a wastewater treated soil. A crop performs a very important form of "immobilization" in the soil nitrogen system. There are several good discussions on the ability of various crops to remove nitrogen and the management practices and decisions which must be considered before implementing crop removal of nitrogen by land application (Day, 1973; Erickson, 1974; Pound and Crites, 1973b; Sopper, 1973; Sullivan et al., 1973).

Plants can remove nitrogen from the soil in either the nitrate or ammonium form. There have been many studies to determine which ion performs best in supplying nitrogen to plants. Viets (1965) and Dibb and Welch (1976) have summarized some of these investigations. These studies have pointed out that either ion may be a better nitrogen source depending on specific soil environmental conditions. Alessi and Power (1973) approached this question by studying nitrogen recovery with various fertilizer nitrogen materials. They found the percent recovery of ammonium and nitrate to be very similar. It is difficult to study the uptake of ammonium by plants growing in soil because of nitrification. Many investigators have used solution cultures because there nitrification is inhibited. Chemical nitrification inhibitors have been used in the soil to maintain ammonium concentrations during uptake studies (Warncke and Barber, 1973). Uptake of other nutrients may be affected by the nitrogen source coupled with soil and plant response (Viets, 1965).

The nitrogen uptake efficiency of crops vary. Also the fertility levels required to maintain maximum nitrogen uptake are different for each crop and its soil environmental conditions.

Warncke and Barber (1974a) have described the nitrate uptake effectiveness of corn, soybeans, sorghum and bromegrass. Corn was found to absorb nitrate more efficiently than the other crops. It stripped nitrate from a 1000 μM solution, reducing the nitrate concentration to as low as 2 μM. At this low level plants yellowed severely and nitrate uptake ceased. A solution of 1000 μM was adequate for optimum growth of corn, sorghum and bromegrass.

Bole and Bell (1978) studied the effect of wastewater on yield and composition of several forages grown in the field. All forages except tall wheatgrass took up more nitrogen than was applied. Fertilizer nitrogen was added to some treatments. Effect of wastewater nitrogen on yield was equal that of fertilizer nitrogen.

Day and Kirkpatrick (1973) found that treated wastewater can be used to produce oats with grain yield and protein content approximately equal to that of oats grown with fertilizer supplemented well water.

Hanway (1963) has sought to describe the identifying characteristics of each stage of physiological and morphological development of the corn plant. According to Hanway, nutrient uptake in corn begins to occur at a rapid rate during the second stage of growth. The second stage is characterized by the appearance of the collar of the eighth leaf, about 28 days after emergence. Maximum nutrient uptake generally occurs during growth stage 5 or about 66 days after emergence when 75% of plants have visible silks.

Edwards and Barber (1976) studied the influence of age on nitrogen uptake of corn roots at low nitrogen concentrations between 0 μM and 150 μM. In this solution culture study maximum influx of nitrogen occurred above 21 μM. Greatest influx occurred with plants 18-24 days old.

Under field conditions Mengel and Barber (1974b) found nutrient uptake of nitrogen in corn to reach a maximum of 1200 μM/day at a plant age of about 50 days. This nitrogen uptake decreased to a minimum of 113 μ M/day per plant at silking (about 70 days). Warncke and Barber (1974b) measured a maximum nitrogen uptake per corn plant of 8.1 mg atoms/plant/day, for plants in the 60 - 67 day age range. This rate dropped dramatically during the transition from the vegetative to the reproductive stage (74 - 81 days).

Corn root development under field conditions has been studied by Mengel and Barber (1974a). They found that for the first 75 days root length increased rapidly. Root length then leveled off and began to decrease rapidly at about 90 days. Nutrient uptake increased in a similar manner but reached a maximum at 50 days and then began to decrease. A maximum nitrogen uptake of 1200 μ M/day was reported for 50 day old plants. Nitrogen uptake dropped to a minimum of 113 μ M day at 80 days.

MATERIALS AND METHODS

This study was conducted in the greenhouse from February 8, 1976 to April 24, 1976. The effects of various crop and irrigation treatments on nitrogen removal from an applied simulated effluent solution were studied using the following techniques.

GREENHOUSE APPARATUS

Columns were constructed from 1.5 m lengths of 10 cm diameter P.V.C. pipe. A plexiglass base was cemented to each column. A .95 cm drainage hole was bored in the wall of each column at the base and fitted with a drainage tube. Drainage samples were collected from the tube in 1 liter plastic bottles wrapped with aluminum foil.

The 36 columns were supported in wooden racks, each rack holding 18 columns. The racks were oriented north to south on the greenhouse bench and were 75 cm apart. Columns were spaced 14.6 cm from center to center in the racks.

The "C" horizon of a Rubicon sand was used as a growth medium. The soil was obtained from an uncultivated area near circle #3 of the Muskegon County Wastewater Treatment Facility. The parent material of the soil profile was used because the surface horizons of these soils are often absent and the "C" horizon has the least organic matter and nitrogen to confound the experiment. The soil was air dried, passed through a 5 mesh sieve, and then mixed.

A plug of glass wool was placed over the drainage hole on the inside of the column to prevent the soil from washing out. A large plastic funnel attached to a 1.5 m length of plastic pipe with a diameter of 2.5 cm was used to distribute the soil evenly in the columns. The soil was poured into the funnel and gently deposited with a slow circular motion. The columns were gently tapped during the filling process to eliminate air pockets and to distribute the soil as uniformly as possible.

The length of the natural daylight period during the experiment ranged from 10 hours and 15 minutes on February 8, 1976 to 13 hours and 46 minutes on April 24, 1976. Supplemental lighting was used to extend the daylight period to 14 hours per day for the duration of the experiment. Two light fixtures were used, each with 4, eight foot long cool white florescent bulbs. They were made from 1.59 cm diameter pipe frames with no reflectors, so that plants would not be shaded from the sun. No incandescent bulbs were used.

Temperature measurements in the greenhouse were recorded with a seven day recording thermometer. The temperature at night was kept at 13^{o}C with steam heat. Windows were opened daily if temperatures reached 24^{o}C or more.

TREATMENTS

Nine treatment combinations were used, a 3 X 3 factorial with 3 cropping systems and 3 irrigation treatments. Each treatment combination was replicated 4 times.

The cropping systems used were corn (Pioneer #8780), rye (Balbo rye), and corn intercropped with rye referred to as corn-rye in the remainder of this thesis. At the Muskegon Wastewater Project, corn is the main cropping system. Rye was included in this experiment because it actively removes nitrogen for a longer period of time.

A simulated effluent was made up daily to match the nitrogen and phosphorus content of the effluent applied to the soil at the Muskegon County Wastewater Project. The solution contained an average of 6.6 ppm nitrogen from NH_4NO_3 and 7 ppm phosphorus from KH_2PO_4.

The irrigation treatments were 5 cm/wk, 10 cm/wk and 15 cm/wk of simulated effluent. Starting with the fourth week supplemental applications of distilled water were given to each column to approximate what was evaporated from the surface of a pan evaporimeter with the same diameter as the columns. The distilled water was applied between irrigation treatments. During the eighth week the 5 cm/wk treatment was changed to 5 cm/wk of simulated effluent plus 5 cm/wk of distilled water. This alteration was necessary to maintain a measurable drainage rate. The total amount of nitrogen applied did not change.

Simulated effluent was applied in units of 2.5 cm per application. No more than one application of simulated effluent was made in any 24 hour period. Table 1 shows a schedule of weekly effluent applications.

TABLE 1 - SCHEDULE OF EFFLUENT APPLICATIONS

RATE OF APPLICATION	SUN.	MON.	TUE.	WED.	THUR.	FRI.	SAT.
cm/wk							
5	-	X	-	-	-	X	-
10	-	X	-	X	-	X	X
15	-	X	X	X	X	X	X

X - denotes application of 2.5 cm of simulated effluent.

EXPERIMENT INITIATION

The packed soil columns were brought to near saturation by flooding with distilled water. They were allowed to drain for 48 hours to bring them to approximate field capacity. Rye was planted on February 2, 1976. The seeds were soaked in aerated water for 24 hours prior to planting to hasten emergence. Twelve rye seeds were planted in each column at a depth of about 1.3 cm. The rye population was thinned to 8 plants per column after one week. Corn seed was soaked 24 hours and planted about 2.5 cm deep. Two corn seeds were planted in each column and later thinned to one plant. All columns were watered with 100 mls of distilled water per day until all seedlings had emerged. Irrigation treatments were started on February 9, 1976.

