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CORN FERTILITY MANAGEMENT AND NITRATE LEACHING TO GROUNDWATER IN SANDY SOILS

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Abstract

A study in the sandy soils of Central Wisconsin was conducted to evaluate the affects of manure and fertilizer application to first and second year corn fields following alfalfa, on corn yields and groundwater quality. A major goal of the project was to make recommendations on optimum fertilizer management for corn production and groundwater quality.

One hundred-fifty wells were installed upgradient and downgradient of 24 plots to evaluate groundwater impacts. Five treatments were used on 15 plots in 1989 including; 20 pounds starter fertilizer/plot, manure inputs of 0, 7.7, 15, and 23 tons/acre, sidedress nitrogen of 65 pounds/acre were used on 4 of 5 sets of plots to supplement alfalfa and manure credits. Five follow up treatments were used on the same 15 plots the second year. Treatments included 20 pounds of starter fertilizer, 0, 11, and 22 tons/acre manure, and 45 pounds/acre as sidedress, and a control plot. All treatments were run in triplicate.

Due to a mixup in communication in 1989, 4 treatments received 66 pounds/acre sidedress nitrogen that were not supposed to be sidedressed. This over application of nitrogen combined with dry growing season resulted in only moderate yields and no significant difference in yields between treatment. Over fertilization resulted in high nitrate-N concentrations reaching groundwater from all but one treatment in 1989 and, in all plots in 1990 as carry over nitrogen continued to leach. In 1990 carry over nitrogen plus starter fertilizer (20 pounds/acre) resulted in 94 and 112 pounds/acre yields. Other 1990 second year plots receiving supplemental nitrogen of 11 and 22 tons/acre manure or 45 pounds/acre sidedress nitrogen resulted in yields of 118, 130, and 141 pounds/acre respectively, indicating that starter plus carry over fertilizer produce good yields, and if supplemented with additional nitrogen gave excellent yields in 1990.

Three new treatments on 9 plots were established with first year corn in 1990. These plots all had starter fertilizer (20 pounds/acre). One set received 11 tons/acre manure, one 45 pounds/acre sidedress, and the third did not receive supplemental nitrogen. Yields were 132, 141, and 101 respectively. Average nitrate-N levels in groundwater for these 3 treatments were 6.5, 8.6, and 11.7 mg/l, respectively. Late summer and early spring nitrate-N values for all treatments did however approach or slightly exceed 20 mg/l, with some values exceeding 40 mg/l. The highest leaching and lowest yield from the control plots indicated that supplemental nitrogen exceeded nitrogen use efficiency and yield.

Nitrate-N concentrations in groundwater upgradient of the plots (originating from woodlots and alfalfa fields) was consistently less than 0.2 mg/l.

Even the control plots used in 1990, receiving 20 pounds/acre nitrogen resulted in some groundwater samples exceeding 10 mg/l nitrate-N, indicating that leaching of nitrogen released from alfalfa can impact groundwater in sandy soil areas.

It can be concluded that the credit from alfalfa alone as calculated using Extension guidelines will in most cases supply sufficient nitrogen for yields in excess of 100 bushels/acre of corn. Additional nitrogen applied from either manure (at 11 tons/acre) or fertilizer (at 45 pounds/acre) resulted in additional yields of 30 to 40 bushels/acre in 1990. Some residual soil nitrogen from 1990 treatments resulted in moderate groundwater nitrate-N levels in 1991. These values were

primarily less than 10 mg/l.

Carry over nitrogen from 1989, plus 20 pounds of starter/ plots provided sufficient nitrogen for 95 to 111 bushels/acre yields compared to 119 to 141 bushels/acre when additional manure or side dress plus nitrogen was used. The 111 bushels/acre would normally be considered a very good yield, and occurred at plots that had 23 tons/acre manure in 1989 indicating carry over of both manure and alfalfa nitrogen for use in 1990. More carry over of available nitrogen appeared to occur in these soils than predicted for sandy soils in Wisconsin. Spring testing for residual nitrate-N and ammonium-N is recommended to estimate carry over nitrogen amounts and take appropriate credit to reduce fertilizer impacts.

It can be concluded from this study that alfalfa credits can provide the majority of nitrogen needs of corn the first year of a rotation, however maximum yields appear to require additional nitrogen inputs from manure or sidedr ess. These additional inputs could, however, easily result in excess nitrogen and leaching during average to poor growing seasons. The use of 7 to 11 tons/acre of manure shortly before planting combined with reduced use of starter fertilizer should result in good yields without excessive leaching to groundwater.

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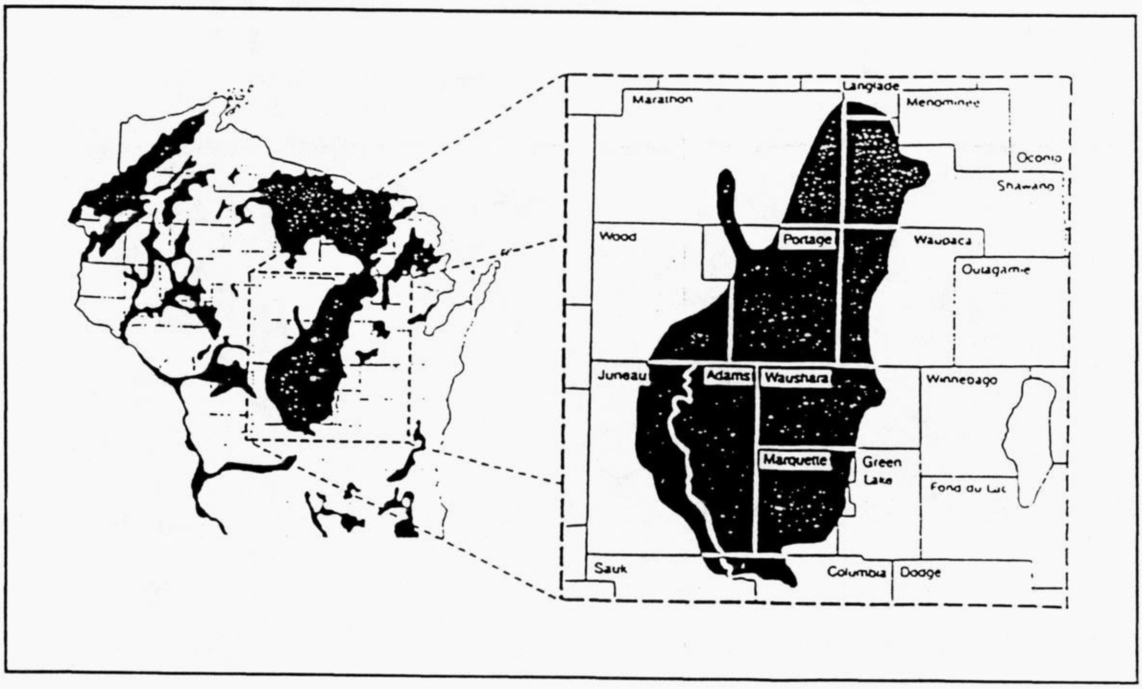
Introduction

Groundwater supplies approximately 100 percent of rural Wisconsin with its drinking water. In Central Wisconsin, Portage, Wood, Adams, Juneau, and Waushara counties are fortunate to have a ready supply of groundwater (Figure 1). They are located over Pleistocene deposits of sand and gravel characteristic of the "Central Sands" region. The high permeability and shallow depth to groundwater that gives this area an abundant water supply, also provide a susceptible path for groundwater contamination.

The common groundwater contaminant in this region is nitrate-nitrogen (nitrate-N). The Safe Drinking Water Act of 1974 set the human consumption standard for nitrate-N in drinking water at 10 milligrams per liter (mg/L). In a 1979-80 Department of Natural Resources study of 11,396 non community public water wells, 311 wells exceeded the 10 mg/L nitrate-N standard. (Wisconsin Groundwater Coordination Council, 1986). That is about 1 in 40, or 2.7 percent of current wells. Between 1985 and 1990, approximately 3200 well water samples were tested for nitrate-N in Portage County, in which 18.3 percent of them exceeded the nitrate-N standard (Portage County 1990 Groundwater Quality Report). Based on this information it is estimated that 10 percent or 70,000 of Wisconsin 700,000 wells exceed the 10 mg/l nitrate-N standard (Wisconsin Groundwater Coordination Council, 1988). In recent years there has been a growing concern from residents in the Central Sands region to identify and control sources of nitrate-N contamination. Nitrate-N contamination has many possible sources which are linked to human activities. The largest contamination comes from nitrogen based chemical fertilizers and animal wastes used in agriculture.

Portage County is intensively farmed for cash crops. In 1988 it ranked number one in the state in cash receipts for all vegetables crops. Portage County leads the state in production of potatoes and snap beans (Wisconsin Department of Agriculture, Trade, and Consumer Protection, 1990). In addition to its cash crops, Portage County has 17,000 dairy cows that produce 241 million pounds of milk each year. To support the dairy industry, approximately 43,000 acres of field corn and 33,000 acres of alfalfa are harvested annually. In addition, these dairy cows produce a substantial amount of manure. Each dairy cow averages 82 pounds of manure daily per 1000 pounds of animal. In Portage County alone, approximately 254,000 tons of manure is produced each year (Petersen et al., 1984).

Figure 1. Central Wisconsin Sand and Gravel Aquifer.
(Adapted from Jackson, et. al. 1985)



If applied on agricultural lands, this manure has many advantages; a ready supply of nitrogen, phosphorus, potassium, and micronutrients. It can improve soil structure, increase moisture retention and rate of infiltration, and decrease bulk density (Tisdale et al., 1985). However, manure is often seen as a waste disposal problem. One disposal technique is application on cropland. Unfortunately, in most cases, land owners do not have sufficient land to do this in an environmentally sound manner. In areas where the soil is sandy and shallow to groundwater, like the Central Sands of Wisconsin, leaching should be a greater concern.

It has been suggested that to obtain the maximum benefits from manure, it should be applied at rates which supply the crop with the most abundant nutrient (Petersen et al., 1984). Based on the total nutrient content of manure, nitrogen should be the nutrient managed for, since it is the most limiting to crop growth and has potential detrimental effects to the environment. Table 1 shows the typical nutrient content of fresh dairy manure. In areas where runoff or wind erosion is likely, phosphorus rather than nitrogen should regulate manure application rates to prevent excessive levels of phosphorus in soils.

Table 1. Nutrient content of fresh dairy manure.

	Nutrient (lb/ton manure)		
	N	**P**	**K**
Total	10	2	7
Amount assumed available the first year	4	1	5

As with manure, the nitrogen produced by alfalfa is not always credited. Even if this nitrogen credit is considered, commercial fertilizer is often also applied. This builds an excess the crop cannot utilize. It was once thought that additional amounts of nitrogen should equal the amount utilized by the crop. This is true if crops were 100 percent efficient at using all available nitrogen. In actuality, crop recoveries of nitrogen are probably no greater than 50 to 70 percent, and most often are considerably less, 30 to 50 percent (Keeney, 1986). Leaching to groundwater and volatilization account for the remaining nitrogen.

If the available nitrogen from manure, legumes, soil organic matter, or fertilizer is not utilized by the crops the remaining nitrogen, once converted to nitrate-N can leach through the soil profile to groundwater. However, it cannot be assumed that all nitrogen not utilized by the crop leaches to groundwater. It is extremely difficult to predict nitrate-N impact on groundwater because of possible interactions such as; nitrate-N movement above and within the aquifer, site specific criteria (soil texture, drainage, depth to and type of bedrock, depth to water table); and timing, form, and method of nitrogen application. Other processes within the nitrogen cycle itself, like mineralization, mobilization, and denitrification, constantly change the potential amounts of nitrate-N leached to groundwater. With rising fertilizer costs, concern over nitrate-N contamination of drinking water, and a move toward more sustainable agricultural practices, the need for better nitrogen management practices is required. Information on optimum manure application rates to maximize crop production, minimize cost to farmers, and protect groundwater quality in the Central Sands region is needed by professionals working with farmers. Substantial research, using manure as a nitrogen source for crop production has been conducted. Unfortunately, little research has focused on the correlation between the use of dairy manure for crop production and on groundwater quality.

This Study

In April 1989, a study was initiated to develop an optimum manure and fertilizer application rate for sustained crop production, while protecting groundwater from nitrate-N contamination. The goal of this two year study was to determine an optimum rate of application of dairy manure in combination with fertilizer, on a field planted to corn rotated from alfalfa. This application rate was to provide nitrogen in addition to the nitrogen credit from alfalfa. Several different application rates were tested to determine which rate would protect groundwater from excess nitrate-N contamination.

The objectives for this study were to:

1.) Demonstrate, by use of field trials, the response of field corn to three rates of dairy manure application, one application rate, plus a commercial fertilizer sidedress, and a control following alfalfa. Each treatment was applied in triplicate.

2.) Determine the impact of each treatment and control on nitrate-N levels in groundwater below each treated plot.

3.) Calculate costs and cost savings from decreased fertilizer use, and compare to yield data.

4.) Recommend an optimum rate of manure application to maximize production and minimize groundwater contamination.

5.) Document the groundwater quality variability on a small area of farmland and determine the number of monitoring wells needed to statistically evaluate groundwater quality from individual fields.

This study was funded by the Department of Natural Resources and Golden Sands Resource Conservation and Development Office. It was also conducted in cooperation with the Soil Conservation Service, Portage County Land Conservation Department, Portage County UW-Extension, UW-Madison Soils Department, UW-Stevens Point, and Klismith Farms.

The following is an overview of limitations and assumptions made during this study:

- Groundwater samples provide information that is time specific and reflect the trends in groundwater quality of the last two years.

- It is assumed that the field conditions are uniform with respect to soils, groundwater flow between sample dates, depth of nitrate-N plume, application of manure and fertilizer, and groundwater samples taken from downgradient wells represent nitrate-N originating from each plot.

-All groundwater samples collected were analyzed for nitrite-N and nitrate-N, and the combined results were used in all calculations. Therefore all references to nitrate-N are both nitrite and nitrate-N.

Literature Review

Since World War II there has been a steady increase in the use of commercial nitrogen fertilizers for crop production. Prior to this increase, farmers used other available nitrogen sources such as animal manures and legumes. With new technology developed to produce nitrogen fertilizers inexpensively, farmers began using commercial nitrogen fertilizer. However, with the increase in energy prices, the large quantities of energy required to produce commercial nitrogen fertilizers, and increased prices, farmers are again using manures and legumes as a source of crop nitrogen.

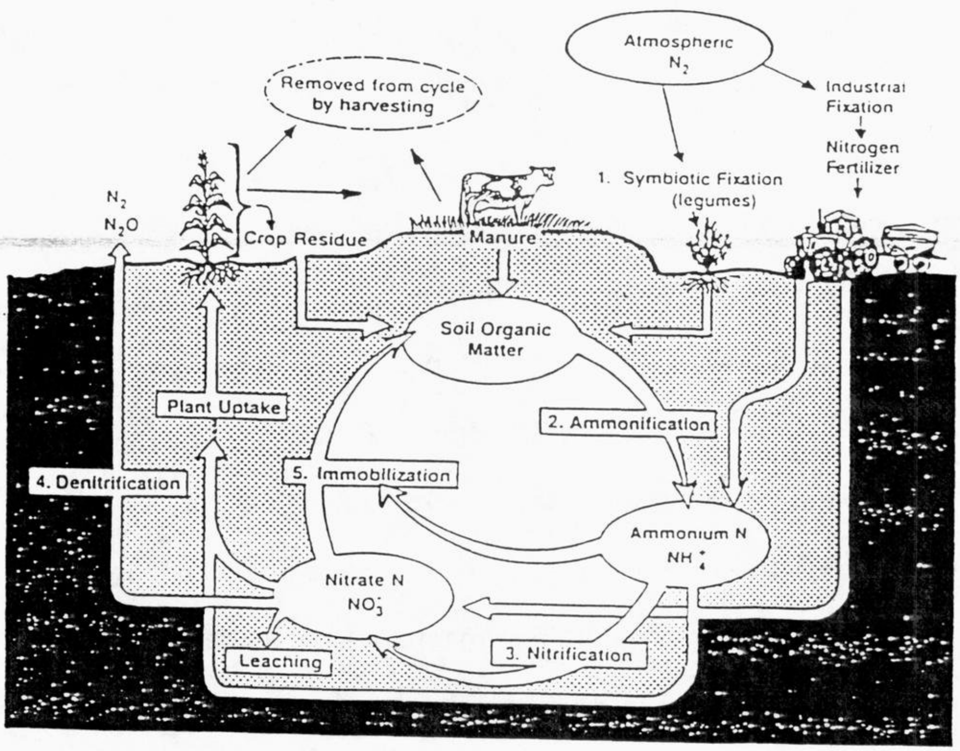
This focus on nitrogen is because of the importance and limits it places on crop production, whether it is from commercial fertilizer, manure, legumes, or soil organic matter mineralization. Countless studies have proved the need for adequate supplies of this nutrient to growing plants, particularly corn. In recent years much of the research has focused on utilizing manures at maximum application rates to obtain maximum crop yields (Mathers and Stewart, 1970; Randall et al., 1975; Turner, 1975; Evans et al., 1977). Unfortunately, little attention has been paid to the environmental consequences to groundwater. This is particularly true in coarse textured soils characteristic of the Central Sand Plain of Wisconsin. Since nitrogen is not retained in the soil profile, nitrogen management is of great concern for farmers in this region. Before further discussion of nitrogen management, it necessary to have a thorough understanding of how nitrogen cycles through the environment and the difficulties in nitrogen management.

The Nitrogen Cycle

(Taken from N.C. Brady, (1974), Tisdale, et al., (1985), and L. G. Bundy (1985))

Nitrogen (N2) is the most abundant gas in our atmosphere, about 78 percent by volume. It can be converted to usable forms for plants by symbiotic fixation of Rhizobia bacteria living in the roots of legumes or by chemical fixation through industrial processes to make nitrogen fertilizer. Other possible sources of nitrogen include soil organic matter, crop residues, and animal manures (Figure 2). What ever the source, once nitrogen is applied to the soil for crop production the same set of reactions take place that convert nitrogen into plant usable forms and into the nitrate-N form that is leached into groundwater. First, the mineralization of organic N compounds into inorganic forms that plants use involve three steps.

Figure 2. The Nitrogen Cycle. (Adapted from Bundy, 1985)



Aminization

Aminization is the first and frequently overlooked step during mineralization. (Not shown in Figure 2) Through numerous reactions, soil microorganisms decompose organic matter, breaking down proteins and releasing amines and amino acids ($R\text{-}NH_2$) for further decomposition during ammonification.

$$\text{Proteins} \dashrightarrow R\text{-}NH_2 + CO_2 + \text{energy} \quad \text{(Reaction 1)}$$

Ammonification

Ammonification is the conversion of organic nitrogen (amines and amino acids) into ammonia (NH_3) and then into ammonium (NH_4^+) by soil microbes (Reaction 2). Plants can absorb ammonium directly as a source of nitrogen. It is also fixed or attracted to negatively charged clay or organic matter particles due to the positive charge of the NH_4^+ ion. Up to 48 percent of total nitrogen in surface and subsurface soils has been found fixed to soil clay particles. For this reason ammonium is not leached through the soil profile. Ammonium is also used by other organisms during decomposition of organic carbon, and can be released back into the atmosphere as elemental nitrogen (N_2), nitrous oxide (N_2O), or ammonia (NH_3) if a high pH condition exists. A major concern in sandy soils is the ease at which ammonium is converted to nitrite-N and nitrate-N through nitrification.

$$R\text{-}NH_2 + H_2O \dashrightarrow NH_3 + R\text{-}OH + \text{energy}$$

$$NH_3 + H_2O \dashrightarrow NH_4^+ + OH^- \qquad \text{(Reaction 2)}$$

Nitrification

The most important process that relates to this study, and is of major concern for the Central Sand Plain region is nitrification. This biological process is actually a two step reaction. In the first reaction, ammonium is converted to nitrite (NO_2^-) by the bacteria Nitrosomonas (Reaction 3). Due to the negative charge, the unstable nitrite-N ion remains in solution and is quickly oxidized to nitrate-N in the presence of oxygen. From Reaction 3, it can be seen that hydrogen ions (H^+) are released, resulting in acidification of the soil.

(Reaction 3)

$$2\ NH_4^+ + 3\ O_2 + \text{Nitrosomonas} \dashrightarrow 2\ NO_2^- + 2\ H_2O + 4\ H^+$$

The last reaction is the conversion of nitrite-N to nitrate-N from a second group of soil bacteria, Nitrobacter (Reaction 4).

$$2\ NO_2^- + O_2 + \text{Nitrobacter} \rightarrow 2\ NO_3\text{-N} \quad \text{(Reaction 4)}$$

Both nitrite-N and nitrate-N are very mobile through the soil profile, due to the negative charge of these ions. However, nitrite-N is not normally found in high concentrations in groundwater, since it is unstable and is quickly oxidized to nitrate-N. So, nitrate-N is the most common form of nitrogen found in groundwater.

