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THE EFFECTS OF AGRICULTURAL PRACTICES
ON TILE DRAINAGE WATER QUALITY

by

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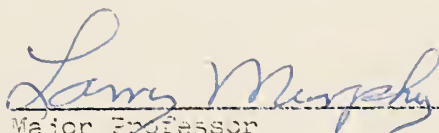
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INTRODUCTION

Increases in arable land, irrigation, and use of nitrogen fertilizers have increased agricultural production. Due to present high fossil fuel prices and passing of legislation to monitor and regulate the quality of surface and subsurface waters, nitrogen fertilizer efficiency is being extensively studied.

Because each soil type has its own set of characteristics, the effects of leaching, denitrification, and plant uptake of residual nitrate can vary widely. The reported investigation was conducted on fine-textured soils that were annually cropped and irrigated in the Bostwick Irrigation District located in northcentral Kansas and southcentral Nebraska. The District is fed by the Republican River via the Harlan County Reservoir and White Rock Creek via Lovewell Reservoir. Soils in this area have been derived primarily on loess or alluvium and remnants of terraces are a common sight. The soils studied comprise approximately 48.4% of the acreage in Republic County, Kansas and are: Crete silt loam, 1 to 3% slopes (21.4%); Crete silty clay loam, 2 to 3% slopes, eroded (11.5%); Hastings soils, eroded-Hobbs complex (10.5%); Muir silt loam, 0 to 1% slope, (5.0%). The Crete series comprises over 37% of the acreage in Republic County and it was most extensively studied.

Public awareness of water pollution has increased in the last few years and nitrate has gained much attention. Because nitrate is a highly soluble anion, it migrates through the soil profile fairly easily. When nitrate is discovered in ground or surface waters the agricultural industry too often becomes the public scapegoat, probably because it is

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such a visible industry and one of the largest users of nitrogen compounds. Experience has shown that it is often difficult to determine the source of nitrate contamination in subsurface waters. There is even a question as to whether much of the nitrate contamination attributed to agriculture is in fact originating from natural causes.

The ingestion of nitrates by infants causes a biochemical disruption known as methemoglobemia. This disruption is brought about by the reduction of nitrate to nitrite in the gastrointestinal tract. The nitrite oxidizes the iron of hemoglobin to ferric iron. Thus, the hemoglobin loses its ability to release oxygen to cells and cell asphyxiation occurs (90). In addition to this reaction, nitrate has been found to be converted to nitrosamines in the body and these compounds are known to be carcinogenic (91).

One purpose of the investigation was to determine if additional nitrogen above that applied by the farmer-cooperator could induce nitrate-nitrogen accumulation in subsurface waters. The investigation was also intended to determine if denitrification is the fate of applied nitrogen, and if so, to determine the role of soil total carbon in this reaction.

Because irrigation districts have come under fire as major sources of agricultural water pollution, in 1972 an investigation was begun of the quality of water flowing from tile lines draining portions of the Bostwick Irrigation District. Water analyses include electrical conductivity, nitrate-nitrogen, calcium, magnesium, potassium, sodium, and some periodic checks of chloride and phosphorous. Flow rates have been determined or estimated since April 1973.

The primary objectives of this study were as follows:
1) to determine through several years of monitoring whether subsurface water cycling back into natural waterways from the District is declining in quality;

2) to determine if nitrate can be induced to move through fine-textured soils into the subsurface drainage water by applying high rates of nitrogen fertilizer; and

3) because denitrification can be important in eliminating groundwater nitrate contamination, attempt to determine the influence oxidizable carbon, soil texture, and nitrogen concentrations have on the nitrate reduction reaction.

REVIEW OF LITERATURE

RELATIONSHIPS OF SOIL CHARACTERISTICS TO PERCOLATION RATES AND ANION MOVEMENT

The Crete series can be described as "deep, well-drained soils that have a loamy surface underlain by a clayey subsoil."(8) These soils have been derived on Peorian loess and it is their clayey subsoils that give them a slow permeability and make them susceptible to water logging under irrigation.

Percolation Rates

In order to determine rate of anion movement through fine textured soils, it is necessary to determine to what extent soil type effects percolation of water. Van Doren et al. (78) experimented on a Flanagen silt loam under tile drainage and found that with an average annual rainfall of 100 cm, percolation was only 3.8 cm per year. Nitrate movement in this soil could be expected to be very small. Wetselaar (87), working on a fallow clay loam soil in the Sudan, determined the mean movement of nitrate ion to be 2.7 cm for each 2.5 cm of rainfall in a six-month period when 60.2 centimeters fell. Though this seems to be much more substantial movement than that on the Flanagen soil, considerable upward movement of nitrate was found to occur during long periods of drought since the dissolved nitrate moved with the water. This upward movement is probably limited to the upper 50 cm.

In a study of nitrate content of percolates from land under continuous corn using lysimeters, Bielby et al. (9) found that most nitrates in the percolates were discharged after corn harvest. Allison (3) points out that nitrate movement is most likely to occur in winter when nitrification and denitrification activity are inhibited by the cold. Thus, fall application

of fertilizers is more likely to result in an influx of nitrate in ground-
water because the nitrate will move out of the zone of biological activity.
On the other hand, during the period of May to October there is little
likelihood of loss of nitrates from regions where annual rainfall is below
127 cm unless the soil is very sandy or the rainfall is unusually heavy
during short periods (1).

McCalla (53) studied percolation rates on Knox, Hastings, and Marshall
silt loams and Marshall silty clay loam, all of which are derived on
Peorian loess. Loessial percolation rates were found to be similar no
matter where he sampled. Puddling of the Peorian loess destroyed what
stable structure it possessed and resulted in a decreased percolation rate.
Several factors were found to influence percolation rates in loessial
surface soils. 1) Stability of soil aggregates influences percolation
when water is applied without raindrop impact to the soil, such as with
irrigation. When the aggregates break down, percolation is drastically
reduced. 2) Soil compaction decreases percolation rate. 3) Destruction
of the weak structure of the Peorian loess will reduce water percolation
and therefore reduce surface infiltration. 4) The organic matter content
of the surface soil can increase percolation rates from 5 to 100 times over
soil with no organic matter. However, when puddling breaks down the soil
aggregates, organic matter presence does not increase percolation.

Anion Movement

The movement of chloride through soil is often used to monitor water
movement and nitrate leaching in soils. Moore (59) found that chloride
movement closely followed that of nitrate in a Dodge silt loam and a
Waupun silt loam and concluded that chloride can be used to measure extent
of nitrate movement in soils. Dyer (30) used chloride as an indicator
of water movement through the soil profile on a Panoche silty clay.

In research on a mixed alluvial silt loam soil irrigated with feedlot lagoon water, Bock (10) noted that nitrate concentration was significantly lower than chloride concentration in the lower soil profile. Because both anions leach at about the same rate, it was concluded that denitrification and plant uptake were depleting the residual nitrate in the profile.

The fate of residual nitrate in the soil profile seems to be a matter of speculation. Olsen et al. (63), working on a Plano silt loam (Typic Hapludalf), estimated that fertilizer nitrogen applied on these soils would require one year to move 30-40 cm and about 10-13 years to move through a four-meter profile. They hypothesized that once nitrate gets below the root zone there are not enough micro-organisms and insufficient available energy sources to allow denitrification to occur. Any decrease in nitrate concentration would probably be due to dilution by water containing no nitrate.

In nitrogen distribution studies using N^{15} on a Brenton silt loam (Aquic Argiudoll), Allen et al. (1) found that at low rates of fertilization, nitrogen is incorporated into the soil biomass by microorganisms. At rates above the minimum requirement of the microbes more nitrogen becomes available to plants. At rates exceeding the requirements of both the microbes and plants, NO_3^- can temporarily accumulate and be lost by leaching and denitrification. The amount of mineralized -N in the soil after one growing season was negligible. However, approximately 97 percent of the fertilizer-derived nitrogen occurred in the organic form. About half of the fertilizer-derived nitrogen remaining in the soil after the first growing season (15 to 20 percent of the initially applied nitrogen) was still accounted for five years later in the upper soil profile (25 cm). Allen et al. conclude that at the recommended rates of fertilizer N application, most of the nitrogen is immobilized in the soil organic fraction and not available for leaching.

Olson et al. (64), working with a Sharpsburg silty clay loam under an ideal irrigation program, found that minimal residual nitrogen accumulation can be expected in soils with a claypan subsoil due to temporary periods of saturation, oxygen depletion, and ultimate denitrification of any nitrate present. Meek et al. (55) found little evidence of leached nitrate under heavily fertilized cotton on a Holtville silty clay loam which was stratified with layers of higher clay content. They attributed this to denitrification in the poorly drained soil and, in fact, found NO_3^--N became unstable when soil moisture content was above 41 percent. This is further substantiated by Willardson et al. (89) on the same soil when denitrification was made to occur by maintaining a saturated soil condition around drainage pipe, thereby keeping the nitrate concentration low.

Other research has demonstrated this relationship between saturated conditions and denitrification. Davenport et al. (27) suggests the establishment of a system where the water table on tile drained land could be controlled. The incorporation of a mobile, oxidizable substrate (such as methanol) would cause denitrification to occur in the anaerobic region below the root zone and eliminate movement of nitrate into tile effluent. Meek et al. (57) suggests that good crop production and denitrification in the lower soil profile can be made to occur simultaneously on irrigated, fine textured soils. They maintain that an aerobic surface soil and anaerobic subsoil can be attained whereby nitrate is denitrified in the lower profile. Again, however, the movement of soluble organic carbon into the lower soil profile is the determinant factor in developing reducing zones.

Herron et al. (37) worked on Sharpsburg silty clay loam and Hastings and Crete silt loams, loessial soils which were under furrow irrigated corn and tile drained. Annual N rates on the corn were 0, 84, 168, and

252 kg/ha. After four years they determined that the NO_3-N content of the upper 30 cm of the Sharpsburg increased for all but the 0 rate, with only minor increases in the lower profile. They found little evidence that fertilizer NO_3^--N was moving below 180 cm in depth for all rates of N. The results were almost identical for the Hastings and Crete series.

Schuman et al. (68) worked on deep loessial soils of soil type Typic Hapludolls, Typic Haplorthents, and Cumulic Hapludolls. These soils are fine silty, mixed, mesics, with moderate to moderately rapid permeability. Nitrate movement within a 6.1 meter soil profile of a watershed fertilized at 448 kg N/ha per year resulted in a 720 kg/ha increase in NO_3^--N below the corn root zone during the three year study. However, on a watershed fertilized at the recommended rate of 168 kg N/ha per year there was no increase in NO_3-N concentration below the root zone.

Nitrate does not readily leach from fine textured soils (34) because it does not necessarily move at the surface of the wetting front. When rain or irrigation water moves through the profile, the water runs quickly through the larger pores carrying only part of the soluble substances in the larger pores. This serves to further decrease the rate of leaching of NO_3^--N from fine textured soils.

Evidence presented by Olson et al. (64) shows that loss of NO_3^--N from soils due to leaching and denitrification is more a result of poor irrigation water management than poor fertilizer practice in Nebraska.

Niedenthal's research (60), on an irrigated Richfield silt loam near Tribune, Kansas, indicated little nitrate accumulation or leaching in the soil profile at rates of N fertilization up to 224 kg/ha. As long as excess nitrogen or water were not applied there was no threat to groundwater in the form of nitrate contamination.

Other researchers substantiate Olson's et al. and Niedenthal's research. At an N rate of 168 kg/ha, Nielson and Banks (61) found NO_3^--N accumulation in the top 5 cm on soils under furrow irrigated corn. They found no evidence of appreciable amounts of NO_3^--N moving below a 60 cm depth. Nitrate was present in an appreciable amount below 60 cm, but the concentration did not increase with time.

The information presented thus far raises an important point. Applications of fertilizer to soil are not always the culprit in groundwater contamination (79). Studies of water tables under native grasslands have sometimes shown unexplained high nitrate concentrations. Olson (65) compared deep soil cores taken from various nonirrigated crop management systems with cores taken from adjacent native grasslands and found that, generally, fertilizer contributions to groundwater nitrate were minimal in Nebraska. However, putting croplands under irrigation did result in the leaching of nitrate into ground water especially on sandy soils with a shallow water table. Another concern (12) is the irrigation of deep loess soils which contain several tons of natural or "geological" origin NO_3^--N per acre.

Kreitler (47), Jones (42), and Viets (81) point out that much of the nitrate in ground water is due to the conversion of grasslands into croplands. The organic nitrogen in the soil is nitrified and therefore susceptible to leaching. In Runnels County, Texas it is postulated (47) that high nitrate contamination of ground water (average of 233 mg NO_3^-/1) is due to cultivation of lands under native buffalo grass, a plant that accumulates nitrate. Since fertilizer use in Runnels County is very limited, it is concluded that nitrate contamination is from natural sources activated by post and current agricultural practices.

Researchers that report high losses of nitrogen on tile-drained fields and correlate these losses to agricultural practices often times are misled by their data, according to Viets (80). Without an unfertilized control, it is impossible to blame high rates of nitrate in groundwater on fertilization practices. It is difficult to ascertain whether a high concentration of nitrate in a soil core section and a low concentration in another soil core section is due to waves of nitrate input or denitrification variances. Even though soluble carbon compound concentrations are low in the subsoil, this is no assurance that denitrification does not occur.

DENITRIFICATION

For the purpose of this investigation, denitrification commonly refers to the gaseous loss of nitrogen through biological or chemical reduction.

Biological Nitrate Reduction

During logical denitrification, nitrate acts as an electron acceptor when oxygen is not present. In the presence of oxygen, the oxidation of carbon compounds occurs (18):

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O$$
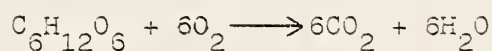
Under anaerobic conditions, bacteria capable of using nitrate in place of oxygen can perform the following:

$$C_6H_{12}O_2 + 4NO_3^- \longrightarrow 6CO_2 + 6H_2O + 2N_2$$
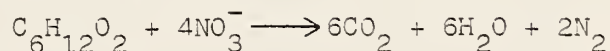
Jones (43) added ammonium nitrate tagged with N^{15} ($N^{15}H_4NO_3$) to a soil and after three days under anaerobic conditions found only traces of N^{15} in the total nitrogen gas evolved. Thus, he proved almost all nitrogen gas evolution comes from denitrification of nitrate.

It is clear the reduction of nitrate does not proceed directly to nitrogen gas but via a series of intermediate compounds and that the final

product is not always nitrogen gas. Some proposed intermediates are hyponitrite, nitramide, and imido-nitric acid, though none of these has been identified (18).

It has been proven experimentally (20, 50) that the sequence of end products in denitrification is:

$$NO_3^- \longrightarrow NO_2^- \longrightarrow N_2O \longrightarrow N_2.$$
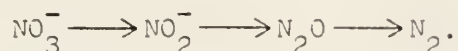
Soil pH seems to determine the final end product, although there is some disagreement on just how and to what extent it influences formation of N_2O and N_2. In an alkaline soil (50), N_2 presence was observed while N_2O concentration was still increasing, but in an acid soil, N_2 was not observed until after N_2O production had reached a peak and was decreasing. Wijler and Delwiche (88) found that at pH's above 7, nitrous oxide could be readily reduced to nitrogen, but below pH 5 its reduction was strongly inhibited.

Bremner and Shaw (14) and also Jansson and Clark (41) found that under acid conditions (pH below 6) denitrification usually does not occur. This is due to the generation of nitrite and subsequently nitrous acid, compounds which are toxic to the soil bacteria that reduce nitrate to nitrite (58). However, it is possible to have denitrification under acid soil conditions if the quantity of nitrate present, when reduced, is insufficient to produce a toxic concentration of nitrous acid. So, as Jansson and Clark point out, it is possible to have soil conditions that are conducive to nitrification and denitrification at the same time.

Mann et al. (51) incorporated sulfur into columns of sandy and silty clay loams and was able to stimulate denitrification by stimulating the growth of Thiobacillus denitrificans. It was suggested that sulfur additions to the anaerobic zones of soils containing low amounts of natural organic

matter may increase the rate of denitrification more rapidly than the additions of exogenous carbon. This is because competition for available carbon among nondenitrifying bacteria is much higher than competition for available sulfur. Consequently, sulfur is more readily available to the autotrophic T. denitrificans than carbon is to the heterotrophic denitrifiers.

Marshall, et al. (52) ran experiments with the denitrifying bacteria Pseudomonas flourescens and Pseudomonas denitrificans and found when equal amounts of ammonium and nitrate were added to cultures, the bacteria exclusively used ammonium for synthesis of cellular components. Denitrification was completely unaffected by ammonium presence which shows that ammonium is not an intermediate step in denitrification.

Schwartzbeck et al. (70) interestingly found that the relative proportions of N_2 and N_2O were greatly influenced by the ratio of ammonium to nitrate in the soil. When ammonium nitrate was added (a 1:1 ratio), N_2O was the main product, whereas when only nitrate was added, N_2 was the principal product. It would appear that in this last case nitrogen losses are possibly caused by some other system in addition to bacterial denitrification.

Delwiche (28) found that N_2O produced during denitrification can be used as an electron acceptor only when nitrate and oxygen are not present in sufficient amounts. It is subsequently reduced to nitrogen gas. This reaction is most evident in heavy soils where there is less penetration of oxygen from the atmosphere and less diffusion out of the soil of nitrous oxide (33).

One suggested intermediate in the reduction process is nitric oxide, NO. Research by a number of workers (20, 33, 88) has determined that

nitric oxide is present only at pHs below 5.5 where rates of denitrification are very low. The postulated reaction for nitric oxide formation involves nonbiological nitrous acid decomposition:

$$3HNO_2 \longrightarrow 2NO + HNO_3 + H_2O$$
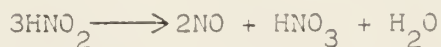
Overrein (66), using tagged N^{15} on acid podzolic forest soil, was unable to detect production of any oxides of nitrogen (NO, N_2O_3, NO_2, N_2O). The amount of nitric oxide found by other researchers was of such small proportions that nitric oxide should not even be considered a major pathway for nitrogen losses. Only in soils with very acid pHs and an accumulation of nitrous acid would one expect to find nitric oxide, and even then it would probably result from the decomposition of the nitrous acid rather than from nitrate reduction.

Chemo-Denitrification

A denitrification reaction which involves nitrite interactions in the presence of ammonia and ammonium compounds (2, 5, 72) has been referred to as chemo-denitrification.

$$RNH_2 + HNO_2 \longrightarrow ROH + H_2O + N_2$$

$$NH_3 + HNO_2 \longrightarrow N_2 + 2H_2O$$
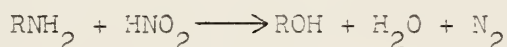
In order for these reactions to occur, pH must be very low and, in the presence of air, the reactions proceed very slowly. The volatilization of ammonia and reduction of nitrite is much more likely to occur, especially in the second reaction, than the combination of nitrite with amine compounds. However, the presence of carbon compounds in the soil does seem to cause appreciable chemo-denitrification of nitrite. Though nitrate reduction with respect to redox potential was not measured in this investigation, it would be useful to understand some of the reactions that could occur in waterlogged soils.

Redox Potential and Chemical Nitrate Reduction

Stum (76) defined redox potential as "the equivalent free energy per mole of electrons associated with a given reduction." It is a soil characteristic that probably plays an important role in the denitrification process. At soil redox potentials below 340 mv, little nitrate has been found (3). This indicates that the oxygen level in the soil is so low that nitrate is serving as the terminal electron acceptor.

Grass et al. (32) found Mn^{+2} and Fe^{+2} dissolution increased with decreasing redox potential. However, when NO_3^--N concentration was greater than 0.2 ppm, Mn^{+2} and Fe^{+2} dissolution was inhibited. Thus, nitrate must be denitrified (a biological anaerobic process) before soil microbes can reduce the oxidized forms of manganese and iron as a source of oxygen. The dissolution of Fe^{+2} and Mn^{+2} is a problem because these ions clog tile drains.

Chao and Kroontje (22) researched the role of the oxidation and reduction of iron in the nitrate reduction process. Studies had already shown that the oxidation of hydroxylamine by ferric iron produces nitrate. But Chao and Kroontje found that in acidic solution, nitrate can be reduced by ferrous iron to N_2 gas through N_2O_4, HNO_2, $H_2N_2O_2$, and N_2O or through NO and N_2O to N_2. These reactions very much resemble the denitrification process. Under basic conditions the reduction of nitrate to N_2 may go through NO, $N_2O_2^{-2}$, and N_2O or it may be reduced to ammonia through hydroxylamine and hydrazine, two compounds very unstable in the presence of iron in solution. In acid solutions ferric iron oxidized hydroxylamine and hydrazine to N_2 and N_2O, the amount of N_2O formed being proportional to the ferric iron concentration in solution. In basic soil solutions iron would probably be in the insoluble $Fe(OH)_2$ form but it may become soluble under the influence of bacteria and heterotrophic micro-organisms.

So it seems that available iron in the soil could cause nitrate
reduction. This would lower the soil nitrate concentration which would
lower the soil redox potential and, in turn, result in an increase of
Fe^{+2} and Mn^{+2} in the soil solution.

This conclusion is supported by the research of Meek et al. (55, 56)
in their work on an irrigated Holtville silty clay loam. Nitrate concentra-
tion decreased with increasing soil depth (or as one approached the water
table), as did soil redox potential. With successive irrigations, Fe^{+2}
and Mn^{+2} concentrations increased below depths of 160 cm due to lowered
redox potential and nitrate concentrations continued to decrease.

Effects of Oxygen on Denitrification

Lowenstein et al. (43) postulated that when an ammonium source is
added to the soil, nitrification occurs and the nitrates are moved (probably
through the soil solution) to oxygen poor regions where they are subject
to denitrification. It is also possible that an aerobic region can become
anaerobic due to rapid consumption of oxygen and/or the evolution of
carbon dioxide by decomposition bacteria.

Liming of the soil greatly increases nitrification due to an increase
in the nitrifying bacteria population. This also results in an oxygen
demand in localized areas and denitrification can occur.

Water content of the soil is also important in regulating oxygen content.
At oxygen concentrations below 0.4%, denitrification readily occurs. Volz,
et al. (82) found that during irrigation the reduction of nitrate was caused
by the presence of organic matter exuded from the roots of barley coupled
with a decreased soil redox potential. The lower redox potential can be
achieved at soil-solution interfaces during irrigation. Microbes can use
the exuded C compounds and maintain decreased oxygen concentrations at
these interfaces even though oxygen is present in the gaseous phase.

As was mentioned before, additions of organic matter can create an oxygen demand in the soil so that denitrification can occur in an aerobic soil due to localized zones of oxygen depletion (20, 74). This brings up an interesting point . . . aerobic denitrification.

Aerobic Denitrification

Korsakova (46) was one of the first to observe aerobic denitrification. He found that certain nitrate reducing bacteria were not effected by aeration or partial pressure of oxygen, but were dependent on amounts of organic matter present in the medium. Meiklejohn (58) obtained similar results. Other researchers found denitrification to occur to varying degrees when in the presence of oxygen (17, 19, 52).

On the other hand, many researchers (4, 14, 21, 41) were unable to obtain any evidence of significant amounts of aerobic denitrification. Where any denitrification on aerated soils was detected, it was always on those soils that had organic matter incorporated or a high percentage of water, both of which cause an oxygen demand in the medium.

Apparently, discrepancies arise in experimental procedure. It is possible that some of the workers that experienced denitrification in aerated soils actually had some volatilization of ammonia derived by ammonification of organic-N compounds. Also, many systems were run in pure cultures (ideal for bacterial growth), and these were compared to field conditions.

Skerman and MacRae (71) reported that the aeration procedures followed by those workers observing denitrification in the presence of oxygen were insufficient to produce adequate aeration in their cultures. In other words, they had run aeration experiments measuring oxygen concentration on the basis of equilibrium with the gas phase used rather than on the basis of oxygen concentration in the solution itself. The procedure of aeration

used by Marshall et al. and others where minute bubbles are passed through
the solution, does not produce an adequate oxygen supply. The competition
between oxygen and nitrate for donor electrons so favors oxygen that nitrate
reduction only occurs when the supply of oxygen is inadequate to meet the
demand.

In almost any aerated soil there are instances where oxygen depletion
occurs. For example, a film of water around a colloid can cause an oxygen
demand within the colloid. Greenwood (33) mathematically postulated that
much denitrification in aerobic soils was due to aggregates in soil having
oxygen-free centers and oxygen-containing surfaces. Oxygen would be avail-
able for nitrification on the aggregate surface, but lack of it would
cause denitrification in the aggregate center. A good term for this
phenomenon would be microniche denitrification. In addition, since nitrifi-
cation lowers pH and denitrification increases pH, both reactions would
probably proceed more slowly in isolation than together.

Effect of Organic Matter on Denitrification

The effect of organic matter on denitrification is two-fold (18).
Because the net free energy change in the reduction of nitrate to elemental
nitrogen is positive, an energy source in the form of an oxidizable substrate
is necessary for the growth of denitrifying bacteria and to also serve as
an electron donor for the denitrification reaction. Secondly, when a
readily oxidizable substrate is present it creates a biological oxygen
demand in the soil and this condition favors denitrification.

When considering organic matter, the question arises as to what types
of organic matter best favor denitrification. Considering the thermodynamics
of the reaction, the point to remember is: there must be enough energy
released by oxidation of the carbonaceous material to move the reaction

to the right (17). For example, in the idealized reaction:

$$C_6H_2O_6 + 4NO_3^- \longrightarrow 6CO_2 + 6H_2O + 2N_2$$
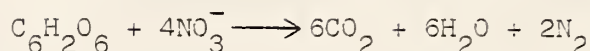
nitrate provides the oxygen for the oxidation of the carbonaceous material
and the energy for the reaction is supplied by the further oxidation of
carbonaceous sources.