SAMPLING AND ANALYTICAL METHODS

Drainage samples were usually collected every other day. They were stored in a cooler at 4^{o}C. Drainage sample volumes were determined by weight. Fresh drainage samples, which had not been in the cooler more than 48 hours, were analyzed for nitrate using the colorimetric cadmium reduction method (Henriksen and Selmer-Olsen, 1970) on the Technicon Auto-Analyzer.

Drainage samples were occasionally analyzed for phosphorus, ammonium and nitrite to determine if these nutrients were being lost in the leachate. Phosphorus was measured using the ammonium molybdate-ascorbic acid method (Watanabe and Olsen, 1965). Ammonium was measured with the colormetric phenate method (U. S. Environmental Protection Agency, 1974). Nitrite concentrations were determined with the method of Henriksen and Selmer-Olsen, (1970). All of these analyses were done with the Technicon Auto-Analyzer.

The rye plants in the corn-rye treatments were cut back to about 5 cm during the eighth week to reduce the stress on the corn plants in this treatment. The harvested rye was saved and added to final yields.

The experiment was terminated after 11 weeks. At this time all plant materials were harvested and oven dried at 60^{o}C. Dry weights were determined. Plants were then ground to pass a 40 mesh screen and analyzed for total nitrogen using the Micro-Kjeldhal procedure.

After all vegetation was removed, the columns were flushed with 3 liters (about 25% of the volume of the column) of distilled water. The first 3 liters of drainage water were collected and analyzed for nitrate to determine how much nitrate accumulated in the column.

After the soil columns were flushed they were allowed to drain for two days. The soil-root plugs were then removed from the P.V.C. pipe by inverting the column and sliding its contents out. A 2 cm slice of soil was taken from a depth of 15 cm, 76 cm and 140 cm of each soil column. The soil samples were air dried for 5 days on the greenhouse bench, put into plastic bags, and later analyzed for total nitrogen using the Micro-Kjeldahl method. Soil samples were very sandy so they were not ground before nitrogen analysis. It was not possible to include a representative sample of roots in each 1 g sample digested for nitrogen analysis, so roots were screened out.

Analysis of variance was conducted on all experimental data using an AOV computer program. AOV tables are in the appendix.

RESULTS AND DISCUSSION

THE GREENHOUSE ENVIRONMENT

The average daylight period temperature in the greenhouse was calculated for each week by averaging the recorded temperatures every third hour from 6:00 am to 6:00 pm each day of the week. The average daylight period temperatures are represented in Figure 1. As expected, there was a trend toward increased average temperature. The daily average greenhouse temperature ranged from 15^{o}C to 36^{o}C. This would be a normal temperature range that might be encountered in the field during the corn growing season. Plants in this experiment were exposed to greater stress than might be encountered in the field even though temperatures were not abnormal. Low humidity of the greenhouse air, rapid temperature fluctuations of air and soil, and small pot size contributed to greater stress. Because pots were small, there was very little soil mass so that soil temperature would quickly equilibrate with ambient air temperature. Pot size also contributed to increased stress because each pot allowed only 78 square cm of soil area. If corn in the field were planted at a population of 28,000 plants per acre each corn plant would have 1445 square cm or over eighteen times more soil area. Corn in the corn-rye

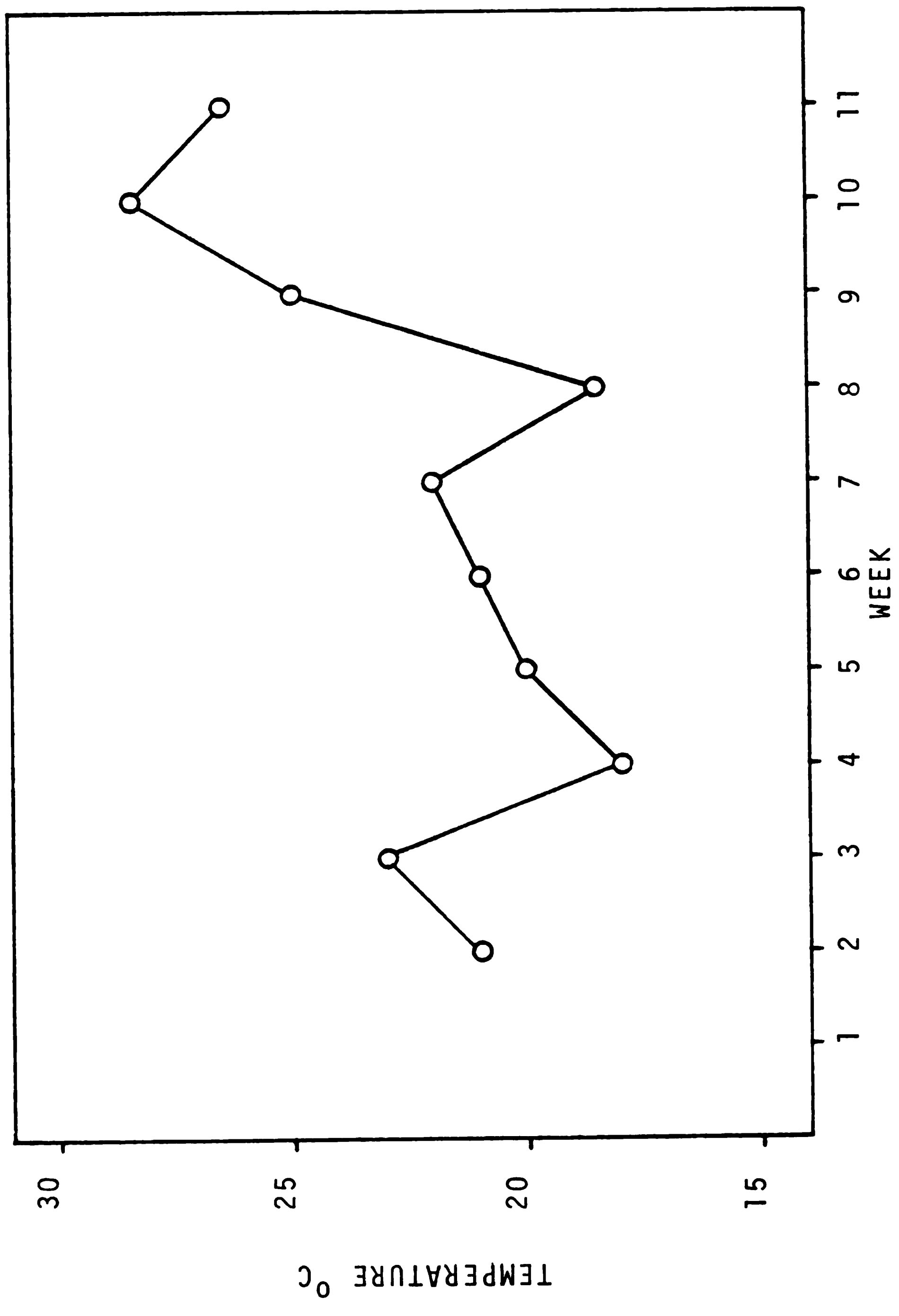

FIGURE 1 - AVERAGE DAYLIGHT PERIOD TEMPERATURE IN THE GREENHOUSE.

pots shared 78 square cm with eight rye plants.

Percent of possible sunshine data for the Lansing, Michigan area was obtained from the National Weather Service office at Capitol City Airport in Lansing. This data was used instead of actual solar energy measurements. Weekly averages of percent of possible sunshine were calculated and are shown in Figure 2. The daytime temperature in the greenhouse was very dependent on the amount of sunshine. Cloudy weather caused cooler temperatures (Figures 1 and 2, weeks 2 and 4). Sunny days resulted in higher greenhouse temperatures. On cloudy days the cold outside air kept the greenhouse temperatures close to the thermostat setting of 13^{o}C.

WATER BALANCE

Water inputs to the soil columns were in the form of irrigation with simulated effluent or distilled water applications. The volumes of all irrigations and distilled water applications for each treatment combination are compiled in Table 2.

