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Results of Vadose Zone Sampling Within the Tri-Basin Natural Resources District

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Table of Contents

List of Figures

Introduction

This report is the culmination of a service agreement for work between the Tri-Basin Natural Resources District (TBNRD) and the University of Nebraska-Lincoln Conservation and Survey Division (CSD). Continuous soil cores were collected from the vadose zone beneath six agricultural fields and analyzed for nitrate-N, ammonia-N, bulk density and moisture content. The vadose zone is defined as the subsurface region from the soil surface to the local water table. Occasionally, localized fine textured soils can impede downward transport of soil moisture, creating a zone of saturation within the vadose zone called "perched water." For this reason, the term *vadose zone* is preferred over the term *unsaturated zone*.

This report does not provide an in-depth evaluation of the impact of management practices at project sites but is intended to offer some insight into the complex nature of nitrate-N transport in the vadose zone. The analysis of agricultural chemical (agrichemical) concentrations in the intermediate vadose zone, the part of the vadose zone below the root zone, can be used to assess agrichemicals no longer accessible to crops and to make general predictions of the impact of nonpoint source agrichemical leachates on the local aquifer. One vadose zone core was collected from six fields in the TBNRD. Two of the sites were sampled in 1990 (GSI, 1990) and 2002 (Burbach, 2002). The location of all six sites is shown in figure 1. Site TB1 is a furrow-irrigated cornfield 14 miles north and 10 miles east of Holdrege. Site TB2 is a furrow-irrigated cornfield 4 miles south and 4 miles east of Kearney. Site TB3 is a furrow-irrigated bean field 3.5 miles south and 11 miles east of Kearney. Site TB4 is a center pivot-irrigated cornfield with a grass cover crop 13 miles north of Holdrege. Site TB5 (previously TB1) is a center pivot-irrigated cornfield located one mile north of Holdrege. Site TB6 (previously TB3) is a furrow-irrigated bean/corn rotation field located about 0.25 miles northeast of Wilcox. A total of 156 ft of core was collected by CSD personnel and analyzed by the Water Sciences Laboratory of the University of Nebraska-Lincoln. By design, the cores at sites TB5 and TB6 were collected near locations cored in 1990 and 2002.

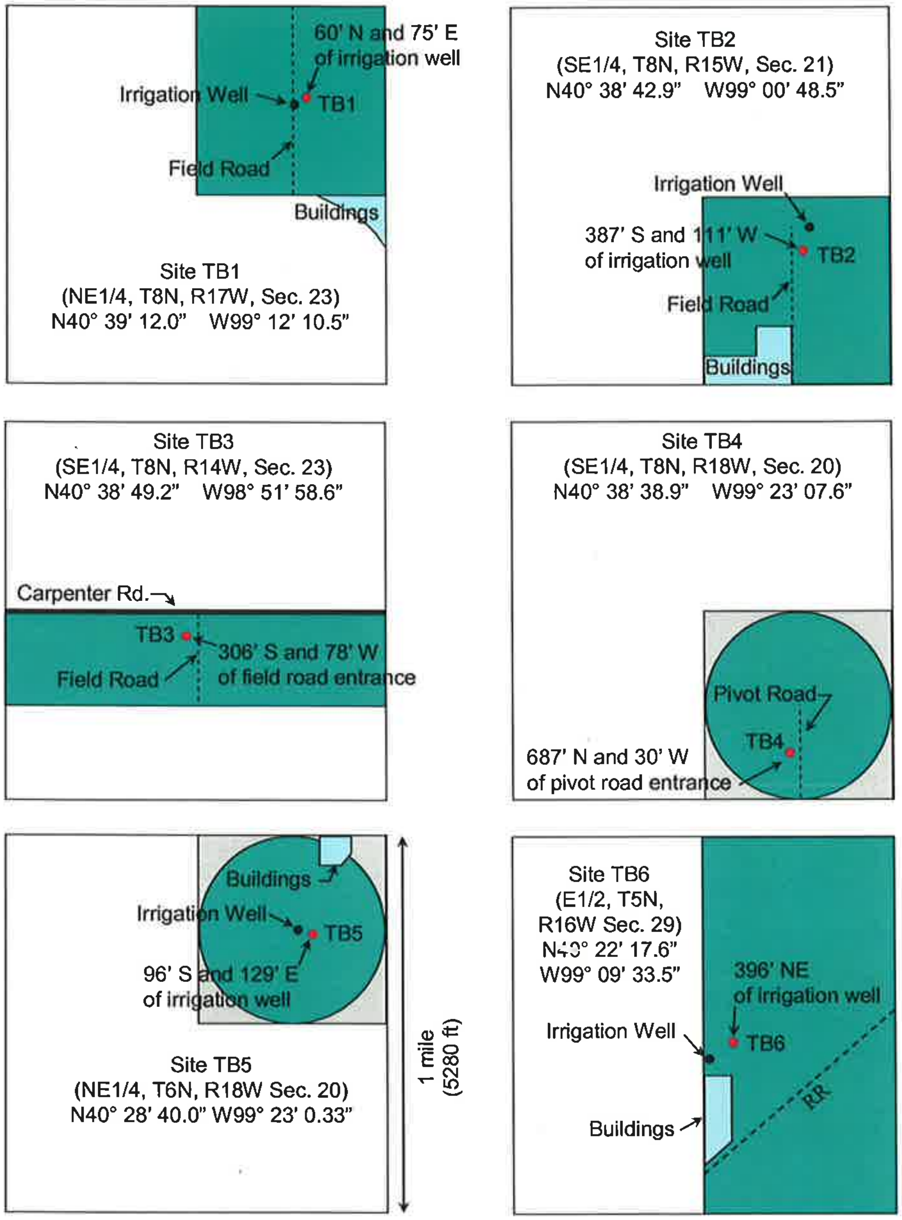


Figure 1. Vadose zone coring locations.

Methods

Continuous soil cores were collected by driving a 4-ft long by 2.5-in. diameter core barrel into the soil until full and retracting the core barrel (Figure 2). All sites were sampled to the water table except for site TB6, which was cored to a depth of 60 ft. Care was taken to prevent cross-contamination during sampling by collecting the cores in new, clean plastic liners inside the core barrel. If the core barrel was driven through collapsed material, the "slough" material was discarded. The liners were removed from the core barrel and capped

(Figure 2). The soil in each core was described by visual inspection on-site, and the soil description was confirmed by follow-up visual estimation of soil texture in the laboratory. After the cores were inspected in the field, they were placed in Styrofoam coolers, frozen, and delivered to the laboratory the day after sampling was completed. All samples remained frozen until analyzed at the laboratory. Appendix A contains the soil description of each core.

Figure 2. Demonstration of vadose zone coring process.

Coring, preservation, and analytical methods followed procedures developed by Spalding and Kitchen (1988). Each core was composited into 2-ft intervals. Each interval was analyzed for bulk density, gravimetric moisture content, soil ammonia-N, and soil nitrate-N (Appendix A). After partial thawing, the cores were removed from the liners, and a 100 g (0.4 lb) sample was removed from each interval for moisture analysis. Each sample was weighed, oven-dried for 24 hrs, cooled in a dessicator, and reweighed. Gravimetric moisture content was calculated by dividing the mass of the water by the mass of the dry sample.

The remaining extruded sediment from each interval was air-dried overnight, ground until the sediment passed through a 0.08 in sieve, and homogenized. Soil extractions for nitrate followed the procedure of Lindau and Spalding (1984) in which 10 g (0.04) lb) aliquots of soil were extracted with 100 ml of 1N KCL. The mixture was shaken and filtered, and the extract analyzed for NO_3-N by the automated cadmium reduction method. Ammonia-

N was analyzed by the automated phenate method. Pore water nitrate-N concentrations (Appendix A) were determined by the following formula:

Pore Water N (mg/L) = Soil NO_3-N (µg/g) / Gravimetric Moisture (g/g)

In order to convert extractable NO_3-N to lbs N/acre-ft, a number of steps are involved. Soil nitrate-N in lbs/ac (Appendix A) was determined by the following formula:

Soil Nitrate (lbs/ac-ft) = Soil NO_3-N (µg/g) x Bulk Density x 2.71 (conversion from µg N/g to lbs N/ac) x Interval Length (2 ft)

Results

Site TB1

The average soil ammonia-N concentration in core TB1 was 2.0 µg/g. The average soil ammonia-N concentration below the root zone was 1.5 µg/g. The bulk density ranged from 1.24 g/cc to 2.10 g/cc. Gravimetric moisture content ranged from 0.07 g/g (7%) to 0.20 g/g (20%).