Research verifying this concept (14, 21, 84, 88) has shown high energy
compounds such as glucose, sucrose, mannitol, sodium citrate, and alfalfa
hay produce much higher rates of denitrification than low energy, slowly
decomposable compounds such as saw dust, lignin, and wheat straw. The increase
of denitrification is most evident when high energy compounds are added to
soils low in organic matter and to soils where inorganic nitrogen is added.
McGarity (54) found a substantial increase in denitrification rates on a
soil having low organic carbon (0.38%) when 0.1 percent glucose was added.
The unamended soil, taken from 75-90 cm depth, had an extremely slow rate
or denitrification indicating that the amount of oxidizable carbon can be a
limiting factor in the reaction.

In addition to the effects of high energy carbonaceous compounds on
denitrification, one must consider the role which the C/N ratio plays in
nitrogen losses. Research has shown (68, 84) that the lower (narrower) the
C/N ratio of plant material incorporated into the soil along with inorganic
nitrogen, the higher will be the nitrogen losses from the soil. Pinck et al.
(68) discovered that there is no significant loss of gaseous forms of nitrogen
from decomposition of plant material having a C/N ratio of 18 or greater.
Gaseous N losses were considerable higher in the 3 to 15 C:N range. MacVicar
et al. (49) believed denitrification at low C/N ratios is due to an accumula-
tion of "free nitrogen, including nitrate." (One would assume that "free
nitrogen" refers to nitrogenous compounds and not elemental nitrogen.)

Meiklejohn (58), experimenting with two _Pseudomonas_ denitrifiers under
anaerobic conditions, found that the narrower the C/N ratio in the medium,
the higher was the bacterial population (where N was in the form of nitrate),
and consequently, the more complete was organic matter breakdown and nitrate
reduction. A C/N ratio below 1.25 did not increase the bacterial efficiency.
Wijler and Delwiche (88) confirmed the findings of Meiklejohn.

The effect of the C/N ratio demonstrates the importance of carbon
in holding nitrogen in the soil. When rapidly decomposable organic material
is added to the soil, there is an accelerated interchange of mineral N
with soil organic N due to increased microbial activity (16). So one would
conclude that when the C/N ratio is large most of the nitrogen in the soil
is incorporated into bacteria as cellular-N. Going a step further, when
inorganic N is added to the soil, the addition of readily decomposable
organic matter will keep the C/N ratio large and therefore prevent the loss
of N from the soil. This was exactly what MacVicar et al. (49) discovered.
Incorporations of large amounts of readily decomposable organic matter at
the time of fertilization with inorganic N prevented large losses of nitrogen.
Broadbent (17) similarly found denitrification losses to be greater on
soils low in soil organic matter than on those high in soil organic matter.
Patrick and Gotoh (67) found that an addition of 0.5% rice straw to a
flooded soil resulted in immobilization of N in an organic form not subject
to denitrification and an overall increase in total N over that soil
which had no organic matter.

This evidence seems to contradict what was previously stated:
that an increase of readily oxidizable organic matter favors denitrification.
Lowenstein et al. (48), as an example, found that denitrification rates were
higher when organic matter (they used 0.5% oat straw) was added to the soil
than when no organic matter was added.

The conflict apparently lies in trying to relate results obtained under controlled laboratory conditions to what happens under field conditions. One problem would be the oxygen content of the medium is very often held constant. Oxygen presence in the soil inhibits denitrification, therefore one would expect to find decomposition of organic matter along with nitrification and the organic fixation of N by soil bacteria.

It is extremely difficult to empirically measure rates of denitrification accurately in the field and equate them to oxygen concentration, organic matter presence, bacterial populations, and forms of nitrogen in the soil. One can conclude that the addition of organic matter along with inorganic N to the soil would create a situation where both nitrification and denitrification occur simultaneously. Both reactions could occur due to variances in the soil of organic matter content, percent water present, oxygen concentration, soil type, to name a few.

An interesting theory is advanced by Clark and Beard (25) regarding N losses from the soil due to nitrite instability in the presence of organic matter. Their findings tend to agree with other research (26, 72): there is some component in the soil which promotes the reactivity of nitrous acid or nitrite to the extent that volatile N losses occur. Clark (24) suggests that organic-reducing compounds of microbial origin might possibly promote the disappearance of nitrite. Stevenson and Swaby (75) also found that organic matter in the form of lignin is capable of combining with nitrites at normal soil pHs resulting in N losses, although they were unable to identify the nitrogen compounds released in this reaction. Considering this phenomenon, it appears possible that much of the N losses in the soil attributed to "aerobic denitrification" are probably due to the gaseous loss of nitrogen during nitrification ($NH_4^+ \longrightarrow NO_2^- \longrightarrow NO_3^-$). Evidence

has shown (26) large losses of nitrogen in poorly buffered soils to be on the order of 25%. They seem to occur during the nitrification process and can be attributed to accumulations of nitrite in an acid medium and its subsequent decomposition.

USE OF NITROGEN ISOTOPE RATIOS TO DETERMINE SOURCE OF GROUND WATER NITRATE

One promising way of identifying sources of nitrate contamination is through the use of nitrogen isotope ratios, although this investigation did not undertake this analysis. By studying the natural nitrogen isotope ratios of nitrate in ground water and comparing them to the nitrogen isotope ratios of nitrate from different soil environments, such as under feed lots, septic tanks, and pastures, the nitrate of certain ground waters can be traced to unique sources.

The variations of mass between N^{14} and N^{15}, the two stable nitrogen isotopes in natural systems, can be measured on a gas-source mass spectrometer in which the unknown is compared to atmospheric nitrogen, the standard (62). The ratio of the unknown to the standard is expressed in isotopic terminology as:

$$\text{del N15 (ppt)} = \frac{(N^{15}/N^{14})\ \text{Sample} - (N^{15}/N^{14})\text{Standard}}{(N^{15}/N^{14})\text{Standard}} \times 1000$$

If the N^{15} in the sample is enriched relative to N^{15} in the atmospheric nitrogen standard the sample is said to have a positive del N15 value. If the sample is depleted in N^{15}, it has a negative del N15 value.

Research (29, 47, 86) has shown that isotopic fractionation occurs during specific soil reactions such as denitrification and nitrification which alters the del N15 of soil nitrogen. For example, during nitrogen fixation the N^{14} isotope is slightly favored by Azobacter (29). Kinetic fractionation of this reaction has been measured and found to favor N^{14} by a factor of 1.004.

The isotopic composition of cultivated soils is probably controlled by the mineralization of soil humus (47). Researchers (15, 23) have observed that organic soil nitrogen is isotopically heavier than atmospheric nitrogen. This is the result of either the addition of N^{15} to the soil system or the removal of N^{14} from the soil system. The addition of N^{15} through nitrogen fixation is unlikely due to lack of fractionation (39) or because of a slight fractionation favoring N^{14} (29). N^{14} is removed by either organic nitrogen mineralization, denitrification, or ammonification.

Though the kinetic fractionation of these reactions is important, it is almost impossible to collectively apply these factors to determine the del N15 of a nitrogen source once it has migrated through the soil profile. However, Kohl·et al. (45) compared the del N15 of a nitrogen fertilizer to the del N15 of nitrate in Decatur Reservoir in Illinois and found that the two values were similar. Their conclusion was that the nitrate in the reservoir originated from nitrogen fertilizers.

Their work was severely criticized (15, 31, 35, 47) for the assumptions that they made. They assumed no isotopic fractionation occurred as the nitrogen fertilizer was integrated into the soil nitrogen cycle and then leached as nitrate. They also assumed there was no variation of del N15 between soil associations and applied the data obtained from a virgin soil to a 900 square mile cultivated area which contained approximately 50 soil series. Research by Bremner and Tabatabai (15) and Edwards (31) showed considerable variation in del N15 between soils. Kohl's et al. attempt to distinguish between fertilizer derived nitrate and soil derived nitrate by making use of natural variations in N^{15} abundance can only lead to inconclusive evidence. Research shows (31, 35) there is no significant difference between the del N15s of nitrate originating from these two sources.

The variation of del N15 between types of nitrogen fertilizers and even within specific fertilizers is so insignificant that only the use of labelled (N^{15}) fertilizers has been successful in determining fertilizer influence on ground nitrate.

Kreitler (47) approached the problem of source identification of nitrate by identifying the del N15 of nitrate from different soil environments. This permitted a direct comparison of the del N15 of nitrate in soil profiles with the del N15 of nitrate in ground water. The soil environments researched by Kreitler were barnyards, septic tank drain fields, cultivated fields where cattle had never grazed, cultivated fields where cattle grazed, and turnrows between cotton fields in Runnels county, Texas.

All profiles examined contained significant amounts of nitrate. Kreitler found that even though nitrate concentration in a profile might vary considerably, the del N15 value remained constant. In the barnyard profile, the average del N15 value (15 ppt) was significantly higher than the average del N15 value (5 ppt) in the cultivated field. No fertilizers had ever been applied to the cultivated field. An examination of the profiles of the cultivated fields where cattle grazed showed a high del N15 (14 ppt) in the upper portion of the profile with a gradual decrease to a smaller del N15 (6 ppt) in the lower profile. Kreitler interpreted this as showing that the dominant source of nitrate has changed with time. The cattle had been grazed on the field for the past 10 to 20 years. The del N15 value of the upper profile correspond to those of the barnyard profile while the del N15 values of the lower profile correspond to those of the ungrazed cultivated field profile.

Ground water samples taken from wells in ungrazed cultivated fields had del N15 values that were remarkably close to those of natural nitrate.

Water samples taken from barnyards showed a significant increase in del N15 values towards those del N15 values of animal waste nitrate. Water samples taken in Macon County, Missouri where nitrate contamination was suspected to be a result of animal wastes had del N15 values almost identical to those del N15 values found in the barnyard soil profile where animal wastes had been the source of nitrate.

MATERIALS AND METHODS

The Bostwick Irrigation District was established in 1948 and provides irrigation water for land in Kansas and Nebraska. Since extensive irrigation was begun, drainage problems have developed on much of the irrigated land which have necessitated the installation of tile drains. The question has arisen as to the influence of agricultural practices (such as fertilization) on the quality of tile drainage water being returned to natural surface waterways.

In an attempt to answer this question, a study of tile drainage water quality was initiated in 1972 in the Bostwick Irrigation District. The purpose of the study was to determine if irrigation practices in the district were influencing tile drainage water quality and, if so, to determine if these influences caused seasonal fluctuations in the water quality. Sampling sites in the district were chosen in areas where drainage problems existed, where the land drained was under cultivation, and where there was easy access to drain openings. Because of the size of the district and number of tile drains, no attempt was made to randomly sample the district. The drains sampled were located in two separate problem areas of the district some twelve kilometers apart. Some of the sites drained only a small area while some drained almost a section of land (Table 1). A numbering system was established (Table 1) and is used throughout the discussion of tile drain water and as site numbers for the nitrogen application study.

After almost a year and a half of monitoring, another study was initiated to determine whether nitrogen could be induced to move into tile drainage water by applying nitrogen fertilizer to irrigated cropland at rates much in excess of recommended rates. In addition, this study

TABLE 1. Description of Drain Sites in Kansas-Bostwick Irrigation District

Drain Site	Principal Soil Type	Approx. Acreage	Parent Material	Legal Description
1.	Butler silt loam	10	Peorian loess	NW¼,NE¼,S17,T3S,R5W
2.	Crete silt loam	160	Peorian loess	NW¼,SW¼,S17,T3S,R5W
3.	Hastings silty clay loam	100	Peorian loess	NE¼,SW¼,S9,T3S,R5W
4.	Hastings silty clay loam	40	Peorian loess	NW¼,NE¼,S17,T3S,R5W
5.	Butler and Crete silt loams	400	Peorian loess	NE¼,NE¼,S29,T3S,R5W
6.	Crete silt loam	160	Peorian loess	NW¼,SE¼,S5,T3S,R5W
7.	Crete silt loam (prior 7/75)	40	Peorian loess	SE¼,SE¼,S33,T2S,R5W
7a.	Muir silt loam (after 7/75)	300	Alluvial terrace	NE¼,NW¼,S33,T1S,R5W
8.	Hastings silty clay loam	100	Peorian loess	NE¼,SW¼,S9,T3S,R5W
9.	Ridge canal	---	---	---
10.	Crete silt loam	320	Peorian loess	SE¼,SE¼,S17,T3S,R5W
11.	Crete silt loam	5	Peorian loess	NW¼,NE¼,S20,T3S,R5W
12.	Crete silt loam	160	Peorian loess	SE¼,SE¼,S10,T3S,R5W
13.	Muir silt loam and Eudora loam	200	Alluvium	NE¼,NE¼,S31,T2S,R5W
14.	Muir silt loam	200	Alluvium	SE¼,SE¼,S30,T2S,R5W
15.	Crete silt loam	40	Peorian loess	NE¼,SE¼,S5,T3S,R5W
16.	Muir silt loam	80	Alluvium	NE¼,NW¼,S33,T1S,R5W
17.	Crete silt loam	200	Peorian loess	NE¼,SE¼,S10,T3S,R5W
18.	Crete silt loam	80	Peorian loess	SE¼,SE¼,S10,T3S,R5W
19.	Muir silt loam	400	Alluvium	NW¼,SW¼,S33,T1S,R5W
20.	Carr fine sandy loam and Muir silt loam	800	Alluvium	SE¼,NE¼,S34,T1S,R5W
21.	Hastings-Crete silt loam	60	Peorian loess	SW¼,NW¼,S3,T3S,R5W
22.	Hastings-Crete silt loam	80	Peorian loess	SW¼,NW¼,S3,T3S,R5W
23.	Hastings-Crete silt loam	150	Peorian loess	SW¼,NW¼,S3,T3S,R5W
24.	Courtland canal	---	---	---
25.	Crete silty clay loam	5	Peorian loess	SW¼,SW¼,S33,T2S,R5W
26.	Hastings soils-eroded Hobbs complex	5	Peorian loess	SW¼,SW¼,S33,T2S,R5W
27.	Muir silt loam	5	Alluvial terrace	NW¼,NW¼,S33,T1S,R5W
28.	Muir silt loam	5	Alluvial terrace	NW¼,NW¼,S33,T1S,R5W
29.	Crete silt loam	60	Peorian loess	NE¼,NW¼,S32,T1S,R5W
30.	Crete silty clay loam	5	Peorian loess	NE¼,SE¼,S32,T2S,R5W
31.	Crete silty clay loam	5	Peorian loess	NE¼,SW¼,S32,T2S,R5W

attempted to determine the effects of oxidizable carbon, soil texture, and nitrogen concentrations on nitrate reduction.

This study was conducted on the land of three different farmer-cooperators. The plot numbers correspond to the numbers given the drain sampling sites from the earlier study. (See Table 1). On plots 25 and 26, Cliff Lindberg applied annually 200 kg/ha nitrogen as ammonium nitrate to continuous corn. On plots 27 and 28, Howard Elliot applied 140 kg/ha nitrogen as ammonium nitrate to corn the first year of the study and 112 kg/ha of 18-23-0 (%N, %P, %K) to soybeans the following years. On plots 30 and 31, George Stransky annually applied 168 kg/ha nitrogen as ammonium nitrate to continuous corn. These three sites were selected on the basis of being irrigated, continuously cropped, and having two short tile drain spurs joining at a manhole from which water samples could be taken. On each site, nitrogen fertilizer (ammonium nitrate) was applied to the land over one tile drain lateral at the rate of 225 kg N/ha. This application was in addition to the nitrogen applied by the cooperator. The other lateral received only the farmer's fertilizer application. Fertilizer was applied on April 18, 1974, May 10, 1975, and April 12, 1976, respectively, for the three years of the study.

The three sites were located in Republic County, Kansas and lie within the Bostwick Irrigation District. Plots 27 and 28 were situated on Muir silt loam, 0-1% slope, which is a fine silty, mixed, mesic Typic Arguistoll. The Muir series is a deep, well-drained, nearly level soil developed in silt and clay alluvium on terraces. This soil has a moderately slow to moderate permeability with a thick grayish brown to dark-gray silt loam A horizon overlying a friable silt loam B horizon. Plots 30 and 31 were located on Crete silt loam, 1-3% slope, and Crete silty clay loam, 2-5% slope

eroded. The Crete series consists of deep, well-drained soils that have a loamy surface layer underlain by a clayey subsoil. These soils developed on loess and are fine, montmorillonitic, mesic Typic Arguistolls. They have a slow to medium runoff and slow internal drainage and permeability. The surface layer is a dark-colored, slightly acid silty clay or silt loam about 30 cm thick. The subsoil, about 75 cm thick, has three parts. The upper part is dark grayish-brown silty clay loam. The middle is dark grayish-brown silty clay that is extremely hard when dry and plastic when wet. The lower part is light brownish-gray silty clay loam and contains many small, hard concretions of lime.

Plot 25 was also situated on Crete silt loam, 1-3% slope, and Crete silty clay loam, 2-5% slope, eroded. Plot 26 was on a Hastings soil, eroded-Hobbs complex. The Hastings soil in this complex is similar to the Crete series. The Hobbs soil has a grayish silty clay loam surface layer and a thin, grayish silty clay subsoil. The soils in this complex are well drained with slow to moderately slow permeability.

Tile Drainage Water Sampling

Water samples were collected every month during irrigation season and several months during fall, winter, and early spring. Drainage water samples from the plots were collected manually using the manhole existing at the junction between drains from the fertilized and unfertilized plots.

Because there was a question as to the influence of agriculture on subsurface drainage water quality, the drainage water from selected sites in the Bostwick Irrigation District was being monitored for any deterioration in quality. The monitoring had begun in August, 1972. Water samples were collected at points in the District where drains emptied into streams or open ditches, except for three drains which were sampled from manholes. Flow rates were taken from all sample points using a 7.6 liter bucket and a stop watch.

Water samples were stored at $5^\circ C$ prior to analysis. The water was analyzed for NO_3^--N, Ca^{++}, Mg^{++}, K^+, Na^+, and electrical conductivity. Drainage water from the plots was analyzed for chloride and spot checked for phosphorus.

Soil Sampling

Soil core samples were collected prior to fertilizer applications in April 1974 and April 1976. However, in 1975 wet weather delayed the soil coring until November instead of at the time of fertilization. Soil core samples were taken with a truck-mounted hydraulic soil probe using a 1.2 m slotted stainless steel sampling tube 5 cm in diameter. The core was cut into 10 cm increments and each increment placed in a sample bag. The coring process was repeated using a 2.5 cm diameter tube and penetrating to a depth of approximately 2 meters. The second core was divided into 20 cm increments. Each plot was sampled three times. Since three 10 cm increments from the 5 cm diameter cores would not fit in a sample bag, these cores were split in half length wise and half of the core was saved. The plots were sampled to a depth of 160 cm in 1974 and 180 cm in 1975 and 1976. It was impossible to sample deeper due to the high water table.

The samples were dried in the laboratory for 7 days at $55^\circ C$. The dried samples were ground with a NASCO soil crusher, screened through a 2 mm screen, mixed, and stored in sealed glass bottles.

The soil samples were analyzed for NH_4^+-N, NO_3^--N, Cl^-, pH, extractable Ca^{++}, Mg^{++}, K^+, and Na^+, CEC, total C, $CO_3^=-C$, and organic C.

Soil Atmosphere Analysis

Soil atmosphere samples were collected to determine if denitrification was playing a significant role in keeping nitrate from migrating into subsurface drainage waters. The presence of nitrous oxide would indicate the reaction was occurring and that anaerobic zones existed in the soil profile.

In 1974 and 1975, soil atmosphere tubes were installed on plots 25 and 26. The tubes were pieces of PVC pipe with a rubber septum on one end and a rubber exterior gasket on the opposite end. The tubes were placed in five replications on each plot at depths of 20, 40, 60, 80, and 100 cm. The replications were 15 cm apart and located 6 m to either side of the drains. Samples were taken from the tubes using a 10 ml hypodermic syringe and placed in an evacuated air sample bottle. Later, the samples were analyzed for N_2, O_2, CO_2, and N_2O using a Carle Model 8000 gas chromatograph with Porapak-Q and molecular sieve columns installed in series (25 ml/min flow rate and 55°C oven temperature).

Soil Solution Analysis

In 1974, porous cup soil solution tubes were placed in five replications on plots 25 and 26 at depths of 15, 30, 50, 70, and 90 cm. Each replication was 15 m from the previous one and six meters to either side of the tile drain. Care was taken to insure that the tubes were placed in an undisturbed soil profile, avoiding the areas where the subsoil had been disturbed at the time the drains were installed. The tubes were installed in the row tops while there was irrigation water running in the furrows. Vacuum was applied to the tubes during irrigation and maintained for six hours. However, no samples could be obtained. Investigation of the soil profile at the time of irrigation showed that water was not penetrating below a depth of 25 cm.

Nitrate and Ammonium Determination

A steam distillation procedure outlined by Bremner and Keeney [13] was used for NH_4^+-N and NO_3^--N determinations in soil. A 2 g portion of each soil sample was weighed and placed in a 300 ml Kjeldahl distillation flask with 10 ml of 2N KCl and 0.1 g of MgO. This mixture was steam distilled

and 25 ml of distillate was collected in a 5 ml aliquot of 2.0 percent boric acid-mixed indicator solution. The distillate was titrated with 0.00524 N sulfuric acid using a microburet. Results were calculated as ppm NH_4^+-N after correcting for deionized water blanks.

Nitrate-nitrogen was recovered on the same soil sample following the ammonium-nitrogen determination by adding 0.2 g of 100 mesh Devarda's alloy to the distillation flask and immediately distilling another 25 ml into 5 ml of the boric acid-indicator solution. The sample was titrated with standardized sulfuric acid and the results were calculated as ppm NO_3^--N.

Water samples were analyzed for NO_3^--N and NH_4^+-N using a similar procedure. A 5 ml aliquot of water was added to the distullation flask with 20 ml of 2N KCl. Magnesium oxide (0.2 g) and 0.2 g Devarda's alloy were added simultaneously at the start of distillation. Twenty-five ml of distillate was collected in 5 ml of boric acid-indicator solution and titrated with 0.00524 N sulfuric acid. The blanks consisted of MgO, Devarda's alloy, and 20 ml of KCl. Results were reported as ppm NO_3^--N.

Total Soil Carbon

Total carbon of each increment of the soil samples was determined using a Leco 70 second carbon analyzer (7, 76). One hundred milligrams of finely ground soil (80 mesh) were weighed into a special ceramic crucible and one scoop (approximately 1 gram) each of iron chips and tin accelerators were added. The crucible was then placed in the combustion tube of an induction furnace through which O_2 was being passed. The sample was combusted at a temperature of over $1670^\circ C$ with the carbon in the sample being oxidized to CO_2. The gas mixture was passed through (1) a dust trap to filter out the solid tin and iron oxides, (2) a sulfur trap containing MnO_2

to absorb sulfur gases which may have been oxidized during the combustion

of the sample, and (3) a heated catalyst to convert any CO formed to CO_2.

Moisture was removed from the gas mixture before it entered the analyzer

by an anhydrone trap. After combustion and passage through the purification

train, the gas mixture was passed into a cylinder housed in a temperature-

controlled oven (45 C) in the analyzer. The thermal conductivity of the

mixture in the cylinder was measured by a thermistor-type thermal conductiv-

ity cell. The output of the thermal conductivity cell was read on a special

DC digital voltmeter as percent carbon.

Organic Carbon

Percent organic carbon was determined by pretreating a portion of

the soil samples with excess sulfurous acid to remove any carbonates present

(6). The samples were dried in a heated vacuum desiccator and the Leco

carbon analyzer was used to determine percent carbon in a 100 milligram

sample of soil.

Carbonate Carbon

The approximate percent carbonate carbon in the soils was determined

by difference between percent total carbon and percent organic-carbon.

Chloride

Chloride was determined in soil samples by two different methods.

In 1974, a modified prodecure outlined by Hipp and Langdale (38) was used

where a 5 gram sample of soil was extracted with 25 mls of deionized water

by shaking and centrifugation. The centrifugate was titrated with standard-

ized $AgNO_3$ using an Orion chloride electrode Model 94-17A, as an end point

indicator.

In 1976, a procedure outlined by Hayden et al. (36) was used to determine chloride directly in the soil. Potassium alum was added as a flocculating agent to a soil/water suspension to eliminate soil particle interference in the chloride readings when the Orion chloride electrode was used.

Determinations of chloride in water samples were accomplished using the chloride electrode following the procedures outlined in the Orion instruction manual for halide electrodes. Results were calculated from a standard curve and reported as ppm chloride.

Ca, Mg, K, Na Determinations

For soil samples, extractable Ca, Mg, K, Na were determined using an ammonium acetate centrifuge extraction procedure described by Jackson (40). Calcium and Mg were determined using a Perkin Elmer Model 303 atomic absorption spectrophotometer. Flame photometry was used for Na and K analyses.

For water samples, atomic absorption spectroscopy was used to analyze for Ca and Mg, with 1% La_2O_3 solution used as a diluent. Sodium and K were analyzed directly using flame photometry, though sodium was diluted with 0.1 N HCl.

Phosphorus

Phosphorus in water samples was determined through May 1975 using the Watanabe and Olsen (83) ascorbic acid method. Samples were read on a Baush and Lomb Spectronic 88 spectrophotometer at 654 nm. Results showed that phosphorus concentrations were negligible so this analysis was discontinued.