The simulated effluent treatments were 5, 10, and 15 cm/wk as described in "Materials and Methods". The maximum irrigation rate at the Muskegon County Wastewater Facility is about 10 cm/wk. The 10 cm/wk irrigation rate was used in this experiment to imitate the maximum rate at Muskegon. Irrigation rates of 5 and 15 cm/wk were included to see how well the crops could strip nitrogen at a rate lower or higher than the rate of water and nutrients applied

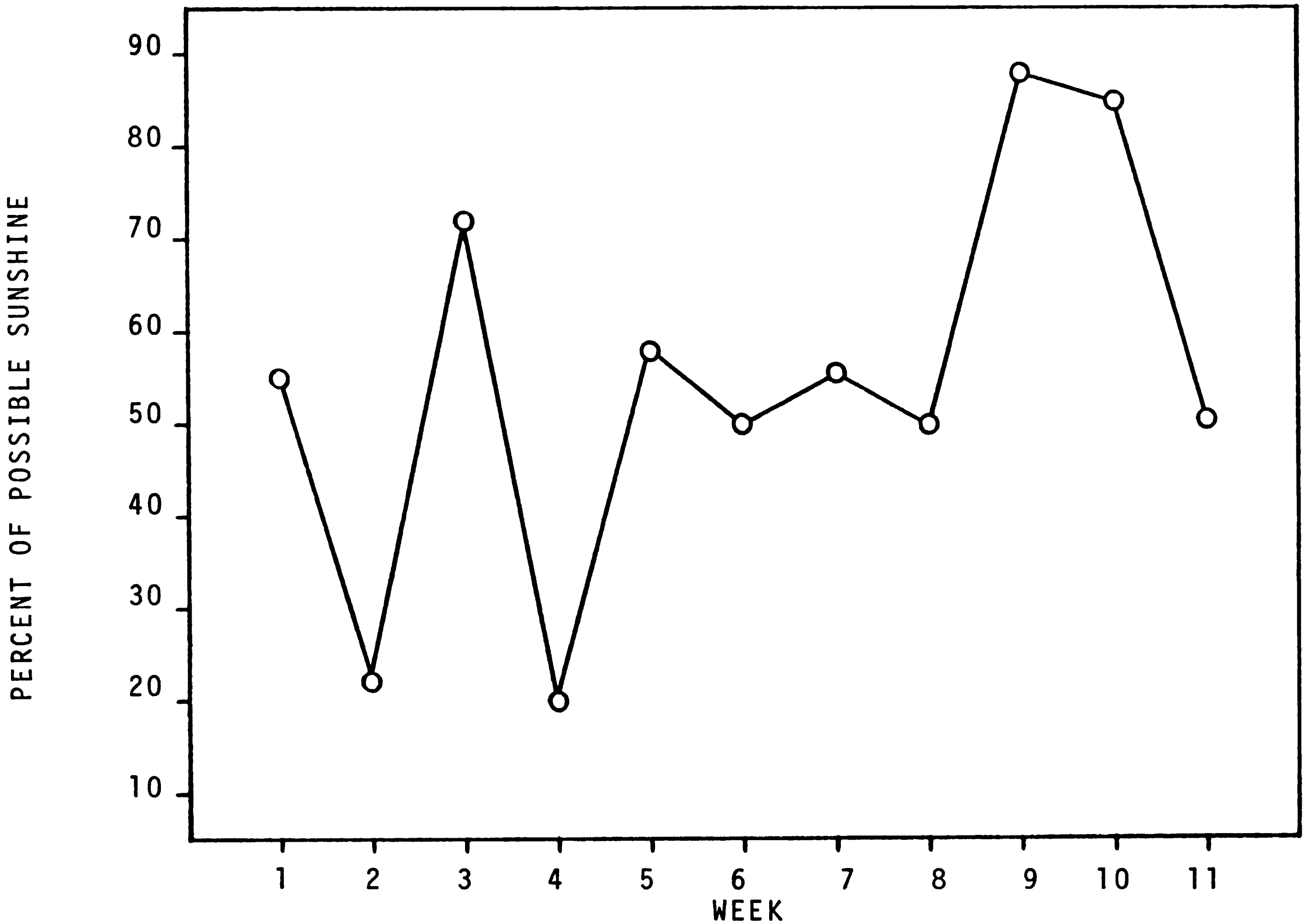

FIGURE 2 - AVERAGE PERCENT OF POSSIBLE SUNSHINE FOR LANSING, MICHIGAN FROM FEBRUARY 8, 1976 TO APRIL 24, 1976.

TABLE 2 - VOLUME OF SIMULATED EFFLUENT AND DISTILLED WATER ADDED TO SOIL COLUMNS.

	WEEK											
IRRIGATION RATE	1	2	3	4	5	6	7	8	9	10	11	Total
	ml											
5 cm/wk:												
Simulated Effluent	412	412	412	412	412	412	412	412	412	412	412	4532
Distilled Water	0	0	0	130	100	150	50	537	612	612	512	2703
Total Volume	412	412	412	542	512	562	462	949	1024	1024	924	7235
10 cm/wk:												
Simulated Effluent	824	824	824	824	824	824	824	824	824	824	824	9064
Distilled Water	0	0	0	130	100	150	50	125	200	200	100	1055
Total Volume	824	824	824	954	924	974	874	949	1024	1024	924	10119
15 cm/wk:												
Simulated Effluent	1236	1236	1236	1236	1236	1236	1236	1236	1236	1236	1236	13596
Distilled Water	0	0	0	130	100	150	50	125	200	200	100	1055
Total Volume	1236	1236	1236	1366	1336	1386	1286	1361	1436	1436	1336	14651

at Muskegon.

Distilled water applications were equal to the water losses from a small pan evaporimeter with the same surface area as the soil columns. The purpose of approximating the evaporation losses and returning them to the soil columns was to maintain continuous water percolation. In spite of this, columns treated with 5 cm/wk of simulated effluent quit draining water during the eighth week of the experiment. At this time an additional 5 cm/wk of distilled water was added to all soil columns receiving 5 cm/wk of simulated effluent.

Water losses occurred either as drainage through the soil columns or as evapotranspiration. All the drainage water was collected and the volumes were measured about every second day. Table 3 shows the average volume of leachate collected for each treatment combination during each week.

The amount of water drained in a natural system would be dependent on the water input, soil physical conditions, weather and crop need or transpiration. In this experiment the soil physical and weather conditions were as nearly identical as possible for all soil columns. Water input and crop need were the variables. Drainage volume differences can be explained in terms of these two variables.

Soil columns with just corn almost always drained more than treatments with rye. This trend was visible by the third week of the experiment. The drainage volumes of

TABLE 3 - AVERAGE VOLUME OF LEACHATE COLLECTED AS DRAINAGE FOR EACH TREATMENT COMBINATION.

		WEEKS											
CROP	IRRIGATION	1	2	3	4	5	6	7	8	9	10	11	total
	cm/wk	ml											
	5	498	304	351	369	212	341	355	440	647	725	578	4820
CORN	10	673	722	604	874	654	741	606	638	518	554	401	6985
	15	1066	1156	891	1354	960	1118	1011	955	983	835	905	11234
	5	495	267	321	279	59	192	220	192	643	530	515	3713
CORN-RYE	10	601	727	504	714	360	458	427	353	589	536	419	5688
	15	1013	1107	731	1178	634	734	584	718	1032	804	897	9432
	5	505	283	305	271	61	194	217	164	376	467	385	3228
RYE	10	632	682	522	752	371	458	431	288	212	329	230	4907
	15	1026	1119	770	1212	606	728	606	722	580	535	699	8603

columns with rye were less than columns with corn because rye germinated and grew faster, so it transpired more. By the end of the experiment the leaf surface area for the eight rye plants appeared to be several times greater than the leaf area of the underdeveloped corn plant. Also the root systems in rye or corn-rye pots were more extensive than in corn pots.

The drainage behavior of the corn-rye cropping system was very similar to that of rye. It was expected that the corn and rye together would provide the greatest reduction in drainage losses. The added benefit of the corn plant was not realized because it was so severely stunted by the eight rye plants growing with it. During the eighth week of the experiment the rye plants in soil columns with corn-rye were cut back to a height of about 5 cm to eliminate their competition with the corn. The loss of this foliage sharply increased the drainage from these columns because of the lost transpiration power. The week after the rye was cut those columns actually drained as much or more water than columns with just corn (Table 3, week 9). The corn plants in the corn-rye treatments allowed more drainage than corn in the corn treatment because they were much smaller.

Under field conditions early drainage differences between fields planted with corn and fields with rye might even be greater than the differences seen in this experiment. Rye would be established in the fall, so by early spring it would begin transpiring and reducing drainage losses long before corn could even be planted.

Leachate data from Table 3 was converted to percent of volume applied using totals from Table 2. The percentages were then averaged for each crop and presented in Figure 3.

