Kansas Geological Survey

Pollution Prevention Demonstration Project
Harvey County, Kansas

FINAL REPORT

Submitted to

U.S. Environmental Protection Agency
and
Kansas Department of Health and Environment

BY

Margaret A. Townsend
Richard O. Sleezer

Kansas Geological Survey Open-File Report 95-74
December 1995

GEOHYDROLOGY

The University of Kansas, Lawrence, KS 66047 Tel. (913) 864-3965

ACKNOWLEDGMENTS

We gratefully acknowledge the assistance of the many landowners who permitted us access to their land and water wells during the two years of the study and to Kirk Miles, Carol Hiebert, and Jack Barnes of the Harvey County Conservation District without whose assistance this project would not have been possible. We wish to thank Mark Schoneweis, who drafted most of the figures, and Steve Yoder and Harsha Jayatilake who created all of the proportional-symbol and site-location maps used in this study. David Young assisted with water sampling and review. Rod Bassler aided with lysimeter and soil sampling and provided cartographic advice. Larry Hathaway and Truman Waugh, Analytical Services Section of the Kansas Geological Survey, performed the water-chemistry analyses. We also wish to thank Larry Hathaway, Marios Sophocleous, and Marla Adkins-Heljeson for their assistance in reviewing the final report. We especially wish to thank John Healey and John Hoch for their assistance with soil sampling and lysimeter installation.

Charles Gray of the Soil Chemistry Laboratory, Agronomy Department and Brian Hopkins of the Soil Testing Laboratory at Kansas State University conducted all the soil nitrate tests. Stephen Macko of the Department of Environmental Sciences, University of Virginia, performed the nitrogen isotope analyses. Richard Schlepp, Paul Finnell, Rick Cox, Bob Murphy, and Gary Parks from the NRCS aided in site selection for pits, pit descriptions, and general soil information. Also we wish to thank personnel from the Natural Resource Conservation Service testing laboratory in Lincoln, Nebraska, for providing soil analyses for samples from the pit sites. In addition we wish to thank Kyle Juracek, Dirk Hargadine, Scott Morgan, Pat Rasmuessen, and others of the U.S. Geological Survey Water Resources Division, Lawrence, for their time and effort in collecting the approximately 200 soil cores that were used in this study.

Finally we wish to thank the U.S. Environmental Protection Agency Region 7 and the Kansas Department of Health and Environment for funding this project.

TABLE OF CONTENTS

List of Tables

List of Figures

Abstract

The goal of this research was to develop a predictive tool for identifying ground-water-pollution potential for nitrate based on cultural and natural factors. Specific factors to be investigated were (1) the rate of fertilizer application, (2) the amount of water applied to the land surface as natural precipitation and irrigation water, and (3) whether the fertilizer was incorporated or not. The effects of these factors on soil/vadose-zone nitrate concentration were investigated using soil cores extracted from 30 irrigated and 30 dryland agricultural fields within the Equus Beds portion of Harvey County.

Fields were selected using two primary criteria. First, each field needed to be planted to sorghum or corn during the period of study. Second, soils in each field were required to have soil DRASTIC ratings of 5 or more. Cores were extracted in the spring before fertilizer application and in the fall after harvest. Each core was sampled in 2-foot intervals to a depth of 10 feet. Cropping practices, fertilizer-application rates, and fertilizer-application methods were obtained from farmers' records for each field.

Additional information pertaining to nitrate movement in the soil and vadose zone was obtained from six nests of porous-cup soil-water samplers (lysimeters). Each nest of lysimeters consisted of four samplers installed at depths of 2, 4, 6, and 10 feet in an irrigated field. Soil-water samples were extracted from each of these samplers on a monthly basis from May to August of 1992.

Near each of the 60 agricultural fields, water samples were obtained from shallow domestic wells. Each of these wells was sampled three times (spring 1992, fall 1992, spring 1993) to determine the concentration of nitrate in the shallow portion of the aquifer near each field and to observe any temporal variations in ground-water nitrate concentration. In the fall of 1993, samples were obtained from 10 of these wells for complete chemical analysis. The complete analyses were used to determine relationships between water chemistry and nitrate concentration. In addition, 25 of the irrigation wells at the irrigated field sites were sampled during July of 1992. These samples were used to compare ground-water nitrate concentrations in the deeper portions of the aquifer to those determined at shallower depths from the domestic wells.

Of the 60 domestic wells sampled for nitrate analysis, 19 were also sampled for nitrogen isotope analysis. Nitrogen isotope analysis can be used to determine sources for ground-water nitrate. In this study, isotopes were used to differentiate between fertilizer and animal-waste sources for nitrate in ground water.

Records of fertilizer-application methods indicated that the bulk of the nitrogen fertilizer was applied as anhydrous ammonia for both irrigated and dryland fields. The remainder of the fertilizer was applied as band starter or knifed in as a post emergence side-dress. All these methods of application involve incorporation of fertilizer into the soil. The method of application (incorporated vs. nonincorporated) was therefore not a factor influencing nitrate concentration in the soil cores.

Unusually high rainfall during the growing season in 1992 and 1993 limited the amount of irrigation water used. These rainfall patterns had the net effect of reducing differences in nitrate-leaching loss between irrigated and dryland sites because the total volume of water available for leaching was similar.

A multiple regression model was developed to predict the amount of nitrate remaining below the root zone (4–10 ft) after the growing season (fall sampling). The

multiple regression model utilized six factors that were found to have significant correlation with nitrate below the root zone for at least one time period (1992 or 1993) and land use (irrigated or dryland). Statistically significant correlations were found between the amount of nitrate below the root zone predicted by the model and the actual amount of nitrate measured in soil cores. The two dominant factors affecting the amount of nitrate below the root zone in the fall are (1) the amount of nitrogen fertilizer applied for that growing season, and
(2) the amount of nitrate in the soil in the spring before fertilizer application.

The lysimeter data also yielded expected results. During the growing season, nitrate moved through the soil in response to large precipitation events. The rate of nitrate movement through the soil was dependent on the volume of precipitation and soil properties affecting vertical water movement (texture, hydraulic conductivity, stratigraphy, etc.). Nitrate moved most rapidly through sandy soils. Permeability barriers within the soil retarded or prevented nitrate-leaching losses.

The occurrence of high ground-water nitrate concentrations (>10 mg/L as nitrate-N) in domestic wells is not spread uniformly over the study area. In order to investigate the factors affecting ground-water nitrate concentrations in these wells, the study area was divided into two sub-regions based on predominant ground-water nitrate concentration. In Area 1, ground-water nitrate concentrations are generally low (< 3 mg/L as nitrate-N). In Area 2, ground-water nitrate concentrations are generally high (>10 mg/L as nitrate-N).

If elevated ground-water nitrate concentrations are associated exclusively with row-crop agricultural practices, then areas with higher irrigation-well density, more irrigated acreage, more total cropland acreage, and higher average fertilizer-application rates should have the highest ground-water nitrate concentrations. Irrigation-well density is three times greater in Area 1 (1.5 wells/sq. mi) vs. Area 2 (0.55 wells/sq. mi). Average fertilizer use is approximately 17 lbs/acre higher in Area 1 (72 lbs/acre) vs. Area 2 (55 lbs/acre). The percentage of irrigated acreage is twice as great in Area 1 (24.3%) vs. Area 2 (12.3%) and the percentage of total cropland acreage is higher in Area 1 (90.6%) vs. Area 2 (79.8%). All of these factors would indicate that Area 1 should have higher ground-water nitrate concentrations than ground water in Area 2. Instead, Area 2 was found to have higher nitrate-N concentrations because of probable point sources.

Madison and Brunet (1985) state that ground-water nitrate-N concentrations ≥ 3 mg/L can be attributed to anthropogenic activities. Within the study area, 19 wells with nitrate-N concentrations ≥ 3 mg/L were selected for nitrogen isotope analysis. Nitrogen-15 values of +2 to +8‰ in ground water are generally interpreted as being the result of a fertilizer source. Nitrogen-15 values >+10‰ are generally attributed to an animal-waste source. All 19 of the sampled wells have $\delta^{15}N$ values outside of the range for a fertilizer source. High ground-water nitrate concentrations in Harvey County appear to originate from animal-waste sources and not from fertilizer sources.

Introduction

This project was initiated to (1) monitor the movement of nitrate within the vadose zone in agricultural fields, (2) determine the volume of nitrate stored in the vadose zone in these fields, and (3) investigate relationships between nitrate movement and storage with respect to three factors. These factors were fertilizer-application rates, the amount of water applied to the land surface by irrigation and rainfall, and the method of nitrogen-fertilizer application (incorporated vs. non-incorporated).

The study area chosen for this project was the Equus Beds portion of Harvey County (fig. 1). The Equus Beds aquifer was selected because it is the principal source of municipal industrial, agricultural, and rural domestic water in portions of four Kansas counties (Reno, Sedgwick, McPherson, and Harvey). The Equus Beds aquifer is potentially vulnerable to non-point source nitrate contamination from agricultural fertilizers. Harvey County was selected for specific study because of the availability of information pertaining to the soils, ground water, surface hydrology, and land use (Hoffman and Dowd, 1974; Stramel, 1956, 1967; Silliams and Lohman, 1947). It was also the site of a previous attempt to model ground-water vulnerability using the DRASTIC model (Martinko et al. 1987).

The principal objectives of the study were to (1) develop a predictive tool for identifying the pollution potential of the combination of cultural and natural factors for a specific area, and (2) provide knowledge that can be incorporated in the development of educational material to be used by the Cooperative Extension Service to reduce pollution potential.

A secondary objective was to evaluate ground-water nitrate concentrations in the Equus Beds aquifer by sampling domestic, monitoring, and irrigation wells. Spatial and temporal patterns of ground-water nitrate concentration were evaluated in the context of the vadose-zone nitrate data, the cultural factors affecting vadose- zone nitrate concentrations, and the natural factors affecting nitrate retention or leaching loss from the vadose zone.

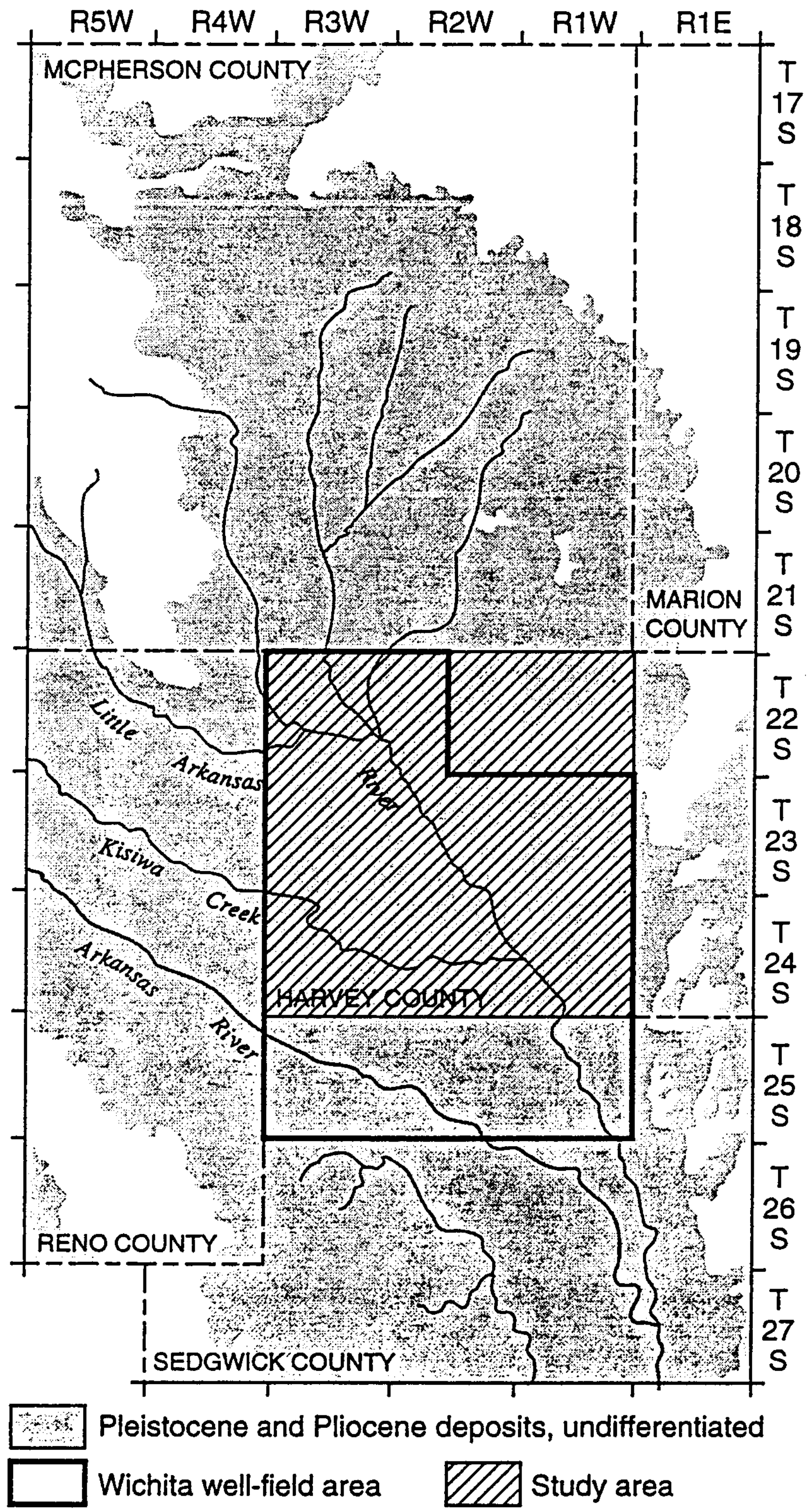


Figure 1. Areal extent of Pleistocene and Pliocene deposits which make up the Equus Beds aquifer. The study area was confined to the western nine townships of Harvey County.

Methods

Site Selection

Sixty agricultural fields within the Equus Beds portion of Harvey County were selected for sampling. Thirty of these fields were farmed using dryland methods and thirty were farmed using irrigated methods (fig. 2; appendix D, fig. D-1, p. 115).

Specific fields were selected based on two primary criteria. First, soil DRASTIC ratings from Martinko et al. (1987) were used to categorize soils in terms of potential for leaching loss. Soil DRASTIC ratings range from 1 to 10 with 10 representing the greatest risk for leaching loss. Selected fields were required to have soils with DRASTIC ratings ≥ 5. Second, the fields were required to be planted to corn or sorghum during the course of the study. Field selection was limited to these crops to facilitate concurrent sampling for atrazine by the U.S. Geological Survey and because corn and sorghum require the largest nitrogen fertilizer-application rates.

Additional requirements were related to landowner cooperation. Landowners were required to allow access to their fields for the length of the study. Operators were required to provide information as to cropping practices and fertilizer-application rates. Cropping practice and fertilizer-application-rate information were collected for the time period from 1986 through the duration of the study. A few of the operators had been farming the fields for shorter time periods and could only supply cropping and fertilizer-application rates for shorter time periods. A summary of fertilizer and crop records for 1991-1993 is provided in appendix B.

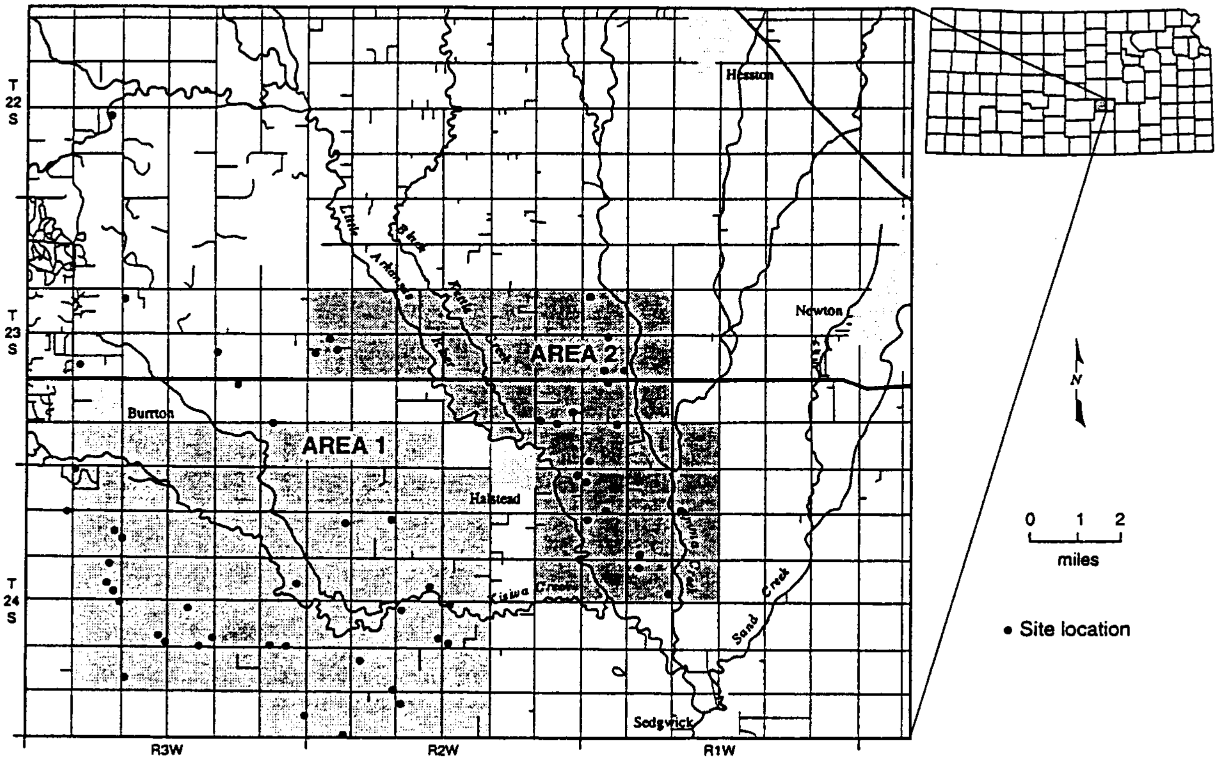


Figure 2. Site location of soil-sampling sites in Harvey County, Kansas. Areas 1 and 2 are subdivisions based on spatial distribution of ground-water nitrate concentrations.

Soil Coring, Laboratory Soil Analysis, and Soil Characterization

Soil samples were collected prior to fertilizer application in the spring and after harvest in the fall. Samples were collected during four sampling periods during the spring and fall of 1992 and 1993. Soil samples consisted of a single core per field to a depth of 10 feet. Cores were subdivided into 2-foot intervals for laboratory analysis. Descriptions of soil texture, color, and stratigraphy were recorded for each core. Soil samples were stored on ice while in the field and refrigerated upon return from the field until laboratory analyses were performed.

Soil laboratory analysis was performed by the Soil Chemistry Laboratory and the Soil Testing Laboratory at Kansas State University. Soil analysis consisted of soil-nitrate concentrations for all sampling periods (appendix D). Approximately, 1,050 soil samples were analyzed during the course of the study. A summary of specific soil-sampling procedures and laboratory methods is presented in appendix F (p. 123).

The number of fields which were sampled varied during the study. In the spring of 1992, all 60 fields were sampled. Subsequent sampling periods were limited to fewer fields. The reduction in the number of fields sampled was caused by adverse weather conditions, crop rotations, and operators dropping out of the second year of the study.

Ten soil-characterization pits were excavated, described, and sampled by the National Resource Conservation Service (NRCS, formerly the Soil Conservation Service) in the spring of 1992. Laboratory analysis of these samples was performed by NRCS at the National Soil Testing Laboratory in Lincoln, Nebraska. The purpose of the soil-characterization pits was to confirm the presence of soils as described in the Harvey County Soil Survey and to provide supplemental information pertaining to soil physical and chemical properties affecting nitrate retention and leaching loss in representative soils. A discussion of soil-profile descriptions, laboratory analysis, and classification of the soils sampled at the pit sites is included in appendix A (p. 58).

Soil Water Samplers (lysimeters)

Six nests of lysimeters were installed in irrigated fields in the spring of 1992. Each nest of lysimeters consisted of four samplers installed at depths of 2, 4, 6, and 10 feet. Soils at the lysimeter sites represented the range of soil DRASTIC ratings in the selected fields. The lysimeters were installed to provide information on the movement of nitrate through the vadose zone during the growing season in response to the rainfall and irrigation.

Each nest of lysimeters was sampled on a monthly basis from May of 1992 to August of 1992. The sample volume and specific conductance of each sample were measured in the field. Nitrate-N concentrations of soil-water samples were determined by the Analytical Services Section at the Kansas Geological Survey.

Soil samples for nitrate analysis were also obtained at the lysimeter nests during the growing season. Samples were collected and analyzed in the same manner as the soil-core samples collected in the spring and fall. These samples were used to investigate relationships between nitrate concentrations obtained from soil samples and those obtained from soi-water samplers. At the request of the farmers, the lysimeters were removed from the fields prior to harvesting 1992. Methods of lysimeter installation and sampling protocol are described in appendix F. Summary tables of nitrate analyses for soil and soil water at these sites are provided in appendix E.

Water Sampling

Sites for collecting shallow ground-water samples were selected based on the location of the domestic, municipal, or Groundwater Management District #2 observation wells in relation to a given dryland or irrigated soil-sampling site (fig. 2, p. 6; appendix C, p. 97). Twenty-four wells were located near dryland sites and 29 wells were located near irrigated sites. Most of these wells were sampled for nitrate three times during the study. A total of 172 samples were analyzed for nitrate during the course of the study. In addition, 10 of the wells were sampled in the fall of 1993 for complete chemical analyses to determine if there were differences in the general water chemistry throughout the study area.

Nineteen wells with high and low nitrate-N concentrations were sampled for nitrogen isotope analyses in the fall of 1993. This method was used to try to determine possible sources for the nitrate observed in the ground water.

Twenty-five irrigation wells were sampled in July 1992. Abnormally wet weather conditions in 1993 precluded sampling irrigation wells in July 1993.

All well owners were contacted by letter prior to each sampling period in March 1992, October 1992, and March 1993. The results of all chemical analyses were sent to each well owner. Chemical analyses for the wells are listed in appendix C.

Regression Analysis

Soil-nitrate data were converted from units of mg/kg to lbs/acre to facilitate comparisons with the common units for fertilizer-application rates. Soil-nitrate data were evaluated in terms of 'root zone' nitrate (0-4 ft), and 'below root zone' nitrate (4-10 ft). It was assumed that nitrate in the root zone was subject to plant uptake as well as leaching loss, while nitrate below the root zone was assumed to be available for leaching loss without the possibility of plant uptake. Nitrate below the root zone was therefore assumed to present the greatest risk for ground-water-nitrate pollution. Factors or sets of factors which resulted in more nitrate below the root zone at the end of the growing season should be good indicators of nitrate-leaching losses from agricultural fields.

Precipitation, fertilizer-application rate, and the amount of nitrate in the soil before fertilizer application were analyzed to determine their influence on the amount of nitrate below the root zone after harvest. Precipitation was analyzed in terms of early growing season precipitation (April through June) and total growing season precipitation (April through September). Nitrogen fertilizer application was evaluated in terms of the application rate for the current growing season and the application rates for the current growing season plus the application rates for the two previous years. The amount of nitrate in the soil in the spring is the other principal source of nitrate potentially contributing to the amount of nitrate below the root zone at the end of the growing season. Spring soil nitrate was evaluated in terms of the effects of root zone nitrate (0-4 ft) and nitrate below the root zone (4-10 ft) on the amount of nitrate below the root zone at the end of the growing season.

The soil-nitrate data set includes data from two land uses (irrigated and dryland) and two growing seasons (1992 and 1993). Regression analysis was performed on each possible time/land-use subset. Data sets for regression analyses were limited to sites for which samples were collected prior to and after the growing season in a given year. The data sets were also limited to sites for which root-zone nitrate was greater than 10 lbs/acre. Nitrate values this low were deemed to be the result of low soil-water-retention characteristics, denitrification losses, or possibly laboratory errors. The final restriction on the data set was the availability of reliable historical fertilizer-application rate information. Fields for which fertilizer data were not available for the two years preceding sampling were excluded. In other words, if the site was sampled in 1993, fertilizer records must include application rates for 1993, 1992, and 1991. If the field was sampled in 1992, fertilizer records must include data for 1992, 1991, and 1990.

Results

Farming Practices

Fertilization records were consulted to determine the method of fertilizer application used at the various fields. The bulk of the nitrogen fertilizer is applied as anhydrous ammonia in the early spring prior to planting. A number of farmers also apply a band of starter fertilizer at the time of planting. Starter fertilizer is generally a relatively small portion of the total nitrogen fertilizer applied (≤ 10%) and a typical application rate is ~ 5–15 lbs/acre.

In very sandy soils, a few of the farmers used split applications to maximize plant utilization and to limit leaching loss. In these cases nitrogen fertilizer was applied three times. First, anhydrous ammonia was applied in the early spring but at a reduced application rate. Second, a band of starter dry NPK fertilizer was applied at the time of planting. Third, a post-emergence side dress application of fertilizer was applied usually in late May or early June.

Throughout the duration of the study all but one of the operators incorporated all of their nitrogen fertilizer applications regardless of timing or type. Application method (incorporated vs. nonincorporated) was not a variable which could be tested against vadose-zone nitrate concentration for the selected fields.

Other sources of nitrogen such as animal waste, legumes, and winter cover crops (green manure) were not used extensively. Only two sites consistently used animal waste as part of their normal nitrogen fertilizer application. Both of these fields were located in close proximity to dairy operations owned by the person farming the field.

Precipitation

Precipitation was measured at 30 gage sites within the study area by the U.S. Geological Survey. Rainfall data from these gages were used in conjunction with 11 National Weather Service gages in the vicinity to estimate precipitation at each core site for the duration of the study (fig. 3).

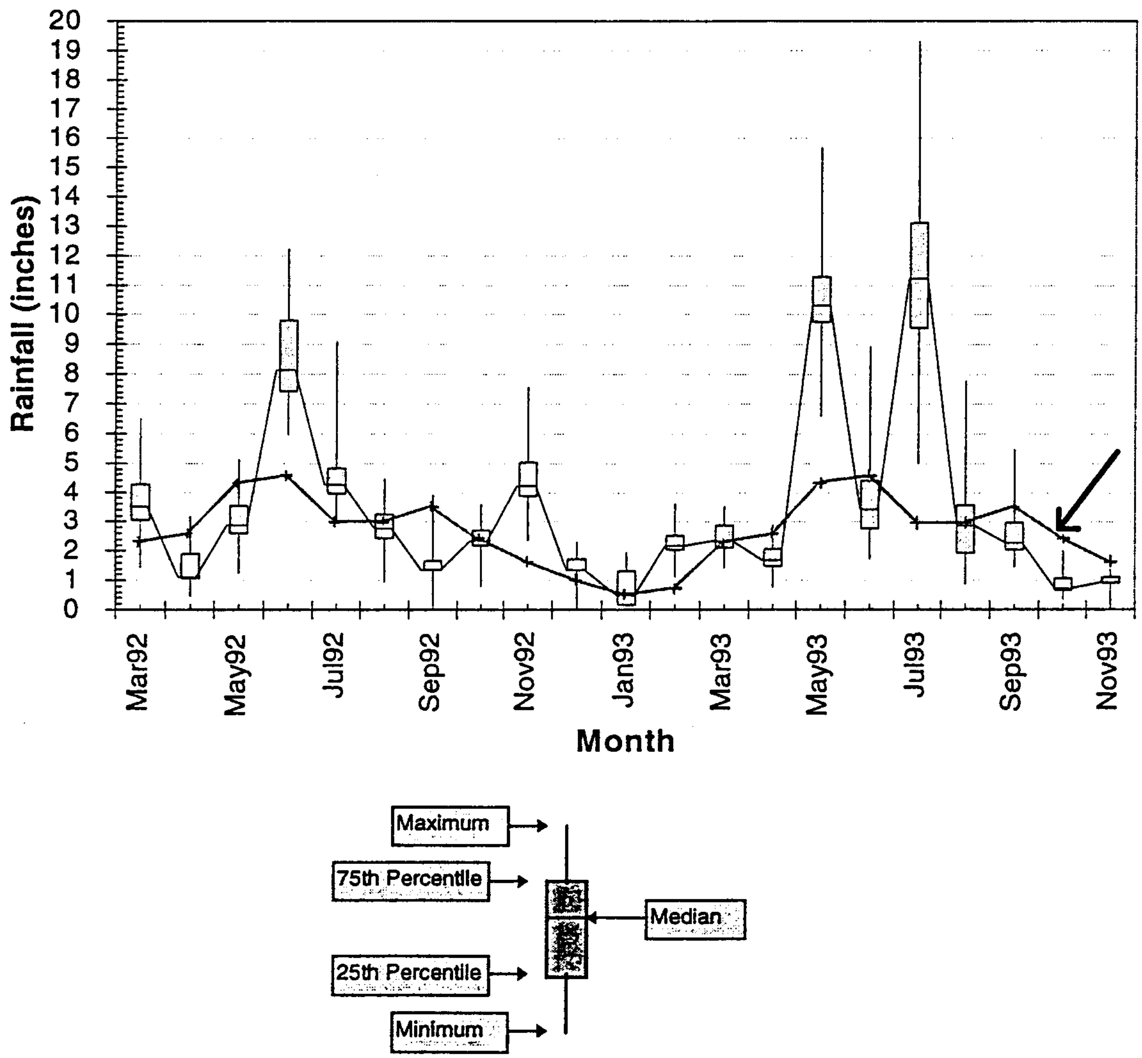


Figure 3. Boxplot of monthly precipitation measured at the 30 U.S. Geological Survey gages and the 11 National Weather Service gages used to estimate precipitation at the soil-coring sites. The light-gray line (arrow) represents normal precipitation based on a 30-year mean (1961-1990) as measured at the National Weather Service Gage at Newton, Kansas.

Precipitation patterns during 1992 were marked by unusually high precipitation in June and November, above-average precipitation in July, and dryer than normal conditions in September (fig. 3). June and July precipitation reduced the amount of irrigation water which was applied during these months. Many operators only used their irrigation systems in late July, August, and September. Several operators used very little, if any, irrigation water. High early-summer precipitation had the net effect of reducing the difference in water applied between dryland and irrigated sites in 1992. Late October and November precipitation limited the number of fields which could be sampled in the fall of 1992.

Precipitation patterns in 1993 reflect the unusually high rainfall which resulted in flooding along the Little Arkansas River during the summer. Normal annual precipitation for the study area is approximately 30-32 inches (National Weather Service, 1993). Most of the gages used in this study recorded greater than 20 inches of precipitation in May and July alone (fig. 3). Precipitation patterns during the 1993 growing season limited the amount of irrigation water applied to an even greater degree than 1992. Differences in applied water between irrigation and dryland fields were minimal.

Soil-nitrate Data

Figure 4 is a boxplot of soil nitrate below the root zone. The solid line connects the median values for dryland sites and the dashed lines connect median values for irrigated sites. Median values of nitrate were essentially the same for all sample periods at dryland sites. Median values for soil nitrate increased from the spring to the fall of 1992 at irrigated sites. Median values of soil nitrate were approximately the same in the spring and fall of 1993, however the range of values (minimum to maximum) was much greater in the fall.

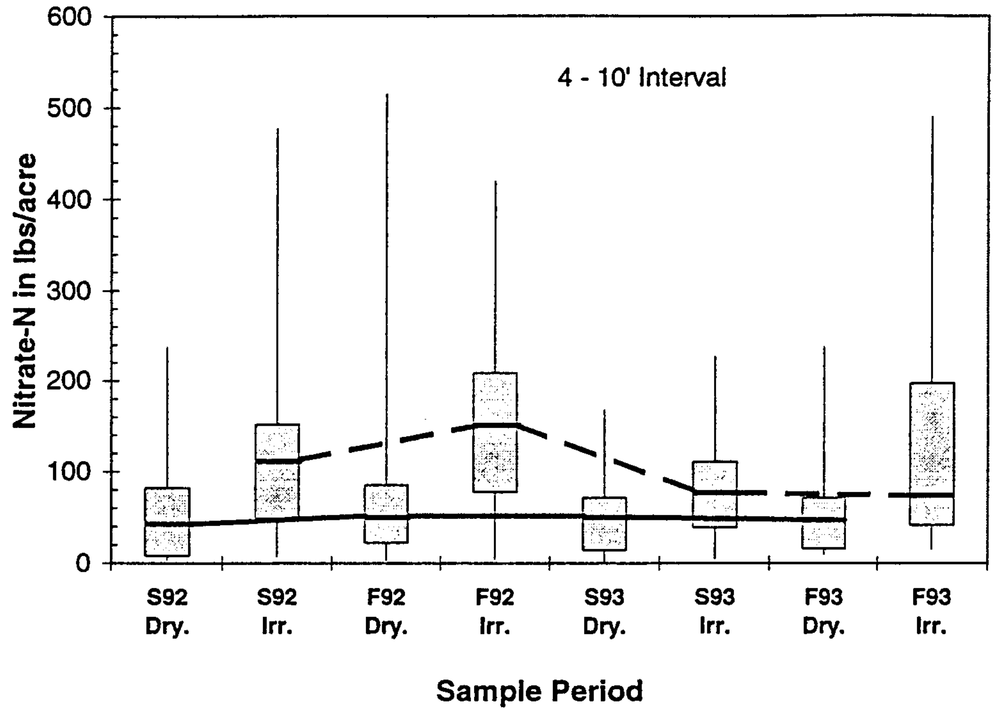


Figure 4. Boxplot of soil nitrate below the root zone for both sample years and land uses. Solid line connects dryland sites. Dashed line connects irrigated sites.

Nitrate Below the Root Zone Versus Individual Predictors

Tables 1A, 1B, and 1C contain the results from statistical comparisons between individual predictors and the amount of nitrate below the root zone at the end of the growing season. The log10 of all soil-nitrate data was used for these comparisons. Comparisons were made using the Pearson correlation coefficient (r). Statistical significance was calculated using an F-test. In table 1A , the variables 'P3' and 'P6' refer to April-June and April-September precipitation totals. In table 1B, the variable 'Fert' is the amount of fertilizer applied for that growing season. FHP3 refers to a weighted fertilizer-application rate for the three growing seasons prior to fall sampling (100% of the current year + 50% of the previous year + 25% of the year before that). In table 1C, S04 is the amount of nitrate in the root zone (0-4 ft) in the spring, and S410 is the amount of nitrate below the root zone (4-10 ft) in the spring.

Table 1A, B, C. Statistical comparison between the amount of nitrate below the root zone in the soil at the end of the growing season versus precipitation, fertilizer-application rates, and soil nitrate in the spring.

Table 1-A. Precipitation Versus Nitrate Below the Root Zone in the Fall

Year	Land Use	Variable	Corr. Coef. (r)	p(*)	# of Pairs (n)
1992	Dryland	P3	-0.5956	0.12	8
1992	Irrigated	P3	0.6079	**0.01**	16
1992	Dryland	P6	0.1099	0.80	8
1992	Irrigated	P6	0.4523	**0.08**	16
1993	Dryland	P3	0.0293	0.92	15
1993	Irrigated	P3	-0.1212	0.68	14
1993	Dryland	P6	-0.1584	0.57	15
1993	Irrigated	P6	-0.1106	0.71	14

Table 1-B. Fertilizer Versus Nitrate Below the Root Zone in the Fall

Year	Land Use	Variable	Corr. Coef. (r)	p(*)	# of Pairs (n)
1992	Dryland	Fert	0.4538	0.26	8
1992	Irrigated	Fert	0.3061	0.25	16
1992	Dryland	FHP3	0.4976	0.21	8
1992	Irrigated	FHP3	0.0688	0.8	16
1993	Dryland	Fert	0.5534	**0.03**	15
1993	Irrigated	Fert	-0.1689	0.56	14
1993	Dryland	FHP3	0.2578	0.35	15
1993	Irrigated	FHP3	0.2501	0.39	14

Table 1-C. Spring Soil Nitrate Versus Nitrate Below the Root Zone in the Fall

Year	Land Use	Variable	Corr. Coef. (r)	p(*)	# of pairs (n)
1992	Dryland	S04	0.8645	**0.006**	8
1992	Irrigated	S04	0.3399	0.2	16
1992	Dryland	S410	0.7622	**0.03**	8
1992	Irrigated	S410	0.6369	**0.008**	16
1993	Dryland	S04	0.4673	**0.08**	15
1993	Irrigated	S04	0.2335	0.42	14
1993	Dryland	S410	0.7318	**0.002**	15
1993	Irrigated	S410	-0.2044	0.48	14

* In column 'p' bold type indicates that the correlation coefficient is significant at the 0.01 level.

No single factor is a good predictor of the amount of nitrate in the soil below the root zone at the end of the growing season (Tables 1A, B, C). The best individual predictor is the amount of nitrate below the root zone in the spring (Table 1C), which had a statistically significant correlation with the amount of nitrate below the root zone at the end of the growing season for dryland 1992, irrigated 1992, and dryland 1993 sites. None of the factors tested had significant correlations with the amount of nitrate below the root zone at the end of the growing season at irrigated sites sampled in the fall of 1993.

Table 2 contains results from comparisons made using different groupings of land use and sample years versus the two fertilizer-application-rate factors (FERT and FHP3). In all cases the correlation coefficients improve and in most cases they become statistically significant when different years and/or land uses are combined. In contrast, only dryland sites sampled in 1993 had statistically significant correlations between fertilizer-application rate and the amount of nitrate below the root zone after the growing season when comparisons were made using individual years and land uses (Table 1B).

Table 2. Statistical comparison between the amount of nitrate in the soil at the end of the growing season versus fertilizer-application rates for different combinations of years and land uses. Irr means irrigated farm, dry means dryland farm.

Fertilizer Versus Nitrate Below the Root Zone in the Fall (Grouped)

Years	Landuse	Variable	Corr. Coef. (r)	p(*)	# of pairs (n)
1992&1993	Dryland	Fert	0.5382	**0.0008**	23
1992&1993	Dryland	FHP3	0.3222	0.13	23
1992&1993	Irr. & Dryland	Fert	0.2273	0.102	53
1992&1993	Irr. & Dryland	FHP3	0.3933	**0.004**	53
1992&1993	Irr. & Dry 1992, and Dry 1993	Fert	0.4236	**0.007**	39
1992&1993	Irr. & Dry 1992, and Dry 1993	FHP3	0.5899	**0.00008**	39
1992	Irr. & Dry	Fert	0.6452	**0.0006**	24
1992	Irr. & Dry	FHP3	0.4653	**0.02**	24

*In column 'p' bold type indicates that the correlation coefficient is significant at the 0.01 level.

Multiple-regression Analyses

Multiple-regression techniques were used to develop statistical models to predict the amount of nitrate below the root zone at the end of the growing season based on the six factors analyzed in the previous section. Multiple-regression analyses were performed on individual time/land-use data sets (i.e. dryland 1992) as well as groups of time/land-use data sets (i.e. dryland 1992 and 1993). The best model for predicting the amount of nitrate below the root zone for each time/land-use data set was determined from a series of multiple-regression model runs using all possible combinations of predictor variables. The multiple linear correlation coefficient (R) and the number of predictor variables used in the multiple-regression model were the two principal criteria used to select the best model. The multiple linear correlation coefficient is analogous to the Pearson correlation coefficient (r) which was used in the previous section. In this case, R is used as a measure of the correlation between the measured amount of nitrate below the root zone after harvest and the multiple-regression model prediction of the amount of nitrate below the root zone after harvest. Values of R range from zero to one, with one representing perfect correlation. The model with the largest R and the smallest number of predictors was selected as the best predictive model for each time/land-use data set.