The average soil nitrate-N concentration in core TB1 was 3.6 µg/g (14.3 lbs N/ac/ft). Note that each core was composited into 2-ft intervals so Appendix A lists the soil N as lbs N/ac/**2ft**). The average soil nitrate-N concentration below the root zone and no longer available to future crops was 2.2 µg/g (10.8 lbs N/ac/ft). The average pore water nitrate-N concentration for the entire core was 26 mg/L, and the average below the root zone was 18 mg/L. There were 86.2 lbs/ac of nitrate-N in the intermediate vadose zone. The water table at this site was 12 ft below the ground surface. Figure 3 shows the nitrate-N profiles for core TB1.

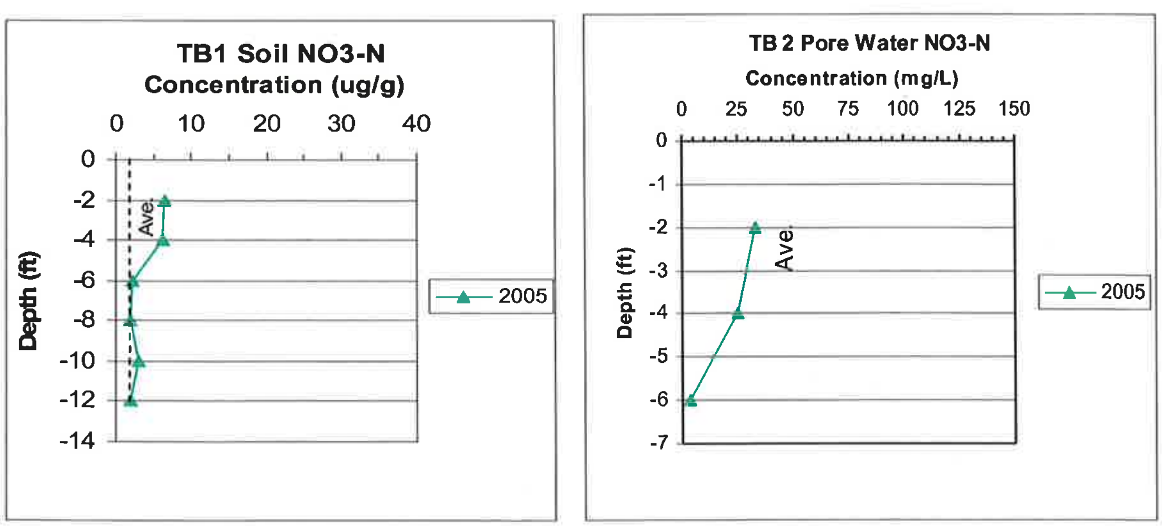
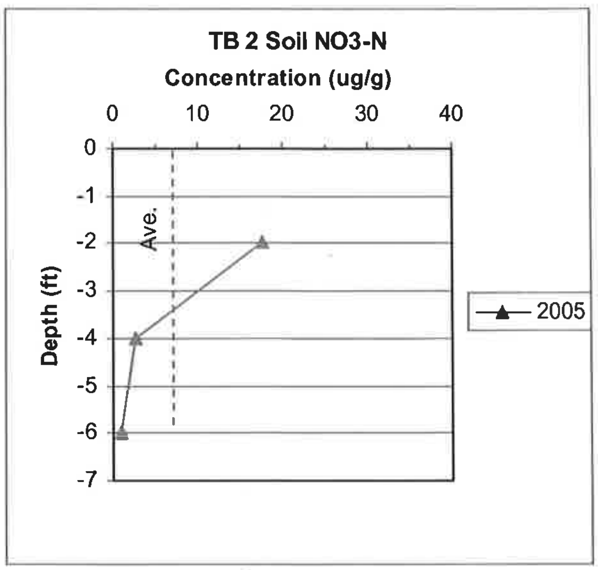


Figure 3. Nitrate-N profiles for core TB1.

Site TB2

The average soil ammonia-N concentration in core TB2 was 1.1 μg/g. The average soil ammonia-N concentration below the root zone was 0.6 μg/g. The bulk density ranged from 1.53 g/cc to 2.08 g/cc. Gravimetric moisture content ranged from 0.15 g/g to 0.17 g/g.

The average soil nitrate-N concentration in core TB2 was 7.1 μg/g (31.1 lbs N/ac/ft). The average soil nitrate-N concentration below the root zone was 1.0 μg/g (9.9 lbs N/ac/ft). The average pore water nitrate-N concentration for the entire core was 44 mg/L, and the average below the root zone was 6 mg/L. There were 9.9 lbs/ac of nitrate-N in the intermediate vadose zone. The water table at this site was 6 ft below the ground surface. Figure 4 shows the nitrate-N profiles for core TB2.



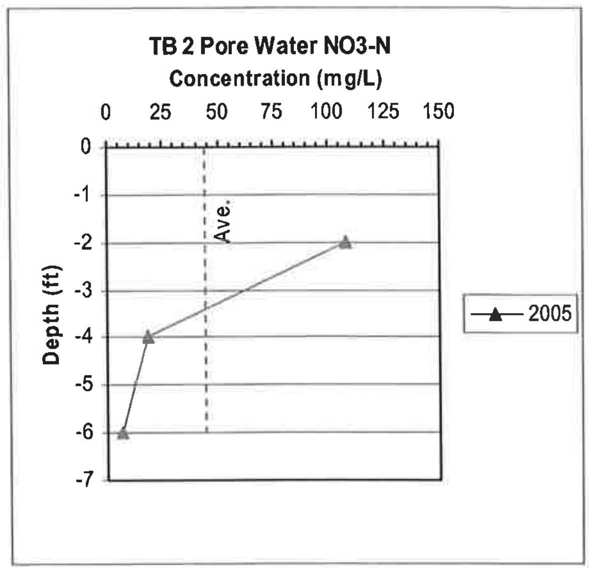


Figure 4. Nitrate-N profiles for core TB2.

Site TB3

The average soil ammonia-N concentration in core TB3 was 1.1 μg/g. The average soil ammonia-N concentration below the root zone was 1.3 μg/g. The bulk density ranged from 1.44 g/cc to 1.89 g/cc. Gravimetric moisture content ranged from 0.13 g/g to 0.17 g/g.

The average soil nitrate-N concentration in core TB3 was 3.2 μg/g (13.0 lbs N/ac/ft). The average soil nitrate-N concentration below the root zone was 0.4 μg/g (1.9 lbs N/ac/ft). The average pore water nitrate-N concentration for the entire core was 20 mg/L, and the average below the root zone was 3 mg/L. There were 3.8 lbs/ac of nitrate-N in the intermediate vadose zone. The water table at this site was 6 ft below the ground surface. Figure 5 shows the nitrate-N profiles for core TB3.

