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NITROGEN FERTILIZATION AND POSSIBLE RELATIONSHIP TO GROUNDWATER

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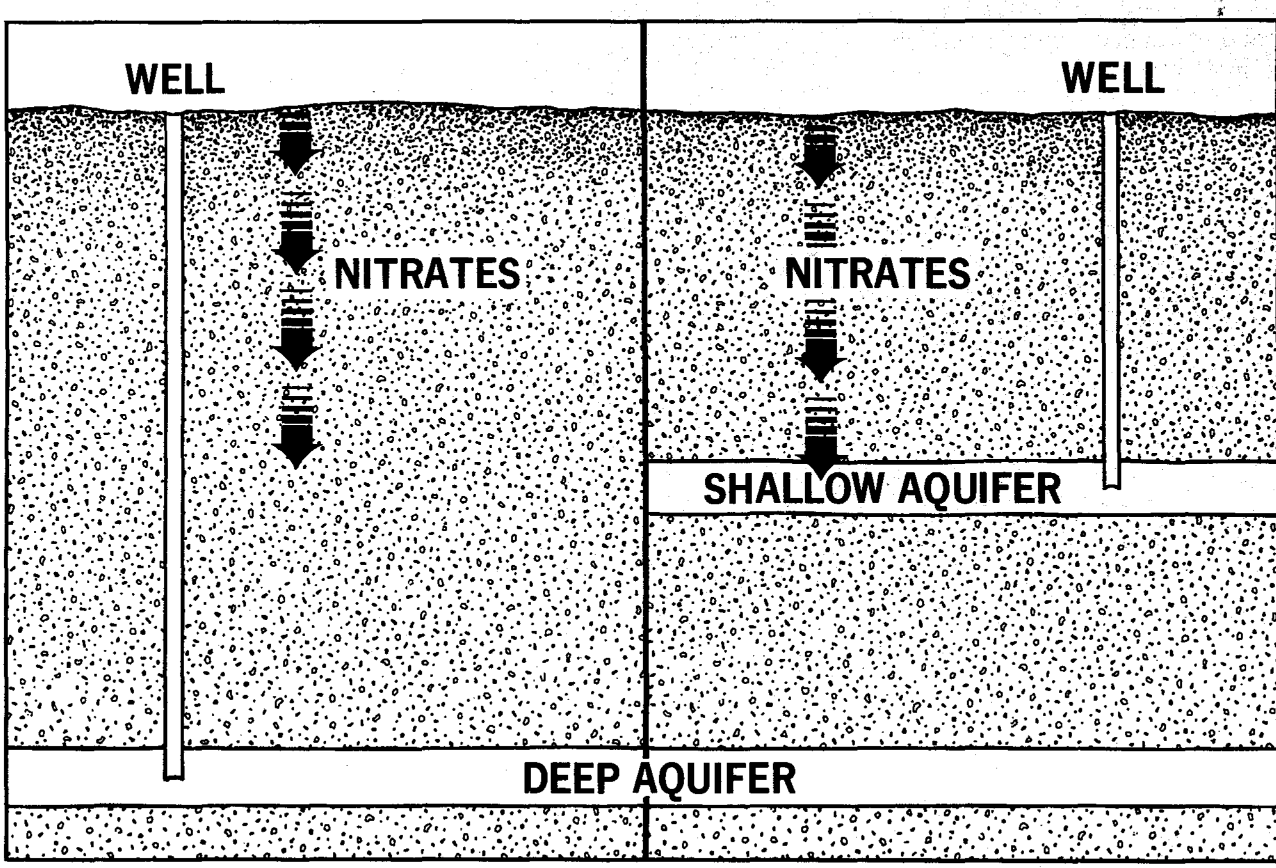

AGRICULTURAL EXTENSION SERVICE ○ UNIVERSITY OF MINNESOTA

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Curtis J. Overdahl*

Introduction

Nitrate nitrogen (NO_3-N) is water soluble: it can move into tile lines and sometimes to groundwater. Understanding nitrogen loss to various points or its accumulation in the soil is a vital factor in management practices for most efficient use of nitrogen fertilizers.

Frequent questions arise on possible groundwater pollution from fertilizer. This publication summarizes soils research from farm areas related to nitrate movement, either to tile lines or to greater depths in the soil profile. University of Minnesota department of Soil Science staff have completed many investigations, helpful in understanding possible problems, and have collected considerable data on varied soil types and from various nitrogen management practices in field trials. Movement has not been monitored to specific aquifers, however.