Figures 5, 6, 7, and 8 are plots of the measured amount of nitrate below the root zone after harvest versus the predicted amount of nitrate below the root zone after harvest for models which included all of the dryland sites, dryland 1992, dryland 1993, and irrigated 1992, respectively. The multiple linear correlation coefficients (R) for the four models and the factors which were included in each model are shown in table 3. Attempts to develop a satisfactory predictive model for irrigated sites sampled in 1993 were unsuccessful.

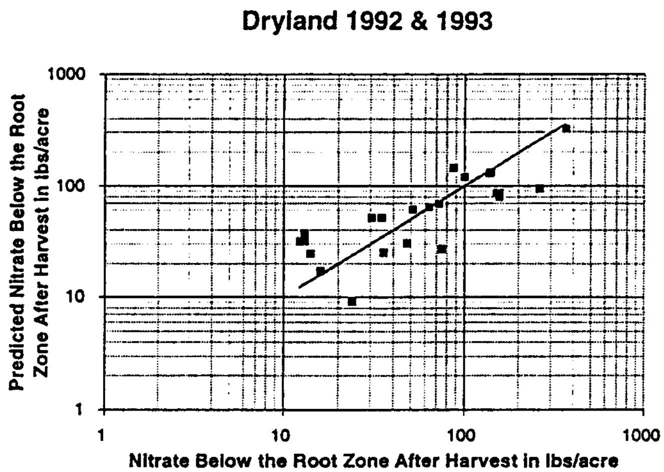


Figure 5. Plot of regression model results for all of the dryland sites.

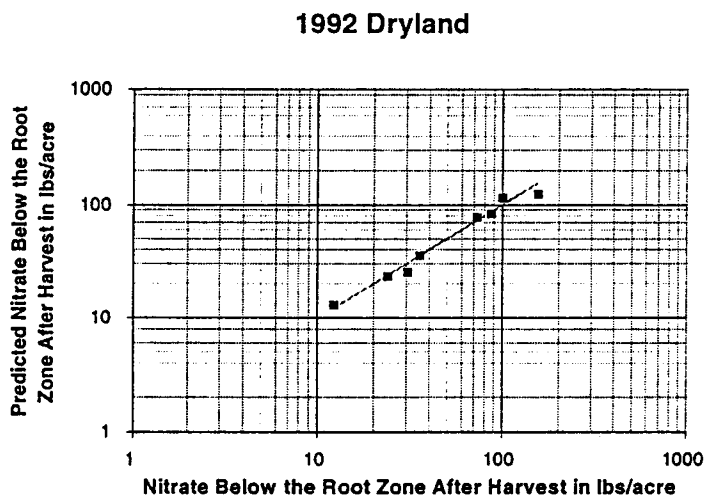


Figure 6. Plot of regression model results for dryland sites sampled in 1992.

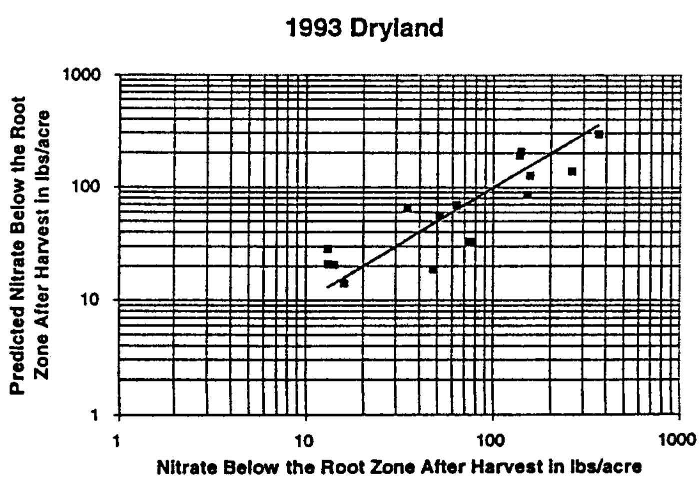


Figure 7. Plot of regression model results for dryland sites sampled in 1993.

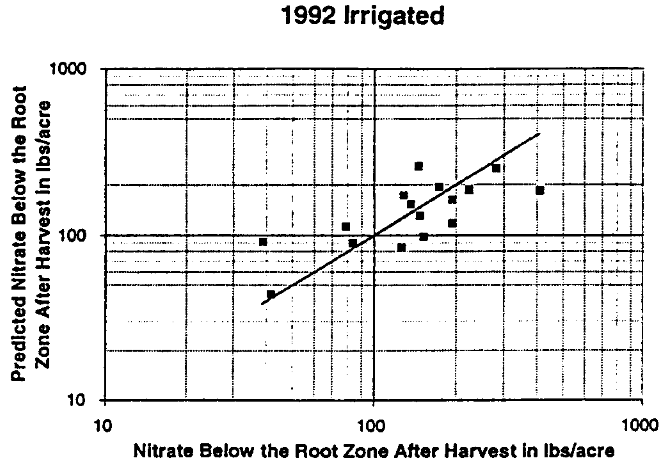


Figure 8. Plot of regression model results for irrigated sites sampled in 1992.

Table 3. Correlation multiple-regression model results.

Model	Factors	(R)	P
All Dryland	PS3, FERT, S04, S410	0.7987	0.0007
Dryland 1992	PS6, FHP3, S04, S410	0.9887	0.0083
Dryland 1993	PS6, FHP3, S410	0.8677	0.0011
Irrigated 1992	PS3, FERT, S410	0.7406	0.0194

In all cases, the best models for each time/land-use data set were obtained with either three or four predictor variables. Regression models for individual land uses within a single year were better at predicting the amount of nitrate below the root zone after harvest than models which incorporated different land uses or multiple years (i.e. the model for dryland 1992 is better than the model which includes dryland 1992 and 1993). Models that were limited to dryland sites were better than those that included irrigated sites.

The correlation between the measured and predicted amount of nitrate below the root zone is reasonably good for the four models presented. It is important however, to keep several factors in mind when interpreting the results of the multiple-regression analysis. First, the regression model for dryland 1992 has the best correlation between measured and predicted nitrate based on its multiple linear correlation coefficient R= 0.9887), but the model is based on only eight spring/fall pairs of data points. In fact, due to sampling problems caused by the weather and stringent data requirements for other parameters, the small number of data points limits the interpretive power of all of the models. Second, the predictions of the model were for the log10 of the amount of nitrate in the soil. The models are therefore reasonable indicators of general trends in the amount of nitrate below the root zone after harvest associated with the predictors used for the models, but they are not necessarily good predictors of the actual amount of nitrate which would be in the soil.

Partial correlation coefficients from multiple-regression results can be used to determine the percentage of a regression model which is explained by individual variables. Figure 9 shows the percentage of each multiple-regression model which is explained by the individual factors used in the four models in the previous section plus a regression model which includes all irrigated and dryland sites sampled in 1992 and 1993.

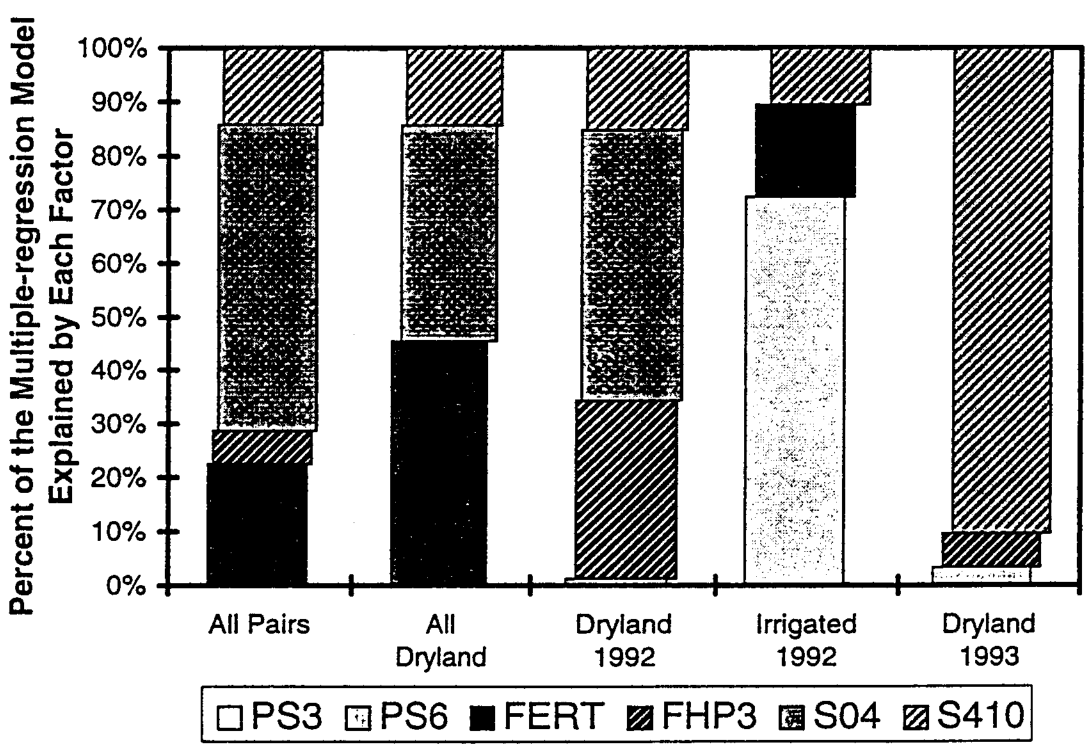


Figure 9. Bar graph depicting the percentage of the regression-model predictions which are explained by individual factors in the models.

In models developed for dryland sites for individual years or for 1992 and 1993 combined, greater than 95% of the regression-model predictions were explained by spring soil nitrate and fertilizer-application rate factors (fig. 9). Of these two factors, the amount of nitrate in the soil in the spring was the most important predictor of the amount of nitrate below the root zone after harvest. The model developed for irrigated sites sampled in 1992 indicates that early growing season precipitation (PS3) explained approximately 70% of the variation in model predictions (fig. 9). Apparently the precipitation factors have a much stronger effect on the amount of nitrate below the root zone at irrigated sites than they have at dryland sites. The model that used all dryland and irrigated sites for both years was statistically significant, but the multiple linear correlation coefficient was considerably lower than models which excluded the 1993 irrigated sites (R=0.5488). For this model all the predicted variation in the amount of nitrate below the root zone after harvest is explained by the amount of nitrate in the soil in the spring and the amount of fertilizer applied at the sites.

Recommended Fertilizer-application Rates

The nitrogen fertilizer-application rate is the dominant factor controlling the amount of nitrate remaining below the root zone after the growing season. Decreasing the amount of fertilizer applied should therefore decrease the amount of nitrate below the root zone. Conversely, over-fertilization should increase the amount of nitrate below the root zone at the end of the growing season and increase the risk of ground-water nitrate pollution.

To determine if farmers were using more nitrogen fertilizer than was necessary for their crops, recommended nitrogen fertilizer-application rates were compared with the amount of nitrogen fertilizer being applied. Recommended fertilizer-application rates were calculated using an equation developed by Kansas State University Agricultural Extension personnel (Corn Production Handbook, CES, 1994).

N Rec = [YG x CF(lb/bu)] x STA - PCA - PYM - PNST

where,

N Rec = nitrogen recommended in pounds per acre.

YG = a realistic yield goal in bushels per acre (150 bushels corn; 65 bushels milo).

STA = soil-texture adjustment (1.1 for sandy soil and 1.0 for medium- and fine-texture soils).

PCA = previous crop adjustment (alfalfa 60-80% stand nitrogen credit = 60 lbs/acre; soybeans nitrogen credit = 30 lbs/acre; 0 for other previous crops).

PYM = previous years manure (0 for no manure history; applied at only two sites in this study).

PNST = profile nitrogen results for 0-2 ft in lbs/acre.

The recommended amount of nitrogen fertilizer (NRec) was subtracted from the actual amount of nitrogen fertilizer applied to determine if farmers in the study area were applying more nitrogen fertilizer than recommended. The results of this calculation were classified into five categories based on the differences between actual and recommended fertilizer-application rates. The percentage of the total fertilizer-application records in each category are shown in figure 10.

At 14% of the sites studied, actual nitrogen fertilizer-application rates were less than the recommended application rate (<NRec; fig. 10). At 26% of the sites, the actual application rate exceeded the recommended rate by less than 25 lbs/acre. In the remaining 60% of the sites, the actual fertilizer-application rate exceeded the recommended rate by greater than 25 lbs/acre. This overfertilization has both an economic impact on the area and a potential environmental impact on the storage of nitrogen in the vadose zone which will be discussed in the following sections.

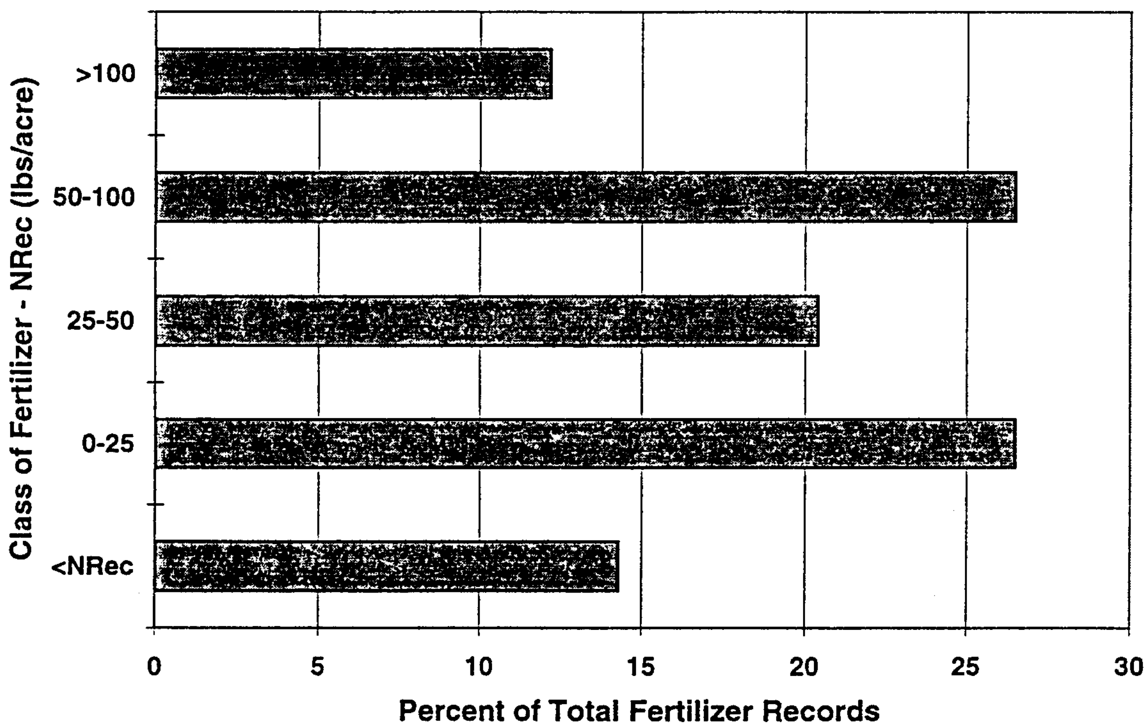


Figure 10. Classes of discrepancy between recommended and actual nitrogen fertilizer-application rates. Vertical axis shows the amount of over-fertilization for the fields studied. Horizontal axis shows percent of total fertilizer records evaluated during the study.

Nitrate in Soil

One of the goals of the project was to determine the volume of nitrate in the vadose zone under agricultural fields. Nitrate in the root zone (0–4 ft) is important for determining the amount of fertilizer needed for a given crop and yield goal. It is also a source of leachable nitrate which can be transported below the root zone and into ground water. In terms of nitrate-pollution potential for ground water, nitrate below the root zone is of greater concern because it is not available for plant uptake. If nitrate is transported below the root zone it will eventually reach the ground water if it is not denitrified.

There is more nitrate in the root zone in irrigated fields than in dryland fields (fig. 11). This is the result of higher fertilizer application rates for irrigated crops. The amount of nitrate in the root zone in dryland fields is very similar for spring 1992, fall 1992, and spring 1993 samples. Lower nitrate concentrations in the root zone of dryland fields in the fall of 1993 is probably a result of abnormally high summer precipitation causing movement of nitrate deeper into the soil profile.

Median nitrate concentrations in the spring and fall of 1992 at irrigated sites are very similar (fig.11). The same statement can be made for the spring and fall of 1993. Concentrations of root-zone nitrate are lower in 1993 than in 1992. Lower fall 1993 concentrations are the result of abnormally high summer precipitation. Lower spring 1993 concentrations are unexplained.

In all time periods more nitrate exists below the root zone (4-10 ft) at irrigated sites (fig. 12). The relationship is very similar to that for the root zone. The amount of nitrate below the root zone at dryland sites did not change much during the course of the study. In irrigated fields, median fall nitrate concentrations were higher than median spring nitrate concentrations. In 1993 median spring and fall nitrate concentrations were very similar, but the maximum and third quartile boundaries for the fall were much higher. This suggests that spring and summer precipitation events cause nitrate to move below the root zone.

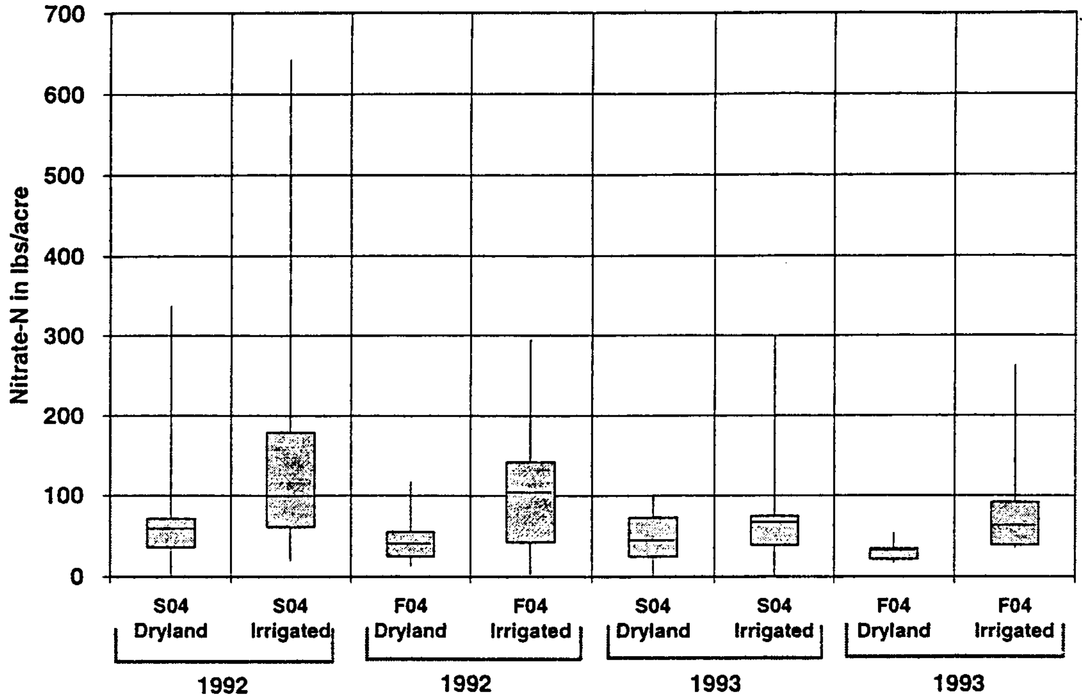


Figure 11. Boxplot of root zone nitrate for all time and land-use groups. The maximum, minimum, median, 25%, and 75% quartile values are shown. Spring sampling period shown by S; fall sampling period shown by F.

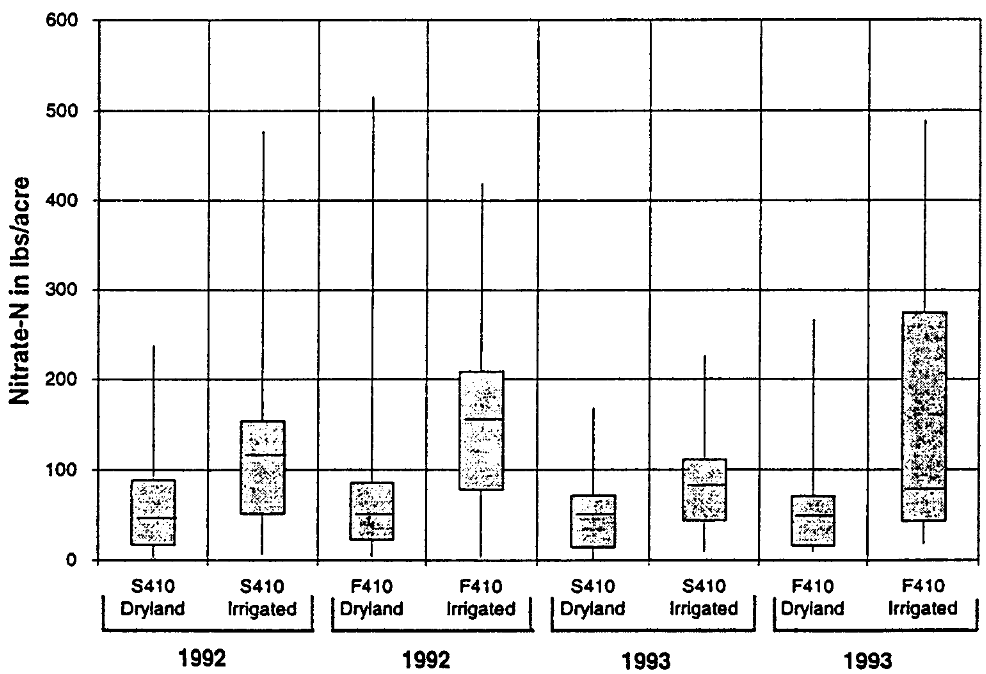


Figure 12. Boxplot of nitrate below the root zone for all time and land-use groups. The maximum, minimum, median, 25%, and 75% quartile values are shown. Spring sampling shown by S; fall sampling shown by F.

Lysimeter Study

Soil-water lysimeters were installed at six irrigated sites (fig.13) in order to determine the effects of soil stratigraphy on the movement of nitrate in the upper 10 feet of the vadose zone. Irrigated sites were selected because of the assumption that the additional water input from irrigation and higher fertilization rates for irrigated crops could result in excessive leaching of nitrate to the ground water.

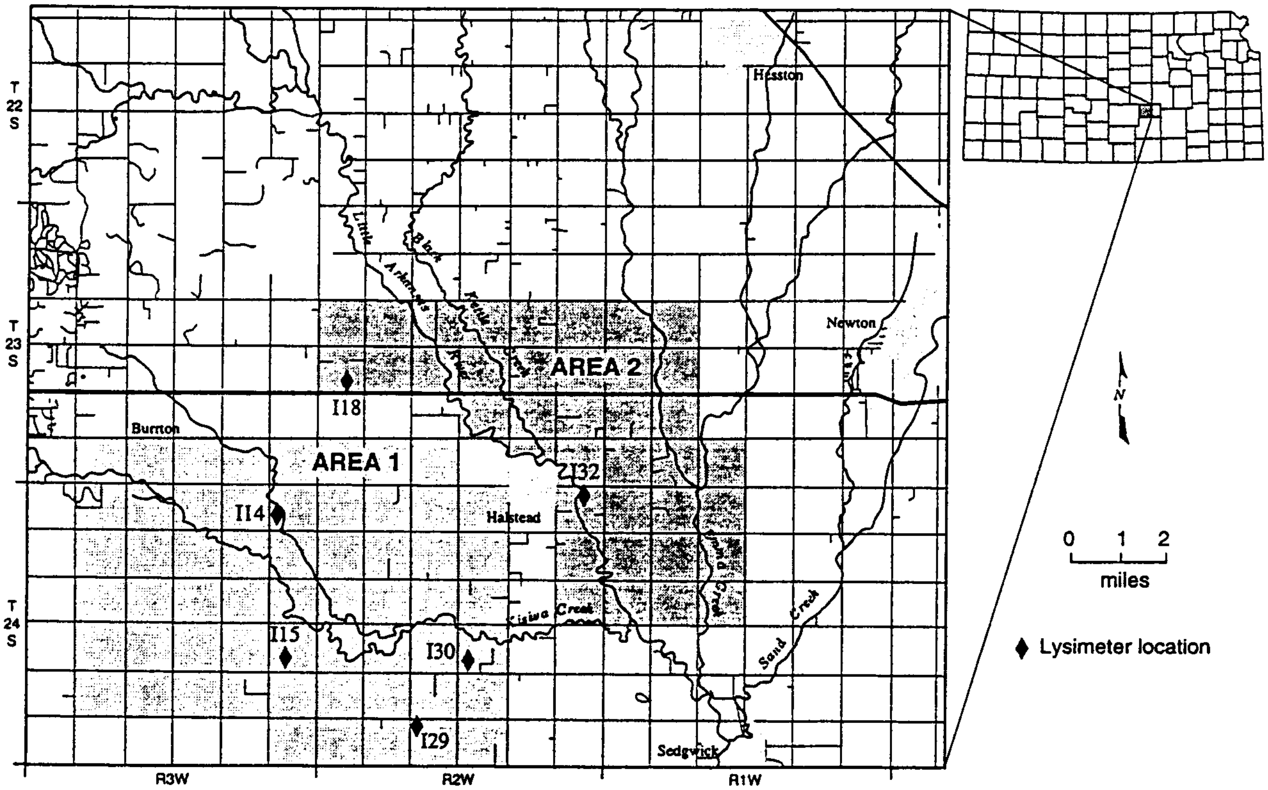


Figure 13. Location of lysimeter sites at six irrigated farms. Sites were chosen to represent possible worst-case scenarios for movement of nitrate through the vadose zone.

Figures 14 to 19 (p. 28-33) illustrate the nitrate-N content of the soil water (A) from lysimeters at 2-, 4-, 6-, and 10-ft depths in six irrigated fields and the soil-nitrate concentration determined from soil cores (B) taken to 10-ft (3-m) depth during the same time periods (appendix E). The concentration of nitrate in the soil water is much greater than in the soil cores from the same sites, indicating that nitrate concentration is a function of soil-water-retention characteristics.

Nitrate moves through the soil in pulses in response to precipitation events and irrigation-water application. The rate of movement is controlled by the hydraulic conductivity of the soil and the magnitude of the precipitation event or irrigation-water application. Permeability barriers associated with low-conductivity layers or abrupt changes in texture limit downward flow of water and concurrent nitrate transport.

It should be noted that at four of the six sites, I-14, I-15, I-18, and I-32. no sample was collected at the 10-ft depth because of a permeability barrier at a depth between 4- and 10-ft (figs. 14 to 19). This permeability difference could be caused by the presence of a fine-textured horizon (such as clay or silt/clay) or the presence of a coarser-textured layer underlying a finer-textured layer. Either situation in an unsaturated soil could result in perched water above the permeability barrier, delayed downward flow, and/or horizontal flow downgradient away from the samplers resulting in no sample at the deeper depth.

Table 4 lists the depth at which maximum sample volume was collected from these four sites during the study period. Each of the four sites has one sampler that has a greater volume of sample relative to the other samplers. Examination of the soil-profile descriptions indicates that the high-volume sampler is frequently above a layer with a large permeability difference such as fine sand over coarse sand or silty clay over sand (appendix E). These textural and permeability differences are probably sufficient to cause temporary perched water zones within the soil profile. However, the presence of low concentrations of nitrate at depth in the soil cores indicates that some water, and consequently the nitrate carried with the water, eventually moves through the profile but not in a quantity sufficient for collection by soil-water lysimeters.

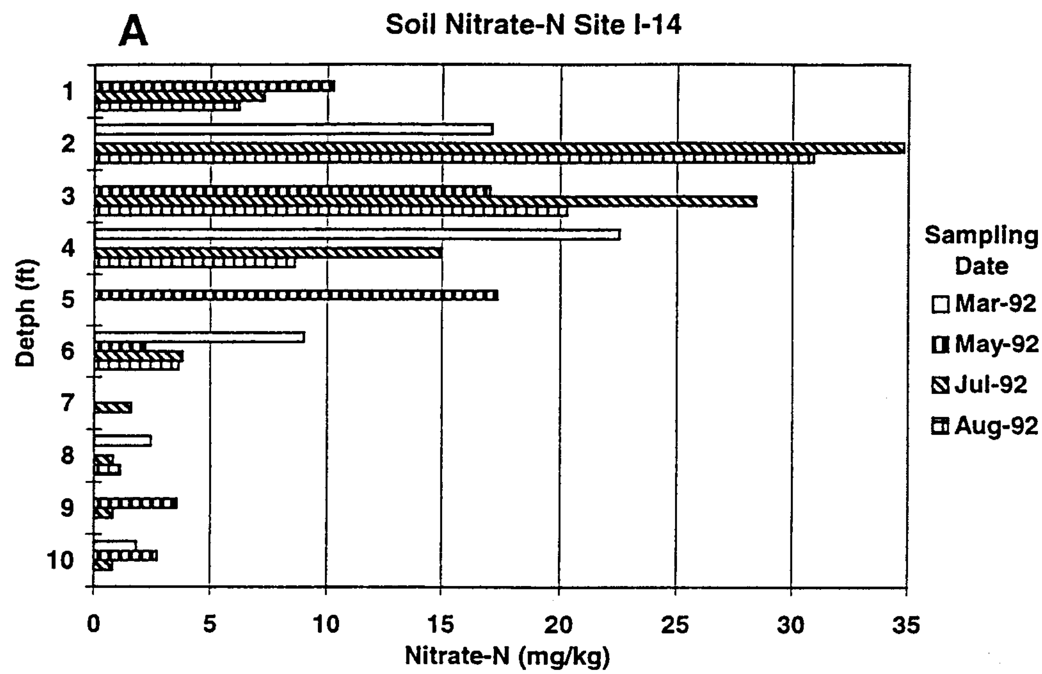
Table 4. Maximum soil-water volume and soil type

Site ID	Sampler Depth (feet)	Maximum Volume (ml)	Soil Layer
I-14	6	850–1025	Sand/coarse sand
I-15	4	390–525	Fine sand/coarse sand
I-18	4	1165–1350	Very fine sandy clay loam
I-32	6	50–1350	Sandy loam/sand

The lysimeters at sites I-29 and I-30 (figs.18, 19) are in sandy profiles in the Pratt or Pratt-Carwile map units. These two sites show water with nitrate-N values above the drinking-water standard of 10 mg/L at the 10-ft depth indicating that at these sites, the nitrate moved with the water and was not impeded by permeability barriers (appendix E).

Fertilizer use for the six sites ranged from 178 to 219 lb/acre (appendix B; p. 94). Several of the sites (I29, I30, I15, and I32) show increases in nitrate-N concentration in the soil-water samples at depth over the growing season (appendix E). The observed increases in nitrate-N concentrations at these sites could be from several sources: slow downward movement of nitrate through the soil profile, the change of mineralized nitrogen to nitrate during the sampling period, lateral flow from other parts of the field along the permeability boundaries discussed above towards the lysimeters, or possibly by-pass flow through macropores from the land surface downward.

The lysimeter data as well as the soil core nitrate-N data suggest that a potential problem may exist because of storage of nitrogen and eventual movement of nitrate in and through the soil profile. However, examination of the nitrate-N concentration of ground-water samples from irrigation wells at these sites (depths from 117 to 236 ft) shows that the nitrate-N concentration are below the 3 mg/L limit (appendix C, p. 97) suggesting that the farming practices have not impacted the ground water at this time.



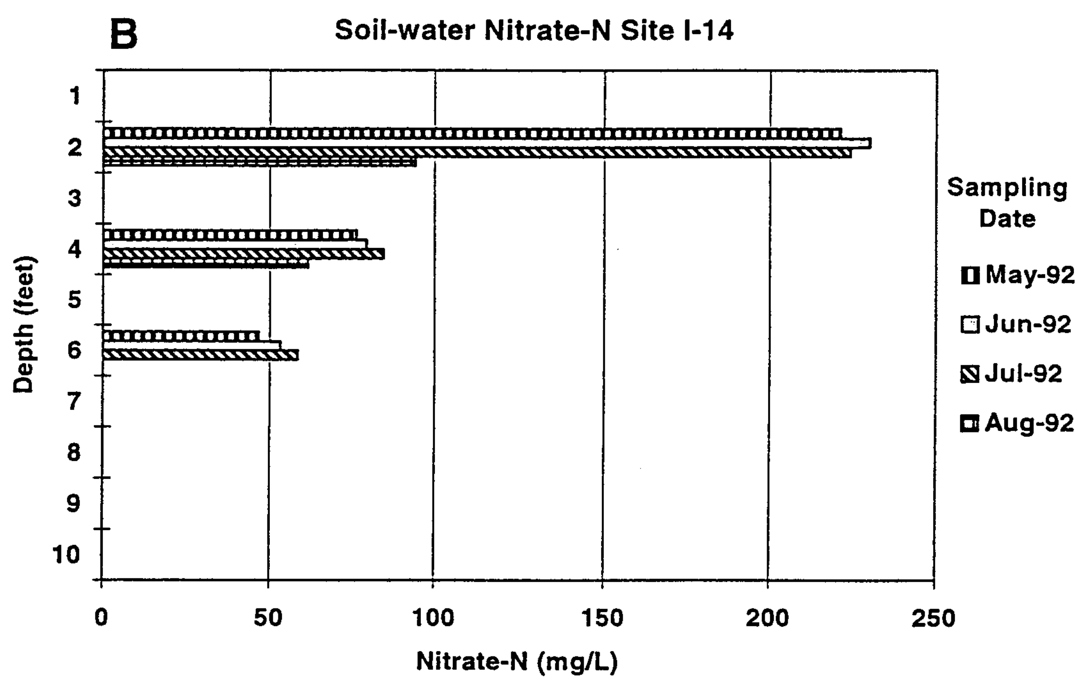


Figure 14. Nitrate-N concentrations from soil cores (fig. 14-A) and from soil-water lysimeters (fig. 14-B). Note that the concentrations from soil cores are in mg/kg and are much less than the values from soil water. The higher nitrate-N values from soil water indicate that nitrate moves with the water through the profile. To convert mg/kg to lb/acre, multiply by 9.26.

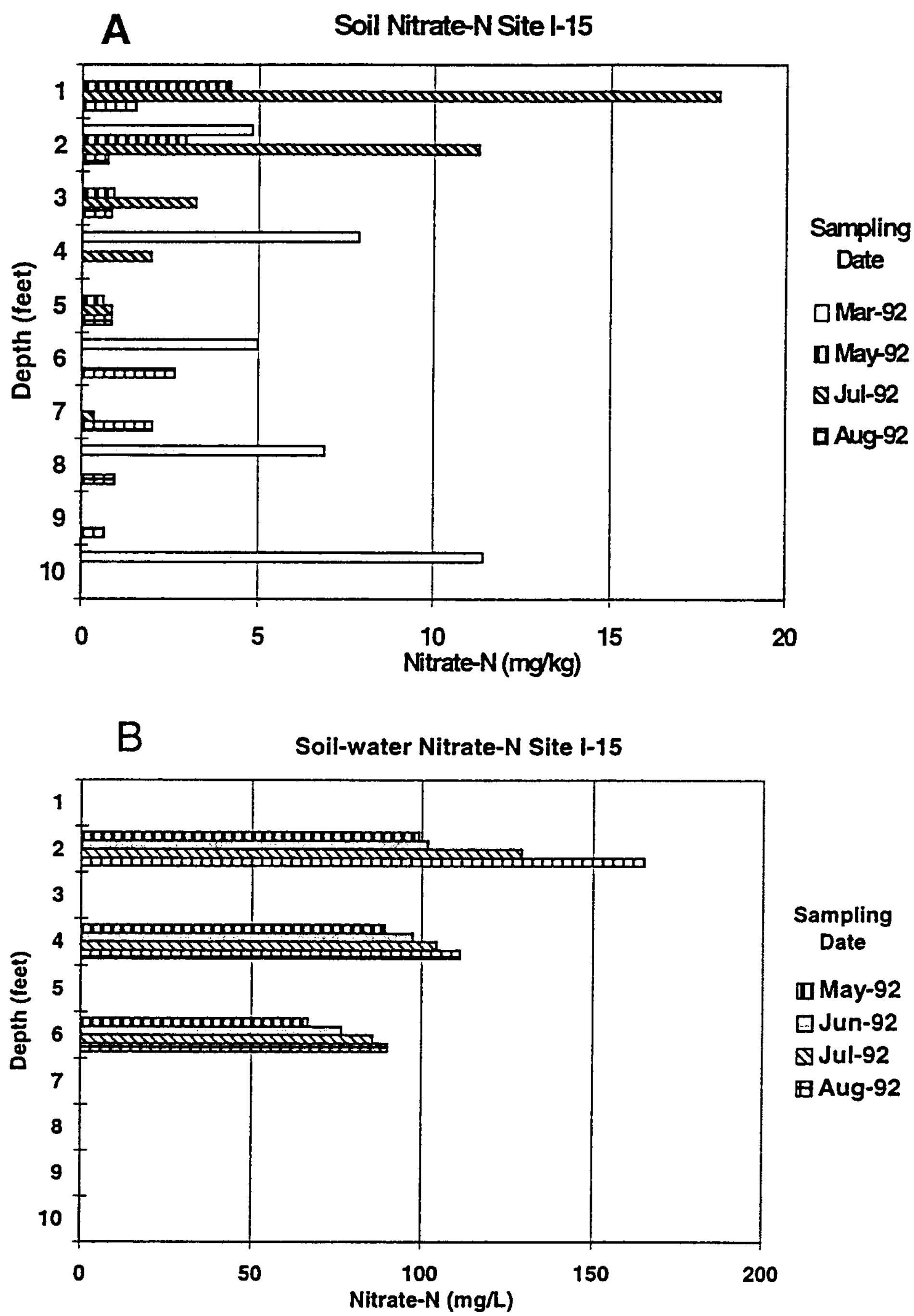
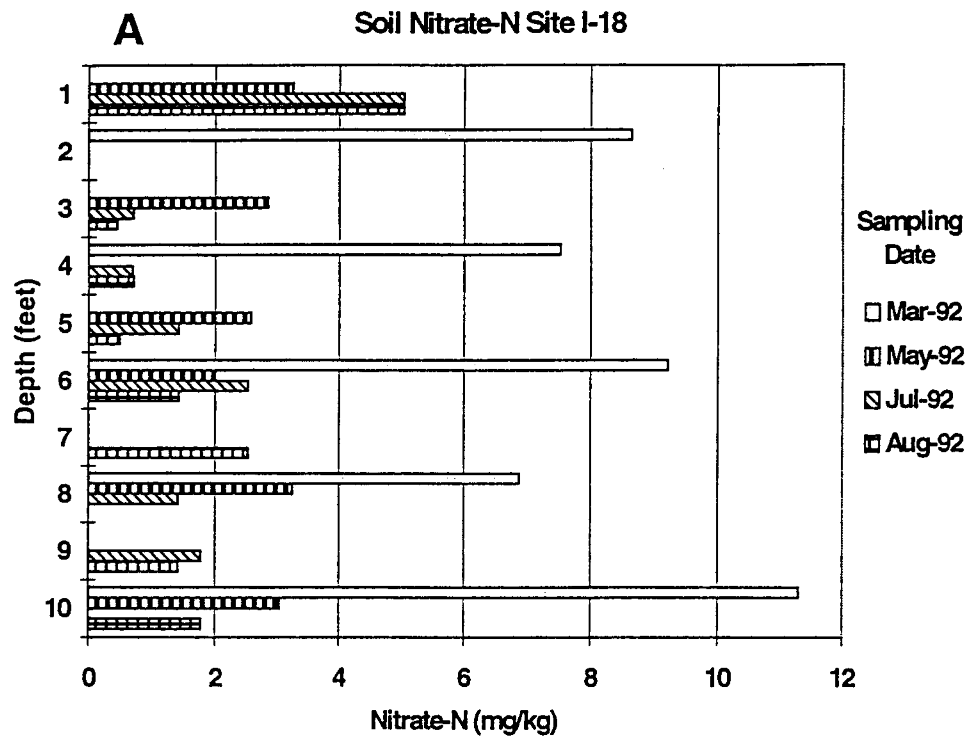


Figure15. Nitrate-N concentrations from soil nitrate-N (fig. 15-A) and from soil-water lysimeters (fig. 15-B). Note that the concentrations from soil cores are in mg/kg and are much less than the values from soil water. The higher nitrate-N values from soil water indicate that nitrate moves with the water through the profile. To convert from mg/kg to lb/acre, multiply by 9.26.