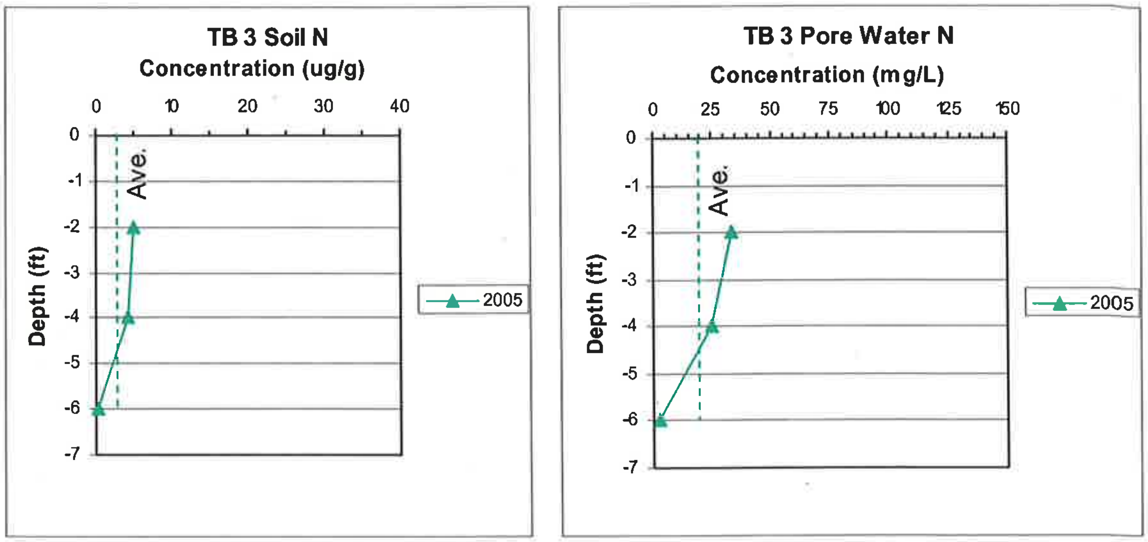


Figure 5. Nitrate-N profiles for core TB3.

Site TB4

The average soil ammonia-N concentration in core TB4 was 0.9 µg/g. The average soil ammonia-N concentration below the root zone was 0.6 µg/g. The bulk density ranged from 1.01 g/cc to 1.71 g/cc. Gravimetric moisture content ranged from 0.08 g/g to 0.18 g/g.

The average soil nitrate-N concentration in core TB4 was 21.9 µg/g (7.6 lbs N/ac/ft). The average soil nitrate-N concentration in core TB4 below the root zone crops was 1.6 µg/g (6.2 lbs N/ac/ft). The average pore water nitrate-N concentration for the entire core was 20 mg/L, and the average below the root zone was 15 mg/L. There were 73.8 lbs/ac of nitrate-N in the intermediate vadose zone. The water table at this site was 16 ft below the ground surface. Figure 6 shows the nitrate-N profiles for core TB4.

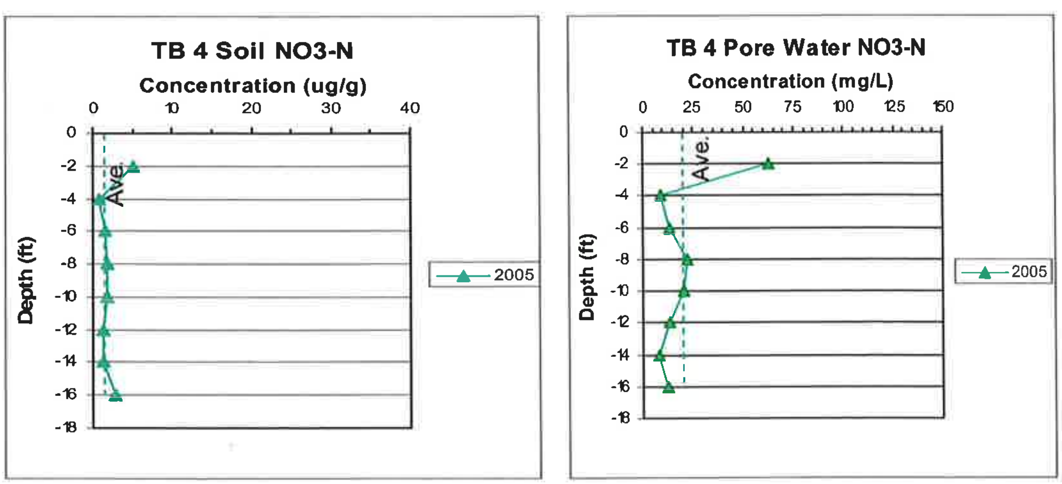


Figure 6. Nitrate-N profiles for core TB4.

Site TB5

The average soil ammonia-N concentration in core TB3 was 1.4 μg/g. The average soil ammonia-N concentration below the root zone was 0.8 μg/g. The bulk density ranged from 1.10 g/cc to 2.06 g/cc. Gravimetric moisture content ranged from 0.09 g/g to 0.25 g/g.

The average soil nitrate-N concentration in core TB5 was 5.2 μg/g (20.7 lbs N/ac/ft). The average soil nitrate-N concentration in core TB5 below the root zone was 4.1 μg/g (17.8 lbs N/ac/ft). The average pore water nitrate-N concentration for the entire core was 29 mg/L, and the average below the root zone was 25 mg/L. There were 926.6 lbs/ac of nitrate-N in the intermediate vadose zone. The water table at this site was 56 ft below the ground surface. Figure 7 shows the nitrate-N profiles for core TB4..

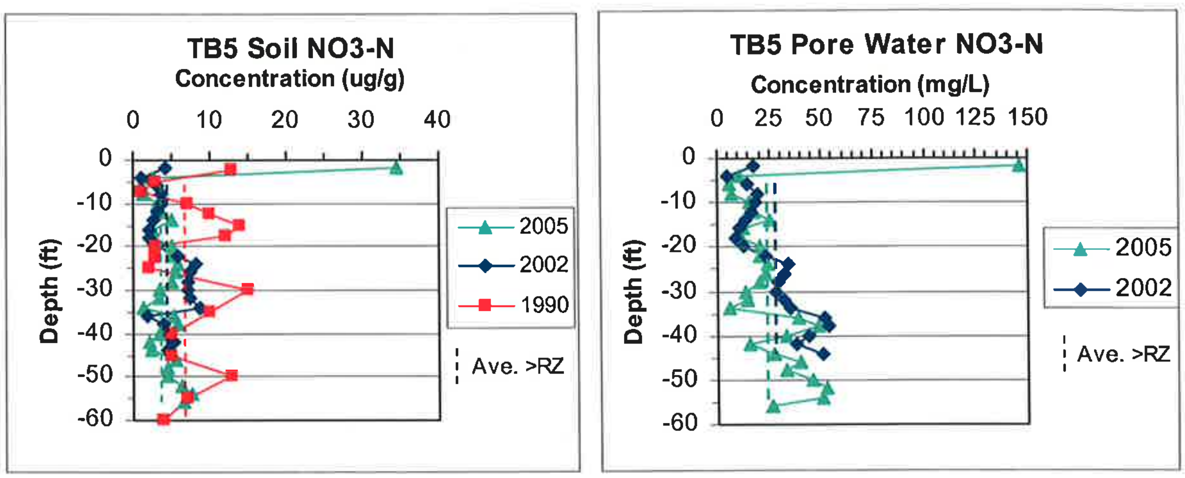


Figure 7. Nitrate-N profiles for core TB5.

For comparison purposes, core TB5 was collected near the same location as cores collected in 1990 and 2002. The 2002 core averaged 4.8 μg N/g from below the root zone to a depth of 44-ft and the 1990 core averaged 7 μg N/g from below the root zone to a depth of 60 ft. (Figure 7).

Site TB6

The average soil ammonia-N concentration in core TB6 was 1.7 μg/g. The average soil ammonia-N concentration below the root zone was 1.6 μg/g. The bulk density ranged from 1.10 g/cc to 2.25 g/cc. Gravimetric moisture content ranged from 0.06 g/g to 0.29 g/g.

The average soil nitrate-N concentration in core TB6 was 2.4 μg/g (10.2 lbs N/ac/ft). The average soil nitrate-N concentration in core TB6 below the root zone was 2.5 μg/g (10.5 lbs N/ac/ft). The average pore water nitrate-N concentration for the entire core was 15 mg/L, and the average below the root zone was 16 mg/L. There were 587.1 lbs/ac of nitrate-N in the intermediate vadose zone to a depth of 60 ft. The water table was estimated to be 120 ft below the ground surface. Figure 8 shows the nitrate-N profiles for core TB5.