Researchers in Nebraska (6) report some NO_3-N concentrations in groundwater over 30 ppm, citing excessive N applications, shallow aquifers, and poor irrigation management as causes. Field experiments show that a 70 pounds per acre reduction of nitrogen in most fields did not result in reduced yield: yield goals were often too high. Nebraska researchers suggested improved timing of N applications, as well as improved irrigation efficiency, as management practices to reduce the NO_3-N concentration in the groundwater.

In 1964, Smith at the University of Missouri (22) reported that much of the groundwater nitrate appeared related to shallow wells' closeness to cattle or hog feedlots. He observed that deep wells had few problems.

Survey of Nitrate-Nitrogen in Minnesota Groundwater

Since 1978 the Minnesota Pollution Control Agency (MPCA) (12) working with the U.S. Geological Survey has conducted a groundwater quality monitoring program. MPCA determined water quality of principal state aquifers at numerous sites. Only NO_3-N is reported here, but MPCA measured a large number of pollutants. This nitrate summary has omitted all well measurements of nitrates from residences and data about wells where location or depth of well was missing. Data reported here are from 98 farm wells which are compared with measurements of 105 city wells (tables 1a and 1b). No connection can be established as to nitrate contamination sources. Exact locations of these wells and further information is available from the actual MPCA report. The nitrate readings are a total of nitrate plus nitrite, but the latter quantity is usually so insignificant that the readings can be considered nitrate. From appendix tables 1 and 2 there is clear evidence that problems are most frequent in the broad sandy soil areas of north central Minnesota. The three high readings in Winona and Fillmore counties might be related to sinkholes.

Table 1a. Summary of nitrate levels in farm wells according to well depth

	Depth of well, feet				
	0-50	51-100	101-200	>200[1]	Total
Number of wells	30	18	19	31	98
Number with >10 ppm NO_3-N	7[2]	0	3	3	13[3]

[1]Readings over 10 ppm are in Winona County 2 wells, Fillmore County 1 well.
[2]All wells with high nitrates were in sandy soil areas.
[3]13 percent of all samples were over 10 ppm NO_3-N.

Table 1b. Summary of nitrate levels in city wells

	Depth of well, feet				
	0-50	51-100	101-200	>200[1]	Total
Number of wells	3	7	21	74	105
Number with >10 ppm NO_3-N	0	0	0	0	0

The Minnesota State Legislature's House of Representatives environmental and natural resources committee states its top three priorities on environment involve water, also mentioning the constant relationship between groundwater and surface water. Lakes and streams can feed aquifers and aquifers feed streams. Much of the winter flow of Minnesota rivers is from groundwater. Nearly 100 percent of rural people obtain their drinking water from wells, the House committee noted.

Special Problems of the Karst Region (Southeast Minnesota)

Southeast Minnesota has many aquifers that are susceptible to contamination: vulnerable from several sources such as surface runoff, domestic sewage, and industrial waste. St. Ores et al. (21) point to many shallow wells that show contamination by coliform bacteria and high nitrate levels; even aquifers that are several hundred feet deep are in danger of pollution.

Extension Bulletin CD-BU-0547 *Groundwater Pollution Prevention in Southeast Minnesota* (21) describes the Karst region. Some pertinent excerpts follow:

> "Karst is a geologic term for a land area characterized by streams which disappear underground or which lose most of their flow into the ground; valleys which have no surface outlet, caves, springs, and circular depressions in the earth referred to as sinkholes. Karsts develop in areas where bedrock near the earth's surface is s. .uble in groundwater. The bedrock, generally limestone (calcium carbonate) or dolomite (calcium and magnesium carbonate), is normally fractured and contains numerous cracks, crevices, channels, and caves.
>
> "Karsts typically have very little flowing surface water. Most of the precipitation that starts running across the soil surface quickly disappears into underground drainage. After flowing underground for varying distances, the water will usually return to the surface in the form of springs. Runoff entering the ground can become groundwater in hours or just minutes. Contaminants in this runoff, including soil and chemicals

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attached to soil, will also become part of the groundwater as evidenced by the number of shallow southeast Minnesota wells which yield soil-rich water after heavy rainfalls.

"Proper well construction and abandonment procedures are essential in southeast Minnesota. Minnesota's Water Well Construction Code (7MCAR), instituted in the mid 1970s, addresses all aspects of proper well construction, maintenance, and abandonment. It further requires that wells be constructed only by drillers licensed by the Minnesota Department of Health.