The rate and the extent of nitrification depends on the activity of the two Nitrobacteria. Brady (1974) reported that under ideal soil conditions daily nitrification rates of 6 to 22 pounds of nitrogen per acre occurred when 100 pounds of NH_4-N was applied. Higher rates occurred with larger applications of NH_4-N, but nitrate-N was supplied at rates that exceeded crop need. Bundy (1985) reported that the ammonium form of nitrogen in fertilizers is converted to nitrate-N within one to two weeks after application. The microbial activity is influenced by several soil environmental conditions: 1) supply of NH_4^+; 2) population of nitrifying organisms; 3) soil pH; 4) soil aeration; 5) soil moisture; and 6) soil temperature.

Some of the most important factors in nitrification are temperature, aeration, moisture, and pH. Nitrification begins slowly at about 4°C (40°F) and increases in intensity until an optimum temperature of 26.6 - 32°C (80 - 90° F) occurs. Nitrification does not take place at or below freezing. Since nitrification is an oxidation reaction, it requires oxygen to take place. Well aerated soils, like sandy soils, encourage nitrification up to a point. Maximum nitrification occurs when soil oxygen is at 20 percent, or near equal to atmospheric oxygen. The moisture content of the soils have a marked effect on nitrification, with it being retarded at very low or very high moisture conditions. Soils that are too moist, or water logged in turn effects aeration. If no oxygen is present, denitrification is possible. Nitrification occurs in a pH range of 5.5 to 10.0 and is optimum at a pH of 8.5.

Losses of Nitrogen

Nitrogen applied for crop production can be lost by one or more of the following: immobilization, volatilization, denitrification, or leaching.

Immobilization

Immobilization is the reverse of mineralization. This process occurs when plant or animal residues that are high in carbon and low in nitrogen are added to soils. During decomposition, microorganisms requiring nitrogen convert inorganic NH_4^+ and NO_3-N in these residues into organic forms for cell development. The nitrogen is temporarily "tied up" causing a decrease in inorganic nitrogen for crop uptake. As the bacteria die, the nitrogen is released, which becomes part of the soil organic matter that once again may be mineralized. Under ideal conditions this release is about one month after tillage of the residues (Bundy, 1985).

Volatilization

When manure or ammonia containing fertilizers are surface applied and not incorporated into the soil, significant amounts of nitrogen may be lost as ammonia gas. Lauer et al. (1976) reported a mean loss of 85 percent NH_3 from dairy manure spread on the field surface. Meteorological conditions of evaporation and precipitation are the principle determinates of NH3 volatilization in the field. Sutton et al. (1975) found that losses due to volatilization may be reduced to 5 percent if immediately incorporated.

Denitrification

Denitrification is another widespread type of volatilization. This microbial biochemical reduction of nitrate-nitrogen (nitrate-N) to gaseous N compounds occurs under anaerobic conditions and the presence of a carbon source (Reaction 5).

$$5\ C\ \text{organic} + 4\ \text{nitrate-N} + H^+ \dashrightarrow 2\ N_2 + CO_2 + 2\ H_2O$$

(Reaction 5)

As with the previous reactions, soil environmental factors like pH, temperature, dissolved oxygen, gas diffusion rate, and readily decomposable organic matter also influence denitrification rates. The rate of organic matter decomposition influences the demand placed on soil oxygen levels. In turn soil oxygen replenishment depends on the soil's diffusion rate. Anaerobic conditions develop when microbial demands for oxygen exceed the diffusion rate. The rate of denitrification is near maximum when soil pH is neutral to slightly alkaline and when temperatures are 30 to 65°C(86-149°F).

It is suggested by Bundy (1985) that denitrification does not take place in deep subsoil or in the groundwater due to the energy requirement. Several studies have reported that the addition of manure, a readily decomposable carbon source, greatly enhances denitrification. Due to difficulty in quantifying gaseous losses from denitrification, general deficits in N balances are used to estimate these losses (Allison, 1965; and Bartholomew and Clark, 1965). Guenzi et al. (1978) showed that gaseous losses of N by denitrification can occur after large amounts of manure are applied to field soils even under aerobic conditions. They used 15N enriched fertilizers to show the presence of nitrous oxide (N2O) and 15N enriched N_2 in soil gases. At application rates of 45 and 90 metric tons/ha recovery of 9.4 percent and 8.1 percent of nitrate-N 15N was recovered on uncropped soils respectively. Soil oxygen concentrations were never below 3.1 percent, indicating that denitrification can occur in anaerobic microsites even when the bulk soil still contains some oxygen. Rolston et al. (1979) also concluded that plots treated with manure had the largest amount of denitrification.

Leaching

Nitrogen is leached when nitrification occurs, forming nitrite and nitrate. Of the two, nitrite is usually not leached as much since it is rapidly oxidized to nitrate. The nitrate anion having a negative charge is not held by soil particles and is easily leached through the soil profile, especially in sandy soils. Sandy soils retain about one inch of water per foot of soil, so small amounts of rain or irrigation water readily move nitrates below the root zone and down into groundwater. Even in well drained finer textured soils, leaching can occur once field capacity is reached and overcome.

Sources of Nitrogen

Numerous sources supply nitrogen to the nitrogen cycle. Some of these are soil organic matter, precipitation, atmospheric fixation, nitrogen fertilizer, legumes, and manures. The first two are important, but are not usually accounted for when calculating N-credits. Depending on the soil, soil organic matter contains 2000 to 6000 lb of organic N per acre. Of this amount 25 to 75 lb N/A is available annually for Wisconsin soils. Precipitation also accounts for about 10 lb N/A annually (Bundy, 1985). Commercial nitrogen fertilizers have become the most popular source of N and are available in many chemical and physical forms, all of which are effective as a ready source of nitrogen. Since World War II the amount of nitrogen fertilizer used for crop production has steadily increased. Between 1950 and 1985 the average N fertilizer rate in lb N/A rose from 3 to 116 lb N/A. With this increase average corn yields have also increased from 52 to 116 bushels/A. In 1987 Wisconsin used 468,802 ton of N fertilizer material or 249,422 tons of actual N

(Nutrient and Pesticide Best Management Practices for Wisconsin Farms, 1989).

Manure

Manure contains substantial amounts of nitrogen, but only 40-59 percent is considered available to the crop the first year. Manure should be analyzed because of the variability of nutrients due to differences in feed rations and manure management practices. If manure is applied to cropland for crop production, nitrogen fertilizer recommendation should be reduced to account for the N from the manure. Nitrogen is both the most limiting element in crop production and the most mobile, so it is logical that manure application rates be based on the amount of nitrogen supplied when considering groundwater impacts. Past literature has focused on maximum yields form maximum rates of manure applied. However, for the Central Sand Plain attention should be given to application rates that produce optimum yields and minimizes nitrate contamination of groundwater.

As reported in Tisdale et al., (1985) a study in Colorado showed that the application of 27 T/A of manure increased corn yields by an average of 20 bu/A over those of applications of 220, 360 , or 460 lb N/A per year of fertilizer. Application rates of 10-15 T/A are common. However, many times farmers do not know how much manure is actually applied or the amount they thick is applied is not accurate. In numerous manure calibration demonstrations in Lancaster County, Pennsylvania most farmers thought they were applying 20 ton/A of dairy manure. Actual manure application rates ranged from 13 to 45 tons/A (Schepers and Fox, 1989).

Petersen et al. (1984), suggests two strategies for determining manure application rates: maximizing nutrient efficiency or maximizing application rate. The first uses a rate of application based on the nutrient present at the highest concentration in terms of the need of the crop. In this case phosphorus is most often the determining factor. The second strategy uses the crop's requirement for nitrogen without leaching nitrate-N. This rate is limited by the amount of N supplied by the manure and what can be utilized by the crop. For the Central Sand Plain region, the later strategy would be the best management practice. However, since not all the N in manure is available the first year, and is susceptible to losses from runoff, volatilization, denitrification, and leaching determination of an application rate that will supply the crop's nitrogen requirement is difficult. Petersen et al. (1984) states that with good management, runoff and leaching should not occur. This may be true for runoff, but due to environmental factors leaching is beyond our control. So, leaching will occur even under the best of management practices. It is purposed by Petersen et al., (1984) that the ideal application rate is calculated as: the amount of N removed in the harvested crop, plus estimated losses due to volatilization and denitrification, plus the change in stored soil nitrogen, all divided by the percentage of total N available the first year from the manure applied.

Aside from the difficulty in estimating losses due to volatilization and denitrification, determining the amount of nitrogen available the first year from manure is also difficult. The rate at which nitrogen becomes available and the total available the first year is an important factor in determining the proper application rate for optimum crop production.

To insure optimum use of nitrogen by the crop and minimize potential groundwater contamination the rate of mineralization of nitrogen is required. When manure is applied for corn production following alfalfa, an estimate of the N supplied from the alfalfa must be taken into account. Once this amount is known, supplemental nitrogen from manure may be applied. Pratt et al. (1973) described a decay constant for manure based on the mineralization of organic nitrogen into inorganic or available nitrogen. The mineralization rate can be determined by using a decay constant. This process is rapid the first year and decreases in subsequent years. Table 2 shows the decay constants for dairy and beef manure in Wisconsin. The percentages after the first year refers to organic nitrogen remaining in the soil that will become available. Mineralization rates of organic N will vary with manure type, soil, and climatic conditions. Wisconsin is categorized as a cold-humid climate region as described by White and Safley (1982). Table 3 shows the mineralization rates for the various climatic regions.

Some manures, like poultry, that contain high percentages of nitrogen as ammonium-N have more rapid decay rates. Manures that have accumulated on outdoor lots or stored outside have lower decay constants since much of the soluble nitrogen has been lost through runoff or volatilization. These manures usually have high carbon to nitrogen (C/N) ratios, which results in rapid immobilization of mineralized nitrogen by microorganisms early in the growing season. Once the C/N ratio decreases, the nitrogen will be released for crop uptake.

Other factors in determining the manure application rate are to account for N losses by volatilization and denitrification. Volatilization is affected by the method of manure application. Within four days of solid manure being broadcast, approximately 21 percent of the nitrogen may be loss through volatilization. If immediately incorporated, the loss can be reduced to 5 percent (USDA, 1979). Denitrification usually occurs in oxygen depleted soils and in the presence of a carbon source. In USDA (1979), denitrification coefficients are assigned according to hydrologic soil groups, (Table 4). To determine to 5 percent (USDA, 1979).

Table 2. Decay constants used by SCS-Wisconsin to estimate availability of manure.

Type of manure		Year 1	2	3	4. . . n
			Decay constant		
Dairy, fresh	0.50	0.15	0.05	0.05	
Dairy, stored	0.30	0.08	0.07	0.05	
Beef, fresh	0.75	0.15	0.10	0.05	
Beef, stored	0.35	0.15	0.10	0.05	

Taken from Petersen et al (1984)

Table 3. Approximate Mineralization Rates of Organic Nitrogen in Soil As Related to Climatic Regions in the United States.

Annual mineralization rate (percent) for year indicated *

Region	First	Second	Third and following
Cold-humid	15-25	10	5
Cool-humid	25-35	5	5
Warm-humid	35-45	5	3
Hot-humid	40-50	5	3
Cold-arid	10-15	10	5
Cool-arid	15-20	10	5
Warm-arid	20-30	10	3
Hot-arid	20-30	5	3

* After first year the mineralization rate is percent of residual organic-N.
Taken from White and Safley (1984)

Table 4. Multiplication factors to adjust manure applied to fields for nitrogen losses due to volatilization and denitrification.

Soil Group	Manure Management	
	Surface applied	Soil incorporated
A (sandy)	1.33	1.05
B (sandy, silty loam)	1.33	1.13
C (shallow, relatively heavy soil)	1.33	1.33
D (heavy clay soils)	1.33	1.67

Taken from USDA (1979)

Denitrification usually occurs in oxygen depleted soils and in the presence of a carbon source. In USDA (1979) denitrification coefficients Table 2. Decay Constants used by SCS-Wisconsin to estimate availability of manure-N.combined losses from volatilization and denitrification, volatilization losses were multiplied by the denitrification and volatilization coefficient (Table 4).

By using decay constants, mineralization rates, and losses the amount of N supplied by manure for optimum crop utilization can be estimated. Often, the nitrogen credit in manure is used for the first year, but not for the subsequent years. For heavier textured soils that have limited nitrate movement, the residual N should be accounted for. In sandy soils, it is difficult to determine how much residual nitrogen to account for since this may vary from year to year depending on spring and fall leaching.

Alfalfa

Legumes like clover, fescues, and alfalfa produce their own nitrogen through symbiotic fixation of atmospheric N_2. This is done by Rhizobium bacteria that live in nodules attached to the roots of legumes. For decades legumes have been used in legume-corn rotations to supply nitrogen to the following crop. Since the energy crisis in 1974, there has been a renewed interest in using legumes as a source of N. This practice continues, however commercial fertilizers are still added often without crediting nitrogen from the legumes. In the temperate zone of the United States, it is possible for legumes to produce 100-200 lb N/A (Tisdale et al. 1985). Alfalfa (Medicago sativa L.) is the most common legume raised by dairy farmers. In Wisconsin alfalfa can supply up to 140 lb N/A for succeeding crops (Bundy, 1985).

The release of available N from the breakdown of alfalfa residue depends on the alfalfa stand density. Bundy (1985) reports that alfalfa will supply 40 lb N/A plus 1 lb N/A for each percent legume density to the succeeding crop or 140 lb N/A for a full stand. If the legume stand is greater than 50 percent, and additional 30 lb N/A can be credited to the second year's crop following the alfalfa. Field trials on Wisconsin soils have shown that a full stand of alfalfa established for at least two years will provide all the N needed for the following corn crop, regardless of increased N fertilizer additions (Bundy et al., A3517).

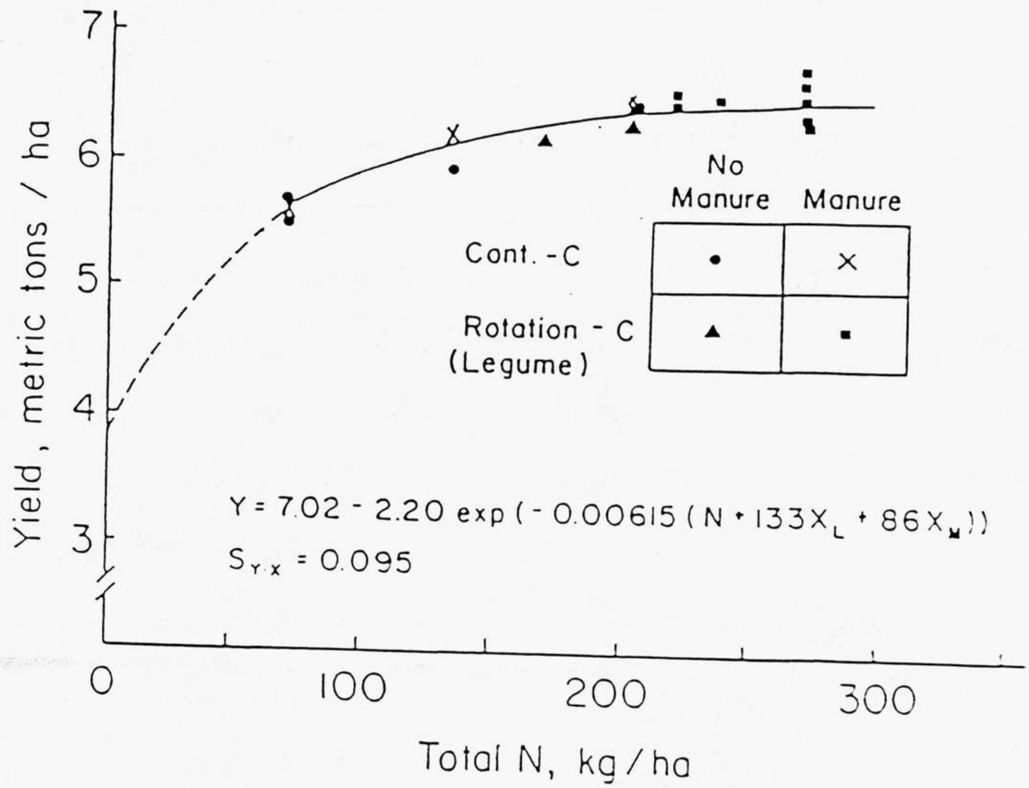
El-Hout and Blackmer (1990) surveyed the nitrogen status of corn after alfalfa in 29 Iowa fields. Farmers applied commercial nitrogen fertilizer at rates from 6 to 227 Kg N/ha (5 to 202 lb N/A) with an average of 136 Kg N/ha (121 lb N/A). Soil tests revealed that 25 out of 29 fields had greater than optimum nitrate concentrations, 17 of 29 had at least twice the critical concentration, and 6 of 29 had three times this concentration. If credits for nitrogen supplied by alfalfa are used, excessive nitrogen fertilization would be reduced increasing profitability of corn production and reducing the potential for groundwater contamination.

Hesterman et al. (1986) conducted research on the economic comparison of alfalfa-corn and continuous grain rotations. The alfalfa-corn rotation was much more profitable than continuous grain based on the alfalfa's forage value and the N contribution. Legumes may contribute more than nitrogen to subsequent years crop. Russelle et al. (1987) suggest that crop rotation along with the N supplied by legumes may improve corn yields. Radke et al. (1987) conducted a five year cropping study using rotation, conventional, and low input practices with legumes and manure rotations. During the first two years low-input systems corn yields were 60 percent of conventional practices. By the third year, corn yields were

80-90 percent of the conventional system and the fourth year corn yields were equal to or greater than conventional corn yields. Tisdale et al. (1985) also reported that under high-yield conditions continuous corn has a yield 15 percent lower than yields of corn in rotations.

Both alfalfa and manure are excellent sources of nitrogen for crop production. Long term studies looking at the effects of these two were performed in New York by Baldock and Musgrave (1980). Field studies conducted on fine-loamy soils from 1955 to 1968 looked at various effects of mineral fertilizers, manure, legumes, and there combinations in various five year rotations. Rotations of continuous corn showed no significant differences for mineral nitrogen applied due to the substantial N contribution from legumes and manure. They concluded through the use of nitrogen response curves that two years of alfalfa contributed the equivalent of 136 Kg N/ha (121 lb N/A) and the manure treatment contributed 68 Kg/ha (60 lb N/A) to the corn. This combination had additive effects of approximately 204 Kg N/ha (182 lb N/A). This cropping system reached the same maximum yield and fit a common nitrogen response curve indicating the N contribution of legume and manure on corn.

Figure 3. **Common N response curve for continuous grain yield, as a function of total N. (Adapted from Baldock and Musgrave, 1980)**



Manure Nitrogen for Corn Production

The value of manure for crop production has been known for many years. Since the early 1970's there have been numerous studies looking at the utilization of manure N for corn (Zea mays L.) production (Randall et al., 1975; Turner, 1975; Evans et al., 1977; Magdoff, 1978; Magdoff and Amadon, 1980; Mathers and Stewart, 1984; and Sutton et al., 1986). Many of these studies have looked at maximizing yields by applying maximum rates of manure, often in excess of crop uptake. From this literature application rates ranged from 34 MT/ha (15.2 T/A) to 636 MT/ha (283 T/A) per year. Most of these studies were on fine to medium textured soils which accumulated some of the excess nitrate-N in the soil column. Excess nitrate leaching to groundwater was a concern, but groundwater monitoring was not performed.

In the past manure was applied at rates for maximum crop production and for disposal rather than for it's optimum potential. Even if manure nitrogen is credited, the optimum rate of application is very difficult to determine. Factors like manure handling and management systems, differing amounts of nitrogen in the manure, rates of decomposition or mineralization, and nitrogen availability to crops are a few that make determination difficult. There are also conflicting conclusions on whether manure alone can supply the required N for optimum corn production.

Magdoff and Amadon (1980) determined that both dairy manure and inorganic N applications were necessary to obtain maximum yields of continuous corn silage on a clay soil. Solid manures are given little credit for supplying N due to volatile N losses from surface applications (Klausner and Guest, 1981; Lauer et al., 1976). However, Evans et al., (1977) showed that beef cattle manure applied at a rate of 224 MT/ha (99 T/A) produced corn yields comparable to commercial fertilizer, but concluded that this rate was too high for continued use due to rapid nitrate-N leaching and detrimental salt effects. Randall et al. (1975) determined that dairy manure incorporated at 400 MT/ha (178 T/A) on a clay loam during optimum summer conditions produced corn with little yield reduction the following year. Motavalli et al. (1985) demonstrated greater downward movement of inorganic nitrogen from commercial fertilizer than nitrogen from comparable [illegible] slurry rates. A study conducted by Mathers and Stewart (1984) incorporated [illegible]

Mg/ha (10 T/A) beef feedlot manure on a Pullman Clay loam soil for 14 years. They concluded that the annual applications supply the fertilizer needs of irrigated corn, wheat, and grain sorghum.