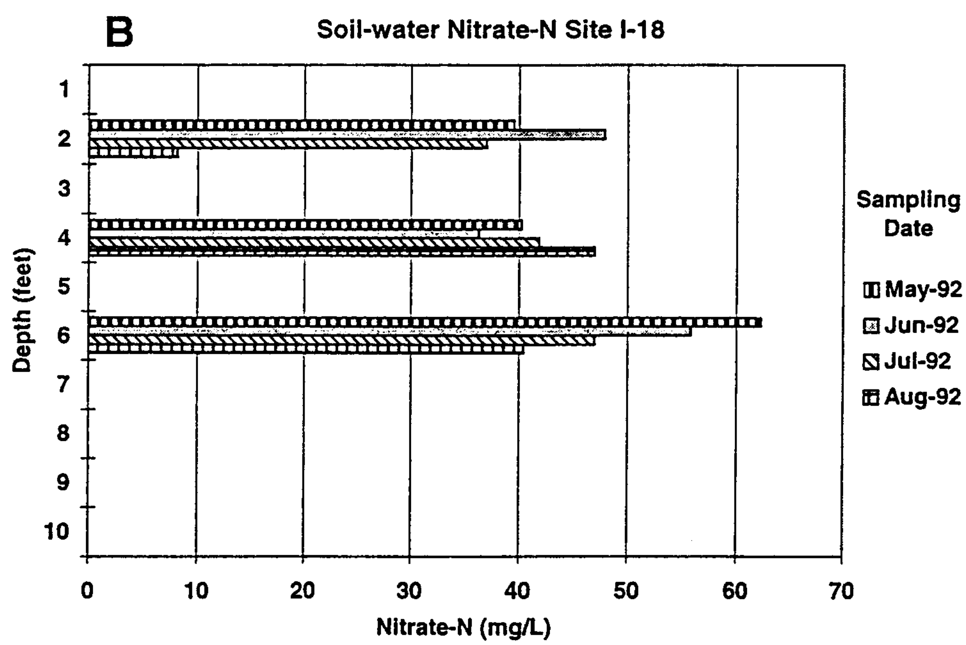


Figure 16. Nitrate-N concentrations from soil cores (fig. 16-A) and soil-water lysimeters (fig. 16-B). Note that the concentrations from soil cores are in mg/kg and are much less than the values from soil water. The higher nitrate-N values from soil water indicate that nitrate moves with the water through the profile. Also, note the lack of water sample below 6-ft depth because of permeability differences. To convert from mg/kg to lb/acre, multiply by 9.26.

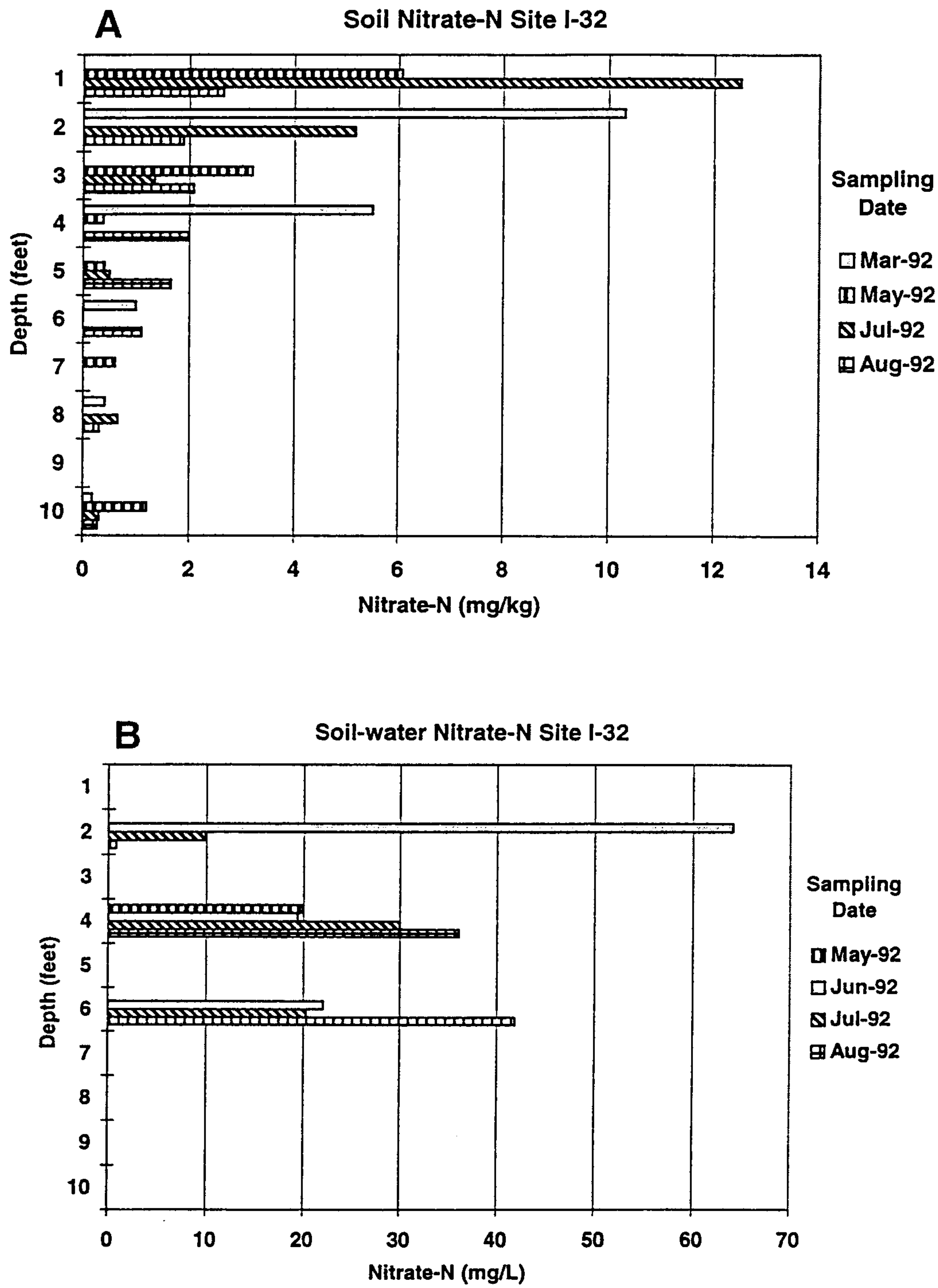


Figure 17. Nitrate-N concentrations from soil cores (fig. 17-A) and soil-water lysimeters (fig.17-B). Note that concentrations from soil cores are in mg/kg and are much less than the values from soil water. The higher nitrate-N values from soil water indicate that nitrate moves with the water through the profile. Also, note the lack of water sample below 6-ft depth because of permeability differences. To convert mg/kg to lb/acre, multiply by 9.26.

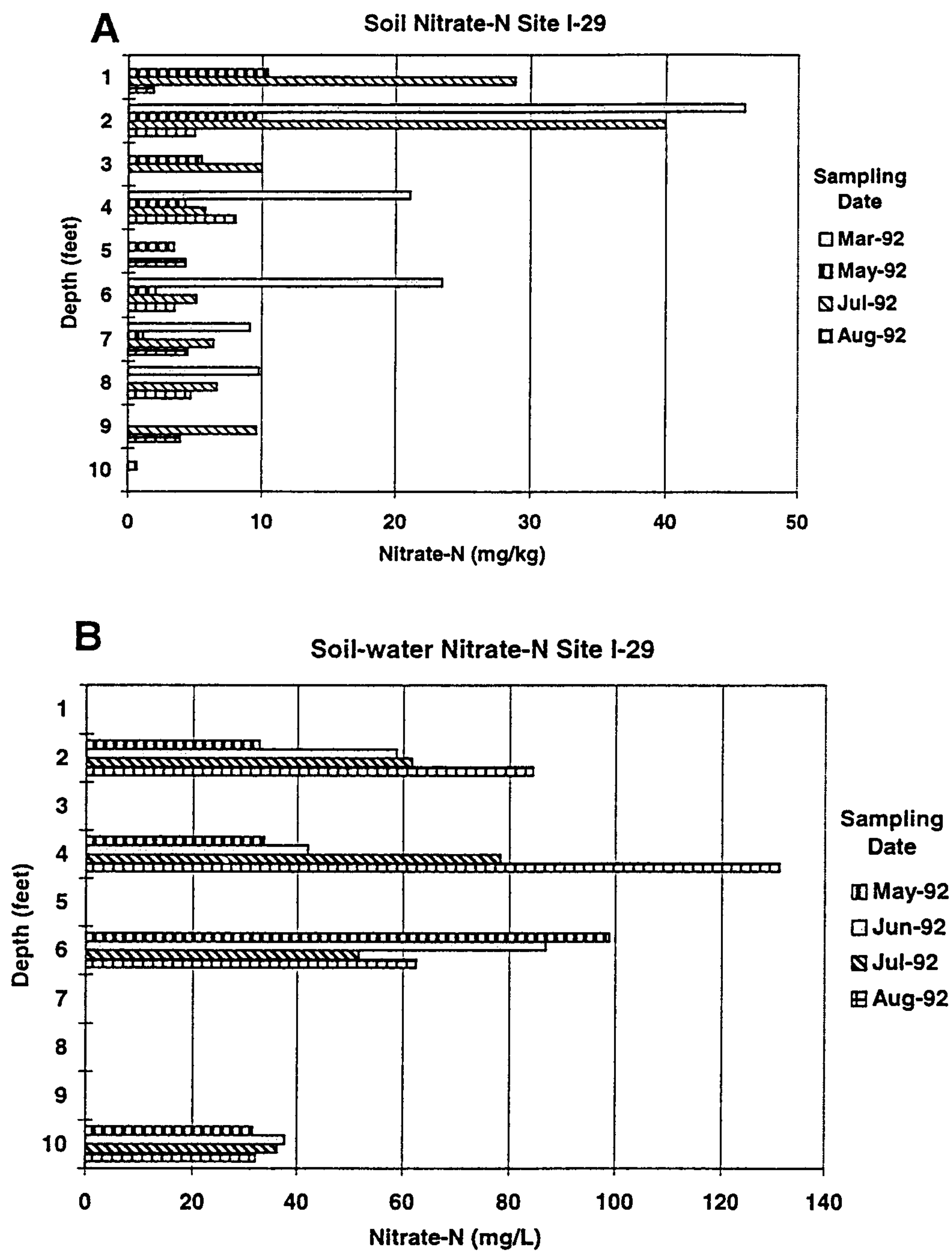
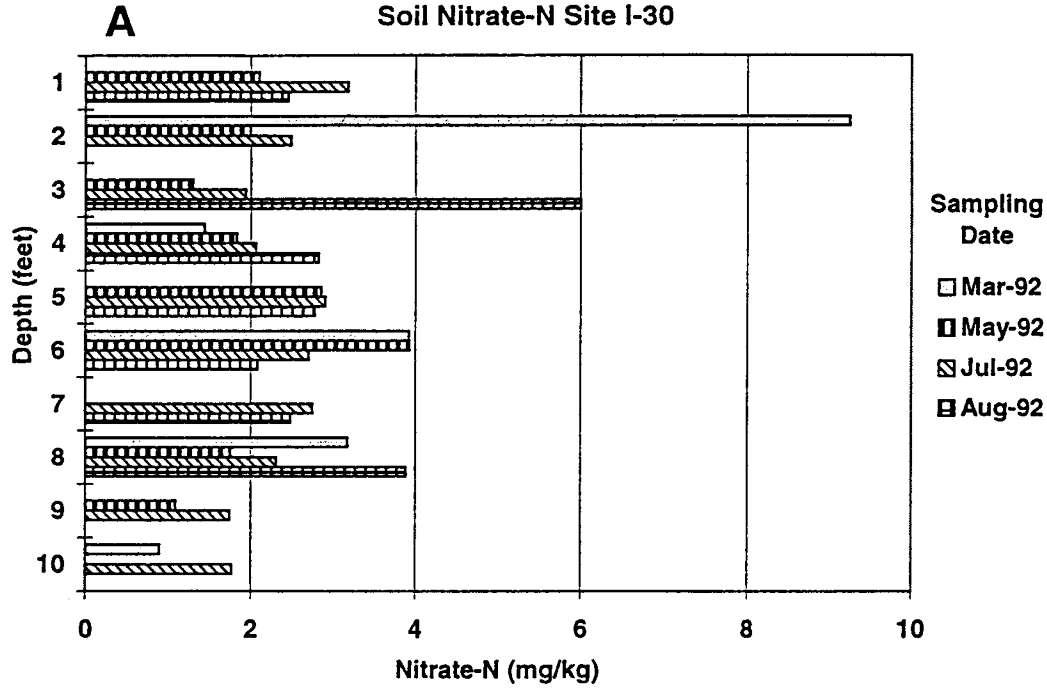


Figure 18. Nitrate-N concentrations from soil cores (fig. 18-A) and soil-water lysimeters (fig. 18-B). Note that concentrations from soil cores are in mg/kg and are much less than the values from soil water. The higher nitrate-N values from soil water indicate that nitrate moves with the water through the profile. Also, note that nitrate occurs in soil-water from 10-ft depth indicating no permeability barriers are present in this profile. To convert mg/kg to lb/acre, multiply by 9.26.

A



B

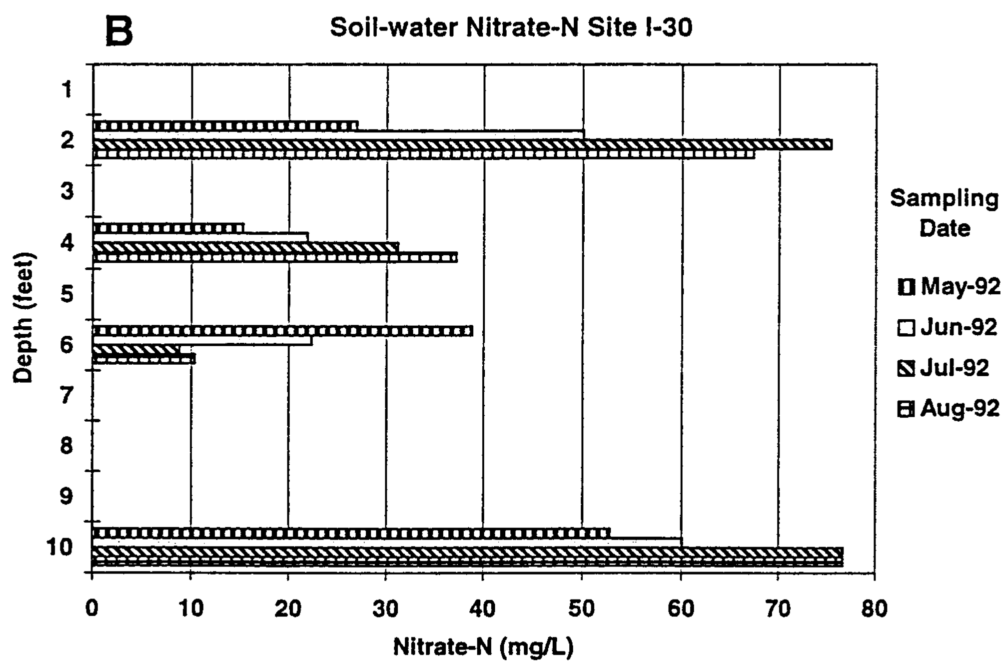


Figure 19. Nitrate-N concentrations from soil cores (fig. 19-A) and soil-water lysimeters (fig. 19-B). Note that concentrations from soil cores are in mg/kg and are much less than the values from soil water. The higher nitrate-N values from soil water indicate that nitrate moves with the water through the profile. Also, note that nitrate occurs at the 10-ft depth indicating that no permeability barriers are present in this soil profile. To convert mg/kg to lb/acre, multiply by 9.26.

Nitrate-nitrogen in Ground Water

Madison and Brunett (1985) provide an overview of the occurrence of nitrate in ground water in the United States. Their work indicated that nitrate-N concentrations less than or equal to (≤) 3 mg/L are indicative of natural background concentrations. Nitrate-N concentrations greater than (>) 3 mg/L are interpreted as resulting from anthropogenic sources. In this report, the 3-mg/L threshold is used as an indicator of ground-water nitrate contamination by anthropogenic sources.

Water samples for nitrate analyses were collected from domestic wells during three sampling periods, March 1992, October 1992, and March 1993, and from irrigation wells in July 1992. Figure 20 represents the March 1992 sampling period as an example of the spatial distribution nitrate in ground water. Nitrate-N concentrations at each site are depicted using graduated circles. The diameter of the circle indicates the nitrate-N concentration at each well. The smallest circle size represents wells with concentrations < 3 mg/L. The largest circle size represents wells with concentrations above the U.S. Environmental Protection Agency (EPA) maximum contaminant level (MCL) of 10 mg/L. The results of nitrate analyses for all sampling periods are listed in tables C-1 to C-3 in appendix C (p. 97). Figures C-1 to C-4 (appendix C) show the spatial distribution of ground-water sampling sites for all sampling periods.

Figure 20 illustrates that high nitrate-N concentrations are not spread uniformly over the study area. The area south and west of Halstead does not appear to have a nitrate-contamination problem at this time. However, many of the wells sampled to the north and east of Halstead have nitrate-N concentrations above the 3-mg/L threshold indicative of an anthropogenic source of nitrate.

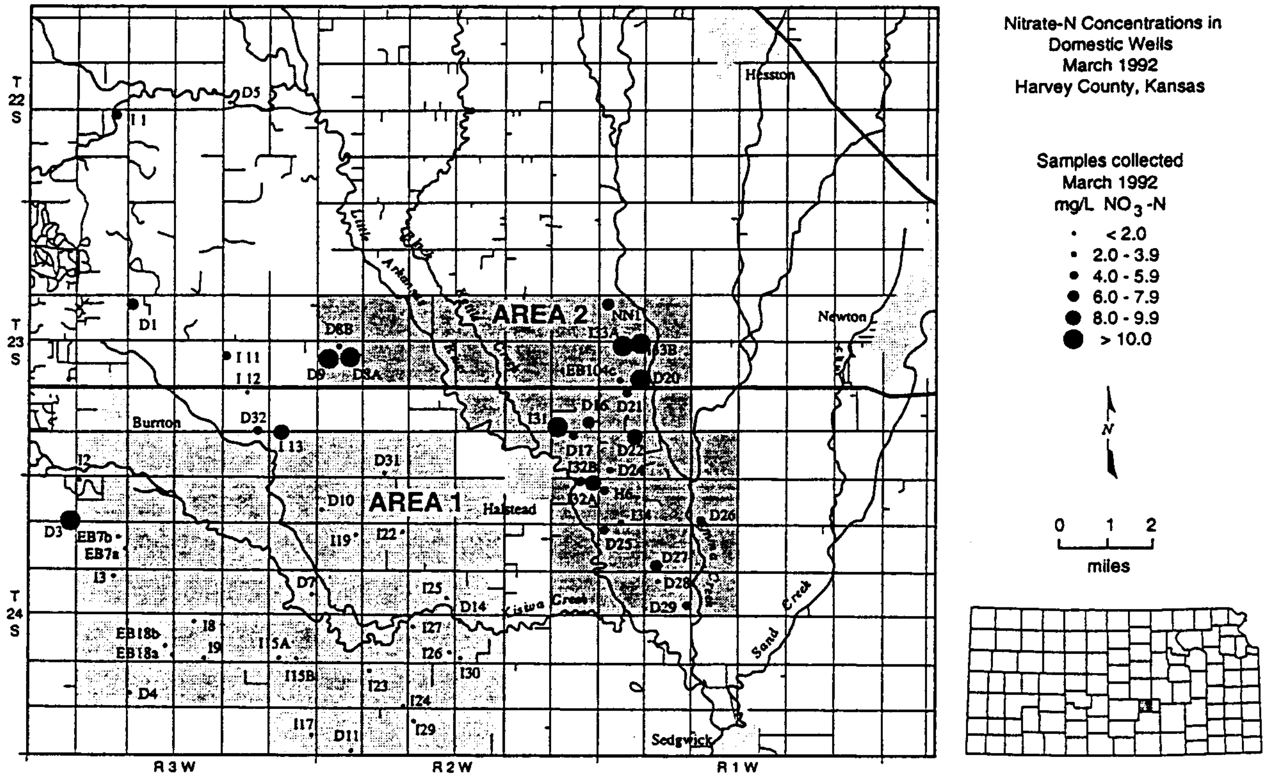


Figure 20. Distribution of nitrate-N in ground water collected from domestic wells in March, 1992 in Harvey County, KS. Area 1 represents more irrigated farms and lower nitrate-N values. Area 2 represents dryland farms and higher nitrate-N values.

Separation of Data by Area

The study area was subdivided into two smaller areas based on spatial patterns of nitrate-N concentrations in the ground water (fig. 20). In Area 1, ground-water nitrate-N concentrations are low. In Area 2 , nitrate-N concentrations in the ground water are higher and more variable in comparison to Area 1. In order to determine why there were large differences in concentration between the areas, a number of factors were evaluated: land use, soils, saturated thickness, historical water quality, general water chemistry, and finally potential sources for the nitrate. Table 5 summarizes the major differences between the two areas other than water quality. Area 1 has more irrigated land, higher fertilizer use, less sandy soil, a greater saturated thickness, and a lower nitrate-N concentration in the ground water than Area 2 (table 5). Higher fertilizer use and a larger percentage of irrigated land suggest that nitrate-N concentrations in Area 1 should be higher than nitrate-N concentrations in Area 2. As can be seen in figure 20, this is not the case. The reasons for this discrepancy will be discussed in the following sections.

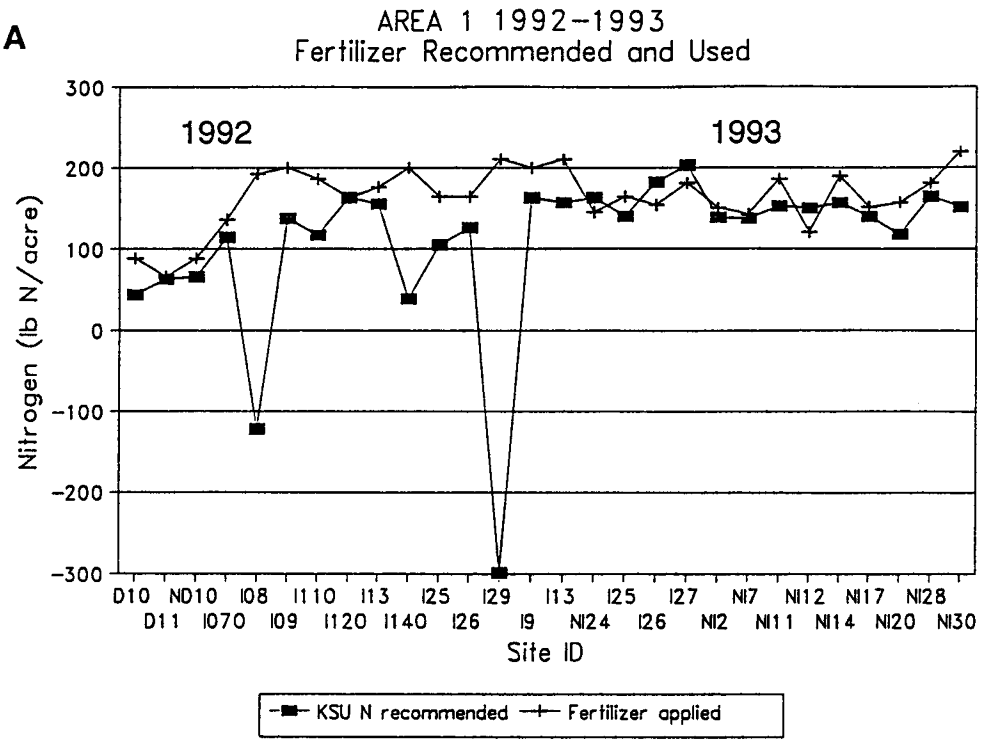
Table 5. Land use and physical differences between areas.

Factors	AREA 1	AREA 2
Irrigation Well Density (# well/s/mi^2)	1.5	0.55
Fertilizer Use (lb/acre)	72	55
Irrigated Acreage	24.3%	12.3%
Dryland Acreage	66.3%	67.5%
Soil Acreage		
Fine-textured soils	96%	87%
Sandy soils	0.4%	8.4%
Saturated Thickness (ft)	180	90
Mean nitrate-N (mg/L) in ground water	< 3	6

Effects of Fertilizer Use

Differences between applied nitrogen fertilizer and KSU-recommended nitrogen fertilizer-application rates were compared by area (fig. 21-A, B). In general both areas exceeded recommended fertilizer application (KSU marker on graph) by greater margins in 1992 than in 1993 (figs. 21-A, B). The overfertilization is represented by the presence of a negative number for the KSU recommendation and a positive number for the amount applied. Farmers in Area 1 tended to over fertilize more than those in Area 2 (fig. 21A). This is probably a reflection of higher fertilizer application rates for irrigated crops and a larger percentage of irrigated land use in Area 1 (table 5). The expected result of overfertilization should be higher nitrate-N concentrations in the ground water in Area1. This is not the case (fig. 20). Reasons for this observation will be presented in the General Water Chemistry section (p. 42).

A



B

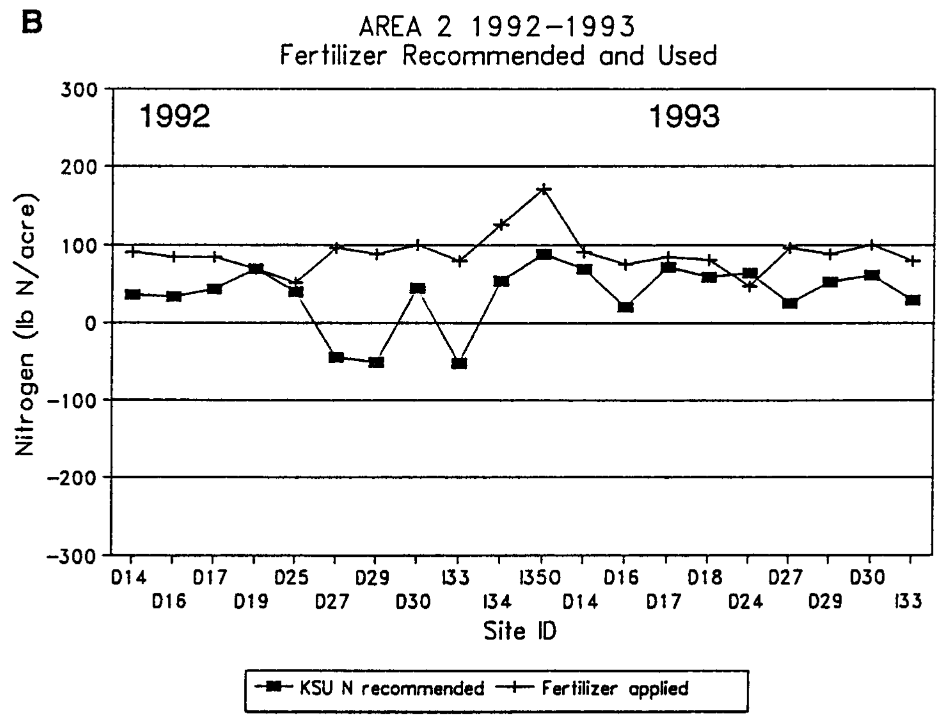


Figure 21. Graphs A and B show recommended and applied fertilizer rates for Area 1 and 2. Negative KSU values indicate overfertilization at given site. Fertilizer applied below KSU value means underfertilized site.

Historical and Recent Water-quality Data

Nitrate-N concentrations from samples collected by Williams and Lohman (1949) were compared with the data obtained from this study to determine if nitrate concentrations in the ground water in Area1 and Area2 were substantially different between the two time periods. Figures 22 A and B show nitrate-N concentrations from wells sampled in Harvey County during 1938–1940 and from this study (1992-1993).

Historical wells less than 160 feet deep were selected to compare with domestic wells 25–170 feet deep sampled during the present study (appendix C). The deeper domestic wells, both historically and from this study, occurred in AREA 1. The comparison does not represent resampling of the same wells. However, the wells used for comparisons are within the same area boundaries as defined in figure 20. Figures 29 A and B compare the historical nitrate-N data from water samples collected in the 1940's (line) with the data collected from this study (bar).

Figure 22 A shows that in Area 1 there are two wells with nitrate-N above 3 mg/L but $\leq$ 10 mg/L in the 1992-1993 sample set (bar), whereas there were none in the 1940 (line) sample set. In addition, there is only one well that is above the 10 mg/L drinking-water limit ($\leq$ 15 mg/L) for both time periods. The majority of wells in Area 1 for both time periods have nitrate-N concentrations $\leq$ 3 mg/L suggesting that overall there has been little increase in the nitrate-N concentration of the ground water in Area 1 in spite of the increased number of irrigation wells in this area in comparison with Area 2.

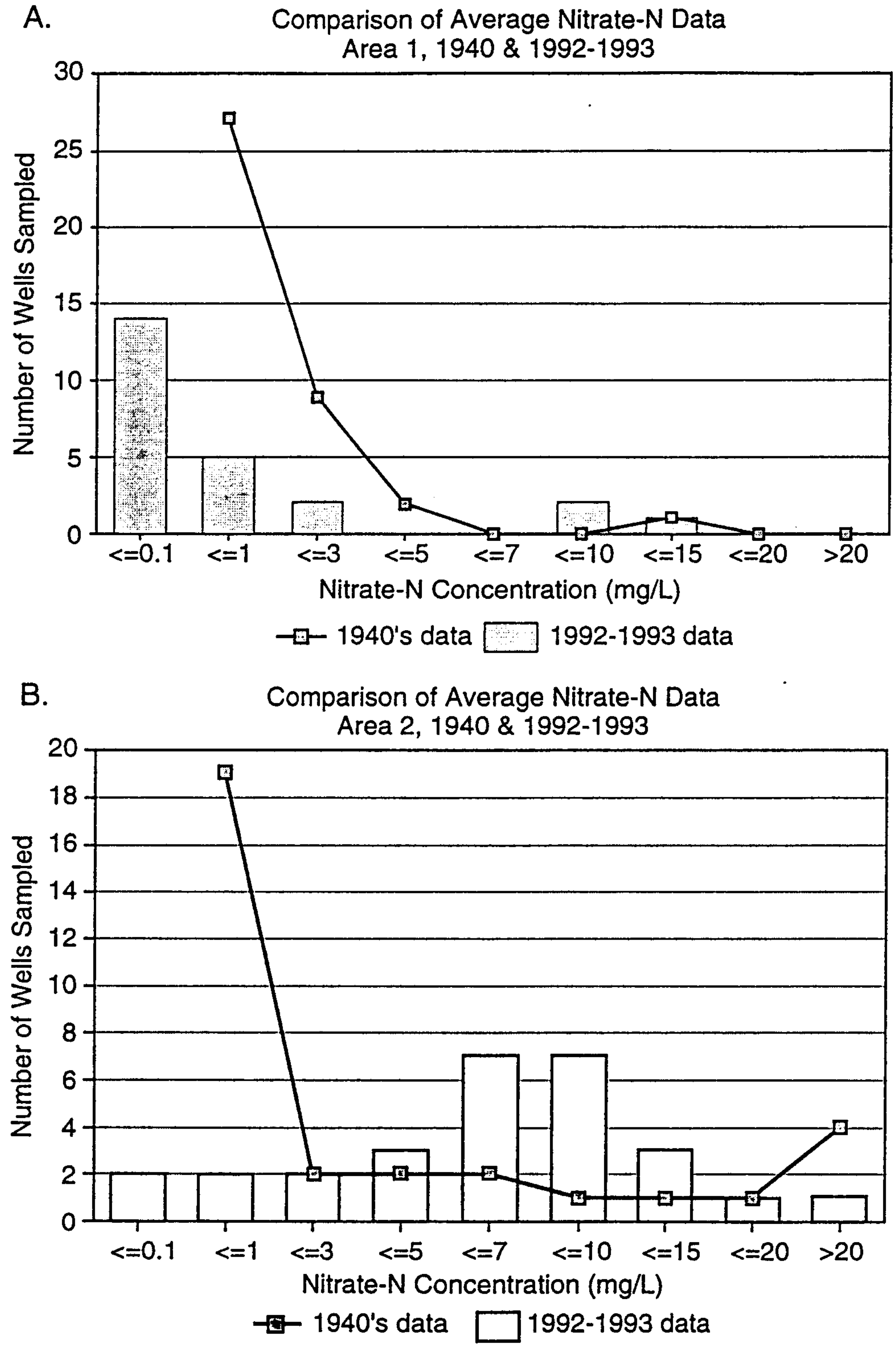


Figure 22. Graph A compares historical and recent nitrate-N values from Area 1. Graph B compares historical and recent nitrate-N values from Area 2. Note that nitrate-N values from Area 2 are higher for both sets of data.

Figure 22 B shows that in Area 2 there are more wells with nitrate-N concentrations between 3 and ≤ 10 mg/L in the 1992-1993 (bar) sample set than in the 1940 (line) sample set. This suggests that since the 1940s, nitrate-N concentrations in the ground water in Area2 have increased. There are fewer wells with > 10 mg/L nitrate-N concentration in the current data set (bar) than in the 1940's data set (line), but this may be an artifact of being unable to resample the same wells.

A comparison of figure 22 A and B shows that in both the 1940's data and the current study, nitrate-N concentration was, and is, higher in the ground water in Area 2 than in Area 1. In addition, these two graphs emphasize that historically and recently Area 1 has more wells with nitrate-N concentrations ≤ 3 mg/L than does Area 2. If nitrate-N concentrations > 3 mg/L are interpreted as the result of anthropogenic activity, then human activity has had the most impact on ground-water nitrate concentrations in Area 2. The potential sources for the nitrate are either fertilizer animal waste from septic systems or manure.

Stratification of Nitrate in Ground Water

Studies in Kansas and across the United States have shown stratification of nitrate-N concentration in shallow ground water (Spalding and Exner, 1993; Hallberg, 1989; Townsend and Young, 1994). Depth of well has often been used as an indicator of depth to water particularly when historical data are used and depth to water information is not available. The deeper the well, the deeper the well screen is installed and presumably the deeper the interval of the aquifer that is sampled. For this evaluation of the data, only wells with reported depths or well logs were used (appendix C, p. 97). No attempt was made to estimate depth of well for sites without a log or a reported depth.

Because shallow wells (≤ 50 ft) are considered more vulnerable to potential contamination, we evaluated the possible relationship of higher nitrate-N concentration with shallower depth of well. Figure 23 shows boxplots of all domestic wells and irrigation wells that have reported depths or depths from well logs with nitrate-N concentrations. The figure also shows the division of the nitrate-N data from Area 1 versus Area 2 against depth of well. The majority of water samples from Area 2 had a median nitrate concentration above the 3 mg/L limit regardless of depth. In contrast, median nitrate-N concentrations from Area 1 are below the 3 mg/L limit regardless of depth, again suggesting that anthropogenic sources have affected the nitrate-N concentration of the ground water in Area2 but not in Area 1.

Figure 23 also shows the range of nitrate-N detected in irrigation wells at depths of ≤ 150 ft and > 150 ft. As can be seen, the median nitrate-N concentration of the irrigation wells are all below the 3-mg/L limit regardless of depth, indicating that the deeper portion of the aquifer is not contaminated by nitrate.

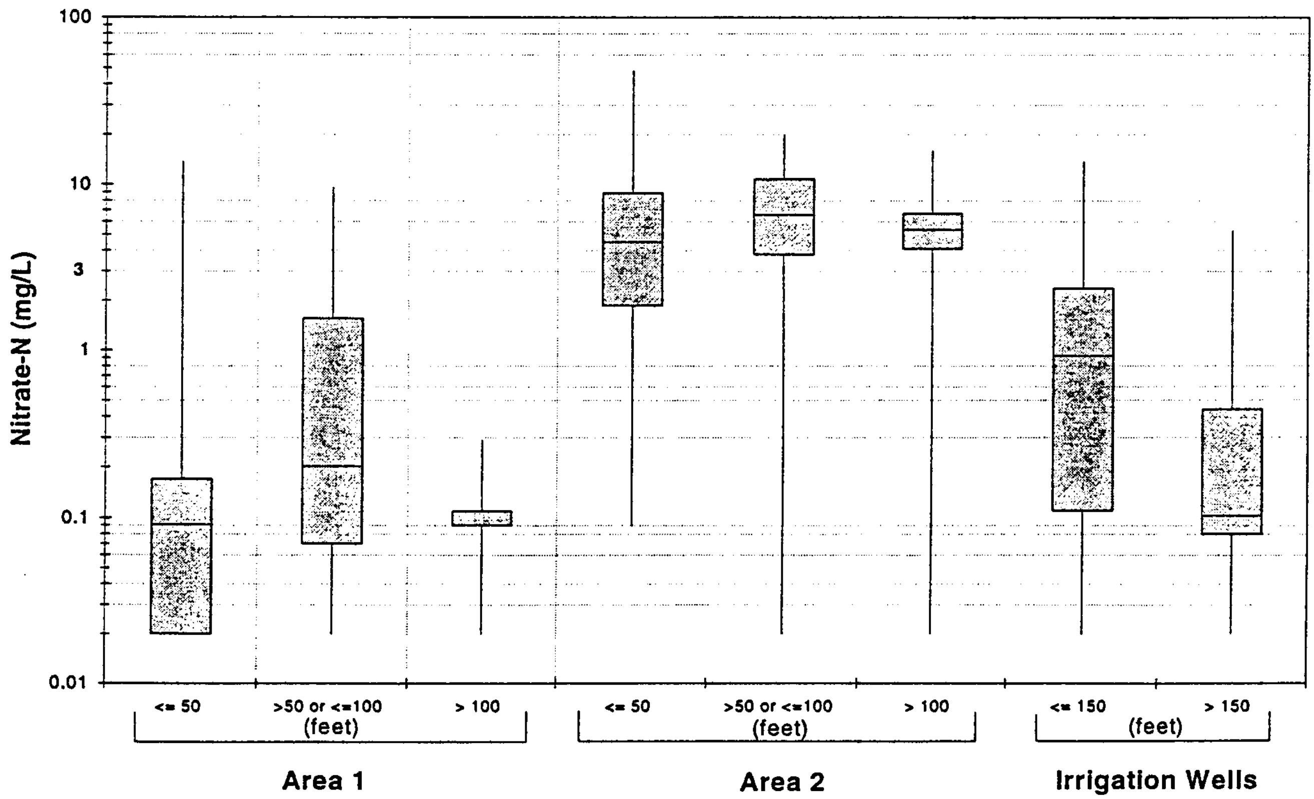


Figure 23. Boxplots showing distribution of nitrate with depth in domestic wells from Areas 1 and 2 and irrigation wells in Harvey County. Plot shows first and third quartiles (top and bottom of gray box), median (line inside gray box), and range of nitrate concentrations(vertical line above and below gray box). Nitrate-N concentration is shown on a log10 scale.