"Improperly constructed wells are a major pathway of pollutant movement to groundwater. Well boreholes are generally larger than well casings. A conduit is created linking the soil surface or upper soil formations to lower aquifers if the space between the wellhole walls and casings is not sealed or grouted properly. Additionally, deteriorating and leaking casings allow materials to enter and move down the well itself. Contaminated runoff or contaminants in the upper soil layers can and will move toward wells and down the outside or inside of the well casing. New well construction must comply with code requirements.

"Feedlots and mature storage areas located on shallow sandy soils overlying fractured limestone can also pollute if the lot or storage area floors have not been sealed. Contaminations can move downward in the soil profile toward groundwater."

Lee (10) has supplied copies of data demonstrating the seriousness of well contamination and the benefits from improved well construction. Table 2 shows 20 years of data from 9,523 samples.

The Olmsted County health department also reported that more than 20 percent of wells in Fillmore County have E. Coli greater than 10 ppm. Although the source was not indicated, feedlots and manure storage, such as lagoons, could be suspected.

Table 2. Summary of NO_3-N test results by well construction type, Olmsted County 1964-1984

	NO_3-N Contamination		
	>10 ppm	1 to 10 ppm	<1 ppm
		Percent	
Old construction	11	46	43
Cased and grouted by code	0.4	8.6	91

Tile lines studies, profile measurements, and related fertilizer application are essential in understanding the nitrate content in the groundwater for rural Minnesota. City wells, usually very deep, appear less affected by what happens in farm fields (table 1b and appendix table 2).

Fate of Nitrogen Applied to Minnesota Soils

Tile line research

Tile line trials under investigation at Waseca and Lamberton provide an excellent study of nitrate movement to surface waters from farm fields. Losses through tile lines and the accounting of soil residual nitrate in the profile can suggest groundwater pollution possibilities.

Randall has reported findings from 1975 through 1984 in a mimeo (17). His work shows that NO_3-N concentrations some years in the Waseca study are greater than 10 ppm in tile water, even where no nitrogen was added. On two consecutive dry years, crop yields were low and no tile flow occurred. This resulted in a buildup of nitrates in the upper 3 or 4 feet which is susceptible to loss in years of normal rainfall. Nitrates in tile water ranged from 31 pounds of NO_3-N per acre for the 60 pounds per acre N application, to 202 pounds of NO_3-N per acre with the 240 pounds per acre rate. Considerably more N was lost through the tile lines with fall applications than with spring treatments. Corn yields were optimal at 180 pounds of N per acre, excess being more vulnerable to loss.

At Lamberton (16, 18), results after 12 years of N treatments show that N lost in the tile discharge accounted for 23 percent of the N applied at the 100 pounds per acre treatment. This treatment was close to the rate needed for maximum corn yield. Where 400 pounds per acre annually was applied, losses in tile lines were as high as 41 percent.

Denitrification losses are not specifically known, nor is the amount of nitrate N reaching the groundwater, but tile line losses plus the residual quantities in the soil indicate that minimal nitrates reach the groundwater when excessive rates of fertilizer N are avoided.

Profile studies

MacGregor (14, 15) measured soil nitrates to depths more than 30 feet in experimental plots at Morris and Waseca. Table 3 shows nitrate concentrations in 1-foot increments with these levels of applied ammonium-nitrate N after 15 years of treatments at Morris on a Barnes loam and after 11 years at Waseca on a LeSueur silty clay loam. This research was conducted from 1957 to 1971.

Table 3 indicates that nitrate movement to groundwater may not occur on fine-textured soils with low percolation rates where rainfall is quite high, but is more apt to occur in western Minnesota in a region of lower rainfall. The explanation is lower amounts of denitrification, no tile drainage, and low amounts of plant uptake due to lower crop yields.

The high nitrates in the profile from the 240 pounds of N per acre at Morris far exceeded plant needs. In this trial, 40 pounds produced optimum corn yields, meaning very small amounts of nitrates move downward if only the adequate rate is applied. Present day yields are higher than in this experiment and optimum N rates would probably be about 100 pounds per acre.

It is apparent from the Waseca data in table 3 that the 240 pounds per acre N results in no downward movement beyond 8 feet. At Waseca, corn yields were more than double the Morris yields, meaning a much greater N drawdown. The frequent wet conditions probably resulted in considerable denitrification, plus the nitrate loss in the tile lines explains the low nitrate readings below 8 feet at Waseca.