The effects of temperature (Figure 1) and sunshine (Figure 2) on drainage (Figure 3) can be seen by comparing this data from week 2 to week 5. Drainage was reduced during week 3 followed by a sharp increase during week 4 and a sharp reduction during week 5. Compare this to the relatively high temperature (Figure 1) and sunshine (Figure 2) occurring during week 3 followed by lower average temperature and sunshine during week 4. Higher energy of week 3 increased evapotranspiration and thus decreased drainage. Week 4 showed an increase in drainage due to the response of evapotranspiration rate to lower temperature and less sunshine.

As previously noted the corn plants in the corn-rye cropping system were severely stunted. In an attempt to reduce the stress on these corn plants, the rye plants were cut back to a height of 5 cm during week 8 (see note Figure 3, week 8). Cutting the rye drastically reduced the leaf surface area of the corn-rye cropping system. Because of this loss of transpiration capacity twice as much water drained from these pots during the following week. Cutting the rye back reduced the competition but not soon enough

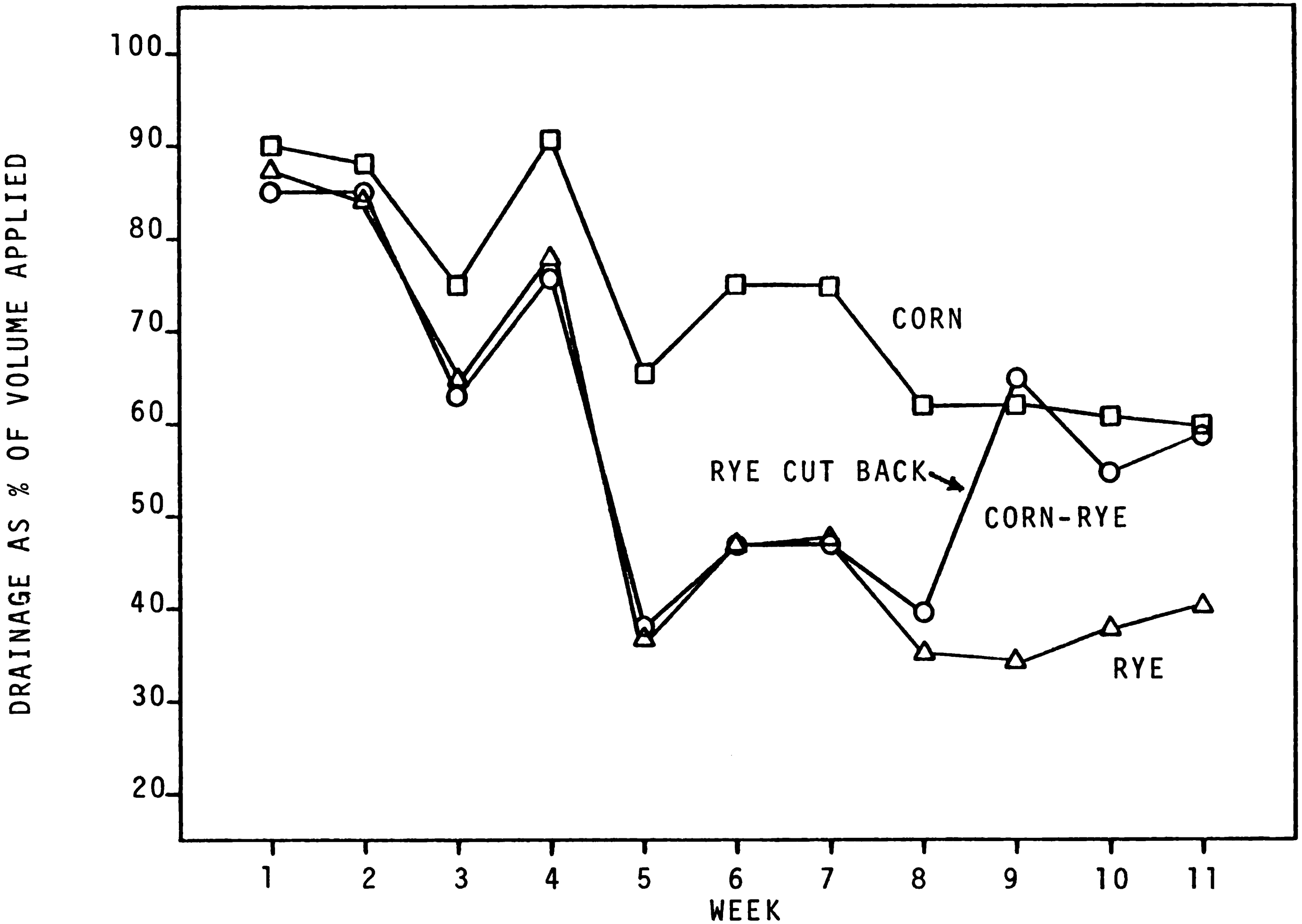

FIGURE 3 - PERCENT OF APPLIED WATER THAT DRAINED FOR EACH CROP (AVERAGED ACROSS IRRIGATION TREATMENTS).

for the corn to recover. The drainage of these columns remained higher than rye for the rest of the experiment.

As expected, increasing the water input increased the drainage of a given treatment combination. Figure 4 shows the average volume of water drained for each irrigation treatment. Each irrigation treatment has been averaged across the three crop systems. Those weeks which had relatively high temperature and more minutes of sunshine exhibit the lowest drainage rates and weeks with low temperatures and less sunshine have higher drainage rates.

The 5 cm/wk simulated effluent treatment shows a sudden increase in drainage from week 8 to 9. This is due to an increase in the distilled water applications for this simulated effluent treatment. Beginning week 8, an extra 5 cm/wk of distilled water was applied to all columns which had been receiving 5 cm/wk of the simulated effluent. This was in addition to the distilled water applied as an estimate of evaporation from the soil surface (see Table 3). This extra 5 cm/wk of distilled water was added because no measurable amount of drainage was occurring. Water was a limiting factor in the growth of plants in these soil columns.

The approximate volume of water evapotranspired was calculated by subtracting average drainage volumes for each treatment combination (Table 3) from the total volume of liquid applied (Table 2). This data is presented in Table 4.

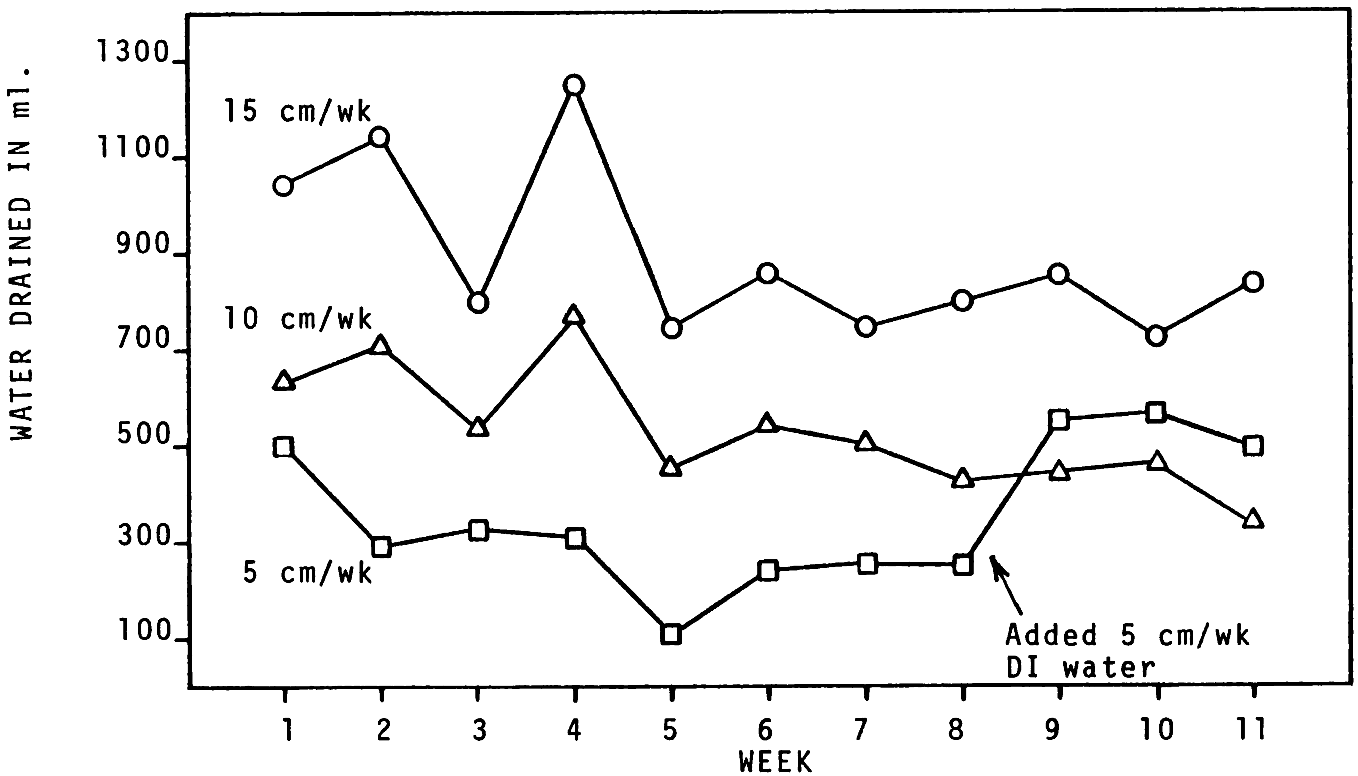

FIGURE 4 - WATER DRAINED BY EACH IRRIGATION TREATMENT (AVERAGED ACROSS CROPS).