Sutton et al. (1986) conducted a six year experiment on a silt loam soil cropped to corn. Solid dairy manure was applied at rates of 34, 67, and 101 MT/ha (15, 30, and 45 T/A) and liquid dairy manure at rates of 112, 224, and 336 MT/ha (50, 100, and 150 T/A). No manure was applied the sixth year to determine the residual nutrient effects from the manure. Corn yields were as great of greater from plots supplied with manure as those with commercial fertilizers. They determined that liquid manure had higher levels of immediately available nitrogen then did solid manure. Even though total nitrogen in the solid manure as organic nitrogen was high, it was not as readily available due to immobilization by micro-organisms. Release of available N may not be at the proper time or in the amounts necessary to meet crop requirements for maximum or optimum yields. They concluded manures are less efficient than commercial fertilizers when comparing equivalent nutrient levels and that excessive applications of either manure increases the potential for considerable groundwater contamination.

Nitrates in Groundwater Associated with Manure Applications

Most studies in the past have looked at nitrate concentrations from manure applications in the soil profile and for crop production. Varying degrees of nitrate leaching have been suggested. During the past twenty years a few studies looked at nitrate-N concentrations in groundwater from manure application rates using well monitoring systems (Adriano et al., 1971; Liebhardt et al., 1979; Hubbard et al., 1987; and Patni and Culley, 1989). Patni and Culley (1989) investigated the effects of four method-and-time combinations of liquid dairy cattle manure on corn silage yields, shallow groundwater quality, and soil composition during a three year period and for two additional residual years with no treatments. The manure was applied at 90 T/ha (40 T/A) by fall plow down, pre-plant broadcast followed by discing, and post emergent sidedressing by injection and broadcast between rows. Also, a control and a treatment of pre-plant broadcast fertilizer to equal the amount of NH4+-N in the manure was added. No significant effects on yield were seen by the method used which was attributed to by the previous alfalfa crop at the site. Shallow (1-2 m deep) groundwater nitrate-N concentrations were all greater than the drinking water limit of 10 mg/L in all treatments including the control. This indicated that the limit is unlikely to be met with the normal recommended manure and fertilizer applications for corn production.

Hubbard et al. (1987) studied the effects of center pivot applied dairy cattle manure on surface runoff and shallow groundwater quality on a loamy sand in Georgia. A high and low rate of 91 and 44 kg/ha (81 and 39 lb/A) per month were used. Shallow groundwater nitrate concentrations were measured at 23 sites, each having piezometers at 1.2, 2.4, 3.6 meters. Mean monthly nitrate-N concentrations of 10-70 mg/L, 10-50 mg/L, and 5-35 mg/L were found in the shallow, intermediate, and deep piezometers, respectively. Between the two application rates no substantial differences in nitrate-N concentration were found in shallow groundwater. Flow net calculation were used to estimate the nitrate-N loads in shallow groundwater. Both high and low flow situations were used along with the highest nitrate-N concentration to estimate the monthly worst case nitrate-N loss. The highest nitrate-N estimates were lost during wet periods and the maximum flow months of December, January, and February at values of 9.0, 8.8, and 7.0 kg/ha/mo, respectively. Loads during the low flow periods of September and October ranged from 0.1 to 1.2 kg/ha/mo. A total of 57 kg/ha were lost from November 1983 to December 1984. During this same period, total nitrogen applied was 1182 kg/ha and 576 kg/ha for the high and low rates. This represents a loss of nitrate-N between 5 and 10 percent of total N applied. For these same two application rates total nitrogen losses from surface runoff were 85 kg/ha for the high rate and 19 kg/ha for the low. For the high and low application rates this represents 7.2 and 3 percent of applied nitrogen, respectively.

Residual Soil Nitrates

Soil profile nitrate test can provides substantial savings to corn grower by allowing reduced nitrogen fertilizer application rates. Residual soil nitrate tests performed at the University of Wisconsin Soil Testing Laboratory found an average of about 200 lb N/A in the top three feet sampling depth in the fall of 1990 (Bundy, 1991). The amount of nitrate-N carry-over will vary between fields based on soil type, over winter precipitation, and past crop management. The probability of significant nitrate carry-over is greatest on medium and heavy textured soils where over winter precipitation is normal to below normal. However, pre-plant nitrate tests are not recommended on sandy soils regardless of over winter precipitation because nitrate found before planting may be easily leached before crop uptake. Crop performance depends on previous crop management. Nitrate-N carry-over is likely where moderate or heavy nitrogen rates from fertilizer, legumes, or manure are used on second year corn or when crop yields are below normal due to weather, diseases, insects or other agronomic factors. No carry-over is likely for second year corn after legume if no fertilizer or manure-N is used on first year corn.

The soil texture is the most important factor that will effect residual soil nitrate accumulations. Another factor is the history of manure or other nitrogen applications. Roth and Fox (1990) concluded from long term studies in Pennsylvania on silt loam soils that manure application generally had greater soil nitrate concentrations than that of fertilizer used as a source of nitrogen. Results confirmed that the potential loss increases when nitrogen increases above crop needs, indicating the priority in managing nitrogen inputs to corn. This potential is increased in corn production systems that rely heavily on manure or fertilizer as a an nitrogen source which appear to pose the greatest threat to groundwater.

Methods and Procedures

Study Site

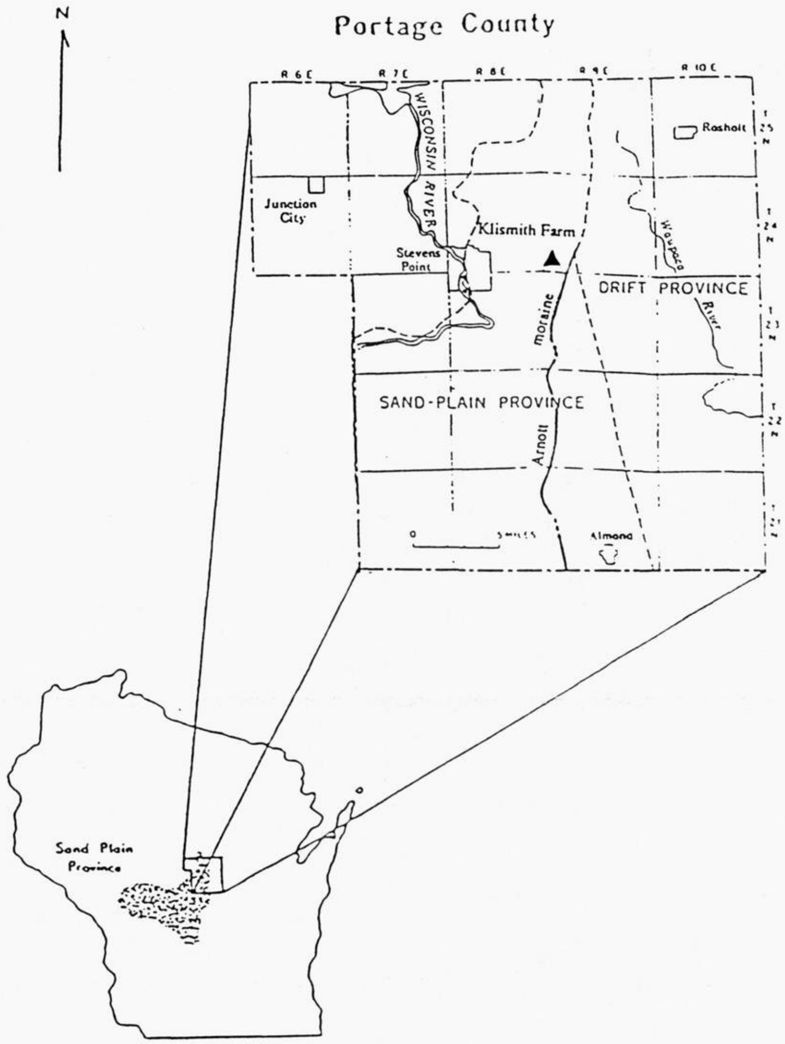
The demonstration field is located one and one half miles east of Stevens Point on Highway 10, in Portage County, Wisconsin on the Jeff and Donna Klismith Farm. (Range 9 East, Township 24 North, Section 30) Figure 4. This study site was selected based on the following three criteria: 1.) the field plots were located on coarse sandy soils; 2.) the groundwater was within four to six feet of the land surface; and 3.) previous animal waste research projects had been conducted at the site (Bowen 1987, and Travis 1988) along with existing owner cooperation.

Site Description

The study area lies within the glaciated sand plain region of Portage County known as the Central Sand Plain. The area consists of a thick and extensive outwash sand and gravel aquifer with small amount of silt and clay. The groundwater divide is west of the Arnott Moraine shown in Figure 4. All groundwater west of this divide flows to the west-southwest toward the Wisconsin River at approximately one meter per day.

The site consists of a Leola loamy sand soil except for the southeast corner of the field which is classified as a Markey shallow muck (USDA, 1978). The Leola series are deep, nearly level, somewhat poorly drained soils on outwash plains. These soils have a rapid permeability and a low available water capacity. The water table is less than three feet during periods of wetness. The Markey shallow muck is a poorly drained organic soil. The organic layer is 16 to 24 inches thick over sand. Permeability is moderately rapid with a high available water capacity. The area is farmed with minimum difficulty since sufficient drainage occurs due to the drainage ditches located along each side of the field.

Figure 4. Manure Best Management Practice field demonstration site location. (Adopted from Saffigna and Keeneym 1978 and Holt, 1965)

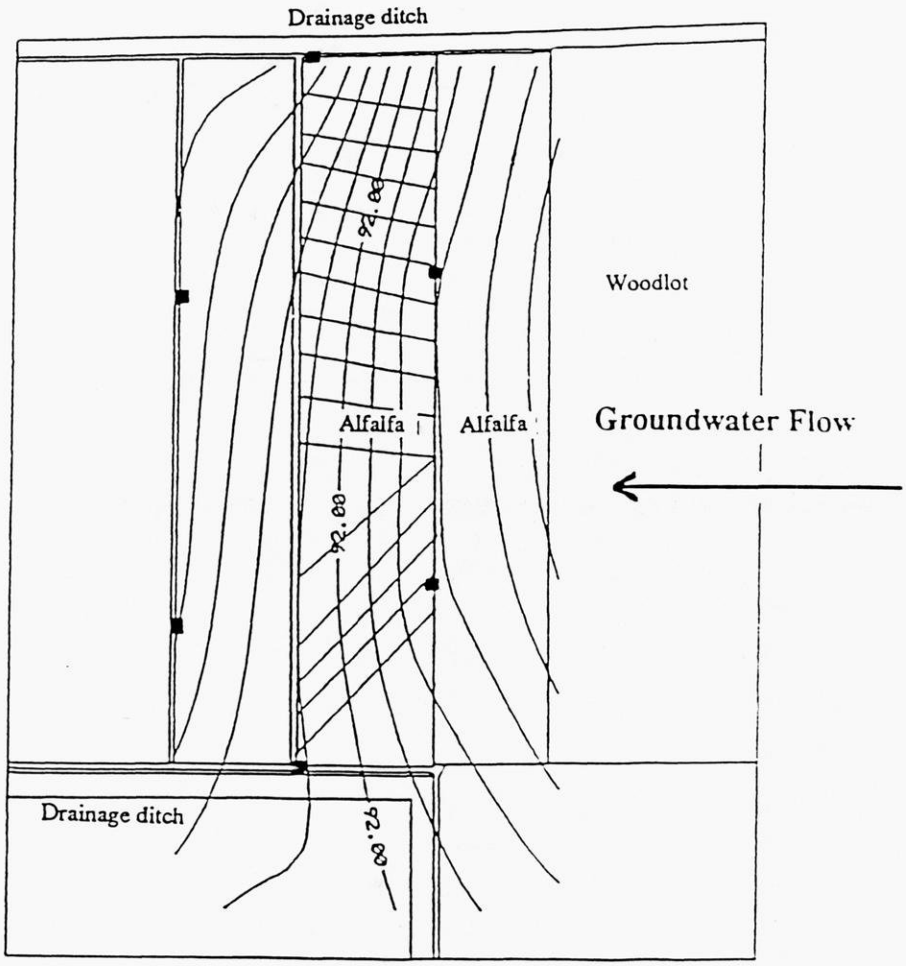


Field Layout

The demonstration plots were located on a ten acre field that been planted to alfalfa for the previous five years. A woodlot lies to the east of the field. The field was bordered by a drainage ditch on the north and the south end and west side.

The ten acre field was split into two fields (Figure 5). For the 1989 growing season, six acres were planted to corn. For the 1990 growing season, the original six acres were used as second year rotation corn and the remaining four acres were planted to corn.

Figure 5. Initial groundwater flow and surrounding land use.



April 7, 1989

Initial Groundwater Investigation and Plot Layout

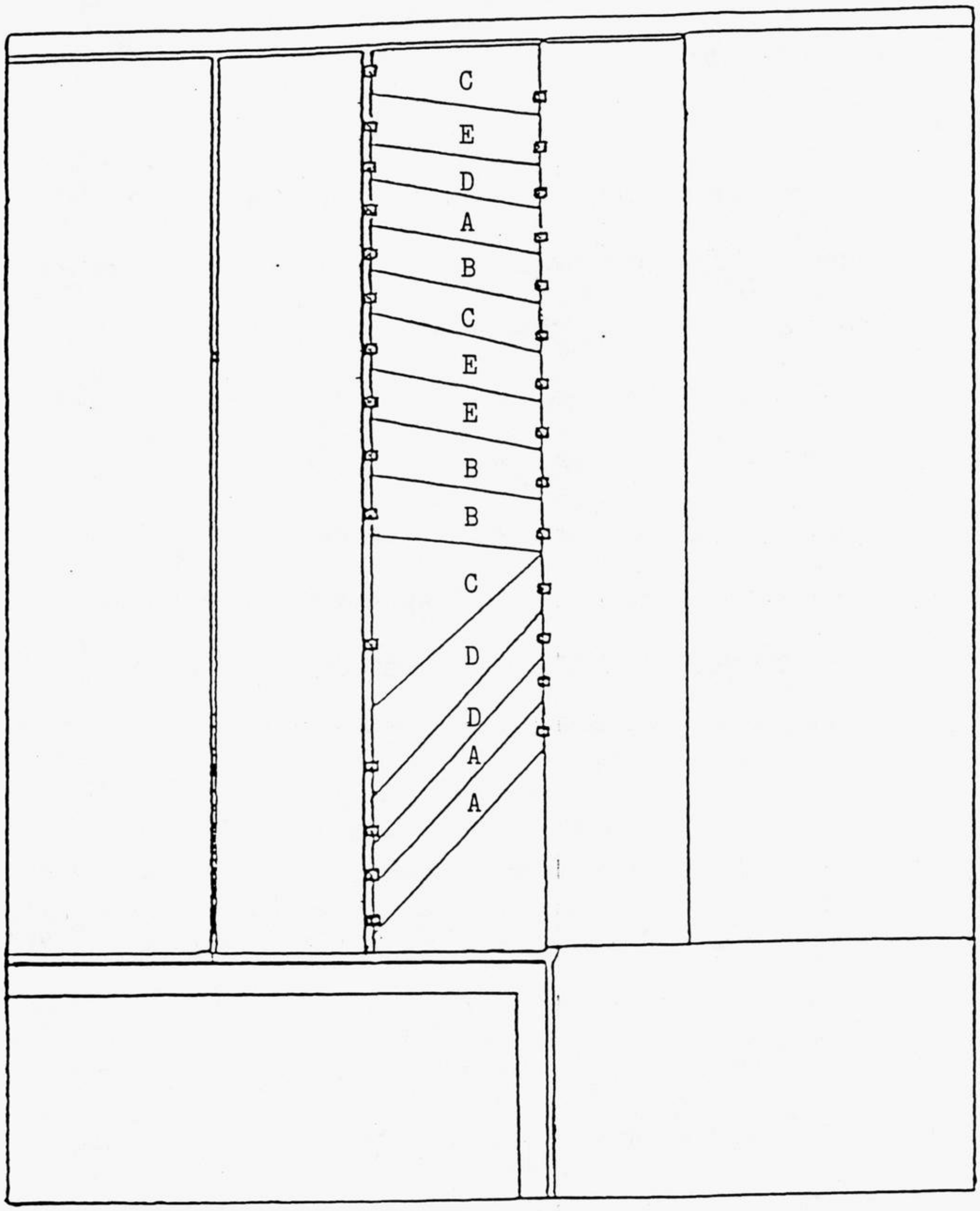
Initially six screened piezometer wells were installed throughout the demonstration field. From these six wells groundwater elevations were used to determine groundwater flow, generally from east to west. The flow was straight east to west in the center of the field, and a gradual change in flow toward each of the ditches at both ends of the field. Figure 5 shows the initial survey wells along with groundwater flow.

From the initial groundwater flow, the plot layout for the 1989 field season was determined. Since groundwater was to be monitored upgradient and downgradient of each plot, the fifteen plots were orientated in the direction of groundwater flow. For the 1990 field season the original fifteen plots remained the same as the 1989 season. The nine new plots were again oriented with groundwater flow. The new plots were approximately doubled in size from the original fifteen plots due to observed changes in groundwater flow that resulted in flow crossing the plot boundaries of the smaller plots used in 1989. Figures 6 A and B show the plot layout for each field season.

Well Construction

The six original survey piezometer wells were constructed of 1.25 inch, inside diameter, Schedule 40 PVC pipe with a one-foot slotted PVC well screen. These were installed approximately five feet into the aquifer using a trailer mounted auger with four foot flights. Once plot layout was determined, the upgradient and downgradient multiport monitoring wells were installed. Each multiport monitoring well or well nest, was constructed of three 0.75 inch, inside diameter, Schedule 40 PVC pipe with a one-foot, 0.01 inch slotted PVC well screen bound together with nylon strapping tape. A four inch bucket auger with extensions was used to bore the holes for well installation. The well nest was placed into the hole at the desired depth and back filled with the removed material from each one-foot interval. Bentonite powder was used to seal the wells for the last two feet to prevent

Figure 6. Plot layout and treatments used for the 1989 and 1990 field seasons.

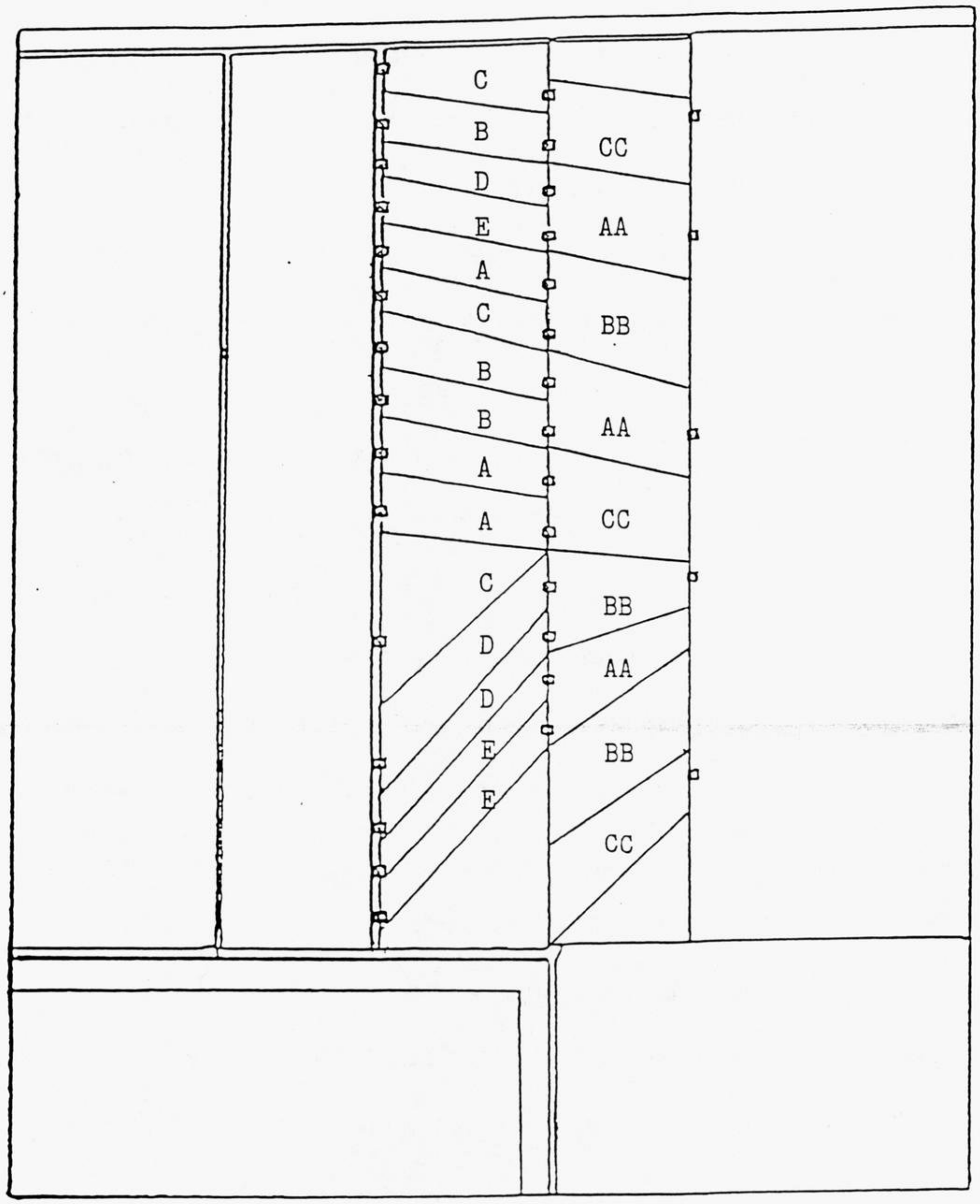


MANURE BEST MANAGEMENT PRACTICE - 1989

Treatments

A - 7.6 Tons/Ac Manure + 65 lbs N/A
B - 15 Tons/Ac Manure + 65 lbs N/A
C - Control + 65 lbs N/A
D - 23 Tons/A Manure + 65 lbs N/A
E - 15 Tons/A Manure

Figure 6 B. Plot layout and treatments for the 1990 field season.