McCaslin (13) studied chloride and nitrate movement at Lamberton under totally controlled conditions on a Nicollet clay loam. He used two small adjacent plots 3 feet by 5.5 feet. A drainage tile was placed beside and beneath the plot at a 5 foot depth. He enclosed the soil with polyethylene film to force water movement uniformly through the soil. Plots were covered to control water additions precisely.

McCaslin monitored chloride movement, which would help predict maximum nitrate movement, since nitrate was subject to denitrification. Chloride movement is very similar to nitrate movement and is often measured to simulate it.

He concluded that maximum penetration of chloride is a function of rainfall; little was leached beyond 10 feet after 13 years of treatment on a nearby experimental site. The maximum concentration of chloride was at a 3 foot depth and movement slightly upward or downward between 2 and 4 feet depended on the

Table 3. Pounds of NO_3-N per acre in LeSueur silty clay loam after 11 years of corn and N fertilization at Waseca and on a Barnes loam after 5 years at Morris

Location	Morris	Waseca	Morris	Waseca	Morris	Waseca
Total N applied (lb/acre)	0	0	600	440	3600	2400
Soil depth (ft)[1]	— — — Pounds per acre of NO_3-N in soil — — —					
0-1	15	29	12	27	11	121
1-2	3	8	3	4	5	65
2-3	2	4	3	3	5	26
3-4	1	3	3	5	12	26
4-5	1	3	3	6	28	10
5-6	1	3	4	4	49	7
6-7	1	4	5	4	54	6
7-8	1	4	4	3	42	6
11-12	2	3	4	3	46	2
15-16	2	2	6	2	25	2
19-20	4	2	4	2	16	2
23-24	1	2	1	2	20	2
27-28	—	2	—	2	13	2
31-32	—	3	—	3	11	2
33-34	—	—	—	—	8	—

[1]All measurements not shown.

frequency and quantity of water supplied. He concluded that pollution of groundwater by nitrates is not a serious problem under the conditions studied.

Gast et al. (7), in studies on a Webster clay loam and Waldorf silty clay loam, reported that less than half of added nitrogen fertilizer, above that removed by corn grain, remains as nitrate. Nitrate and chloride accumulation in the profile short distances away form tile lines, compared to untiled areas, indicate that denitrification is apparently a major mechanism responsible for disappearance of unused fertilizer N, rather than leaching or lost through tile lines.

Through use of isotopic N in fertilizer, Castro (3) accounted for 96 percent of applied N on a Doland silt loam at Morris. He found 69 percent in roots and above ground portions of corn and the rest in the soil to only a 3-foot depth.

Gerwing (8, 9) studied nitrate movement on an irrigated Sverdrup sandy loam at Staples. He observed that high nitrogen rates on irrigated land resulted in nitrate movement to the aquifer (table 4). With proper timing and rates of N application, however, he could reduce the problem. Applications of 160 pounds per acre of N, split four times, resulted in little if any nitrate movement to the shallow aquifer, while 70 percent from a one-time application moved below the corn root zone, some reaching the aquifer.

Buzicky (1) also studied fertilizer movement to the aquifer on an irrigated Sverdrup sandy loam. He traced the N movement with isotopic nitrogen (15N).

Plants recovered only 17 percent N from a single application at planting time and 56 percent from the same N rate applied in four applications. The total accounting, soil plus plants, from 160 pounds per acre was 88 percent from split rates and 68 percent in a single application.

Buzicky monitored the downward movement of nitrogen by use of wells installed at 2.5- and 5-foot depths. Nitrate concentration reached a peak at 2.5 feet the first week of July and peaked at 5 feet in late July from split application. Most of the nitrate from the single application had moved past the 5-foot well in late August. Split applications continued to show nitrate at the 2.5-foot depth throughout the year.

Buzicky concluded that nitrates from fertilizer N on sandy soils are moving to the shallow aquifers, but this problem can be

Table 4. Nitrate nitrogen in the aquifer below irrigated and fertilized corn

Nitrogen treatment lbs/A	Sub sample[1]	Date						
		5/13	6/3	7/1	8/2	9/2	10/4	11/8
		— — — NO_3-N (ppm) concentration — — —						
160 once	1	1	1	0	0	2	1	11
	2	0[2]	0	0	0	5	6	6
	3	tr[3]	0	tr	2	8	4	4
160 split	1	0	0	0	0	0	0	0
	2	8	4	3	6	8	7	9
	3	17	17	17	16	16	14	9
240 once	1	4	5	10	19	16	9	8
	2	12	11	11	16	20	18	17
	3	11	14	16	17	23	18	18
240 split	1	0	0	0	0	0	tr	2
	2	0	0	0	0	3	0	0
	3	0	0	0	0	1	tr	2

[1]Three subsamples were taken from each plot.
[2]Concentration was less than detection limits of 0.07 ppm.
[3]Trace was detectable.

minimized by applying nitrogen in split application through much of the growing season.