Electrical Conductivity

The electrical resistance of all water samples was determined using a Wheatstone bridge. Electrical conductivity was calculated in millimhos by dividing resistance into the cell constant.

Cation Exchange Capacity

Cation exchange capacity of the soil samples was determined using Bower's et al. (11) centrifuge procedure with some modifications. The soil was treated four times with 1 N sodium acetate (pH 8.2) and washed three times with ethanol. Three treatments with 1 N ammonium acetate (pH 7.0) were used to extract the sodium and flame emission spectroscopy was used to determine milliequivalents of sodium in the supernatant liquid. Cation exchange capacity was expressed as me /100 g of soil.

RESULTS AND DISCUSSION

Tile Drain Water Quality of Bostwick Irrigation District

The investigation of the quality of water flowing from selected tile drains on the district was begun in 1972 and continually expanded up to April 1974 when the nitrogen fertilization study began. The drains were monitored frequently throughout the year and rough estimates have been made of the approximate land area drained by each (Table 1). Flow rates from drains were also measured (Table 2).

Tables 3, 7, 8, 9, 10, 11, 16, and 17 report the quality of the water over the last four years. The water quality was relatively constant throughout the sampling period. Seasonal irrigation practices did not seem to effect tile drain water quality. In all but one case, nitrate concentrations showed only minor fluctuations with no overall increases. In the effluent from drain site number 1, however, an already high nitrate concentration increased even more during the period. This can be traced to contamination from a septic tank. This particular drain was adjacent to a farm house, and the drain passed very close to the house and only a short distance beyond. Sodium chloride, and nitrate concentrations were very high and E.C. measurements indicated a very high concentration of dissolved solids.

It is difficult to determine the effects of agricultural fertilization practices on subsurface water quality in the Bostwick district. Water analysis shows that in August 1972 at the start of the investigation, certain drain effluents had significant nitrate-N concentrations (above 10 ppm). However, no one can say with certainty whether this contamination is from decomposition of organic matter or due to the farming operations.

TABLE 2.   FLOW RATES OF TILE EFFLUENT IN THE BOSTWICK IRRIGATION DISTRICT

GALLONS PER MINUTE

SITE NO.	1973									1974				
	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	JUN	AUG	SEP	OCT
1	10	8	8	60	6	6	16	8	10	10	5	8	18	18
2	60	60	15	5	60	15	150	80	75	80	40	120	100	100
3	120	60	60	100	60	60	100	75	30	--	12	30	33	33
4	20	15	60	20	15	15	20	12	8	8	6	30	13	13
5	300*	200*	200	120	150	100*	400*	150*	150	250*	250*	250*	100	100
6	120	80	60	40	60	80	150	80	40	80	40	30	50	50
7	10	5	5*	--	10*	10	12*	5*	1*	20*	5	2*	<1	0
8	120	5	40	30	30	30	100	40	30	--	3	60	15	0
**9	--	--	--	--	--	--	--	--	--	--	--	--	--	--
10	120	60	60	60	60	60	120	80	75	80	75	60	40	20
11	--	--	--	--	--	--	--	--	--	--	--	--	--	0
12	120	90	50	60*	80*	50*	80*	80	60*	60*	40*	24	20*	3
13	--	500*	500*	400*	400*	400*	500*	400*	180	250*	200*	175	125	100*
14	--	250	300*	150*	150	120	240	250	300*	180	80	120	67	40
15	--	--	--	--	--	--	--	30	15	20	8	20	14	9
16	60	80	50	100	100	120	120	180	100	120	80	120	100	50
17	300*	250*	250*	200*	300*	180*	300*	200*	200*	200*	120*	250*	125*	25*
18	80	60	40	80	60	30*	60*	60	40*	40	20	24	2*	0
19	120	150	80	80	80	120	150	180	120	180	60	250	125	3
20	150	150	150	250*	300*	200*	500*	--	240	250*	150*	500*	250*	200*
21	200	80	50	40	60	40	150	60	60	--	30	24	14	1
22	40	30	25	15	15	10	40	30	25	30	8	4	<1	0
23	150	100	60	60	80	80*	120	80	60	80	70	60	50	20
**24	--	--	--	--	--	--	--	--	--	--	--	--	--	--
25	--	--	--	--	--	--	--	--	--	2+	9	1	1	4
26	--	--	--	--	--	--	--	--	--	--	2	--	--	--
27	--	--	--	--	--	--	--	--	--	--	20	--	40	14
28	--	--	--	--	--	--	--	--	--	--	--	--	--	--
29	--	--	--	--	--	--	--	--	--	6+	10	40	60	3
30	--	--	--	--	--	--	--	--	--	1+	1	2	<1	0
31	--	--	--	--	--	--	--	--	--	1+	2	2	<1	0

** CANAL   * ESTIMATED   + SAMPLED APRIL, 1974

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TABLE 2. (cont.)   FLOW RATES OF TILE EFFLUENT

GALLONS PER MINUTE

SITE NO.	1975								1976			
	JAN	MAR	MAY	JUN	JUL	AUG	OCT	NOV	MAR	MAY	JUN	SEP
1	5	3	3	1	3	3	<1	<1	5	--	--	5*
2	10*	17	33	33	40	29	14	14	20	50	--	15*
3	1	0	0	7	100	100	0	0	0	3	75	20
4	1*	0	2	3	10	17	<1	<1	1	--	--	10
5	2	3	50	100*	200*	67	20	10	25	100	200*	150*
6	33	25	25	50	45	33	20	15	25	33	25	40
7	0	0	0	2*	400*#	800*	50	50	50	100	300*	150*
8	0	0	0	1	25	30	0	0	0	1	2	7
**9	--	--	--	--	--	--	--	--	--	--	--	--
10	17	20	33	50	50	40	13	13	25	50	50	25
11	0	0	0	50*	--	0	0	0	0	--	--	--
12	0	0	0	50	50*	10	0	0	0	35	50*	10*
13	100*	100*	200*	200*	400*	200*	100*	80	100	200	150*	500*
14	25	25	14	67	100	150	20	14	14	14	40	100
15	4	3	3	7	5	3	2	2	1	4	2	12
16	50*	75	50	8	200	400	13	10	20	100	100	75
17	20*	25*	40*	150*	150*	150*	15*	25*	25*	75*	100*	150
18	0	0	0	50	30	5	0	0	0	35*	30*	0
19	100	29	33	67	--	200*	50*	50*	30	50	300*	--
20	10	8	10	100	800*	400	75	33	0	13	10	300
21	7	75	14	50	40	11	<1	<1	3	10	<1	5
22	0	<1	<1	10*	--	5*	0	0	<1	10	67	0
23	25	20	20	100	100	67	14	13	17	50	67	50
**24	--	--	--	--	--	--	--	--	--	--	--	--
25	<1	1	--	--	--	--	--	--	--	<1#	1*	2
26	--	--	--	--	--	--	--	--	--	<1#	1*	0
27	5*	17	13	20*	--	25	5*	5	7	10	35	15
28	--	--	--	--	--	--	--	--	--	--	--	--
29	15*	33	25	25	33	100	25	15*	20	33	33	25
30	0	0	0	1	2	0	0	0	0	0	0	0
31	0	0	0	2	2	0	0	0	0	0	0	0

** CANAL   * ESTIMATED   # NEW DRAIN

Because there was no increase in nitrate concentrations during the four years, it can be assumed that the data base gathered for nitrate (and other ions for that matter) is representative of that particular area for several years.

An important consideration that law makers frequently overlook with regards to water quality is solute travel-time within a soil profile. Jury (44) developed a model for estimating the time of travel of mobile ions on tile-drained fields of various textural classes. His results point out the problem with legislation which contain proposed target dates for lowering of contaminant levels in U.S. waterways. Regulation of agricultural sources of contamination in areas where tile effluent discharge concentrations are high could be the result of misinterpretation of the effluent reading. For example, suppose the acceptable level of effluent quality were set at 20 ppm of nitrate for a tile drained system on a fine textured soil in which the current nitrate concentration was 40 ppm. The rate of solute travel would not allow this system to meet the proposed level for 10 years after the cessation of all solute input.

Another example is the case where the effluent monitoring is begun several years after a good surface management system has been initiated. Misinterpretation of the effluent readings could result in the assumption that current management practices were not working when in fact the effluent readings were only a lingering influence of previous management practices.

One observation for which there is probably no simple answer is that soils derived on Peorian loess appear to have a higher soluble salt content than those derived on alluvium. Drain sites 7a, 13, 14, 16, 19, and 20 drain soils derived from alluvium. The Ca, NO_3^--N, Na, and Cl values are lower for these drain effluents than those from drains under soils derived

on Peorian loess. Electrical conductivity values, a good indicator of total dissolved solids, are considerably lower for water draining from alluvium than for water draining from Peorian loess.

Water Nitrate-Nitrogen

Because of the limited two year duration of the project, nitrate from fertilizer applied at the start of the study has apparently not had sufficient time to migrate through the profile into the subsurface drainage water of the treated plots. However, an investigation begun in 1972 of the quality of water flowing from selected tile drains shows that in almost all cases nitrate concentration in subsurface water under cropped land is not increasing (Table 3). Figures 1, 2, and 3 show that the flow rate from three tile drains is independent of the water nitrate concentration. This seems to be generally true for all the sampled drains in the district.

Table 3 shows that plots 27 and 28 exhibited high concentrations throughout the year. The cooperator grazed his cattle on stubble during fall and winter and the cattle congregated on these plots because their water was pumped from the manhole and into a watering tank nearby. Manure and urine contributed much nitrogen to these plots and, because the soil was a well drained silt loam, probably caused the high concentrations of nitrate in the subsurface tile effluent.

Nitrate concentrations in tile effluent under the other plots were fairly constant. Drains 30 and 31 carried water only during the irrigation season, three months out of the year. Leaching could be expected to be low on these plots and, in fact, this was the case. Figure 6 shows that nitrate concentrations were low throughout the lower zones of the profile. This would suggest that nitrate is remaining in the root zone long enough to be taken up by the plant.

TABLE 3.   NITRATE-NITROGEN CONTENT OF TILE EFFLUENT IN THE BOSTWICK IRRIGATION DISTRICT

PPM NITRATE-NITROGEN

SITE NO.	1972 AUG	SEP	OCT	1973 APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	1974 JAN	JUN	JUL
1	17.3	15.9	16.7	14.4	16.8	17.0	17.6	19.4	19.0	18.8	18.5	18.5	17.6	21.9	20.6
2	14.6	13.0	13.3	13.0	13.3	13.3	13.3	15.0	12.4	15.1	14.0	14.3	14.7	15.8	13.7
3	--	0.1	2.0	0.0	0.0	0.9	2.3	2.3	2.4	1.9	1.6	1.9	--	2.9	3.0
4	5.5	5.8	6.6	5.2	4.0	5.5	6.6	6.1	5.3	5.8	5.8	5.8	4.6	6.5	5.3
5	--	8.7	8.1	7.5	7.2	9.2	8.1	8.4	10.6	10.6	11.4	10.1	9.8	10.4	9.8
6	--	--	10.7	8.1	6.6	8.1	10.4	11.0	10.6	11.6	10.6	10.6	9.0	10.4	10.8
7	--	--	--	16.2	15.3	14.2	1.1	0.9	1.1	18.0	17.5	7.1	5.7	11.8	12.6
8	--	--	--	10.1	9.0	9.2	11.0	15.0	13.5	13.5	10.6	11.4	--	5.3	13.8
*9	--	--	--	--	--	--	0.0	1.2	--	--	--	--	--	0.4	0.6
10	7.5	8.4	9.5	5.2	0.0	6.9	6.9	8.1	9.3	8.5	8.2	8.7	8.6	8.0	8.2
11	--	--	--	8.1	27.5	12.7	8.7	12.4	11.1	13.5	14.0	15.6	14.4	16.9	12.0
12	17.9	16.4	18.7	14.4	6.6	17.0	14.4	15.0	14.0	18.0	18.0	17.2	17.6	14.5	13.4
13	0.6	0.0	--	--	0.0	3.8	2.6	4.0	4.5	4.0	4.8	5.3	2.5	5.1	6.8
14	--	--	--	--	0.3	0.3	13.6	2.0	2.4	2.1	2.1	2.1	1.9	2.9	2.9
15	--	--	--	--	--	--	--	--	--	13.5	14.5	15.9	14.9	14.2	13.8
16	11.5	10.4	13.3	13.6	13.0	14.7	15.3	14.4	15.1	13.5	14.3	15.9	14.5	16.9	17.4
17	13.3	8.9	9.8	9.2	9.2	10.4	8.1	10.1	9.5	11.1	10.6	11.6	--	9.7	9.4
18	13.3	14.1	14.4	12.7	10.7	5.8	15.3	13.0	12.7	16.1	14.5	13.6	12.4	14.7	14.4
19	4.6	5.2	5.5	5.2	1.7	2.3	5.8	6.6	6.6	7.1	7.4	6.3	6.9	7.3	7.5
20	1.7	--	--	2.0	5.2	2.0	3.5	3.8	2.4	4.0	3.4	3.2	--	3.5	3.0
21	3.2	4.0	4.6	2.3	3.8	3.5	4.6	5.8	3.7	4.5	4.2	4.8	--	4.8	5.3
22	--	--	--	2.0	4.3	11.0	5.5	5.2	4.2	5.0	5.6	5.3	3.3	5.7	5.5
23	8.7	10.7	11.2	10.4	11.0	11.3	10.7	12.7	11.1	13.0	13.8	14.2	7.9	12.7	11.3
*24	0.0	0.0	--	--	--	--	0.0	1.2	--	--	--	--	--	1.4	1.0
25	--	--	--	--	--	--	--	--	--	--	--	--	5.8+	7.6	8.3
26	--	--	--	--	--	--	--	--	--	--	--	--	--	5.4	5.4
27	--	--	--	--	--	--	--	--	--	--	--	--	--	21.2	--
28	--	--	--	--	--	--	--	--	--	--	--	--	--	20.5	--
29	--	--	--	--	--	--	--	--	--	--	--	--	5.8+	6.6	8.0
30	--	--	--	--	--	--	--	--	--	--	--	--	9.5+	8.7	4.1
31	--	--	--	--	--	--	--	--	--	--	--	--	13.7+	14.1	10.2

* CANAL   + SAMPLED APRIL, 1974

TABLE 3. (cont.)   NITRATE-NITROGEN CONTENT OF TILE EFFLUENT

PPM NITRATE-NITROGEN

SITE NO.	1974 AUG	1974 SEP	1974 OCT	1975 JAN	1975 MAR	1975 MAY	1975 JUN	1975 JUL	1975 AUG	1975 OCT	1975 NOV	1976 MAR	1976 MAY	1976 JUN
1	19.9	22.3	19.0	24.1	19.3	20.9	16.8	22.6	5.0	16.8	18.9	23.8	20.3	22.8
2	12.4	14.8	13.4	20.3	16.4	15.7	12.2	11.6	10.8	13.3	10.9	14.7	15.4	13.9
3	2.2	16.3	1.7	6.2	--	--	3.2	0.8	1.1	--	--	--	3.6	3.1
4	7.5	5.5	5.7	11.3	6.6	6.9	2.8	4.5	3.9	7.3	5.6	7.7	4.5	4.1
5	8.9	10.0	9.4	11.8	10.4	8.7	6.7	8.7	7.1	8.0	6.9	8.1	8.8	8.8
6	12.6	13.0	10.8	9.4	--	10.9	9.2	7.4	9.9	9.7	10.2	10.2	9.1	8.8
7	12.9	--	--	--	--	--	9.8	8.3#	5.2	5.0	4.2	7.4	5.5	6.6
8	13.4	9.7	--	--	--	--	5.5	16.9	12.7	--	--	--	6.6	7.8
*9	1.0	--	0.6	--	--	--	--	0.4	0.4	--	--	--	--	1.1
10	10.0	3.0	--	7.1	9.1	8.7	9.5	8.8	8.1	9.8	9.1	9.5	9.5	11.8
11	12.3	11.1	--	--	--	--	7.3	7.7	--	--	--	--	--	3.9
12	16.2	7.7	--	--	--	--	16.2	13.9	4.5	--	--	--	17.5	14.7
13	6.8	8.2	5.5	5.3	4.8	5.5	3.8	7.8	6.0	7.0	5.0	5.2	5.6	6.7
14	2.6	3.6	2.2	1.4	3.9	4.2	1.1	4.6	0.7	5.7	1.4	3.2	2.0	3.2
15	14.9	13.6	2.2	11.6	11.6	12.6	12.5	13.9	10.6	13.6	9.4	10.5	10.9	12.0
16	12.2	14.0	15.4	12.6	11.6	14.3	10.6	15.0	7.0	19.9	18.9	14.4	14.4	11.3
17	9.7	17.7	6.2	9.5	9.4	9.7	10.1	11.5	7.4	11.2	9.4	9.5	10.2	7.0
18	16.2	9.5	--	--	--	--	15.1	16.2	11.1	--	--	--	17.5	19.5
19	6.2	6.6	1.3	5.0	6.4	5.6	3.4	--	4.2	5.5	3.8	4.9	--	--
20	4.0	4.7	3.8	2.8	--	3.8	3.5	4.3	5.0	5.3	4.5	--	6.4	6.0
21	4.7	3.9	4.6	3.9	5.5	6.2	3.4	5.7	4.1	5.5	5.3	5.7	12.2	6.0
22	5.8	6.8	--	--	5.6	--	6.6	--	4.8	--	--	6.2	10.8	7.0
23	12.3	10.8	8.7	13.0	15.4	15.8	10.1	13.4	9.8	9.0	10.6	15.5	18.1	10.1
*24	1.0	0.6	--	--	--	--	--	0.0	0.8	--	--	--	--	1.3
25	7.5	9.0	2.5	3.1	4.3	--	--	--	--	--	--	--	10.3#	9.0
26	3.3	4.8	--	--	2.2	--	--	--	--	--	--	--	18.1#	17.5
27	--	20.5	23.0	23.8	18.6	19.6	11.1	14.0	11.9	22.3	9.7	17.6	16.7	13.2
28	--	17.0	19.6	20.9	25.4	28.0	19.2	22.0	17.8	24.4	9.8	29.1	25.8	23.1
29	5.3	5.5	5.6	4.1	7.0	6.0	0.3	7.4	4.8	4.2	5.6	6.0	5.3	8.1
30	7.6	9.0	--	--	--	--	4.6	4.6	--	--	--	--	--	--
31	14.0	--	--	--	--	--	4.5	8.8	--	--	--	--	--	--

* CANAL   # NEW DRAIN

FLOW RATE (GPM)

DRAIN 14

X——X FLOW RATE
X——X NITRATE CONC.

NITRATE (PPM)

Fig. 3. Tile effluent nitrate concentration and flow rate from Drain 23
         from 1973-1976.

FLOW RATE (GPM)

DRAIN 23

X—X FLOW RATE
X—X NITRATE CONC.

NITRATE (PPM)
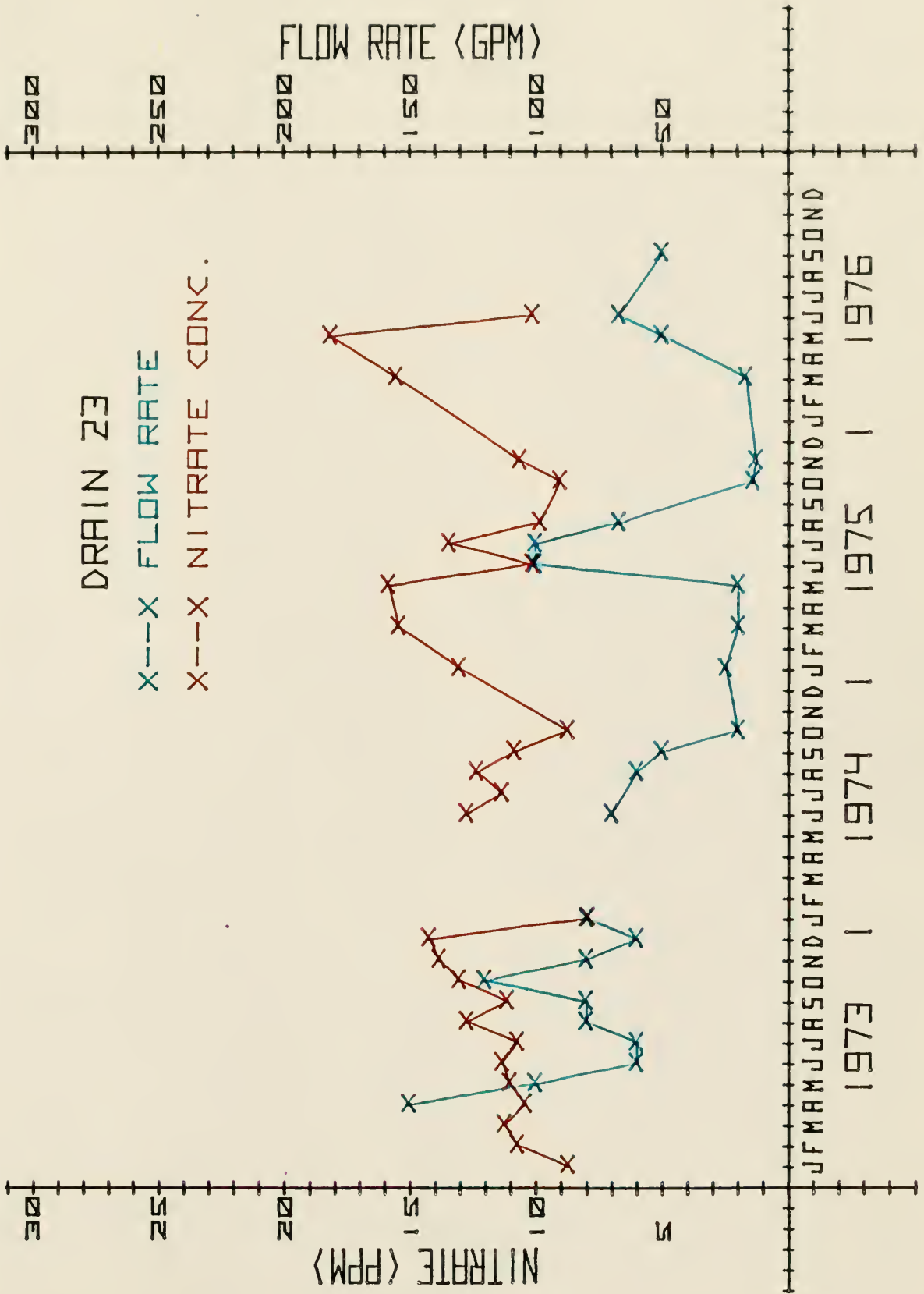
Soil Nitrate-Nitrogen

An examination of Figures 4, 5, and 6 shows a substantial increase in nitrate-N concentration in the upper soil profiles of the treated plots, 25, 27, and 31 from 1974 to 1975. This is to be expected, for during the 19 months between the initial soil sampling in 1974 and the second sampling in 1975 two applications of nitrogen fertilizer were made at the rate of 225 kg-N/ha. This N was in addition to that supplied by the cooperator. The small increases in nitrate on the untreated plot profiles originate from the cooperator's nitrogen fertilizer applications. During the time between sampling dates two irrigation seasons passed, but NO_3^--N has not been flushed out of the surface profile.

On plot 25 (Figure 4), nitrate appears to have leached to about 70 cm in depth by the second sampling date. It is doubtful that the increase in concentration from 70 to 120 cm resulted from the superimposed fertilizer applied in the last 19 months. Infiltration in the silty clay lower profile is very slow. Unfortunately, there is no 1976 graph because the manhole on the plots had mistakenly been removed in May, 1975. It was the point of reference from which the tile drain spurs were identified. These plots (25 and 26) were subsequently abandoned.

On plot 26 in 1974 (Figure 4) the nitrate concentration in the lower depths of the soil profile was relatively high. However, in November, 1975, this low profile bulge had disappeared. Up until the manhole was removed in May, 1975, there was no increase in nitrate concentration in the tile drain water from plot 26 (Table 3). However, because there is no water quality data after that date, one can only guess the fate of the nitrate accumulation. The nitrate could have been leached into the drain water by the water from two seasons of irrigation (1974 and 1975) and from rainfall

Fig. 4. Nitrate-N content of soil cores from plot 25 (treated) and
plot 26 (untreated) as related to depth for 1974-1975.