MANURE BEST MANAGEMENT PRACTICE - 1990

Treatments

A - 11 Tons/A Manure
B - 22 Tons/A Manure
C - Control
D - No Treatment

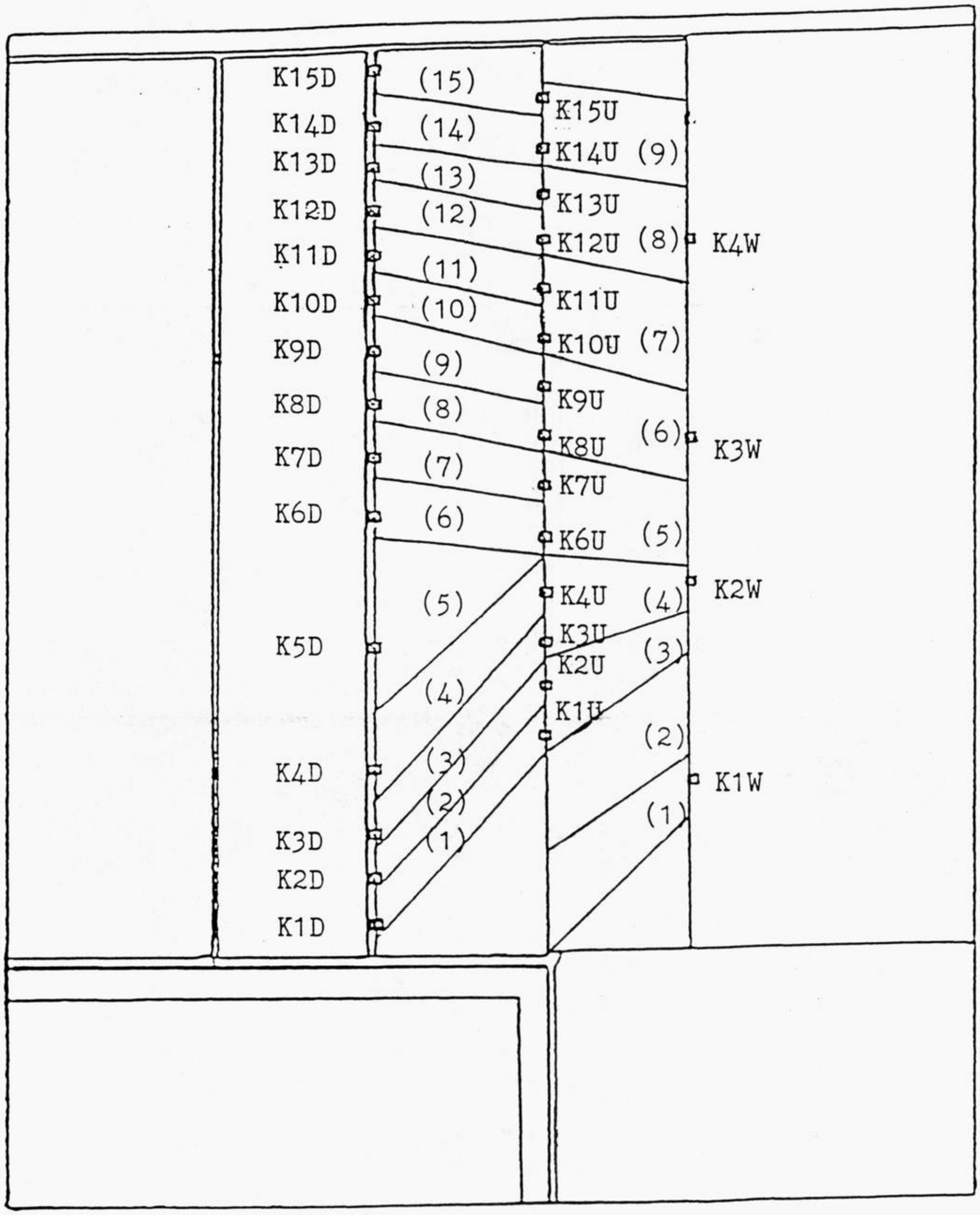
E - Sidedress N 45 lbs/A
AA - 11 Tons/A Manure
BB - Sidedress N 45 lbs/A
CC - Control

vertical water movement along the pipes. An eight inch steel culvert, with cap, was placed over each well nest for protection.

Each well nest was designed to sample at various depths. Originally, the three wells were positioned to sample water at: one-foot above the initial water table, which would allow for rises in water; one-foot into the aquifer; and two -feet into the aquifer. Due to a falling water table during the summer of 1989, a fourth single well point was installed in September at each downgradient well nest to sample three feet into the aquifer. Figure 8 shows a well nest profile and how they were arranged. At the end of 1989 there were fourteen upgradient well nests with three points each, and fifteen downgradient well nests with four points at each nest.

For the 1990 field season it was determined that fewer upgradient wells were needed for the new field. So, only four multiport well nests, with four points each, were installed at intervals along the upgradient side of the new field. The downgradient wells for the new field were 1989's upgradient wells. To complete downgradient monitoring of the new field, four four-point multiport well nests were also installed. The original fifteen downgradient well nests were left in place for monitoring the second year of the rotation. A fifth single well point was installed four feet into the aquifer, at six well nests along the downgradient side. Figure 7 indicates where the well nests were installed, and Table 5 outlines the wells and the number of points at each.

Figure 7. Plot layout and monitoring well locations.



MANURE BEST MANAGEMENT PRACTICE

Monitoring Well Locations

☐ - 3/4" multi-port Wells
() - Plots

Figure 8. Well nest profile.

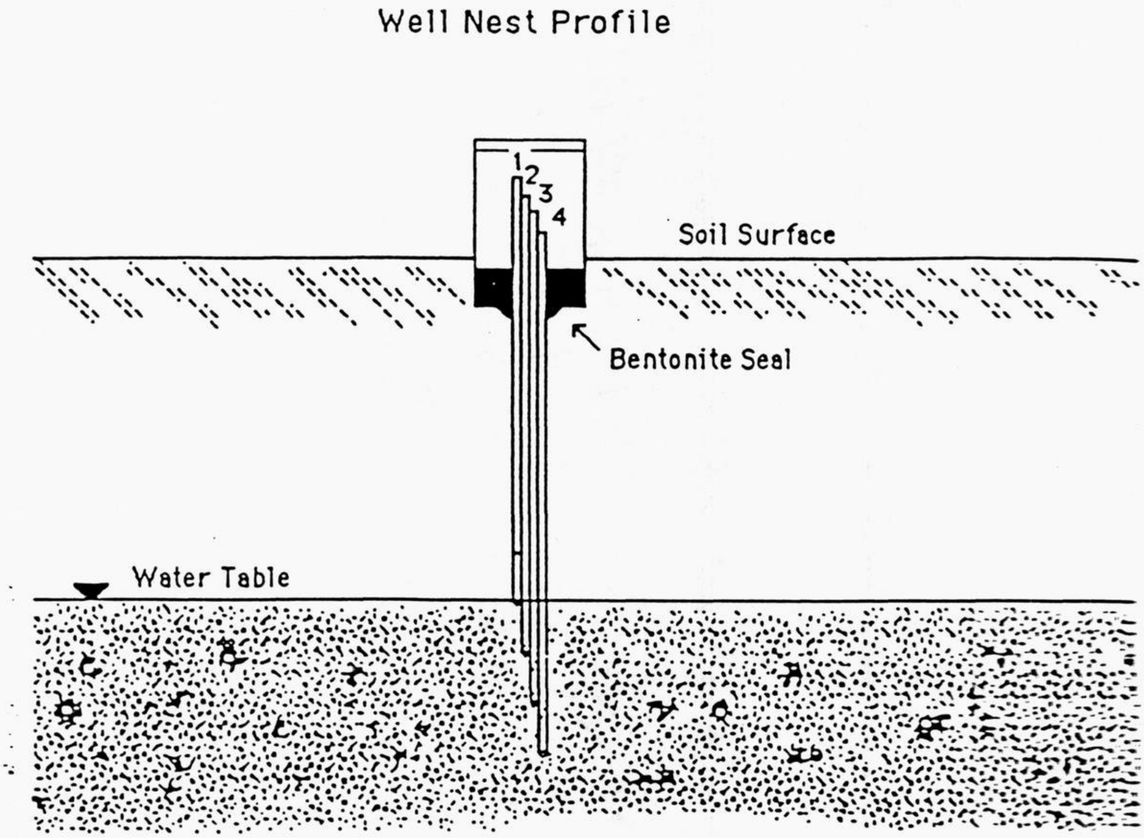


Table 5. Well locations and number of points.

Old Field

Plot	Upgradient	Number of points	Downgradient	Number * of points
1	K1U	3	K1D	4
2	K2U	3	K2D	5
3	K3U	3	K3D	4
4	K4U	3	K4D	5
5	----		K5D	5
6	K6U	3	K6D	4
7	K7U	3	K7D	5
8	K8U	3	K8D	4
9	K9U	3	K9D	5
10	K10U	3	K10D	4
11	K11U	3	K11D	4
12	K12U	3	K12D	5
13	K13U	3	K13D	4
14	K14U	3	K14D	4
15	K15U	3	K15D	4
Total		42		66

* Fourth point installed Sep 1989
Fifth point installed Jul 1990

New Field

1	K1W	4	K1N	4
			K2N	4
2	None		K3N	4
			K4N	4
3	None		K1U	
			K2U	
4	K2W	4	K3U	
			K4U	
5	None		K6U	
			K7U	
6	K3W	4	K8U	
			K9U	
7	None		K10U	
			K11U	
8	K4W	4	K12U	
			K13U	
9	None		K14U	
			K15U	
Total		16		16

One and one-quarter inch wells

K1W	1	N1A	1
K2W	1	N1B	1
K3W	1	N1C	1
K4W	1	N2A	1
K5W	1	N2B	1
K6W	1	N2C	1
Total	6		6

Total number of well points = 152

Groundwater Sampling

Groundwater sampling was scheduled throughout the year. During the growing season, May to October, it was attempted to sample all wells twice a month. The rest of the year, November to April, wells were sampled once a month, weather permitting.

Groundwater elevations were determined on all wells from which samples were taken, by using a measuring tape with a brass popper attached at zero. The water table was recorded to the nearest 0.01 of a foot. All recorded depths were then converted to relative elevations from an arbitrary datum of 100.00 selected at the site.

Samples were taken by inserting one end of teflon tubing to the bottom of the well with the other end attached to a peristaltic pump. Water was purged until approximately three well volumes was discharged as recommended by Wisconsin DNR, (1987). Distilled water was used to rinse the pump tubing before taking samples. A grab sample was then pumped into 125 ml or 250 ml bottles. The bottles were prepared by acid washing, triple rinsing, and filling with distilled water. Samples were stored on ice during warm weather and then transported to the lab and refrigerated until analyzed. No preservatives were used for the normal grab samples. Concentrated sulfuric acid was used to preserve samples to be analyzed for Chemical Oxygen Demand (COD) and total phosphorus.

Water Analysis

Analysis was performed by the UWSP Environmental Task Force, a state certified analytical lab in the College of Natural Resources, using standard methods. Each sample was analyzed for pH, conductivity, nitrate-N and nitrite-N, ammounium-N, Cl-, and reactive PO4. On one sample date additional samples were taken for COD and total phosphorus analysis. Initial water samples were also analyzed for total hardness, alkalinity, Na^+, K^+, and $SO4^-$ to document initial groundwater chemistry. Dissolved oxygen of samples using the Winkler Method was conducted on wells that were thought to have denitrification occurring. Water was overflowed two to three times the D.O. bottles' volume and then fixed with concentrated H_2SO_4 for transport to the lab for titration. A Technicon Autoanalyzer II and Lachat Quik Chem Autoanalyzer was used for analyzing nitrate and nitrite-nitrogen, ammonium-nitrogen, chloride, reactive and total phosphorus.

Soil Sampling

Soil sampling was conducted throughout the project. Soil fertility tests were taken each year prior to planting for proper fertility recommendations and corrections. In addition to the fertility tests, a pre-plant, late spring, and fall residual soil nitrate sampling was done each year. Residual soil nitrate samples were taken as recommended by the University of Wisconsin Soil & Plant Analysis Laboratory (University of Wisconsin Extension, Bulletin A3512). One soil sample was collected from the center of each plot using a four inch bucket auger and composited in foot intervals from 0-1, 1-2, and 2-3 foot depths. The samples were air dried 24 to 48 hours. They were then sieved through a No. 10 sieve and analyzed by the Bremner-Keeney Method (Keeney and Nelson, 1982) of direct steam distillation for ammonium-N and nitrate-N.

Manure and Fertilizer Treatment, Analysis and Application

To determine the rate of manure application, calibration of the manure spreader was required. Each year before manure application three six by eight foot sheets of plastic were laid out in a row. The tractor and the spreader was driven over the sheets at the normal ground speed and spreader setting used by Jeff Klismith.

Each sheets contents were weighed and converted to a tons per acre application rate. During application, one trip was made over the plot for the lighter application rate. For the plots receiving heavier rates, a second or third pass was made over the plot. The manure was applied in late April to the designated plots and incorporated with a tandem disc the next day. Figure 6 shows the application rates for each plot for 1989 and 1990.

Before the manure treatments were applied each year composite manure samples were collected from the stacked manure piles as it was being loaded into the spreader for application. Samples were placed in zip lock bags and frozen until transport to the lab. The manure samples were taken to the University of Wisconsin Experimental Research Farm Laboratory at Marshfield, Wisconsin for analysis. The lab analyzed for percent dry matter, total N, NH_4-N, S, K, and P expressed as K_20 and P_2O_5, respectively. The results showed the total amount in the sample and estimated how much would be available the first year, expressed in pounds per ton.

Commercial sidedress nitrogen fertilizer was applied to the designated plots in late June 1989 and early July 1990. Dry ammonium nitrate fertilizer (containing 37 percent N) was incorporated in the rows with a two row cultivator capable of turning the fertilizer flow off and on between plots. The cultivator applicator was calibrated in the same manner as the manure spreader and converted to pounds nitrogen per acre. Figure 6 shows the plots and rates applied for 1989 and 1990.

Tillage, Fertilization, and Planting

All tillage was by conventional methods following practices used by Jeff Klismith. Each year alfaifa fields were disced in the fall 1988 for the 1989 season and in the spring of 1990 for the second field.

Each year before planting, 0-0-60 potash fertilizer was broadcast and incorporated at a rate of 200 pounds per acre to the field. In the spring of 1989, two tons per acre lime was applied and incorporated.

Pioneer variety 3737, 100-day corn, was planted at a population of 21,000 seeds per acre in 38 inch rows on May 23 and May 22 for the 1989 and 1990 field seasons, respectively. During planting a starter fertilizer of 10-20-19 was applied at a rate of 200 pounds per acre.

Each year weed control was achieved without the use of herbicides. After emergence, a rotary hoe was used for initial weed control. In late June and early July additional weed control was accomplished by one trip with a row cultivator in conjunction with the nitrogen sidedress application. No insecticide applications were used either year.

Yield Test

In late October of each year yield tests were taken from each plot. In 1989 representative samples were taken from each plot by picking four twenty-five foot sections of rows in the center of the plot, at random distances across the plot. In 1990, six twenty-five foot sections were picked for a better representative sample. From each harvested sample total weights, number of ears, and number of stalks were recorded. Four to six representative ears were selected at random from each sampling, shelled, and placed in zip lock bags for moisture tests. The shelled corn was air dried to constant weight and sub-samples oven dried to calculate percent moisture. All weights were then corrected to 15.5 percent moisture.

Determination of Density of Alfalfa Stand

The density of alfalfa stands was determined each year by taking numerous random samples throughout the field. A one foot square inside diameter ring was tossed throughout the field and the number of alfalfa crowns counted for density stand to give proper nitrogen crediting to the alfalfa.

Precipitation and Evapotranspiration Data

Precipitation records used during this study were supplied by the Stevens Point Water Department. An on-site precipitation event recorder was installed during the summer of 1990 for comparison of data. Also installed was a water level recorder. The data obtained is limited due to continued mechanical difficulties.

Evapotranspiration (ET) data used was obtained from the University of Wisconsins' Hancock Agricultural Experimental Research Farm, Hancock Wisconsin.

Water Budget Calculations

A water budget was calculated each year to find when and how much recharge occurred. Precipitation and evapotranspiration (ET) was divided into weekly amounts for the month. Evapotranspiration data that was not obtained from the Hancock Experimental Farm was estimated. In April a beginning soil water content was determined. This was done based on the average available water capacity of the top thirty-six inches of the Leola soil series (USDA, 1978, Table 7) An averages of 0.12 inches of available water per inch of soil equals 4.32 inches of water in the top 3 feet of the soil profile. The end soil water content was calculated by subtracting ET from precipitation and in turn adding that to the beginning soil water content. If this amount was greater than 4.32 inches, the excess amount was shown as recharge. The rest of the weeks were calculated the same way. If there was recharge then the next weeks beginning soil water content started at 4.32 inches. If there was not enough precipitation for recharge to occur than that ending soil water content was used as the next weeks beginning soil water. The amount of this ending water soil depended on the amount of precipitation that week. If it rained enough to make up the deficit the next week would start at 4.32 inches. If there was no rain than the deficit would continue. The water budget for the two years can be found in Appendix C. The amount of recharge for each month is shown in Table 7 in the results and discussion section.

Hydraulic Conductivity Measurements and Calculations

In April 1991 groundwater hydraulic conductivity measurements were taken with a programmable pressure transducer data-logger. The data-logger measured changes in hydraulic head to 0.01 feet at a rate of five readings per second for a total of 300 measurements every minute. The measurements were taken three times on each of the initial six 1.25 inch survey wells. During each run, the pressure transducer probe and a three or five foot by 0.50 inch weighted slug were lowered into the well. Water levels were allowed to stabilize for approximately five minutes. The data logger was turned on and the slug was rapidly pulled out of the well. After automatically turning it-self off, a paper tape print out was retrieved for a hard copy of the results. The data-logger stored each run in it's memory were it was downloaded into a computer. Each run was plotted using Hvorslev's method which determines hydraulic conductivity of a formation with screens installed and for wells which the length is eight times the radius of the well screen, $L/R > 8$ (Fetter, 1988). The data is plotted by computing h/ho verses time, were h is the height of the water level after some time t, and ho is the height of static water level before the slug is removed, and plotted on semi-logarithmic paper. The drawdown data should plot a straight line (Figure 9). From the graph, To is read at 37 percent and applied to the following formula:

$$K = \frac{r^2 \ln (L/R)}{2LT_o} \qquad \text{(Equation 1)}$$

where:

K - is hydraulic permeability
r - is the radius of the well casing
R - is the radius of the well screen
L - is the length of the well screen
T_o - is the time it takes for the water level to rise or fall to 37 percent of the initial change

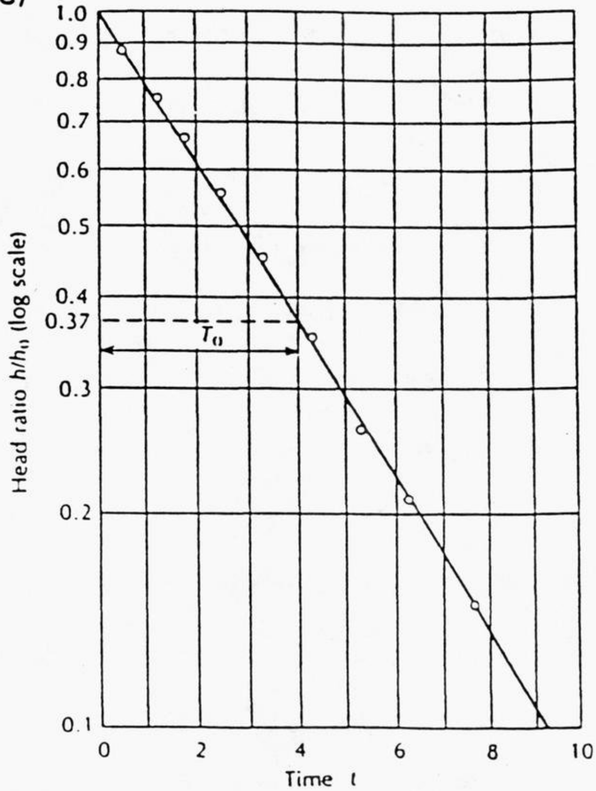
To find the rate of water movement under each plot, the results from above were used in Equation 2 to calculate an average linear velocity, which is the rate that water actually moves through a porous medium:

$$V_x = \frac{Kdh}{n_e dl} \qquad \text{(Equation 2)}$$

where:

Vx - is the Average Linear Velocity
K - is the hydraulic conductivity
dh/dl - is the hydraulic gradient
n_e - is the effective porosity

Figure 9. Plot of head ratio versus time used for Hvorslev method. (Adopted from Fetter, 1988)



Groundwater Mass Balance Calculations

The next series of calculations were done to estimate the amount of nitrate-N leached to and in the groundwater below each plot. Since not enough wells were placed deeper in the aquifer at all sites so that a more accurate plume depth could be determined, best estimates of plume depth were used. For each sample nitrate-N results were graphed for concentration verses depth for downgradient wells. Concentration gradients and the slope of plotted data would reflect recharge events between sample dates which may help estimate plume depth.