TABLE 4 - APPROXIMATE VOLUME OF WATER EVAPOTRANSPIRED.

CROP	IRRIGATION	WEEK 1	2	3	4	5	6	7	8	9	10	11
	cm/wk	ml										
	5	0	108	61	173	300	221	107	509	377	299	346
CORN	10	151	102	220	80	270	233	268	311	506	470	523
	15	170	80	345	12	376	268	275	406	453	601	431
	5	0	145	91	263	453	370	242	757	381	494	409
CORN-RYE	10	223	97	318	240	564	516	447	596	435	488	505
	15	223	129	505	188	702	652	702	643	404	632	439
	5	0	129	107	271	451	368	245	785	648	557	539
RYE	10	192	142	302	202	553	516	443	661	812	695	694
	15	210	117	466	154	730	658	680	639	856	901	637

During the first week of the experiment soil columns irrigated with 5 cm/wk show zero evapotranspiration. The first week these soil columns drained about 120% of the volume of water applied so approximate volume of water evapotranspired could not be calculated. Columns irrigated with 10 or 15 cm/wk lost 75 - 85% of the volume applied. It was expected that all columns would drain nearly the same percentage of water the first week. It is possible that the soil had not yet reached field capacity when irrigation treatments were started so that drainage volumes were amplified the first week. Another possible explanation is that temperatures were unusually high during this time and decreased the surface tension of the water allowing more to drain from soil pores. The recording thermometer was not operating the first week, but percent of possible sunshine data indicates that temperatures may have been high.

To compare the water use of the three cropping systems, data from Table 4 was averaged for each crop across all irrigation treatments. This data is represented by Figure 5. Rye transpired the most for the experiment but corn-rye did as well until week 8 when rye plants were cut back. This figure shows how treatments with rye started transpiring faster and earlier than treatments with corn (Figure 5, week 2). The influence of temperature (Figure 1) and percent of possible sunshine (Figure 2) on evapotranspiration (Figure 5) can be seen by comparing weeks 2 through 5.

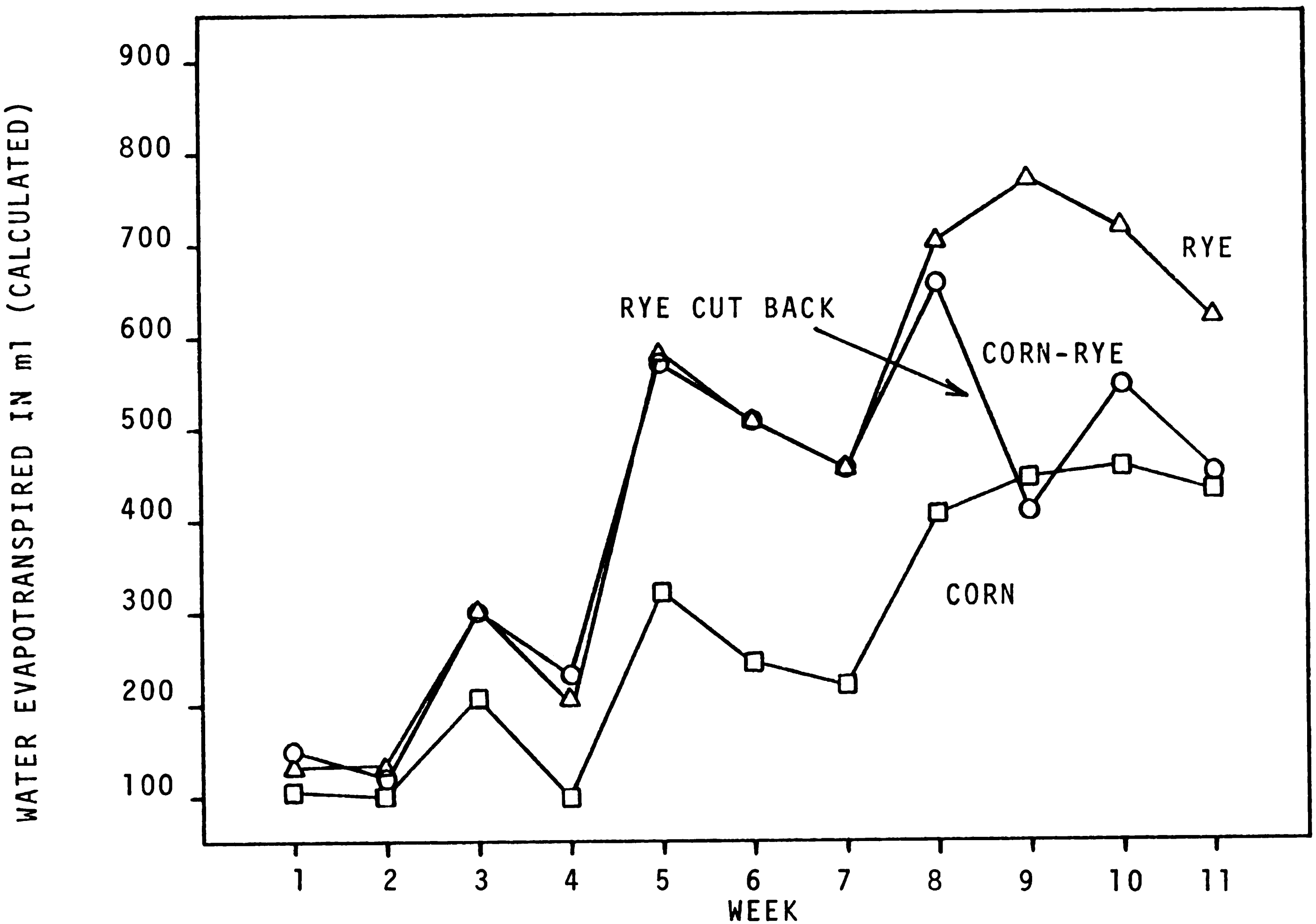

FIGURE 5 - CALCULATED VOLUME OF WATER EVAPOTRANSPIRED BY EACH CROP (AVERAGED ACROSS IRRIGATION TREATMENTS).

PLANT GROWTH

Corn height was measured during the fifth and ninth weeks and at the termination of the experiment. The data is presented in Table 5. Within corn treatments corn height increased with time and simulated effluent application rate. This growth response to increasing simulated effluent rate was due to greater amounts of water, nitrogen, and phosphorus supplied to the plant. Corn plants in the corn-rye treatments showed no significant response to increasing simulated effluent rate. At the time of harvest, corn plants in corn treatments were about twice as tall as the stunted corn plants in corn-rye treatments. Rye plants were not measured

TABLE 5 - HEIGHT OF CORN PLANTS.

CROP	IRRIGATION	WEEK 5	WEEK 9	TERMINATION
	cm/wk	cm		
	5	26	51	57
CORN	10	28	59	68
	15	28	62	74
	5	21	27	31
CORN-RYE	10	20	27	30
	15	23	29	31

At the termination of the experiment all plant materials above the soil were harvested. Plant materials removed when the rye was cut back in the corn-rye treatments were included. Table 6 shows the average dry weight of plant materials harvested from each treatment combination. Individual weights for corn and rye from the corn-rye treatments are shown. Corn treatments produced the most dry plant materials at all levels of irrigation. This would be expected under field conditions also. Corn-rye treatments produced less dry matter than rye treatments. This is due to severely stunted corn plants and the early cutting of rye which reduced its growth. If corn and rye were intercropped in the field we would expect the dry matter yield to be nearly equal to the sum of the yields of the crops if grown seperately.