PLOT 25
(TREATED)

X--X 1974
X--X 1975

PLOT 26
(UNTREATED)

X--X 1974
X--X 1975
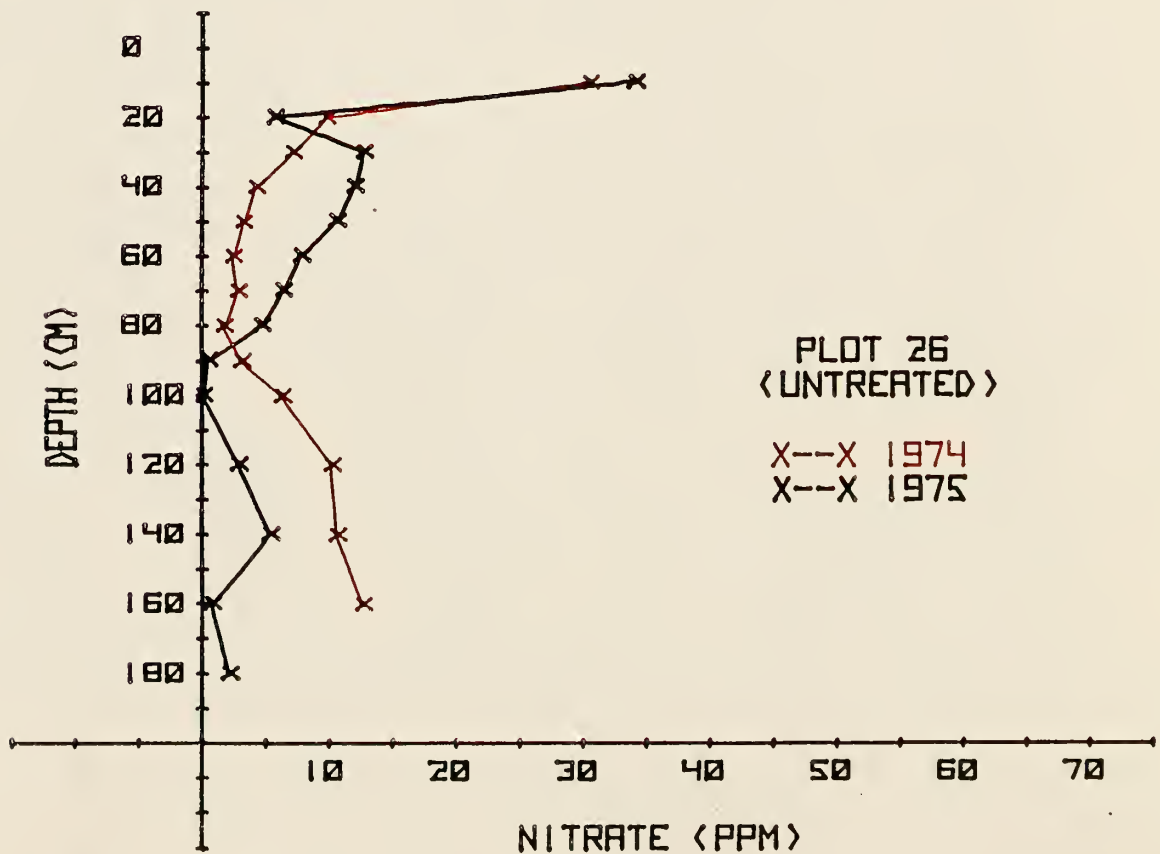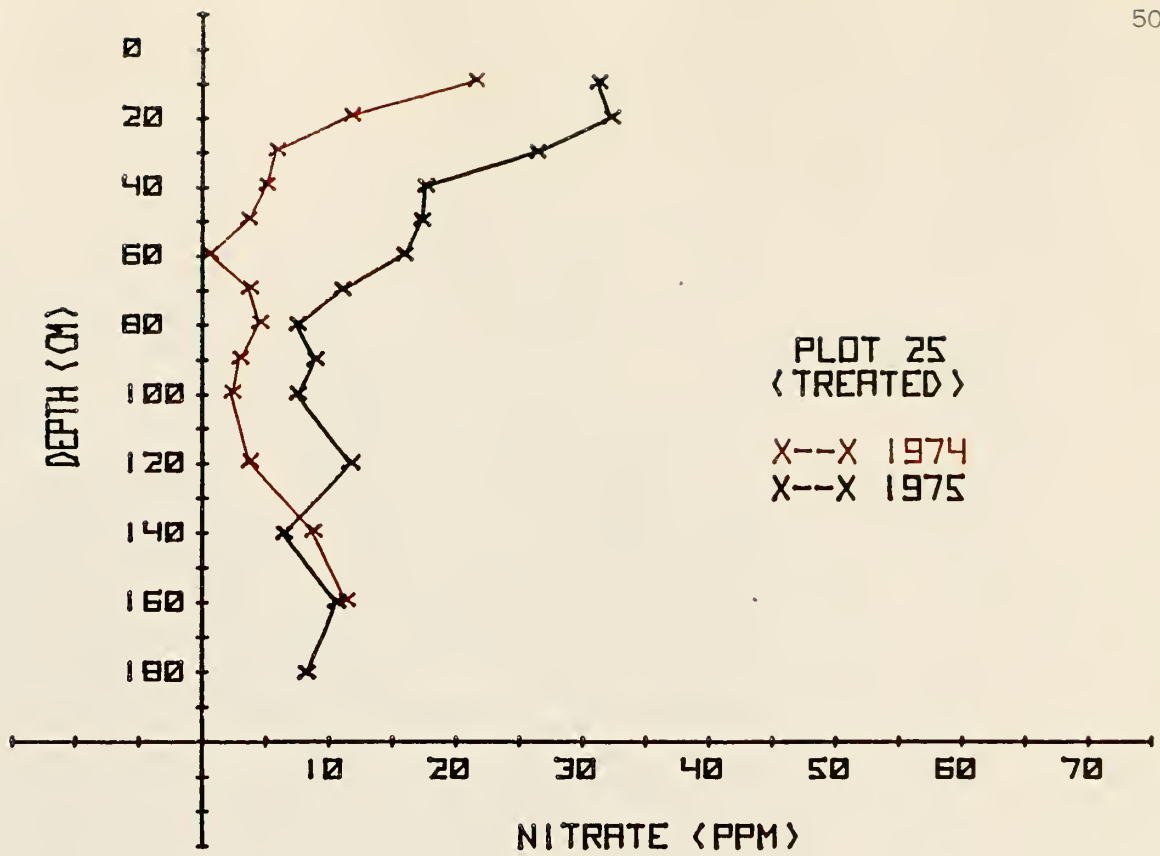
Fig. 5.   Nitrate-N content of soil cores from plot 27 (treated) and
          plot 28 (untreated) as related to depth for 1974-1976.

PLOT 27
(TREATED)

X--X 1974
X--X 1975
X--X 1976

DEPTH (CM)

NITRATE (PPM)

PLOT 28
(UNTREATED)

X--X 1974
X--X 1975
X--X 1976

DEPTH (CM)

NITRATE (PPM)
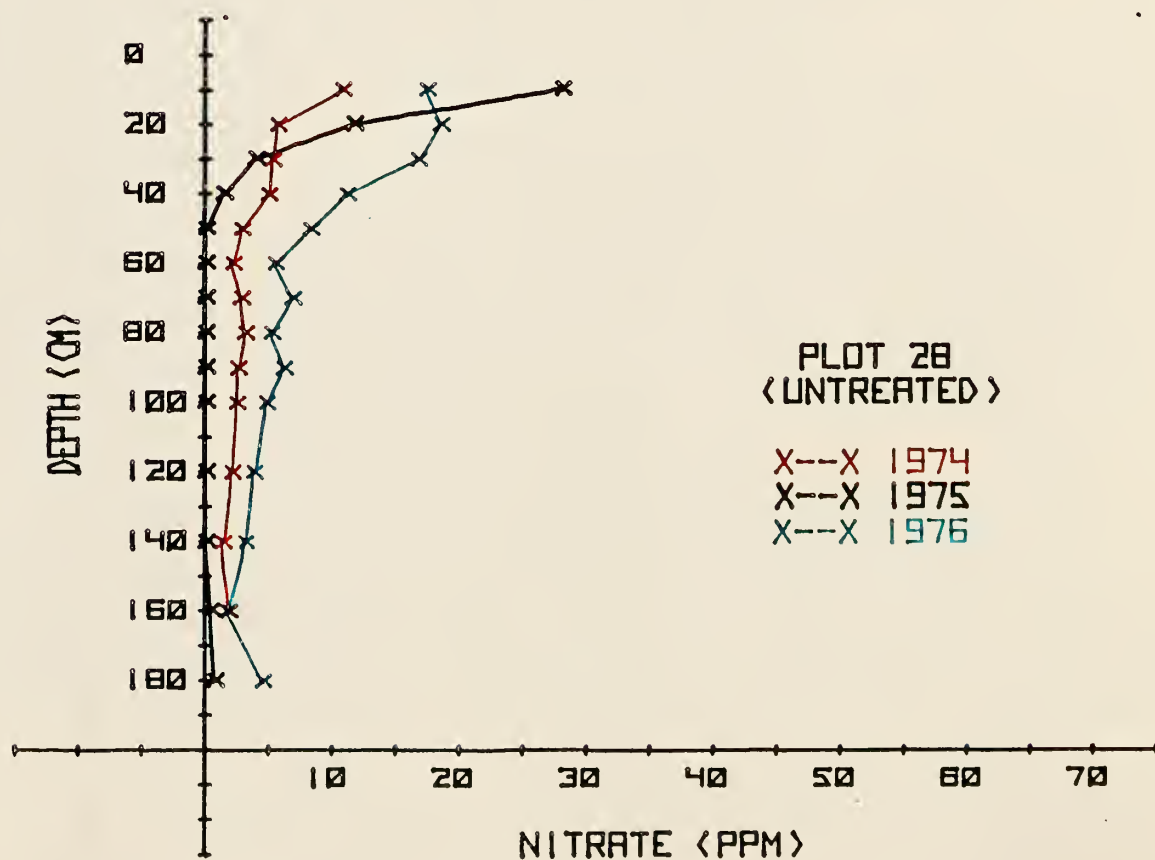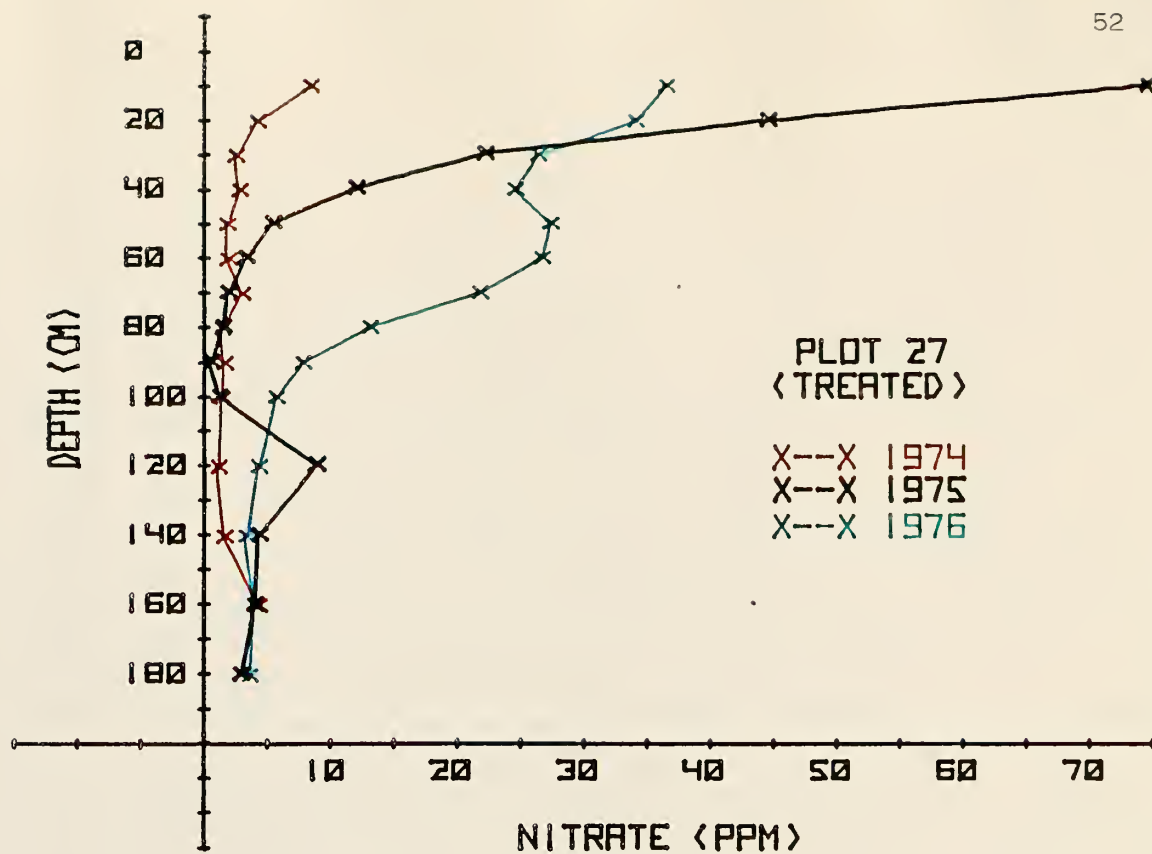
Fig. 6. Nitrate-N content of soil cores from plot 30 (untreated) and plot 31 (treated) as related to depth for 1974-1976.
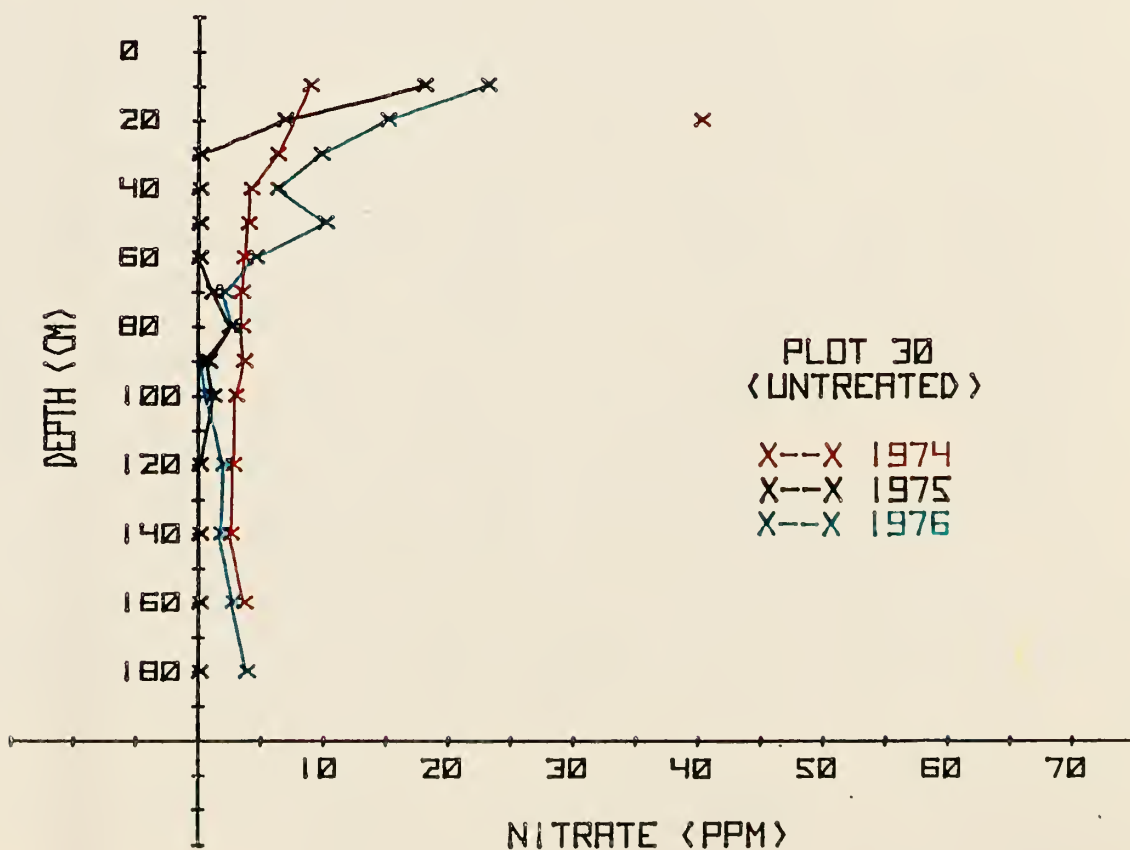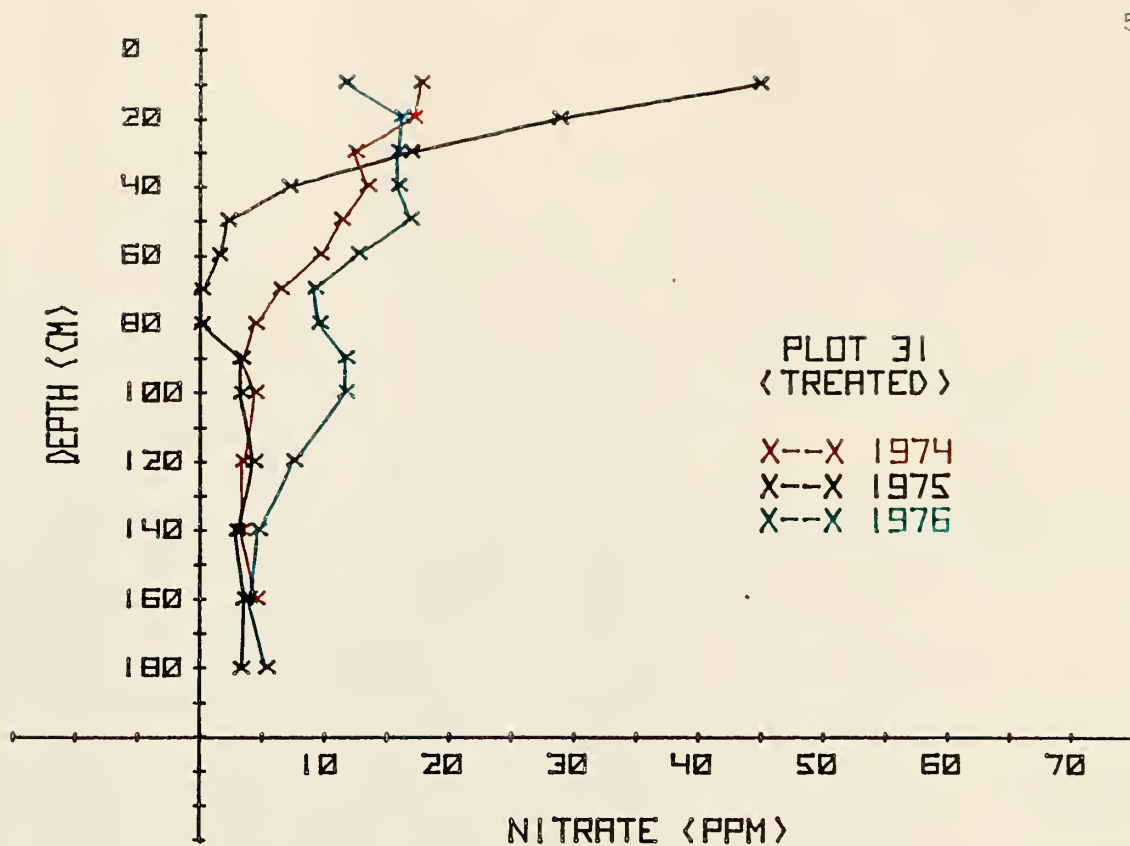
(which was especially heavy in spring of 1975). The percent oxidizable carbon is probably too low (0.27% or below, Appendix Table 3) to warrant consideration of denitrification as the major pathway of nitrate loss. The nitrate could have been removed if the water table rose creating a reducing zone in the lower profile. Because the water table is so shallow (approximately two meters on this plot) this occurrence is very possible. Thus, conditions could have existed whereby nitrate was reduced by available Fe^{+2}, Mn^{+2}, or through the use of nitrate as a terminal electron acceptor.

The accumulation of nitrate at the 20 to 80 cm depth of plot 26 in 1975 is due to movement of nitrate that was applied by the cooperator in the spring of 1974 and 1975. Although organic matter was adequate for denitrification to take place (Figure 7) the reaction does not seem to be occurring to any great extent. It might be possible that the profile from 20 to 70 cm was not anaerobic long enough for denitrification to proceed very rapidly. It was observed that the length of time of water application during irrigation was not long enough to allow water to penetrate much below 25 cm. This was due partly to slow infiltration rates and partly to the location of these plots at the lower end of the irrigation run. A zone of clay accumulation from 40 to 70 cm substantially slowed water percolation. One would expect that if this layer became even partly saturated, there would be enough anaerobic pockets for denitrification to rapidly occur. The fact that the nitrate peak does exist would tend to indicate that the zone is not often subject to periods of anaerobiosis.

Of course, it is difficult to make specific conclusions based on observations of one plot. Plot 25 shows such a substantial accumulation of nitrate in the upper profile that it would appear that denitrification is not playing a significant role there. As with plot 26, in the middle

Fig. 7. Organic carbon content of soil cores from plots 25 and 26 as
related to depth.
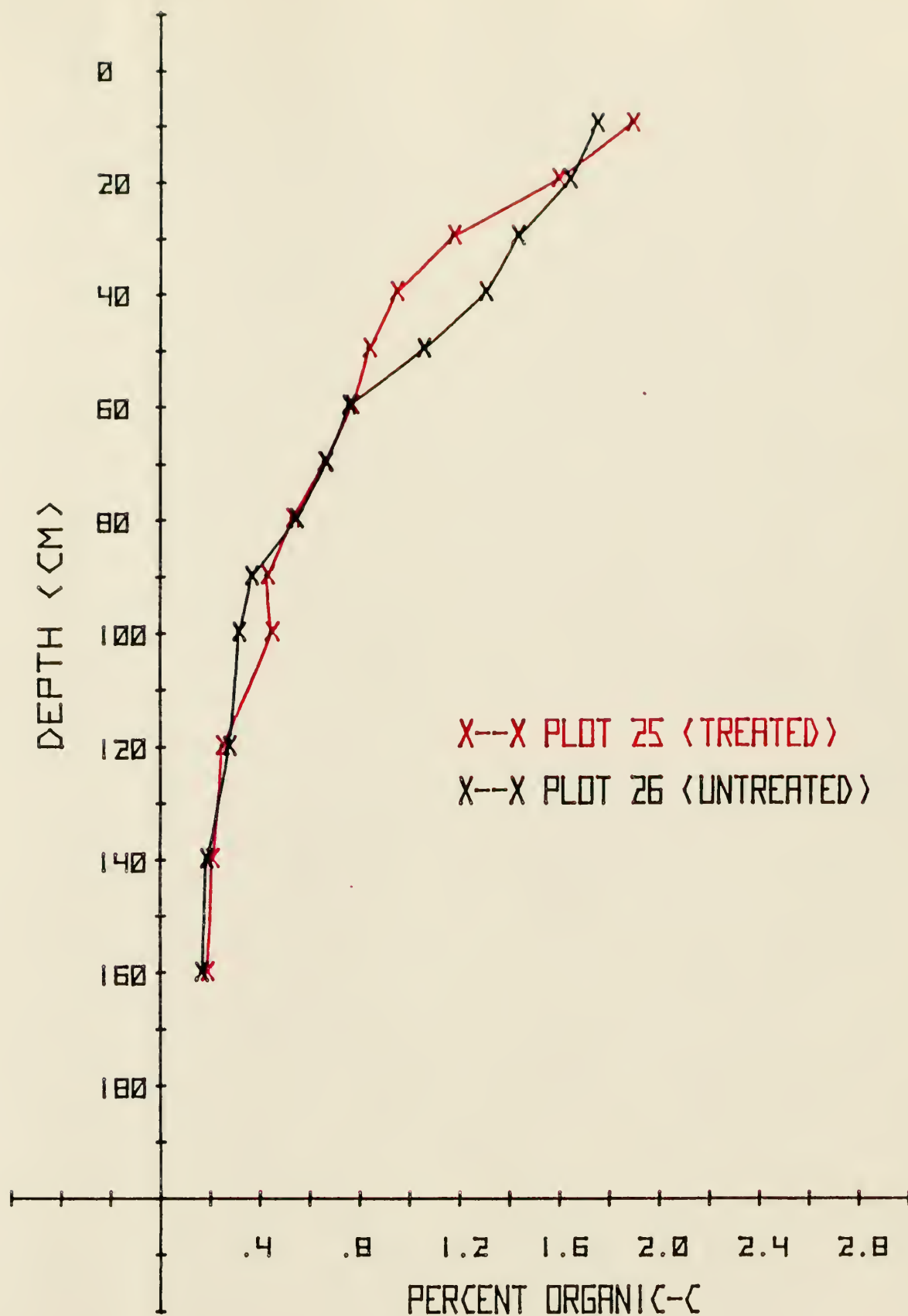
Fig. 8.   Organic carbon content of soil cores from plots 27 and 28 as
related to depth.
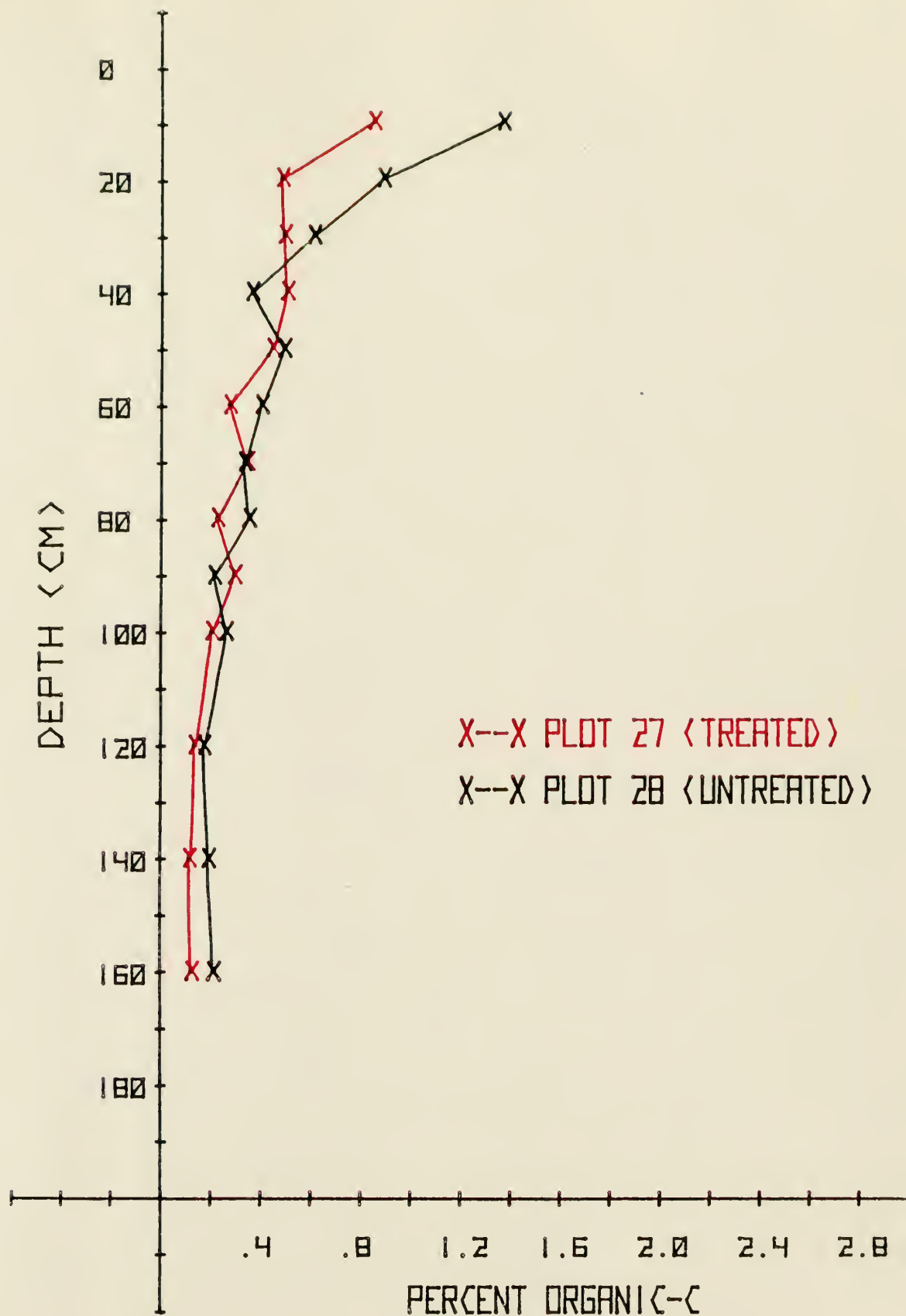
Fig. 9. Organic carbon content of soil cores from plots 30 and 31 as
         related to depth.