To calculate the concentration of nitrate in the groundwater a weighted average method was used. Each well monitors one foot of water with its one foot screen. The upper well point sampled for each well nest would have more than or less than one foot of water above the bottom of the screen, depending were the water elevation was at time of sampling. To find the depth of water in the upper well the well point elevation was subtracted from that well's groundwater elevation. The depth of water was then multiplied by that well's nitrate-N concentration resulting in a weighted nitrate concentration. These weighted concentrations were than averaged with the rest of the wells in the nest to get an average nitrate-N concentration for that sample date. This same procedure was also done for the next sample date and an average nitrate-N concentration for that well nest was calculated between the sample dates.

Nitrate-N values in groundwater varied widely with depth and over time. This makes the use of plume data from estimating nitrate-N loading to groundwater subject to many errors. A simple method using only groundwater nitrate-N data for the shallowest well port was chosen to estimate nitrogen loss to groundwater from each plot. The average nitrate-N concentrations over the sample year was multiplied by the calculated amount of groundwater recharge to obtain the estimate of pounds per acre nitrogen loss to groundwater for each plot and treatment.

Statistical Analysis

All statistical analysis was done using the SPSS-X 3.1 Statistical Program. An Analysis of Variance (ANOVA) test for statistical differences between the different treatments applied two design structures were used. The corn yields were tested using a Oneway completely random design structure. The second design is based of the of the quantities of nitrate in groundwater from each of the different treatments. A repeated measures design structure was used for this analysis. (Hicks, 1982, Rogers, 1991)

Results

Precipitation, Recharge, and Evapotranspiration

The amount of leaching of nitrate-N to groundwater is largely effected by the timing and amount of precipitation, which also effects water use by plants as well as plant growth. Large differences occurred in 1989 and 1900.

Table 6 presents the precipitation data for the study period duration from the normal and the calculated evapotranspiration and groundwater recharge. These data show a deficit of precipitation occurring through most of the growing season in 1989, with little groundwater recharge occurring after the heavy rains in May. In 1990, adequete precipitation resulted in much better growing conditions and better crop yields, as presented later in this report. Excess precipitation in early 1990 resulted in significant groundwater recharge resulting in large amounts of leaching of nitrate-N that was in the soil from 1989 nitrogen inputs. These data are presented graphically in Figures 9 A through C. The significance of these data will become obvious as yield and groundwater results are presented.

Figure 10 presents the hydraulic conductivities measured for 6 wells in the study site. This figure also presents the average linear velocities calculated for these well locations.

After performing the slug tests on the six survey wells, an average horizontal hydraulic conductivity (K) for the field was calculated using Hvorslev's Method (Equation 1, Methods and Procedures). Obviously there was a great variation in the results from each of the slug tests, but to estimate the outflow of groundwater from the plots, an average K was used for simplicity. The K ranged from 342.00 to 828.28 ft/day (1.2 x 10-3 to 2.91 x 10-3 m/s), with an average of 526.48 ft/day

Table 6. Monthly summary of Precipitation, Evapotranspiration (ET) and Recharge. April 1989 to April 1991.

Environmental Data

1989 Field Season

Month	Precipitation	Monthly Total: Departure from Normal	(Inches) ET	Recharge
January	0.42	-0.55	----	----
February	0.53	-0.48	----	----
March	2.43	0.43	----	----
April	0.71	-2.14	0.27*	0.44
May	8.52	4.74	2.21	6.31
June	1.27	-2.33	2.29	0.42
July	2.48	-1.31	5.34	0.00
August	3.68	-0.11	3.83	0.00
September	3.23	-0.49	1.18	0.00
October	4.12	1.81	0.77	0.00
November	1.27	-0.54	0.46*	0.00
December	0.32	-0.99	0.12*	0.10
Total since April	25.60	-1.36	16.47	7.27
Year Total	28.98	-1.96		

Temperature Growing season temp = -1.3 degrees F below normal

First Fall Frost September 23

* - Estimated

1990 Field Season

Month	Precipitation	Monthly Totals (Inches) Departure from Normal	ET	Recharge
January	1.11	0.14	0.05*	1.07
February	0.63	-0.38	0.08*	0.54
March	2.86	0.00	0.15*	2.75
April	2.28	-0.57	0.28*	1.96
May	4.25	0.47	1.95	3.62
June	6.46	2.86	4.30	1.14
July	2.82	-0.97	4.91	0.00
August	4.72	1.15	4.03	0.00
September	3.23	-0.49	3.13	0.00
October	2.00	-0.31	2.30	0.00
November	0.83	-0.98	0.95	0.00
December	2.17	0.86	0.29	0.00
Total	33.36	1.78	22.42	11.08

Temperature Growing season temp = -.1 degree F below normal

* - Estimated

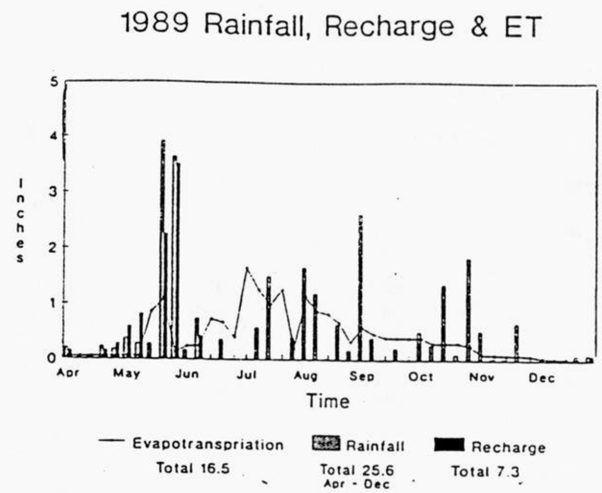
First Fall Frost October 10

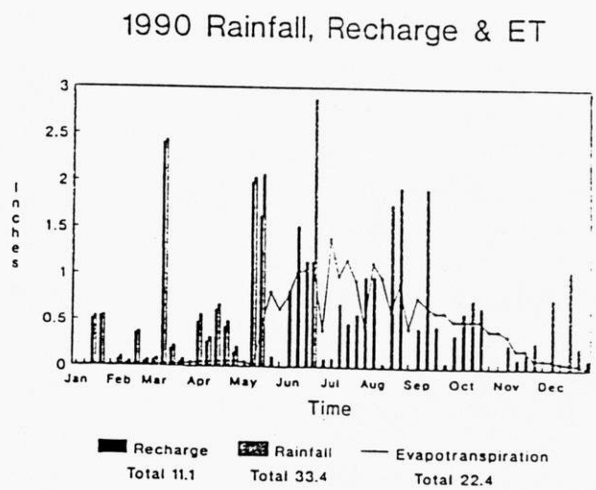
Table 6 (continued)

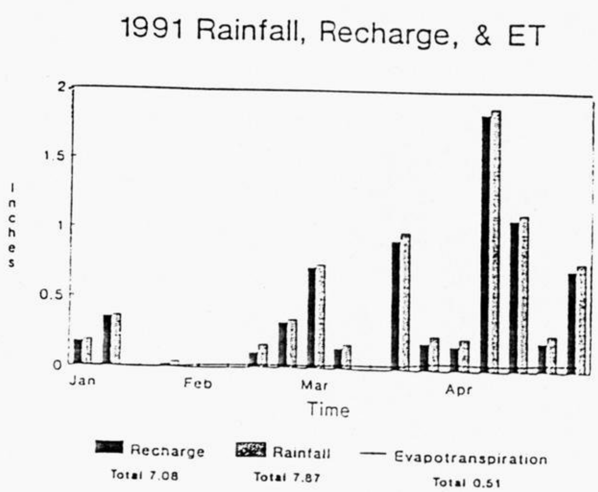
1991 Month	Monthly Totals (inches) Precipitation	Departure from normal	ET	Recharge
January	0.61	-0.36	0.04*	0.57
February	0.80	-0.21	0.08*	0.44
March	2.17	0.02	0.16*	2.01
April	4.29	1.31	0.23*	4.06
Total	7.87	0.76	0.51	7.08

* - Estimated

Figure 10. Rainfall, Reacharge and Evapotranspiration for 1989 to 1991.





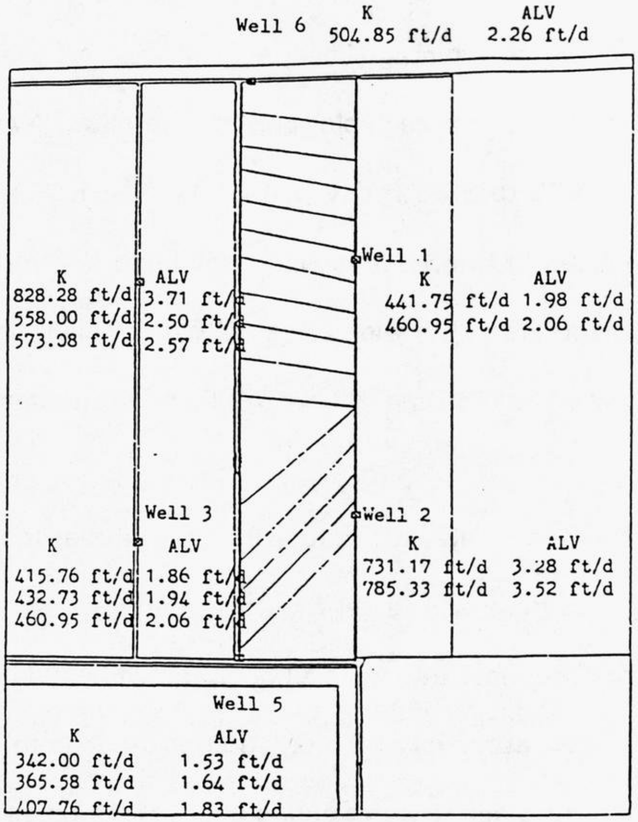


(1.85 x 10-3 m/s). Using this average K, the hydraulic gradient from each plot, and an effective porosity of 0.30, an average linear velocity (using Equation 2 Methods and Procedures) was calculated for each plot and sample date. Average linear velocities ranged from 0.695 to 5.60 ft/day (2.44 x 10-6 to 1.96 x 10-5 m/s). Comparing these the values to the Stevens Point well field, which is approximately two miles from the project site, all of the values fall within this range and are feasible for outwash materials (Portage County Wellhead Protection Ordinance, 1990).

The plotted groundwater elevations for 1989 reveal that the flow rate at the northern end of the field is generally faster than the center and southern end. Reviewing the distances groundwater traveled between sample dates, a large variation in calculated flow rate exists from one end of the field to the other. For most samplings the flow rate at the north end is about three times faster than the southern end and about twice as fast as the center of the field. This is in agreement with the K and average linear velocity values (Figure 10). Between the two fields, the second year field had overall faster groundwater flow than the first year field. The first year field had a flow rate of about 1.5 ft/day (5.28 x 10-6 m/s), which is close to that of the southern plots of the second year field.

During the two years several minor changes in groundwater flow and elevation took place. One change was the direction of groundwater flow under some of the southern plots of the second year field. During both summers, mainly June, July, and August, groundwater flow under Plots 1 through 4 changed from the curved pattern of the original flow (Figure 5) to more of a straight east-west direction (Figures 11 A, B, C, and Figures 12 A, B, and C). This can be accounted

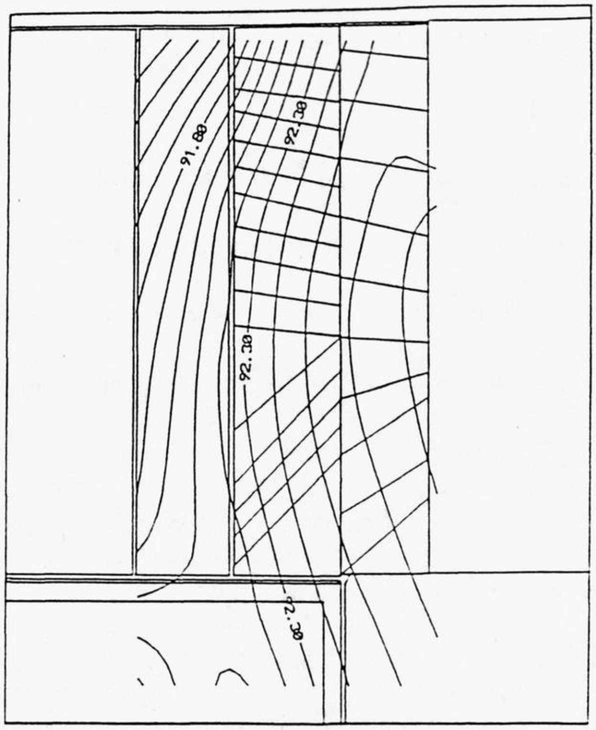
Figure 11. Measured hydraulic conductivities and average linear velocities.



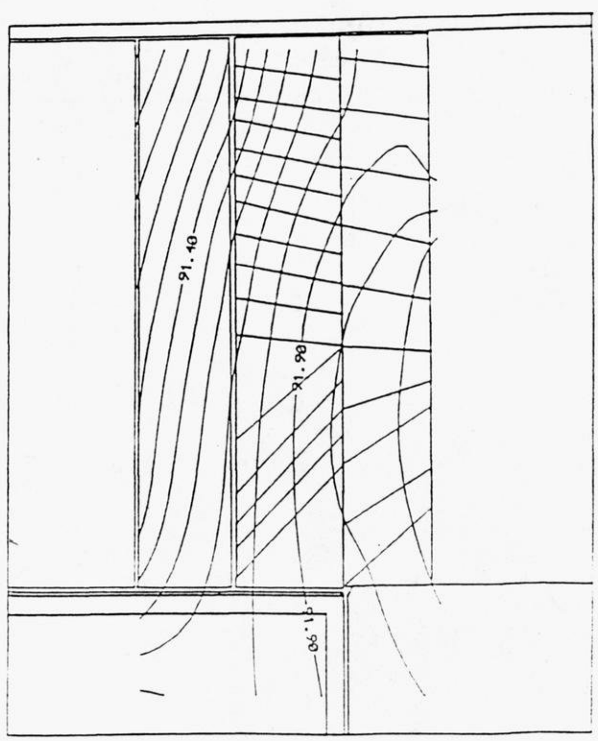
for by a lower water table during the dryer summer months. During dryer periods, the service ditch adjoining the plots was dry and did not act as a discharge source. During the wetter periods of the year, the southerly flow resumed. Due to these changes, the groundwater samples for Plots 1 and 3 were not used in calculation of nitrate-N concentrations. These flow changes may have caused water that infiltrated from one plot to flow across to the next plot, possibly affecting the groundwater under these plots and not reflecting what truly came from those treated plots. For this reason, the plots for the 1990 field season were made twice as wide as the original plots.

Another change was the groundwater elevation itself. The water table ranged from about 3.5 to 6 feet (1.06 to 1.82 meters) below the land surface. All the wells were placed in relation to the original water table from the six survey wells in the spring of 1989 (Figure 11). Over the two years the groundwater elevation had an average of 91.45 feet with a fluctuation of 2.19 feet. In Figure 14 the fluctuation over the two years can be seen. The two inches of below normal precipitation in 1989 caused a drop in the water table. However, the 8.52 inches on rain in May 1989 caused the water table to peak at 92.18 feet for the year. The lower water levels in 1989 are in part a result of the drought conditions in 1988. The water table continued to drop throughout the summer months and reached a low of 90.63 feet in October before rising slightly. Due to the drop, only the number 3 port in the downgradient wells was yielding water. Since not enough samples were being collected from each plot, in September a fourth well was installed in each downgradient well nest one foot deeper than the number 3 well. After below normal levels in 1989 normal spring rains and snow melt helped return groundwater elevations to an average level of 91.48 feet in 1990. Above normal precipitation in May and June 1990 caused a summer peak in June of 92.08 feet. After June, elevations fell due to lack of recharge, increased ET, and crop uptake

Figure 12. Groundwater flow direction below the study plots for three dates in the summer of 1990.

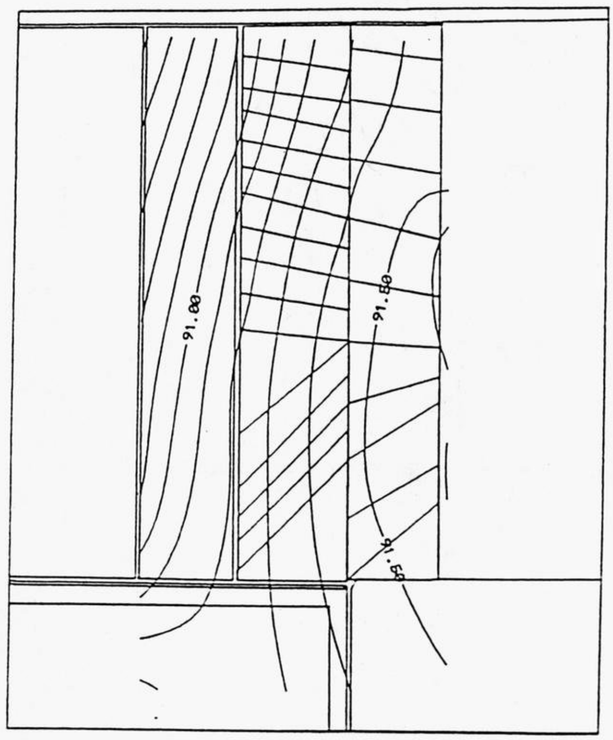


June 27, 1990



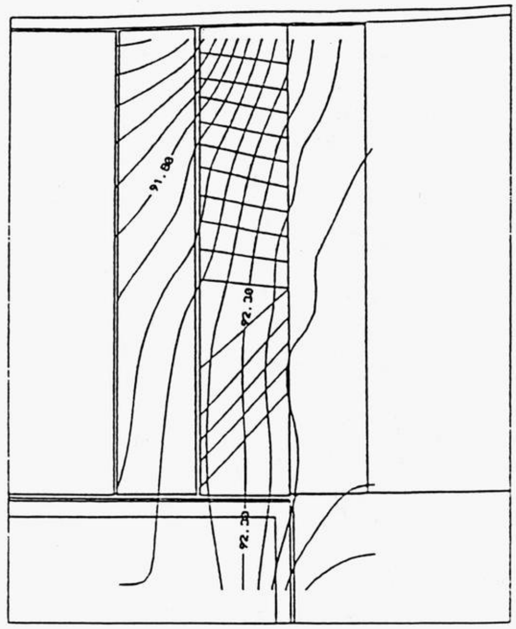
July 18, 1990

Figure 12(continued)

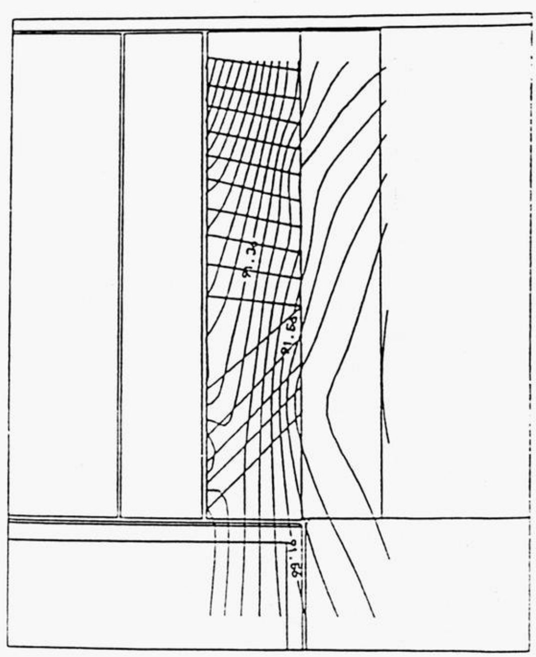


August 8, 1990

Figure 13. Groundwater flow direction below the study plots for three dates in the summer of 1989.