TABLE 6 - AVERAGE DRY WEIGHT OF PLANT MATERIALS.

CROP TREATMENT		SIMULATED EFFLUENT TREATMENT 5 cm/wk	10 cm/wk	15 cm/wk
		g		
CORN		2.60	4.16	5.54
CORN-RYE				
CORN PLANTS		0.48	0.42	0.50
RYE PLANTS		1.64	2.55	3.32
	TOTAL	2.12	2.97	3.82
RYE		2.16	3.06	4.32

Because of the difficulty of getting good seperation of soil from roots, no attempt was made to quantify the root differences between treatments. Only visual observations were made. All three crop treatments had continuous root systems to the base of the columns at all three irrigation levels. There were very obvious rooting differences between irrigation treatments on rye.

Approximately twice as many roots were in the upper 20 cm of the colums containing rye treated with 15 cm/wk as were in the columns containing rye treated with 5 cm/wk. Corn root systems were much less dense than rye. There were no visual differences in corn rooting due to increased irrigation rate.

NUTRIENT BALANCE

The main purpose of this experiment was to study the nitrogen losses in the drainage water of each treatment combination. The nutrients applied were nitrate, ammonium, and phosphate. Nitrate concentrations of drainage water samples were determined each time samples were collected. Ammonium, phosphate, and nitrite concentrations were only measured occasionally. Under the conditions of this experiment it is unlikely that these nutrients would be lost in the drainage water. Phosphorus movement in soils is very limited. The phosphorus applied to the soil columns would probably be absorbed in the first few cms of soil. The concentration of phosphorus was less than 0.05 ppm in all drainage samples analyzed. Some ammonium could have been fixed by the soil or used by the plants. Most of the ammonium would have been oxidized to nitrate before it could reach the base of the columns. All drainage samples analyzed for ammonium contained less than 0.05 ppm ammonium nitrogen. Nitrite is of concern in wastewater treatment systems because it is highly toxic to higher plants and animals. Nitrite is not stable in aerobic soils. In this experiment it should have been quickly converted to nitrate. Nitrite concentrations in drainage samples were always less than 0.05 ppm nitrite nitrogen.

The rate of simulated effluent applied to soil columns determined the amount of nitrogen each received. The 5, 10 and 15 cm/wk treatments received 2.7, 5.4 and 8.2 mg of nitrogen per week respectively. The average nitrogen content of the simulated effluent during the eleven week experiment was 6.6 ppm. Nitrogen additions to the soil columns are explained in Table 7.

TABLE 7 - NITROGEN APPLIED IN SIMULATED EFFLUENT.

EFFLUENT RATE	WEEKLY EFFLUENT VOLUME	NITROGEN APPLIED EACH WEEK*	TOTAL NITROGEN APPLIED FOR EXPERIMENT
cm/wk	ml/wk	mg/wk	mg
5	412	2.72	29.9
10	824	5.44	59.8
15	1236	8.16	89.7

* AVERAGE NITROGEN CONCENTRATION OF SIMULATED EFFLUENT WAS 6.6 ppm.

The concentrations of nitrate nitrogen in drainage samples from each treatment combination have been averaged for each week, and are presented in Table 8.

Initially the average nitrate nitrogen concentrations in the drainage samples were very low (0.1 to 1.2 ppm nitrogen). There was a lag time before the nitrate applied in the simulated effluent leached through the soil column. Therefore there was some dilution of nitrate as the

TABLE 8 - AVERAGE CONCENTRATION OF NITRATE NITROGEN IN DRAINAGE WATER.

CROP	IRRIGATION	WEEK 1	2	3	4	5	6	7	8	9	10	11
	cm/wk	ppm										
	5	1.2	1.1	1.7	3.6	3.2	5.3	8.5	6.8	2.7	0.2	0.1
CORN	10	0.2	2.4	4.8	8.9	8.2	7.0	3.0	1.3	0.8	0.1	ND*
	15	1.2	3.4	6.2	8.6	6.3	5.7	2.0	1.2	0.4	ND	ND
	5	0.1	0.6	1.2	3.0	2.9	3.3	3.5	ND	ND	ND	ND
CORN-RYE	10	0.2	1.4	2.4	5.2	4.5	4.8	1.7	ND	ND	ND	ND
	15	0.3	1.2	1.7	2.9	0.5	1.1	0.5	ND	ND	ND	ND
	5	0.2	0.2	0.7	2.5	2.0	3.0	4.5	0.1	ND	ND	ND
RYE	10	0.1	1.4	2.4	5.3	5.0	5.4	2.8	ND	ND	ND	ND
	15	0.1	0.8	1.0	4.8	0.4	1.0	0.2	ND	ND	ND	ND

* NOT DETECTABLE, AVERAGE NITRATE NITROGEN CONCENTRATION LESS THAN 0.05 ppm.

simulated effluent mixed with the distilled water which had been added to the soil columns to bring them to field capacity.

By the third week drainage samples from all treatments except the lowest effluent rye treatment contained an average of at least 1.0 ppm nitrogen. All treatment combinations showed a relatively sharp increase in concentration of nitrate nitrogen in drainage samples from week 1 to week 4. During this time the crop had very little effect on the nitrate concentration of the drainage samples because the root system would still have been very limited. All crops irrigated with 15 cm/wk of simulated effluent showed a maximum nitrate concentration in drainage water during the fourth week. We would expect drainage samples from these treatments to show a maximum nitrate concentration earlier than the other treatments because they received the greatest volume of simulated effluent and the largest amount of total nitrogen. All crop treatments receiving 5 cm/wk of simulated effluent showed maximum nitrate nitrogen concentrations in drainage water during the seventh week. This also would be expected because this irrigation treatment put the smallest amount of nitrate and water on the soil. In this situation it should take longer for nitrate to reach the bottom of the soil profile. Nitrate nitrogen concentrations in drainage samples for corn and corn-rye irrigated with 10 cm/wk reached maximum levels in 4 weeks. Rye irrigated with 10 cm/wk required an additional two weeks for average nitrate nitrogen concentrations to be maximized but there was no significant difference between nitrate nitrogen concentrations of the fourth and sixth week.

Soon after nitrate nitrogen concentrations reached maximums, they declined steadily to very low levels. The maximum concentrations occurred when the dilution effect of the distilled water in the soil profile at the beginning of the experiment had reached a minimum. The subsequent decline in nitrate concentration was the effect of the plants root system becoming established in the column and stripping the nitrate from the soil solution.

In many instances the nitrate nitrogen concentrations of the drainage water samples were greater than 3.3 ppm, the concentration of nitrate nitrogen in the simulated effluent. In a few cases it was even higher than the total nitrogen concentration of the simulated effluent. Examples of this can be seen in Table 8, corn irrigated with 10 cm/wk of simulated effluent, week 4 and 5. These high nitrate nitrogen concentrations could occur from the combined effects of nitrification and evapotranspiration. The conditions in the soil columns were favorable to nitrification. Most of the ammonium applied in the simulated effluent would have been converted to nitrate. In the absence of any other nitrogen transformations or losses, the nitrate nitrogen concentration in the soil could theoretically be equal to the total nitrogen concentration of the simulated effluent. Evapotranspiration has a concentrating effect on the salts in soil solution.

The possibility of nitrate nitrogen concentration in drainage water being greater than the nitrate nitrogen concentration of the applied effluent is an important consideration for land treatment facilities. Selection of crop, volume and timing of irrigations are important in controlling nitrate concentration in drainage water.

Corn-rye and rye reduced the nitrate nitrogen concentrations in drainage samples to less than 0.05 ppm for all treatment combinations, except rye at 5 cm/wk, within eight weeks (Table 8). It took corn significantly longer to strip nitrate to the same level. In the field this would mean better nitrate control earlier in the season if rye were used. Corn irrigated with 5 cm/wk never reduced nitrate levels below the detection limit during the experiment. These plants were so undernourished that they were incapable of stripping this low level nitrate.

The average amount of nitrate nitrogen lost each week in the leachate of each treatment combination is shown in Table 9. The last column on the right side of the table shows the total amount of nitrate nitrogen leached through each treatment during the experiment. No measurable amounts of other forms of nitrogen were leached through the soil columns.

Treatments that contained rye or corn-rye lost less nitrate nitrogen in leachate than corn, every week of the experiment, at all irrigation rates. Nitrate levels were

TABLE 9 - AVERAGE AMOUNT OF NITRATE NITROGEN LOST IN DRAINAGE WATER.