General Water Chemistry

Ten ground-water samples were collected in October 1993 to determine if the observed differences in nitrate-N concentration between Area 1 and Area2 (fig. 20) were associated with differences in the general water chemistry. The wells were selected on the basis of nitrate-N concentration and location in the study area (fig. 24). The majority of the domestic (Dom) or stock (Barn) wells were less than 100 feet deep. A few wells in Area1 were between 100 and 170 feet deep (appendix C, p. 97).

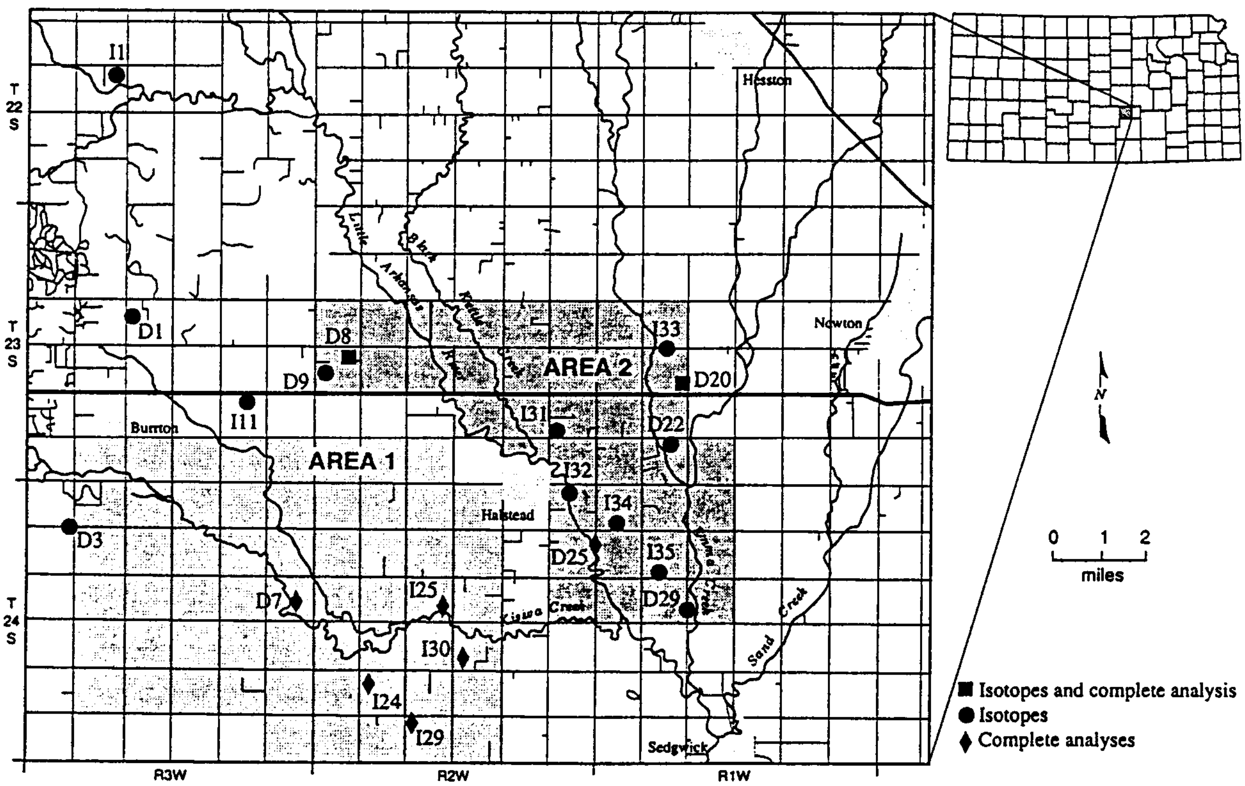


Figure 24. Location of sampling sites for complete chemical and nitrogen-15 isotope analyses. Sites were chosen on the basis of nitrate-N concentrations observed during previous sampling period (appendix C, tables C-1 and C-2).

All the sampled wells in Area 1 have ammonium and iron present, little to no nitrate-N, and higher specific-conductance values than those samples in Area 2 (table 6). In addition, when these particular samples were collected, a strong hydrogen sulfide odor was detected suggesting that these wells are in a chemically reducing zone within the aquifer. This finding agrees with earlier work by Hathaway et al. (1981) in describing water chemistry in the southwest portion of Harvey County as having a chemically reducing zone with higher iron concentrations (Fe > 1.5 mg/L), higher sulfate concentrations, and high electrical-conductivity values in the irrigation water.

Table 6. Selected Water Chemistry.

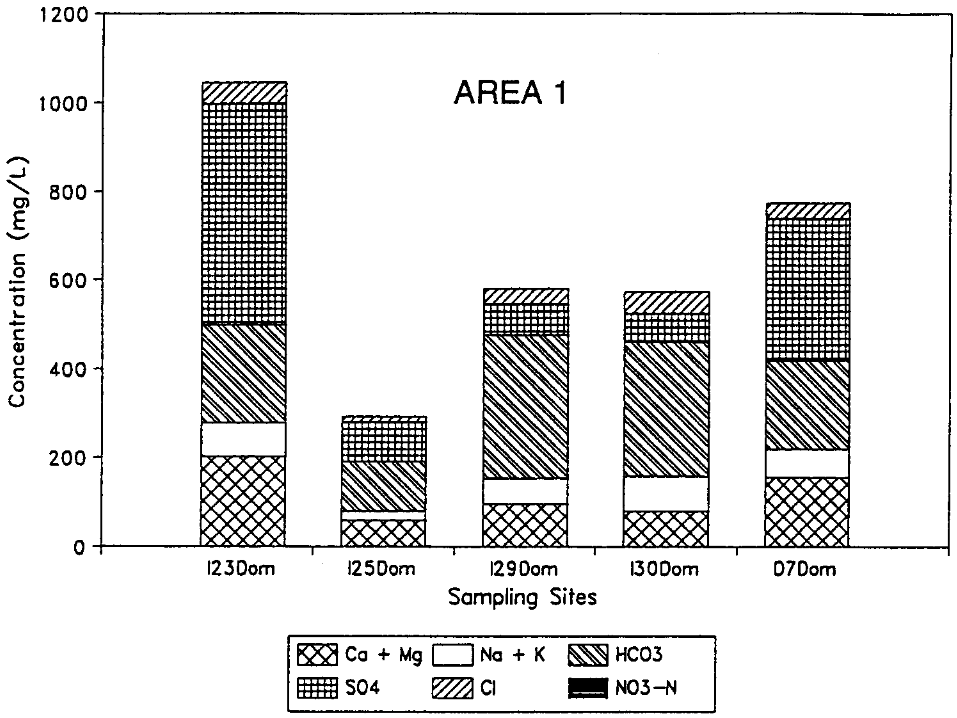
Site ID	Depth (ft)**	Specific Conductance (μS/cm)	NO_3-N (mg/L)	NH_4-N (mg/L)	Fe^{+2} (mg/L)
Area 1					
I-23 D	ND*	1405	0.2	0.2	20.2
I-25 D	ND	417	BD*	0.2	3.75
I-29 D	98	740	BD	0.1	1.35
I-30 D	66	750	BD	0.3	2.82
D-7 D	60	1040	0.9	0.2	4.26
Area 2					
D-8 B	82	568	16.7	BD	BD
D-8 D	43	412	4.0	0.1	BD
D-20 D	50	830	28.9	BD	BD
I-13 D	60	347	15.8	BD	BD
D-25 D	ND	420	3.7	BD	BD

* BD means below detection limit given in appendix F. * ND means no data available.
**Feet x 0.305 m/ft = meters. D = domestic well; B = barn well.

The wells with iron, ammonium, and little to no nitrate are present in the portion of the study area with limited surface-water drainage (Area 1, fig.24). In addition, descriptions of soils in the area include the presence of gleyed, green to gray clay zones in the soil and vadose zones indicating the presence of a reduced chemical zone. These observations can be used to infer that subsurface clay may reduce vadose-zone nitrate concentration through denitrification processes.

The presence of higher specific conductance, total dissolved solids, sulfate, and chloride concentrations in Area 1 (fig. 25; table C-4; appendix C, p. 97) suggests that in this part of the study area, ground water has moved a longer distance before discharging to Kisiwa Creek or the Little Arkansas River. Longer residence times in the aquifer, a reducing zone within the aquifer which would permit denitrification (microbial breakdown of nitrate) of any nitrate that reached the ground water, and dilution factors because of a greater saturated thickness would all contribute to the lower than expected nitrate concentrations of the ground water in this area.

The wells in Area 2 (fig. 25) have no detectable iron or ammonium but do have significant nitrate-N levels above the 10 mg/L limit for the most part (table 6; appendix C, p. 97). The specific conductance measurements for Area 2 (table 6) and the total analyte concentrations are approximately one-half of those in Area 1 (fig. 25 A, B). The implication of the scale difference is that samples from Area 2 are from a recharge zone and the water moving through the vadose zone and ground water does not remain in the system long enough to dissolve additional ions. Evaluation of well logs from AREA 2 show that the vadose zone is thinner in this area and the saturated thickness is less than in Area 1. The presence of high nitrate-N in the ground water in Area 2 indicates the presence of a thin vadose zone of relatively permeable sediment which allows a rapid movement of water and nitrate to an oxygenated water table.



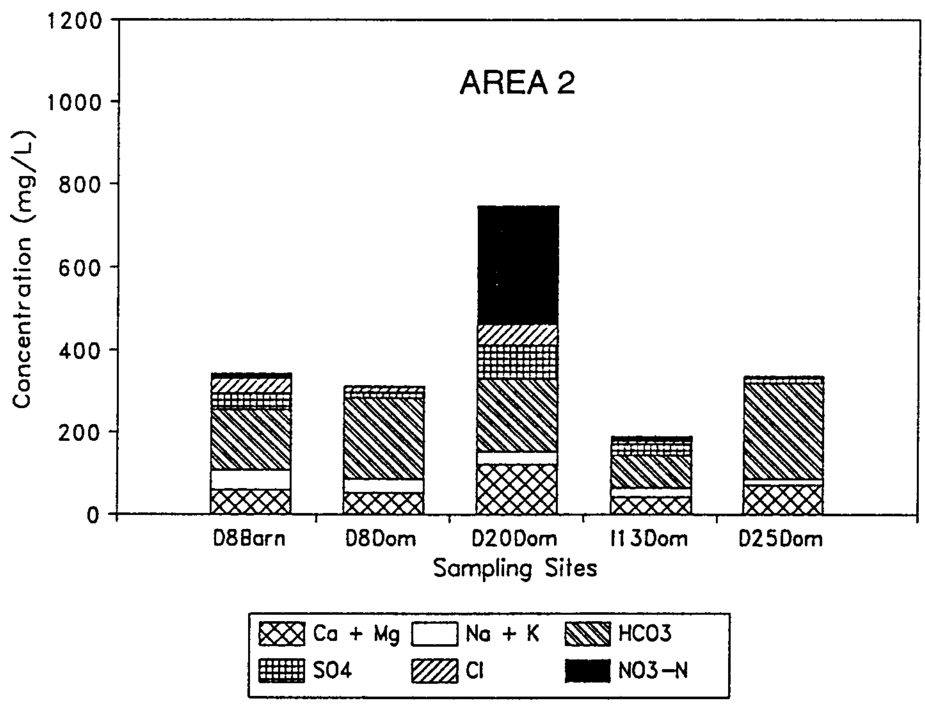


Figure 25. General water chemistry from Areas 1 and 2, Harvey County. Note the lack of nitrate-N concentration in Area1 (black color) and the presence of ammonium and iron, indicating that this area has a reducing water chemistry. Note the presence of nitrate-N in Area 2 (black color).

Use of Nitrogen Isotope Method in the Study Area

Studies in other parts of Kansas and in the United States suggest that using nitrogen isotope to determine sources of nitrate contamination works best in areas with a shallow water table and permeable soils (Kreitler, 1975; Gormly and Spalding, 1979; Townsend et al., 1994). These criteria are present in the Harvey County study area. Use of nitrogen isotopes in other parts of south-central Kansas indicated that irrigated farming and the presence of feedlots on permeable soils could be a source of nitrate to the ground water (Townsend et al., 1994; Young, 1992). The study area in Harvey County has irrigated farming, dryland farming, dairies, feedlots, and septic systems as possible sources for nitrate in the ground water.

Because a number of water samples from shallow domestic wells showed nitrate concentrations above the drinking-water limit of 10 mg/L, the nitrogen isotope method was used as a tool to determine potential sources for the nitrate. The method was used to determine if the high nitrate wells were contaminated from fertilizer sources ($\delta\ ^{15}N < {}^{+}8$) or animal wastes ($\delta\ ^{15}N > {}^{+}10$). If low nitrate-N concentrations are observed with enriched $\delta\ ^{15}N > +10$, then denitrification enrichment of the isotope has occurred (breakdown of nitrate by bacteria). If high nitrate-N values are observed with $\delta\ ^{15}N >$ +10, then an animal waste source is suspected. Additional background information on the nitrogen isotope method is presented in appendix F, p. 123.

Nineteen sites in the study area were sampled for nitrogen isotope analyses (fig. 24). A number of these wells are associated with dairy farms and feedlots (table 7). These wells were sampled to determine the source for the high nitrate (> 10 mg/L nitrate-N) observed in the wells. These wells had enriched $\delta\ ^{15}N$ values above + 10, which is indicative of an animal waste source.

All of the irrigation wells with low nitrate-N values and enriched nitrogen-15 values (unpublished data, Townsend, 1995) occur in Area 1 (fig. 24; table 7). Much of the enrichment may be attributed to denitrification above fine-textured layers in the vadose zone and/or reducing ground-water conditions in the aquifer as discussed in the general water chemistry section. Conditions such as long travel time through the vadose zone, perched water tables that act as reducing zones, and chemical-reducing zones in the ground water can permit enrichment of nitrogen isotopes by denitrification processes. The presence of the low nitrate-N values and the enriched nitrogen isotopes supports the hypothesis of a reducing water chemistry in the area that prevents nitrate buildup in this portion of the county.

Table 7. Nitrate-nitrogen and nitrogen isotope data, Harvey County, Kansas.

Site ID	Well Type	Depth (ft)	NO3-N mg/L	$\delta^{15}N$ ‰	Land use
D1	S	25	9.2	13.3	Well in feedlot. Possible denitrification above clays.
I1	D	60	3.8	16.2	Irrigated fields. Feedlot upgradient.
D3	D	50	12.2	12.7	Irrigated fields. Denitrification above clays.
		AREA 1			
I4*	I	165	1.2	9.9	Irrigated field. Clay zones.
I14*	I	236	0.02	10.1	Irrigated field. Clay zones.
I18*	I	226	0.02	20.1	Irrigated field. Clay zones.
I26*	I	117	2.1	10.9	Irrigated field. Clay zones.
I29*	I	140	1.1	15.8	Irrigated field. Clay zones.
		AREA 2			
D8	D	108	6.9	14.6	Dairy feedlot near well.
D8	S	75	15.1	12.6	Dairy feedlot near well.
D9	D	73	14.4	13.4	Feedlot near well.
I11	D	45	6.5	14	Intermittent cattle pasture. Possible denitrification.
I13	D	68	6.5	11.1	Intermittent feedlot. Possible denitrification.
D20-1	D	80	35.6	12.5	Dairy farm in past.
D20-2	D	50	20.5	11.5	Dairy farm in past.
D22	D	90	9.3	12.6	Irrigated fields. Denitrification above clays. Manure source.
D29	D	70	11.2	10.7	Feedlot nearby.
I31	D	65	14.4	11.3	Well in dairy barn.
I32	D	74	11.6	11.6	Dairy and irrigated fields.
I32	S	74	9.4	8.4	Dairy and irrigated fields.
I33	D	70	18.2	11.7	Long-term dairy. Manure as fertilizer.
I33	S	96	13.9	13.8	Long-term dairy. Manure as fertilizer.
I34	D	80	3.6	16.3	Irrigated fields. Denitrification above clays.
I35	D	80	8.5	16.6	Feedlot nearby. Irrigated fields. Manure as fertilizer.
I35*	I	169	3.8	12.1	Irrigated field. Feedlot upgradient.

D = domestic well; S = stock well; I = irrigation well; * unpublished data from other studies

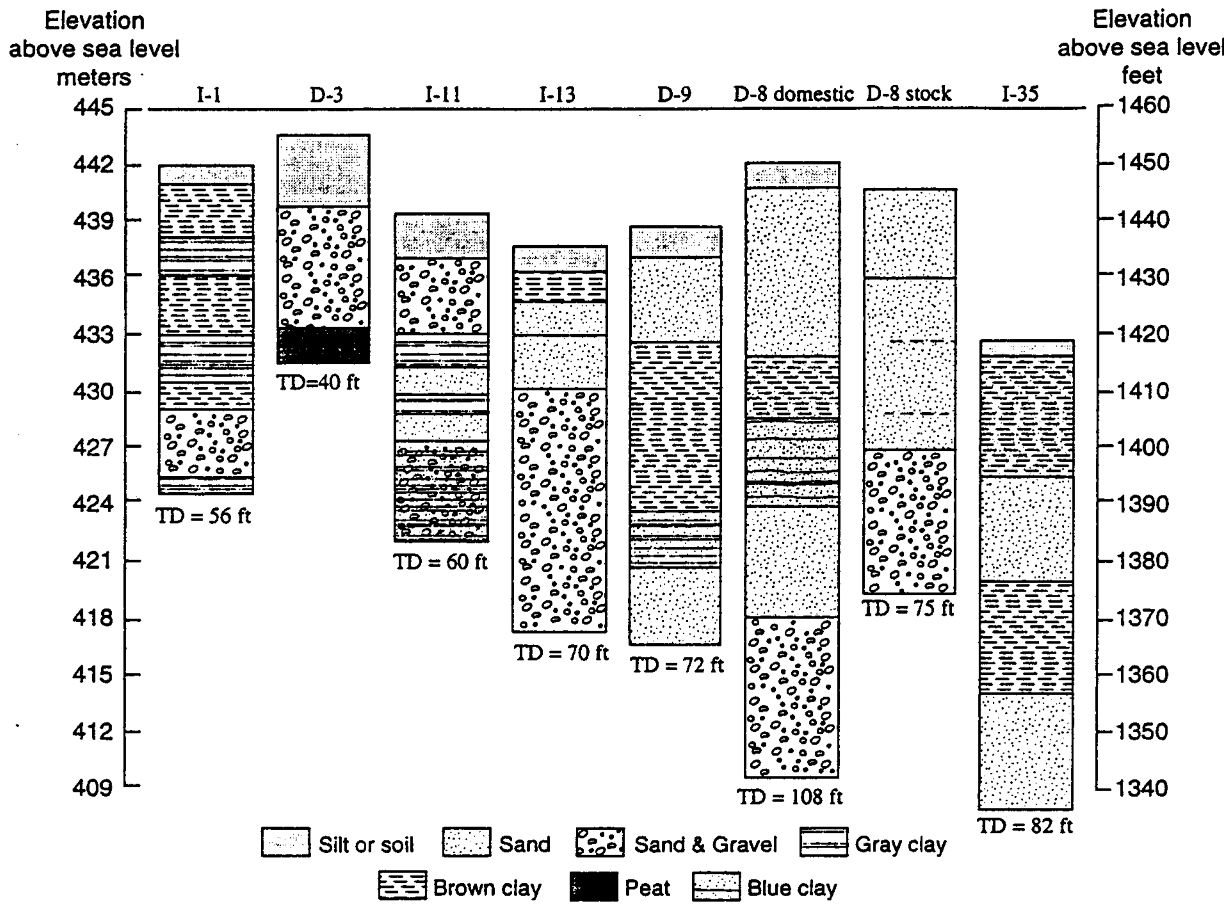


Figure 26. Selected well logs from shallow wells sampled for nitrogen-15 isotope analyses. Logs show distribution of clays in the vadose zone and aquifer. Presence of clay in the profile may contribute to denitrification enrichment of nitrogen-15 because of reducing conditions present with perched water above clay layers.

Figure 26 shows the stratigraphy from available well logs at sites where nitrogen isotope samples were collected. As can be seen from figure 26 and table 7, well I-1 has several clay zones in the profile, a moderate nitrate-N concentration, and an enriched $\delta^{15}N$ value. These factors strongly suggest that the enriched $\delta^{15}N$ value may be due to a mixture of animal-waste sources and possible denitrification processes.

Well D-3 is situated near a sand dune in the western portion of the county (fig. 24). At present no feedlot or septic system upgradient of the house is indicated. There is a feedlot several sections away. A feedlot may have existed at the site prior to the current owner. The stratigraphy of the well (fig. 26) shows sand and gravel with peat at the bottom of the well. The location on a sand unit suggests that if a source of contamination is upgradient, this well would be susceptible to contamination. The isotope signature and the high nitrate-N concentration suggests an animal-waste source either from a feedlot or septic system (table 7).

Well D-1 may have an enriched $\delta^{15}N$ signature because of its location in the stockyard, but the presence of gray clays in the stratigraphy may also suggest that denitrification could be contributing to an enriched isotope signature (fig. 26). The nitrate-N concentration in this well is not as high as is usually observed at sites with animal-waste contamination. Other tests of the well water such as bacterial-indicator tests for possible surface contamination into the well and general water-chemistry data need to be collected in order to determine the actual source.

Wells D-8 stock and domestic and D-9 all lack fine-textured zones in the upper stratigraphy of the wells (fig. 26). The nitrate-N concentrations of all of these wells are high (table 7) in comparison with the nearby irrigation well (I-18 0.11 mg/L; Table C-3, appendix C). Depth to water at these sites is approximately 30-40 ft (9-12 m). All the well logs show that there is no clay until approximately 30 feet (9 m) deep. If the general geology of the area is similar to this, then the possibility of contamination of the shallow aquifer is high. The enriched $\delta^{15}N$ signature is possibly due to point-source pollution from a long-term dairy or feedlot present at each site. The septic system for each house is located downgradient from the sampled wells so it is unlikely that this is a source for the high nitrate.

The stratigraphy for wells I-11 and I-13 shows that clay zones are present in the upper 30 to 40 ft (9-12 m). Both sites have moderate nitrate-N and enriched $\delta^{15}N$ values (table 7). The lower nitrate concentrations in combination with the enriched nitrogen isotope values suggests a possible mixing of an animal-waste source with denitrification enrichment.

Site I-35 has sandy clay in the upper 25 feet of the log and clay from 40 to 60 feet depth (fig. 26). The nitrate-N concentration is 8.5 mg/L (table 7). The enriched isotope value suggests the possibility of an animal-waste source from the use of manure as fertilizer or from an upgradient small feedlot.

In summary, the nitrogen isotope method was used to determine potential nitrate sources for wells that had repeated high nitrate-N concentration during the course of the study. The results indicate that Area 2 has a possible nitrogen point source problem from animal-waste sources and Area 1 has no obvious overall nitrate problem in the ground water at this time.

Conclusions

Vadose-zone Nitrate

The amount of nitrate below the root zone at the end of the growing season is to a large degree controlled by three factors: (1) The amount of nitrogen fertilizer applied for that growing season; (2) The amount of nitrate which was below the root zone in the spring; and (3) The amount of nitrate which was in the root zone before fertilizer application. Precipitation and fertilizer history also have some effect on nitrate below the root zone, but they are minor controls compared to the first three. It is presumed that the quantity of irrigation-water applied would have an effect on the movement of nitrate through the vadose zone, but in this study the abnormal rainfall patterns precluded evaluation of this factor.

Nitrate measurements from soil cores collected before and after the growing season measure the amount of nitrate retained in the soil before and after the growing season. They may not, however, be good measures of the flux of nitrate through the vadose zone. Concentrations of nitrate from soil-water samplers are generally higher than those determined from soil cores. In sandy soils, where movement of nitrate occurs rapidly in response to precipitation events, soil cores will underestimate the amount of nitrate moving through the soil. Horizons below the root zone with low clay content may drain rapidly when soil-moisture content is near saturation, facilitating rapid movement of nitrate. The amount of nitrate determined from a single core should therefore be considered a conservative estimate of the actual amount of nitrate moving through the vadose zone.

The logical conclusion from the soil-nitrate data is that if nitrogen fertilizer - application rates are reduced, the volume of nitrate in the soil and vadose zone would be reduced over time. Comparisons between actual fertilizer-application rates and recommended rates (NREC) show that many farmers could reduce their nitrogen fertilizer application rates without fear of diminishing production. More economical use of nitrogen fertilizer should increase net profits while reducing environmental risks.

Nitrate in the Ground Water

We expected to find correlations between factors influencing the amount of nitrate in the vadose zone under crop land and ground-water nitrate concentrations. In other words, areas with high nitrogen fertilizer inputs should have high ground-water nitrate concentrations. We found an inverse relationship. For example, areas which were dominantly farmed using dryland techniques with relatively low fertilizer-application rates had elevated ground-water nitrate concentrations in domestic wells (nitrate-N > 3 mg/L). Areas which were dominantly farmed using irrigation techniques with high fertilizer-application rates generally had low nitrate concentrations (nitrate-N < 3 mg/L) in the ground water.

The reasons for the unexpected results were that the dryland farming areas had a thin, permeable vadose zone, a saturated thickness of approximately 90 feet, and oxygenated ground water which permitted nitrate to move rapidly to and remain in the ground water. The irrigated areas had a thicker vadose zone, a greater saturated thickness of approximately 180 feet which would permit some dilution to occur, and a reducing water chemistry which permitted a decrease in nitrate concentration either by denitrification or chemical processes.

Nitrogen-15 and complete water-chemistry analyses were used to determine the source of nitrate in the ground water. In all cases nitrogen isotope analyses indicated that elevated ground-water nitrate concentrations were associated with animal-waste sources and not fertilizer sources. Nitrogen isotope and water-chemistry analyses suggested that low nitrate concentrations in areas with high fertilizer-application rates were the result of denitrification processes in the vadose zone and aquifer.

Multiple-regression Models

Multiple-regression models can be used to predict general trends in the amount of nitrate which will be present below the root zone after harvest based on fertilizer application-rate information, spring soil-nitrate concentrations, and precipitation data. These models indicate that for dryland sites the amount of nitrate below the root zone is controlled in large part by the amount of nitrogen fertilizer applied and the amount of nitrate in the soil before fertilizer application. The model developed for irrigated sites sampled in 1992 indicates that precipitation may be a more important factor controlling the amount of nitrate below the root zone after harvest at irrigated sites than at dryland sites.

Recommendations

1. Nitrogen fertilizer application does not seem to be adversely affecting ground-water quality at this time. Nitrate concentrations in the vadose zone are, however, quite substantial. Reducing fertilizer-application rates in accordance with recommendations from Kansas Agricultural Extension Service guidelines should be a simple measure to help insure that nitrate-pollution potential to the vadose zone and ground water is reduced.
2. Animal-waste management is an issue that needs further evaluation in this area. A number of the farmers in Area 2 of the county have dairies, which are likely sources of contamination, associated with their farming operations. Several of the farmers use manure as part of their fertilizer allotment, but the majority do not. Evaluation of waste-storage practices and application recommendations from the Agricultural Extension Service at KSU might help to control the problem.
3. Recommendations from the Agricultural Extension Service and the Natural Resource Conservation Service concerning use of specific soil types for siting future

dairy operations might prevent the current problem of dairy farms sited on more permeable soils and thus permitting contamination of the vadose zone and aquifer.

Future Research

Additional work in the Equus Beds area is needed to more completely define the areas of high and low nitrate concentrations within Harvey County and in adjacent counties. Some suggestions for further work are given below.

1. A detailed water-quality survey in both portions of Harvey County in order to better define the effects of oxydizing and reducing water chemistry on nitrate-pollution potential. Use nitrate concentrations to define areas of high and low nitrate. Use nitrogen-15, complete water-chemistry analyses, fecal coliform, and perhaps caffeine analyses to determine if the animal-waste source is solely from cattle or if septic tank waste also is part of the problem. Nitrogen-15 is usable to define fertilizer vs. animal-waste sources, but it does not distinguish between human and animal waste.

3. Use of GIS methodology to compare and contrast the two areas in Harvey County in terms of vadose zone, geologic, geomorphic, ground-water chemistry, and land use controls on potential nitrate contamination of the aquifer.

4. Work in conjunction with the NRCS to evaluate how map unit changes to incorporate soil-stratigraphic relationships based on remapping in the area may affect farming and water-management issues.

REFERENCES

American Public Health Association, AWWA, and WPCF. 1985. Nitrogen (nitrate) 418A ultraviolet spectrophotometric screening method. *in* Standard Methods for the Examination of Water and Wastewater. 16th ed. American Public Health Association. Washington, D.C. p. 392–393.

Buol, S.W., Hole, E.D., and McCracken, R.J.1989. Soil Genesis and Classification. Third edition. Iowa State University Press. Ames, Iowa. 446 p.

CoHort Software, 1990. CoStat software package for PC. Berkley, CA.

Gormly, J.R. and Spalding, R.F. 1979. Sources and concentrations of nitrate-nitrogen in ground water of the central Platte region, Nebraska. Ground Water. 17:291-301.

Hallberg, G.R. 1989. Nitrate in ground water in the United States. *in* Follet, R.F. (ed.), Nitrogen Management and Ground Water Protection. Developments in Agricultural and Managed-forest Ecology 21. Elsevier. New York. p. 35-74.

Hathaway, L.R., Waugh, T.C., Galle, O.K., and Dickey, H.P. 1981. Chemical quality of irrigation waters in the Equus Beds area. Kansas Geological Survey. Chemical Quality Series 10. 45 p.

Hathaway, L.R. 1990. Nitrate UV-spectrophotometric screening method for the Technicon autoanaylzer II system. Kansas Geological Survey Open-File Rpt. 90-49.

Heaton, T.H.E. 1986. Isotopic studies of nitrogen pollution in the hydrosphere and atmosphere: a review. Chemical Geology. 59:87-102.

Herbel, M.J., and Spalding, R.F. 1993. Vadose zone fertilizer-derived nitrate and $\delta^{15}N$ extracts. Ground Water. 31:376-382.

Hoffman, B.R., and Dowd, L.W. 1974. Soil survey of Harvey County, Kansas. USDA., Washington, D.C. 55 p.

Kissel, D.E., Bidwell, O.W., and Kientz, J.F. 1982. Leaching classes of Kansas soils. Kansas Agricultural Experiment Station Bulletin 641. Kansas State University. Manhattan, KS.

Kreitler, C.W. 1975. Determining the source of nitrate in ground water by nitrogen isotope studies. Univ. of Texas, Austin. Bureau Economic Geology. Report of Investigations 83. 57 p.

Macko, S. A., Estep, M.L.F., Hare, P.E., and Hoering , T.C., 1987. Isotopic fractionation of nitrogen and carbon in the synthesis of amino acids by microoganisms. Isotope Geoscience 65:70-62.

Madison, R.J., and Brunett, J.O. 1985. Overview of the occurrence of nitrate in ground water of the United States. *in* National water summary 1984 hydrologic events, selected water-quality trends, and ground-water resources. U.S. Geological Survey. Water-Supply Paper 2275. p. 93-105.

Martinko, E.E., Merchant, J.W., Whittemore, D.O., and Whistler, J.L. 1987. Development of a prototype geographic information system for groundwater quality protection in Kansas. Final report for KS. Dept. Health and Environment.

National Oceanograpic and Atmospheric Administration (NOAA). 1993. Climatological data annual summary, Kansas, 1993. National Climatic Data Center. Ashville, N.C. 107(13).

Natural Resources Conservation Service. 1992. Soils report for Harvey County for Equus Beds project. Laboratory data and pedon descriptions. Salina, KS.

SAS Institute, Inc. 1991. Master index to SAS system documentation. Version 6.09. Third edition. Gary, North Carolina.

Spalding, R.F., and Exner, M.E. 1993. Occurrence of nitrate in groundwater - a review. Journal Environmental Quality 22:392-402.

Stramel, G.J. 1967. Progress report on the ground-water hydrology of the Equus Beds area, Kansas - 1966. Kansas Geological Survey. Bulletin 187, Part 2. 27 p.

Stramel, G.J. 1956. Progress report on ground-water hydrology of the Equus beds area, Kansas. Kansas Geological Survey. Bulletin 119, pt. 1. 59 p.

Tapper, R., Macko, S.A., and Zieman, J. 1994. An assessment of inorganic nitrogen input to the ground water near an agricultural area of eastern Virginia. Geological Society of America Abstracts with Programs. Oct. 1994. Seattle, WA. p. A-103.

Townsend, M.A., Macko, S.A., Young, D.P., and Sleezer, D.O. 1994. Natural ^{15}N isotopic signatures in ground water: a cautionary note on interpretation. Kansas Geological Survey Open-file Rpt. 94-29. 24 p.

Townsend, M.A. and Young, D.P. 1994. Factors affecting nitrate concentrations in ground water in Stafford County, Kansas: Current Research on Kansas Geology. Kansas Geological Survey. Bulletin 238 p. 1-7.

Williams, C.C., and Lohman, S.W. 1947. Geology and ground-water resources of a part of south-central Kansas, with special reference to the Wichita municipal water supply. Kansas Geological Survey. Bulletin 79. 455 p.

Wolterink, T. J., Willliams, H.J., Jones, D.C., Grimshaw, T.W., and Holland, W.F. 1979. Identifying sources of subsurface nitrate pollution with stable nitrogen isotopes. EPA-600/4-79-050 final report. Robert S. Kerr Environmental Research Laboratory. Ada, OK. 151 p.

Young, D. P., 1992. Nitrate contamination of ground water in northern Stafford County, Kansas: unpublished M.S. thesis, Univ. Kansas, Dept. of Environmental Health Engineering. 94 p.

APPENDIX A

Soil Characterization Pits

Appendix A .

Soil Characterization Pits

In the Spring of 1992 ten soil characterization pits were excavated in the study area (fig. A1). Soils at each pit were described and sampled by SCS (Soil Conservation Service) personnel. Laboratory analyses of physical, chemical,and mineralogical properties were performed by SCS personnel at the National Soil Survey Center in Lincoln, Nebraska.

The purpose of the soil characterization pits was to verify that the available soil survey information for Harvey County was accurate and to provide needed physical, chemical, and mineralogical data for interpretation of soil nitrate and atrazine analysis within the study area.

Pit sites were chosen to represent the range of soil properties at the study sites. Actual site selection for the pits was performed by the Area Soil Scientist, Rick Cox.

Summary of Terms Used

A soil pit characterization is a means to classify a soil based on a number of properties observed in the field and measured in the laboratory. The definitions for a number of terms used to classify the soils in this study are provided in this section (Soil Survey Staff, 1992; Buol and Hole 1989). The values for these terms are presented in the accompanying tables.

COLE - The coefficient of linear extensibility is used as a measure of shrink-swell potential. It reflects changes in the lengths of clods from a moist (33 kPa tension) state to a dry state. The equation used to calculate COLE is: (Length moist - length dry)/(length dry).

LE - Linear extensibility for a soil horizon is the thickness of the horizon in centimeters multiplied by the COLE of the horizon. The LE for a given soil is the sum of the LE values for all horizons.

Hue, Value, and Chroma - Munsell colors used to describe soils in the field in order to relate the color to specific chemical, physical, and biological properties of the soil.

Gleyed Colors - Bluish to greenish gray matrix colors in the soil indicative of the reduction of iron under anaerobic (waterlogged) soil conditions.

Redoximorphic Features - Features formed by the reduction and oxidation of Fe and Mn compounds in seasonally saturated soils. They include Fe and Mn concretions, Fe and Mn depletion's, and reduced soil matrices (gleyed colors).

Aquic conditions - Redoximorphic features are used to indicate aquic conditions (saturation for extended periods). Aquic conditions infer reducing environments within soils or horizons. In most cases, such reducing environments would lead to significant denitrification losses if microbial populations and an adequate source of organic matter are present.

SAR - The sodium adsorption ratio is a standard measure of the amount of sodium present in the soil in relation to the amount of calcium and magnesium. Soil with SAR values of 13 or more have increased dispersion of organic matter and clay particles, reduced permeability and aeration, and a general degradation of soil structure.

EC - Electrical conductivity is a standard measure soil salinity. Standard units are mmhos/cm or dS/m. It is generally used as a measure of salinity levels in soils.

CEC - Cation exchange capacity is the capacity of a soil to sorb or hold cations and to exchange species of these ions in reversible chemical reactions.

Taxonomic comparison:

A taxonomic comparison between the map units at the pit sites and the classification from the pit data shows that at three pits the map unit and NRSC (formerly the SCS) pit classifications for the soils match exactly (numbers 1,8 and 9, table A1). Three soils have properties for which differences between classifications are relatively insignificant for assessing non-point source pollution potential (numbers 2,3 and 5, table A1).

The remaining four soils (numbers 4,6,7, and 10 table A1) are problematic. The map unit at pit number 4 is Farnum-Slickspots (Fs) and no classification or estimates of physical and chemical properties are available for the Slickspots portion of this map unit. From cores taken at other locations within the field and at other sites it appears that similar soils are quite common within the study area. It is also apparent that within Fs map units, soils which key out as Vertic Natrustolls (Punkin and taxadjunct) are more common than those which key out as Pachic Argiustolls (Farnum and taxadjunct (table A1).

Pits 6 and 7 (table A1) were within map units which are generally mapped as Typic Argiaquolls (Carwile). These soils keyed out as a Sodic Haplustert and a Udertic Argiustoll. From cores in this vicinity and at other sites it is clear that similar soils with high shrink-swell are also common throughout the study area south of U.S. Highway 50 and west of the Little Arkansas River.

The soil at Pit 10 (table A1) is typically found in close proximity to soils similar to those described at pits 4, 6, and 7. It tends to pond water at the surface and during dry periods it tends to have a frosty appearance at the surface. The salts in these soils seem to be closer to the surface under dryland and pasture landuses than they are at irrigated sites. It is likely that under these land uses these soils would key out as Typic Natraquolls rather thanTypicArgiaquolls.