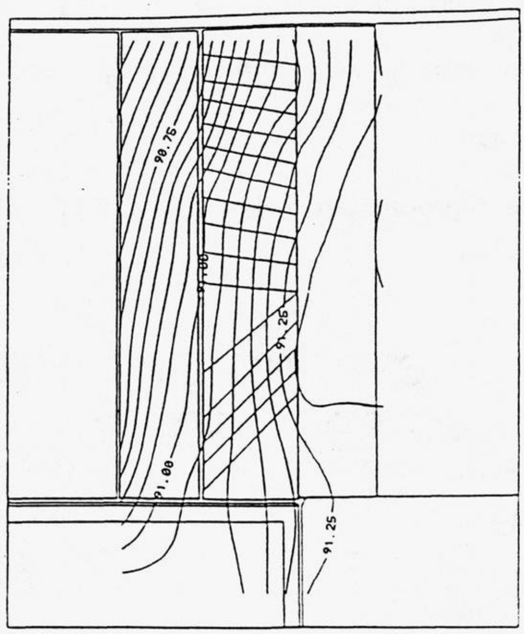


June 21, 1989

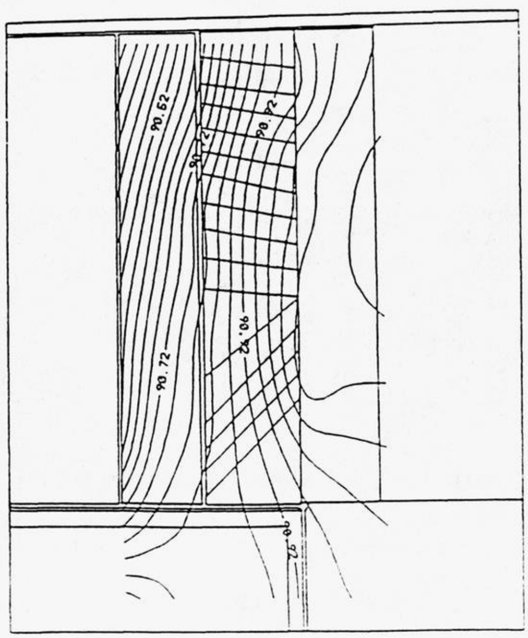


July 24, 1989

Figure 13 (continued)



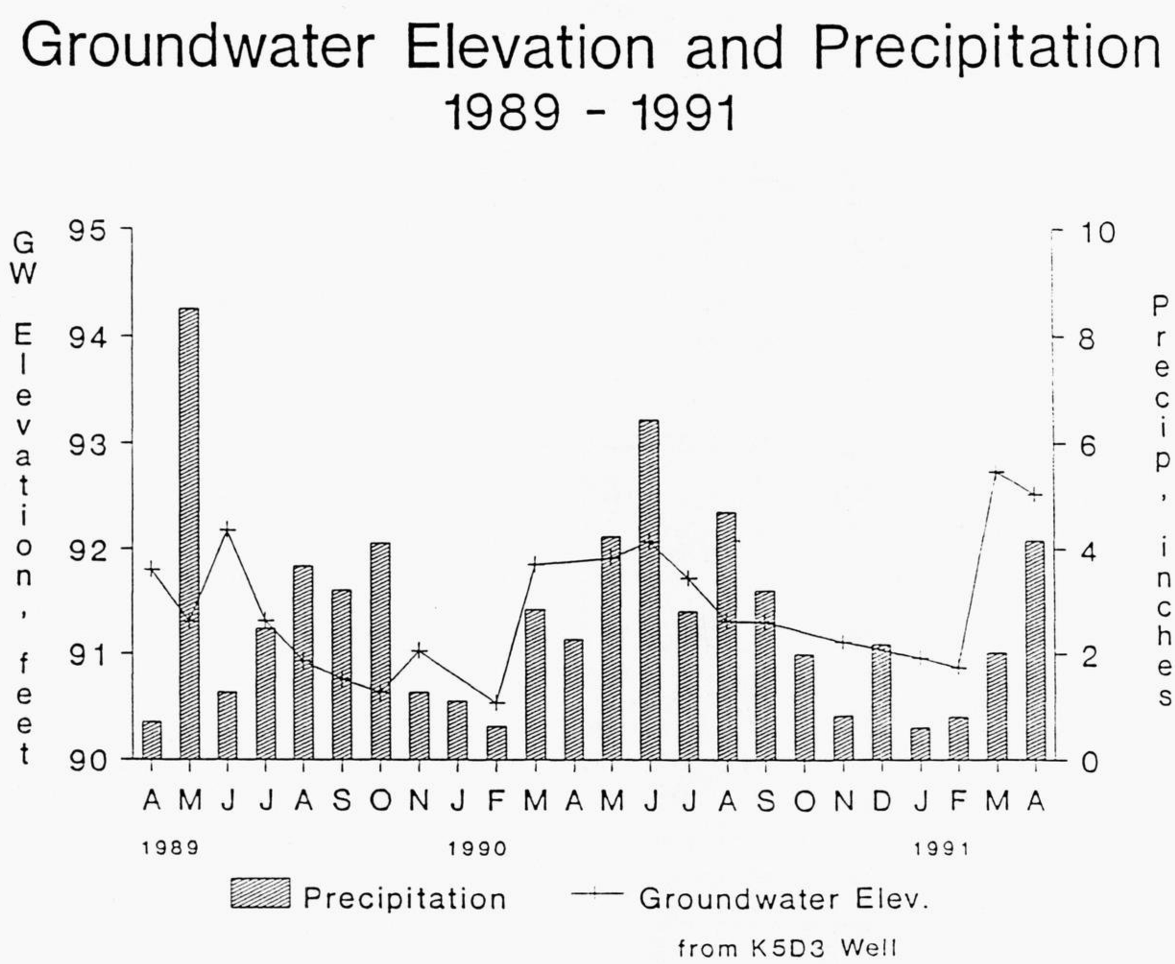
August 7, 1989



August 24, 1989

water levels leveled off in August and September 1990 before continuing to drop to a winter low of 90.87 feet in February 1991. In March 1991, elevations reached a project high of 92.73 feet even though there was normal precipitation. This indicated that most of the recharge was from the winters above average snowfall and subsequent snow melt.

Figure 14. Precipitation and groundwater elevation at well K5D3 during the study.



All well nests installed in 1990 had four ports. The alfalfa field proved to be a good buffer against upgradient contamination entering the plots in 1989. It was determined that the woodlot would also provide the same protection in 1990 for the first year field. With little nitrate showing up in the upgradient well samples in 1989, only four well nests were installed at regular intervals along the upgradient side of the first year field. In the summer of 1990, a fifth well was installed at six downgradient well nests of the second year field to help estimate the depth of nitrate contamination coming from the treated plots.

Manure Analysis and Treatment

Table 7 presents the results of manure analyses which were used to determine nitrogen loading from manure applications. Tables 8 and 9 and Figure 15 present the nitrogen application and nitrogen credit data for the plots used in 1989 and 1990. It should be noted that many of the 1989 plots received sidedress of 68 pounds/acre nitrogen as ammonium nitrate that were not to be sidedressed. The results of these applications is important to yield and groundwater results. This resulted in over application of nitrogen to all plots in 1989, including plots designated as central plots. It should also be noted that all plots received 20 pounds/acre of nitrogen as part of the starter fertilizer, in addition to manure and sidedress nitrogen.

Table 7. Dairy manure analysis results for 1989 and 1990.

	% Dry Matter	Total N	P2O3	K2O	S	NH4-N
1989						
Calf Manure						
Total		10.3	4.3	17.5		
Est. Available		3.7	2.4	13.1		
Cow Manure						
Total		10.8	4.4	7.4		
Est. Available		3.7	2.4	5.4		
1990						
Cow Manure						
Total	19.1	9.6	4.9	13.3	1.38	0.2
Est. Available		2.4	2.7	10.0	0.76	

Table 8. Treatment Summary for 1989 and 1990.

Code	Treatment * 1989	Plots Second Year Field	Code	Treatment 1990
A	7.5 T/A calf *	1	E	45 lbs. N/S S.D.
A	7.5 T/A calf *	2	E	45 lbs. N/A S.D.
D	23 T/A calf *	3	D	No Treatment
D	23 T/A calf *	4	D	No Treatment
C	Control *	5	C	Control
B	15 T/A cow *	6	A	11 T/A
B	15 T/A cow *	7	A	11 T/A
E	15 T/A cow *	8	B	22 T/A
E	15 T/A cow *	9	B	22 T/A
C	Control *	10	C	Control
B	15 T/A cow *	11	A	11 T/A
A	7.5 T/A calf *	12	E	45 lbs. N/A S.D.
D	23 T/A calf *	13	D	No Treatment
E	15 T/A cow	14	B	22 T/A
C	Control *	15	C	Control
		New Field		
		1	CC	Control
		2	BB	45 lbs. N/A S.D.
		3	AA	11 T/A
		4	BB	45 lbs. N/A S.D.
		5	CC	Control
		6	AA	11 T/A
		7	BB	45 lbs. N/A S.D.
		8	AA	11 T/A
		9	CC	Control

Table 9. Total nitrogen applied by treatment and source for 1989 and 1990.

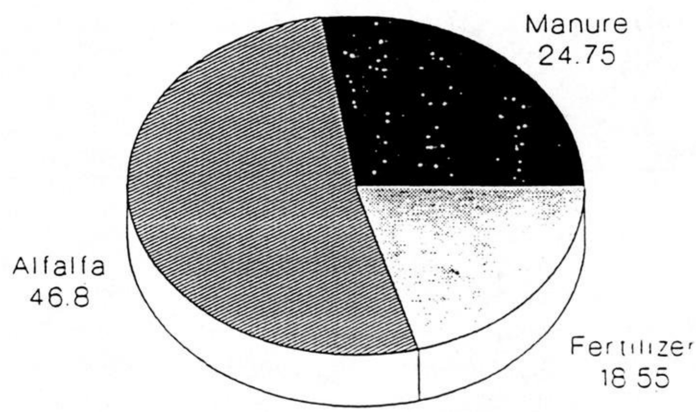
Treatment	Manure	Alfalfa	Starter	Sidedress	Total N
	(Precentage of Total N from that source)				
1989					
A 7.5 T/A +	28 (13)	100 (46)	20 (10)	68 (31)	216
B 15 T/A +	56 (23)	100 (41)	20 (8)	68 (28)	244
C Control +	0	100 (53)	20 (11)	68 (36)	188
D 23 T/A +	85 (31)	100 (37)	20 (7)	68 (25)	273
E 15 T/A	56 (32)	100 (57)	20 (11)	0	176

Treatment	Manure	Alfalfa	Starter	Sidedress	Total N
1990					
Second Year Field					
A 11 T/A	26 (34)	30 (40)	20 (26)	0	76
B 22 T/A	53 (51.5)	30 (29)	20 (19.5)	0	103
C Control	0	30 (60)	20 (40)	0	50
D No Treat.	0	30 (60)	20 (40)	0	50
E 45 lb N/A	0	30 (31.5)	20 (21)	45 (47.5)	95
First Year Field					
AA 11 T/A	26 (15.5)	120 (72.5)	20 (12)	0	166
BB 45 lb N/A	0	120 (65)	20 (11)	45 (24)	185
CC Control	0	120 (86)	20 (14)	0	140

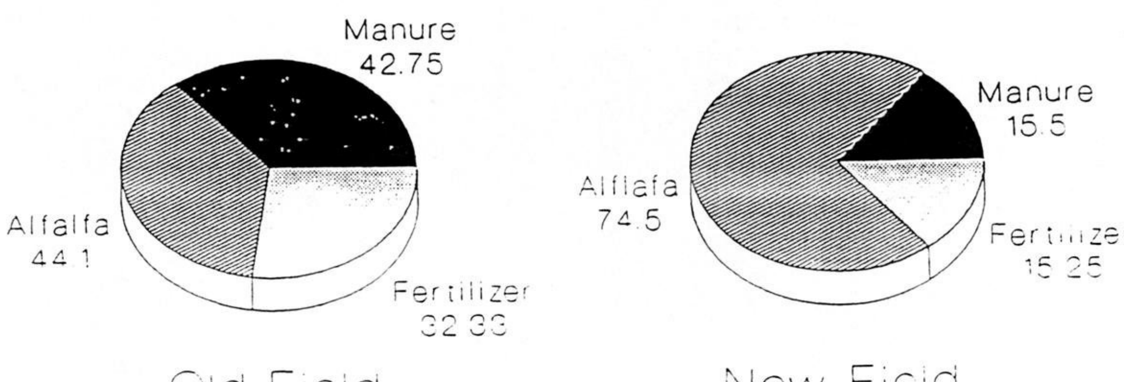
+ - 68 lb N/A sidedress fertilizer

Figure 15. Breakdown of total applied nitrogen by source.

1989 Total N Applied
Percentage from Source



1990 Total N Applied
Percentage from Source



Soil Nitrogen Results

Soil analysis was performed to determine available nitrogen as both nitrate-N and ammounium-N. Table 10 summarizes the results of these analyses. While this is not routinely practiced in Wisconsin, and not used as part of the nitrogen management program on sandy soils, these data provide valuable information on the fate of nitrogen applied to various plots.

1989 samples were only analyzed for nitrate-N and collected as composites for three treatments. 1990 sampling was done five times and included all treatments and analyzed for both nitrate-N and ammonium-N. These data clearly show that significant amount of both nitrate-N and ammonium-N occurred in both 1989 and 1990. The high concentrations found in March of 1990 is likely due to carry over of the excess nitrogen applied the previous year. Reduction of these concentrations by April of 1991 indicated more complete utilization of nitrogen in 1990, and removal by leaching of any excess nitrogen. Groundwater data presented in this report indicate that significant leaching did occur in 1990.

Table 10. Summary of pre-plant, early and post season residual soil nitrate-N analysis.

		Nitrate-N (pounds/Acre)				
1989 Depth	Pre-plant (April)		(June) Early Season	(June) Control + S.D.	(Oct) 15 T/A	(Oct) 23 T/A + S.D.
0 - 1	53		62	46	50	85
1 - 2	14		23	4	6	53
2 - 3	15		23	20	14	25
Total	82	Ave = 95	108	70	70	163

Corn Yields

The yield of corn on the various plots is presented in Tables 11 A and B. Table 12 shows which treatment had differences in yield that were statistically significant.

No significant yield difference were found between treatments in 1989. Yields ranged from 85 to 95 bushels/acre. This was generally a very dry growing season and even with high amounts of available nitrogen yields were below average.

Yield difference did occur between treatments used on the second year corn plots and the new plots established in 1990. Second year plots C and D (which received only starter fertilizer treatment in 1990 to evaluate carry over of nitrogen from 1989) had yields of 94 and 111 bushels/acre. These are respectable yields, but significantly less than treatments receiving additional nitrogen inputs as manure or sidedress nitrogen. Plot E received 45 pounds/acre nitrogen as sidedress, and had the highest yield (141 bushels/acre). This was not significantly different than Treatment B, receiving 23 tons/acre manure and yielding 130 tons/acre. This data indicates that carry over of excess fertilizer from 1989 plus starter fertilizer can support up to 100 bushels/acre corn production, however, excellent growing conditions in 1990 allowed additional production to occur on plots with additional nitrogen inputs from either 11 tons/acre manure or 45 lbs/acre fertilizer.

Results from the new plots established in 1990, where more reasonable nitrogen rates were used, showed a typical nitrogen/yield response curve Figure 16. The control plot which received 20 pounds/acre starter fertilizer plus 120 pounds/acre alfalfa credit had 101 bushel/acre yield. Supplemental nitrogen of 11 tons/acre manure and 45 pounds/acre sidedress nitrogen produced yields of 132

Table 11. Average annual corn yield results by treatment for 1989 and 1990.

1989 Average Corn Yield Results by Treatment.

Treatment	Total N lbs/A	Yield, bushels/A * Mean	Standard Deviation	Plant Population per acre
A 7.5 T/A + S.D.	216	96.33	15.29	20,925
B 15 T/A + S.D.	244	90.75	4.58	20,740
C Control + S.D.	188	84.73	9.26	20,046
D 23 T/A + S.D.	273	94.75	5.32	19,490
E 15 T/A	176	91.38	11.19	20,647
Average Total	219	91.59	10.09	20,369

1990 Average Corn Yield Results by Treatment.

Treatment	Total N lbs/A	Yield, bushels/A * Mean	Standard Deviation	Plant Population per acre
Second Year Field				
A 11 T/A	76	118.63	12.84	20,709
B 22 T/A	103	130.20	7.06	20,863
C Control	50	94.32	13.13	21,604
D No Treatment #	50	111.64	22.55	19,752
E 45 lb N/A	95	141.37	21.44	21,326
Average Total	75	119.23	21.44	20,851
New Field				
AA 11 T/A	166	132.27	11.20	21,234
BB 45 lb N/A	185	141.43	10.14	20,678
CC Control	140	101.35	23.71	20,585
Total	164	125.02	23.42	20,832

* Yields corrected to 15.5% moisture.
\# Amount includes N from 1989 alfalfa carryover and 20 lb/A starter fertilizer.

and 141 bushel/acre respectively. This data points out that in an excellent growing year supplemental nitrogen can increase yields significantly from those produced with alfalfa credits alone. Groundwater results for these treatments will be addressed later.

In 1989, there were no significant differences between yields from any of the treatments at the 95 percent confidence limit. The control had the lowest yield, but had the second to lowest nitrogen impact, the yield differences between Treatment A, 7.5 tons/acre plus sidedress, and the lowest yield from treatment C, control plus sidedress was only 11.6 bushels/acre.

Table 12. Significant differences in 1990 corn yields at the 95 percent confidence interval.

Second Year Field

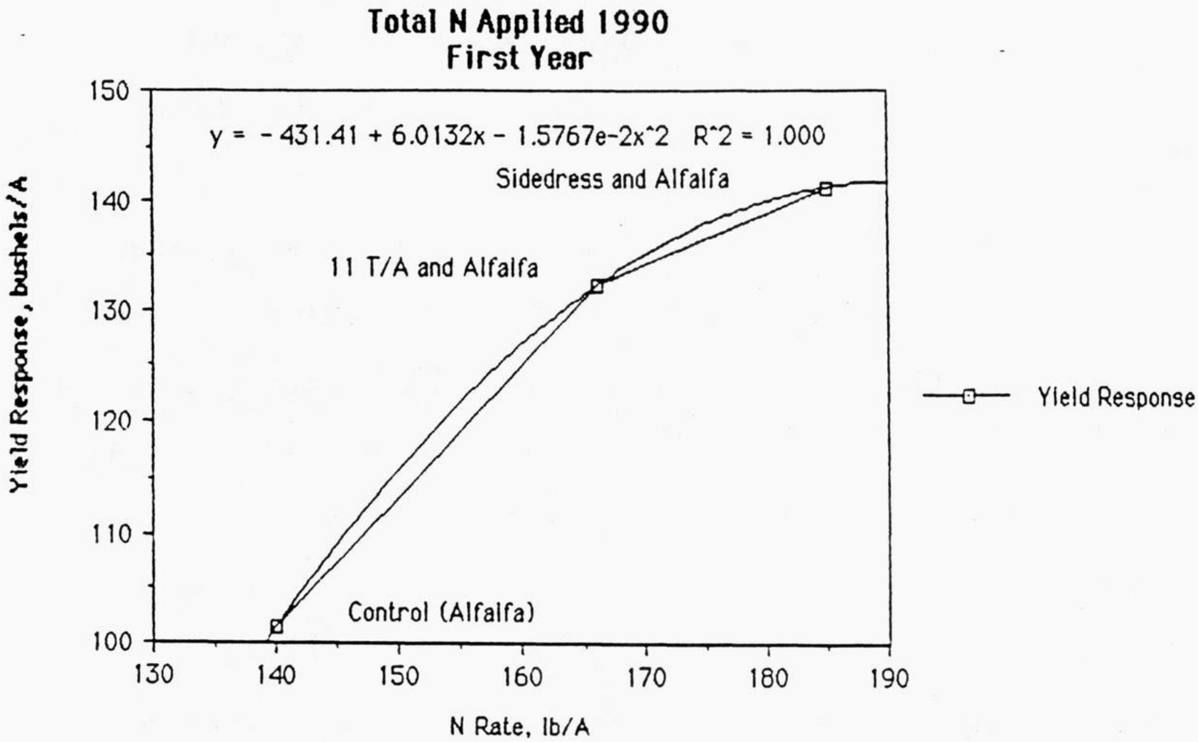
Mean	Treatment	C	D	A	B	E
94.32	C					
111.64	D					
118.63	A	*				
130.20	B	*				
141.37	E	*	*	*		

First Year Field

Mean	Treatment	CC	AA	BB
101.35	CC			
132.27	AA	*		
141.43	BB	*		

* pairs of groups significantly different at 0.05 level.