		WEEK											
CROP	IRRIGATION	1	2	3	4	5	6	7	8	9	10	11	Total
	cm/wk	mg											
	5	0.6	0.3	0.6	1.3	0.7	1.8	3.0	3.0	1.7	0.1	0.1	13.2
CORN	10	0.2	1.7	2.9	7.8	5.4	5.2	1.8	0.8	0.4	0.1	ND*	26.3
	15	1.3	3.9	5.5	11.7	6.1	6.4	2.0	1.1	0.4	ND	ND	38.4
	5	ND	0.2	0.4	0.8	0.2	0.7	0.8	ND	ND	ND	ND	3.1
CORN-RYE	10	0.1	1.0	1.2	3.7	1.6	2.2	0.7	ND	ND	ND	ND	10.5
	15	0.3	1.4	1.2	3.4	0.3	0.8	0.3	ND	ND	ND	ND	7.7
	5	0.1	0.1	0.2	0.7	0.1	0.6	1.0	<.02	ND	ND	ND	2.8
RYE	10	0.1	0.6	1.3	4.0	1.8	2.5	1.2	ND	ND	ND	ND	11.5
	15	0.1	0.6	0.8	5.8	0.3	0.8	0.1	ND	ND	ND	ND	8.5

* NOT DETECTED, AVERAGE TOTAL NITRATE NITROGEN LESS THAN 0.05 mg.

reduced to below the detection limit two or three weeks earlier by treatments that contained rye or corn-rye. In the field this would mean rye or corn intercropped with rye would provide much greater control of nitrate losses to ground water. The dense root system of rye would quickly reach into a greater soil volume than corn and begin stripping nitrate to lower levels.

Differences between the total amount of nitrate nitrogen lost by corn and treatments containing rye were quite significant at all irrigation levels. Corn lost the most nitrate nitrogen for the experiment at all three irrigation levels. Corn irrigated with 5 cm/wk, receiving 29.7 mg of nitrogen for the experiment lost more than four times as much nitrate nitrogen as treatments containing rye, irrigated at the same rate.

Treatments containing corn-rye and irrigated with 15 cm/wk lost only 8.6% of the total nitrogen applied, while corn treatments irrigated at the same rate lost 42.8%. Rye and corn-rye treatments receiving 2 or 3 times more nitrogen than corn still lost less total nitrate nitrogen for the eleven week experiment.

As more nitrogen was applied to columns with corn, more nitrate was lost. Rye and corn-rye lost more nitrate as the simulated effluent treatment was increased from 5 cm per week to 10 cm/wk, but when the rate was increased to 15 cm/wk, nitrate losses were reduced to less than the losses at the 10 cm/wk treatment. In the field this could mean better water renovation at higher wastewater application rates. This data seemed to indicate that there was a threshold moisture or fertility level above which rye was able to perform better. This suggests that the 5 cm/wk treatment may not have provided any crop system with enough water or nutrients. If the experiment had been conducted with greater simulated effluent rates, corn may have responded like rye by reducing its nitrate losses after sufficiency levels of moisture and nutrients were reached.

Results of the Micro-Kjeldahl nitrogen analysis of plant samples are listed in Table 10. Dry weights of plant materials (from Table 6) and the calculated total amount of nitrogen removed from each treatment are also included. All above ground plant materials for each soil column were combined and analyzed together. Corn plants had the lowest nitrogen content. Even when supplied the maximum amount of nitrogen, the nitrogen content of corn was lower than plants in any of the rye or corn-rye treatments. The nitrogen content of healthy corn plants should be at least four times as great. There was no significant increase in the nitrogen content of corn with increasing nitrogen application. This suggests that plants were severely stressed or that moisture and nutrients were below the sufficiency level necessary for a nutrient uptake response.

TABLE 10 - AVERAGE NITROGEN CONTENT OF PLANTS.

CROP	IRRIGATION	NITROGEN IN PLANTS	DRY WEIGHT OF PLANTS	TOTAL NITROGEN IN PLANTS
	cm/wk	%	g	mg
	5	0.72	2.60	18.7
CORN	10	0.73	4.16	30.4
	15	0.79	5.54	43.8
	5	1.60	2.12	33.9
CORN-RYE	10	1.55	2.97	46.0
	15	1.59	3.82	60.7
	5	1.17	2.16	25.3
RYE	10	0.95	3.06	29.1
	15	0.97	4.32	41.9

The mixed plant material from the corn-rye treatments had the highest percentage of nitrogen. They were twice as high as corn, but still only half that of healthy corn or rye. Again, there was no significant increase in nitrogen percentage with increased nitrogen application. It was surprising to find that the nitrogen content of rye treatments were so much lower than corn-rye treatments. The two crops responded alike through most of the experiment. Sometimes a dilution effect can be seen in the concentration of a nutrient in plant material as the total dry matter increases and nutrient supply does not. This seems unlikely here because total dry matter of rye treatments was not much greater than that of corn-rye treatments.

Increasing simulated effluent and nitrogen application rate resulted in significant increases in yield of dry matter. Corn yielded the most dry matter for a given irrigation level, which would be expected because of the stature of the plant. Corn-rye treatments had the lowest yield of dry matter, but not much less than rye. The corn plants in corn-rye treatments were about the size of rye plants.

The total amount of nitrogen contained in plant parts is crucial in this experiment. One goal of a land application facility and this study is to see how much nitrogen can be harvested or immobilized from the applied wastewater so that it is not lost to ground water. In this experiment corn-rye removed the greatest amount of nitrogen in plant materials at all irrigation levels. Corn and rye removed about the same amount. In the field only the corn grain would be removed from the site, but the stover would immobilize nitrogen and then slowly release it to the growing cover-crop. This release would be slow enough that it would probably not increase the amount of nitrogen leached but would benefit the cover-crop. If bands of the cover crop were killed by herbicide the following spring, so no-till corn could be planted again, the decaying cover crop would then slowly release the nitrogen again, to the growing corn. The amount of decaying plant material could be increased each year thus immobilizing more nitrogen. Moisture holding capacity of the soil could also be improved over the years. Harvesting all the plant materials, cover-crop, grain and stover, would allow the greatest amount of nitrogen to be removed from the land treatment system but only the grain could be sold. If a high bio-mass forage or energy crop could be grown and sold, it would be a better alternative than corn in terms of total nutrients removed.

Soil slices, 2 cm thick, from depths of 15 cm, 76 cm, and 140 cm were analyzed for total nitrogen. The results are shown in Table 11. There were no significant differences in nitrogen concentrations due to treatments. The soil samples ranged from .020% to .028% nitrogen. Each soil column contained approximately 18.9 kg of soil so they held from 3780 mg to 5290 mg of nitrogen at the end of the experiment. The untreated soil contained .021% nitrogen giving the soil columns approximately 3970 mg of nitrogen initially. Roots were not included in the nitrogen analysis of soil samples because it was impossible to include a representative amount. If roots had been included there may have been some significant differences in nitrogen content due to irrigation rates, especially for rye and corn-rye.

The variation in the percent nitrogen of the soil samples make it impossible to calculate a rigorous nitrogen balance. Differences in the total nitrogen content of some of the soil columns used in one treatment were more than

TABLE 11 - AVERAGE PERCENT NITROGEN OF SOIL SAMPLES FROM THREE DEPTHS.

CROP	IRRIGATION	SOIL DEPTH 15 cm	76 cm	140 cm	AVE.
	cm/wk	%			
CORN	5	.024	.022	.020	.022
	10	.023	.021	.021	.022
	15	.022	.021	.025	.023
CORN-RYE	5	.022	.022	.025	.023
	10	.025	.020	.024	.023
	15	.024	.020	.022	.022
RYE	5	.024	.021	.024	.023
	10	.028	.022	.024	.025
	15	.027	.022	.023	.024

ten times the total nitrogen applied in the maximum simulated effluent treatment. Nitrogen inputs, nitrogen drainage losses, and nitrogen removed by crops can be used to calculate an approximate nitrogen balance.