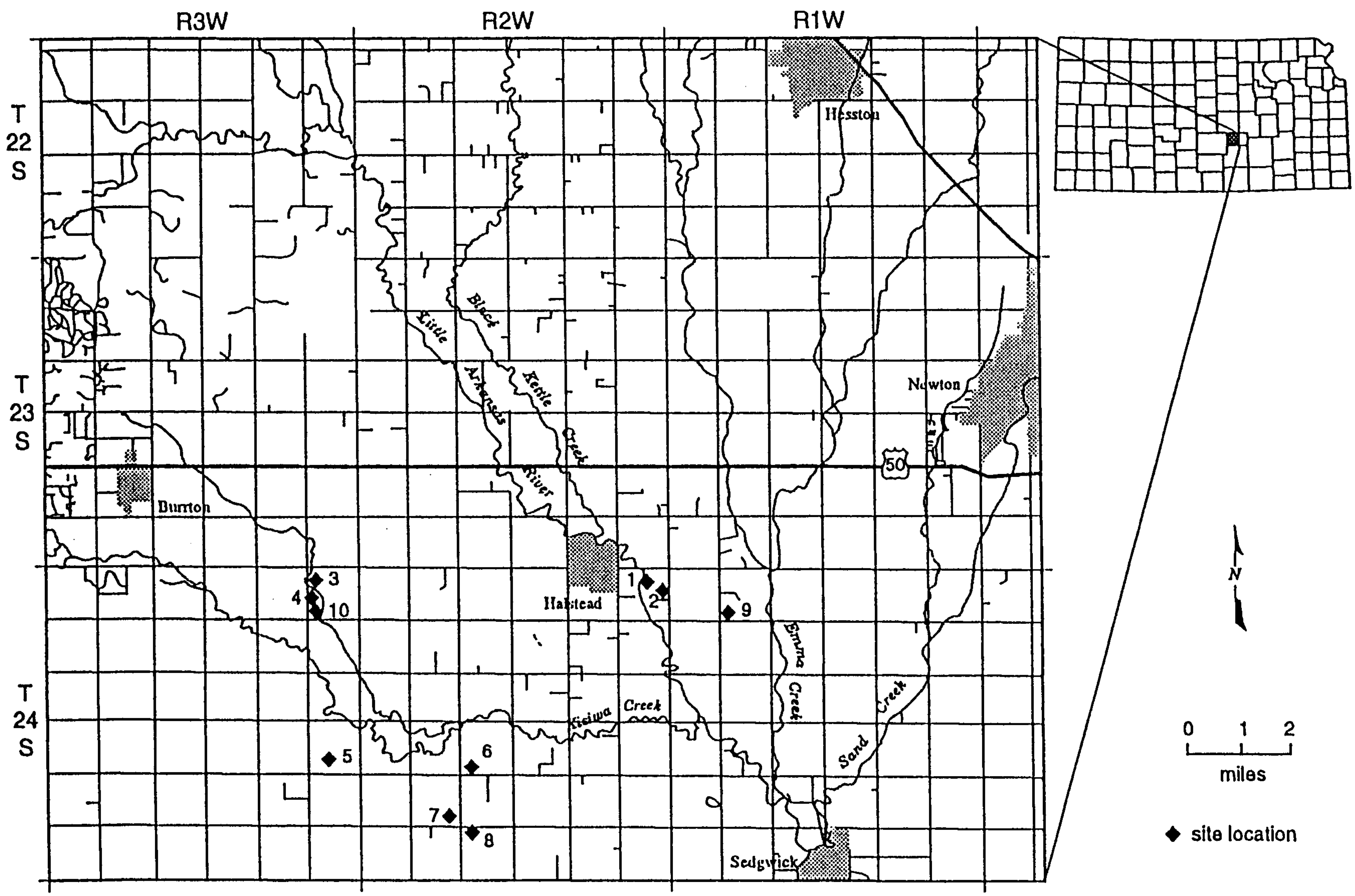


Figure A1. Location of soil characterization pits in Harvey County, Kansas.

Table A-1. Series mapunit classification (mu) and classification from SCS pit information for ten representative profiles.

Site	Series	Family	Subgroup
1mu	Naron	fine-loamy,mixed,thermic	Udic Argiustoll
1SCS	Naron	fine-loamy,mixed,thermic	Udic Argiustoll
2mu	Hobbs	fine-silty,mixed,mesic	Cumulic Haplustoll
2SCS	Elandco	fine-silty,mixed,thermic	Cumulic Haplustoll
3mu	Farnum	fine-loamy,mixed,thermic	Pachic Argiustoll
3SCS	Naron-like	fine-loamy,mixed,thermic	Udic Argiustoll
4mu	Farnum-Slickspots	Farnum part of the mapunit same as above	
4SCS	Punkin	fine,mixed,thermic	Vertic Natrustoll
5mu	Naron	fine-loamy,mixed,thermic	Udic Argiustoll
5SCS	Farnum	fine-loamy,mixed,thermic	Pachic Argiustoll
6mu	Carwile	fine,mixed,thermic	Typic Argiaquoll
6SCS	SND 1	fine,mixed,thermic	Sodic Haplustert
7mu	Pratt-Carwile (Ca)	fine,mixed,thermic	Typic Argiaquoll
7SCS	SND 2	fine,montmorillonitic, thermic	Udertic Argiustoll
8mu	Pratt-Carwile (Pa)	sandy,mixed,thermic	Psammentic Haplustalf
8SCS	Pratt	sandy,mixed,thermic	Psammentic Haplustalf
9mu	Pratt	sandy,mixed,thermic	Psammentic Haplustalf
9SCS	Pratt	sandy,mixed,thermic	Psammentic Haplustalf
10mu	Drummond	fine,mixed,thermic	Mollic Natrustalf
10 SCS	SND 3	fine-silty,mixed,thermic	Typic Argiaquoll

Relative Non-Point Source Pollution Potential:

Soil properties which effect nitrate transport can be divided into two broad categories: 1) Properties which effect the concentration of nitrate available for leaching in the soil such as cation exchange capacity, organic carbon content, and pH; and 2) Properties which effect the rate of movement of the soil water which is carrying nitrate such as soil structure, macroporosity, and hydraulic conductivity.

Pratt Series

Pits 8 and 9 were correlated as the Pratt series (table A2, A3; figs. A2, A3). Pit 8 was located in an area of dune sand south of Halstead. Pit 9 was located in the area of dune sand east of Halstead. Pratt soils have developed in eolian sands and are commonly found in all three of the prominent sand dune areas in Harvey County. Pratt soils typically consist of greater than 85 percent sand throughout their profiles, have low organic carbon contents (<.5%) in their A horizons and low clay contents (<10%, figs. A2, A3). The B horizons of these soils have thin bands of clay accumulations called lamellae. It is common for these soils to have paleosols at some depth greater than one meter. These paleosols can be identified by small increases in organic carbon, clay and silt (figs. A2, A3) as well as greyer colors and structural differences.

Pratt soils are generally classified as having rapid permeability (6-20 in/hr,15-51 cm/hr). This classification may be too high however. Data from laboratory and field measurements of permeability indicates that a better estimate may be moderately rapid (2-6 in/hr, Sleezer and Kluitenberg, 1994). It appears that the prominent lamellae in the B horizon significantly reduce the vertical permeability of these soils. No measurements of permeability have been conducted on the paleosols near the base of these soils, but field indications such as perched water, gleyed colors, and large sample volumes from lysimeters located above these layers would indicate that the permeability of these layers is even lower.

Pratt soils under irrigated crops with high fertilization rates are probably the highest risk soils for non-point source pollution of ground water in the study area. Soil core and lysimeter data demonstrate that nitrate moves quickly and conservatively to depths greater than two meters in these soils. The risk of nitrate leaching may be reduced somewhat by the presence of thick lamellae and paleosols within these profiles which reduce the overall profile conductivity. There are also indications from well logs and deep cores that in some areas a thick, dense, slowly permeable clay layer may exist below some of the sand dunes which the Pratt soils have developed in. Where present these clay layers would significantly reduce the pollution potential for underlying ground water.

Table A2. Soil characteristics of pit 8, site ID I-29.

Soil Classification: Pratt, sandy, mixed, thermic Psammentic Haplustalf.
NRCS ID: S92KS-079-008

Interval (cm)	Horizon	Clay (%)	Silt (%)	Sand (%)	Organic Carbon (%)	pH H2O	CEC meq/100g	COLE (cm/cm)	LE
0-16	Ap1	2.5	7.4	90.1	1.11	6.8	4.9		
16-29	Ap2	2.8	6.5	90.7	0.33	5.4	3.2		
29-54	Bt1	4.5	4.8	90.7	0.2	5.9	3.7		
54-79	Bt1	6.5	4.8	88.7	0.22	5.9	5.4		
79-104	Bt1	4.3	5.2	90.5	0.1	5.4	4.3		
104-129	Bt1	5.2	4.5	90.3	0.16	5.4	5		
129-164	Bt1	2.7	5.3	92	0.08	5.5	3.2		
164-182	2Bt2	17.2	28.5	54.3	0.26	5.8	12.4		
182-195	2Bt3	17.3	18.2	64.5	0.18	5.9	11.9		
195-212	2C	7.6	6.9	85.5	0.08	6	5.9		

Interval (cm)	Horizon	1/3 Bar (%)	2 Bar (%)	15 Bar (%)	SAR (%)	Hue	Value	Chroma
0-16	Ap1		4.6	3.5		10yr	4	3
16-29	Ap2		3	2.1		10yr	4	4
29-54	Bt1		3.7	2.6		7.5yr	4	4
54-79	Bt1		4.6	3.8		7.5yr	4	4
79-104	Bt1		4.5	2.9		7.5yr	4	4
104-129	Bt1		4.8	3.4		7.5yr	4	4
129-164	Bt1		12.2	2.4		7.5yr	4	4
164-182	2Bt2		11.3	8.4		10yr	4	3
182-195	2Bt3		10.8	8.1		7.5yr	4	4
195-212	2C		4.2	4.1		7.5yr	4	6

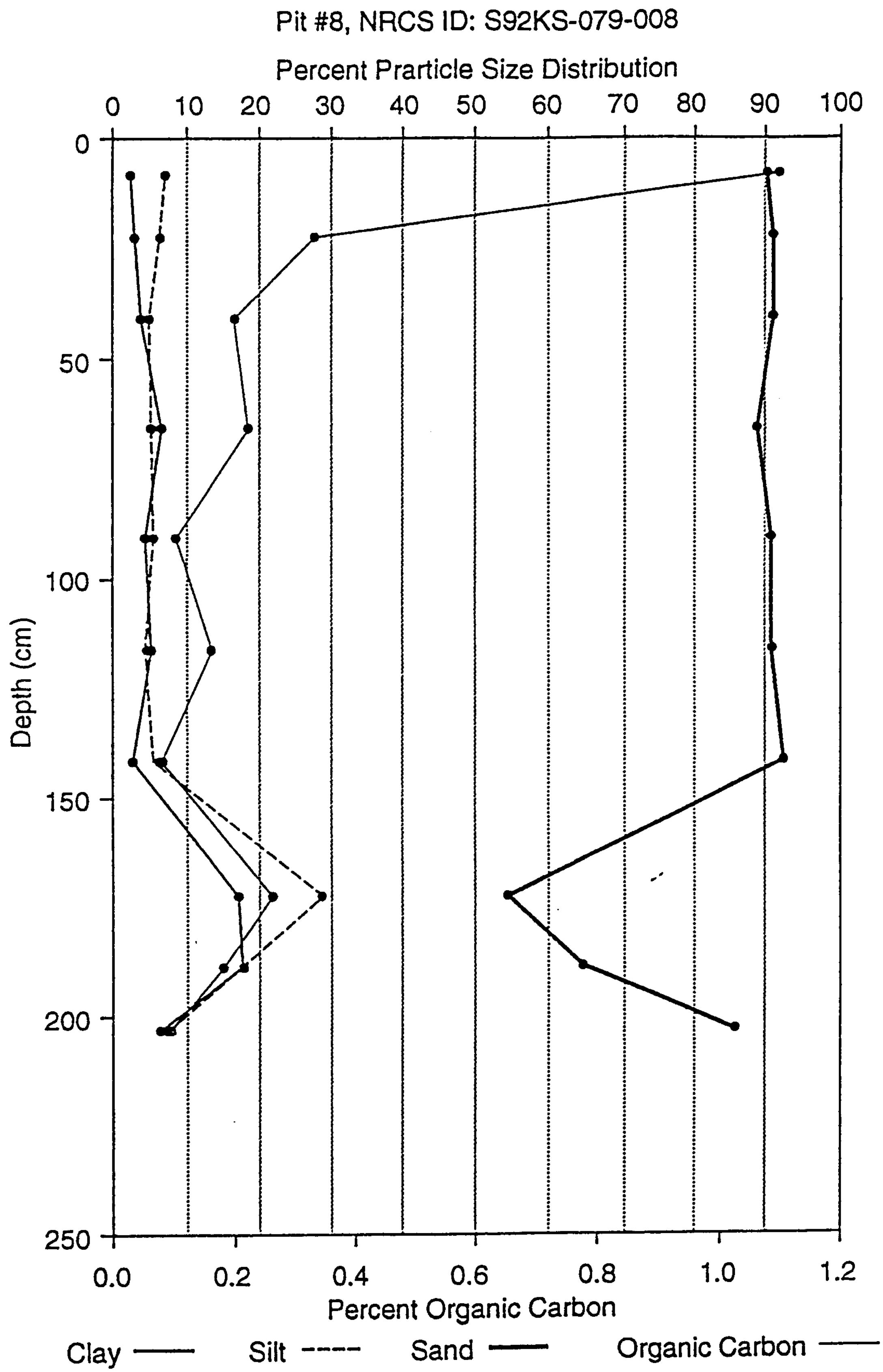


Figure A2. Particle size distribution and percent organic carbon for Pratt soil type, site I-29.

Table A3. Soil characteristics of pit 9, site ID D-26.

Soil classification: Pratt, sandy, mixed, themic Psammentic Haplustalf
NRCS ID: S92KS-079-009

Interval (cm)	Horizon	Clay (%)	Silt (%)	Sand (%)	Organic Carbon (%)	pH H2O	CEC meq/100g	COLE (cm/cm	LE
0-3	Ap	4	10.9	85.1	0.47	4.7	4.4	0.004	0.012
3-10	Bt1	8.4	7.2	84.4	0.29	4.9	6.8	0.042	0.294
10-40	Bt2	6.1	5.7	88.2	0.15	5.7	5.1	0.016	0.48
40-54	Bt3	4.9	5.1	90	0.07	6	4.2	0.015	0.21
54-82	Bt4	4.4	6.3	89.3	0.1	6.2	4.4	0.01	0.26
82-100	Bt5	2.5	5.7	91.8	0.06	6.1	3	0.009	0.162
100-121	Bt6	8.2	10	81.8	0.14	6.3	6.5	0.008	0.168
121-149	Bt7	12.2	11.5	76.3	0.14	6.2	8.8	0.021	0.588
149-177	Bt8	7.9	9.4	82.7	0.07	6.2	6.6	0.01	0.28
177-202	Bt9	17	22.7	60.3	0.09	6.1	10.2	0.035	0.875

Interval (cm)	Horizon	1/3 Bar (%)	2 Bar (%)	15 Bar (%)	SAR (%)	Hue	Value	Chroma
0-3	Ap	7.6	6.1	2.9		10yr	4	3
3-10	Bt1	13.6	4.8	4.5		10yr	4	4
10-40	Bt2	9.3	4	3.3		10yr	4	4
40-54	Bt3	8.5	4	3.1		10yr	4	4
54-82	Bt4	9.6	4.2	3.2		10yr	4	4
82-100	Bt5	5.5	2.9	2.4		10yr	5	4
100-121	Bt6	10.8	6.7	4.8		10yr	5	4
121-149	Bt7	14.6	8.9	6.6		7.5yr	4	6
149-177	Bt8	12.6	6.4	4.6		10yr	5	4
177-202	Bt9	16.8	11.1	8.7		7.5yr	5	6

Pit #9, NRDS ID: S92KS-079-009

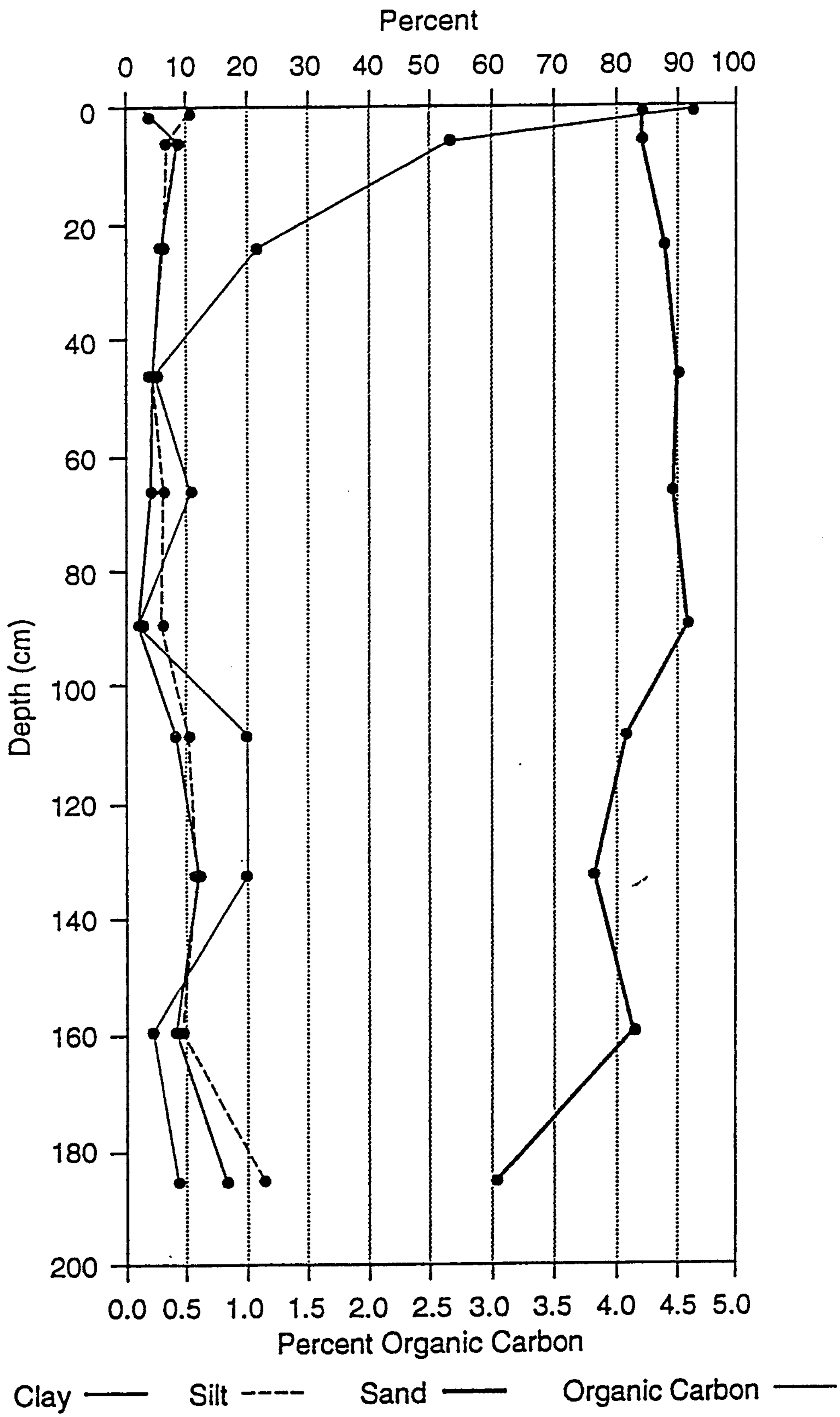


Figure A3. Particle size distribution and percent organic carbon for Pratt soil type, site D-26.

Elandco

Pit #2 was located just east of Halstead in the floodplain of the Little Arkansas River (fig. A1). Pit 2 was correlated as the Elandco series (table A4). These soils formed in silty alluvial overbank deposits along streams whose headwaters are in predominately fine textured material to the north. Compared to many of the soils in Harvey County the Elandco soils is fairly uniform with depth (fig. A4). There are no sharp textural boundaries within the profile which would be expected to perch water by impeding flow. High organic carbon contents to a depth of 140 cm, its floodplain landscape position and the presence of a buried A horizon are evidence that the accumulation of sediment is an ongoing process for these soils.

Cores taken to a ten foot (3.05 meter) depth indicate that sandier material underlies the silt and clay which the Elandco has formed in. These same cores show that the total thickness of these overbank deposits decreases with distance away from the modern streams. Gleyed colors at the base of the overbank deposits (table A4) may indicate a seasonally high water table associated with high streamflow bank storage or possibly water perching above the much coarser sandy material commonly found underneath these deposits.

The high silt plus clay content of this soil would indicate a low permeability (fig. A4), but no measurements of permeability have been made. The fact that the field in which pit #2 was described is flood irrigated and the lack of sample obtained from a lysimeter installed at a depth of ten feet (3.05 meters) in this field are consistent with a low permeability estimate.

The Elandco soil would be a moderately low risk soil for nitrate leaching loss due to its low permeability, high CEC, high organic carbon content, and good water retention characteristics (table A4). The potential for ground water contamination within these soil mapunits will probably increase somewhat with distance from modern streams as the thickness of the overbank deposits decreases. The significance of the thinning process may be negated somewhat by the tendency of sediments deposited a greater distance from the stream to be somewhat finer.

Table A4. Soil characteristics of Pit 2, site ID I-32.

Soil Classification: Elandco, fine-silty,mixed, thermic Cumulic Haplustoll
NRCS ID: S92KS-079-002

Interval (cm)	Horizon	Clay (%)	Silt (%)	Sand (%)	Organic Carbon (%)	pH (H2O)	CEC meq/100	COLE (cm/cm)	LE
0-14	Ap1	20.3	51.5	28.2	1.37	6.1	17.1	0.023	0.322
14-35	Ap2	20.9	45.8	33.3	1.28	6.2	17.4		
35-66	A1	30.5	44	25.5	1.09	6.3	22.6	0.055	1.155
66-96	A2	32.6	55.9	11.5	0.98	6.3	25.5	0.043	1.29
96-126	Ab1	29.4	60	10.6	1.11	6.2	25.1	0.035	1.05
126-159	Ab2	33	61.3	5.7	0.62	6.5	26.9	0.064	2.112
159-193	Ab3	33.6	58	8.4	0.53	6.4	26.5	0.044	1.496
193-227	Bg1	35	54.1	10.9	0.36	6.6	28.2	0.057	1.938
227-259	Bg2	31.1	55.2	13.7	0.31	6.6	25	0.06	1.92

Interval (cm)	Horizon	1/3 Bar (%)	2 Bar (%)	15 Bar (%)	SAR %	Hue	Value	Chroma
0-14	Ap1	19.1	14.5	10.2		10yr	3	1
14-35	Ap2		14.8	10.5		10yr	3	1
35-66	A1	26.7	20.2	14.3		10yr	3	2
66-96	A2	26.2	21.2	14.8		10yr	3	2
96-126	Ab1	23.2	20.8	14.9		10yr	2	1
126-159	Ab2	25.7	23.3	16.3		10yr	3	2
159-193	Ab3	23.4	23.8	16.3		10yr	3	2
193-227	Bg1	27.6	24.6	17.6		10yr	4	1
227-259	Bg2	26.2	22.7	15.8		10yr	4	2

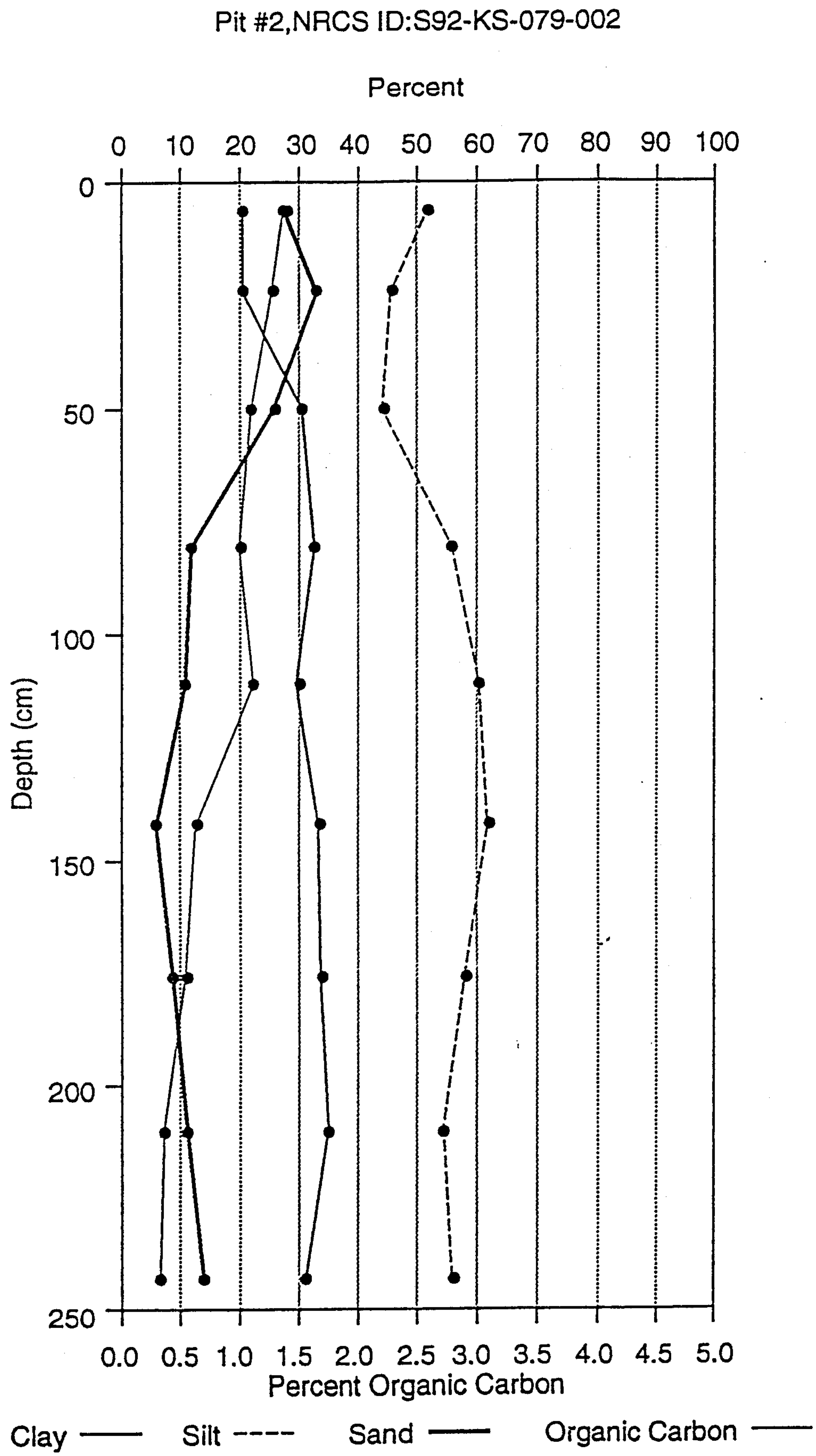


Figure A4. Particle size distribution and percent organic carbon for Elandco soil type, site I-32.

Naron-like or Taxadjunct

Soils at pits 1 and 3 (fig. A1) are taxonomically identical to the Naron series, but would not be considered typical for that series (tables A5, A6; figs. A5, A6). The Naron series is described as having formed in loamy eolian material and outwash on uplands (Hoffman and Dowd 1974). In Harvey county the soils similar to those at pits 1 and 3 would be better described as having formed in loamy alluvium with admixtures of fine sandy or loamy eolian material to their upper horizons. They are typically found on low to mid-level fluvial terraces.

Permeability for the Naron series is estimated as moderate (0.6-2in./hr,1.5-5cm/hr). Field and laboratory work at pit 3 indicates that the actual permeability may be as high as moderately rapid (2-6in/hr,5-15cm/hr, Sleezer and Kluitenberg, 1994). A moderately rapid designation seems high for a soil with 20 to 25% clay in its argillic horizon (figs. A5, A6). A possible reason for the higher than expected permeability is the presence of large numbers of continuous macropores. Pores were described as being "..common very fine and fine continuous tubular... " in the description for pit 3. Very fine pores have inside diameters < .5mm and fine pores have inside diameters between 1 and 2mm. During the excavation and laboratory analysis of large diameter (25 cm) undisturbed cores, tubular pores greater than 2mm in diameter (earth worm burrows) were found throughout the Bt horizons at pit 3. In certain zones within the Bt pore concentrations were sufficient to be classified as many rather than common.

The presence of significant macroporosity in these soils not only increases their hydraulic conductivity, it also increases the risk of nitrate contamination for these soils under heavy fertilization. Preferential flow processes utilizing the large macroporosity to bypass much of the soil matrix would greatly increase the rate of movement of nitrate and agrichemicals below the root zone. For this reason, soils similar to those described at these pits are moderately high risk soils in terms of non-point source pollution potential.

Table A5. Soil characteristics of pit 1, site south of I-32.

Soil classification: Naron-like, fine-loamy, mixed, thermic Udic Argiustoll.
NRCS ID: S92KS-079-001

Interval (cm)	Horizon	Clay (%)	Silt (%)	Sand (%)	Organic Carbon (%)	pH H2O	CEC meq/100g	COLE (cm/cm)	LE
0-12	Ap	6.2	17.8	76	0.55	6.1	5.5	0.002	0.024
12-25	Bt1	19.7	18.6	61.7	0.71	5.5	12.5	0.015	0.195
25-40	Bt2	19.3	19.2	61.5	0.51	6.3	12.1	0.012	0.18
40-59	Bt3	16.2	18.2	65.6	0.29	6.6	10.2	0.017	0.323
59-76	Bt4	19.5	25.3	55.2	0.35	6.9	12.5	0.013	0.221
76-101	Bt5	16.2	18.9	64.9	0.27	7	9.5	0.02	0.48
101-128	Bt6	9.8	18.9	71.3	0.14	7.1	6.1	0.006	
128-163	Bt7	16	15.8	68.2	0.16	7.3	9.8	0.0017	
163-169	B/C	8	11.1	80.9	0.07	7.2	5.3	0.009	
169-189	C1	4.9	7.4	87.7	0.04	7	4		
189-216	C2	4.1	7	88.9	0.02	6.9	2.8		
216-242	C3	3.4	5.7	90.9	0.02	6.8	3.3		

Interval (cm)	Horizon	1/3 Bar %	2 Bar %	15 Bar %	SAR %	Hue	Value	Chroma
0-12	Ap	12.3	5.3	3.1		10yr	3	3
12-25	Bt1	15.8	11.7	8.3		7.5yr	3	3
25-40	Bt2	16.1	11.7	8.5		7.5yr	4	4
40-59	Bt3	13	10.2	6.9		7.5yr	3	4
59-76	Bt4	14	12.1	7.8		7.5yr	4	4
76-101	Bt5	14.9	9.3	5.9		7.5yr	4	4
101-128	Bt6	10.1	6.5	4.3		7.5yr	4	4
128-163	Bt7	14.7	10.1	7.1		5yr	4	4
163-169	B/C	9.9	5.8	3.6		7.5yr	6	4
169-189	C1		3.7	2.8		10yr	5	3
189-216	C2		3	2.3		7.5yr	4	4
216-242	C3		3.2	2.5		7.5yr	4	6

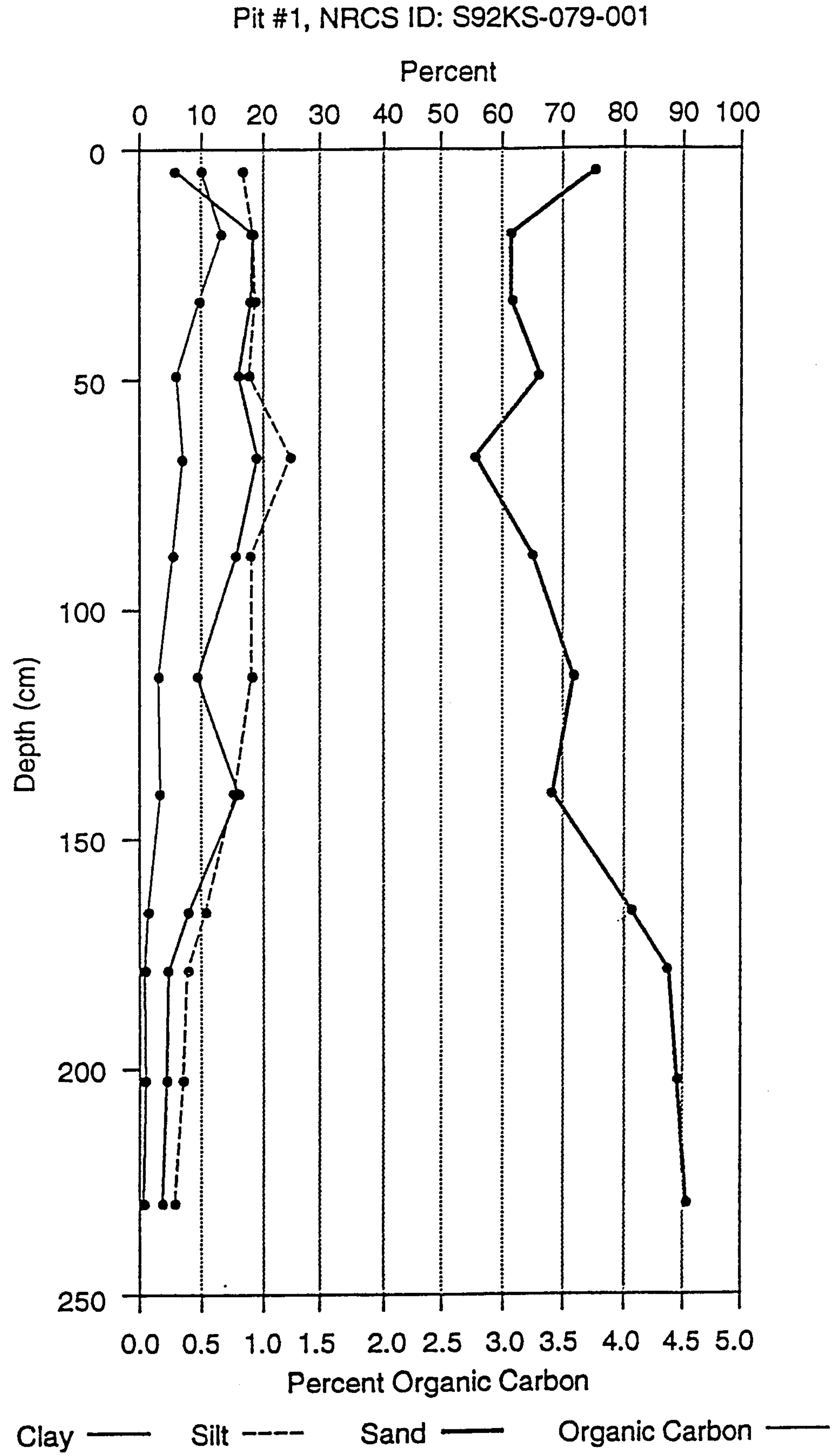


Figure A5. Particle size distribution and percent organic carbon for Pratt soil type.

Table A6. Soil characteristics of pit 3, site ID I-14 North.

Soil Classification: Naron-like, sandy, mixed, thermic Udic Argiustoll
NRCS ID: S992KS-079-003

Interval (cm)	Horizon	Clay (%)	Silt (%)	Sand (%)	Organic Carbon (%)	pH (H2O)	CEC meq/100g	COLE (cm/cm)	LE
0-10	Ap1	12.2	36.1	51.7	0.96	6.8	10.4	0.006	0.06
10-23	Ap2	14	36.5	49.5	0.93	5.5	10.7	0.01	0.13
23-35	A	22.2	33.9	43.9	1.11	6	14.6	0.029	0.348
35-40	AB	24.8	27	48.2	0.93	6.5	16.1	0.029	0.145
40-71	Bt1	26.7	18.5	54.8	0.56	6.6	15.4	0.034	1.054
71-100	Bt2	16.8	14.3	68.9	0.26	6.6	10.4	0.021	0.609
100-125	Bt3	12.3	13.6	74.1	0.15	6.4	8	0.012	0.3
125-145	B/C1	9.5	11.7	78.8	0.07	6.3	5.6	0.003	0.06
145-169	B/C2	6.5	10.5	83	0.05	6.2	4.2		
169-206	C1	3.6	1.4	95	0.04	6.3	2.9		
206-280	C2	2.6	1.7	95.7	0.02	6.4	2.5		

Interval (cm)	Horizon	1/3 Bar (%)	2 Bar (%)	15 Bar (%)	SAR %	Hue	Value	Chroma
0-10	Ap1	15.9	8.4	5.7		10yr	3	2
10-23	Ap2	13.7	9.3	6.4		10yr	3	2
23-35	A	22	13.4	9.8		10yr	2	2
35-40	AB	20.6	15.1	10.7		7.5yr	3	2
40-71	Bt1	18.9	14.8	11.2		7.5yr	3	4
71-100	Bt2	14.4	10	7.5		10yr	5	3
100-125	Bt3	11.6	8.1	5.4		10yr	6	3
125-145	B/C1	5.8	5.9	4.1		10yr	5	4
145-169	B/C2		4.7	3.3		10yr	6	3
169-206	C1		3	1.9		10yr	6	4
206-280	C2		2.6	1.9		10yr	5	4

Pit #3, NRCS ID: S92KS-079-003

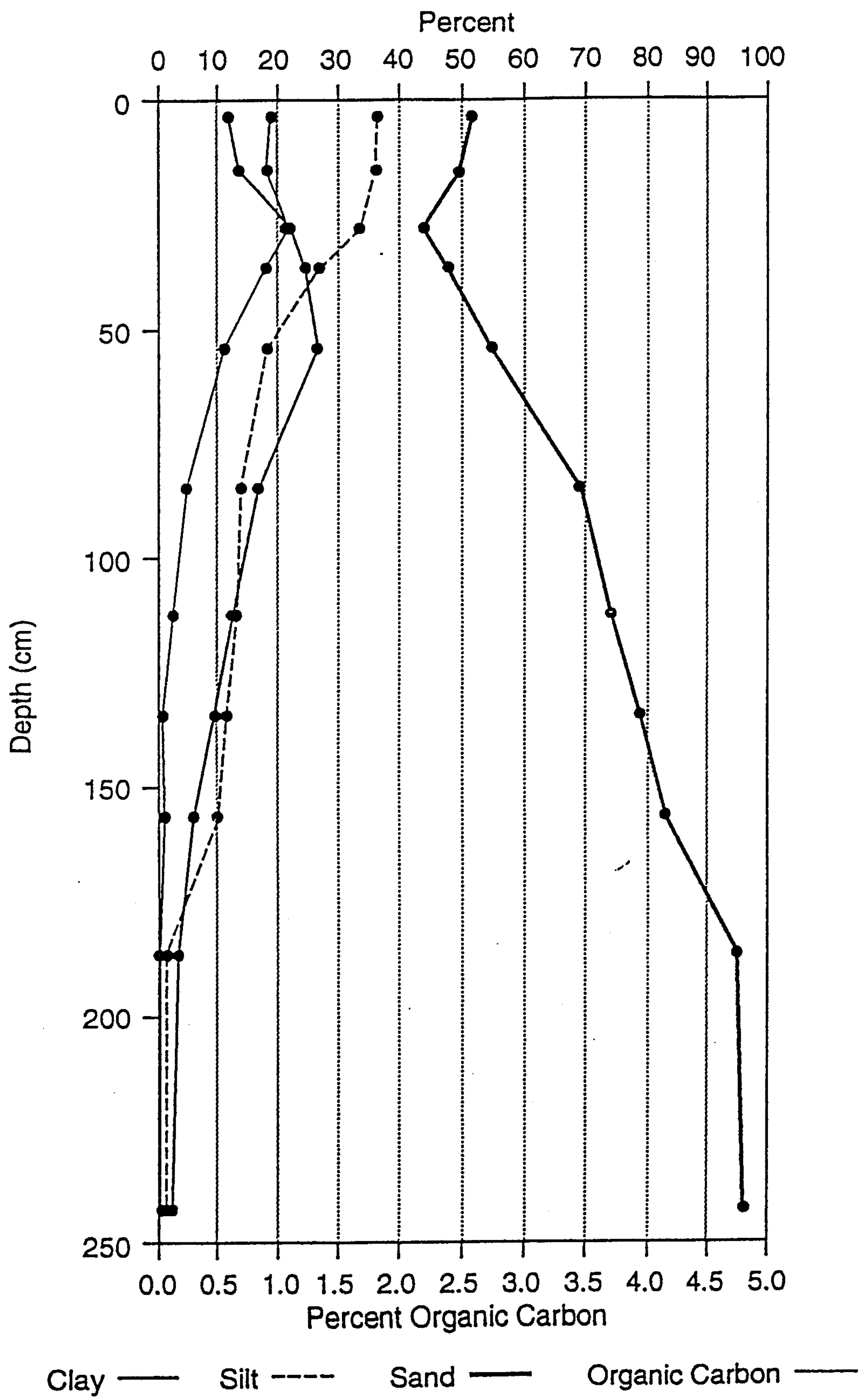


Figure A6. Particle size distribution and percent organic carbon for Naron-like soil type, site I-14 north.