X--X PLOT 30 (UNTREATED)
X--X PLOT 31 (TREATED)
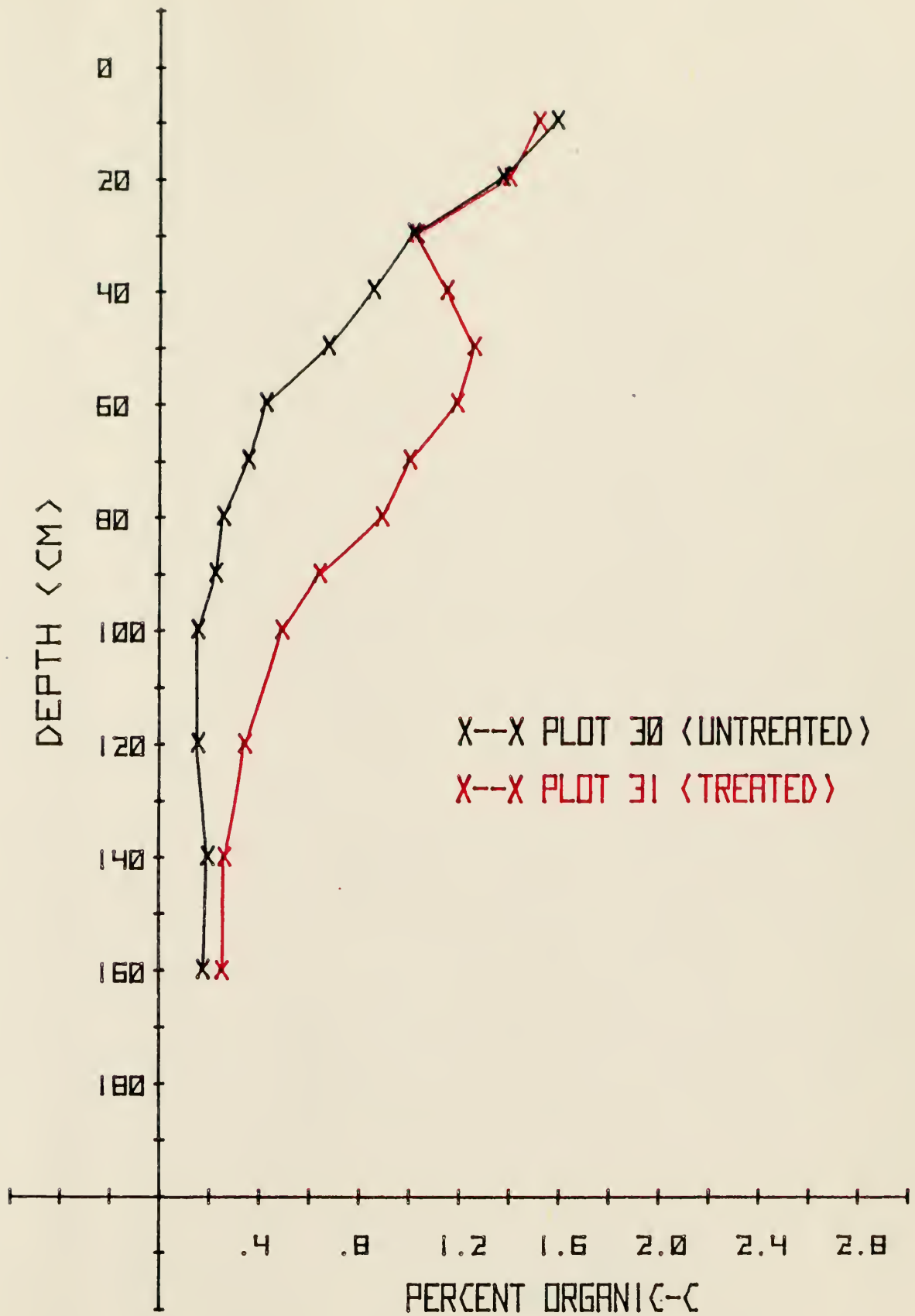
profile (70-120 cm) of plot 25, nitrate concentration has increased over 1974 concentrations. An anaerobic zone here would be expected to keep nitrate concentrations low if there was a sufficient microbial population with an adequate energy source.

Plots 27 and 28 were located on a silt loam soil and after 1974 were planted in pinto beans. There was a substantial difference in nitrate concentrations between the treated and untreated plots in 1975. Because no N-fertilizer was applied between the 1975 and 1976 sampling dates, the nitrate accumulation on plot 27 at the 40 to 60 cm depth is NO_3^- movement from the surface layers which had high NO_3^- in the 1975 fall samples. Because organic matter is low in these profiles (Figure 3), and because they are well drained, denitrification probably does not occur for extended periods of time. Therefore this accumulation (on plot 27) will probably continue to move downward until it reaches the water table (about 180-200 cm).

Plots 30 and 31 were located on soils very similar to those of plots 25 and 26: silty clay loam with clayey subsoil and slow internal drainage and permeability. It is likely that anaerobic conditions conducive to denitrification could exist on these plots (30 and 31) and Figure 3 seems to bear this out.

On both plots in 1975 nitrate concentrations dropped to zero at some point in the profile indicating that either denitrification was occurring or plant extraction of NO_3 was greater than the addition of N from fertilizer and from soil release. The plot of organic-carbon (Figure 9) shows a very high amount of oxidizable carbon in plot 31 at the same depth at which nitrate concentration decreased (40-80 cm). This presence of organic-C may be one reason why there was not as much difference between plots 30 and

31 as there was between the other treated and untreated plots in the study. Plot 31 might be an example where nitrate presence in a profile is controlled by the amount of organic matter present and the profile's poor drainage capabilities.

Most of the soils in the Bostwick District overlie fine textured, loessial parent material. The lower profiles are highly susceptible to canal seepage, and water logging in the lower profile has been a problem in the district. Because of this condition, nitrate that should leach into the lower profile could be subject to reduction before it enters the tile effluent.

In cases where fertilizer nitrogen is influencing drainage water quality, it might be possible to stimulate denitrification through several means. One would be to control the redox potential of the lower profile by manipulating the level of water saturation and adding readily oxidizable organic compounds to the resulting anaerobic zone. Another method could involve the additions of some form of sulfur to the soil to encourage the growth of T. denitrificans. Additions of organic matter into the upper soil profile would enable microbes to incorporate more fertilizer-derived N into the soil biomass. At some later time, the nitrogen could become available to the plant through the gradual mineralization of these organic compounds. Probably the best means of controlling nitrogen movement is through the use of a soil test. The farmer could determine how much available nitrogen he has in the root zone and apply only the amount necessary to produce a good crop. It is the indiscriminate use of fertilizer on easily leached soils that leads to most instances of subsurface water nitrate contamination.

Soil Ammonium-Nitrogen

Ammonium-nitrogen concentration in the soil profile in 1974 was high in the upper profile of all plots except for plots 27 and 28 (Table 4). Plots 27 and 28 were fairly low in organic matter content (Figure 3) and so contributions to ammonium concentration from organic matter decomposition would be less. Ammonium concentrations in plots 25 and 26 (1974) and in the new site of plot 26 (1976) suggest that fertilizer contamination has probably occurred in the top 10 cm of the profile. In both years, ammonium concentrations were essentially those expected throughout a soil profile where nitrification is taking place.

Although the data are sketchy, the increase in ammonium concentration at the 140-180 cm depth in plot 28 might be an instance where, in the presence of iron and at a basic pH (7.9), nitrate is being reduced to ammonium through hydroxylamine and hydrazine. Further information on iron concentration and redox potential would be necessary before this could be accurately determined.

Total Soil Carbon

Total soil carbon determinations included all organic and carbonate carbon in the soil. Results (Table 5) show that percent total carbon was high in the surface of the profile and decreased steadily with increasing depth. Though results for plots 25 and 26 are not available for 1976, analysis run on 1975 samples showed no change in percent total carbon, carbonate carbon, or organic carbon. Percent total carbon varied from 0.11 to 1.93 percent.

TABLE 4.   EXTRACTABLE SOIL AMMONIUM-NITROGEN (PPM)

1974

SITE NUMBER

DEPTH CM	25 TREATED	26 UNTREATED	27 TREATED	28 UNTREATED	30 UNTREATED	31 TREATED
0-10	39.6	41.7	9.8	9.2	13.7	15.3
10-20	16.5	13.0	8.1	8.3	10.2	10.1
20-30	6.0	10.6	9.1	3.4	8.0	7.4
30-40	5.9	8.3	7.7	6.9	7.0	7.3
40-50	5.6	6.9	6.4	6.7	6.2	9.0
50-60	5.6	7.3	4.6	5.2	7.0	3.5
60-70	7.0	9.7	4.5	5.9	7.7	7.3
70-80	6.7	6.4	8.7	5.3	7.6	6.9
80-90	7.3	7.8	6.3	4.6	8.1	5.0
90-100	6.9	8.8	5.6	7.7	4.8	6.0
100-120	4.1	9.3	3.9	3.4	4.3	3.4
120-140	4.5	2.2	3.5	3.8	7.4	2.5
140-160	1.8	3.5	5.2	10.9	6.3	4.1

1976

SITE NUMBER

DEPTH CM	25* TREATED	26* UNTREATED	27 TREATED	28 UNTREATED	30 UNTREATED	31 TREATED
0-10	6.3	322.6	3.9	4.2	6.0	4.2
10-20	3.9	7.4	1.1	5.3	5.6	6.7
20-30	5.3	4.6	4.8	2.5	3.2	4.9
30-40	3.9	3.5	2.8	1.4	4.9	4.6
40-50	4.2	5.3	1.1	0.7	2.1	3.9
50-60	4.6	3.5	0.0	0.7	2.5	4.6
60-70	2.5	3.5	1.4	0.4	3.2	5.6
70-80	3.2	3.9	0.7	2.5	3.2	2.5
80-90	4.6	3.9	0.0	0.4	2.1	3.9
90-100	3.9	7.0	0.7	0.0	2.6	2.5
100-120	4.2	4.2	1.4	0.0	2.5	2.5
120-140	3.5	4.2	1.8	3.2	4.2	4.2
140-160	3.5	3.9	0.4	2.8	4.9	4.2
160-180	0.0	3.9	0.0	6.3	4.2	3.2

* NEW SITE

TABLE 5.   TOTAL SOIL CARBON (%)

1974

SITE NUMBER

DEPTH CM	25 TREATED	26 UNTREATED	27 TREATED	28 UNTREATED	30 UNTREATED	31 TREATED
0-10	1.93	1.79	0.97	1.45	1.62	1.58
10-20	1.63	1.66	0.59	0.83	1.37	1.43
20-30	1.19	1.45	0.51	0.70	1.06	1.13
30-40	0.99	1.34	0.48	0.71	0.87	1.36
40-50	0.85	1.09	0.54	0.67	0.64	1.38
50-60	0.74	0.83	0.39	0.72	0.53	1.23
60-70	0.66	0.74	0.42	0.77	0.44	1.11
70-80	0.52	0.64	0.36	0.72	0.39	1.05
80-90	0.48	0.52	0.36	0.54	0.50	0.90
90-100	0.49	0.54	0.28	0.66	0.39	0.61
100-120	0.32	0.31	0.23	0.28	0.24	0.55
120-140	0.31	0.28	0.26	0.44	0.28	0.46
140-160	0.24	0.24	0.21	0.35	0.23	0.26

1976

SITE NUMBER

DEPTH CM	25* TREATED	26* UNTREATED	27 TREATED	28 UNTREATED	30 UNTREATED	31 TREATED
0-10	1.20	1.40	0.94	1.28	1.29	1.30
10-20	1.32	1.05	0.82	1.09	1.24	1.20
20-30	1.35	1.13	0.67	0.77	1.11	1.12
30-40	1.19	1.14	0.55	0.74	0.88	1.14
40-50	0.92	1.23	0.71	0.82	0.72	1.03
50-60	0.78	1.30	0.63	1.06	0.62	1.03
60-70	0.55	1.10	0.51	0.81	0.49	0.99
70-80	0.37	1.20	0.51	0.78	0.54	1.04
80-90	0.44	1.16	0.32	0.54	0.54	0.45
90-100	0.24	1.06	0.21	0.33	0.32	0.56
100-120	0.18	0.88	0.18	0.22	0.24	0.51
120-140	0.18	0.48	0.12	0.20	0.14	0.28
140-160	0.20	0.24	0.08	0.17	0.15	0.17
160-180	0.16	0.20	0.11	0.19	0.18	0.19

* NEW SITE

Organic Carbon

Percent organic carbon was high in the upper profile, due to the presence of organic matter, and decreased with increasing depth. There was no apparent change in percent organic carbon between the 1974 and the 1976 analyses (Figures 7, 8, and 9).

The importance of the percent organic carbon analysis is for determining if there is sufficient oxidizable carbon present to permit biological denitrification to occur. Of the three treated plots, only plot 27 had a low amount of oxidizable carbon which might have hindered denitrification.

As was mentioned earlier, the high organic matter content on plot 31 (Figure 9) seemed to be influencing nitrate content by supplying energy for the denitrification reaction. However, on plot 27, another treated plot, organic matter content (Figure 8) was much lower. This might influence the denitrification to proceed more slowly which might be one reason why there was such a large accumulation of nitrate in the upper profile in 1976. On the other hand, it could be possible that this part of the profile was not anaerobic long enough to allow substantial denitrification.

Without more extensive analysis for denitrification, it is impossible to speculate any further on the role that organic matter was playing in this reaction on these six plots. There are many outside factors influencing the reaction such as farming practices, irrigation practices, soil pH, soil redox potential, soil permeability, and amount of N taken up by a crop.

Carbonate Carbon

Carbonate carbon was low in the upper and lower portions of the soil profile (Table 6). However, in the middle of the profile of plots 27, 28, 30, and 31, a zone of carbonate accumulation was found. This zone was never higher than 0.46 percent. Percent carbonate carbon did not change throughout the period of investigation.

Water Chloride

Chloride concentration of the tile drain effluent was monitored throughout the duration of the study. The water from plot 25 decreased in chloride from June 1974 until sampling was discontinued (Table 7). The high chloride concentration is not unexpected, for chloride was extremely high in 1974 at the lower depths in the soil profile of plot 25.

Plots 27 and 28 showed a gradual increase in chloride concentration (Table 7) which probably was due to the use of the land for grazing purposes.

Plot 31 showed extremely high chloride concentration which is in drastic contrast with the neighboring plot 30. The chloride concentration in the lower profile was not particularly high (25 ppm) suggesting that the tile drain passes through a zone of salt contamination since the sodium concentration in the effluent from plot 31 was also extremely high (Table 11).

Soil Chloride

Chloride can be useful in determining water movement through a profile. Because nitrate and chloride migrate at about the same rate, an accumulation of chloride found at a certain depth in a soil profile would lead to expectation of nitrate accumulation. If nitrate is not found, then one can assume that either denitrification has occurred or

TABLE 6.   SOIL CARBONATE-CARBON (%)

1974

SITE NUMBER

DEPTH CM	25 TREATED	26 UNTREATED	27 TREATED	28 UNTREATED	30 UNTREATED	31 TREATED
0-10	0.04	0.04	0.12	0.08	0.33	0.06
10-20	0.04	0.02	0.11	0.00	0.01	0.03
20-30	0.02	0.02	0.02	0.09	0.05	0.10
30-40	0.05	0.04	0.00	0.35	0.02	0.21
40-50	0.02	0.04	0.10	0.18	0.00	0.17
50-60	0.00	0.08	0.12	0.32	0.11	0.04
60-70	0.01	0.09	0.08	0.44	0.09	0.11
70-80	0.00	0.10	0.14	0.37	0.14	0.16
80-90	0.06	0.16	0.07	0.33	0.28	0.26
90-100	0.05	0.23	0.08	0.40	0.23	0.12
100-120	0.08	0.04	0.10	0.11	0.09	0.21
120-140	0.11	0.10	0.15	0.25	0.09	0.20
140-160	0.06	0.08	0.09	0.14	0.06	0.01

1976

SITE NUMBER

DEPTH CM	25* TREATED	26* UNTREATED	27 TREATED	28 UNTREATED	30 UNTREATED	31 TREATED
0-10	0.12	0.16	0.04	0.21	0.16	0.19
10-20	0.10	0.09	0.07	0.24	0.12	0.14
20-30	0.16	0.07	0.05	0.06	0.12	0.13
30-40	0.17	0.05	0.09	0.13	0.10	0.00
40-50	0.15	0.07	0.31	0.20	0.04	0.03
50-60	0.18	0.11	0.46	0.44	0.06	0.13
60-70	0.16	0.12	0.26	0.30	0.13	0.17
70-80	0.09	0.09	0.33	0.30	0.19	0.35
80-90	0.22	0.14	0.18	0.20	0.34	0.09
90-100	0.03	0.21	0.05	0.08	0.15	0.01
100-120	0.04	0.17	0.07	0.07	0.06	0.14
120-140	0.05	0.05	0.02	0.03	0.02	0.06
140-160	0.07	0.01	0.00	0.06	0.03	0.04
160-180	0.05	0.02	0.06	0.05	0.04	0.03

* NEW SITE

TABLE 7.   CHLORIDE CONTENT OF TILE EFFLUENT
          IN THE BOSTWICK IRRIGATION DISTRICT

PPM CHLORIDE

SITE	1974						1975	
NO.	APR	JUN	JUL	AUG	SEP	OCT	JAN	MAR
25	150	237	185	150	150	120	98	98
26	---	80	65	52	65	---	---	52
27	---	80	---	---	65	80	65	65
28	---	80	---	---	65	80	98	98
29	65	65	43	43	43	65	52	52
30	52	65	43	43	65	---	---	---
31	345	345	185	280	---	---	---	---

PPM CHLORIDE

SITE	1975						1976	
NO.	JUN	JUL	AUG	OCT	NOV	MAR	MAY	JUN
1	405	407	356	368	395	422	435	419
2	189	165	174	235	266	202	227	200
3	168	104	103	---	---	---	140	93
4	110	96	87	162	173	158	97	88
5	134	116	102	168	176	164	141	128
6	141	132	125	133	144	158	155	120
7	---	89	74	87	99	105	96	86
8	156	73	64	---	---	---	145	143
*9	---	26	25	---	---	---	---	34
10	235	208	197	229	225	228	222	210
11	111	105	---	---	---	---	---	71
12	111	105	82	---	---	---	207	110
13	31	30	29	31	29	69	87	33
14	21	22	23	22	22	105	114	23
15	202	194	180	199	203	202	178	181
16	98	91	81	103	103	105	91	37
17	164	122	105	143	140	164	150	114
18	148	130	123	---	---	---	151	137
19	78	---	64	72	71	79	---	---
20	47	42	40	37	31	181	44	43
21	152	132	116	170	177	358	166	151
22	407	---	279	---	---	---	410	337
23	159	115	94	124	141	187	148	128
*24	---	30	27	---	---	---	---	37
25	---	---	---	---	---	---	145	137
26	---	---	---	---	---	---	113	116
27	86	93	84	85	85	103	94	93
28	109	108	106	115	134	123	123	115
29	109	72	69	71	78	146	72	73
30	73	53	---	---	---	---	---	---
31	57	209	---	---	---	---	---	---

* CANAL

nitrate was taken up by plant roots prior to its arrival at the zone of chloride accumulation.

In Figure 10, a dramatic increase in chloride concentration below 120 cm can be seen in plot 25 in 1974. Nitrate concentration increased slightly below 120 cm in this plot. On plot 26, the chloride zone of accumulation below 120 cm also corresponds to a zone of nitrate accumulation (Figure 1). No fertilizer was applied to plot 26 prior to the 1974 samples making the Cl^- and NO_3^- levels found the result of prior treatments which were not identified.

On plot 27 (Figure 11) in 1976, a zone of chloride accumulation occurs at 50 to 60 cm which corresponds with the zone of nitrate accumulation that year. It is evident that not all the nitrate-N was being subjected to immediate denitrification here. Chloride was high at the lower depths in plot 31 (Figure 12) but the lack of any nitrate accumulation suggests that denitrification or prior plant uptake has occurred. Of course, at the extremely high rates of N application, approximately 400 kg N/ha, it is unlikely that all N will be absorbed. At some time in the future one would expect to see some instances of nitrate moving into the lower profile as a result of a continued high rate of application.

Water Cations

Tables 8, 9, 10, and 11 present cation concentrations of all drain sites sampled in the Bostwick District, numbers 25, 26, 27, 28, 30, and 31 corresponding to the drains under the treated and untreated plots of the nitrogen application study. Magnesium and potassium concentrations in the effluent under those plots did not fluctuate significantly throughout the duration of the study. Calcium did fluctuate considerably and seemed to be related to the time of year. Readings were highest during

Fig. 10. Chloride content of soil cores from plots 25 and 26 as related to depth for 1974.