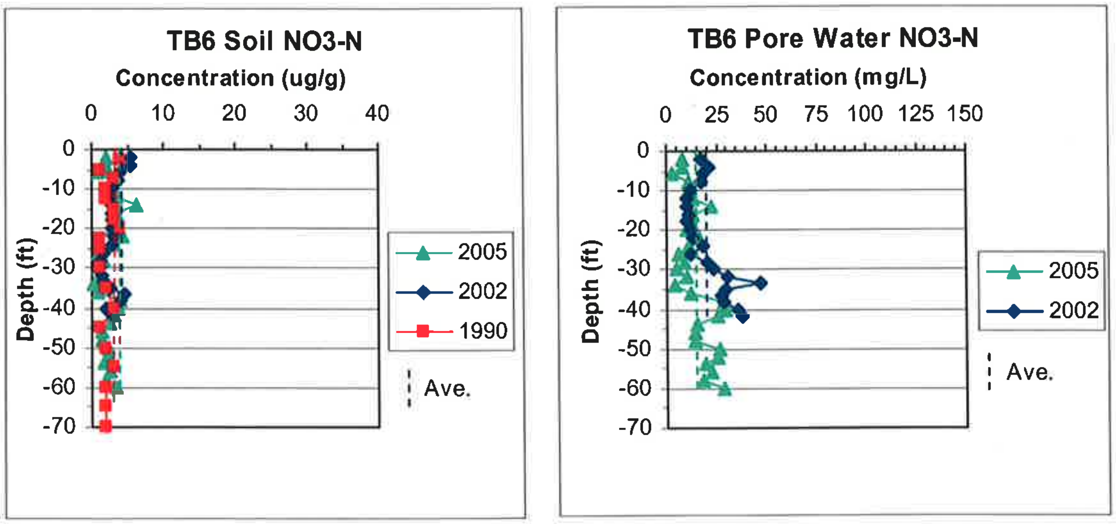


Figure 8. Nitrate-N profiles for core TB6.

For comparison purposes, core TB6 was collected from near the same location as cores collected in 1990 and 2002. The 2002 core averaged 2.9 µg N/g throughout the entire 42-ft core, and the 1990 core averaged 2 µg N/g to a depth of 70 ft (Figure 8).

Discussion

Nitrate-N concentrations usually vary with depth in vadose zone cores beneath agricultural fields such as corn on which large quantities of nitrogen fertilizer are applied and "spikes" in nitrate-N indicate specific nitrogen leaching events. These spikes of nitrate-N can be caused by over application of fertilizer and/or water beyond what the crop can absorb. Heavy rains soon after fertilizer application or too much irrigation on all or part of a field can flush water and nitrate through the vadose zone.

Nitrate is extremely soluble in water and leaches downward with bulk movement of soil moisture (pore water). In moist soils, most nitrate-N will be dissolved in the pore water. If the vadose zone moisture content is high, the average pore water N concentration could be used to interpret the future trend of nitrate concentrations in the aquifer below. For example, if the porosity of the soil is 25 percent and the pore space filled with water, a soil nitrate-N concentration of 2.5 ug/g will be equivalent to a pore-water N concentration of 10 mg NO_3-N/L. In this case, an average soil nitrate-N concentration in the vadose zone greater than 2.5

ug/g could result in nitrate-N concentrations in the shallow portion of the aquifer at or above 10 mg/L.

Pore water nitrate levels can become more concentrated when pore water is lost to the vapor phase. Hypothetically, if the soil nitrate remained at 2.5 μg/g and the moisture decreased from 25% to 5%, the pore water nitrate concentration would increase from 10 mg/L to 50 mg/L. At some point, as the moisture content decreases, nitrate will begin to precipitate out of the pore water. In soil intervals where soil pore water values are very low, the pore water nitrate-N value may be positively skewed. Thus, in cores with depleted moisture content, pore water nitrate concentrations are generally higher than in the impacted underlying ground water. Of the six cores collected in the Tri-Basin NRD, cores TB1, TB4, TB5 and TB 6 have a few intervals with sandy soil that have extremely low gravimetric moisture content. The pore water concentrations in these intervals may be positively skewed.

The soil N in lbs N/ac-ft can also be used to estimate potential nitrate loading. Appendix B describes two possible scenarios. In scenario 1, assuming uniform vadose zone N across the field, the entire nitrate-N load below the root zone from this field is flushed into a nitrate-free aquifer in one season or one event and the nitrate mixed homogeneously throughout a 25-foot saturated thickness of sand and gravels having 25 percent porosity. The resulting nitrate-N concentration would be ~20 mg/L. Normally, such flushing would take many years with incremental spikes in aquifer nitrate-N concentrations. Concentrations are dependent on the magnitude of the source, source of recharge (pumped ground water, surface water, or precipitation), residual soil nitrate-N, and ground water concentrations. Normally, it takes many years of continuous nitrogen loading from excessive flushing of high nitrate-N water during gravity irrigation for the top 25 ft of an aquifer to have a homogeneous nitrogen concentration. In scenario 2, the bottom 6 ft of the vadose zone is leached into the top 5 ft of the aquifer. The resulting nitrate-N concentration would be ~23 mg/L.

Summary of Results

The average soil ammonia-N concentrations below the root zone ranged from 0.6 ug/g at site TB4 to 1.6 ug/g at site TB6. Based on data from previous coring in Nebraska, these concentrations are not unusual for the vadose zone beneath nitrogen fertilized corn fields. Most of the ammonia-N applied to cornfields is utilized by crops, fixed into organic forms, or converted to nitrate-N in the root zone where moisture, pH and other conditions are most favorable for microbial activity. Depending on the soil pH and cation exchange capacity (CEC), however, some of the residual soil ammonia-N may leach below the root zone. Vertical transport of ammonia is favored in sandy soils with low pH and CEC, and high salt content. (Stevenson, 1982). Increased levels of residual ammonia may also occur beneath fields where excess nitrogen is applied. Because the rate of nitrification of residual ammonia in the unsaturated zone is very low compared to that in the topsoil, however, it is unlikely that this pool of nitrogen contributes a significant amount of nitrate to ground water.

The average soil nitrate-N concentrations below the root zone in cores from sites TB1 through TB4 range from 0.4 ug/g at TB3 to 2.2 ug/g at TB1. The average pore water concentrations below the root zone at these four sites range from 3 mg/L TB3 to 18 mg/L at TB1. The 18 mg/L at TB1 is probably positively skewed because of low gravimetric moisture content from 6 to 10 feet below the surface.

The average soil nitrate-N concentration below the root zone at site TB5 was 4.1 ug/g. This is a 15% decrease from the 2002 concentration and nearly a 40% decrease from 1990 concentration. It appears that nitrate concentration at this site has decreased slightly. The decrease, however, could be the result of heterogeneous nitrogen concentrations across this site, even though the cores were collected from near each other.

The average pore water nitrate-N concentration below the root zone at site TB5 was 25 mg/L. This concentration is slightly positively skewed because of low gravimetric moisture content at several intervals. The average pore water nitrate-N concentration was about 10% less than in 2002.

The average soil nitrate-N concentration below the root zone at site TB6 was 2.5 ug/g. This is an 8% decrease from the 2002 concentration but a 25% increase from the 1990 concentration, so it appears that the nitrate concentration at this site is decreasing. As at site TB5, the differences could be the result of variable nitrogen concentrations across this site.

The average pore water nitrate-N concentration below the root zone at site TB6 was 16 mg/L. This concentration is slightly positively skewed because of very low gravimetric moisture content at several intervals. The average pore water nitrate-N concentration was about 25% less than in 2002.