Farnum-like

Pit 5 was located in a Naron map unit south of Kisiwa Creek (fig. A1). In terms of taxonomy, the soil at pit 5 is the same as the Farnum series (table A1, A7). The clay content of the Bt is outside of the range described for a typical Farnum soil but other properties are very similar. Soils similar to the profile described at pit 5 are common in the area west of the Little Arkansas River and south of U.S. Highway 50. These soils are generally found on fluvial terraces in close proximity to soils similar to the Naron Series. In many cases it is impossible to distinguish between these soils without detailed transect work because their landscape positions are essentially the same and surface textures are very similar.

No hydraulic conductivity measurements have yet been made at this site but high clay contents in the Bt3 (49%) and C3 (54%, figure B6) horizons would indicate very low profile conductivities. Further evidence for low profile conductivity is the fact that no sample was recovered from the deepest lysimeters installed at this site (10 ft,3.05m) even though water was ponded at the surface in a large part of the field from early June to August 1992.

Non-point source pollution potential for these soils would be regarded as moderately low due to its apparently low profile hydraulic conductivity, high clay content in several horizons and the complexity of its stratigraphy in the C horizons (fig. A7, table A7).

Table A7. Soil characteristics of pit 5, site ID I-15.

Soil classification: Farnum, fine, mixed, thermic Pachic Argiustoll
NRCS ID: S92KS-079-005

Interval (cm)	Horizon	Clay (%)	Silt (%)	Sand (%)	Organic Carbon (%)	pH H2O	CEC meg/100g	COLE (cm/cm)	LE
0-14	Ap1	7.3	23.5	69.2	0.82	4.4	6.2	0.002	0.028
13-33	Ap2	7.4	23.8	68.8	0.6	4.2	6.6	0.004	0.08
33-52	A	17	24.9	58.1	1.02	5.4	12.1	0.008	0.152
52-66	Bt1	28.9	33.3	37.8	1.04	5.7	18	0.021	0.294
66-81	Bt2	37.5	43.1	19.4	0.84	6	23.4	0.052	0.78
81-99	Bt3	49.2	41	9.8	0.6	6.3	29.9	0.052	0.936
99-120	Bt4	25.4	39.1	35.5	0.39	6.4	18.1	0.018	0.378
120-134	B/C	16.4	7.8	75.8	0.14	6.5	10.2	0.019	0.266
134-150	C1	40.5	37.5	22	0.53	7.7	27.6	0.062	0.992
150-166	C2	6	3.5	90.5	0.09	6.9	3.9		
166-174	C3	54.1	12.7	33.2	0.2	6.9	35.3		
174-185	C4	2.1	2.3	95.6	0.05	6.7	2		
185-190	C5	30.6	10.5	58.9	0.11	6.9	16.4		
190-220	C6	0.6	1	98.4	0.01	6.4	1.3		

Interval (cm)	Horizon	1/3 Bar (%)	2 Bar (%)	15 Bar (%)	SAR %	Hue	Value	Chroma
0-14	Ap1	9.7	5.9	3.2		10yr	3	2
13-33	Ap2	11.2	6.1	4		10yr	3	2
33-52	A	16	10.7	7.5		10yr	2	2
52-66	Bt1	17.8	16.6	11.5		10yr	3	2
66-81	Bt2	23.9	20.8	15.2		10yr	4	3
81-99	Bt3	25.7	23.7	17.7		10yr	4	3
99-120	Bt4	20.7	15.4	10.2		10yr	4	4
120-134	B/C	14	8.7	6.4		10yr	5	3
134-150	C1	27.5	23.5	16.5		5yr	5	1
150-166	C2		3	2.4		10yr	5	4
166-174	C3		24	18.7		10yr	4	3
174-185	C4		1.5	1.1		10yr	6	3
185-190	C5		13	9.1		10yr	5	2
190-220	C6		1	0.08		10yr	6	3

Pit #5, NRCS ID: S92KS-079-005

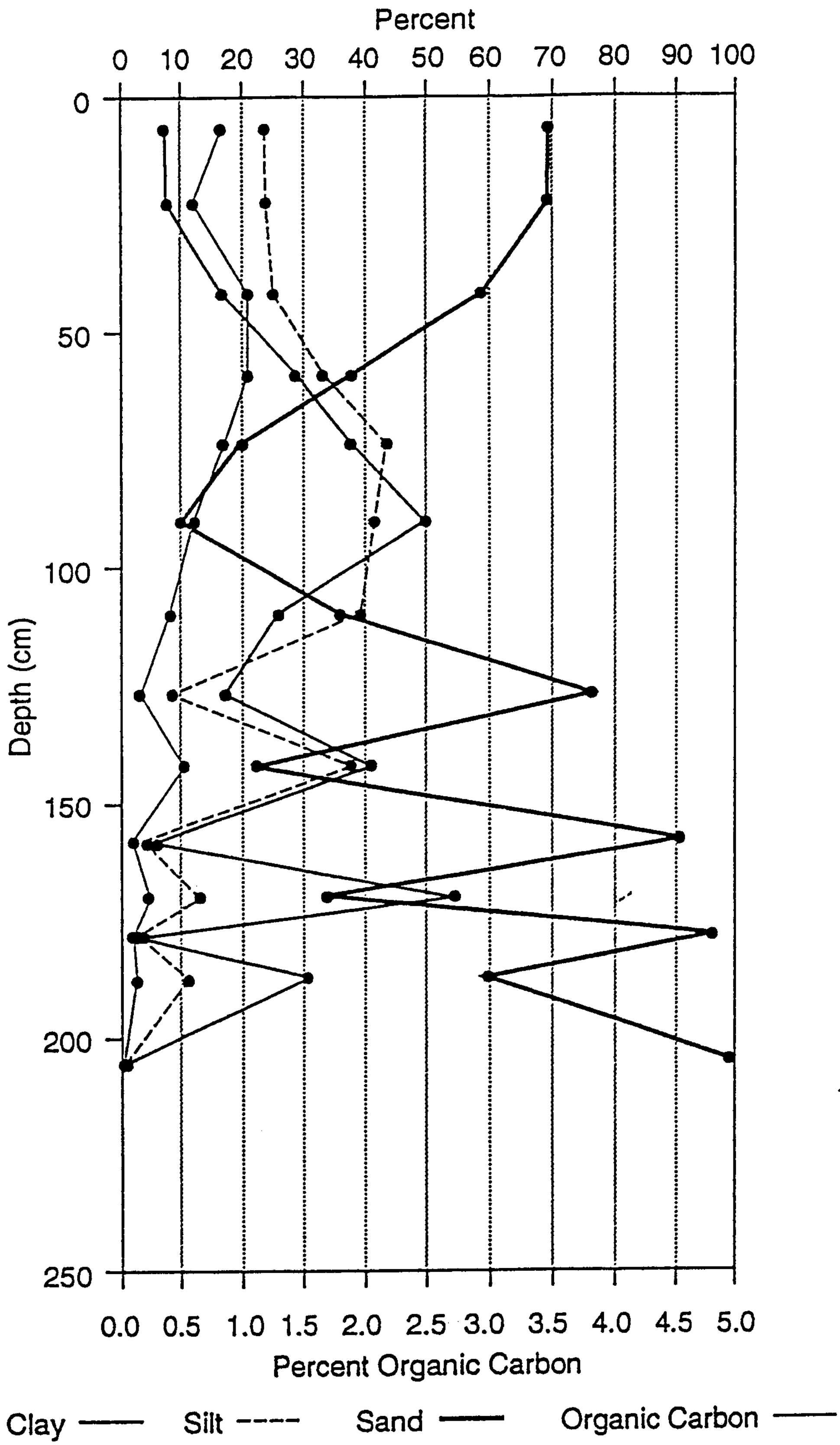


Figure A7. Particle size distribution and percent organic carbon for Farnum-like soil type, site I-15.

Punkin and SND3

Pits 4 and 10 were excavated a short distance from each other in the same field along the North Branch of Kisiwa Creek (fig. A1). The soil at pit 4 was correlated as the Punkin series. The soil at pit 10 did not correlate with a known series from the area and is referred to as SND3 (tables A8, A9; figs. A8, A9). Both of these soils are taxonomically different than the dominant soil in their assigned map units but based on subsequent transect and grid sampling within these map units, they appear to be representative soils for this area.

Field hydraulic conductivity measurements at pit 4 indicate that the Punkin series should be classified as very slow (<.06in./hr, <.15cm/hr). Field measurements on soils similar to pit 10 (SND3) indicate that its permeability would be slightly higher, and be categorized as slow (.2-.06in/hr, .5-.15cm/hr). It should be noted however that the soils at the study site have been treated with gypsum which may have significantly increased their conductivity.

The major differences between these soils are: 1) Higher clay content in the control section of the Punkin soil (figs. A8, A9; tables A8, A9), 2) The Punkin soil has more organic carbon in its mollic epipedon, 3) More salts are accumulated in the Punkin soil, 4) Strongly gleyed colors in SND3, 5) Higher shrink/swell potential for the Punkin soil, 6) SND3 is located in a micro-depression.

Both of these soils are probably at moderately low risk for non-point source pollution. If hydraulic conductivity and clay content are used as the sole criteria for nitrate potential, then SND3 is at slightly higher risk of leaching loss. Aquic conditions at SND3 coupled with adequate organic carbon contents and near optimal pH values in the upper two horizons would indicate significant losses of nitrate through denitrification processes. If adequate microbial populations are present, the potential for leaching loss should be reduced due to gaseous losses.

The Punkin soil has a high shrink/swell potential which results in it being classified in a Vertic Subgroup. High shrink/swell is generally assumed to increase the possibility for leaching loss due to by-pass flow utilizing cracks as conduits to circumvent the soil matrix. Two factors may decrease the assumed effects of high shrink/swell for this soil. First, the period of maximum evaporation is from late June through August when irrigation water is being applied to compensate for precipitation shortages and evaporative losses. The subsoil which has the highest shrink/swell potential is rarely allowed to get dry enough to form large cracks to great depth (tables A8, A9). Secondly, the upper horizons have low clay contents, low linear extensibility, and significantly lower water retention characteristics. For these reasons the upper horizons may in effect act as a mulching layer limiting the amount evaporative loss from underlying finer textured horizons.

Table A8. Soil characteristics of pit 4, site ID I-14 Middle.

Soil Classification: Punkin, fine, mixed, thermic Vertic Natrustoll
NRCS ID: S92KS-079-004

Interval (cm)	Horizon	Clay (%)	Silt (%)	Sand (%)	Organic Carbon (%)	pH H2O	CEC meq/100g	COLE (cm/cm)	LE
0-12	Ap1	8.7	47.7	43.6	0.81	7.2	8.4	0.008	0.096
12-19	Ap2	9.8	47.1	43.1	0.6	6.3	8.5	0.006	0.042
19-31	Btn1	16.4	45.9	37.7	0.52	7.4	13.9	0.114	1.368
31-40	Btn2	33.4	44.4	22.2	0.56	7.9	26.2	0.132	1.188
40-54	Btn3	44.1	44.3	11.6	0.37	8	33.8	0.126	1.764
54-72	Btknz	40	46.3	13.7	0.25	8	28.7	0.107	1.926
72-85	Btk1	30.6	44.7	24.7	0.16	8.4	24.6	0.084	1.092
85-103	Btk2	24.9	42.2	32.9	0.16	8.3	19.8	0.056	1.008
103-131	Btk3	21	31	48	0.15	8.3	15	0.017	0.476
131-155	Bt	14.5	22	63.5	0.1	7.7	9.6	0.008	0.192
155-189	C1	7.7	13.6	78.7	0.03	7.4	5.9	0.007	0.238
189-230	C2	3.8	7.4	88.8	0.03	7	3.1	0.006	0.186

Interval (cm)	Horizon	1/3 Bar (%)	2 Bar (%)	15 Bar (%)	SAR %	Hue	Value	Chroma
0-12	Ap1	17.3	8	5.3		10yr	3	2
12-19	Ap2	15.2	8.6	5.5	7	10yr	3	2
19-31	Btn1	31.7	15.5	9.7	18	10yr	2	1
31-40	Btn2	35.9	24.8	18.8	18	10yr	3	2
40-54	Btn3	33.9	31	21.5	23	10yr	4	2
54-72	Btknz	31.7	27.5	19.5	21	10yr	4	2
72-85	Btk1	29.6	26.9	17.8	33	10yr	4	3
85-103	Btk2	25.5	23.8	14.2	38	10yr	3	3
103-131	Btk3	16.5	19.5	11.5	32	7.5yr	4	2
131-155	Bt	14.3	12.5	7.9	28	7.5yr	4	2
155-189	C1	9.8	6.5	4	22	7.5yr	4	3
189-230	C2	5.6	3.4	1.2	18	10yr	4	3

Pit #4, NRCS ID: S92KS-079-004

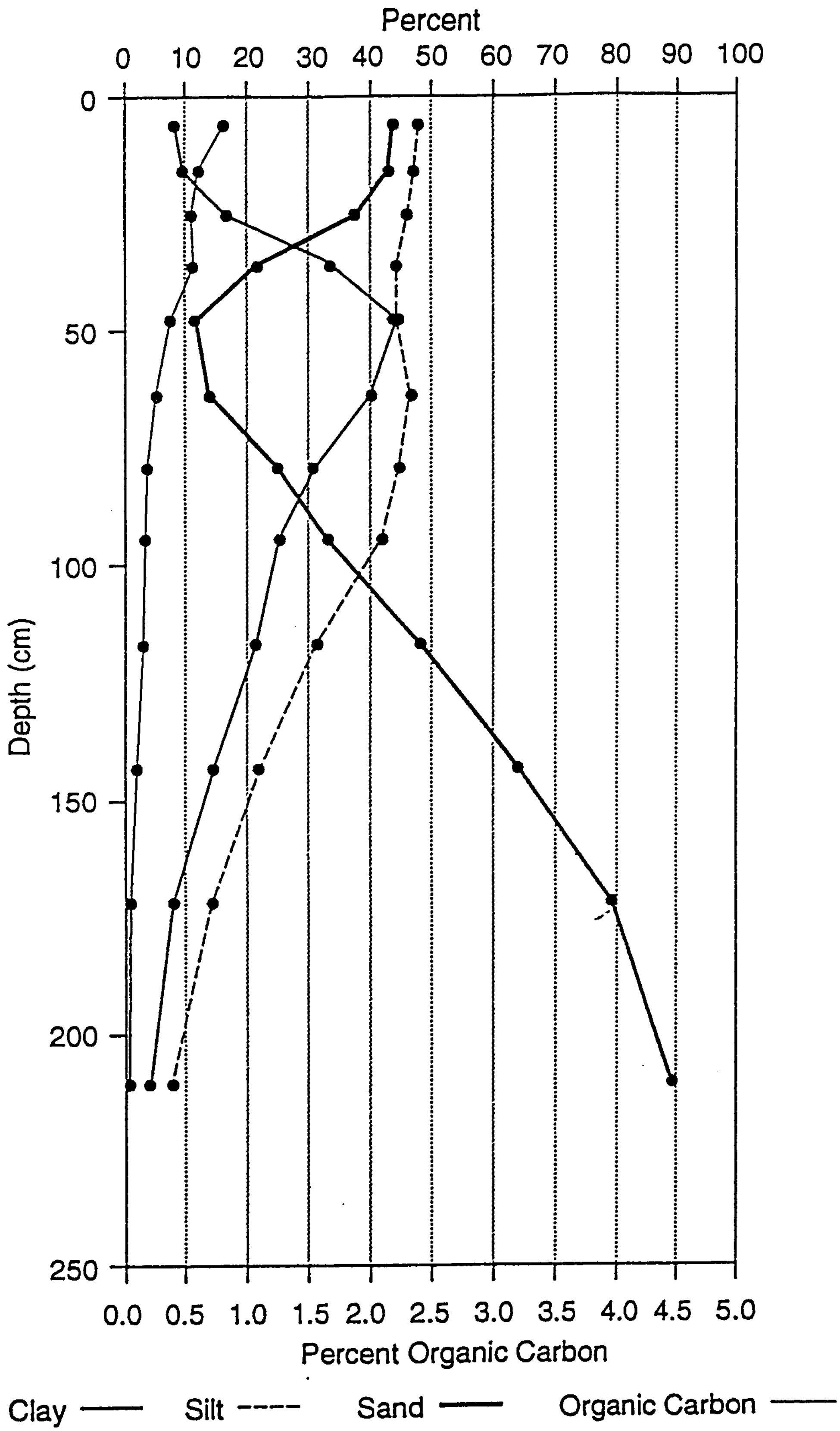


Figure A8. Particle size distribution and percent organic carbon for Punkin soil type, site I-14 middle.

Table A9. Soil characteristics of pit 10, site ID I-14 South.

Soil Classification: SND3, fine-silty, mixed, thermic Typic Argiaquoll
NRCS ID: S92KS-079-010

Interval (cm)	Horizon	Clay (%)	Silt (%)	Sand (%)	Organic Carbon (%)	pH H2O	CEC meq/100g	COLE (cm/cm)	LE
0-14	Ap	23.5	56.6	19.9	1.31	6.4	19.9	0.027	0.378
14-26	Btn1	28.6	55.5	15.9	1.07	7.6	24.3	0.036	0.432
26-42	Btn2	37.5	52.1	10.4	0.55	7.7	31	0.076	1.216
42-74	Btngk	28.9	47.2	23.9	0.26	8	23.3	0.058	1.856
74-116	Btgk	19.8	33.8	46.4	0.11	8.4	15.6	0.054	2.268
116-147	Btgy	12.4	22.6	65	0.04	7.9	10.8	0.031	0.961
147-164	B/C	7.7	9.1	83.2	0.03	7.6	7.1	0.011	0.297
164-204	2C	1.9	3.3	94.8		7.4	2.6		

Interval (cm)	Horizon	1/3 Bar (%)	2 Bar (%)	15 Bar (%)	SAR (%)	Hue	Value	Chroma
0-14	Ap	19.6	17.7	11.7	1	10yr	2	1
14-26	Btn1	17.9	22.3	15.2	4	10yr	3	1
26-42	Btn2	28.6	26.1	19.5	4	5y	4	1
42-74	Btngk	26.2	21.9	15.3	9	5y	5	1
74-116	Btgk	22.4	17.9	11.5	18	5y	5	1
116-147	Btgy	16.2	11.8	7.2	6	5y	6	2
147-164	B/C	8.3	8	5	13	5y	6	2
164-204	2C		2.5	2	16	10yr	5	3

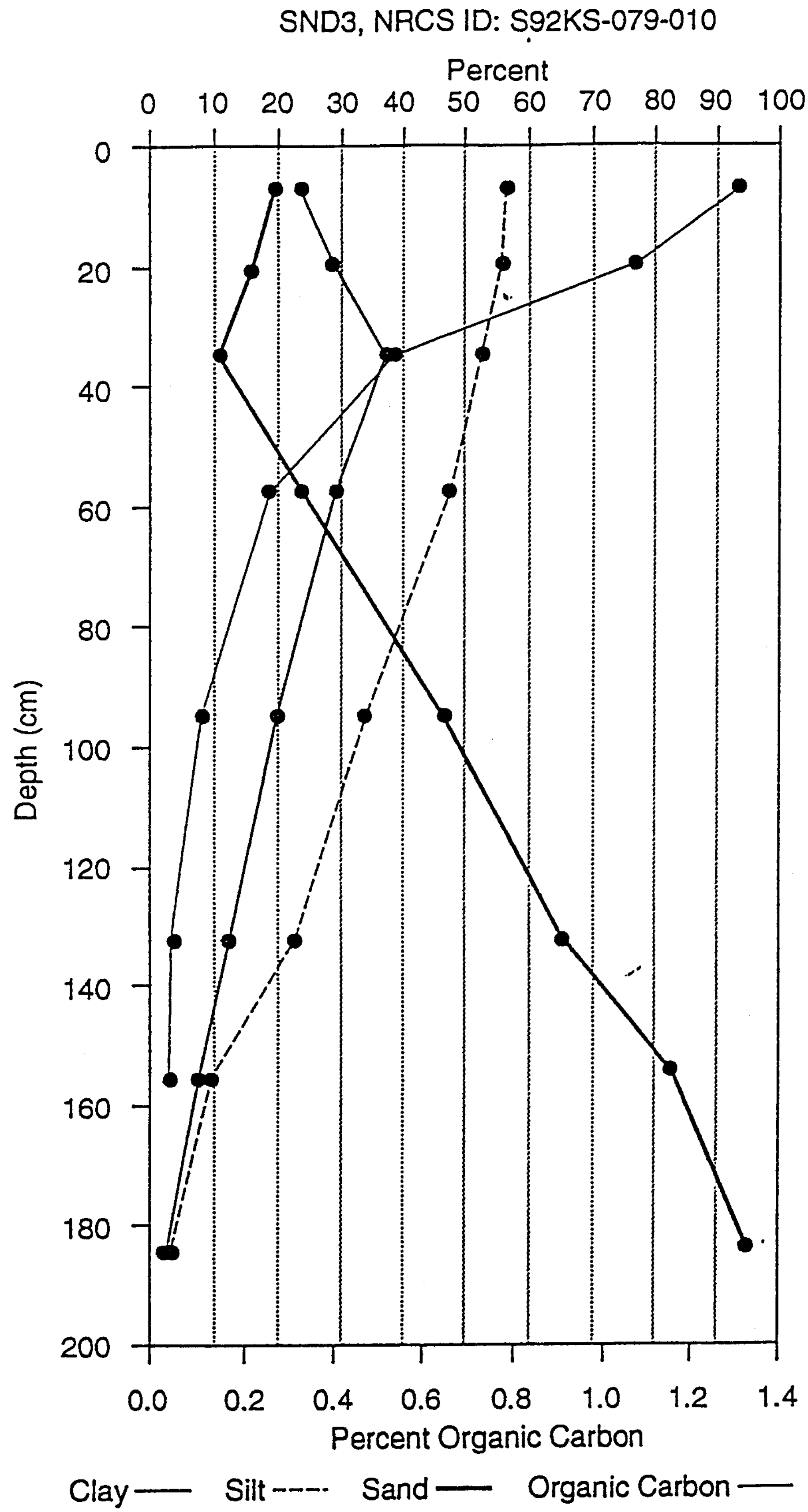


Figure A9. Particle size and percent organic carbon for soil series not designated #3, site I-14 south.

SND1 and SND2

SND1 (pit 6) and SND2 (pit 7) are representative of soils found in Carwile and Pratt-Carwile mapunits in the area west of the Little Arkansas River and south of U.S. 50 highway (fig. A1). These soils have formed in clay rich alluvial sediments with a varying thickness of eolian sand in their surface horizons. They are generally found in close proximity to Pratt soils. The clay rich alluvium in which the B horizon of soils similar to SND1 (pit 6) and SND2 (pit 7) have formed is believed to be the same clay rich strata which is often encountered at depth under Pratt soils.

These soils have high clay+silt contents in their B horizons (>95%, figs. A10 and A11), high shrink/swell potential, high CEC, and low hydraulic conductivity (tables A10 and A11). They tend to pond water at the surface for some time after precipitation events, and they have strongly gleyed colors in their lower horizons. The major differences between SND1 (pit 6) and SND2 (pit7) are: 1) Lower clay contents in the A and C horizons of SND2, 2) Higher linear extensibility in the A horizons of SND1, 3) Higher exchangeable sodium and sodium adsorption ratios in SND1 (tables A10 and A11).

Both of these soils would be considered at low risk for non-point source pollution potential based on their high clay content, high CEC, and low hydraulic conductivity values. High shrink/swell might increase the risk for SND1 because the surface horizons have relatively high linear extensibility and similar clay contents and water retention characteristics when compared to underlying horizons. A crack filled with sandy loam material was described at SND1 (pit 6) extending from approximately a 30 cm depth to a depth of around 100 cm. If such cracks are common, they would allow water and solutes to move quickly to considerable depth.

Table A10. Soil characteristics of pit 6, site ID I-28.

Soil Classification: SND1, fine, mixed, thermic Sodic Haplustert
NRCS ID: S92KS-079-006

Interval (cm)	Horizon	Clay (%)	Silt (%)	Sand (%)	Organic Carbon (%)	pH H2O	CEC meq/100g	COLE (cm/cm)	LE
0-12	Ap1	28.3	44.9	26.8	1.36	6.3	21.1	0.056	0.672
12-26	Ap2	33.3	40.6	26.1	0.99	6.6	24.4	0.061	0.854
26-50	Btn	37.6	35.9	26.5	0.58	7.7	27.3	0.111	2.664
50-75	Btgz	33.7	38.7	27.6	0.29	7.4	24.2	0.08	2
75-108	Btgzss1	40.3	53.4	6.3	0.27	7.9	28.6	0.046	1.518
108-123	Btgzss2	38.8	58	3.2	0.25	7.8	28.1		
123-149	Btg1	42.4	55.2	2.4	0.18	7.7	31.7	0.072	1.872
149-171	Btg2	41.3	56.3	2.4	0.13	7.6	30.9	0.045	0.99
171-231	B/Cg	30.7	54.3	15	0.11	7.4	21.6	0.029	1.74

Interval (cm)	Horizon	1/3Bar (%)	2 Bar (%)	15 Bar (%)	SAR %	Hue	Value	Chroma
0-12	Ap1	21.9	20	13	5	10yr	3	1
12-26	Ap2	21.5	22.2	15.9	8	10yr	3	1
26-50	Btn	29.5	25.1	16.8	11	10yr	2	1
50-75	Btgz	27	21.3	14.3	10	5y	4	1
75-108	Btgzss1	28.6	27.7	18.8	17	5y	4	1
108-123	Btgzss2		27.6	18.5	17	5y	4	1
123-149	Btg1	31.8	31.1	20.8	17	5y	4	1
149-171	Btg2	31.8	31.1	20.7	14	5y	6	2
171-231	B/Cg	24.2	22.2	14.5	12	5y	5	2

Pit #6, NRCS ID: S92KS-079-006

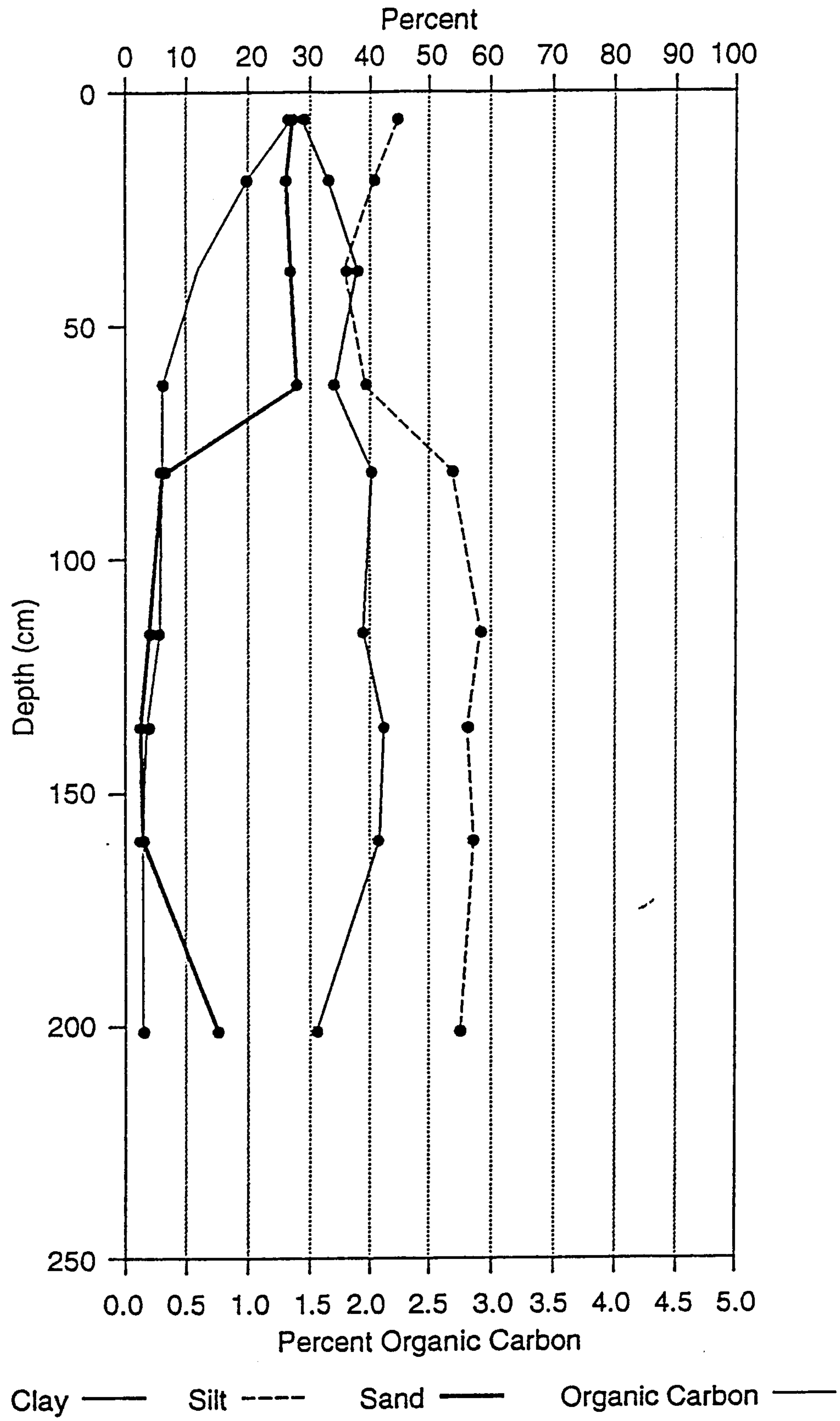


Figure A10. Particle size distribution and percent organic carbon for soil series not designated #1, site I-28.

Table A11. Soil characteristics of pit 7, site ID I-24.

Soil Classification: SND2, fine, montmorillonitic, thermic Udertic Argiustoll
NRCS ID: S92KS-079-007

Interval (cm)	Horizon	Clay (%)	Silt (%)	Sand (%)	Organic Carbon (%)	pH H2O	CEC meq/100g	COLE (cm/cm)	LE
0-16	Ap	6.8	20	73.2	0.6	6.8	6.9	0.019	0.304
16-25	A	23	27.8	49.2	0.67	6.2	18.3	0.015	0.135
25-40	Bt1	42.3	34.4	23.3	0.62	6.8	33.4	0.112	1.68
40-64	Bt2	41.3	38	20.7	0.47	7.5	32.7	0.107	2.568
64-72	Btss	40.1	42.5	17.4	0.33	8.1	31.8	0.096	0.768
72-84	Btk1	38.8	45	16.2	0.25	8	31.7	0.084	1.008
84-102	Btkz	39.9	52.2	7.9	0.17	7.8	33.1	0.096	0.768
102-115	Btg1	39	57	4	0.13	7.6	31.4	0.052	0.676
115-136	Btg2	36.2	52	11.8	0.11	7.6	27.5	0.056	0.616
136-158	Btg3	22	31.4	46.6	0.11	7.6	16.4	0.011	0.242
158-202	2C	6.6	6.2	87.2	0.03	7.6	4.9		

Interval (cm)	Horizon	1/3 Bar (%)	2 Bar (%)	15 Bar (%)	SAR (%)	Hue	Value	Chroma
0-16	Ap	13.8	5.9	3.9		10yr	3	2
16-25	A	15.2	14.8	9.6		10yr	3	1
25-40	Bt1	30.1	24.6	17.8	3	10yr	2	1
40-64	Bt2	27.9	24.8	17.7	3	2.5y	3	2
64-72	Btss	27.1	25.3	18	4	2.5y	4	2
72-84	Btk1	27.1	26.9	18.8	5	2.5y	4	2
84-102	Btkz	28.1	30.8	21	6	5y	5	2
102-115	Btg1	30.8	30.7	19.9	6	5y	6	1
115-136	Btg2	31.9	29.2	18.6	7	10yr	5	2
136-158	Btg3	17.7	17.6	10.7	7	10yr	5	2
158-202	2C	14	5.5	3.6		10yr	5	3

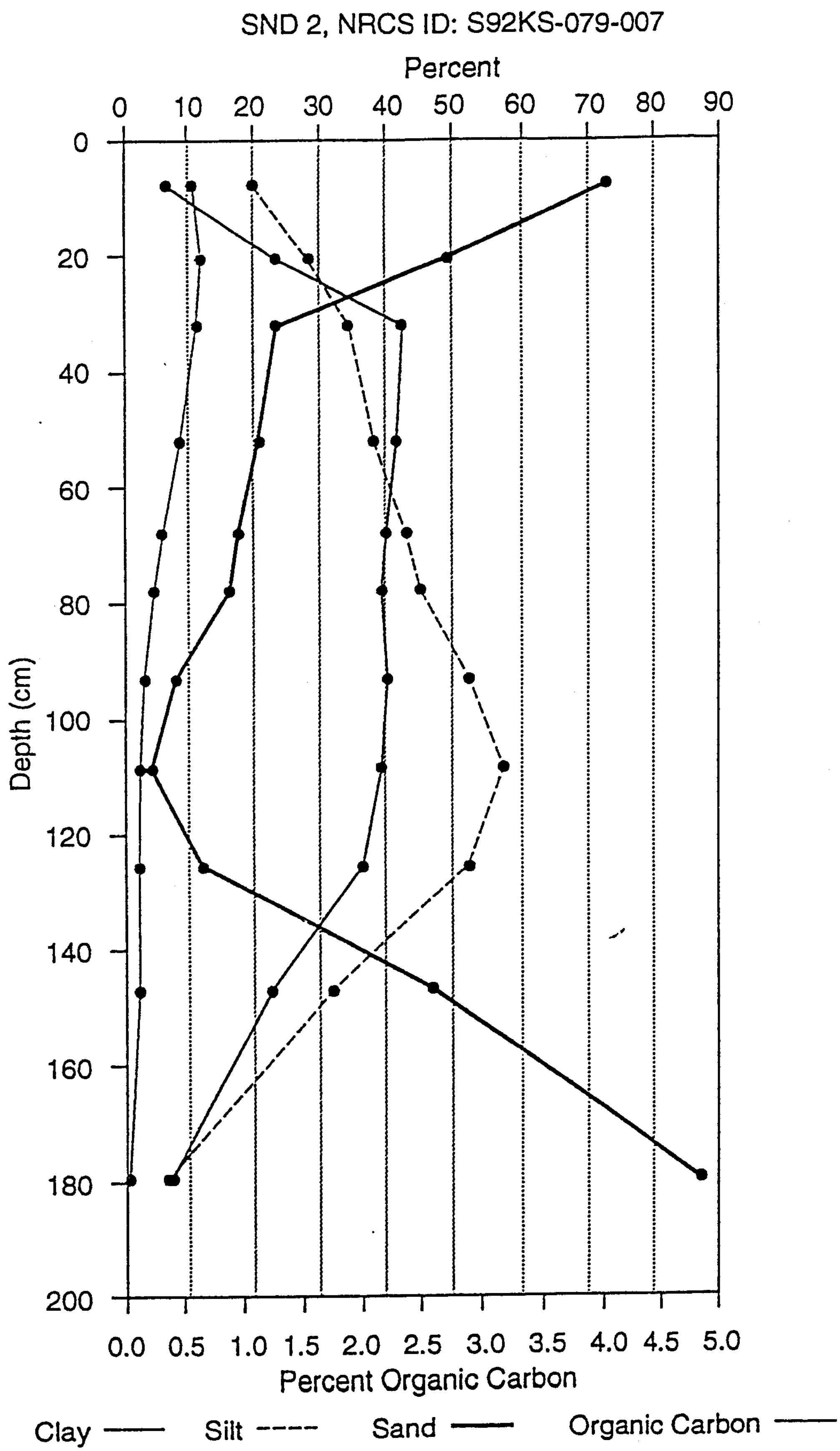


Figure A11. Particle size and percent organic carbon for soil series not designated #2, site I-24.

Summary and Interpretation of Soil Pit Data

Sites were chosen for this study based on high soil DRASTIC ratings for non-point source pollution potential, yet only four of the 10 soils sampled would be at high or moderately high risk for significantly nitrate leaching based on the taxonomic criteria cited in this study (appendix A).

The Pratt and similar dunal soils in Harvey County are at the greatest risk for nitrate leaching. This remains true even though hydraulic conductivity measurements indicate that this soil's profile conductivity is much lower that anticipated. Soils similar to the Naron series have moderately high risk of leaching loss. This finding is higher than initially expected and is probably due to the presence of large numbers of continuous macropores.

Three of the soils sampled had high shrink/swell potential as evidenced by the presence of slickensides, pressure faces, and high COLE values (SND1, SND2, and the Punkin; appendix A, tables A8, A9, A10, A11). DRASTIC would assign these soils a rating of 7, indicating that these soils were at high risk for leaching loss (rating scale 0-10, 10 having greatest risk). This is a higher rating than what is suggested for soils of sandy loam texture (rating 6) and is inappropriate for soils with vertic properties in this region. It is probably necessary to consider stratigraphic and lad-use factors which will influence the formation and depth of large cracks to determine an appropriate rating for soils with vertic properties.

The soils at pits 2,4,5,6, and 7 have indications such as gleyed colors (gray-green to black), manganese concretions, mottle patterns, or salt accumulations which suggest extended periods of saturation (appendix A, tables A4, A6-A8, A10, and A11). These properties are not always reflected in the taxonomic classifications for the soils and might be easily overlooked. Reducing zones within soil profiles are exceedingly important when considering whether nitrate might migrate through a given soil.

A major consideration is whether these indicators of saturation reflect current ongoing processes or relict conditions. The accumulations of salts in the soils and the chemistry of the underlying ground water in areas where gleying at the base of the B horizon is common, are consistent with a hypothesis that this was a gound-water-discharge zone (see Water Chemistry discussion). If this is the case then gleying is an indication of conditions prior to major pumpage from the Equus Beds Aquifer which has lowered the water table in this area.