Figure 16. Yield response curve for Total Nitrogen applied for new field treatments in 1990.



Reviewing Table 11 A, a large variation in yield between plots did exist; 74.7 to 112.6 bushels/acre. Along with the highest yield, Treatment A also had the largest standard deviation and plant population per acre (Table 11 A). the control had the 68 pound N/A sidedress, which resulted in more total N applied (from alfalfa plus sidedress) than Treatment E, but still had the lowest yield. Treatment E, 15 tons/acre manure only, had 12 pounds N/A less total nitrogen applied and had a higher yield than the control.

Yields for 1990 did exhibit significant differences for treatments in both the second year and new fields. Table 12 indicates which treatments had significantly different yields. One of the objective was to calculate costs and cost saving from decreased N fertilizer use compared to yields. This cost savings is easily calculated for commercial N fertilizer, but is difficult when comparing the savings to manure treatments. The actual cost and value of the manure is difficult to calculate. Manure is more labor and time intensive, and less concentrated than commercial N fertilizer applications, but there are many other benefits of manure over commercial N fertilizer like: manure is a source of primary, secondary, and micronutrients; and organic components of manure improve soil moisture, increase downward movement of nutrients. Manure N is more variable and depends on storage and handling, but through laboratory analysis, an estimate of the amount of N supplied con be determined. Presented in Table 13 are the value of manure based on annual analysis for the three primary nutrients available the first year. These values are based on commercial fertilizer equivalents. Urea was used as the N source for comparison since it is the most common used N fertilizer by area farmers (Simson, 1992). Using the total value for each year, a total manure value in dollars per acre was calculated for each treatment. This is, for all practical purposes "free," except for the time and labor of applying the manure. Most dairy farmers have an abundant supply of manure and could dramatically reduce the amount of commercial N fertilizer required if given the proper credit. Looking at the manure strictly as an N source, it is an economical alternative. Compared to the price Mr. Klismith paid for the ammonium-nitrate sidedress and at the rate applied, on a dollar per acre basis, three out of the five manure rates applied over the two growing seasons were cheaper than the sidedress used. Ultimately, the yield achieved by the various treatments and the income received will be one of the most important factors farmers will look at to decide whether manure should be used as a sole N source following alfalfa. The need to dispose of manure produce on the farm must also be considered.

The income received from the yields will vary year to year due to yields and by the price of corn. The price of corn can be as variable as the yields from year to year, and an exact price per bushel received is as impossible to determine. To compare the costs of treatments, the twelve month price average for corn in Portage County was used each year. In 1989 average corn price per bushel was $2.45 and $2.35 per bushel in 1990. Table 13 shows the income based on yield, price of corn, and costs due to commercial N fertilizer. For each year the treatments yield was multiplied by that years average corn price to get an income in dollars per acre. In 1989 the treatments that received N sidedress had the cost per acre of sidedress subtracted from the income giving an adjusted income per acre. As mentioned earlier, in theory the more N applied the greater the yield and thus greater the income. However, once the fertilizer costs are subtracted from the income the greater yields did not give the best income for 1989. Before costs were subtracted, the greater yields gave the greatest income. But, once costs were

Table 13. Manure value, fertilizer cost and average corn prices for 1989 and 1990.

Manure Value

<u>1989</u>	N	P_2O_5	K_2O	Total Value (N, P, & K)
Estimated Available (lbs/T)	3.7	2.4	9.3	
Nutrient Value ($/T)	0.78	0.58	1.21	2.57
<u>1990</u>				
Estimated Available (lbs/T)	2.4	2.7	10.0	
Nutrient Value ($/T)	0.50	0.65	1.30	2.45

Value based on estimated available manure nutrient and fertilizer cost obtained from Marshfield Plant and Soil Analysis Laboratory October 4, 1988:
N (Urea) $0.21/lb, P_2O_4 (Triple Superphosphate) $0.24/lb, K_2O (Potash) $0.13/lb

Value on a dollar per acre basis from the manure treatments

Treatment (T/A)	N/A applied (lb)	N Value ($/A)	Total Manure Value ($/A)
<u>1989</u>			
7.5	28	5.85	19.28
15	56	11.70	38.55
23	85	17.94	59.11
<u>1990</u>			
11	26	5.50	26.95
12	53	11.00	53.90

Cost of ammonium nitrate sidedress fertilizer applied in 1989 and 1990

$162/T for 34% NH_4NO_3 in 1989 and 1990 = $0.24/lb N

1989: N applied at 68 lb N/A = $16.20/A
1990: N applied at 45 lb N/A = $10.80/A

Twelve month average price of corn in Portage County for 1989 and 1990:

1989 $2.45/bu 1990 $2.35/bu

subtracted, the results changed. Strictly from an economic perspective, the one plot that did not receive N sidedress, 15 T/A manure, had the greatest income per acre. This ties in with the efficiency of the corn for 1989. Lower yield efficiency resulted in lower yields for the amount of N applied and did not make it economical to apply N sidedress for the return received. In 1990 the opposite was true. Since 1990 was an exceptional growing year, there was a greater yield efficiency thus greater yields and return for the N applied. Even with the added cost of N sidedress, the sidedress treatment for both fields gave the greatest return per acre. Again, it should be pointed out that for the second year field the sidedress treatment had the second largest amount of N applied, but had the greatest yield and shows move effects from time of application than amount applied.

It can be debated whether the increase in yield and return is worth applying sidedress N. In 1990 the additional $15.45 per acre between the two top yields (N sidedress and 22 T/A) for the second year field, and $10.73 per acre increase for the first year field treatments (N sidedress and 11 T/A) may not seem justified. When these increases are added up over a number of acres, the additional income probably justifies the use of N sidedress in this case. From an environmental perspective this may be questioned. The amount of N leached into groundwater from these treatments needs to be discussed and may out weigh the economics involved. In the next section the results of the groundwater monitoring portion of this project will be presented and discussed.

Groundwater Nitrate-N Results

A major objective of this study was to determine the nitrate-N impact to groundwater from various fertility inputs on corn. Results of more than 3000 analyses preformed on the samples from 150 wells is summarized in Tables 14 A, B, and C. Data presented in these tables are from downgradient well nests, and represent averages for three replicate plots for each treatment. Nitrate-N values represent 6 to 16 separate analyses for each date depending upon the number of wells in a nest that yielded water, as the water table fluctuated. The values are averages weighted for the thickness of aquifer sampled by each well. Table 16 presents average nitrate-N data from the shallowest yielding well in each downgradient well nest.

Table 14 A shows that nitrate-N levels started out relatively low in April of 1989, with some nitrate-N in groundwater from decomposition of alfalfa which was disced the previous fall. Concentrations rose sharply in most wells in May, following a six inch rainfall that resulted in significant leaching and groundwater recharge. Starter fertilizer and manure had been applied to the field prior to this major leaching event. Concentrations generally remained constant, with gradual decline later in the year as the dry weather prevented any additional leaching and groundwater recharge, until the following spring when concentrations again rose sharply. The residual soil nitrogen data (discussed earlier) obviously had significant effect on groundwater in 1990, as presented in Table 14 B. Average concentrations of nitrate-N increased to between 20 to 50 mg/l in wells downgradient of the second year fields', average concentrations downgradient of the 1990 first year fields remained well below 10 mg/l through 1990. Average concentrations in the upper foot of the aquifer (shown in Table 15) were much higher, and most exceeded the groundwater standard during most of the summer of 1990 and spring of 1991. Nitrate-N concentrations did vary relative to treatment in 1989. Mean values for the five treatments ranged from 6 to 22 mg/l, with the plot receiving sidedress plus starter showing the lowest nitrogen concentration in

Figure 17. Groundwater nitrate-N concentrations (mg/l) in the shallowest yielding downgradient well ports for Plots 11 and 12 for each sampling from 1989 through 1990.

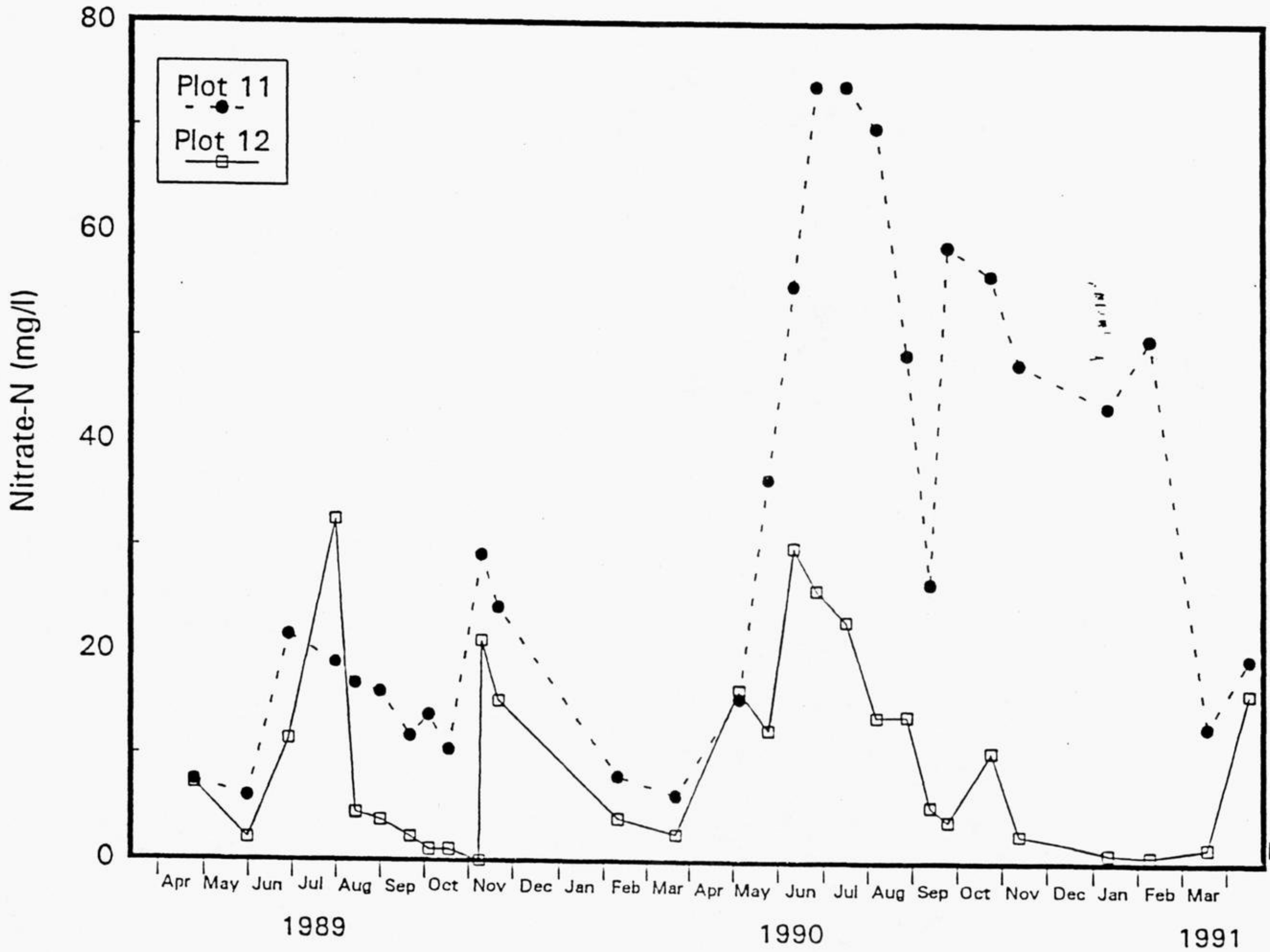


Table 14 A. Mean and standard deviations of concentrations of nitrate-N (mg/l) in groundwater for all downgradient well for each treatment in 1989.

	Treatment A 7.5 T/A		Treatment B 15 T/A + SD		Treatment C Control + SD		Treatment D 23 T/A + SD		Treatment E 15 T/A		Popluation	
Observation	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
1	6.87	3.79	3.00	0.70	1.07	0.61	6.03	3.53	4.13	3.49	4.22	3.22
2	20.47	11.46	15.03	12.46	5.60	4.11	19.27	4.73	16.27	10.53	15.33	9.58
3	33.50	10.32	29.70	16.33	9.93	1.43	37.33	16.62	24.57	13.36	27.01	14.69
4	27.13	9.14	30.37	17.44	10.20	7.43	34.37	22.71	18.63	13.61	24.14	15.63
5	22.40	15.31	34.60	13.33	10.90	9.80	27.23	19.20	19.83	19.74	22.99	15.72
6	14.57	8.75	28.10	11.95	6.87	8.31	20.20	16.26	18.43	19.11	17.63	13.53
7	10.50	7.04	22.97	12.92	2.57	2.29	16.53	13.44	17.00	20.32	13.91	12.95
8	8.20	5.91	21.73	16.42	1.37	1.46	14.23	13.33	14.83	21.03	12.07	13.52
9	14.37	2.05	25.63	13.97	2.67	2.52	21.63	7.92	16.33	23.93	16.13	13.62
10	19.20	0.92	27.97	9.65	3.43	3.23	32.13	11.75	18.47	24.99	20.24	15.11
11	12.47	2.02	19.23	5.49	3.50	4.09	21.90	6.64	14.30	16.87	14.28	9.88
12	12.03	6.27	11.53	4.26	10.57	9.60	13.47	4.47	9.20	7.98	11.36	5.96
13	20.47	10.29	17.20	6.66	12.60	9.21	20.53	7.50	10.20	10.01	16.20	8.63
Treatment Average	17.09		22.08		6.25		21.91		15.55		16.58	

Year Average 16.58
Std Dev 5.77

Observation

1 Apr 16 - May 23	8 Sep 27 - Oct 11
2 May 23 - Jun 21	9 Oct 11 - Nov 3
3 Jun 21 - Jul 24	10 Nov 3 - Nov 15
4 Jul 24 - Aug 7	11 Nov 15 - Feb 6
5 Aug 7 - Aug 24	12 Feb 6 - Mar 20
6 Aug 24 - Sep 14	13 Mar 20 - May 4
7 Sep 14 - Sep 27	

Table 14 B. Mean and standard deviations of concentrations of nitrate-N (mg/l) in groundwater for each treatment of the second year fields in 1990.

1990 Second Year Field

	Treatment A		Treatment B		Treatment C		Treatment D		Treatment E		Popluation	
	11 T/A		22 T/A		Control		No Treatment		45 lb N/A			
Observations	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
1	22.73	5.19	14.53	13.39	12.77	5.08	22.77	4.58	22.50	11.39	19.06	8.71
2	36.43	9.80	18.33	11.24	15.43	9.01	27.30	2.50	28.90	10.47	25.28	11.02
3	46.83	18.42	28.10	2.91	19.33	10.82	37.53	3.65	37.70	11.96	33.90	13.53
4	55.53	23.34	31.87	0.71	19.30	10.68	45.27	10.09	42.60	19.91	38.91	18.14
5	53.27	22.98	21.67	7.00	11.60	10.40	31.70	18.38	27.73	12.56	29.19	19.32
6	38.63	10.66	20.60	5.80	12.80	11.05	24.13	15.09	18.23	8.43	33.88	12.74
7	29.10	7.29	19.97	7.00	15.97	15.33	25.23	15.42	22.93	16.10	22.64	11.86
8	28.87	9.51	16.10	13.30	17.83	19.33	25.47	13.73	23.43	19.72	22.34	14.08
9	29.70	6.28	14.90	13.71	17.00	15.68	22.57	11.89	20.50	16.00	20.93	12.35
10	28.60	8.61	12.63	14.72	15.93	13.81	19.47	17.32	16.47	10.66	18.62	12.63
11	25.10	7.86	10.70	9.96	13.90	12.14	20.50	21.82	14.47	9.98	16.93	12.45
12	24.00	8.84	12.53	11.04	11.57	10.73	17.13	17.78	14.23	11.09	15.89	11.32
13	28.67	2.11	21.70	14.10	11.50	10.51	18.97	16.51	16.87	12.56	19.54	11.86
14	29.17	7.48	27.03	10.65	12.00	8.37	22.20	12.86	17.17	8.30	21.51	10.50
Treatment Average	34.04		19.33		14.78		25.73		23.12		23.40	

Year
Average 23.40
Std DEv 5.91

Observations		
	1 May 4 – May 25	8 Sep 14 – Sep 26
	2 May 25 – Jun 18	9 Sep 26 – Oct 26
	3 Jun 18 – Jun 27	10 Oct 26 – Nov 14
	4 Jun 27 – Jul 18	11 Nov 14 – Jan 15
	5 Jul 18 – Aug 8	12 Jan 15 – Feb 18
	6 Aug 8 – Aug 29	13 Feb 18 – Mar 25
	7 Aug 29 – Sep 14	14 Mar 25 – Apr 24

Table 14 C. Mean and standard deviations of concentrations of nitrate-N (mg/l) in groundwater for each treatment of the first year fields in 1990.

1990 First Year Field

Observations	Treatment AA 11 T/A Mean	Treatment AA 11 T/A Std Dev	Treatment BB 45 lb N/A Mean	Treatment BB 45 lb N/A Std Dev	Treatment CC Control Mean	Treatment CC Control Std Dev	Popluation Mean	Popluation Std Dev
1	1.00	1.14	0.40	0.26	3.00	2.30	1.47	1.75
2	1.97	2.18	0.63	0.29	3.03	2.11	1.88	1.84
3	3.17	2.80	0.73	0.42	3.33	2.31	2.41	2.22
4	7.10	4.35	3.07	0.59	6.33	2.62	5.50	3.16
5	8.00	4.36	4.93	1.39	8.27	3.37	7.07	3.34
6	4.87	3.16	6.87	1.59	8.93	5.54	6.89	3.73
7	4.00	3.31	8.63	5.17	9.50	5.63	7.38	4.89
8	4.53	2.48	8.70	4.45	8.70	3.04	7.31	3.63
9	4.43	2.92	7.07	3.55	7.13	1.86	6.21	2.81
10	3.27	2.56	6.50	3.34	6.90	3.03	5.56	3.11
11	2.53	0.68	7.20	3.38	7.00	2.33	5.58	3.09
12	2.67	0.81	7.37	1.72	4.93	1.43	4.99	2.36
13	3.97	2.11	8.30	1.64	7.03	3.89	6.43	3.05
14	9.33	0.70	13.17	2.17	13.30	1.99	11.93	2.47
Treament Average	4.35		5.97		6.96		5.76	

Year Average	5.76
Std Dev	1.08

Observations

1 May 4 - May 25	8 Sep 14 - Sep 26
2 May 25 - Jun 18	9 Sep 26 - Oct 26
3 Jun 18 - Jun 27	10 Oct 26 - Nov 14
4 Jun 27 - Jul 18	11 Nov 14 - Jan 15
5 Jul 18 - Aug 8	12 Jan 15 - Feb 18
6 Aug 8 - Aug 29	13 Feb 18 - Mar 25
7 Aug 29 - Sep 14	14 Mar 25 - Apr 24

groundwater, while treatments receiving 15 and 23 tons/acre manure plus sidedress nitrogen and starter showed the highest nitrogen concentrations in groundwater. Plots receiving only manure resulted in intermediate leaching of nitrate-N to groundwater.

First year plots results in 1990 show all treatment to have mean nitrate-N concentrations in groundwater below the 10 mg/l standard. All downgradient wells were averaged in Table 14 C. Table 15 shows a different pattern when only the shallowest well is considered. Average nitrate-N from the plots often exceeded the 10 mg/l standard, with treatment averages showing the least leaching from the control plots and those receiving sidedress nitrogen. The estimated amounts of nitrogen leached to groundwater is presented in Tables 15 and 16. The treatment with the least leaching was the plot receiving alfalfa credits, starter fertilizer plus 45 pounds/acre nitrogen sidedress. These plots had higher yields and lower nitrate-N than the control plots receiving only alfalfa credit plus starter fertilizer. The most probable reason for these results is that the additional nitrogen must have enhanced growth and nitrogen use efficiency during an excellent growing season in 1990. Both treatment applying supplement nitrogen as manure and sidedress nitrogen produced significant yield increases over the control. It is uncertain if similar results would occur during a normal or dry year, when the additional fertilizer would result in surplus nitrogen with more leaching.

Table 15 shows the average nitrate-N concentrations in the shallowest downgradient well from each plot and treatment. We feel they are the most representative wells for quantifying nitrate-N in groundwater recharge from the plots. There is minimal mixing with water originating outside of the plot area with the shallowest groundwater downgradient of the plots.

Table 15. Average nitrate-N concentrations (mg/l) in the shallowest yielding downgradient well from each sample set. Presented by treatment type and plot number.