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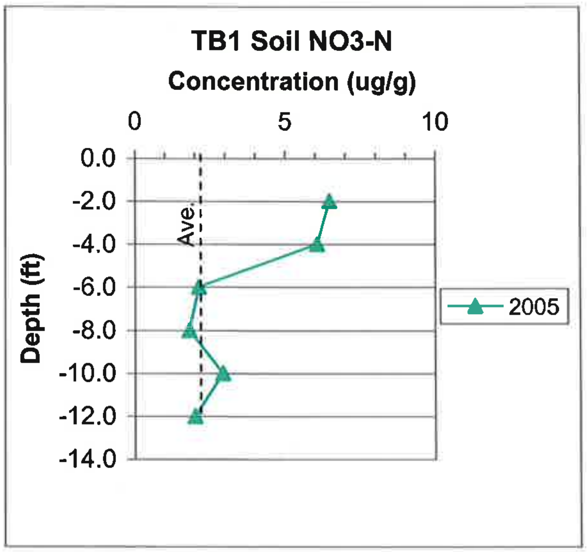
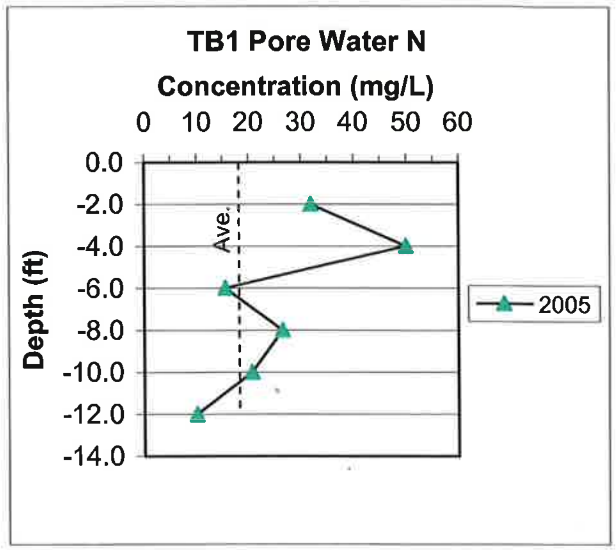
Appendix A
Analytical Results

TB1

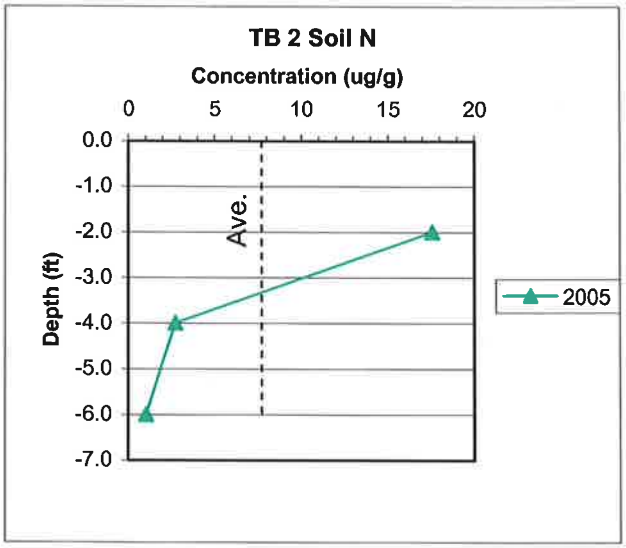
Site	Depth (ft)	Soil Description	Bulk Density (g/cc)	Grav. Moist. (g/g)	Soil NH3-N (ug/g)	Soil NO3-N (ug/g)	Pore Water NO3-N (mg/L)	Soil NO3-N (lbs/ac/2ft)
TB1	-2.0	Topsoil , silty loam	1.25	0.20	2.47	6.46	32	43.8
TB1	-4.0	silty clay loam	1.28	0.12	3.93	6.05	50	42.0
TB1	-6.0	silty sand	1.24	0.14	0.83	2.13	16	14.3
TB1	-8.0	sand, fine to coarse	1.68	0.07	0.73	1.80	26	16.4
TB1	-10.0	sand and gravel	2.06	0.14	4.00	2.93	21	32.7
TB1	-12.0	sand and gravel	2.10	0.20	0.24	2.00	10	22.8
Average					2.0	3.6	26	28.6
Ave. (>RZ)					1.5	2.2	18	21.5
Total (>RZ)								86.2

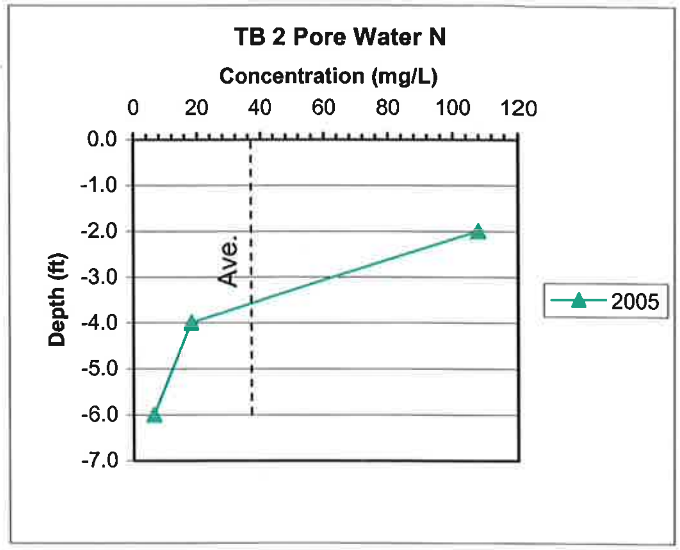




TB2

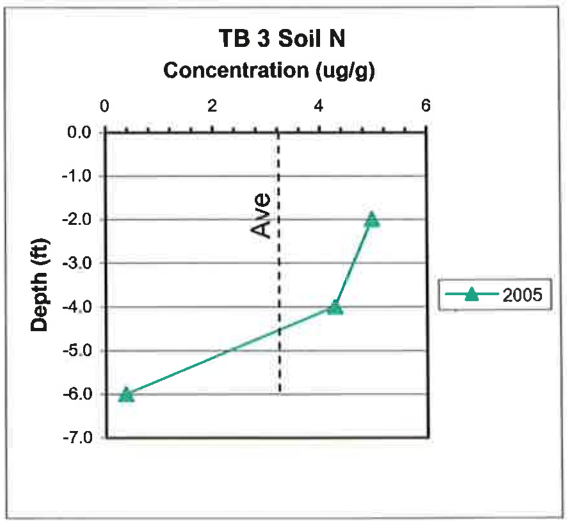
Site	Depth (ft)	Soil Description	Bulk Density (g/cc)	Grav. Moist. (g/g)	Soil NH3-N (ug/g)	Soil NO3-N (ug/g)	Pore Water NO3-N (mg/L)	Soil NO3-N (lbs/ac/2ft)
TB2	-2.0	Topsoil , silty loam	1.53	0.16	1.09	17.58	108	145.8
TB2	-4.0	silty clay loam	2.08	0.15	1.59	2.72	18	30.6
TB2	-6.0	silty sand	1.78	0.17	0.64	1.03	6	9.9
Average					1.1	7.1	44	62.1
Ave. (>RZ)					0.6	1.0	6	9.9
Total (>RZ)								9.9