Walters (23) studied the fate of fertilizer N over three seasons, using lysimeters and 15N labeled urea. This was on an Estherville sandy loam at Westport. He measured about 17 percent of added N in the leachate from 80 pounds per acre of N and with 160 pounds he found 30 percent loss, so rate was a major factor in losses.

Manure studies

Evans (4) conducted extensive manure treatment studies over several years at Morris. In one trial he used 32 tons per acre of undried soild manure annually for 5 years. The sixth year he measured nitrates in 1-foot increments to 10 feet (table 5). In comparison to unmanured plots, a considerable buildup is obvious, but only to about 5 feet. It is unlikely that bacteria, such as E. Coli, reach the groundwater under these conditions.

Table 5. Effect of manure application on nitrate content of soil after 6 years (1978)

Depth feet	No manure	32 tons annual total N=3,360 lbs.
	— — — — — NO_3-N (ppm) — — — — —	
0-1	5	16
1-2	2	58
2-3	3	102
3-4	6	34
4-5	7	14
5-6	6	7
6-7	6	7
7-8	5	6
8-9	4	6
9-10	4	4

Nitrogen Studies

Fenster et al. (5) conducted nitrogen studies for seven years in Waseca and Martin counties using rates up to 400 pounds of N per acre.

Profile analysis at the Waseca County location "illustrates that when nitrogen is applied at normal rates such as 150 to 200 pounds per acre that little accumulation occurs."

At Martin County where rainfall was lower than in Waseca County, the 100 pounds of N per acre was closest to ideal and nitrate accumulation was low at that rate. At 200 pounds per acre, nitrate accumulation was higher than at this same rate at Waseca.

Table 6. Soil nitrate levels for various nitrogen application rates at Waseca and Martin counties, 1975

	Annual nitrogen treatment lbs/A since 1971											
	Waseca County						Martin County					
Soil depth	0	50	100	150	200	400	0	50	100	150	200	400
	NO_3-N (ppm)											
0-1	3	5	4	8	10	39	7	8	9	18	30	60
1-2	2	2	2	5	7	32	2	2	6	16	12	45
2-3	2	2	3	6	9	32	3	2	18	18	21	51
3-4	3	3	3	10	7	17	4	4	12	16	20	35
4-5	4	5	5	10	8	13	6	7	10	16	20	37
5-6	-	-	-	--	-	--	8	13	11	17	19	31

The nitrate levels from the excessive rate of 400 pounds per acre were highest at the upper 3 feet at Waseca. In Martin County the nitrates were higher at these depths, but were still nearly as high at 6 feet (table 6). More denitrification probably occurred on the Waseca locations in addition to the greater nitrogen drawdown accompanying higher yields. Tile line flow, not measured in this trial, could also have drained off more nitrogen at Waseca.

Commerford and Malzer (2) show that soil nitrate measurements could allow for reduced application rates of N. They developed a formula involving soil moisture, soil test measurements of nitrates, and other factors to predict nitrogen needs more reliably than merely using cropping history. This formula is now being used to make N recommendations in western Minnesota and is included in the 1985 recommendations (19, 20).

Nitrate studies in Karst area

Jokela et al. (11) conducted field trials attempting to relate soil nitrate tests, and N additions to corn yield responses in southeast Minnesota. The amount of nitrate N in the soil profile showed only a general link to N response, not consistent enough to be used in a soil testing program. Tables 7 and 8 show an example of these 1980 results. Plot data from other years were similar. Currently, cropping history is still the most reliable prediction of N needs in the Karst area. Nitrate tests are used, however, as indictors of extremes such as the conditions after excess N treatments.

Other Plant Nutrients

Only nitrate N is reported in this publication, but movement of other plant nutrients has also been studied. Since the soil has a negative charge, the positively charged nutrients are held and will not move appreciably except by mechanical movement by soil tillage. Calcium, potassium, magnesium, and several micronutrients have positive charges. Phosphate, even though not positively charged, moves very little. Nearly all nutrients farmers apply in appreciable quantities, other than nitrogen, will be filtered by the soil and will not contaminate groundwater. The exception is when nutrients, pesticides, or other foreign matter run in directly, such as through sinkholes. E. Coli would be restricted also from reaching groundwater, except through direct flow.