Appendix B

Fertilizer Application Rates by Site

Table B-1 . Fertilizer Use and Crops Grown, Dryland Sites 1991-1993

ID	1991 Fertilizer lb/acre	Crop 1991	1992 Fertilizer lb/acre	Crop 1992	1993 Fertilizer lb/acre	Crop 1993
D01	82	Milo	76	Milo	76	Milo
D02	82	Milo	76	Milo	76	Milo
D04	60	Sorghum	60	Sorghum	68	Milo
D06	93	Milo	82	Milo	82	Milo
D07	82	Milo	82	Milo	85	Milo
D08	0	Soybeans	80	Milo	80	Milo
D10O	82	Milo	88	Milo	60	Wheat
D10N	--	--	60	Wheat	88	Milo
D11	65	Milo	65	Milo	65	Milo
D12	18	Milo	18	Milo	18	Milo
D14	111	Milo	91	Milo	91	Milo
D16	66	Milo	85	Milo	75	Milo
D17	65	Milo	85	Milo	85	Milo
D18	60	Wheat	80	Milo	80	Milo
D19	69	Milo	69	Milo	69	Milo
D21	65	Milo	65	Milo	60	Milo
D22	126	Milo	126	Milo	87	Milo
D23	--	Soybeans		Milo	--	Milo
D24	47	Milo	47	Milo	47	Milo
D25	51	Milo	51	Milo	51	Milo
D26	--	Milo		Milo		Milo
D27	96	Milo	96	Milo	96	Milo
D28	--	Fallow		Milo	--	Milo
D29	88	Milo	88	Milo	88	Milo
D30	107	Milo	100	Milo	100	Milo
D32	87	Milo	87	Milo	87	Milo
D33	125	Milo	125	Milo	125	Milo

O = 1992 sampling site; N = 1993 sampling site
- = means no information available

Table B-2 . Fertilizer Use and Crops Grown, Irrigated Sites 1991-1993

ID	1991 Fertilizer lb/acre	Crop 1991	1992 Fertilizer lb/acre	Crop 1992	1993 Fertilizer lb/acre	Crop 1993
I01	10	Soybeans	51	Corn	--	--
I02N	150	Corn	7	Soybeans	150	Corn
I02O	7	Soybeans	150	Corn	7	Soybeans
I03	7	Soybeans	127	Milo	127	Milo
I04	200	Corn	200	Corn	200	Corn
I05	7	Soybeans	120	Sorghum	120	Milo
I06	162	Corn	162	Corn	162	Corn
I07N	142	Corn	8	Soybeans	142	Corn
I07O	0	Soybeans	135	Corn	8	Soybeans
I08	50	Soybeans	192	Corn	192	Corn
I09	11	Soybeans	200	Corn	200	Corn
I11N	186	Corn	7	Soybeans	186	Corn
I11O	7	Soybeans	186	Corn	7	Soybeans
I12N	--	--	0	Soybeans	120	Corn
I12O	162	Corn	162	Corn	0	Soybeans
I13	175	Corn	175	Corn	210	Corn
I14N	--	--	18	Soybeans	189	Corn
I14O	199	Corn	199	Corn	18	Soybeans
I15	200	Corn	200	Corn	200	Corn
I17N	151	Corn	7	Soybeans	151	Corn
I17O	7	Soybeans	151	Corn	7	Soybeans
I18	75	Sorghum	185	Corn	0	Soybeans
I19	--	Corn	--	Corn	--	Corn
I20N	156	Corn	7	Soybeans	156	Corn
I20O	7	Soybeans	156	Corn	7	Soybeans
I22	164	Corn	--	Corn	--	Corn
I23	199	Corn	199	Corn	199	Corn
I24O	0	Soybeans	145	Sorghum	0	Soybeans
I24N	145	Corn	0	Soybeans	145	Corn
I25	164	Corn	164	Corn	164	Corn
I26	18	Soybeans	164	Corn	154	Corn
I27	180	Corn	116	Milo	180	Corn
I28N	180	Corn	8	Soybeans	180	Corn
I28O	8	Soybeans	180	Corn	8	Soybeans
I29	210	Corn	210	Sorghum	--	--
I30N	219	Corn	0	Soybeans	219	Corn
I30O	0	Soybeans	219	Sorghum	0	Soybeans
I32	178	Corn	178	Corn	0	
I33	0	Milo	79	Milo	79	Milo
I34	200	Corn	125	Milo	125	Milo
I35O	178	Milo	170	Milo	--	--
I35N	--	--	--	--	178	Milo

O = 1992 sampling site; N = 1993 sampling site
- = means no information available

Appendix C
Ground-Water Nitrate-N Concentrations by Site

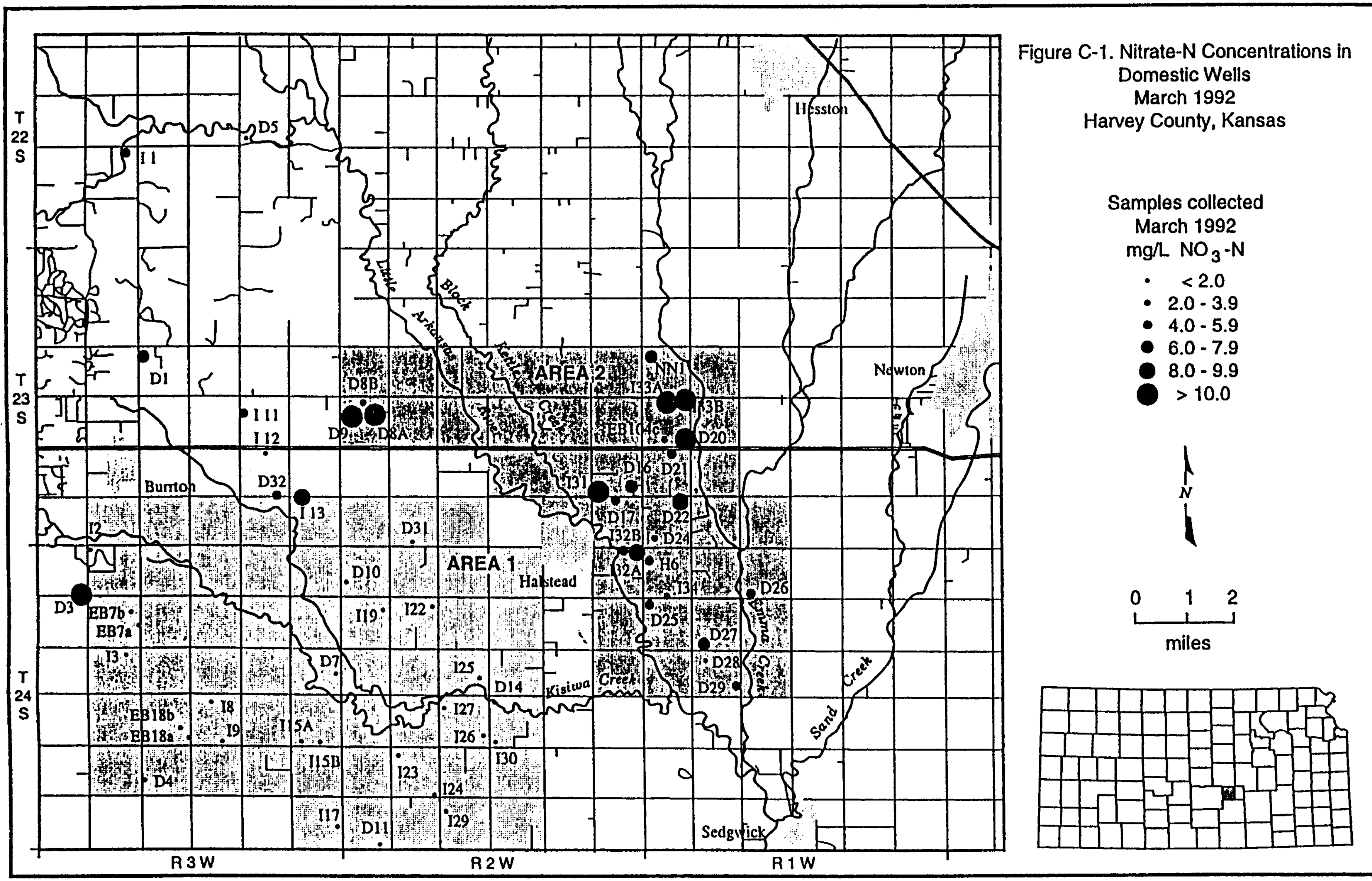


Figure C-1. Nitrate-N Concentrations in Domestic Wells
March 1992
Harvey County, Kansas

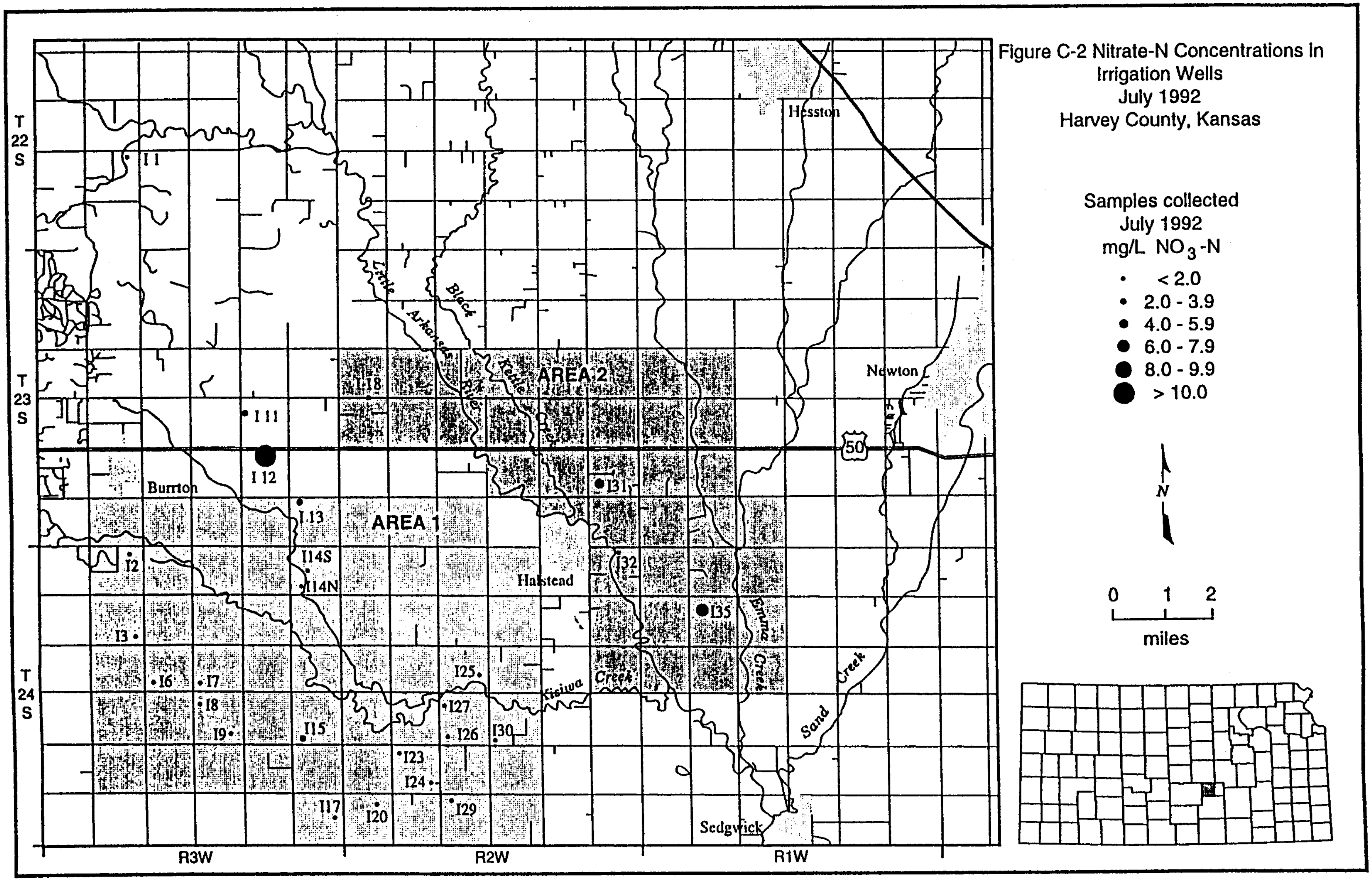


Figure C-2 Nitrate-N Concentrations in Irrigation Wells
July 1992
Harvey County, Kansas

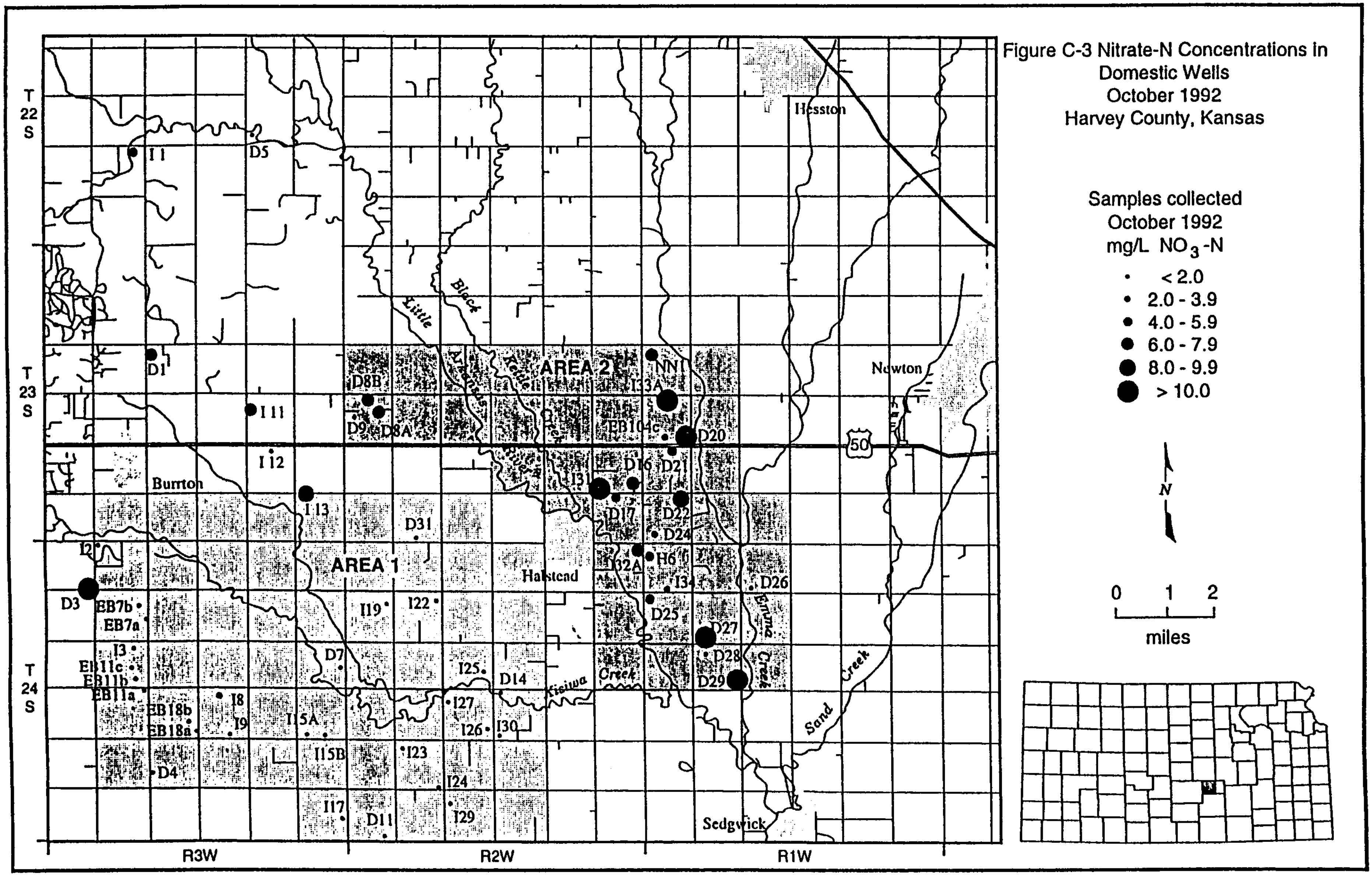


Figure C-3 Nitrate-N Concentrations in Domestic Wells October 1992 Harvey County, Kansas

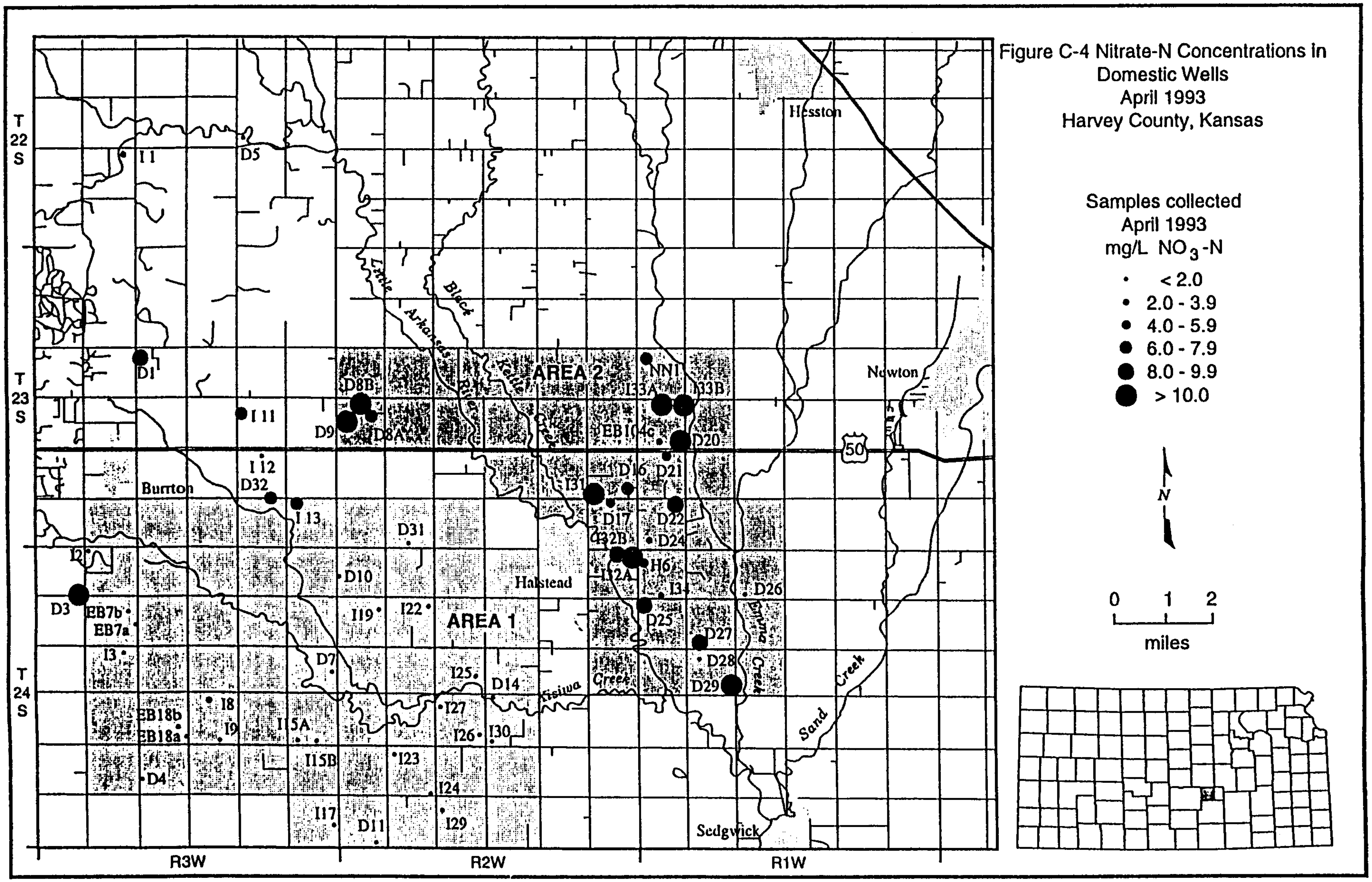


Figure C-4 Nitrate-N Concentrations in Domestic Wells
April 1993
Harvey County, Kansas

Table C-1. Nitrate-N concentration domestic wells near dryland sites.

SITE #	Well Type	Depth ft	Log Avail	Sample Date 1	Nitrate-N mg/L	Sample Date 2	Nitrate-N mg/L	Sample Date 3	Nitrate-N mg/L
NN1	C	150	Y	3/16/92	6.00	10/20/92	6.73	04/20/93	6.58
EB104c	O	47	Y	3/16/92	2.30	10/20/92	1.02	04/19/93	2.56
H6	C	74	Y	3/16/92	5.42	10/20/92	5.42	04/20/93	5.60
EB7a	O	43	Y	3/16/92	0.02	10/19/92	0.02	04/19/93	0.13
EB7b	O	75	Y	3/16/92	0.47	10/19/92	0.34	04/19/93	1.24
EB18a	O	20.5	Y	3/16/92	0.14	10/19/92	0.09	04/19/93	0.02
EB18b	O	86	Y	3/26/92	0.02	10/19/92	0.02	04/19/93	0.02
EB11a	O	46	Y			10/19/92	0.09		
EB11b	O	79.5	Y			10/19/92	0.70		
EB11c	O	196	Y			10/19/92	0.14		
D1	D	25	R	03/09/92	7.34	10/22/92	6.48	04/26/93	9.19
D3	D	38	Y	03/09/92	11.74			04/26/93	
D3	D	38	Y	03/17/92	11.99	10/15/92	13.81	04/26/93	12.18
D4	D	25	R	03/09/92	1.42	10/15/92	1.72	04/26/93	0.74
D4	D	25	R	03/16/92	1.42			04/26/93	
D5	D	78	Y	03/09/92	0.14	10/22/92	0.02	04/26/93	0.02
D7A	D	135	Y	03/02/92	0.02				
D7B	D	80	Y			10/22/92	0.77	04/26/93	0.97
D8A	D	108	Y	03/10/92	16.12	10/15/92	6.75	04/26/93	6.83
D8B	B	75	Y	03/10/92	3.25	10/15/92	7.02	04/26/93	15.08
D9	D	73	Y	3/10/92	10.84	10/15/92	5.24	04/26/93	14.36
D10	D	.	NA	3/09/92	0.02			04/26/93	0.07
D11	D	49	Y	03/10/92	0.02	10/15/92	0.02	04/26/93	0.02
D14	D	50	R	03/10/92	0.02	10/13/92	0.02	04/26/93	0.11
D16	D	85	R	03/03/92	6.21	10/13/92	6.48	04/26/93	6.45
D17	D	100	R	03/03/92	4.70	10/13/92	4.11	04/26/93	3.82
D20	D	50	R	03/03/92	23.93	10/13/92	48.31	04/26/93	35.51
D21	D	123	Y	03/03/92	5.12	10/13/92	5.08	04/26/93	5.42
D22	D	90	R	03/03/92	8.31	10/13/92	9.14	04/26/93	9.39
D24	D	80	Y	03/03/92	2.48	10/13/92	2.44	04/26/93	2.04
D25	D	48	Y	03/09/92	4.15	10/13/92	5.10	04/26/93	8.72
D26	D	.	NA	03/04/92	5.28	10/13/92	1.49	04/26/93	1.53
D28	D	140	Y	03/09/92	0.07	10/13/92	0.36	04/26/93	0.02
D29	D	.	R	03/09/92	5.03	10/15/92	20.59	04/26/93	11.17
D31	D	110	NA	03/09/92	0.14	10/22/92	0.29	04/26/93	0.13
D32	D	48	Y	03/09/92	4.36			04/26/93	7.87

A= Domestic well; B= Stock well; D= Domestic well; O= Observation well
Y= yes; NA= not available; R= reported

Table C-2. Nitrate-N concentration in domestic wells near irrigated sites.

SITE #	Well Type	Depth ft	Log Avail	Sample Date 1	Nitrate-N mg/L	Sample Date 2	Nitrate-N mg/L	Sample Date 3	Nitrate-N mg/L
I1	D	55	Y	03/09/92	4.27	10/20/92	5.64	04/26/93	3.78
I2	D	.		03/09/92	0.05	10/22/92	0.05	04/26/93	0.02
I3	D	.		03/09/92	0.14	10/15/92	0.02	04/26/93	0.07
I3	D	.		03/17/92	0.14			04/26/93	
I8	D	55	Y	03/02/92	1.56	10/15/92	2.21	04/26/93	5.12
I8	D	55	Y	03/16/92	1.78			04/26/93	
I9	D	.		03/09/92	0.20	10/15/92	0.14	04/26/93	0.31
I9	D	.		03/16/92	0.11			04/26/93	
I11	D	58	Y	03/09/92	5.67	10/15/92	7.49	04/26/93	6.47
I12	D	58	R	03/10/92	0.09	10/15/92	002	04/26/93	0.02
I13	D	68	Y	03/10/92	9.59	10/15/92	6.48	04/26/93	6.52
I15A	D	120	R	03/09/92	0.09	10/15/92	0.09	04/26/93	0.09
I15B	D	64	Y	03/09/92	0.09	10/22/92	0.02	04/26/93	
I17	D	.		03/10/92	0.07	10/15/92	0.09	04/26/93	0.07
I19	D	80	Y	03/09/92	0.09	10/15/92	0.02	04/21/93	0.04
I22	D	135	R	03/09/92	0.09	10/22/92	0.02	04/21/93	0.11
I22	D	135	R	03/16/92	0.07				
I23	D	73	Y	03/10/92	0.14	10/13/92	0.11	04/02/93	0.11
I24	D	90	Y	03/10/92	0.11	10/15/92	0.09	04/02/93	0.18
I25	D	72	Y	03/02/92	0.32	10/13/92	0.07	04/21/93	0.16
I27	D	.		03/10/92	0.09	10/15/92	0.07	04/02/93	0.02
I28	D	92	Y	03/10/92	0.09	10/13/92	0.07	04/21/93	0.04
I29	D	.		03/10/92	0.09	10/13/92	0.09	04/02/93	0.02
I30	D	167	Y	03/10/92	0.11	10/13/92	0.11	04/21/93	0.02
I31	D	65	R	03/03/92	12.89	10/13/92	13.72	04/21/93	14.36
I32	B	74	R	03/03/92	8.15	10/13/92	6.98	04/21/93	9.37
I32	D	74	D	03/03/92	4.02			04/21/93	11.57
I33A	D	70	R	03/03/92	14.74	10/13/92	16.95	04/21/93	18.09
I33B	B	105	R	08/04/92	15.55			04/21/93	13.82
I34	D	80	R	03/03/92	3.66	10/13/92	3.70	04/21/93	3.64
I35	D	82	Y	03/09/92	6.61	10/13/92	13.23	04/21/93	8.45
D8A	B	75	Y	08/04/92	8.06				
D8B	D	108	Y	08/04/92	4.54				
D20	D	50	R	08/04/92	32.28				

A= Domestic well; B= Stock well; D= Domestic well; O= Observation well

Table C-3. Nitrate-N concentration from irigation wells.

Site ID	Depth	Well Log	Well Type	Date	Nitrate-N mg/L
I1		N	I	08/04/92	0.09
I2	52	Y	I	08/05/92	0.11
I3	50	Y	I	08/06/92	0.07
I6	72	Y	I	08/04/92	0.02
I7	85	Y	I	08/05/92	0.05
I8	51	Y	I	08/05/92	0.11
I9	120	Y	I	08/05/92	1.38
I11	--	N	I	08/06/92	2.66
I12	128	Y	I	08/06/92	13.75
I13	--	N	I	08/05/92	2.37
I14N	236	Y	I	08/05/92	0.07
I15	117	Y	I	08/05/92	2.53
I17	104	Y	I	08/05/92	1.17
I18	226	Y	I	08/18/92	0.11
I20	--	N	I	08/05/92	1.42
I23	234	Y	I	08/05/92	0.09
I24	222	Y	I	08/05/92	0.27
I25	111	Y	I	08/05/92	0.11
I27	221	Y	I	08/05/92	0.09
I28	--	N	I	08/05/92	0.14
I29	--	N	I	08/05/92	1.35
I30	201	Y	I	08/05/92	0.61
I31	--	N	I	08/06/92	6.91
I32	--	N	S	08/18/92	0.61
I35	169	Y	I	08/06/92	5.30

I14N means north well in field.
I14S means south well in field.
S = sample collected from Little Arkansas River
Y means log available. N means no log available.
- means no information available.

Table C4. General water chemistry from Harvey County, Kansas

Site ID	Date (mo-d-yr)	Depth Feet	Lab Spec. Cond (uS/cm)	Lab pH	TDS calc. mg/L	SiO2 mg/L	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	Sr mg/L
D8Barn	12/01/93	83	568	6.95	276	23.8	48.4	10.3	47	2.6	0.27
D8Dom	12/01/93	43	412	7.60	219	21.5	45.1	5.7	32.6	2.1	0.23
D20Dom	12/01/93	50	830	6.80	406	29.7	99.2	22.3	30.9	1.8	0.46
I13Dom	12/01/93	60	347	6.95	155	27.5	33.3	7.6	19.9	1.8	0.23
D25Dom	12/01/93	.	420	7.60	224	27.1	64.4	5.8	15.5	1.3	0.25
I23Dom	12/01/93	.	1405	6.85	960	29.3	171	32.9	73.6	3.5	1.25
I25Dom	12/01/93	.	417	7.05	243	25.1	49.7	8	19.3	2.4	0.31
I29Dom	12/01/93	100	740	7.85	423	19.1	81.1	14.8	56.9	2.4	0.62
I30Dom	12/01/93	65	750	7.80	427	22.8	68.2	12	76.1	2.6	0.49
D7Dom	12/01/93	60	1040	7.40	679	21.1	130	24.1	59.8	4.5	0.93

Site ID	Date (mo-d-yr)	Depth Feet	HCO3 mg/L	SO4 mg/L	C1 mg/L	NO3-N mg/L	NH4 mg/L	Fe mg/L	PO4 mg/L
D8Barn	12/01/93	83	150	42	34.5	16.7	BD	BD	0.44
D8Dom	12/01/93	43	200	16.1	14	3.9	0.1	BD	0.65
D20Dom	12/01/93	50	178	83.6	50.2	28.9	BD	BD	0.7
I13Dom	12/01/93	60	80.2	29.2	7.1	15.8	BD	BD	0.22
D25Dom	12/01/93	.	236	13.1	3.4	3.7	BD	BD	0.32
I23Dom	12/01/93	.	221	498	49.7	0.2	0.2	20.2	0.52
I25Dom	12/01/93	.	114	90.2	12.5		0.2	3.75	0.68
I29Dom	12/01/93	100	325	70.6	35.4	0.02	0.1	1.35	0.39
I30Dom	12/01/93	65	305	65.8	48.2		0.3	2.82	0.73
D7Dom	12/01/93	60	200	321	34.6	0.9	0.2	4.26	0.63

'.' means not available
BD means below detection limit of test.

Appendix D

Soil-core Nitrate-N Data by Sampling Period and Site

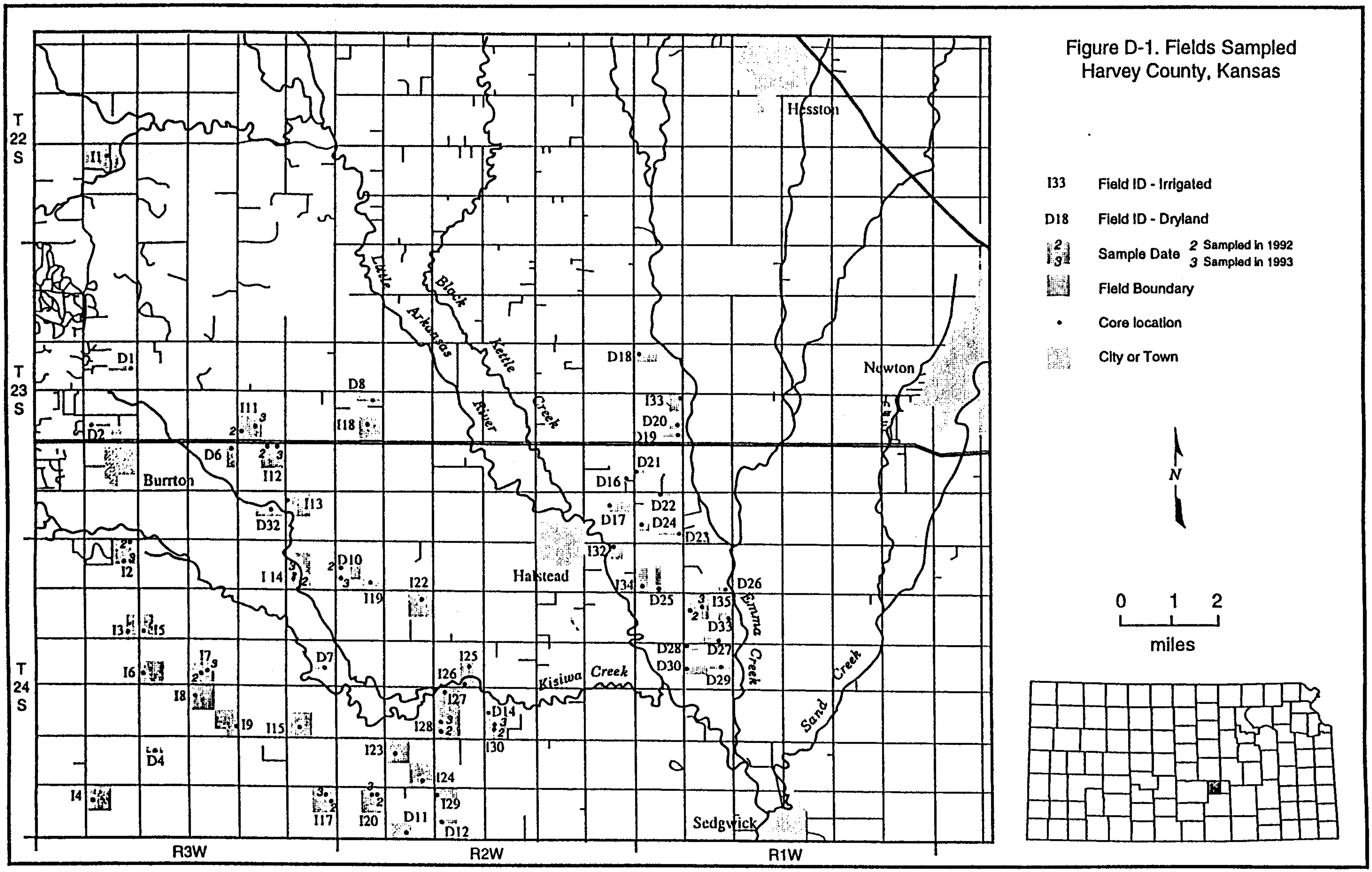


Figure D-1. Fields Sampled Harvey County, Kansas

Table D-1. March 1992 soil samples from dryland sites.

ID	0-2 ft (0.6 m)	2-4 ft (1.2 m)	4-6 ft (1.8 m)	6-8 ft (2.4 m)	8-10 ft (3 m)	Depth Fine Textured Layer ft	Thickness Fine Textured Layer ft
	Nitrate-N Concentrations (mg/kg)						
D1	2.51	0.78	BD	BD	1.89	.09	9.1
D2	5.52	2.56	0.19	0.95	BD	0	8
D4	3.14	3.26	0.28	BD	BD	0	2
D6	5.69	1.12	2.15	2.31	.	0	6.4
D7	BD	BD	BD	2.7	2.3	0	2
D8	5.62	4.9	2.96	4.05	6.77	0.7	1.1
D10	4	3.08	2.52	2.03	1.46	0.2	2.5
D11	1.95	0.4	1.05	0.78	1.01	0	0
D12	0.38	0.38	0.21	0.36	BD	7.7	1.1
D14	4.7	1.83	0.8	0.48	0.92	3.8	1.5
D16	5.02	2.2	2.42	4.8	7.44	1	3
D17	3.92	0.32	0.2	0.33	3.01	0	0.8
D18	4.34	1.39	0.4	0.28	0.18	2	0.7
D19	1.23	0.77	1.25	3.71	3.53	0	0
D21	3.89	4.3	2.5	3.24	.	2.4	1.3
D22	2.51	1.5	3.31	2.22	1.23	0	0
D23	2.97	1.03	3.25	4.92	2.3	3.3	6.7
D24	2.52	1.24	0.71	0.3	.	5	3
D25	4.36	0.43	0.2	0.36	0.56	2	8
D26	5.84	3.25	2.08	1.52	0.99	2	8
D27	13.12	22.12	6.1	0.36	1.78	4.7	5.3
D28	4.15	1.82	2.07	1.37	0.63	0.9	9.1
D29	13.79	6.49	5.61	3.96	3.56	0	0
D30	3.82	17.78	6.07	12.13	6.57	0	6
D32	5.28	0.63	0.42	0.54	.	0	2.8
D33	0.64	0.53	0.43	BD	BD	9	1
D10N	.	.	.	.	.	.	.

BD = Below Limit of Detection (0.05 mg/kg)
'.' = No Sample Collected
N means new site selected in same soil series.

Table D-2. October 1992 soil samples from dryland sites.

ID	0-2 ft (0.6 m)	2-4 ft (1.2 m)	4-6 ft (1.8 m)	6-8 ft (2.4 m)	8-10 ft (3 m)	Depth Fine Textured Layer ft	Thickness Fine Textured Layer ft
	Nitrate-N Concentrations (mg/kg)						
D1	.	.	.	.	.	.	.
D2	.	.	.	.	.	.	.
D4	.	.	.	.	.	.	.
D6	.	.	.	.	.	.	.
D7	.	.	.	.	.	.	.
D8	5.47	6.78	13.96	16.08	23.67	1.6	0.4
D10	1.18	1.32	1.07	1.03	1.17	0	2.75
D11	1.14	0.2	0.33	BD	BD	0	0
D12	.	.	.	.	.	.	.
D14	5.95	1.94	0.87	2.41	0.51	2	1
D16	1.48	1.31	2.29	2.31	3.16	1.4	2.3
D17	1.61	1.28	BD	0.13	1.16	0	1.4
D18	.	.	.	.	.	.	.
D19	0.85	0.59	1.07	1.26	5.15	0	0
D21	.	.	.	.	.	.	.
D22	.	.	.	.	.	.	.
D23	1.22	BD	BD	.	.	0	6.3
D24	1.02	2.37	0.97	0.78	0.8	4.4	5
D25	2.27	1.23	0.2	0.19	0.41	0	9.6
D26	1.23	1.09	0.43	0.92	0.94	6.5	1.5
D27	1.89	3.91	5.48	4.72	0.49	6	4
D28	2.89	2.79	4.31	.	.	0.5	5.5
D29	2.83	6.34	7.64	5.73	3.2	0	0
D30	2.66	1.72	5.84	3.17	0.27	0	2
D32	.	.	.	.	.	.	.
D33	1.05	1.6	BD	0.95	.	3.6	4.4
D10N	.	.	.	.	.	.	.

BD = Below Limit of Detection (0.05 mg/kg)
'.' = No Sample Collected
N means new site selected in same soil series.

Table D-3. March 1993 soil samples from dryland sites.