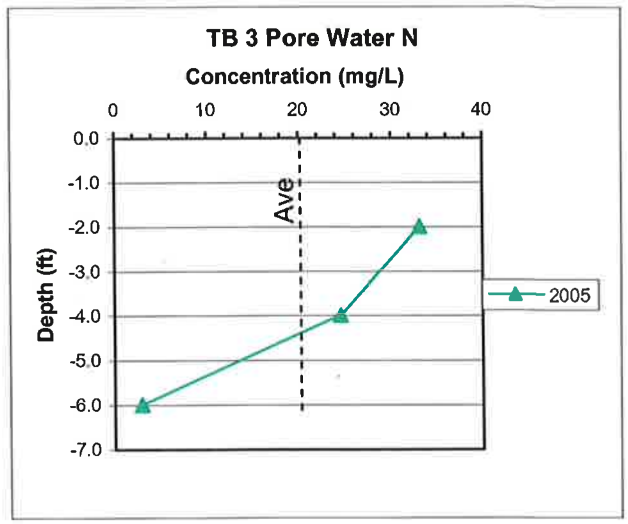




TB3

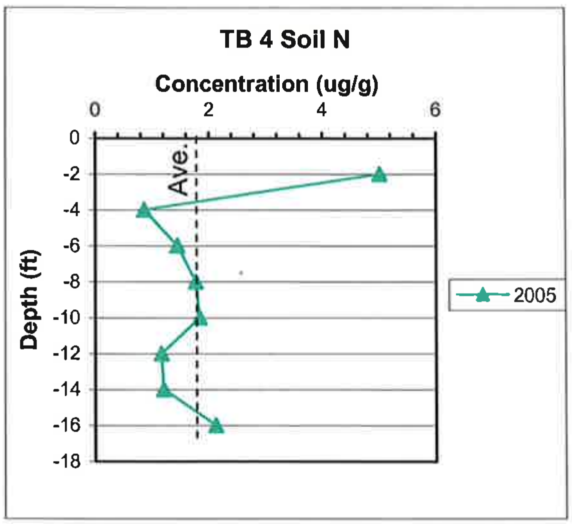
Site	Depth (ft)	Soil Description	Bulk Density (g/cc)	Grav. Moist. (g/g)	Soil NH3-N (ug/g)	Soil NO3-N (ug/g)	Pore Water NO3-N (mg/L)	Soil NO3-N (lbs/ac/2ft)
TB3	-2.0	Topsoil , fine sandy loam	1.51	0.15	1.00	4.97	33	40.7
TB3	-4.0	very sandy loam	1.44	0.17	1.08	4.28	25	33.4
TB3	-6.0	sand	1.89	0.13	1.33	0.37	3	3.8
Average					1.1	3.2	20	25.9
Ave. (>RZ)					1.3	0.4	3	3.8
Total (>RZ)								3.8

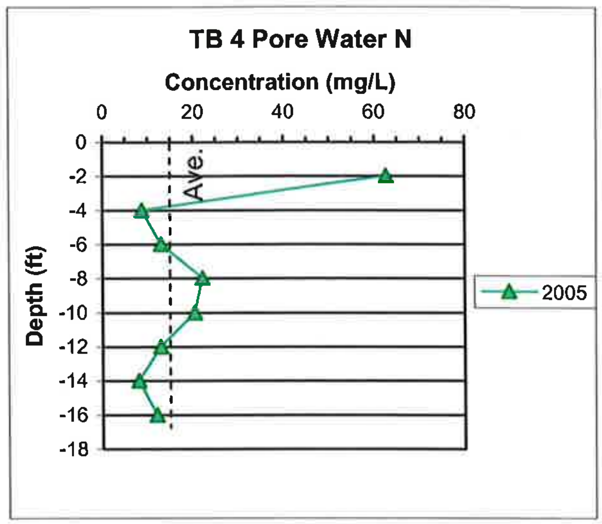




TB4

Site	Depth (ft)	Soil Description	Bulk Density (g/cc)	Grav. Moist. (g/g)	Soil NH3-N (ug/g)	Soil NO3-N (ug/g)	Pore Water NO3-N (mg/L)	Soil NO3-N (lbs/ac/2ft)
TB4	-2.0	Topsoil, loamy sand	1.53	0.08	2.26	5.01	63	41.5
TB4	-4.0	sand, fine to medium	1.28	0.10	1.12	0.87	9	6.0
TB4	-6.0	sand, fine to coarse	1.26	0.11	0.34	1.44	13	9.8
TB4	-8.0	sand, fine to coarse	1.65	0.08	0.57	1.77	22	15.8
TB4	-10.0	sand, fine to coarse	1.01	0.09	0.16	1.84	20	10.1
TB4	-12.0	sand, fine to coarse	1.44	0.09	0.16	1.16	13	9.1
TB4	-14.0	sand, fine to coarse	1.43	0.15	1.00	1.20	8	9.3
TB4	-16.0	sand, fine to coarse	1.71	0.18	1.45	2.12	12	19.6
Average					0.9	1.9	20	15.2
Ave. (>RZ)					0.6	1.6	15	12.3
Total (>RZ)								73.8





TB5-2005

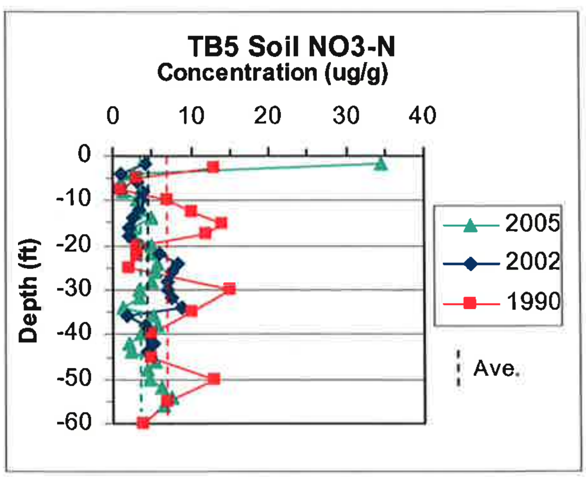
Site	Depth (Ft)	Soil Description	Bulk Density (g/cc)	Grav. Moist (g/g)	Soil NH3-N (ug/g)	Soil NO3-N (ug/g)	Pore Water NO3-N (mg/L)	Soil NO3-N (lbs/ac/2ft)
TB5	-2.0	Topsoil, sicl loam	1.16	0.24	14.10	34.46	146	216.6
TB5	-4.0	Peorian Loess, sicl	1.25	0.23	2.97	2.53	11	17.1
TB5	-6.0	Peorian Loess, sicl	1.32	0.21	0.77	1.15	5	8.2
TB5	-8.0	Peorian Loess, sicl	1.37	0.20	1.21	1.39	7	10.3
TB5	-10.0	Peorian Loess, sicl	1.10	0.20	1.58	3.16	16	18.8
TB5	-12.0	Peorian Loess, sicl	1.57	0.20	1.36	3.63	18	30.9
TB5	-14.0	Peorian Loess, sicl	1.79	0.19	2.50	4.91	25	47.7
TB5	-16.0	Peorian Loess, sicl	1.36	0.20	0.42	2.64	13	19.5
TB5	-18.0	Peorian Loess, sicl	1.27	0.22	0.88	2.62	12	18.0
TB5	-20.0	Peorian Loess, sicl	1.17	0.24	0.20	5.05	21	32.0
TB5	-22.0	Peorian Loess, sicl	1.33	0.25	1.58	5.03	20	36.3
TB5	-24.0	Peorian Loess, sicl	1.21	0.24	0.65	5.80	24	38.0
TB5	-26.0	Peor. Loess, sicl (>cl)	1.22	0.24	0.60	5.48	23	36.2
TB5	-28.0	Peor. Loess, sicl (>cl)	1.57	0.24	0.51	4.92	20	41.9
TB5	-30.0	Peorian Loess, sicl	1.44	0.25	2.36	3.36	13	26.2
TB5	-32.0	Peorian Loess, sicl	2.02	0.23	0.37	3.35	15	36.6
TB5	-34.0	Peorian Loess, sicl	1.75	0.25	0.74	1.42	6	13.4
TB5	-36.0	fine sand	2.06	0.13	0.83	5.28	39	58.9
TB5	-38.0	Peorian Loess, sicl	2.02	0.12	0.63	5.83	49	63.9
TB5	-40.0	silty fine sand	1.16	0.11	0.24	3.53	33	22.2
TB5	-42.0	silty fine sand	1.58	0.14	0.60	2.13	16	18.2
TB5	-44.0	fine sand	1.84	0.09	0.48	2.31	27	23.1
TB5	-46.0	fine sand	1.86	0.14	0.60	5.43	40	54.7
TB5	-48.0	fine sand	1.97	0.13	0.54	4.42	34	47.2
TB5	-50.0	fine sand	1.6	0.10	0.41	4.56	46	39.6
TB5	-52.0	fine sand	1.9	0.12	1.18	6.19	52	63.7
TB5	-54.0	fine sand	1.58	0.15	0.59	7.54	51	64.6
TB5	-56.0	fine sand	1.60	0.25	0.10	6.50	26	56.4
Average					1.4	5.2	29	41.4
Ave. (>RZ)					0.8	4.1	25	35.6
Total (>RZ)								926.6