Table 7. Residual nitrate N in the soil profile in the spring and the influence of N rate on nitrate N in the soil profile in the fall after harvest — six locations in southeast Minnesota —1980

	Nitrate-Nitrogen (lb/A)							
	Winona County				Goodhue County			
Depth (ft.)	Spring[1]	Fall N Rate (lb/A)			Spring[1]	Fall N Rate (lb/A)		
		0	100	200		0	100	200
0-1	34	18	24	24	28	16	34	40
1-2	18	9	14	16	14	8	22	42
2-3	14	8	10	14	12	8	8	13
3-4	14	8	10	19	13	8	8	9
4-5	15	9	13	15	16	8	10	13
0-2	52	27	38	40	42	24	56	82
0-5	92	52	71	88	83	48	82	117

	Houston County				Olmsted County			
Depth (ft.)	Spring[1]	Fall N Rate (lb/A)			Spring[1]	Fall N Rate (lb/A)		
		0	100	200		0	100	200
0-1	17	20	22	21	30	28	39	40
1-2	22	18	10	12	26	12	36	52
2-3	22	14	8	14	38	10	33	67
3-4	15	10	9	16	29	18	52	48
4-5	11	10	14	14	18	22	32	38
0-2	39	38	32	33	56	40	75	92
0-5	87	72	63	77	141	90	192	245

	Steele County				Wabasha County			
Depth (ft.)	Spring[1]	Fall N Rate (lb/A)			Spring[1]	Fall N Rate (lb/A)		
		0	100	200		0	100	200
0-1	33	32	48	66	32	20	41	38
1-2	20	11	26	52	56	12	42	38
2-3	19	10	25	44	76	15	24	55
3-4	20	11	23	32	98	34	66	84
4-5	18	14	16	25	86	59	98	90
0-2	53	53	74	118	88	32	83	66
0-5	110	78	138	219	348	140	271	295

[1]Spring was at zero rate, or before any N was spread for that year.

Table 8. Influence of nitrogen rate on grain yield and nitrogen content of earleaf — six locations in southeast Minnesota — 1980

N Rate[1] (lb/A)	Winona	Goodhue	Houston	Olmsted	Steele	Wabasha
	Yield (bu/A)					
0	121	141	110	131	107	133
50	128	157	136	144	112	147
100	135	161	127	147	130	137
150	138	163	135	148	140	152
200	134	161	138	152	135	147
250	128	161	137	151	128	144
Signif.	ns	+	ns	**	**	ns
BLSD[2](.05)	-	16	-	11	16	-
	Earleaf N (%)					
0	2.64	1.83	2.49	2.68	2.16	2.39
50	2.50	2.40	2.84	2.80	2.30	2.44
100	2.62	2.66	2.93	2.90	2.40	2.53
150	2.73	2.69	2.78	3.05	2.66	2.80
Signif.	ns	**	+	*	*	ns
BLSD[2](.05)	-	.26	.33	.24	.29	-

[1]All plots received an additional 10 to 20 lbs/acre nitrogen as a starter.
[2]Stands for significance with 95 percent level of confidence.
+ = 10 percent, * = 5 percent, ** = 1 percent level of confidence.

Summary

Based on Soil Science department research and the survey of wells in various parts of the state, several observations can be made. Nitrates are high in wells of sandy textured areas where aquifers and farm wells are shallow. This is especially apparent in Wadena and Crow Wing counties. Nitrates are high in southeast Minnesota wells because of geological conditions even where wells are deep. These conditions permit direct flow of nitrates to the aquifer. In most areas of the state, where wells are deeper than 200 feet, nitrate contamination is not a problem.

Information concerning observed contamination should point out the soil types, depth of well, and area of the state concerned, to prevent undue alarm in unaffected areas.

Where contamination is noted, there are specific practices farmers can adopt to reduce or eliminate nitrate downward movement. These are listed in the following recommendations.

Recommendations

From studies reviewed in this publication, the following actions can be taken to reduce or eliminate nitrate contamination of groundwater.

- Avoid excess nitrogen additions.
- Use proper soil nitrate testing, where appropriate, to establish a quantitative measure of residual nitrates in the profile. Cropping history is helpful in the absence of the test.
- On course (sandy) textured soils, use split application methods for nitrogen additions.
- Use nitrification inhibitors to reduce rate of conversion from ammonium to nitrate.
- Reduce soil movement to surface waters.
- Give proper credit to manure applications, N supplied by legumes and the previous crop when making N recommendations.