PLOT 25
(TREATED)

X--X 1974

PLOT 26
(UNTREATED)

X--X 1974
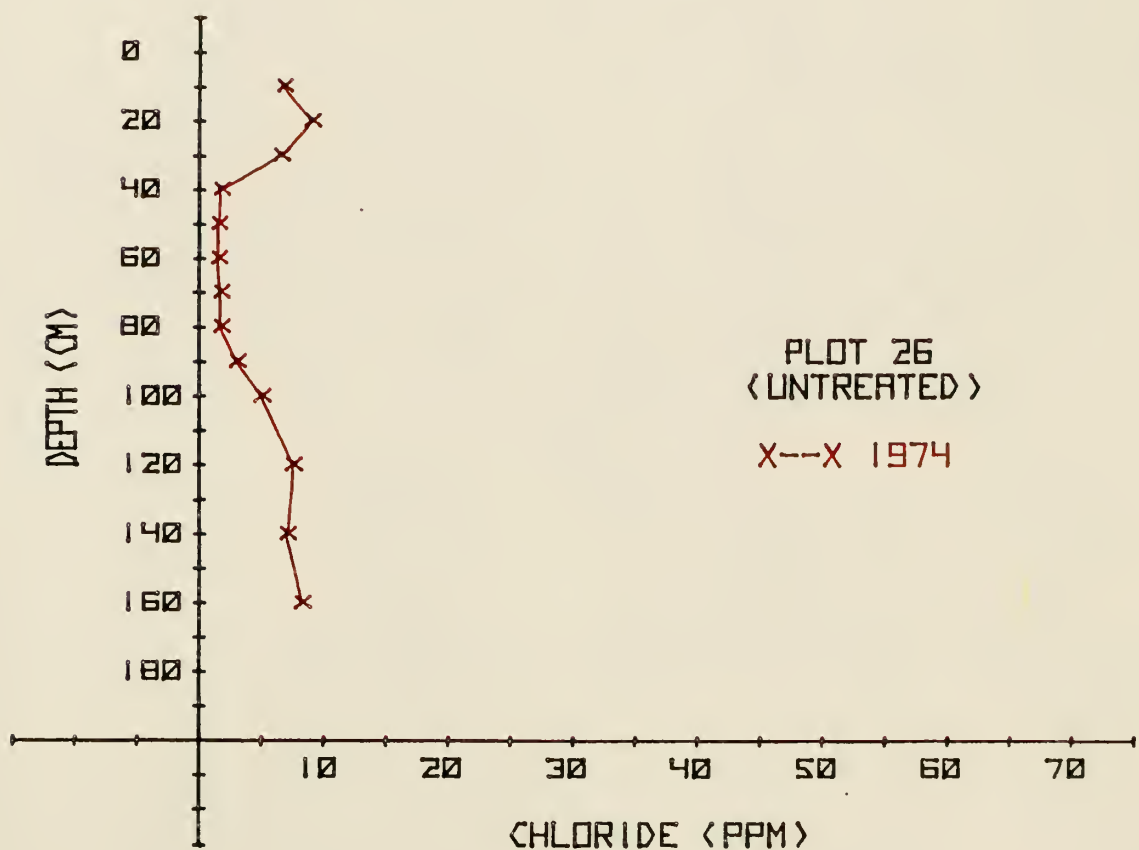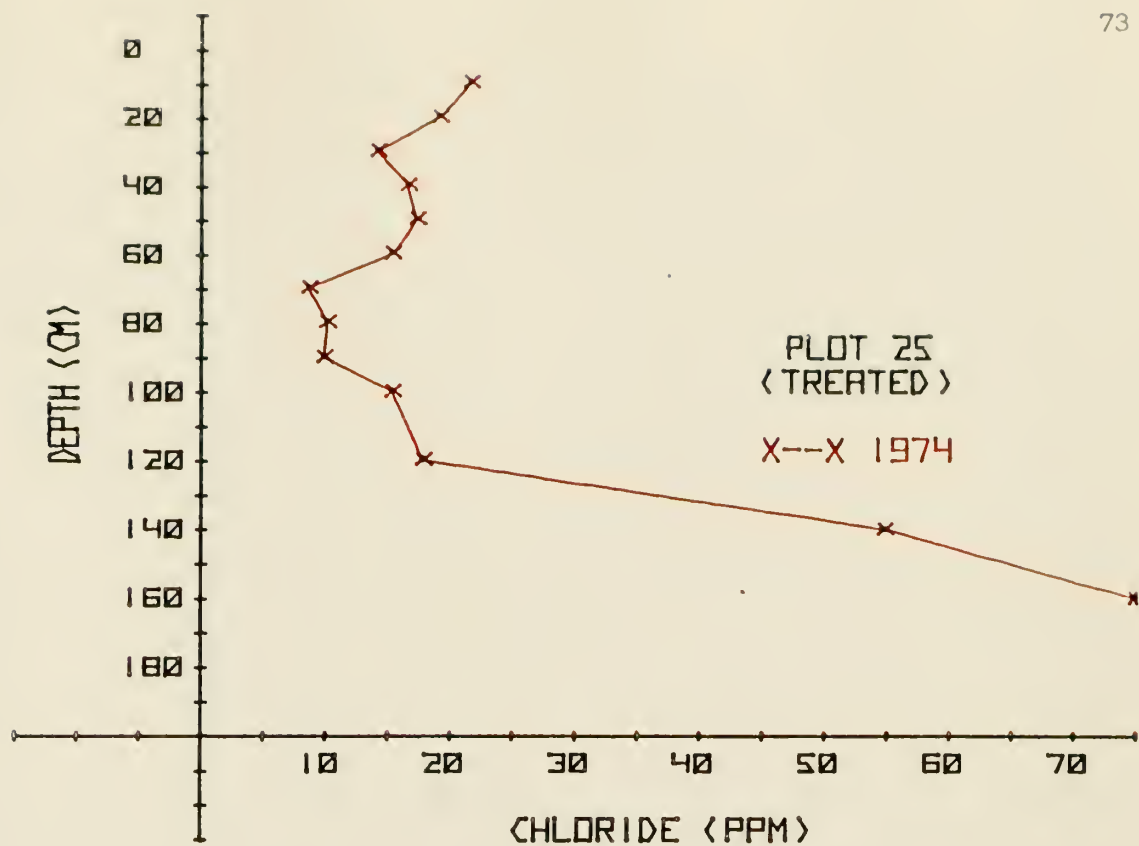
Fig. 11. Chloride content of soil cores from plots 27 and 28 as related
to depth for 1974 and 1976.
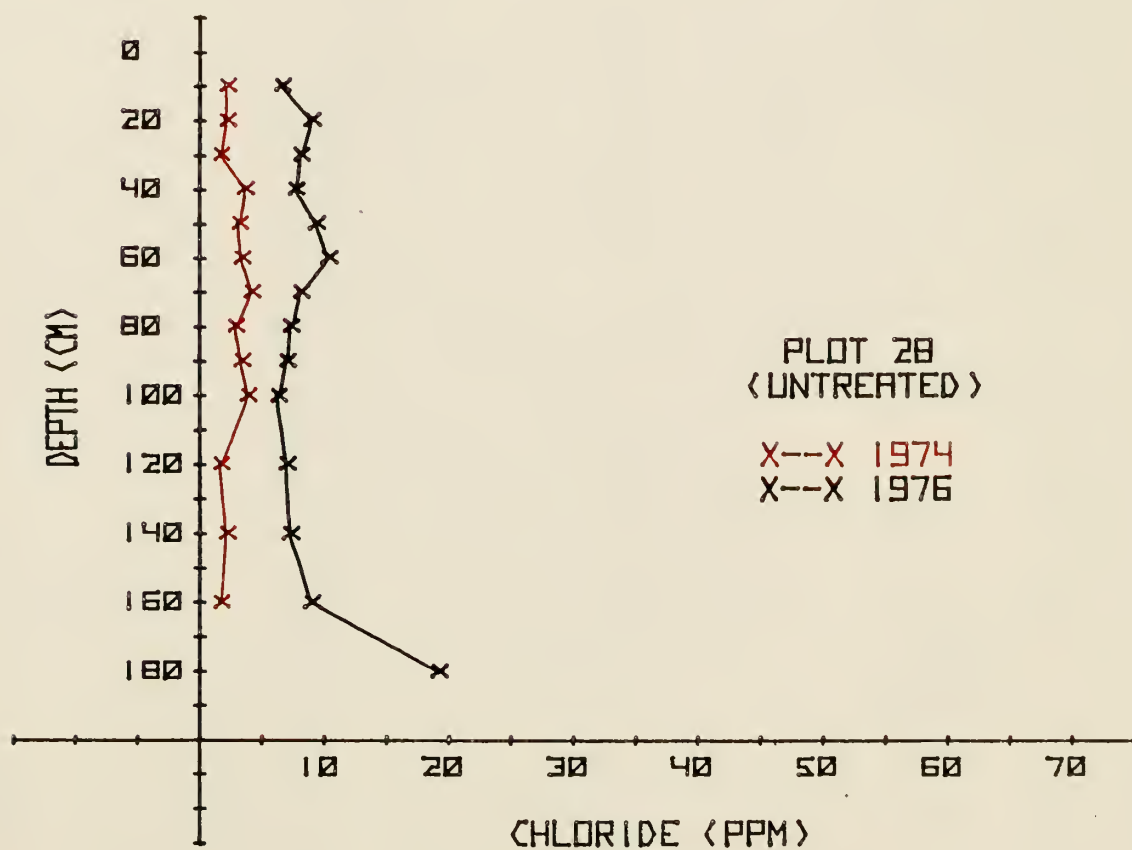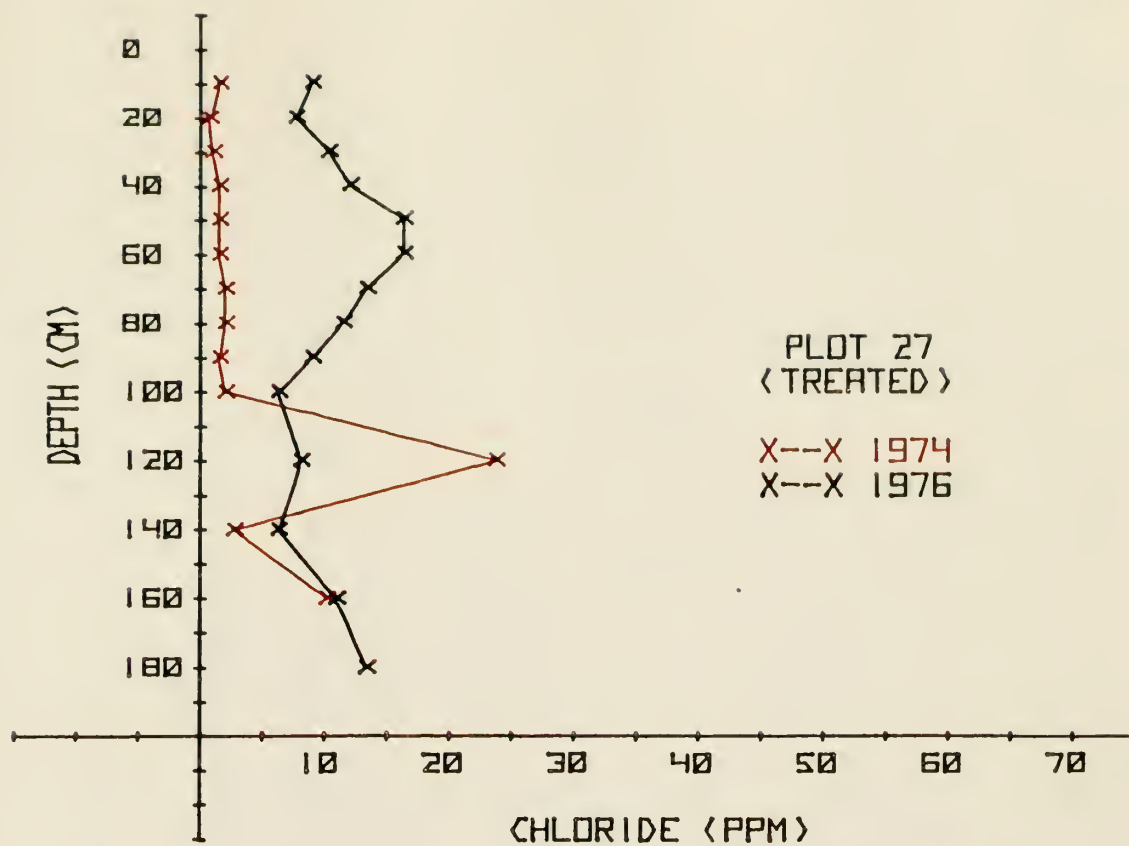
Fig. 12.   Chloride content of soil cores from plots 30 and 31 as related
to depth for 1974 and 1976.
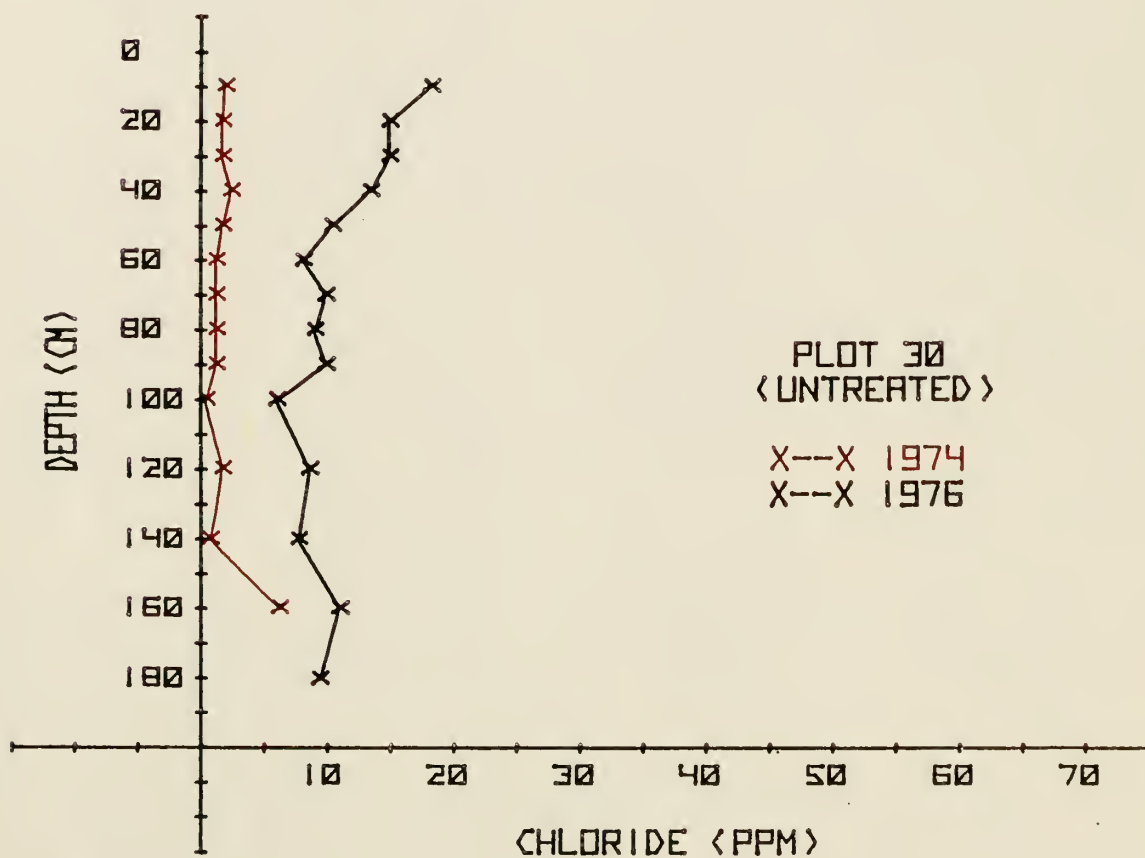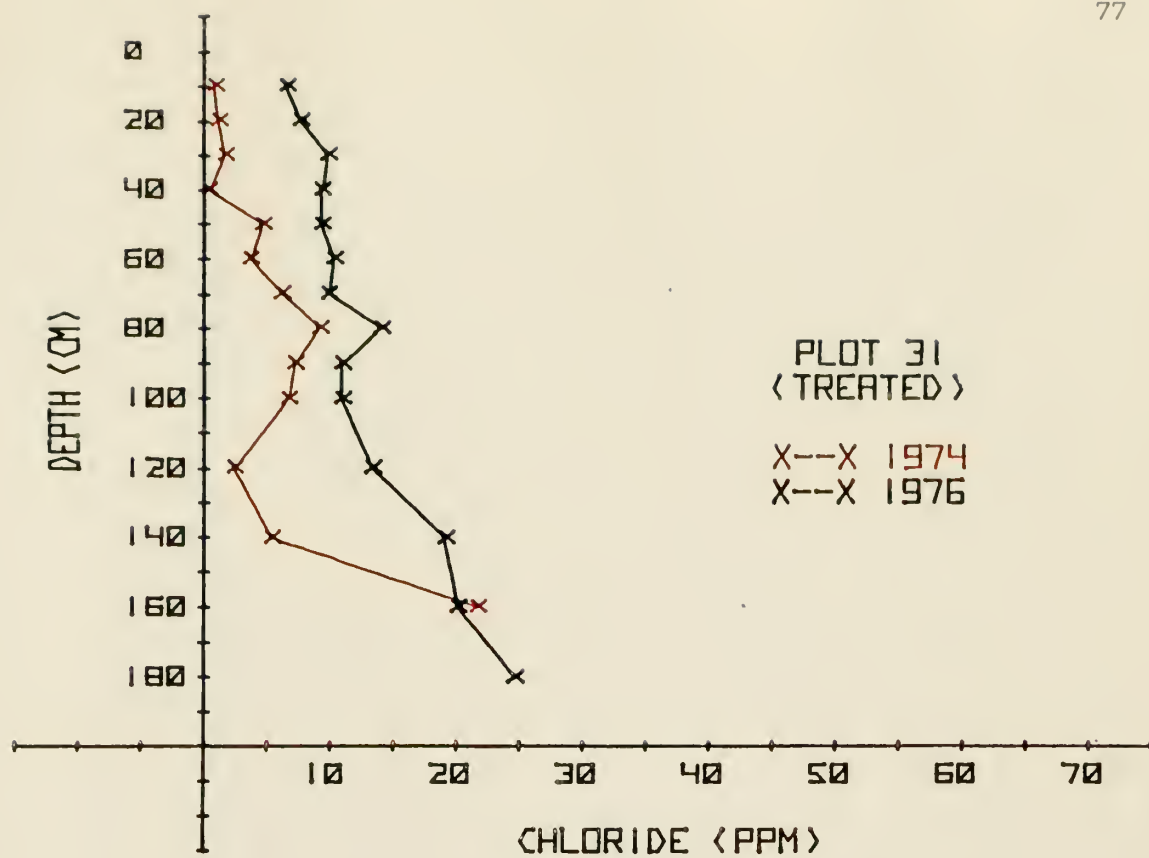
TABLE 8. CALCIUM CONTENT OF TILE EFFLUENT IN THE BOSTWICK IRRIGATION DISTRICT

PPM CALCIUM

SITE NO.	1972			1973									1974		
	AUG	SEP	OCT	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	JUN	JUL
1	587	561	557	651	598	514	600	573	525	573	666	562	646	408	420
2	306	260	297	296	245	278	230	247	270	230	226	242	330	163	152
3	---	252	244	277	221	272	220	190	208	197	178	206	---	130	105
4	362	344	392	363	333	354	294	326	339	330	378	345	417	237	230
5	---	313	348	380	330	283	268	296	340	290	268	300	388	209	223
6	---	---	296	352	238	330	354	268	303	256	237	265	318	200	204
7	---	---	---	221	194	129	78	45	63	176	186	35	121	206	269
8	---	---	---	313	254	267	233	229	277	246	214	231	---	150	198
*9	---	---	---	---	---	---	44	30	---	---	---	---	---	39	32
10	468	428	457	505	431	408	465	451	397	408	360	416	478	274	320
11	---	---	---	254	214	241	158	179	257	189	195	151	210	89	122
12	328	259	328	381	324	325	264	277	295	287	278	289	333	256	212
13	75	62	---	---	61	71	44	25	117	30	40	31	169	30	95
14	---	---	---	---	55	40	23	18	20	22	21	22	90	71	79
15	---	---	---	---	---	---	---	---	---	---	358	411	483	284	303
16	211	185	139	240	224	174	168	192	229	196	193	182	218	150	148
17	243	244	295	368	327	265	239	248	250	293	272	304	---	219	153
18	454	444	443	524	449	414	448	446	429	451	382	454	521	294	334
19	189	146	132	202	164	175	156	152	183	157	165	151	227	129	96
20	54	---	---	122	122	109	35	32	35	28	25	33	119	71	71
21	445	514	522	591	510	514	390	409	376	410	392	471	---	455	302
22	---	---	---	833	654	582	620	637	637	584	553	616	722	481	411
23	307	277	291	349	296	297	270	221	252	295	261	270	377	346	202
*24	49	53	---	---	---	---	59	41	---	---	---	---	---	52	44
25	---	---	---	---	---	---	---	---	---	---	---	---	150+	153	217
26	---	---	---	---	---	---	---	---	---	---	---	---	---	120	113
27	---	---	---	---	---	---	---	---	---	---	---	---	---	140	---
28	---	---	---	---	---	---	---	---	---	---	---	---	---	195	---
29	---	---	---	---	---	---	---	---	---	---	---	---	93+	84	129
30	---	---	---	---	---	---	---	---	---	---	---	---	68+	78	71
31	---	---	---	---	---	---	---	---	---	---	---	---	223+	332	221

* CANAL   + SAMPLED APRIL, 1974

TABLE 8. (cont.)   CALCIUM CONTENT OF TILE EFFLUENT

PPM CALCIUM

SITE NO.	1974			1975								1976		
	AUG	SEP	OCT	JAN	MAR	MAY	JUN	JUL	AUG	OCT	NOV	MAR	MAY	JUN
1	386	365	388	573	543	456	495	597	527	509	491	620	585	408
2	158	133	212	314	249	252	269	229	295	303	322	432	389	269
3	137	117	154	228	--	--	213	191	207	--	--	--	302	130
4	215	182	263	426	--	306	284	284	292	421	409	459	334	296
5	200	174	265	360	201	322	316	302	332	374	376	408	408	281
6	193	148	231	316	230	253	288	358	291	351	282	358	408	258
7	248	--	--	--	--	--	197	162#	107	176	65	180	186	104
8	169	114	--	--	--	--	215	298	343	--	--	--	309	186
*9	21	--	--	--	--	--	--	49	50	--	--	--	--	52
10	269	252	293	406	343	354	354	470	440	438	594	506	505	494
11	132	85	--	--	--	--	226	243	--	--	--	--	--	201
12	186	111	--	--	--	--	277	231	231	--	--	--	452	240
13	61	22	99	102	58	108	96	84	77	55	92	90	131	79
14	45	12	78	75	42	49	82	74	46	36	37	129	124	81
15	272	240	298	416	319	350	361	367	383	340	353	458	466	351
16	139	101	153	--	123	178	185	177	225	170	173	250	242	150
17	160	134	221	302	259	254	254	275	291	260	278	452	407	224
18	267	245	--	--	--	--	401	438	440	--	--	--	515	481
19	115	73	122	164	99	159	161	--	153	176	186	220	--	--
20	44	30	88	96	27	24	107	100	31	85	51	--	197	68
21	260	173	347	554	503	518	455	425	398	428	447	535	521	400
22	414	445	--	--	625	--	540	--	503	--	--	704	544	574
23	160	97	163	285	235	243	243	244	227	152	197	381	345	131
*24	24	27	--	--	--	--	--	56	60	--	--	--	--	--
25	167	154	175	193	168	--	--	--	--	--	--	--	294#	207
26	105	99	--	--	41	--	--	--	--	--	--	--	241#	415
27	--	145	165	211	129	186	279	225	221	177	204	252	245	185
28	--	163	179	283	416	198	236	251	208	222	230	347	350	201
29	131	91	119	176	203	148	173	203	177	139	165	240	254	279
30	84	36	--	--	--	--	233	95	--	--	--	--	--	--
31	201	--	--	--	--	--	509	373	--	--	--	--	--	--

* CANAL   # NEW DRAIN

TABLE 9.   MAGNESIUM CONTENT OF TILE EFFLUENT IN THE BOSTWICK IRRIGATION DISTRICT

PPM MAGNESIUM

SITE NO.	1972 AUG	SEP	OCT	APR	MAY	JUN	JUL	1973 AUG	SEP	OCT	NOV	DEC	JAN	1974 JUN	JUL
1	64	61	58	69	67	50	54	66	63	60	61	64	61	66	65
2	42	38	37	32	29	34	31	36	33	33	33	36	34	40	33
3	--	43	42	47	32	33	29	35	35	39	37	40	--	42	27
4	51	47	47	45	44	35	38	45	43	43	42	46	44	43	44
5	--	40	39	43	32	33	33	39	39	40	39	46	39	43	37
6	--	--	37	43	43	34	37	41	41	36	40	45	43	45	48
7	--	--	--	28	22	18	7	7	9	31	30	15	20	60	53
8	--	--	--	46	43	34	37	40	43	41	39	39	--	46	36
*9	--	--	--	--	--	--	15	15	--	--	--	--	--	19	18
10	60	58	54	64	56	43	49	55	53	53	54	57	55	55	54
11	--	--	--	30	23	24	23	32	33	31	30	29	27	26	21
12	47	41	42	47	45	35	33	41	33	45	43	45	45	42	37
13	22	18	--	--	18	19	20	20	22	21	22	21	20	20	21
14	--	--	--	--	17	19	19	20	21	22	23	21	22	20	19
15	--	--	--	--	--	--	--	--	--	--	62	65	63	66	60
16	35	29	29	34	29	28	30	35	34	34	37	35	34	34	32
17	24	32	35	39	31	30	28	33	30	37	37	41	--	33	30
18	60	44	43	56	48	35	38	45	43	45	44	47	45	33	41
19	28	27	27	27	24	23	24	28	29	29	29	29	27	25	26
20	25	--	--	22	22	26	23	21	22	23	24	22	22	25	25
21	42	42	43	47	48	35	33	39	32	39	40	46	--	53	42
22	--	--	--	79	60	46	48	58	54	54	56	59	51	53	57
23	35	36	35	38	30	29	27	33	29	37	37	40	38	38	31
*24	15	15	--	--	--	--	14	13	--	--	--	--	--	17	17
25	--	--	--	--	--	--	--	--	--	--	--	--	43+	42	42
26	--	--	--	--	--	--	--	--	--	--	--	--	--	19	18
27	--	--	--	--	--	--	--	--	--	--	--	--	--	34	--
28	--	--	--	--	--	--	--	--	--	--	--	--	--	48	--
29	--	--	--	--	--	--	--	--	--	--	--	--	31+	30	32
30	--	--	--	--	--	--	--	--	--	--	--	--	27+	26	18
31	--	--	--	--	--	--	--	--	--	--	--	--	74+	74	47