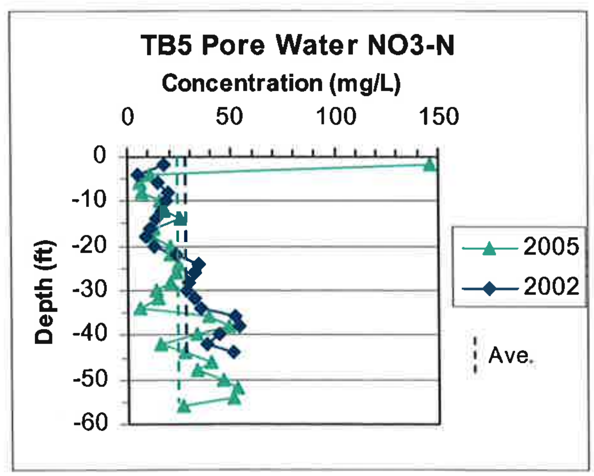
TB5-2002

Site (formerly TB1-1)	Depth (Ft)	Soil Description	Bulk Density (g/cc)	Grav. Moist (g/g)	Soil NH3-N (ug/g)	Soil NO3-N (ug/g)	Pore Water NO3-N (mg/L)	Soil NO3-N (lbs/ac/2ft)
TB5	-2.0	Topsoil, sicl loam		0.24		4.2	18	31.5
TB5	-4.0	Peorian Loess, sicl		0.23		1.1	5	8.1
TB5	-6.0	Peorian Loess, sicl		0.21		3.1	15	23.8
TB5	-8.0	Peorian Loess, sicl		0.20		3.8	19	28.7
TB5	-10.0	Peorian Loess, sicl		0.20		3.7	19	28.3
TB5	-12.0	Peorian Loess, sicl		0.20		3.3	16	24.9
TB5	-14.0	Peorian Loess, sicl		0.19		2.6	14	20.1
TB5	-16.0	Peorian Loess, sicl		0.20		2.2	11	16.6
TB5	-18.0	Peorian Loess, sicl		0.22		2.0	9	15.3
TB5	-20.0	Peorian Loess, sicl		0.24		3.2	13	24.1
TB5	-22.0	Peorian Loess, sicl		0.25		5.9	24	44.8
TB5	-24.0	Peorian Loess, sicl		0.24		8.2	34	62.5
TB5	-26.0	Peor. Loess, sicl (>cl)		0.24		7.5	32	56.8
TB5	-28.0	Peor. Loess, sicl (>cl)		0.24		7.0	29	53.1
TB5	-30.0	Peorian Loess, sicl		0.25		7.1	29	54.2
TB5	-32.0	Peorian Loess, sicl		0.23		7.4	32	56.5
TB5	-34.0	Peorian Loess, sicl		0.25		8.7	35	66.3
TB5	-36.0	Peorian Loess, sicl		0.03		1.8	51	13.5
TB5	-38.0	silty very fine sand		0.08		4.1	54	34.9
TB5	-40.0	silty fine sand		0.11		4.6	43	39.8
TB5	-42.0	silty fine sand		0.14		5.3	38	45.2
TB5	-44.0	fine sand (43-44')		0.09		4.4	51	37.5
Average						4.6	27	35.8
Ave. (>RZ)						4.8	28	37.4
Total (>RZ)								747.1

TB5-1990

Site (formerly TB1-1)	Depth (Ft)	Soil Description	Bulk Density (g/cc)	Grav. Moist (g/g)	Soil NH3-N (ug/g)	Soil NO3-N (ug/g)	Pore Water NO3-N (mg/L)	Soil NO3-N (lbs/ac/2ft)
TB5	-2.5	Topsoil, silty clay				13		
TB5	-5.0	Peorian Loess, sicl				3		
TB5	-7.5	Peorian Loess, sicl				1		
TB5	-10.0	Peorian Loess, sicl				7		
TB5	-12.5	Peorian Loess, sicl				10		
TB5	-15.0	Peorian Loess, sicl				14		
TB5	-17.5	Peorian Loess, sicl				12		
TB5	-20.0	Peorian Loess, sicl				3		
TB5	-22.5	Peorian Loess, sicl				3		
TB5	-25.0	Peorian Loess, sicl				2		
TB5	-30.0	Peorian Loess, sicl				15		
TB5	-35.0	Peorian Loess, sicl				10		
TB5	-40.0	Loveland Loess, siscl				5		
TB5	-45.0	Loveland Loess, siscl				5		
TB5	-50.0	Loveland Loess, siscl				13		
TB5	-55.0	Loveland Loess, siscl				7		
TB5	-60.0	Loveland Loess, siscl				4		
Average						7		
Ave. (>RZ)						7		





TB6-2005

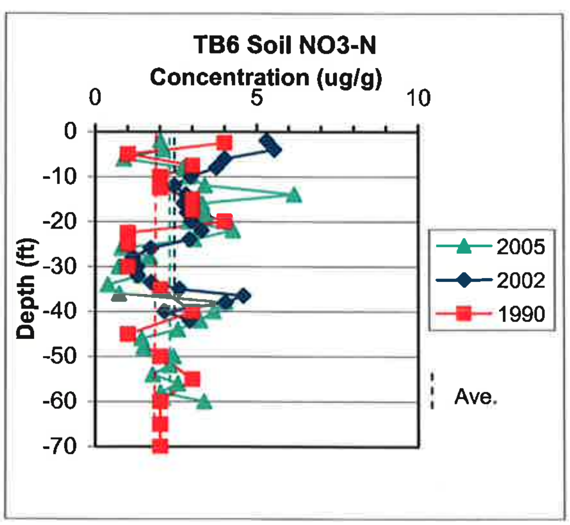
Site	Depth (ft)	Soil Description	Bulk Density (g/cc)	Grav. Moist. (g/g)	Soil NH3-N (ug/g)	Soil NO3-N (ug/g)	Pore Water NO3-N (mg/L)	Soil NO3-N (lbs/ac/2ft)
TB6	-2.0	Topsoil , silty clay loam	1.1	0.26	3.53	2.00	8	11.9
TB6	-4.0	Peorian Loess, sicl	1.12	0.25	1.25	2.07	8	12.6
TB6	-6.0	Peorian Loess, sicl	1.41	0.25	0.67	0.87	4	6.7
TB6	-8.0	Peorian Loess, sicl	1.38	0.25	0.82	2.72	11	20.3
TB6	-10.0	Peorian Loess, sicl	1.11	0.26	1.39	2.89	11	17.4
TB6	-12.0	Peorian Loess, sicl	1.35	0.26	0.96	3.39	13	24.8
TB6	-14.0	Peorian Loess, sicl	1.09	0.27	1.40	6.16	23	36.4
TB6	-16.0	Peorian Loess, sicl	1.21	0.25	0.70	3.30	13	21.7
TB6	-18.0	Peorian Loess, sicl	1.13	0.27	0.92	3.40	13	20.8
TB6	-20.0	Peorian Loess, sicl	1.18	0.29	0.84	2.86	10	18.3
TB6	-22.0	Peorian Loess, sicl	1.29	0.26	1.24	4.24	16	29.6
TB6	-24.0	Loveland Loess, siscl	1.13	0.27	0.16	3.04	11	18.6
TB6	-26.0	Loveland Loess, siscl	1.89	0.14	2.00	0.80	6	8.2
TB6	-28.0	silty fine sand	1.79	0.19	2.79	1.68	9	16.3
TB6	-30.0	fine sand	2.13	0.14	0.95	0.73	5	8.4
TB6	-32.0	fine sand	1.95	0.13	1.74	1.39	11	14.7
TB6	-34.0	fine sand	1.78	0.10	1.76	0.38	4	3.7
TB6	-36.0	fine sand	1.79	0.06	1.52	0.73	12	7.1
TB6	-38.0	fine sand	1.93	0.14	3.62	4.01	29	41.9
TB6	-40.0	silty clay	2.11	0.12	6.49	3.65	29	41.7
TB6	-42.0	fine sand	2.20	0.13	1.70	3.23	25	38.5
TB6	-44.0	fine sand	1.42	0.17	0.91	2.54	15	19.5
TB6	-46.0	fine sand	1.69	0.10	0.85	1.42	14	13.0
TB6	-48.0	fine sand	1.77	0.10	0.77	1.47	15	14.1
TB6	-50.0	fine sand	2.25	0.09	0.63	2.39	27	29.2
TB6	-52.0	fine sand	1.62	0.09	0.75	2.28	25	20.0
TB6	-54.0	fine sand	1.87	0.09	2.85	1.76	20	17.8
TB6	-56.0	fine sand	1.63	0.11	1.19	2.53	22	22.4
TB6	-58.0	fine sand	1.67	0.11	1.84	2.00	18	18.1
TB6	-60.0	fine sand	2.08	0.12	3.35	3.36	29	37.9
Average					1.7	2.4	15	20.4
Ave. (>RZ)					1.6	2.5	16	21.0
Total (>RZ)								587.1