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APPENDIX

Table 1. Nitrate N from farm wells in Minnesota listed according to farmer's name, address and well depth

	Location	Well depth feet	Nitrate-N ppm
1978			
Donald Blaha	Verndale	50	11.00
Gordon Berg	Staples	81	.03
Mrs. Wayne Hunter	Wadena	12	.03
H. Vogel	Staples	13	16.00
Herman Miller	LeRoy	123	.01
Glennis Wold	Mabel	355	.20
Ervin Feine	Rushford	612	.03
Percy Steffersrud	Harmony	355	.03
Ole Brokken	Harmony	397	.01
Anthony Schnitzler	Holloway	113	.03
Arnold Lachowitzer	Perham	68	5.00
Leonard Rustedt	Otter Tail	24	5.10
John Shertler	Wadena	535	.01
U. of M. Experiment Station	Rosemount	415	.01
Clarence Horsager	Verndale	60	.04
Milford Dalchow	Waconia	535	.03
J. Cairns	Appleton	110	.10
R. Brown	Appleton	59	.40
Dale Erickson	Appleton	42	.90
Dreyer Bros	Otter Tail	55	.02
Marvin Heisler	Otter Tail	56	3.20
Robert Riestenberg	Perham	115	15.00
Art Ternus	Perham	105	17.00
John Duchner	Pierz	18	9.40
Russell Persons	St. Charles	365	.02
1979			
Herman Miller	LeRoy	123	.01
Glennis Wold	Mabel	355	.22
Conrad Hulstein	Hardwick	193	1.20
Wayne Wold	Mabel	445	.47
Ray Karlstad	Warroad	175	.01
Harlan Almen	Plummer	265	.01
Russell Carter	Park Rapids	49	.01
Frank Boots	Redwood Falls	214	4.80
Roger Thompson	Lake Bronson	190	.01
Henry Nelson	Roseau	128	.01
Rueben Rabenhorst	Viking	171	.01
Charles Andress	Akeley	45	23.00
W.L. James	Nevis	48	.29
1980			
Howard Gray	Clearwater	80	5.70
Kenneth Bergren	Grove City	97	.01
David Jackson	St. Cloud	24	3.00
John Woztancwiez	Rice	35	30.00
John Dankel	Long Prairie	15	8.30
Joe Drayna	Browerville	276	.01
Don Johnson	Verndale	24	.50
Larry Lehner	Verndale	18	17.00
David Holmberg	Motley	85	.01
Walfrid Walkoma	Menahga	33	.78
Richard Nanik	Staples	15	8.70
Bruce Burrows	Motley	13	.01
Dave Miller	Brainerd	53	.01
Ed Rothstein	Paynesville	30	.01
Paul Bierman	Belgrade	116	.01
Terry Goert	Sauk Center	64	.01
Donald Johnson	Litchfield	75	.01
Rodney Hartman	St. Cloud	25	16.00
Willard Petron	Rice	70	.01
Henry Kelzenberg	Royalton	76	.01
Westby Bros.	Sebeka	100	.01
Richard Sandberg	Menahga	35	3.01
Paul Malek	Sebeka	86	.01
Walter Sowers	Verndale	40	.11

Table 1 (continued). Nitrate N from farm wells in Minnesota listed according to farmer's name, address and well depth

	Location	Well depth feet	Nitrate-N ppm
1981			
Mike Finnemann	Blaine	410	.05
Lavern Fritz	Minnesota City	237	.01
James Bronk	Winona	195	.01
Robert Miller	Lewiston	291	11.00
David Larson	Rosemount	120	25.00
Dale Vosberg	Avoca	384	.01
Marvin Strom	Fulda	348	.01
LaRell Kettner	Springfield	126	4.00
E.G. Siverson	Milan	132	.01
Julian Ellingson	Watson	230	.02
Edward Dosdall	Hancock	186	.01
Roger Holmer	Ponsford	65	.87
Van Swanson	Grygla	156	.01
1982			
Lavern Fritz	Minnesota City	237	.01
John Champeau	Winona	114	1.36
James Bronk	Winona	195	.01
Don Galewski	Winona	542	1.28
Robert Miller	Lewiston	291	11.00
Keith Beach	Lewiston	125	1.92
Roger Swanson	Dunnell	297	.01
Bruce Dornink	Harmony	345	13.00
Robert Jostock	Lake City	555	.01
Gerald Vanderbeek	Brooten	22	5.49
Morton Olson	Glenwood	327	.23
Palmer Ophdall	Starbuck	143	.01
F. Fredrickson	Starbuck	208	.01
Lester Rupp	Glenwood	35	12.00
Jim Jacobs	Glenwood	30	8.80
Bruce Hanson	Villard	26	2.40
Roland Kirchner	Onamia	100	.28
U.S. Forest Service	Grand Marais	65	.04
Marland Hanson	Lutsen	27	1.40
U.S. Forest Service	9 Mile Lake	40	.04
Richard Olson	Nerstrand	227	.01
Pat Murphy	Henderson	600	.01
Lee Brazil	Green Isle	338	.01
Dennis Westzenkamp	Winthrop	305	.01