* CANAL   + SAMPLED APRIL, 1974

TABLE 9. (cont.)   MAGNESIUM CONTENT OF TILE EFFLUENT

PPM MAGNESIUM

SITE NO.	1974 AUG	SEP	OCT	1975 JAN	MAR	MAY	JUN	JUL	AUG	OCT	NOV	1976 MAR	MAY	JUN
1	65	49	47	61	81	67	54	68	67	67	71	67	65	67
2	32	23	36	37	43	42	38	30	33	40	42	38	38	38
3	32	26	26	47	--	--	49	25	28	--	56	--	48	25
4	41	30	34	51	--	46	41	38	39	54	48	47	35	38
5	35	27	30	40	45	45	44	36	36	49	45	43	45	45
6	38	28	34	43	46	47	46	46	47	46	45	45	43	45
7	62	--	--	--	--	--	63	25#	24	24	22	44	24	25
8	37	25	--	--	--	--	51	36	42	--	--	--	49	50
*9	17	--	--	--	--	--	--	16	17	--	--	--	--	17
10	54	42	42	53	57	57	56	56	60	62	61	57	57	58
11	28	20	--	--	--	--	34	28	--	--	--	--	--	28
12	36	19	--	--	--	--	44	34	21	--	--	--	45	35
13	22	16	16	19	21	22	20	21	21	21	21	22	21	22
14	21	15	17	19	20	21	21	22	22	21	21	22	21	21
15	53	45	43	56	63	64	58	62	62	61	61	59	61	61
16	32	23	26	--	31	32	33	33	31	39	38	35	33	34
17	30	21	24	31	36	33	33	32	29	30	33	40	37	32
18	42	31	--	--	--	--	48	47	44	--	--	--	49	49
19	26	20	22	27	29	29	29	--	27	30	29	28	--	--
20	24	17	20	26	28	28	27	29	25	26	27	--	48	30
21	34	21	34	51	54	57	49	45	41	57	59	55	57	49
22	53	48	--	--	68	--	55	--	51	--	--	68	58	66
23	28	18	20	34	36	39	34	31	24	27	31	37	36	35
*24	13	14	--	--	--	--	--	16	18	--	--	--	--	16
25	36	26	21	23	24	--	--	--	--	--	--	--	31#	25
26	15	12	--	--	14	--	--	--	--	--	--	--	22#	32
27	--	27	27	25	33	34	36	33	31	40	42	33	34	34
28	--	47	37	47	52	43	46	46	49	52	53	52	54	37
29	30	23	23	30	33	30	30	31	31	30	29	30	32	37
30	17	13	--	--	--	--	26	24	--	--	--	--	--	--
31	85	--	--	--	--	--	70	48	--	--	--	--	--	--

* CANAL   # NEW DRAIN

TABLE 10.   POTASSIUM CONTENT OF TILE EFFLUENT IN THE BOSTWICK IRRIGATION DISTRICT

PPM POTASSIUM

SITE NO.	1972 AUG	SEP	OCT	1973 APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	1974 JAN	JUN	JUL
1	14	11	11	15	14	13	13	13	16	15	14	12	16	17	17
2	13	10	10	13	12	11	11	11	12	13	11	10	14	15	14
3	--	6	6	8	8	7	7	6	8	7	6	6	--	9	10
4	14	11	11	14	13	12	12	12	14	13	12	11	14	15	15
5	--	12	12	16	15	13	14	13	14	15	13	12	17	18	17
6	--	--	8	10	9	7	8	9	9	10	9	7	10	11	12
7	--	--	--	14	13	11	7	6	6	14	13	8	12	14	14
8	--	--	--	16	13	12	12	13	16	16	13	11	--	8	17
*9	--	--	--	--	--	--	--	14	--	--	--	--	--	16	20
10	16	14	13	17	16	15	15	16	17	16	15	14	18	19	19
11	--	--	--	16	14	13	13	13	15	15	14	13	17	17	16
12	14	12	12	16	14	13	12	13	15	15	14	13	19	17	16
13	18	16	--	--	17	15	16	16	17	16	14	13	17	19	19
14	--	--	--	18	18	18	18	19	23	19	17	16	21	22	23
15	--	--	--	--	--	--	--	--	--	--	2	2	4	4	5
16	18	16	16	20	19	16	19	20	21	21	19	16	22	22	22
17	13	11	11	14	13	12	13	13	13	15	12	11	--	15	15
18	13	12	11	13	12	13	13	11	13	14	11	11	13	14	15
19	9	8	8	11	10	9	10	9	11	11	9	9	11	13	12
20	22	--	--	21	21	29	23	21	21	21	18	18	21	21	26
21	11	10	9	13	13	12	12	12	13	14	11	11	--	15	14
22	--	--	--	17	16	15	15	15	17	18	15	15	18	18	17
23	12	10	10	12	12	10	10	10	11	13	11	11	13	13	13
*24	15	14	--	--	--	--	--	12	--	--	--	--	--	12	14
25	--	--	--	--	--	--	--	--	--	--	--	--	16+	15	17
26	--	--	--	--	--	--	--	--	--	--	--	--	--	12	12
27	--	--	--	--	--	--	--	--	--	--	--	--	--	26	--
28	--	--	--	--	--	--	--	--	--	--	--	--	--	24	--
29	--	--	--	--	--	--	--	--	--	--	--	--	9+	9	10
30	--	--	--	--	--	--	--	--	--	--	--	--	15+	16	15
31	--	--	--	--	--	--	--	--	--	--	--	--	23+	27	25

* CANAL   + SAMPLED APRIL, 1974

TABLE 10. (cont.)   POTASSIUM CONTENT OF TILE EFFLUENT

PPM POTASSIUM

SITE NO.	1974 AUG	SEP	OCT	1975 JAN	MAR	MAY	JUN	JUL	AUG	OCT	NOV	1976 MAR	MAY	JUN
1	16	14	14	13	11	10	12	16	15	13	15	11	11	17
2	13	11	11	11	10	9	14	12	12	12	13	9	9	14
3	8	14	7	4	--	--	4	8	8	--	--	--	2	9
4	14	13	12	13	--	9	11	12	12	13	14	9	7	13
5	15	14	14	13	11	10	14	14	13	16	15	10	12	17
6	10	8	8	8	7	6	9	9	9	9	9	7	7	11
7	11	--	--	--	--	--	9	13#	14	11	12	10	10	14
8	15	6	--	--	--	--	6	14	14	--	--	--	4	8
9	18	--	--	--	--	--	--	17	16	--	--	--	--	18
10	18	16	15	14	13	13	14	16	16	16	16	13	13	19
11	15	14	--	--	--	--	14	13	15	--	19	15	13	15
12	14	12	--	--	--	--	14	13	12	--	--	--	16	16
13	16	16	16	15	14	13	15	15	15	17	16	13	13	17
14	21	21	19	18	16	15	18	20	19	20	19	15	16	20
15	3	3	2	3	3	3	3	5	4	5	4	2	2	5
16	21	19	19	17	16	15	16	17	17	20	19	16	16	20
17	14	12	11	10	9	9	12	13	13	12	12	9	9	15
18	14	12	--	--	--	--	11	12	12	--	--	--	9	16
19	11	10	9	9	8	8	9	--	10	12	12	8	--	--
20	23	22	22	21	20	20	16	21	20	23	23	9	20	23
21	12	10	10	11	9	9	13	13	12	13	13	7	11	16
22	16	9	--	--	7	--	15	--	14	--	--	9	13	13
23	11	9	10	10	9	9	11	10	10	13	12	--	9	13
*24	17	15	--	--	--	--	--	15	14	--	--	--	10#	16
25	13	12	11	9	8	--	--	15	--	--	--	--	8#	15
26	10	10	--	--	8	--	--	--	--	--	--	--	--	13
27	--	22	21	18	17	18	20	20	19	22	22	17	18	22
28	--	20	17	18	18	7	20	20	19	21	21	17	18	23
29	7	8	19	8	7	7	9	10	9	9	9	6	7	11
30	12	17	--	--	--	--	12	14	--	--	--	--	--	--
31	22	--	--	--	--	--	11	18	--	--	--	--	--	--

* CANAL   # MN DRAIN

TABLE 11.   SODIUM CONTENT OF TILE EFFLUENT IN THE BOSTWICK IRRIGATION DISTRICT

PPM SODIUM

SITE NO.	1972 AUG	SEP	OCT	1973 APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	1974 JAN	JUN	JUL
1	370	352	344	381	352	381	433	319	415	425	415	478	346	328	313
2	337	337	337	337	337	344	389	274	361	381	381	434	290	290	273
3	---	292	292	292	274	292	338	249	292	337	352	389	---	257	209
4	221	249	257	249	249	265	319	221	274	300	352	352	226	209	209
5	---	300	300	319	300	328	337	265	319	361	406	296	273	257	241
6	---	319	319	344	319	361	396	300	389	361	434	434	313	313	290
7	---	---	---	283	283	309	213	136	187	352	381	309	218	426	455
8	---	---	---	319	300	319	433	265	328	344	396	389	---	257	265
*9	---	---	---	---	---	---	154	73	---	---	---	---	---	58	58
10	352	337	344	372	352	389	415	242	389	389	450	450	328	320	306
11	---	---	---	352	309	352	372	292	425	396	434	415	278	265	265
12	337	319	337	337	328	372	389	265	361	389	434	434	298	290	273
13	37	32	---	---	48	47	46	46	59	55	58	57	50	74	66
14	---	---	---	42	42	43	43	41	53	49	55	51	40	58	58
15	---	---	---	---	---	---	---	---	---	---	469	478	312	354	346
16	220	159	179	184	193	208	237	159	212	203	261	256	159	186	170
17	370	283	292	305	309	174	297	221	285	304	378	364	---	265	241
18	250	292	265	300	283	213	344	257	329	352	396	389	329	249	249
19	210	164	164	169	164	309	216	125	203	203	450	241	273	154	140
20	48	---	---	42	44	39	46	43	59	57	59	61	80	95	74
21	330	283	274	319	300	337	361	249	328	352	396	396	---	281	242
22	---	---	---	425	389	433	459	352	440	450	500	406	360	369	346
23	210	292	283	292	300	252	361	309	309	344	406	406	258	273	249
*24	33	29	---	---	---	---	145	49	---	---	---	---	---	58	58
25	---	---	---	---	---	---	---	---	---	---	---	---	293+	293	278
26	---	---	---	---	---	---	---	---	---	---	---	---	---	168	165
27	---	---	---	---	---	---	---	---	---	---	---	---	---	135	---
28	---	---	---	---	---	---	---	---	---	---	---	---	---	146	---
29	---	---	---	---	---	---	---	---	---	---	---	---	157+	146	146
30	---	---	---	---	---	---	---	---	---	---	---	---	227+	223	110
31	---	---	---	---	---	---	---	---	---	---	---	---	454+	454	238

* CANAL   + SAMPLED APRIL, 1974

TABLE 11. (cont.) SODIUM CONTENT OF TILE EFFLUENT

PPM SODIUM

SITE NO.	1974 AUG	SEP	OCT	1975 JAN	MAR	MAY	JUN	JUL	AUG	OCT	NOV	1976 MAR	MAY	JUN
1	308	328	309	302	298	279	268	306	310	301	306	306	306	307
2	273	267	267	270	270	219	310	259	249	277	277	259	268	233
3	213	248	225	228	--	--	249	183	202	--	--	--	216	135
4	193	206	211	233	--	167	197	188	188	230	268	235	197	146
5	223	243	225	228	228	242	249	216	235	245	249	216	212	181
6	268	295	300	256	302	302	315	292	292	301	306	277	315	265
7	436	--	--	--	--	--	560	141#	136	141	136	146	136	122
8	233	229	--	--	--	--	245	235	235	--	--	--	235	211
*9	35	--	--	--	--	--	--	42	42	--	--	--	--	48
10	288	309	304	265	302	312	310	292	310	315	310	296	306	290
11	273	286	--	--	--	--	310	259	--	--	--	--	--	219
12	263	275	--	--	--	--	273	240	197	--	--	--	273	235
13	45	56	70	42	51	74	70	37	56	70	70	70	65	63
14	40	56	47	33	47	47	47	51	47	56	47	37	47	51
15	308	332	328	288	321	321	329	329	329	329	353	320	315	321
16	154	169	169	158	153	167	160	160	146	193	169	169	169	121
17	233	225	234	205	233	223	240	226	226	226	226	226	249	224
18	218	231	--	--	--	--	245	235	235	--	--	--	249	206
19	124	164	145	126	130	158	155	--	155	169	160	150	--	--
20	50	61	42	37	37	42	65	61	61	47	47	--	51	63
21	203	215	234	246	172	233	263	202	216	232	287	268	268	251
22	327	276	--	--	242	--	367	--	230	--	--	254	358	261
23	228	220	220	219	270	260	249	226	207	230	235	254	240	191
*24	45	47	--	--	--	--	--	28	41	--	--	--	--	48
25	308	295	253	237	181	--	--	--	--	--	--	--	287#	287
26	179	178	--	--	126	--	--	--	--	--	--	--	226#	208
27	--	155	155	84	98	139	160	136	136	164	164	141	146	123
28	--	159	122	79	93	177	169	163	160	164	164	160	164	137
29	169	173	112	74	157	172	174	164	179	174	169	179	160	141
30	184	203	--	--	--	--	230	150	--	--	--	--	--	--
31	427	--	--	--	--	--	400	268	--	--	--	--	--	--

* CANAL # NEW DRAIN

the irrigation season, which could mean that water moving through the profile was flushing out free calcium that accumulated over the winter months. Another possibility is that nitrification within the soil profile had lowered the water pH resulting in increased dissolution of calcium carbonate. Another consideration is the calcium in the irrigation water. Though the concentration is very low, frequent irrigation with this water could be adding enough calcium to the profiles so that calcium concentrations in drainage water would increase.

Sodium concentrations were relatively constant though some fluctuations did occur. Concentrations were highest under plots 25 and 31, possibly reflecting salt accumulation in the profile of the soils through which the drains pass.

Extractable Soil Cations

Extractable soil cation concentrations were determined in a study of the plot soil profile to see if any change in cation concentration within the profiles occurred during the period of study (Tables 12, 13, 14, 15).

As was expected, calcium concentrations were high when a calcium carbonate layer was encountered in several profiles. This was particularly evident in plots 27 and 28. Magnesium concentrations generally increased with depth in all profiles. Potassium concentrations were fairly constant throughout any given profile although concentrations were highest in the upper 10 cm, probably due to fertilization practices of the cooperators and plant accumulations of K. Sodium was by far the most variable of the cations. Where near-saturated conditions existed, and these were always just above the tile drains, sodium concentrations were highest (Table 15). This was true on almost all the plots at one

TABLE 12.   EXTRACTABLE SOIL CALCIUM (PPM)

1974

SITE NUMBER

DEPTH CM	25 TREATED	26 UNTREATED	27 TREATED	28 UNTREATED	30 UNTREATED	31 TREATED
0-10	2143	1504	3526	3110	1946	1561
10-20	2143	1663	3650	3913	2184	1561
20-30	3014	2016	4258	3401	3249	1704
30-40	3263	2746	4754	6858	3763	1971
40-50	3332	2343	7782	8088	3671	1914
50-60	2890	2951	8039	13550	5268	1914
60-70	3263	3805	11563	27266	5194	2438
70-80	3401	4124	9195	20988	4332	4614
80-90	3401	3539	6828	21251	5011	6209
90-100	3844	3862	6993	13923	5359	5377
100-120	2959	3543	4166	3719	4253	5491
120-140	3581	3384	2680	4687	3671	5765
140-160	3968	3167	3175	4355	4093	4181

1975

SITE NUMBER

DEPTH CM	25 TREATED	26 UNTREATED	27 TREATED	28 UNTREATED	30 UNTREATED	31 TREATED
0-10	2431	1745	3700	4609	2109	2019
10-20	1909	1818	3700	2249	2704	2610
20-30	2610	3227	4850	4632	3672	2999
30-40	3434	2292	4996	3987	4256	3075
40-50	3809	3356	4623	5131	4170	4320
50-60	4100	3713	4895	4926	4270	3278
60-70	3645	3946	5603	5338	4036	3836
70-80	4473	3633	4553	5486	4637	3959
80-90	4244	4444	4313	5934	4342	3446
90-100	4592	4395	2198	4170	3903	3251
100-120	3713	4256	3987	4608	3932	3342
120-140	4117	4016	4342	4328	3512	3768
140-160	3565	3606	3512	4142	4213	3446
160-180	3200	3434	3266	3225	3768	3124

1976

SITE NUMBER

DEPTH CM	25* TREATED	26* UNTREATED	27 TREATED	28 UNTREATED	30 UNTREATED	31 TREATED
0-10	2925	2645	4488	3987	2494	2678
10-20	2631	3681	4488	3898	2713	2632
20-30	2827	3736	4138	4809	3527	3502
30-40	3903	2950	5737	5159	5573	3055
40-50	5355	2212	8397	9286	5380	2947
50-60	4518	2396	8327	8557	5113	3738
60-70	4758	3175	7488	8627	6252	4700
70-80	4713	2716	8259	8745	6252	5159
80-90	4973	3918	6341	5788	6025	4488
90-100	4401	4929	4780	5237	5821	4531
100-120	3890	4900	4488	4720	5606	6165
120-140	3862	4546	4041	4720	4825	5821
140-160	3877	5411	4001	3987	4403	5380
160-180	3850	4647	4900	4262	5190	5720

* NEW SITE

TABLE 13.   EXTRACTABLE SOIL MAGNESIUM (PPM)

1974

SITE NUMBER

DEPTH CM	25 TREATED	26 UNTREATED	27 TREATED	28 UNTREATED	30 UNTREATED	31 TREATED
0-10	338	382	370	407	344	350
10-20	409	389	380	478	209	337
20-30	611	491	353	527	594	340
30-40	764	630	492	531	731	390
40-50	904	753	493	481	666	413
50-60	780	803	564	446	505	518
60-70	787	761	590	326	610	678
70-80	739	710	521	341	599	823
80-90	658	677	572	391	600	734
90-100	622	604	580	391	501	705
100-120	548	586	533	455	565	639
120-140	483	503	560	446	520	295
140-160	485	522	503	455	472	518

1975

SITE NUMBER

DEPTH CM	25 TREATED	26 UNTREATED	27 TREATED	28 UNTREATED	30 UNTREATED	31 TREATED
0-10	307	361	503	437	447	337
10-20	395	402	528	437	676	433
20-30	562	580	745	516	544	443
30-40	620	542	585	625	585	484
40-50	645	680	592	683	644	509
50-60	619	720	465	543	594	530
60-70	560	595	363	471	584	462
70-80	580	625	453	471	541	461
80-90	440	625	450	642	541	475
90-100	541	625	435	532	556	445
100-120	457	493	458	523	513	445
120-140	566	493	458	593	488	429
140-160	471	526	448	502	452	423
160-180	535	520	445	447	391	405

1976

SITE NUMBER

DEPTH CM	25* TREATED	26* UNTREATED	27 TREATED	28 UNTREATED	30 UNTREATED	31 TREATED
0-10	417	380	541	484	384	448
10-20	431	363	603	476	374	448
20-30	459	405	673	703	503	610
30-40	596	346	953	611	825	523
40-50	693	340	730	983	821	504
50-60	628	374	669	710	750	692
60-70	592	469	746	689	930	714
70-80	547	478	714	756	742	735
80-90	509	478	746	722	708	705
90-100	530	674	743	688	708	823
100-120	523	703	743	671	660	942
120-140	484	627	686	641	642	720
140-160	461	722	606	678	620	635
160-180	417	783	853	574	534	610

* NEW SITE

TABLE 14. EXTRACTABLE SOIL POTASSIUM (PPM)

1974

SITE NUMBER

DEPTH CM	25 TREATED	26 UNTREATED	27 TREATED	28 UNTREATED	30 UNTREATED	31 TREATED
0-10	428	516	415	516	453	478
10-20	377	302	239	402	390	465
20-30	415	415	365	390	377	390
30-40	352	453	390	377	365	390
40-50	390	327	327	352	352	377
50-60	252	327	327	327	340	365
60-70	365	390	314	252	302	440
70-80	327	340	402	201	302	490
80-90	327	264	352	239	302	465
90-100	340	289	340	277	289	465
100-120	226	289	390	277	352	415
120-140	264	314	214	277	327	352
140-160	264	340	377	277	302	327

1975

SITE NUMBER

DEPTH CM	25 TREATED	26 UNTREATED	27 TREATED	28 UNTREATED	30 UNTREATED	31 TREATED
0-10	643	710	475	583	500	558
10-20	583	480	445	435	420	510
20-30	643	495	445	435	460	460
30-40	835	485	430	460	480	430
40-50	885	490	420	450	450	465
50-60	855	480	400	420	415	460
60-70	710	455	385	345	385	455
70-80	678	440	435	310	390	485
80-90	495	390	445	340	330	535
90-100	405	375	455	395	390	510
100-120	405	350	445	380	405	523
120-140	270	345	435	405	405	523
140-160	350	345	430	335	415	535
160-180	390	355	415	365	395	500

1976

SITE NUMBER

DEPTH CM	25* TREATED	26* UNTREATED	27 TREATED	28 UNTREATED	30 UNTREATED	31 TREATED
0-10	445	569	460	618	495	435
10-20	390	335	390	400	335	395
20-30	410	300	365	395	295	335
30-40	410	250	385	380	350	350
40-50	350	260	335	365	375	345
50-60	360	295	335	380	385	400
60-70	315	315	335	360	345	460
70-80	325	335	350	390	325	445
80-90	340	320	380	395	345	450
90-100	325	340	390	390	340	475
100-120	300	355	425	415	330	485
120-140	335	360	420	410	370	405
140-160	345	340	425	395	380	405
160-180	340	375	385	380	360	330

* NEW SITE

TABLE 15. EXTRACTABLE SOIL SODIUM (PPM)

1974

SITE NUMBER

DEPTH CM	25 TREATED	26 UNTREATED	27 TREATED	28 UNTREATED	30 UNTREATED	31 TREATED
0-10	47	47	47	47	35	35
10-20	70	117	35	59	129	35
20-30	129	70	82	70	117	82
30-40	164	35	105	94	70	105
40-50	59	117	222	94	82	59
50-60	234	176	199	222	117	59
60-70	421	246	187	82	152	82
70-80	421	246	257	70	129	82
80-90	468	269	234	82	152	117
90-100	480	293	211	117	140	140
100-120	445	304	293	94	35	129
120-140	491	222	152	94	187	164
140-160	468	503	304	94	246	140

1975

SITE NUMBER

DEPTH CM	25 TREATED	26 UNTREATED	27 TREATED	28 UNTREATED	30 UNTREATED	31 TREATED
0-10	105	110	105	100	105	115
10-20	100	90	120	110	150	95
20-30	90	30	190	115	195	100
30-40	120	120	225	160	215	105
40-50	130	150	295	210	215	115
50-60	135	155	310	225	220	130
60-70	145	165	300	225	245	125
70-80	135	185	355	195	265	110
80-90	145	195	345	220	300	200
90-100	150	190	325	235	330	165
100-120	155	195	315	245	350	185
120-140	265	240	310	260	440	225
140-160	165	315	295	265	465	260
160-180	375	375	280	250	425	295

1976

SITE NUMBER

DEPTH CM	25* TREATED	26* UNTREATED	27 TREATED	28 UNTREATED	30 UNTREATED	31 TREATED
0-10	65	50	50	60	45	55
10-20	75	50	100	65	50	50
20-30	85	55	140	90	60	55
30-40	115	65	210	115	80	50
40-50	145	70	235	145	90	45
50-60	155	80	295	170	75	55
60-70	160	85	340	200	80	75
70-80	170	100	310	205	80	95
80-90	155	105	320	220	105	95
90-100	160	120	215	195	115	120
100-120	225	135	385	210	140	150
120-140	230	125	330	195	250	135
140-160	300	155	300	185	325	200
160-180	360	190	275	220	345	185

* NEW SITE

time or another. This sodium accumulation indicates that extensive leaching has occurred or is occurring on these soils. A sodium accumulation could also indicate the limit of water penetration.

With the exception of sodium, there was no appreciable change in cation concentrations within the soil profiles throughout the duration of the study. Of the cations, sodium is preferentially leached so its fluctuations within the profile came as no surprise.

Water Phosphorus

Phosphorus was determined in water samples taken from April 1974 through May 1975 (Table 16). Phosphorus concentrations were found to be extremely low, ranging from 0 to 0.25 ppm, and measurements were discontinued.

Electrical Conductivity

Electrical conductivity (EC) is useful in determining water quality, a high EC indicating a large amount of dissolved solids in the water. Plot 31, having high Na and Ca concentrations, exhibited the highest EC of the six effluents (Table 17).

Cation Exchange Capacity

Cation exchange capacity (CEC) was determined to give a better understanding of the chemical characteristics of the plot soil profiles. Because most of the profiles were fairly high in clay content, high CECs were expected.