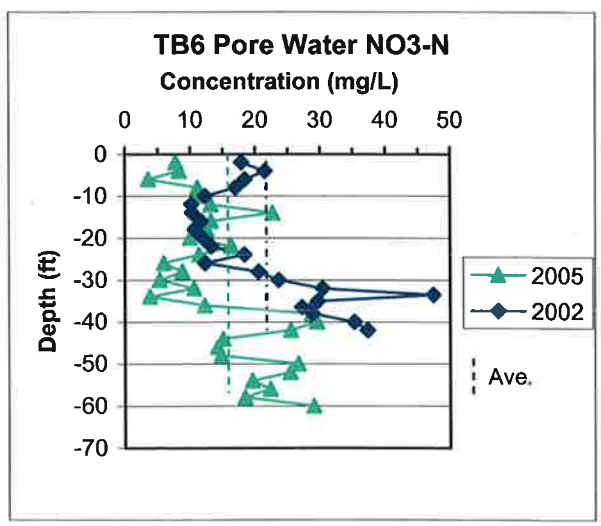
TB6-2002

Site (formerly TB3-1)	Depth (ft)	Soil Description	Bulk Density (g/cc)	Grav. Moist. (g/g)	Soil NH3-N (ug/g)	Soil NO3-N (ug/g)	Pore Water NO3-N (mg/L)	Soil NO3-N (lbs/ac/2ft)
TB6	-2.0	Topsoil , silty clay loam		0.30		5.3	18	40.4
TB6	-4.0	Peorian Loess, sicl		0.26		5.6	21	42.2
TB6	-6.0	Peorian Loess, sicl		0.22		4.0	18	30.4
TB6	-8.0	Peorian Loess, sicl		0.22		3.7	17	28.4
TB6	-10.0	Peorian Loess, sicl		0.24		2.9	12	22.3
TB6	-12.0	Peorian Loess, sicl		0.24		2.4	10	18.5
TB6	-14.0	Peorian Loess, sicl		0.27		2.8	10	21.2
TB6	-16.0	Peorian Loess, sicl		0.23		2.7	12	20.7
TB6	-18.0	Peorian Loess, sicl		0.27		2.8	11	21.5
TB6	-20.0	Peorian Loess, sicl		0.25		3.0	12	22.5
TB6	-22.0	Peorian Loess, sicl		0.25		3.3	13	24.9
TB6	-24.0	Peorian Loess, sicl		0.16		2.9	18	22.1
TB6	-26.0	silty fine sand		0.14		1.7	12	14.7
TB6	-28.0	silty fine sand		0.06		1.1	20	9.9
TB6	-30.0	fine sand		0.05		1.3	24	11.0
TB6	-32.0	fine sand		0.04		1.3	30	11.1
TB6	-33.5	fine sand		0.04		1.7	47	14.8
TB6	-35.0	fine sand		0.09		2.6	30	22.3
TB6	-36.5	silty clay		0.17		4.6	27	34.7
TB6	-38.0	silty clay		0.14		4.0	29	30.6
TB6	-40.0	fine sand		0.06		2.1	35	18.3
TB6	-42.0	fine sand		0.08		2.9	37	25.0
Average						2.9	21	23.1
Ave. (>RZ)						2.7	21	21.2
Total (>RZ)								425.0

TB6-1990

Site (formerly TB3-1	Depth (ft)	Soil Description	Bulk Density (g/cc)	Grav. Moist. (g/g)	Soil NH3-N (ug/g)	Soil NO3-N (ug/g)	Pore Water NO3-N (mg/L)	Soil NO3-N (lbs/ac/2ft)
TB6	-2.5	Topsoil, silty clay				4		
TB6	-5.0	Peorian Loess, sicl				1		
TB6	-7.5	Peorian Loess, sicl				3		
TB6	-10.0	Peorian Loess, sicl				2		
TB6	-12.5	Peorian Loess, sicl				2		
TB6	-15.0	Peorian Loess, sicl				3		
TB6	-17.5	Peorian Loess, sicl				3		
TB6	-20.0	Peorian Loess, sicl				4		
TB6	-22.5	Peorian Loess, sicl				1		
TB6	-25.0	Loveland Loess, siscl				1		
TB6	-30.0	Loveland Loess, siscl				1		
TB6	-35.0	sand				2		
TB6	-40.0	sand				3		
TB6	-45.0	sand				1		
TB6	-50.0	sand				2		
TB6	-55.0	sand				3		
TB6	-60.0	sand				2		
TB6	-65.0	sand				2		
TB6	-70.0	sand				2		
TB6	-75.0	sand				2		
TB6	-80.0	silty sandy clay				1		
TB6	-85.0	silty sandy clay				3		
TB6	-90.0	silty sandy clay				3		
TB6	-95.0	silty sandy clay				2		
TB6	-100.0	Alluv., sicls w./cobbles				3		
TB6	-105.0	Alluv., sicls w./cobbles				4		
TB6	-110.0	Alluv., sicls w./cobbles				3		
Average						2		
Ave. (>RZ)						2		





Appendix B
Nitrate-Nitrogen Loading Scenario

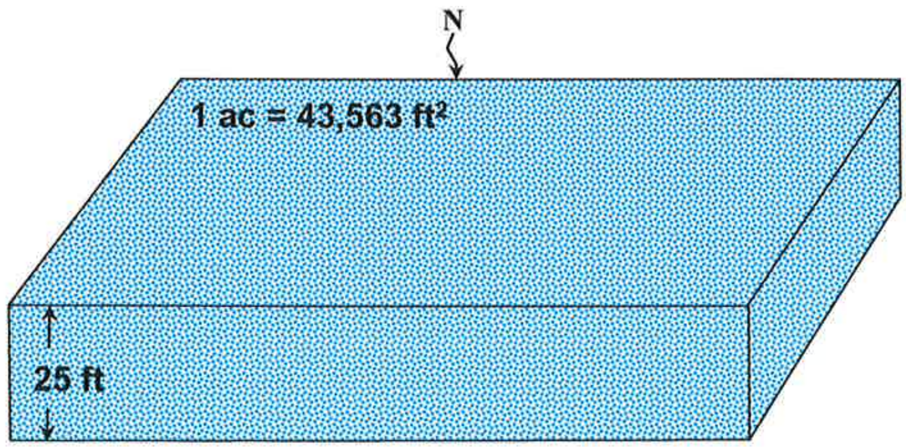
Scenarios of Nitrate-Nitrogen Loading Beneath an Irrigated Corn Field

Scenario 1: Entire vadose zone N flushed into a N-free, 25-ft thick aquifer and homogeneously mixes.

341 lbs N/ac-ft x 454,000 mg/lb = 154,814,000 mg N/ac-ft

43,462 ft^2 x 25 ft = 1,089,050 ft^3 x 0.25 = 272262.5 ft^3 x 28.32 L/ft^3 = 7,710,474 L

154,814,000 mg N/ac-ft / 7,710,474 L = 20.1 mg NO_3-N/L



Scenario 2: Bottom 6 ft of vadoze zone N leaches in one season into the top 5-ft of a N-free aquifer.

78.9 lbs N/ac-ft x 454,000 mg/lb = 35,820,600 mg N/ac-ft

43,462 ft^2 x 5 ft = 217,310 ft^3 x 0.25 = 54,452.5 ft^3 x 28.32 L/ft^3 = 1,542,095 L

35,820,600 mg N/ac-ft / 1,542,095 L = 23.2 mg NO_3-N/L