Treatment	1989 Plot #	Nitrate-N (mg/l)	Nitrate-N (lbs/A)
7.6 T/A Manure + 65 lbs N/A	1	13.9	26.4
	2	20.2	38.4
	12	7.7	14.6
Average		13.9	32.3
16 T/A Manure + 65 lbs N/A	6	23.4	44.5
	7	31.4	59.7
	11	14.6	27.7
Average		23.1	44.0
23 T/A Manure + 65 lbs N/A	3	22.6	42.9
	4	29.6	56.2
	13	18.4	35.0
Average		23.5	49.6
16 T/A Manure	8	30.1	57.2
	9	12.9	24.5
	14	6.3	12.0
Average		16.4	40.9
Control + 65 lbs N/A	5	10.4	19.8
	10	6.9	13.1
	15	3.6	6.8
Average		7.0	16.5

Treatment	1990 Second Year Fields Plot #	Nitrate-N (mg/l)	Nitrate-N (lbs/A)	1990 First Year Fields Plot #	Nitrate-N (mg/l)	Nitrate-N (lbs/A)
11 T/A Manure	6	36.3	104.4	3	10.3	25.8
	7	33.9	107.7	6	5.4	23.1
	11	45.9	35.4	8	3.9	28.5
Average		38.7	105.9		6.5	25.8
22 T/A Manure	8	30.1	108.9			30.9
	9	25.8	101.7			16.2
	14	45.9	137.7			11.7
Average		33.9	116.1			19.6
45 lbs/A Sidedress N	1	34.8	100.5	2	8.6	
	2	35.9	146.1	4	7.7	
	12	11.8	52.8	7	9.5	
Average		27.5	123.3		8.6	
Control	5	31.2	90.3	1	11.3	
	10	23.3	77.4	5	9.8	
	15	3.7	137.7	9	14	
Average		19.4	88.9		11.7	
No Treatment	3	33.5	93.6			33.9
	4	48.7	69.9			29.4
	13	17.6	11.1			42.0
Average		33.3	81.8			35.1

Table 16. Summary of plot results for yield, nitrate-N in groundwater, and fertilizer treatment.

		Treatment			Nitrogen Applied		Corn Yield	Nitrogen in groundwater			Soil residual nitrogen	
		Manure (T/A)	Alfalfa Credits	Fertilizer (#/A)	(#/A)	Incl. residual soil NO3-N (#/A)	(Bu/A)*	Average Nitrate-N (mg/l)	Upper Port (mg/l)	Recharge (#/A)	Spring Nitrate-N (#/A)	Following year NO3+NH4 (#/A)
1989	A	7.5	102	86	216	311	91	17	17	32	83	129
	B	15	102	86	244	339	85	22	23	44	75	127
	C	0	102	86	188	283	96	6	9	17	74	134
	D	23	102	86	273	368	91	22	26	50	78	128
	E	15	102	20	176	271	95	16	22	41	96	161
1990	A	11	30	20	76	147	118	34	39	116	11	42
	B	22	30	20	103	174	130	19	28	84	44	87
	C	0	30	20	50	121	94	15	27	82	26	67
	D	0	30	20	50	121	112	26	41	123	14	33
	E	0	30	65	95	166	141	23	35	106	10	33
1990	AA	11	120	20	166	210	132	4	18	53	33	78
	BB	0	120	65	185	229	141	6	9	26	53	97
	CC	0	120	20	140	164	101	7	12	35	18	42

*Bushels per acre = pounds nitrogen per acre

While these data clearly indicate there was nitrate-N impacts to groundwater from all treatments, there are large differences in leaching amount both within and between treatments.

Data is arranged in Table 15 to follow separate treatments for plots 1 through 15 for 1989 and 1990, and to compare the results of similar treatments used in new 1990 plots with second year corn plots.

The most striking results from this table is the comparison between nitrate-N values for the 1990 treatments. These data indicate large concentrations of nitrate-N downgradient of the second year field, compared to the first year field. The major difference between these two fields is the carry-over nitrogen from 1989, emphasizing how impacting this can be to groundwater quality the following year.

Averages calculated for each treatment excluded data from plots 12 through 15. The data from this end of the field was very erratic, and most likely was effected by denitrification. Figure 16 is a graph of the nitrate-N concentrations in the shallowest well port downgradient of Plots 11 and 12, which are adjacent and received similar amounts of nitrogen inputs. It is obvious that nitrate-N leaches to groundwater from both plots, however, the nitrate-N quickly disapears from groundwater under Plot 12. Due to the uncertainty of the validity of data from these plots, they were also not included in the summary nitrogen budget calculations and average values for treatment.

Table 15 also shows the large difference in nitrogen leaching which occurred from first year plots receiving the same supplemental nitrogen treatments as second year corn. Treatments AA lost 33 lbs/acre nitrogen compared to second year corn Treatment A which lost 116 lbs/acre nitrogen to groundwater. This is despite less alfalfa credit available for the second year corn. Similar results were observed for Treatments BB and E, which received starter fertilizer plus 45 pounds per acre nitrogen as sidedress. Leaching estimates in 1990 were 26 and 106 pounds per acre nitrogen, respectively. These comparisons reinforce the conclusion that much of the nitrogen leached from the second year corn plants was residual nitrogen from 1989 applications. This carry-over nitrogen becomes obvious when we put nitrogen inputs and outputs into a nitrogen budget.

Tables 17, 18, and 19 present three different nitrogen budgets, with increasing number of components considered. Table 17 only considered fertilizer credits and applications as inputs, with corn removed and nitrogen leached as outputs. Table 18 included soil test nitrate-N in the upper 3 plots at the beginning and end of the year. Residual nitrogen in 1989 was very large, averaging 91 lbs/acre. Nitrogen residuals for 1990 were all negative due to increased leaching losses. The combined 1989 and 1990 residual data for the 15 plots Table 18 showed very low residual of residual for nitrogen. Nitrogen budget result for the first year plot in 1990 was very good showing very low soil nitrogen residuals. By including residual soil nitrogen in the budget as shown in Table 18, the nitrogen residual was improved dramatically showing the importance of using it as part of nitrogen management. Including NH_4-N as well as nitrate-N showed further inprovement in the 1990 nitrogen budget presented in Table 20.

In addition to the item in Table 17, Table 19 includes initial and final soil nitrate-N, nitrogen estimated to be released from soil organic matter, and the residual nitrogen in stover and soil. Table 19 also shows the difference between using soil nitrate-N and soil nitrate-N plus NH_4-N at the beginning and end of the year.

The nitrogen budget came out surprisingly well. Some plots and treatment did not come out as sell as other, however, the combined residual for the two year study as shown in Table 18 average only 9 lbs/acre. Larger nitrogen residual occurred with the more complicated budget used in Table 19 & 20.

Some of the discrepancies in the nitrogen budget may be due to large amounts of nitrogen stored in the soil as exchangeable NH_4-N. The soil data presented in Table 20 shows large amounts of exchangeable NH_4-N in the spring of 1990 from the fertilizer applied in 1989. This has not been considered in existing nitrogen crediting programs, and needs further evaluation as NH_4-N is not as likely to be lost by spring leaching events as is nitrate-N. Including soil NH_4-N in the 1990 nitrogen budget resulted in improvement in the residuals for most plots.

Additional nitrate-N is likely stored in the soil between the three foot depth samples and the water table, which is nitrate-N on its way to groundwater, but not included in the groundwater budget.

Table 17. Nitrogen budget excluding nitrogen contributed by precipitation, soil organic matter, and soil available nitrogen at the beginning and end of the year.

		Fert Input 1	Corn Yield* 2	Ground Water 3	Residual excluding residual soil N (1 - 2 - 3)	Residual excluding residual soil N 1989+1990
1989	A	216	91	32.3	93	-65
	B	244	85	43.9	115	4
	C	188	96	16.5	75	-50
	D	273	91	49.6	132	-53
	E	176	95	40.9	40	-112
Average		**219**	**92**	**36.6**	**91**	**-55**
1990	A	76	118	116.1	-158	
	B	103	130	84.0	-111	
	C	50	94	81.9	-126	
	D	50	112	123.3	-185	
	E	95	141	105.9	-152	
Average		**75**	**119**	**102.2**	**-146**	
1990	AA	166	132	52.8	-19	
	BB	185	141	25.8	18	
	CC	140	101	35.1	4	
Average		**164**	**125**	**37.9**	**1**	

*Bushels per Acre = pounds nitrogen used per acre
Fertilzer input includes manure, alfalfa, fertilizer, and soil nitrate-N.

Table 18. Nitrogen budget including soil test nitrate-N from the beginning and end of each year.

		Fert Input 1	Corn Yield* 2	Ground Water 3	Residual Soil N 4	Residual (1 - 2 -3 - 4)	Residual 1989+1990
1989	A	311	91	32.3	83	105	7
	B	339	85	43.9	75	135	51
	C	283	96	16.5	74	96	16
	D	368	91	49.6	78	149	21
	E	271	95	40.9	96	39	-52
Average		**314**	**92**	**36.6**	**81**	**105**	**9**
1990	A	147	118	116.1	11	-98	
	B	174	130	84.0	44	-84	
	C	121	94	81.9	26	-81	
	D	121	112	123.3	14	-128	
	E	166	141	105.9	10	-91	
Average		**146**	**119**	**102.2**	**21**	**-96**	
1990	AA	210	132	52.8	33	-8	
	BB	229	141	25.8	53	9	
	CC	164	101	35.1	18	10	
Average		201	125	37.9	35	4	

*Bushels per Acre = pounds nitrogen removed per acre
Fertilzer input includes manure, alfalfa, fertilizer, and soil nitrate-N.

Table 19. Nitrogen mass balance by plot for 1989 and 1990.

1989 Treatment	Applied N*	SOM-N^	Begining Soil Nitrate-N	Residual Manure N from 1989	Total Available N	Harvested Corn N Bu/A=#/A	Groundwater Nitrate-N '	Ending Soil Nitrate-N	Corn Stover N~	Unaccounted N
A	216	99	82	N/A	397	96	32.3	84	74	111
B	244	109	82	N/A	435	90	44.0	75	69	157
C	188	141	82	N/A	411	84	16.5	74	65	172
D	273	119	82	N/A	474	94	49.6	78	72	180
E	176	118	82	N/A	376	91	40.9	95	70	79
Treatment Average	219	117	82	N/A	419	91	36.7	81	70	140
1990-Second Year Fields										
A	76	109	75	13	273	119	116.1	11	92	-65
B	103	118	95	13	329	130	83.9	44	100	-29
C	50	141	74	N/A	265	94	81.8	23	72	-6
D	50	119	78	19	266	112	123.3	14	86	-69
E	95	99	84	6	284	141	105.9	10	109	-82
Treatment Average	75	117	82	13	283	119	102.2	20	92	-50
1990-First Year Fields										
AA	166	82	44	N/A	292	132	19.6	33	102	5
BB	185	83	45	N/A	313	142	25.8	53	109	-17
CC	140	75	39	N/A	254	102	35.1	18	79	20
Treatment Average	164	80	43	N/A	286	125	26.8	35	96	3

* Includes alfalfa and manure credits plus fertilizer

~ Corn stover nitrogen was calculated by multiplying lb/A corn harvested by 0.77

^ Soil organic matter nitrogen (SOM-N) was calculated by multiplying SOM x *****.

' Does not include plots 12 - 15

Table 20. Nitrogen mass balance by plot for 1989 and 1990 using both nitrate-N and soil nitrate-N plus ammonium-N as input and residual.

Plot	Applied N* (lb/A)	SOM N^ (NO3-N)	Begining Soil Nitrate-N	Begining Soil NO3+NH4-N	Residual Manure N from 1989	Total Available N 2+3+5+6	Total Available N 2+3+4+6	Harvested Corn N Bu/A=#/A	Groundwater Nitrate-N	Ending Soil Nitrate-N	Ending Soil NO3+NH4	Corn Stover N~	Unaccounted N using soil NO3+NH4	Unaccounted N using soil Nitrate-N	Unaccounted N (1989 + 1990) Nitrate-N
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1989 April 1989 - April 1990															
1	216	98	82		N/A		396	113	26.4	111		87		59	
2	216	108	82		N/A		406	90	38.4	89		69		120	
3	273	128	82		N/A		483	97	42.9	80		75		188	
4	273	136	82		N/A		491	98	56.2	128		75		134	
5	188	130	82		N/A		400	94	19.8	56		72		158	
6	244	100	82		N/A		426	89	44.5	54		69		170	
7	244	112	82		N/A		438	93	59.7	92		72		121	
8	176	110	82		N/A		368	87	57.2	140		67		17	
9	176	124	82		N/A		382	91	24.5	67		70		130	
10	188	150	82		N/A		420	85	13.1	88		65		169	
11	244	114	82		N/A		440	91	27.7	78		70		173	
12	216	90	82		N/A		388	87	14.6	51		87		188	
13	273	94	82		N/A		449	89	35.0	27		69		229	
14	176	120	82		N/A		378	96	12.0	79		74		117	
15	188	144	82		N/A		414	75	6.8	79		58		195	
Average	219	117	82				419	92	32	81		71		143	
1990 April 1990 - April 1991															
Second Year Field															
1	95	98	111	172	6	371	310	139	104.4	5	26	107	-5	-45	14
2	95	108	89	142	6	351	298	151	107.7	21	56	116	-80	-98	22
3	50	128	80	121	19	318	277	122	100.5	21	49	94	-48	-61	128
4	50	136	128	204	19	409	333	112	148.1	6	20	86	45	-17	117
5	50	130	56	98	N/A	278	236	98	93.6	34	82	75	-71	-65	93
6	76	100	54	97	13	286	243	122	108.9	14	61	94	-100	-96	74
7	76	112	92	162	13	363	293	116	101.7	7	30	89	26	-21	100
8	103	110	140	228	13	454	366	131	90.3	49	94	101	38	-5	12
9	103	124	67	131	13	371	307	128	77.4	43	70	99	-3	-40	90
10	50	150	88	159	N/A	359	288	86	89.9	12	20	66	117	54	223
11	76	114	78	122	13	325	281	118	137.7	11	33	91	-55	-77	96
12	95	90	51	76	6	267	242	134	35.4	3	17	103	-22	-33	135
13	50	94	27	61	19	224	190	101	52.8	14	28	78	-36	-56	173
14	103	120	79	122	13	358	315	132	137.7	41	98	102	-112	-98	19
15	50	144	79	148	N/A	342	273	99	11.1	33	99	77	56	53	248
Average	75	117	81	136	10	338	283	119	92	21	52	92	-17	-40	103
1990 First Year Field															
1	140	80	38	60	N/A	280	258	92	33.9	15	43	71	40	46	
2	185	74	34	49	N/A	308	293	142	25.8	12	33	109	-2	4	
3	166	90	57	73	N/A	329	313	132	30.9	45	93	102	-29	3	
4	185	82	69	89	N/A	356	336	138	23.1	69	129	106	-40	-0	
5	140	68	41	62	N/A	270	249	108	29.4	8	22	83	28	21	
6	166	62	41	62	N/A	290	269	130	16.2	26	69	100	-25	-3	
7	185	92	32	46	N/A	323	309	146	26.5	76	120	112	-92	-55	
8	166	94	35	59	N/A	319	295	135	11.7	26	71	104	-3	16	
9	140	76	37	52	N/A	268	253	106	42.0	32	63	82	-25	-9	
Average	164	80	41	61		305	288	125	27	35	72	97	-18	3	

* Includes alfalfa and manure credits plus fertilizer

~ Corn stover nitrogen was calculated by multiplying lb/A corn harvested by 0.77

^ Soil organic matter nitrogen (SOM-N) was calculated by multiplying SOM x *****.

7 = 2 + 3 + 5 + 6

8 = 2 + 3 + 4 + 6

14 = 7 - (9 + 10 + 12 + 13)

15 = 8 - (9 + 10 + 11 + 13)

Summary and Conclusions

Table 15 presents summary data for each treatment, including nitrogen inputs; corn yield, average nitrate-N in downgradient groundwater, residual soil nitrogen, and estimated leaching loss of nitrate-N.

From these data it is obvious that significant leaching losses of nitrate-N occurred from each of the original 15 plots in 1989 and 1990. Yields and leaching increased significantly in 1990, with leaching most likely primarily a result of carry over of excess nitrogen from 1989.

Estimated nitrogen loss to groundwater was very high for the original 15 plots, with the highest amounts occurring from plots receiving the most nitrogen. The high residual soil nitrogen in April of 1990 shows the large amount available for leaching and plant growth the second year. Much of this nitrogen apparently leached out of the root zone before crops were able to use it, as yields on Treatments C and D were much lower than other treatments, even though they had large soil nitrogen concentrations early in the year. Input of this nitrogen was important to the corn yield, however, additional inputs were required to achieve maximum yield. Treatment E had the largest carry over from 1989, and when combined with sidedress nitrogen of 45 pounds per acre in 1990, yielded and excellent 141 bushels/acre. Similar yields occurred in Treatment B, receiving 22 tons/acre manure in 1990, and of sidedress nitrogen in 1990. Both of these sets of plots lost large amounts of nitrate-N to groundwater.

Estimating the total loss of nitrogen to groundwater from each plot was done using the nitrate-N concentrations of the shallowest well for each plot for each date. We assumed this data represents the undiluted recharge occurring from each plot and used the season average for these values, multiplying this value times the estimated groundwater recharge we obtained a pounds/acre nitrogen loss value. These are summarized in Table 20.

1. The 1989 growing season had below normal rainfall and corn yields, despite more than sufficient nitrogen application to all plots. Even the lowest nitrogen application had yields similar to the high application rate.

2. All but one set of plots from 1989 had nitrate-N leaching to groundwater exceeding 10 mg/l nitrogen and all had even larger concentrations in 1990, when carry-over nitrogen was leached. 1989 average nitrate-N ranged from 8.7 to 26 mg/l downgradient of these five treatments. 1990 values for the same plots ranged from 27 to 41 mg/l, largely due to carry-over nitrogen from 1989.

3. It is concluded that all nitrogen applications for 1989 were excessive relating to expected yield, particularly with poor growing conditions. It is impossible to use this data to recommend an optimum application rate. The plots receiving only sidedress nitrogen resulted in lower nitrate-N concentrations in groundwater in 1989 and averaged 8.7 mg/l in the shallowest wells. The same plot averaged 27 mg/l in 1990 as residual nitrogen leached to groundwater.

4. Results from 1990 on plots in the second year of the rotation produced more useful data on optimizing application rates. Carry-over nitrogen from 1989 did occur on the second year plots, and contributed to corn growth, however, much of the carry-over leached to groundwater.

5. Average nitrate-N concentrations in shallow groundwater downgradient of plots established in 1990 and receiving more reasonable nitrogen applications ranged from 3.9 to 14 mg/l, however most concentrations exceeded 10 mg/l in the late summer of 1990 and early spring of 1991. Yields for these plots ranged from 111 to 144 bushels/acre.

6. Nitrate-N concentrations were less than 0.2 mg/l in most wells sampling groundwater originating in actively growing alfalfa fields and woodlots upgradient of the study plots, indicating little or no impact to groundwater nitrate-N concentrations from land uses.

7. The lowest nitrate-N concentrations observed in groundwater for this project occurred downgradient of plots receiving manure at 11 tons/acre plus 120 lbs/acre alfalfa credit and 20 lbs/acre starter fertilizer. The second lowest impact to groundwater occurred from plots receiving 120 lbs/acre alfalfa credits plus starter and sidedress nitrogen of 45 lbs/acre. The average annual nitrate-N concentration in the shallowest downgradient well was 6.5 and 8.0 mg/l respectively for these two treatments. Average nitrate-N downgradient of control plots was 11.7 mg/l nitrate-N.

8. Nitrogen application rates alone did not correlate to nitrate-N concentrations reaching groundwater. Additional nitrogen as manure and sidedress nitrogen increased yield and decreased nitrogen leaching in 1990 plots, apparently due to more efficient nitrogen use by the higher yielding plots.

9. Carry-over of both ammonium-N and nitrate-N occurred from 1989. Analysis and crediting for soil ammonium-N should be considered, along with nitrate-N.

10. Nitrogen credits from decomposition of soil organic matter need to be considered when calculating nitrogen credits for crop production.

11. Manure and alfalfa credits as currently used by extension apply fairly well to corn growth on sandy soils.

12. Nitrogen management on sandy soils should include credits from manure and alfalfa, crediting carry-over nitrogen from the previous year should also be considered in nitrogen management plans.

13. Ammonium-N may be more input than nitrate-N on these soil types, and should be analyzed for possible use in reducing nitrogen input.

14. Growing corn on sandy soils with even the best combination of nitrogen credits and inputs is likely to result in nitrate-N levels exceeding 10 mg/l in groundwater recharge.

15. Results of this study suggest supplementing alfalfa credits with 25-45 lbs/acre nitrogen as manure or sidedress nitrogen can ensure yield and possibly even reduce leaching losses to groundwater at least in the first year of corn in a rotation.

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APPENDIX