Table 12 gives the approximate nitrogen balance neglecting soil nitrogen. At the end of the experiment each soil column was flushed with 3 liters of distilled water to leach out any remaining nitrate. The first three liters of drainage water from each column were collected and analyzed for nitrate. Nitrate was present in only 7 of the 36 soil columns. Two columns from corn at 5 cm/wk and two from corn at 10 cm/wk lost nitrate. One column from corn-rye at 10 cm/wk and one from 15 cm/wk lost nitrate. And one column from rye at 10 cm/wk lost nitrate. The average amounts of nitrate nitrogen flushed from each treatment were small, ranging from 0 to .4 mg of nitrogen. This was expected because the data in Table 8 showed very low or undetectable levels of nitrate loss during the last week of the study. There was no relationship between treatment and the amount of nitrate lost. Small amounts of nitrate were apparently held in isolated areas of a few of the soil columns. The data in Table 12 labled "Nitrogen Leached" includes the amount of nitrate nitrogen flushed from the columns at the end of the study.

The merits of each crop in relation to the amount of nitrogen lost in leachate have already been discussed, but Table 12 summarizes this information again. Corn lost

TABLE 12 - APPROXIMATE NITROGEN BALANCE.

CROP TREATMENT	IRRIGATION TREATMENT	TOTAL N APPLIED	NITROGEN LEACHED	PERCENT LEACHED	NITROGEN HARVESTED	PERCENT HARVESTED	NITROGEN ACCOUNTED FOR	PERCENT ACCOUNTED FOR
	cm/wk	mg	mg	%	mg	%	mg	%
	5	29.9	13.6	45.5	18.7	62.5	32.3	108.0
CORN	10	59.8	26.5	44.3	30.3	50.7	56.8	95.0
	15	89.7	38.4	42.8	43.9	48.9	82.3	91.8
	5	29.9	3.1	10.4	33.9	113.4	37.0	123.7
CORN-RYE	10	59.8	10.7	17.9	46.0	76.9	56.7	94.8
	15	89.7	7.7	8.6	60.7	67.7	68.4	76.2
	5	29.9	2.8	9.4	25.3	84.6	28.1	94.0
RYE	10	59.8	11.8	19.7	29.1	48.7	40.6	68.4
	15	89.7	8.5	9.5	41.9	46.7	50.4	56.2

42.8% of the nitrogen applied in 15 cm/wk of simulated effluent while corn-rye lost only 8.6% and rye only 9.5% at the same irrigation rate.

Corn was planted with rye in the corn-rye crop to see if greater nitrogen uptake and greater nitrate stripping could be acheived by the additive effects of the two crops. In the drainage water data corn-rye looked much like rye, there did not seem to be any additive effects. The additive effect is visible in the data from Table 12 showing total nitrogen harvested in plants. It indicates that much more nitrogen was removed by corn-rye than other crops, at all three irrigation levels. Corn-rye irrigated with 15 cm/wk recovered 67.7% of the nitrogen applied while corn and rye recovered 43.8% and 41.9% respectively. In all treatment combinations more nitrogen was harvested in plant materials than was lost in drainage water. If the nitrogen in wastewater effluent can be made available to the crop in sufficient amounts, the crop will immobilize it. All crops removed a greater percentage of nitrogen at the 5 cm/wk treatment than at greater simulated effluent rates. For example corn-rye irrigated with 5 cm/wk removed 113.4% of the applied nitrogen and at the 10 cm/wk it removed only 76.9%. This indicates that nitrogen may have been a growth limiting factor in all treatments which received 5 cm/wk. A land application facility would need to be sure the crop was receiving enough wastewater, or ground water quality might be reduced because the crop would not be vigorous enough to adequately strip nitrogen.

In two treatments, corn and corn-rye irrigated with 5 cm/wk, more nitrogen was accounted for in drainage and plants than was applied. Plants in these treatments apparently needed more nitrogen than was available in the simulated effluent. This extra nitrogen was probably supplied by residual soil nitrogen or possibly microbial fixation.

The nitrogen balances of all treatments except corn-rye irrigated with 15 cm/wk and rye irrigated with 10 and 15 cm/wk are probably within the limits of experimental error. The three exceptions show rather large amounts of nitrogen unaccounted for. This nitrogen was probably immobilized in the roots. We would expect the root systems of corn-rye and rye with higher effluent application to tie up more nitrogen. It was observed that these root systems were more profuse and they had greater percentages of nitrogen which could not be accounted for than other treatments.

In a land application system roots of the crop cannot be harvested but they are still quite important in the immobilization of nitrogen. In this study, the root system of rye irrigated with 15 cm/wk of simulated effluent may have immobilized up to 44% of the applied nitrogen, while the above ground portion of the plants tied up 46.5%. A similar ratio of roots to foliage would be quite possible in the field. This nitrogen in the roots would be held until the crop died and then it would be slowly used by microorganisums and the next crop.

In this study the use of rye as a crop gave less drainage water losses, lower concentrations of nitrate in drainage water, and therefore less loss of nitrogen than corn. The use of rye with corn gave greater amounts of removable nitrogen in plant materials, and rye probably immobilized greater amounts of nitrogen in its roots than corn. Although this study was conducted in the greenhouse and therefore subjected to greater stress than would be experienced in the field, a field study would probably lead to a similar conclusion, that rye can be beneficially used in the management of a land application system as a more effective nitrogen stripper than corn.

CONCLUSIONS

Plants in this study were exposed to greater stress than might be encountered in the field because of the dry greenhouse air, rapid fluctuations of soil and air temperature, and small pot size.

The 5 cm/wk treatment of simulated effluent did not provide adequate water or nutrients. Drainage from these treatments ceased at one point indicating a need for more water. All crops removed a greater percentage of nitrogen in plant materials at the 5 cm/wk treatment. Corn-rye irrigated with 5 cm/wk removed more nitrogen than was applied, indicating nitrogen was in short supply.

Corn and rye were intercropped in the corn-rye treatment to try to illustrate the additive effect of having two different crops with different growing seasons and different growth patterns acting together to strip nitrogen. The corn in this treatment was severely stunted by the small pot and the eight rye plants growing with it. The net effect was that corn-rye treatments behaved very much like rye except that they harvested a significantly greater amount of nitrogen than either corn or rye treatments. The most significant conclusions can be drawn by comparing corn treatments with rye treatments.

Rye germinated and grew faster than corn, thus it evapotranspired more water, earlier. Drainage was less in treatments with rye than corn. Rye treatments also reduced nitrate nitrogen concentrations of drainage samples to lower levels faster than corn. Rye lost less total nitrate nitrogen than corn every week, at all irrigation rates.

The 15 cm/wk simulated effluent treatment placed the greatest nitrogen stripping load on the crops, but overall the quality of drainage water was better (less nitrate) at this rate than the others.

In this study rye performed the task of stripping nitrate nitrogen better than corn. It would seem that a cover-crop such as rye-grass could successfully be used with corn to achieve better removal of nitrates from wastewater at a facility such as the Muskegon County Wastewater Project.

APPENDIX

APPENDIX TABLE 1 - ANALYSIS OF VARIANCE FOR VOLUME OF DRAINAGE, NITRATE NITROGEN CONCENTRATION OF DRAINAGE, AND TOTAL AMOUNT OF NITRATE NITROGEN LOST IN DRAINAGE.

		VOLUME OF DRAINAGE		CONCENTRATION OF N IN DRAINAGE		AMOUNT NITRATE N LOST IN DRAINAGE	
SOURCE	DEGS OF FREEDOM	MEAN SQUARE	F STATISTIC	MEAN SQUARE	F STATISTIC	MEAN SQUARE	F STATISTIC
CROP	2	1.24	246.9**	157.9	44.7**	126.3	194.5**
IRRIGATION	2	9.64	1918.1**	23.6	6.7**	43.6	67.1**
CROP X IRRIGATION	4	.026	5.2**	4.17	1.2	13.2	20.3**
ERROR (a)	27	.005		3.52		.649	
WEEKS	10	.406	329.8**	112.3	158.2**	59.9	311.8**
CROP X WEEKS	20	.080	65.0**	6.37	9.0**	7.31	38.0**
IRRIGATION X WEEKS	20	.214	173.7**	19.0	26.8**	13.7	71.5**
CROP X IRR. X WEEKS	40	.008	6.2**	4.40	6.2**	3.14	16.3**
ERROR (b)	270	.001		.710		.192	
TOTAL	395						

** Significant at .05% level.

APPENDIX TABLE 2 - ANALYSIS OF VARIANCE FOR DRY WEIGHT OF PLANTS.

SOURCE	DEGREES OF FREEDOM	DRY WEIGHT OF PLANTS	
		MEAN SQUARE	F STATISTIC
CROP	2	4.32	67.8**
IRRIGATION	2	15.5	242.5**
CROP X IRRIGATION	4	.418	6.6*
ERROR	27	.064	
TOTAL	35		

** Significant at .05% level.
* Significant at 1% level.

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