Table 2. Nitrate-N from city wells and well depth in Minnesota

Location	Well depth feet	Nitrate-N ppm
1978		
Montrose	693	.02
Howard Lake #2	148	.02
Chanhassen #1	518	.01
Mantorville	181	.02
Red Wing #7	630	.02
Red Wing #1	488	.20
Red Wing #2	474	.20
Red Wing #4	620	.01
Holloway #2	59	.20
Appleton #2	101	.03
Battle Lake #1	71	4.30
Rogers #1	300	.10
Edina #9	1130	.10
Shoreview	155	.01
St. Paul Civic Center	416	.02
Blaine #3	681	.02
Anoka #4	660	.03
Hamburg	745	.03
Inver Grove Heights #2	431	.01

Table 2 (continued). Nitrate-N from city wells and well depth in Minnesota

Location	Well depth feet	Nitrate-N ppm
1978		
Inver Grove Heights #1	435	.04
Eagan	450	.02
Mendota Heights	488	.01
Rogers	300	.01
Rochester #12	464	.02
Rochester #13	442	.60
Winona #5	502	.03
Winona #6	486	.02
Winona #13	517	.02
Winona #15	1072	.01
1979		
New Brighton #6	543	.01
New Brighton #4	500	.01
Howard Lake	148	.01
Rogers #1	300	.01
Worthington #16	37	.08
Worthington #17	43	.01
Worthington #25	71	.01
Worthington #26	76	.11
Fairmont	184	.01
Redwood Falls #0	92	.01
Redwood Falls	182	.02
Jordan	564	.01
Savage	250	.01
Warren	107	.01
Moorhead #10	124	.01
Park Rapids #5	50	5.10
Brooklyn Park #4	736	.01
Brooklyn Park #3	319	.01
Edina #4	500	.01
Edina #5	443	.02
Hopkins #5	500	.01
1980		
Anoka #4	660	.01
Hopkins #4	548	.85
Burnsville #1	298	.01
So. St. Paul #3	340	6.10
So St. Paul #1	404	.01
Hastings #3	302	4.30
Hastings #2	197	3.96
Faribault #4	407	.01
Faribault #3	410	.01
Stillwater #5	225	.96
White Bear Lake #4	476	.71
No. St. Paul #3	470	.04
Northfield #1	401	.90
Northfield #3	418	.20
Fridley #5	845	.01
Hibbing #18	112	.01
Hibbing #7	118	.11
Virginia	157	1.50
Cottage Grove #7	370	1.10
Rochester #11	455	.04
Austin #4	132	1.35
Owatonna #4	700	.01
Owatonna #5	774	.01
Little Falls #4	100	.01
1981		
Rogers	300	.01
Stillwater #5	225	.96
No. St. Paul #3	470	.04
Blaine #8	500	.01
Minnetonka Beach #2	393	6.10
Edina #12	953	.03
New Germany	375	.01
Burnsville #5	335	.01
No. St. Paul #1	470	.01
Stillwater #6	271	2.60
Cottage Grove #9	380	.37
Carlos #2	138	.01
Watson #2	53	.01
Montevideo #10	69	.01
Graceville #1	212	.01
Moorhead #8	116	.02
Bemidji #11	113	.01
Bemidji #10	238	.01
1982		
Willmar #7	349	.01
Willmar #8	205	.02
Tracy #3	632	.28
Tyler #5	180	.01
Wells #2	700	.01
Harmony #2	748	.70
Brainerd #3	120	.06
Brainerd #6	145	.25
Andover #1	601	.01
Courtland #2	432	.03
Shafer	550	.01
Mora #5	203	.01

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