Table 18 shows CEC for the six profiles. On profiles 25, 26, and 30 the CEC was above 30 meq/100 g soil, which is quite high. Highest CEC values at depths of 20 to 80 cm would indicate a zone of clay accumulation. Plots 25 and 26 have been irrigated for many years, while plots 30 and 31 are relatively new to irrigation. Possibly the

TABLE 16.   PHOSPHORUS CONTENT OF TILE EFFLUENT
            IN THE BOSTWICK IRRIGATION DISTRICT

PPM PHOSPHORUS

SITE NO.	1974						1975		
	APR	JUN	JUL	AUG	SEP	OCT	JAN	MAR	MAY
25	0	0.01	0	0	0	0	0	0.14	---
26	---	0.03	0.01	0	0.06	---	---	0.04	---
27	---	0	---	---	0	0.14	0.04	0.03	0.11
28	0	0	---	---	0	0	0	0.06	0.01
30	0.02	0.03	0.23	0.07	0	---	---	---	---
31	0.04	0.09	0.25	0.02	---	---	---	---	---

TABLE 17. ELECTRICAL CONDUCTIVITY OF TILE EFFLUENT IN THE BOSTWICK IRRIGATION DISTRICT

MILLIMHOS

SITE NO.	1972			1973									1974		
	AUG	SEP	OCT	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	JUN	JUL
1	4.00	4.00	3.60	3.97	4.01	3.86	3.82	3.89	3.89	3.86	3.75	3.75	3.68	3.71	3.82
2	2.91	3.04	2.51	2.92	2.72	2.34	2.61	2.70	2.65	2.63	2.55	2.65	2.36	2.48	2.26
3	---	2.51	2.42	2.36	3.36	2.34	2.01	2.17	2.16	2.30	2.18	2.23	---	2.15	1.67
4	2.63	2.70	2.51	2.51	2.55	2.55	2.48	2.51	2.50	2.51	2.45	2.42	2.34	2.32	2.26
5	---	2.84	2.55	2.76	2.84	2.68	2.51	2.51	2.65	2.70	2.58	2.58	2.36	2.44	2.31
6	---	---	2.63	2.84	2.96	2.92	2.80	2.53	2.88	2.68	2.80	2.82	2.61	2.76	2.61
7	---	---	---	2.14	2.14	1.87	0.78	0.87	0.87	2.36	2.24	1.28	2.68	3.71	3.82
8	---	---	---	2.28	2.61	2.55	2.22	2.55	2.53	2.55	2.26	2.45	---	2.05	2.36
*9	---	---	---	---	---	---	0.53	0.56	---	---	---	---	---	0.57	0.55
10	3.72	3.44	3.30	3.42	3.42	2.55	3.37	3.63	3.34	3.34	3.37	3.37	3.15	3.20	3.31
11	---	---	---	2.48	2.42	2.39	2.28	2.61	2.65	2.56	2.39	2.27	1.95	1.77	1.76
12	3.00	2.82	2.95	3.10	3.10	3.01	2.72	2.96	2.61	3.01	2.96	2.96	2.68	2.51	2.56
13	0.53	0.58	---	---	0.95	0.91	0.92	0.96	0.95	0.96	0.92	0.92	0.66	0.60	0.86
14	---	---	---	---	0.86	0.86	0.86	0.94	0.92	0.93	0.76	0.83	0.54	0.53	0.86
15	---	---	---	---	---	---	---	---	---	---	3.28	3.37	3.15	3.18	3.20
16	1.91	1.76	1.76	1.99	2.01	1.91	1.99	2.04	1.94	1.94	1.94	1.88	1.63	1.84	1.71
17	2.61	2.52	2.62	2.84	2.92	2.92	2.51	2.53	2.35	2.70	2.70	2.76	---	2.48	2.07
18	3.00	2.99	2.88	3.01	2.84	2.72	2.83	3.06	2.94	2.94	2.88	2.90	2.84	2.76	2.79
19	1.65	1.65	1.64	1.74	1.76	1.68	1.74	1.81	1.79	1.79	1.84	1.68	1.37	1.53	1.28
20	0.92	---	---	0.88	0.81	0.88	0.90	0.92	0.93	0.96	0.86	0.91	0.55	0.79	0.79
21	2.75	2.82	2.71	2.92	2.92	2.76	2.55	2.72	2.34	2.67	2.67	2.68	---	3.13	2.55
22	---	---	---	3.82	3.82	3.93	3.97	4.13	3.35	3.75	3.75	3.78	3.37	3.93	3.42
23	2.54	2.75	2.55	2.32	2.76	2.80	2.39	2.51	2.26	2.68	2.55	2.61	2.51	2.48	2.37
*24	0.50	0.48	---	---	---	---	0.56	0.52	---	---	---	---	---	0.66	0.66
25	---	---	---	---	---	---	---	---	---	---	---	---	2.65+	2.65	2.90
26	---	---	---	---	---	---	---	---	---	---	---	---	---	1.57	1.52
27	---	---	---	---	---	---	---	---	---	---	---	---	---	1.77	---
28	---	---	---	---	---	---	---	---	---	---	---	---	---	2.16	---
29	---	---	---	---	---	---	---	---	---	---	---	---	1.52+	1.47	1.73
30	---	---	---	---	---	---	---	---	---	---	---	---	1.67+	1.68	1.10
31	---	---	---	---	---	---	---	---	---	---	---	---	4.18+	4.27	2.72

* CANAL   + SAMPLED APRIL, 1974

TABLE 17. (cont.)   ELECTRICAL CONDUCTIVITY OF TILE EFFLUENT

MILLIMHOS

SITE NO.	1974			1975									1976	
	AUG	SEP	OCT	JAN	MAR	MAY	JUN	JUL	AUG	OCT	NOV	MAR	MAY	JUN
1	3.89	3.68	3.32	3.82	3.93	3.52	3.93	3.97	3.93	3.82	4.05	3.82	4.09	4.18
2	2.65	2.20	2.68	2.92	2.94	2.76	2.70	2.42	2.45	2.92	3.01	2.96	2.92	2.55
3	2.09	2.01	2.16	2.48	--	--	2.48	1.67	0.76	--	--	--	2.47	1.53
4	2.48	2.15	2.68	3.13	--	2.74	2.42	2.26	2.21	3.01	3.10	2.88	2.28	2.16
5	2.48	2.23	2.68	2.76	2.72	2.82	2.72	2.41	2.39	2.92	3.01	2.76	2.88	2.63
6	2.80	2.42	2.92	2.92	2.96	2.94	3.01	2.92	2.76	2.96	3.10	2.99	2.78	2.76
7	4.23	--	--	--	--	--	4.10	1.33#	1.32	1.37	1.34	1.53	1.17	1.46
8	2.48	1.95	--	--	--	--	2.45	2.28	2.42	--	--	--	2.36	2.23
*9	0.54	--	--	--	--	--	--	0.55	0.51	--	--	--	--	0.61
10	3.37	3.20	3.37	3.55	3.55	3.52	3.48	3.37	3.39	3.42	3.55	3.42	3.55	3.46
11	2.39	1.95	--	--	--	--	2.67	2.21	--	--	--	--	--	2.09
12	2.76	1.84	--	--	--	--	2.92	2.50	1.81	--	--	--	3.06	2.28
13	0.95	0.59	0.98	0.81	0.79	1.02	0.99	0.96	0.96	0.95	1.19	0.80	0.70	0.64
14	0.65	0.51	0.83	0.56	0.66	0.66	0.86	0.72	0.63	0.83	0.81	0.71	0.55	0.83
15	3.42	3.15	3.31	3.20	3.31	3.31	3.37	3.31	3.34	3.37	3.39	3.42	3.23	3.31
16	1.24	1.43	1.86	1.71	1.60	1.84	1.87	1.74	1.63	2.03	2.07	1.77	1.84	1.77
17	2.48	2.07	2.55	2.65	2.76	2.53	2.55	2.31	2.16	2.42	2.51	2.92	2.80	2.28
18	2.44	2.55	--	--	--	--	3.01	2.84	2.76	--	--	--	3.06	2.82
19	1.58	1.40	1.67	1.44	1.36	1.71	1.71	--	1.63	1.68	1.63	1.43	--	--
20	0.90	0.59	0.81	0.58	0.58	0.62	1.01	0.93	0.88	0.93	0.98	--	0.79	0.90
21	2.36	1.86	2.80	3.31	3.37	3.34	3.01	2.56	2.51	3.31	3.39	3.26	3.31	3.20
22	3.55	3.66	--	--	3.89	--	3.89	--	3.48	--	--	3.86	3.97	3.82
23	2.15	1.71	2.15	2.82	2.76	2.74	2.51	2.16	1.94	1.99	2.34	2.84	2.58	2.03
*24	0.51	0.55	--	--	--	--	--	0.52	0.52	--	--	--	--	0.62
25	2.65	2.42	2.36	2.03	2.11	--	--	--	--	--	--	--	2.55#	2.53
26	1.33	1.36	--	--	1.13	--	--	--	--	--	--	--	1.86#	2.15
27	--	1.77	1.93	1.95	1.66	1.86	1.87	1.75	1.63	2.03	2.11	1.81	1.81	1.34
28	--	1.93	1.99	2.27	2.09	2.16	2.27	2.18	2.09	--	2.34	2.26	2.10	2.05.
29	1.71	1.55	1.74	1.66	1.89	1.77	1.87	1.84	1.31	1.79	1.87	1.66	1.81	1.71
30	1.39	1.24	--	--	--	--	2.05	1.53	--	--	--	--	--	--
31	3.89	--	--	--	--	--	3.97	2.76	--	--	--	--	--	--

* CANAL   # NEW DRAIN

TABLE 18. SOIL CATION EXCHANGE CAPACITY

MEQ/100 G SOIL

SITE NUMBER

DEPTH CM	25 TREATED	26 UNTREATED	27 TREATED	28 UNTREATED	30 UNTREATED	31 TREATED	25* TREATED	26* UNTREATED
0-10	21	22	25	26	16	17	24	21
10-20	22	21	27	25	18	17	24	20
20-30	32	24	25	26	22	17	28	21
30-40	36	30	28	25	32	19	33	18
40-50	38	33	25	25	31	19	33	18
50-60	36	34	24	26	30	23	32	22
60-70	34	32	24	24	28	23	32	23
70-80	31	31	23	24	27	23	30	26
80-90	31	30	22	27	26	22	29	27
90-100	29	29	23	26	26	26	26	30
100-120	26	27	24	24	25	25	25	29
120-140	26	28	22	23	25	25	26	29
140-160	25	32	22	24	23	26	26	27
160-180	26	30	22	24	24	24	26	27

* NEW SITE SAMPLED APRIL, 1976

extensive farming practices over the years have caused the clay colloids to be moved from A to the B horizon causing CEC to increase in the B horizon. This zone of clay accumulation would also serve to hinder water percolation and nitrate might accumulate in these zones of slow permeability during the fall and winter. In spring and summer, wet, anaerobic conditions would facilitate denitrification of nitrate. Plots 25 and 26 showed an increase of NO_3^- in this area of the profile in November 1975, with the NO_3^- concentration being higher in plot 25 due to the superimposed nitrogen treatment. Unfortunately, these plots could not be sampled in 1976 to determine if the NO_3^- had been denitrified or leached from the zone of clay accumulation.

None of the high CECs found on the other three plots were encountered on plots 27 and 28. These profiles consisted entirely of silt loam, which has a lower CEC than the silty clay and silty clay loam in the other profiles.

Soil pH

pH ranged from 5.5 in the surface of profile 25 to 8.1 at the bottom of profile 31 (Table 19). Data indicated high pHs in the profiles high in carbonate. There was relatively little change in pH in the surface profile of the treated and untreated plots during the two years of the study except on plot 31. No explanation for its surface pH variation can be offered.

TABLE 19.   SOIL PH

1974

SITE NUMBER

DEPTH CM	25 TREATED	26 UNTREATED	27 TREATED	28 UNTREATED	30 UNTREATED	31 TREATED
0-10	6.0	5.0	7.0	7.9	6.6	6.5
10-20	6.0	5.8	8.1	7.7	6.6	7.1
20-30	6.0	6.3	7.6	7.6	6.7	6.9
30-40	6.6	6.4	7.5	7.6	6.9	6.3
40-50	7.1	6.6	7.6	7.4	6.9	6.3
50-60	7.0	7.0	7.8	7.9	7.6	6.4
60-70	7.5	7.6	7.7	7.5	7.3	6.9
70-80	7.7	7.7	7.8	7.4	7.8	8.2
80-90	7.9	7.7	7.7	7.6	8.0	7.8
90-100	7.8	7.8	7.6	7.6	7.9	7.8
100-120	7.5	7.5	7.7	7.8	7.9	8.0
120-140	7.6	7.5	8.0	7.9	8.0	8.1
140-160	7.6	7.6	7.5	7.8	8.0	8.1

1975

SITE NUMBER

DEPTH CM	25 TREATED	26 UNTREATED	27 TREATED	28 UNTREATED	30 UNTREATED	31 TREATED
0-10	5.5	5.7	7.0	7.0	6.5	5.6
10-20	5.6	5.4	7.3	7.3	6.6	6.3
20-30	6.2	6.0	7.3	7.2	6.8	6.5

1976

SITE NUMBER

DEPTH CM	25* TREATED	26* UNTREATED	27 TREATED	28 UNTREATED	30 UNTREATED	31 TREATED
0-10	7.1	7.1	7.5	7.7	6.4	6.7
10-20	7.0	6.6	7.5	7.7	6.4	5.9
20-30	6.4	6.5	7.3	7.5	6.4	6.3
30-40	7.0	6.5	---	---	---	---
40-50	7.6	6.2	---	---	---	---
50-60	7.6	6.4	---	---	---	---
60-70	7.8	6.8	---	---	---	---
70-80	7.9	6.6	---	---	---	---
80-90	7.6	7.1	---	---	---	---
90-100	7.7	7.1	---	---	---	---
100-120	7.7	7.2	---	---	---	---
120-140	7.5	7.3	---	---	---	---
140-160	7.4	7.3	---	---	---	---
160-180	7.5	7.1	---	---	---	---

* NEW SITE

SUMMARY AND CONCLUSIONS

The quality of the drainage water from tile drains in the Bostwick Irrigation District was found to be relatively constant. There was no noticeable decrease in drainage water quality during the irrigation season even though flow rates from many of the tile drains increased tremendously. Although small nitrate fluctuations did occur, they seemed unrelated to the rate of flow of water from the tile drains. The data indicate that variable agricultural practices are not affecting the drainage water quality in the Bostwick Irrigation District. A more in depth review of the relationship between agricultural practices and water quality (such as nitrate or sodium content) requires more extensive sampling.

The fact that there is nitrate present in the district's drainage water can be partially explained by the conversion of uncultivated land to cultivated land. Cultivation increases the oxidation of organic matter releasing nitrogenous compounds which go through various chemical and biological transformations, among these is nitrification. The increase of nitrate concentration makes the probability of its leaching more likely. Support for this natural origin of nitrate comes from no increase in nitrate concentration in water samples taken over a period of four years.

Water analysis data from the Bostwick Irrigation District show stable concentrations of nitrate in the drainage water. Because this water is not truly ground water, it might be more susceptible to nitrogen fertilizer additions to the land. However, evidence has shown that fertilizer-derived nitrogen is readily incorporated into the biomass of the soil and a substantial amount can be held in the organic form for

a number of years, thus lowering nitrogen availibility for leaching.
By the same token, the biological binding of nitrogen would also serve
to slow its release from the soil at a steady rate which might account
for the continuing presence of nitrate in tile drainage water over the
years of the study.

Additions of large amounts of fertilizer nitrogen to three sites
in the district resulted in accumulations of nitrate in or below the
root zone after two years. These additions, much in excess of crop
needs, apparently resulted in an overload of the microbiological nitrogen
balance in the soil profile. In other words, excessive fertilizer-
derived nitrogen may not be incorporated into the biomass and would
therefore be available for leaching. This phenomenon would be related
to the carbon content of the soil and the resulting biological activity.
A longer period of study is necessary to determine whether such accumula-
tions of nitrate will eventually enter the tile drains. It is possible
that much of the nitrate will be biologically or chemically reduced
before it reaches the drains. However, this depends partly on irrigation
practices, seasonal precipitation, the presence of oxidizable carbon
compounds, biological activity, and the soil type. A more extensive
study of denitrification is necessary to understand to what extent this
reaction influences nitrate concentrations in these soil profiles and
nitrate movement into drainage water.

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APPENDIX

TABLE 1.   EXTRACTABLE SOIL NITRATE-NITROGEN (PPM)

1974

SITE NUMBER

DEPTH CM	25 TREATED	26 UNTREATED	27 TREATED	28 UNTREATED	30 UNTREATED	31 TREATED
0-10	21.3	30.4	8.3	10.7	8.3	17.5
10-20	11.5	9.7	4.1	5.6	40.1	16.9
20-30	5.6	7.1	2.4	5.2	6.2	12.2
30-40	4.3	4.2	2.7	4.9	4.1	13.2
40-50	3.4	3.2	1.7	2.8	3.9	11.1
50-60	0.3	2.4	1.8	2.1	3.6	9.4
60-70	3.5	2.8	2.9	2.8	3.4	6.2
70-80	4.3	1.7	1.3	3.1	3.4	4.2
80-90	2.7	3.1	1.5	2.5	3.6	3.1
90-100	2.1	6.3	1.3	2.4	2.9	4.2
100-120	3.5	10.2	1.0	2.0	2.7	3.2
120-140	8.5	10.6	1.5	1.3	2.5	3.1
140-160	11.1	12.6	4.2	1.8	3.6	4.3

1975

SITE NUMBER

DEPTH CM	25 TREATED	26 UNTREATED	27 TREATED	28 UNTREATED	30 UNTREATED	31 TREATED
0-10	31.2	34.0	74.6	28.0	17.9	44.8
10-20	32.2	5.6	44.5	11.6	6.7	28.7
20-30	26.3	12.6	22.1	3.9	0.0	16.8
30-40	17.5	11.9	11.9	1.4	0.0	7.0
40-50	17.2	10.5	5.3	0.0	0.0	2.1
50-60	15.8	7.7	3.2	0.0	0.0	1.4
60-70	10.9	6.3	1.8	0.0	1.1	0.0
70-80	7.4	4.6	1.4	0.0	2.5	0.0
80-90	8.8	0.4	0.4	0.0	0.7	3.2
90-100	7.4	0.0	1.1	0.0	1.1	3.2
100-120	11.6	2.3	3.8	0.0	0.0	4.2
120-140	6.3	5.3	4.2	0.0	0.0	2.8
140-160	10.5	0.7	3.9	0.4	0.0	3.5
160-180	8.1	2.1	2.8	0.7	0.0	3.2

1976

SITE NUMBER

DEPTH CM	25 * TREATED	26 * UNTREATED	27 TREATED	28 UNTREATED	30 UNTREATED	31 TREATED
0-10	10.9	63.0	36.4	17.5	23.1	11.6
10-20	6.3	15.4	34.0	18.6	15.1	16.1
20-30	6.0	17.9	26.3	16.8	9.8	15.8
30-40	5.6	23.8	24.5	11.2	6.3	15.8
40-50	2.8	29.1	27.3	8.4	10.2	16.8
50-60	3.9	25.6	26.6	5.6	4.6	12.6
60-70	4.6	24.5	21.7	7.0	2.1	9.1
70-80	3.9	19.6	13.0	5.3	2.8	9.5
80-90	4.9	15.4	7.7	6.3	0.4	11.6
90-100	3.5	8.4	5.6	4.9	0.7	11.6
100-120	7.4	5.3	4.2	3.9	2.1	7.4
120-140	2.8	2.1	3.2	3.2	1.8	4.6
140-160	2.1	1.8	3.9	1.8	2.8	3.9
160-180	0.7	2.5	3.5	4.6	3.9	5.3

* NEW SITE

TABLE 2.   SOIL ORGANIC-CARBON (%)

1974

SITE NUMBER

DEPTH CM	25 TREATED	26 UNTREATED	27 TREATED	28 UNTREATED	30 UNTREATED	31 TREATED
0-10	1.89	1.75	0.85	1.37	1.59	1.52
10-20	1.59	1.64	0.48	0.89	1.37	1.40
20-30	1.17	1.43	0.49	0.61	1.01	1.03
30-40	0.94	1.30	0.50	0.36	0.85	1.15
40-50	0.83	1.05	0.44	0.49	0.67	1.26
50-60	0.76	0.75	0.27	0.40	0.42	1.19
60-70	0.65	0.66	0.34	0.33	0.35	1.00
70-80	0.52	0.54	0.22	0.35	0.25	0.89
80-90	0.42	0.36	0.29	0.21	0.22	0.64
90-100	0.44	0.31	0.20	0.26	0.15	0.49
100-120	0.24	0.27	0.13	0.17	0.15	0.34
120-140	0.20	0.18	0.11	0.19	0.19	0.26
140-160	0.18	0.16	0.12	0.21	0.17	0.25

1976

SITE NUMBER

DEPTH CM	25* TREATED	26* UNTREATED	27 TREATED	28 UNTREATED	30 UNTREATED	31 TREATED
0-10	1.08	1.74	0.90	1.07	1.13	1.11
10-20	1.22	0.96	0.75	0.85	1.12	1.06
20-30	1.19	1.06	0.62	0.71	0.99	0.99
30-40	1.02	1.09	0.47	0.61	0.78	1.15
40-50	0.77	1.16	0.49	0.62	0.68	1.00
50-60	0.57	1.19	0.22	0.62	0.56	0.90
60-70	0.39	0.98	0.25	0.51	0.36	0.82
70-80	0.28	1.11	0.18	0.49	0.25	0.69
80-90	0.22	1.02	0.14	0.34	0.20	0.76
90-100	0.21	0.85	0.16	0.25	0.17	0.55
100-120	0.14	0.71	0.11	0.15	0.18	0.37
120-140	0.13	0.43	0.10	0.17	0.12	0.22
140-160	0.13	0.23	0.09	0.11	0.12	0.13
160-180	0.11	0.18	0.05	0.14	0.14	0.16

* NEW SITE

TABLE 3. EXTRACTABLE SOIL CHLORIDE (PPM)

1974

	SITE NUMBER					
DEPTH	25	26	27	28	30	31
CM	TREATED	UNTREATED	TREATED	UNTREATED	UNTREATED	TREATED
0-10	21.5	6.7	1.5	2.0	1.7	0.7
10-20	19.0	9.0	0.7	2.0	1.5	1.0
20-30	14.0	6.5	1.0	1.5	1.5	1.5
30-40	16.5	1.7	1.5	3.5	2.2	0.2
40-50	17.2	1.5	1.5	3.0	1.5	4.5
50-60	15.2	1.5	1.5	3.2	1.0	3.5
60-70	8.5	1.7	2.0	4.0	1.0	6.0
70-80	10.0	1.7	2.3	2.7	1.0	9.0
80-90	9.7	3.0	1.5	3.2	1.0	7.0
90-100	15.2	5.0	2.0	3.7	0.2	6.5
100-120	17.7	7.5	23.7	1.5	1.5	2.2
120-140	54.7	7.0	2.7	2.0	0.5	5.2
140-160	75.0	8.2	10.2	1.5	6.0	21.5

1976

	SITE NUMBER					
DEPTH	25*	26*	27	28	30	31
CM	TREATED	UNTREATED	TREATED	UNTREATED	UNTREATED	TREATED
0-10	11.4	7.6	8.9	6.5	18.1	6.5
10-20	8.9	7.2	7.6	8.9	14.8	7.6
20-30	10.9	7.2	10.3	8.0	14.8	9.8
30-40	14.8	8.0	12.0	7.6	13.3	9.3
40-50	16.3	7.6	16.3	9.3	10.3	9.3
50-60	20.1	8.0	16.3	10.3	8.0	10.3
60-70	24.6	7.2	13.3	8.0	9.8	9.8
70-80	9.8	8.0	11.4	7.2	8.9	14.0
80-90	10.9	8.9	8.9	6.9	9.8	10.9
90-100	11.4	10.9	6.2	6.2	5.9	10.9
100-120	9.3	7.2	8.0	6.9	8.5	13.3
120-140	9.8	10.9	6.2	7.2	7.6	19.1
140-160	10.3	17.2	10.9	8.9	10.9	20.1
160-180	13.3	12.0	13.3	19.1	9.3	24.6

* NEW SITE

THE EFFECTS OF AGRICULTURAL PRACTICES
ON TILE DRAINAGE WATER QUALITY

by

MICHAEL K. SNYDER

B.S., Kansas State University, 1971

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AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agronomy

KANSAS STATE UNIVERSITY

1973

This investigation was initiated in 1972 to evaluate the tile drainage water quality in the Bostwick Irrigation District. Selected tile drain outlets were sampled monthly and the water samples analyzed for calcium, magnesium, potassium, sodium, nitrate, and electrical conductivity. Tile drain flow rates were measured or estimated. The purpose of the water quality investigation was to determine if agricultural practices within the district were effecting drainage water quality and, if so, to see if these effects were seasonal in nature.

A second investigation was initiated in 1974 to determine if application of excessive rates of nitrogen fertilizer (rates in excess of crops needs) could induce nitrate to move into tile drainage water under fertilized, irrigated land. Nitrogen in the from of ammonium nitrate was applied to the land above a tile drain spur on three different sites at the rate of 225 kg N/ha. This treated drain spur was adjacent to another spur which was left untreated. Both spurs drained into a manhole from which water samples were taken. The land above both drains on all three sites received fertilizer that the cooperator normally applied during the cropping season. Soil core samples were taken in April, 1974, November, 1975, and April, 1976, and were analyzed for total cations, nitrate-N, ammonium-N, chloride, pH, cation exchange capacity, and carbon content.

The quality of the water throughout the four years of the study was found to be relatively constant. No seasonal changes in quality were seen. Nitrate concentration in the tile drain effluents was relatively stable and did not tend to increase in any drain, except one. This drain was short and passed close to a septic tank. Nitrate concentration of all the drain effluents was apparently independent of effluent flow rate.

Soil nitrate-nitrogen concentrations increased in the upper profiles of the treated plots during the two years of fertilizer application. Fertilizer-derived nitrate had not moved into the drainage water by the end of the study. However, high nitrate concentration had moved lower in the soil profile by 1976. It is possible these accumulations would eventually move into the drainage water.

Soil carbon content on plots 27 and 28 (Muir silt loam) was much lower than on the other four plots (Crete silty clay loam). The nitrate accumulation on plot 27 (treated) was much more pronounced than on the other two treated plots. The low amount of carbon and the excellent drainage in this profile might be hindering denitrification. On plot 31 (treated) a very high carbon content from 40-80 cm corresponded to a zero nitrate concentration in November 1975. The availability of oxidizable carbon and the slow internal drainage of this profile might indicate the occurrence of denitrification.

Soil chloride concentrations were used to indicate the movement of water through the profiles. On plot 27 a zone of chloride accumulation corresponded directly with the zone of nitrate accumulation. On the other treated plots there were no nitrate accumulations corresponding to accumulation of chloride. This indicates that denitrification of prior plant uptake of nitrate has occurred.