ID	0-2 ft (0.6 m)	2-4 ft (1.2 m)	4-6 ft (1.8 m)	6-8 ft (2.4 m)	8-10 ft (3 m)	Depth Fine Textured Layer ft	Thickness Fine Textured Layer ft
	Nitrate-N Concentrations (mg/kg)						
D1	2.32	1.35	4.53	BD	BD	2	2
D2	2.97	6.03	7.98	BD	0.2	0	3.7
D4	4.38	4.19	5	2.31	1.78	0	0
D6	1.7	1.88	2	1.99	3.47	0	2
D7	1.62	4.62	BD	1.15	0.47	0	4
D8	3.16	1.11	5.44	10.18	.	0	3.3
D10	1.93	0.57	0.92	1.09	1.09	0	2.7
D11	0.22	BD	BD	BD	BD	0	0
D12	BD	BD	BD	0.41	0.64	5.5	0.5
D14	1.32	2.74	2.1	BD	3.61	0	0
D16	6.56	3.99	2.46	2.77	1.92	0	3
D17	1.08	0.54	0.39	0.48	0.56	0	1
D18	2.47	0.17	0.25	1.01	BD	0	5
D19	3.18	0.95	0.48	1.61	6.68	1.5	3.5
D21	.	.	.	.	.	.	.
D22	1.19	1.02	0.89	0.46	BD	2	1
D23	0.9	0.57	0.29	2.28	.	4	3.25
D24	1.84	2.37	2.13	2.56	.	4.5	2.9
D25	5.84	0.52	0.2	0.43	0.66	0	10
D26	5.78	1.62	2.01	2.82	1.68	1.5	1.5
D27	6.02	1.64	5.04	6.1	2.62	5	4.5
D28	1.99	3.53	3.57	6.63	.	0.5	9.5
D29	3.17	5.08	6.89	6.2	4.46	0	0
D30	2.21	1.31	5.65	1.67	BD	0	3
D32	1.96	0.22	0.91	BD	.	0	2
D33	5.07	0.43	1.09	0.83	1.25	5	10
D10N	1.7	0.15	0.56	2.27	1.84	0	2

BD = Below Limit of Detection (0.05 mg/kg)
'.' = No Sample Collected
N means new site selected in same soil series.

Table D-4. October 1993 soil samples from dryland sites.

ID	0-2 ft (0.6 m)	2-4 ft (1.2 m)	4-6 ft (1.8 m)	6-8 ft (2.4 m)	8-10 ft (3 m)	Depth Fine Textured Layer ft	Thickness Fine Textured Layer ft
	Nitrate-N Concentrations (mg/kg)						
D1	3.8	1.1	BD	.	.	1.5	3
D2	2.9	0.7	2.2	2.2	2.4	0.5	0.5
D4	1.5	1.3	0.5	4.8	0.2	1.2	0.4
D6	.	.	.	.	.	.	.
D7	2.8	0.5	0.5	0.2	0.7	0	0
D8	1.1	4.3	18.4	20.4	.	0.5	1
D10	.	.	.	.	.	.	.
D11	2.4	0.5	0.3	0.3	0.4	0	0
D12	3	1.4	2.7	1	0.5	5.5	1.5
D14	1.3	1	1	1.7	1	1.5	1.5
D16	4	1.6	3	4	9.1	2	1
D17	1.5	0.7	0.5	0.4	0.6	0	0
D18	2	0.9	0.5	0.5	0.4	2	1.6
D19	1.6	1.3	0.7	1.85	2.2	7	9
D21	.	.	.	.	.	.	.
D22	3	2.5	1.5	3	3.5	0	0
D23	.	.	.	.	.	.	.
D24	1	0.7	1.4	1.8	1.9	4.5	5.5
D25	.	.	.	.	.	.	.
D26	1.6	2	1.9	1.8	1.1	0	4
D27	6	2	5.7	9.2	.	4.5	2.5
D28	1.7	0.2	0.4	0.6	0.6	0.5	9.5
D29	1	0.7	5	5.6	4.1	.	.
D30	1.3	0.6	3.6	7.6	5.4	0	0
D32	2.2	0.6	0.6	0.5	0.6	0.5	2
D33	3	1	5	4.5	18.3	5.8	10
D10N	1	1.2	1.1	0.6	0.6	8	2

BD = Below Limit of Detection (0.05 mg/kg)
'.' = No Sample Collected
N means new site selected in same soil series.

Table D-5. March 1992 soil samples from irrigated sites.

ID	0-2 ft (0.6 m)	2-4 ft (1.2 m)	4-6 ft (1.8 m)	6-8 ft (2.4 m)	8-10 ft (3 m)	Depth Fine Textured Layer ft	Thickness Fine Textured Layer ft
	Nitrate-N Concentrations (mg/kg)						
I1	53.98	21.34	4.86	1.09	1.69	2.6	2.3
I2	1.96	1.62	3.14	4.43	.	0	6.5
I3	2.05	BD	BD	1.31	BD	6	1.6
I4	1.79	7.16	3.38	2.96	1.77	0	4
I5	2.76	3.15	1.96	0.82	1.78	1	2.4
I6	4.32	1.99	0.28	BD	0.39	0.8	1.6
I7	6.13	8.58	5.34	6.66	12.08	0	8
I8	30.67	6.51	17.41	5.48	1.96	0	6
I9	3.65	3.8	3.69	2.94	5.1	0	3
I11	5.83	3.31	1.43	1.25	2.2	0	9.4
I12	4.21	1.49	0.44	0.84	0.44	0	7.2
I13	5.02	4.29	3.38	1.05	1.39	0	6
I14	17.12	22.52	9	2.44	1.82	0	4
I15	7.32	38.22	5.35	0.66	0.71	0	4
I17	20.31	1.4	4.9	0.29	0.75	1.8	2.2
I18	8.65	7.52	9.05	6.88	11.01	0.7	4.6
I19	3.42	2.46	4.61	2.15	6.02	0	10
I20	3.4	2.05	3.45	4.75	4.91	0	10
I22	9.92	8.7	5.93	5.49	3.04	0	10
I23	3.09	3.81	4.32	3.91	4.65	4.8	3
I24	4.39	5.3	3.28	2.1	2.91	2	6
I25	10.23	8.46	20.38	17.96	11.43	0	4.3
I26	4.87	6.31	16.78	12.29	15.51	0	8
I27	2.98	1.46	11.6	3.8	2.11	2	6
I28	3.18	2.64	7.23	6.4	2.4	2.3	5.7
I29	45.93	21.07	23.46	9.11	10.24	0	0
I30	9.26	1.43	3.92	3.17	0.88	5.5	2.5
I32	10.31	5.41	0.99	0.41	0.18	0	6
I33	15.31	5.41	4.23	0.65	0.48	0	10
I34	4.2	3.65	2.52	6.23	6.4	1	1.5
I35	5.5	4.58	2.53	0.65	0.95	9	1

BD = Below Limit of Detection (0.05 mg/kg)
'.' = No Sample Collected

Table D-6. October 1992 soil samples from irrigated sites.

ID	0-2 ft (0.6 m)	2-4 ft (1.2 m)	4-6 ft (1.8 m)	6-8 ft (2.4 m)	8-10 ft (3 m)	Depth Fine Textured Layer ft	Thickness Fine Textured Layer ft
	Nitrate-N Concentrations (mg/kg)						
I1	BD	0.7	3.76	2.83	1.4	3.3	3.2
I2	8.47	12.34	11.01	4.81	BD	0	7
I3	.	.	.	.	.	.	.
I4	3.49	BD	BD	BD	0.81	0	3
I5	.	.	.	.	.	.	.
I6	.	.	.	.	.	.	.
I7	3.21	11.44	13.11	3.84	3.9	0	8
I8	1.98	7.77	5.77	3.96	4.1	2	2
I9	6.23	11.44	13.11	3.84	3.9	0	0
I11	BD	3.89	5.38	4.49	3.75	2.6	5.9
I12	5.19	3.48	3.58	BD	0.84	0	1.5
I13	6.84	6.21	2.98	6.53	6.81	0.5	3.4
I14	3.42	27.38	21.21	11.6	10.93	0	4
I15	.	.	.	.	.	.	.
I17	.	.	.	.	.	.	.
I18	5.95	12.46	10.71	11.56	8	0	6
I19	2.22	3.22	4.19	4.91	6.03	0	10
I20	1.45	3.97	3.84	5.11	.	2	5.9
I22	2.15	15.45	2.71	3.05	5.91	0	9.5
I23	0.98	4.29	7.49	6.93	7.6	4	4
I24	.	.	.	.	.	.	.
I25	7.28	6.24	5.09	9.85	3.67	0	4.5
I26	8.86	9.04	2.34	10.06	11.62	0	6
I27	0.92	2.3	11.64	9.3	6.35	1.5	4.5
I28	6.82	8.05	9.6	10.88	5.87	2	2
I29	3.54	7.36	5.27	6.12	4.25	0	0
I30	.	.	.	.	.	.	.
I32	1.47	2.54	0.51	0.27	BD	0	8
I33	3.12	2.2	1	2.38	5.05	0	2.3
I34	BD	0.23	BD	BD	0.36	0	3
I35	2.51	9.16	1.64	1.14	1.7	8.5	1.5

BD = Below Limit of Detection (0.05 mg/kg)
'.' = No Sample Collected
N means new site sample in same soil series.

Table D-7. March 1993 soil samples from irrigated sites.

ID	0-2 ft (0.6 m)	2-4 ft (1.2 m)	4-6 ft (1.8 m)	6-8 ft (2.4 m)	8-10 ft (3 m)	Depth Fine Textured Layer ft	Thickness Fine Textured Layer ft
	Nitrate-N Concentrations (mg/kg)						
I1	0.28	0.6	BD	0.54	3.61	3	3
I2	6.24	6.09	6.36	1.51	1.01	0	6
I3	5.23	1	2.35	3.55	BD	1	2
I4	4.34	3.03	0.57	0.55	1.47	0	0
I5	6.47	6.26	2.09	4.96	5.09	1.4	1.4
I6	1.2	2.32	2.56	3.54	2.28	0	4
I7	3.31	2.39	1.32	0.54	BD	0	8
I8	5.69	10.06	7.35	5.02	3.25	0	6
I9	4.26	3.59	4.58	5.41	5.14	0	0
I11	0.83	2.64	2.61	0.69	0.52	2.6	5.4
I12	5.78	2.85	1.98	1.33	0.98	5	1
I13	5.05	2.69	1.43	4.61	3.89	0	4
I14	10.63	20.57	12.76	6.37	4.5	0	5.6
I15	2.49	4.6	4.55	1.82	1.13	0	0
I17	2.5	2.75	2.71	1.87	2.23	2	3
I18	0.4	1.19	4.79	4.52	2.8	0	2.8
I19	3.42	2.45	1.66	3.28	4.98	0	2
I20	4	3.57	2.11	2.23	.	1.5	4.5
I22	.	.	.	.	.	.	.
I23	1.09	0.59	0.35	6.26	4.72	5	1
I24	4.27	4.71	5.61	6.3	5.43	1.5	5.5
I25	6.8	3.59	4.18	5.35	0.87	0	4
I26	2.28	4.9	4.87	6.67	5.34	7.3	1
I27	BD	BD	1.76	2.34	2.95	2	6
I28	2.91	4.24	4.65	5.83	0.9	2	5.5
I29	1.23	3.8	4.35	3.53	2.45	0	0
I30	0.81	1.05	5.61	5.84	4.12	5.5	3.1
I32	3.19	1.61	3.92	1.5	BD	0	8
I33	6.35	1.39	1.45	1.51	4.86	0	9.25
I34	3.86	0.09	0.31	0.31	0.77	0	3
I35	3.01	3.92	2.78	0.91	1.5	9.3	0.45
NI2	3.73	0.5	BD	0.33	0.59	0	8
NI7	3.84	3.02	1.35	0.68	BD	0	10
NI11	2.26	1.98	1.12	0.05	0.45	2	6
NI12	2.43	0.53	0.2	0.29	BD	0	1.5
NI14	1.8	2.05	4.32	4.59	2.93	0	4
NI17	3.56	4.05	4.06	3.11	2.91	0	2.6
NI20	5.91	13.32	10.62	1.97	BD	0	10
NI24	1.05	0.61	1.18	2.43	2.25	0.6	1.4
NI28	6.08	7.6	1.46	1.28	0.54	2.3	7.7
NI30	1.12	2.18	4.15	3.8	0.83	5	1
NI35	3.18	0.9	0.26	0.8	0.95	0	0

BD = Below Limit of Detection (0.05 mg/kg)
'.' = No Sample Collected
N means new site sample in same soil series.

Table D-8. October 1993 soil samples from irrigated sites.

ID	0-2 ft (0.6 m)	2-4 ft (1.2 m)	4-6 ft (1.8 m)	6-8 ft (2.4 m)	8-10 ft (3 m)	Depth Fine Textured Layer ft	Thickness Fine Textured Layer ft
	Nitrate-N Concentrations (mg/kg)						
I1	.	.	.	.	.	.	.
I2	.	.	.	.	.	.	.
I3	.	.	.	.	.	.	.
I4	.	.	.	.	.	.	.
I5	.	.	.	.	.	.	.
I6	16.9	15.7	2.3	2.85	.	0	0
I7	.	.	.	.	.	.	.
I8	.	.	.	.	.	.	.
I9	5.7	2.4	1	0.7	2	2.5	0.5
I11	.	.	.	.	.	.	.
I12	.	.	.	.	.	.	.
I13	4.6	1.6	1.3	2.5	2.9	0.5	4
I14	.	.	.	.	.	.	.
I15	.	.	.	.	.	.	.
I17	.	.	.	.	.	.	.
I18	.	.	.	.	.	.	.
I19	.	.	.	.	.	.	.
I20	.	.	.	.	.	.	.
I22	.	.	.	.	.	.	.
I23	.	.	.	.	.	.	.
I24	.	.	.	.	.	.	.
I25	8	3.1	1.6	0.4	.	3.1	2.9
I26	20	7.5	9.9	23.6	17.5	7.2	0.3
I27	2	1.6	1.5	2.6	0.5	1.6	2.15
I28	.	.	.	.	.	.	.
I29	.	.	.	.	.	.	.
I30	.	.	.	.	.	.	.
I32	.	.	.	.	.	.	.
I33	3.1	0.5	1.4	1.5	1.6	5.2	1.2
I34	.	.	.	.	.	.	.
I35	.	.	.	.	.	.	.
NI2	1.1	2.9	2.8	2	3.5	2	8
NI7	2.6	2.6	5.2	9.2	14.2	2	8
NI11	5.2	2.5	2.8	3.5	2.9	2	4
NI12	1.1	0.7	0.7	1.8	1.6	0.5	2
NI14	2.4	2.9	6.2	4	2.2	0	0
NI17	5	1.5	1	0.5	0.3	0.5	2.5
NI20	3.1	6.5	7.3	9.6	17.1	0.5	7.5
NI24	2.3	1.7	2.9	3.5	.	0.5	1.5
NI28	4.6	7.5	10.6	13.8	13.7	3	7
NI30	9.5	1.6	2.9	3.5	1.3	5	1
NI35	2.5	1.3	0.6	1	1	0	0

BD = Below Limit of Detection (0.05 mg/kg)
'.' = No Sample Collected N means new site sample in same soil series.

Appendix E

Nitrate-N Data from Lysimeter Sites

Table E 1. Nitrate-N concentrations from lysimeter samples and soil cores site I-14.

Lysimeter Water Samples					Soil Cores from Lysimeter Sites			Soil Description	
Date	Depth ft	Sample Volume ml	Specific Cond. umhos/c	Nitrate-N mg/L	Date	Depth ft	Nitrate-N mg/kg	Texture	Color/hue
05/28/92	2	50	15,500	221.2	3/26/92	2	17.1		
	4	210	19,500	76.1		4	22.5		
	6	1025	17,400	46.7		6	9		
	10	0				8	2.4		
						10	1.8		
06/18/92	2	40		230.2					
	4	200	22,800	79.2	5/26/92	1.4	10.2		
	6	850	20,100	53.3		3	17		
	10	0				5	17.4		
						6.3	2.2		
07/14/92	2	60		224.2					
	4	250	21,650	84.4		9.5	3.6		
	6	925	19,250	58.2		10	2.7		
	10	0							
					07/92	1	7.3	silt loam	
8/92	2	0				2	34.8	silty clay	
	4	325	19,800	94.1		3	28.4	clay	
	6	950	17,800	61.4		4	14.9	clay	
	10	0				5		clay to sandy clay	
						6	3.8	sand	
						7	1.6	coarse sand	
						8	0.8	coarse sand	
						9	0.8	coarse sand	
						10	0.8	coarse sand	
						1	6.2	silt loam	10YR 3/2
						2	30.9	silty clay	2.5YR 3/2
						3	20.3	silty clay	10YR
						4	8.6	Fn. sandy clay loam	7.5YR 5/8
						5		fine sandy loam	10YR 3/2
						6	3.6	loamy sand to sand	5YR 5/8
						7		coarse sand	10YR 4/3
						8	1.1	sand to coarse sand	10YR 6/4

Table E-2. Nitrate-N concentrations from lysimeter water samples and soil cores site I-15.

Lysimeter Water Samples					Soil Cores from Lysimeter Sites			Soil Description	
Date	Depth ft	Sample Volume ml	Specific Cond. uS/cm	Nitrate-N mg/L	Date	Depth ft	Nitrate-N mg/kg	Texture	Color/hue
05/28/92	2	525	4,250	99.1	3/92	2	4.8		
	4	525	3,450	89.2		4	7.9		
	6	310	4,000	66.8		6	4.9		
	10	0				8	6.9		
						10	11.4		
06/18/92	2	525	3,620	101.8					
	4	490	3,450	97.5	5/92	1	4.2		
	6	275	4,400	76.7		2	2.9		
	10	0				3	0.9		
						4			
07/14/92	2	450	3,570	129.1		5	0.6		
	4	390	3,790	104.3					
	6	375	4,250	85.8	7/92	1	18.1	silt loam	
	10	0				2	11.3	silt loam	
						3	3.2	loamy fine sand	
8/18/92	2	225	3,500	164.8		4	1.9	fine sand	
	4	425	3,600	111.1		5	0.8	coarse sand	
	6	300	4,300	90.1		6		coarse sand	
	10	0				7	0.3	coarse sand	
						8	BD	coarse sand	
						9	BD	coarse sand	
						10	BD	coarse sand	
					8/92	1	1.5	silt loam	10YR 3/2
						2	0.7	silt loam	10YR 4/4
						3	0.8	very fine silt loam	2.5YR 5/4
						4		fine sand	2.5YR 5/4
						5	0.8	fine sand	2.5 Y 6/4
						6	2.6	fine sand	2.5 Y 6/4
						7	1.9	medium sand	2.5 Y 6/4
						8	0.9	med. to coarse sand	2.5Y 6/4
						9	0.6	med. to coarse sand	2.5Y 6/4

Table E-3. Nitrate-N concentrations from lysimeter water samples and soil cores at site I-18.

Lysimeter Water Samples					Soil Cores from Lysimeter Sites				
		Sample	Specific					Soil Description	
Date	Depth ft	Volume ml	Cond. uS/cm	Nitrate-N mg/L	Date	Depth ft	Nitrate-N mg/kg	Texture	Color/hue
05/28/92	2	300	1,325	39.5	3/92	2	8.6		
	4	1335	1,340	40.2		4	7.5		
	6	200	2,180	62.3		6	9.2		
	10	0				8	6.9		
						10	11.3		
06/18/92	2	50		47.9					
	4	1275	1,290	36.3	5/92	1.5	3.2		
	6	150	2,150	55.8		2.5	2.8		
	10	0				4	2.6		
						5.5	2		
						7	3.2		
07/14/92	2	90		37.0		10	3		
	4	1165	1,300	41.8					
	6	190	1,825	47.0	7/92	1	5.8	silt loam	7.5YR 3/2
	10	0				2.5	7.8	fine sandy loam	7.5YR 3/3
						4	5.6	fine sandy loam	10YR 4/6
08/18/92	2	125	1,270	8.1		5	3.3	fine sandy loam	10YR 4/6
	4	1350	1,335	47.9		6	5.8	sandy clay to clay	2.5Y 6/2
	6	150	1,400	40.4		7	3.9	sandy clay	2.5Y 6/2
	10	0				8	4.6	loamy to cs. sand	10YR 4/6
						9	4.4	sand	7.5YR 4/6
						10	3.9	coarse sand	10YR 4/4
					8/92	1.5	5	silt loam	7.5YR 3/2
						2	5	vf sandy loam	10YR 3/3
						3	0.4	vf sandy loam	10YR 4/4
						4	0.7	vf sandy clay loam	10YR 5/4
						5	0.7	sandy clay loam	2.5Y 5/2
						6	1.4	sandy clay	7.5YR 5/8
						7	2.5	loamy sand	2.5YR 5/4
						8			
						9	1.4	coarse sand	10YR 4/4
						10	1.8	coarse sand	10YR 4/4

Table E-4. Nitrate-N concentrations from lysimeter water samples and soil cores at site I-29.

Lysimeter Water Samples					Soil Cores from Lysimeter Sites				
		Sample	Specific					Soil Description	
Date	Depth ft	Volume ml	Cond. uS/cm	Nitrate-N mg/L	Date	Depth ft	Nitrate-N mg/kg	Texture	Color/hue
05/28/92	2	750	535	32.7	3/92	2	45.9		
	4	975	1,385	33.6		4	221.1		
	6	1050	2,125	98.9		6	23.5		
	10	500	1,190	31.6		7	9.1		
						8	9.8		
06/18/92	2	675	935	58.7					
	4	975	1,200	42.0	5/92	1	10.4		
	6	1175	2,220	86.9		2	9.6		
	10	575	1,410	37.7		3	5.4		
						4	4.2		
07/14/92	2	700	640	61.6		5	3.4		
	4	970	925	78.3		6	2		
	6	1900	1,285	51.7		7	1.1		
	10	725	1,210	36.3		8			
						9			
08/18/92	2	750	810	84.4		10	0.7		
	4	1110	1,290	131.2					
	6	925	1,450	62.5	7/92	1	28.9	loamy fine sand	
	10	625	910	32.1		2	39.9	loamy fine sand	
						3	9.9	sand	
						4	5.7	coarse sand with	
						5		clay lamellae	
						6	5	sand	
						7	6.3	fine sand	
						8	6.6	fine sand	
						9	9.6	sand	
					8/92	1	1.8	loamy fine sand	10YR 4/3
						2.5	4.9	sandy clay loam	10YR 4/2
						4	7.9	fine sandy loam	10YR 4/2
						5	4.2	loamy fine sand	7.5YR 5/8
						6	3.4	fine sandy loam	7.5YR 5/8
						7	4.4	loamy fine sand	7.5YR 5/8
						8	4.6	loamy fine sand	7.5YR 6/8
						9	3.8	loamy fine sand	10YR 6/4

Table E-5. Nitrate-N concentrations from lysimeter water samples and soil cores at site I-30.

Lysimeter Water Samples					Soil Cores from Lysimeter Sites				
		Sample	Specific					Soil Description	
Date	Depth ft	Volume ml	Cond. uS/cm	Nitrate-N mg/L	Date	Depth ft	Nitrate-N mg/kg	Texture	Color/hue
5/92	2	475	2,100	26.9	3/92	2	9.3		
	4	925	1,550	15.3		4	1.4		
	6	80	1,230	38.8		6	3.9		
	10	375	1,625	52.8		8	3.2		
						10	0.9		
6/92	2	400	1,800	50.1					
	4	1050	1,465	21.9	5/92	1	2.1		
	6	200	1,395	22.4		2	1.9		
	10	550	2,200	60.05		3	1.3		
						4	1.8		
7/92	2	325	1,590	75.4		5	2.8		
	4	875	1,145	31.2		6	3.9		
	6	200	1,820	8.8		7	1.7		
	10	200	1,820	67		8	1.1		
8/92	2	300	1,390	67.3	7/92	1	3.2	fine sandy loam	
	4	475	1,090	37.2		2	2.5	fine sandy loam	
	6	200	1,830	10.4		3	1.9	fine sand	
	10	500	2,700	76.7		4	2.1	fine sand	
						5	2.9	silty clay	
						6	2.7	clay	
						7	2.7	sandy loam	
						8	2.3	loamy sand	
						9	1.7	fine sand	
						10	1.7	sand	
					8/92	1	2.5	fine sandy loam	7.5YR 3/2
						3	6	fine sandy loam	10YR 4/4
						4	2.8	loamy fine sand	10YR 4/4
						5	2.8	sandy clay loam	10YR 3/1
						6	2.1	fine sandy loam	10YR 5/6
						7	2.5	fine sandy loam	10YR 5/3
						8	3.9	sandy clay	2.5Y 6/2

Table E-6. Nitrate-N concentrations from lysimeter water samples and soil cores at site I-32.

Lysimeter Water Samples					Soil Cores from Lysimeter Sites				
		Sample	Specific					Soil Description	
Date	Depth ft	Volume ml	Cond. uS/cm	Nitrate-N mg/L	Date	Depth ft	Nitrate-N mg/kg	Texture	Color/hue
5/92	2	0			3/92	2	10.3		
	4	100	5,500	19.9		4	5.5		
	6	50	5,400			6	0.9		
	10	0				8	0.4		
						10	0.2		
6/92	2	50		64.1	5/92	1	6.1		
	4	90		19.4		2	3.2		
	6	150	5,100	22.2		3	0.4		
	10	0				4	0.4		
						5			
7/92	2	600	2,360	9.9		6	0.6		
	4	275	5,550	30		7			
	6	1350	4,420	20.3		8			
	10	0				9			
						10	1.2		
8/92	2	200	3,050	0.8	7/92	1	12.5	silty clay loam	10YR 3/1
	4	200	5,200	36.1		2	5.2	silty clay	10YR 3/1
	6	550	4,300	41.8		3	1.3	silty clay loam	2.5Y 4/2
	10	0				4	BD	fine sandy clay	2.5Y 5/2
						5	0.5	fine sandy clay	2.5Y 6/2
						6	BD	fine sandy clay	2.5Y 6/2
						7	BD	fine sandy clay	7.5YR 5/8
						8	0.6	fine sandy clay	7.5YR 5/8
						9	BD	fine sandy clay	7.5YR 5/8
						10	0.3	loamy sand	7.5YR 4/6
					8/92	1	2.6	silty clay loam	10YR 3/1
						2	1.9	silty clay	10YR 4/1
						3	2.1	silty clay	10YR 4/1
						4	1.9	sandy clay	2.5Y 5/2
						5	1.6	sandy loam	2.5Y 5/2
						6	1.1	sandy loam	2.5Y 6/2
						7	1.1	sandy loam	2.5Y 6/2
						8	0.3	loamy sand	2.5Y 6/3
						9	0.3	sand	10YR 5/4
						10	1.3	loamy fine sand	10YR 5/4

Appendix F

Equipment Installation and Sampling Methods

METHODS

Soil Sampling Methods

Soil samples were collected in the spring, 1992 using the USGS Failing auger rig. The first round of samples were to be analyzed before choosing the sites for the deep soil cores to the water table. After the spring, 1992 sampling the weather prevented the use of the auger rig and samples were collected by hand auger in the fall, 1992 and spring and fall, 1993. The Kansas Geological Survey Giddings auger was used in the fall, 1993 on the few occassions when it was dry enough. Because the USGS rig could not be used, cores greater than 10 ft (3 m) were not collected. The presence of hard caliche zones and perched water tables prevented the use of the Giddings rig in the fall of 1993 to collect deep cores.

The soils were collected in March of 1992 with the USGS failing auger-rig with a split spoon sampler. The sampler and tools were rinsed with deionized water between each 2-foot (0.6 m) sampling interval. In the fall of 1992, the weather was too wet to use the auger rig so hand augers were used instead. The hand augers were lined with plastic sleeves to prevent cross contamination of the samples. The sleeves, auger bit, and tools for removing the samples from the sleeve were washed with deionized water between each 2-foot (0.6 m) interval.

A maximum of five 2-foot (0.6 m) samples were collected to a depth of 10 ft (3 m) during each sampling period. Each 2-foot (0.6 m) interval was removed from the sleeve and placed in trays that were lined with freezer or waxed paper or aluminum foil. The soil samples were split in half and placed in zip-lock bags marked with the site number, date, and sampling interval and stored on ice for transport to Kansas State University for nitrate analysis. The samples were stored under refrigeration until analyzed. The soils were described by texture and color prior to bagging. When the 4–6 ft (1.2–1.8 m) sample was collected for the atrazine analysis by USGS the person removing and splitting the sample wore rubber gloves to prevent contamination of the sample.

The holes were filled one-half to two-thirds full with bentonite to prevent surface drainage to the 10 ft (3 m) depth. The location was noted by a combination of pacing and noting the relative location of landmarks at the sites.

Soil Chemistry Analyses

Soils from the March and October 1992 and March 1993 sampling periods were analyzed for nitrate by the Soil Chemistry Laboratory at Kansas State University. Each 2-foot interval was homoginized prior to a removal of a 10g sample for analysis. The samples were analyzed using a wet-chemistry calcium sulfate extraction method (10 g sample/ 20 ml calcium-sulfate solution). The leachate was analyzed using Ion Chromatography techniques. The detection limit was 0.05 mg/kg of nitrate-N.

Because of time constraints and the volume of samples to be analyzed, samples from the October 1993 round were analyzed by the Soil Testing Laboratory at Kansas State University. The method used was a KCl extraction procedure with the leachate being analyzed by standard colorimetric autoanalyzer techniques. The detection limit was 0.05 mg/kg nitrate-N.

Soil-water Sampling Methods

The samplers were installed using a Gidding soil probe to collect soil cores to the appropriate depth. The shallow samplers (2, 4, and 6 ft; 0.6, 1.2, 1.8 m) consisted of a single PVC pipe with a porous cup at the base. Vacuum was applied via a single tube through the cap. Samples were collected by removal of the cap and inserting a 1/4"-diameter polyethylene tube. The tube was connected to a sample volumetric flask that was connected to the handpump by tubing. The vacuum thus applied by the pump pulled the sample through the tubing into the flask without risk of contaminating the pump. After sample collection the sample tubing was inserted into a bucket of deionized water and the tubing and flask were rinsed with several volumes of deionized water before the next sample was collected.

One sampler at each site at the 10 ft (3 m) depth was sampled directly from a dedicated sampling tube inserted into the sampler. These samples were pumped into the flask and then transferred to the sample bottle. These methods are similar to those suggested by the manufacturer (Soil Moisture 2006G pump instructions).

Soil-water samples were collected four times during the growing season and soil cores for nitrate analysis were collected three times at each lysimeter site. Both water and soil samples were stored on ice during transport to either the Kansas State University or Kansas Geological Survey laboratories.

Water-sampling Procedures

At each sampling site the water from the well was pumped until the conductivity and temperature stabilized. The sample for nitrate was collected in a clean, 250-ml polyethylene bottle marked at 100-ml and acidified with 1-ml 6N HCl as a preservative. The ten water samples for major and minor ion analyses were collected in a 500-ml unacidified polyethylene bottle and a 250-ml acidified polyethylene bottle. After collection these samples were stored on ice until return to the Kansas Geological Survey for analysis by the Analytical Services Section. The samples were refrigerated until analyzed at the Kansas Geological Survey.

Water Chemistry Analyses

Nitrate (± 0.2 mg/L) was determined using the UV-spectro-photometric screening method for the Technicon Autoanalyzer II system which is based on the method from Standard Methods (Hathaway, 1990; APHA et al., 1985). Standard deviations listed for parameters marked with an '*' indicate data from analyses of 15 duplicate sets of irrigation- water samples collected in 1980 (Hathaway et al., 1990). Specific conductance (± 11 mS/cm)* was measured in the laboratory with a Lab-line meter at 25°C. Specific conductance was measured in the field using a Horiba Twin conductivity meter (model B-173, ± 50 µS/cm).

Complete chemical analyses included calcium, magnesium, sodium, potassium, strontium, ammonium, chloride, sulfate, nitrate, and bicarbonate. Cations (Ca^{+2},± 0.8

mg/L; Mg^{+2}, ± 0.4 mg/L; Na^{+}, ± 2.2 mg/L; K^{+}, ± 0.2 mg/L)* were measured with a Jarrel-Ash inductivity-coupled plasma (ICP) unit, and bicarbonate (± 0.4 mg/L) was measured by potentiometric titration using an autotitrimeter. pH was measured at the same time. Anions ($SO_4^{=}$, ± 1.5 mg/L and Cl^{-}, ± 2.1 mg/L)* and ammonium (± 0.1 mg/L) concentrations were measured by standard colorimetric autoanalyzer methods. Complete analyses agree within ± 2% on the charge balance.

A total of 19 water samples also were analyzed for nitrogen isotopes. These samples were analyzed at the University of Virginia using a PRISM stable- isotope ratio mass spectrometer using the methods of Macko et al. (1987) and Tapper et al. (1994). Isotope values were within ± 0.2 per mil (‰) the unit of measurement for isotope analyses.

Nitrogen Isotope Method

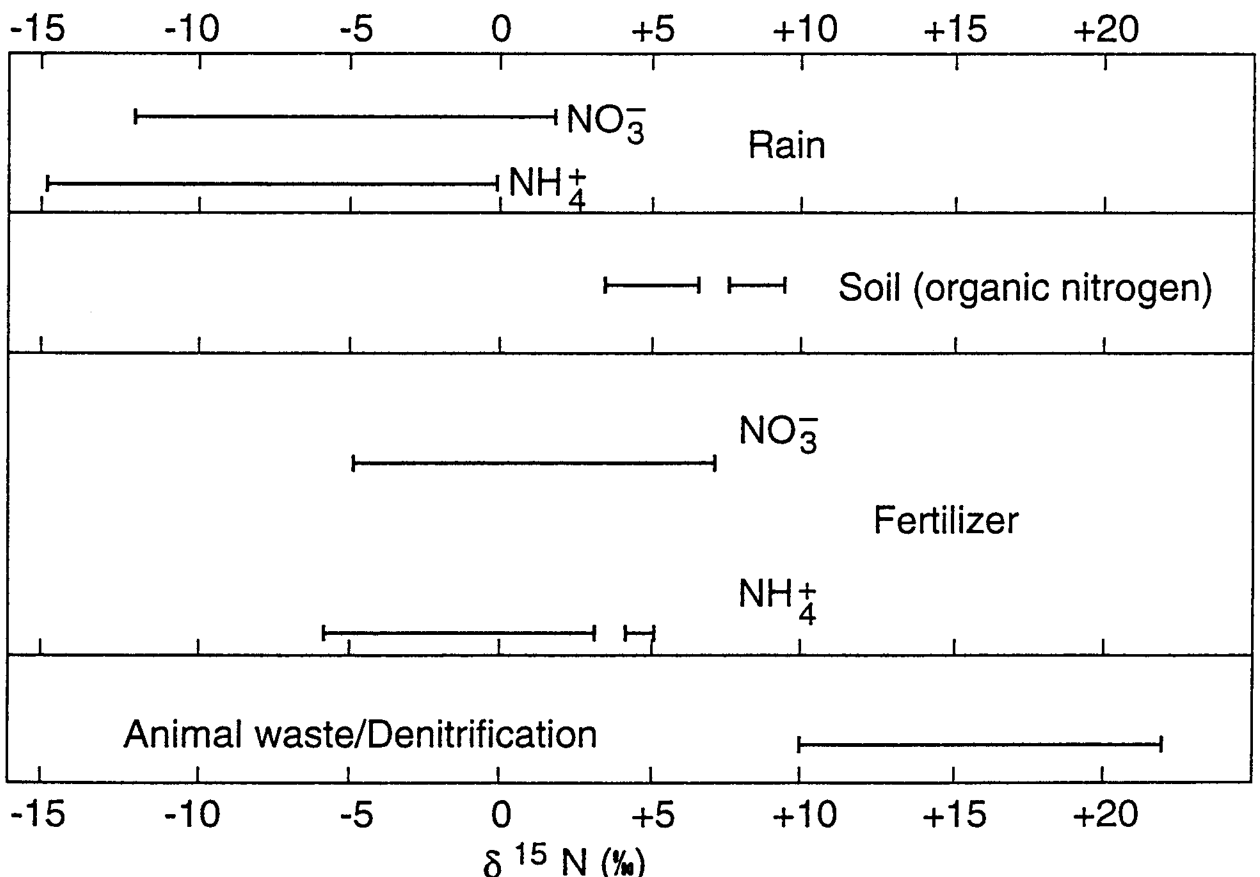
The major use of nitrogen-15 (^{15}N) in ground-water studies is to determine a source for the nitrate concentration in the water. The method is useful because there are two naturally occurring, stable isotopes of nitrogen, ^{14}N and ^{15}N. The nitrogen gas in the air is composed of 99.632 percent ^{14}N and 0.368 percent ^{15}N (Wolterink et al., 1979). The ^{15}N content of any particular nitrogen species (such as nitrate, nitrate, ammonium, or ammonia) is expressed in terms of the nitrogen isotope ratio del value (d) in parts per thousand (ppt), defined as follows:

$$\delta^{15}N = (R_{sample} / R_{standard} - 1) X 1000$$

where $R = {}^{15}N/{}^{14}N$.

The nitrogen isotope ratio for air is used as the standard and has a d value of zero. A $\delta^{15}N$ value of + 3.5 means that the sample contains 3.5 parts per thousand more ^{15}N than the standard. Conversely, a ^{15}N value of - 3.5 means that the sample contains 3.5 parts per thousand less ^{15}N than the standard.

Figure F-1 shows the range of ^{15}N isotope values obtained from several published studie for a variety of source materials (Heaton, 1986). The typical isotope range for fertilizer nitrogen is 0 to +8 ppt (Herbel and Spalding, 1993). The range for animal waste is +10 and above.



(after Heaton, 1986)

Figure F-1. Range of nitrogen-15 for a variety of sources. Data are from published articles. Both nitrate and ammonium based fertilizers are in the range from - 6 to +8 ‰. Animal waste is typified by high nitrate-N concentrations and $\delta^{15}N$ values > +10‰.

Work by Heaton (1986) and Herbel and Spalding (1993) show that denitrification can also result in enriched ^{15}N isotope values in the same range as animal waste. Denitrification causes enrichment because of the bacterial preference for the lighter isotope (^{14}N) if it is present in a compound. The utilization of ^{14}N results in an enrichment of ^{15}N in the residual nitrogen compound. Although denitrification processes can result in enriched isotope values, usually there is a much depleted nitrate concentration which accompanies the observed isotope value as well as other chemical and physical indicators of a reducing environment. With an animal waste source there are commonly high nitrate values present as well as other indicators of an oxidizing environment.

Statistical Methods

The SAS statistical package version 6 (1990) for UNIX network was used for statistical analysis of data. Nonparametric methods were used for the statistical analyses because the nitrate-N data for the soil profiles, water samples, and farming practices categories were strongly skewed and the variances and sample sizes were generally unequal. A natural log transform of the data was tried but in general did not improve the distribution of the data. In addition, the Shapiro-Wilks test for normality showed that the data were non-normal in distribution, and therefore the median rather than the mean was considered the best estimator of central tendency for various tests.

The Proc Univariate procedure was used to determine the maximum, minimum, first and third quartiles, and median values for construction of the box-plots presented in this study. Boxplots were used to present the data that showed statistical differences. We felt that the graphical display of the observable statistical differences was more effective than use of tables. All of the presented data showed statistical differences that were significant at less than $\alpha=0.10$ which was our level of acceptance or rejection for any given test.

Regression analysis was run using the PC Cohort COSTAT program ver. 2.2. Graphs were generated with the best-fit line for description of the data using the Microsoft Excel Program ver. 5.0. Multiple regression analysis was also done with the Cohort Costat program. Regression correlation coefficients (R^2) were considered significant if the calculated p was less than $\alpha = 0.10$.