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Scientific Investigations Report 2004–5123

U.S. Department of the Interior
U.S. Geological Survey

Cover photographs. Top—Agricultural fields in eastern North Carolina. Bottom—USGS hydrologist collecting a water-quality sample from a tile drain in an agricultural field in Greene County.

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Suggested citation:
Harden, S.L., and Spruill, T.B., 2004, Ionic composition and nitrate in drainage water from fields fertilized with different nitrogen sources, Middle Swamp watershed, North Carolina, August 2000–August 2001: U.S. Geological Survey Scientific Investigations Report 2004–5123, 14 p.

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Conversion Factors and Datum

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
meter (m)	3.281	foot (ft)
	Area	
hectare (ha)	2.471	acre
	Mass	
gram (g)	0.03527	ounce avoirdupois (oz)

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Concentrations of chemical constituents in water are given in milligrams per liter (mg/L).

Acronyms and Abbreviations:

BMP	best-management practice
g N/ha/d	grams of nitrogen per hectare per day
L/d	liter per day
L/min	liter per minute
mg/L as N	milligram per liter as nitrogen
USGS	U.S. Geological Survey

Ionic Composition and Nitrate in Drainage Water From Fields Fertilized with Different Nitrogen Sources, Middle Swamp Watershed, North Carolina, August 2000–August 2001

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Abstract

A study was conducted from August 2000 to August 2001 to characterize the influence of fertilizer use from different nitrogen sources on the quality of drainage water from 11 subsurface tile drains and 7 surface field ditches in a North Carolina Coastal Plain watershed. Agricultural fields receiving commercial fertilizer (conventional sites), swine lagoon effluent (spray sites), and wastewater-treatment plant sludge (sludge site) in the Middle Swamp watershed were investigated. The ionic composition of drainage water in tile drains and ditches varied depending on fertilizer source type. The dominant ions identified in water samples from tile drains and ditches include calcium, magnesium, sodium, chloride, nitrate, and sulfate, with tile drains generally having lower pH, low or no bicarbonates, and higher nitrate and chloride concentrations. Based on fertilizer source type, median nitrate-nitrogen concentrations were significantly higher at spray sites (32.0 milligrams per liter for tiles and 8.2 milligrams per liter for ditches) relative to conventional sites (6.8 milligrams per liter for tiles and 2.7 milligrams per liter for ditches). The median instantaneous nitrate-nitrogen yields also were significantly higher at spray sites (420 grams of nitrogen per hectare per day for tile drains and 15.6 grams of nitrogen per hectare per day for ditches) relative to conventional sites (25 grams of nitrogen per hectare per day for tile drains and 8.1 grams of nitrogen per hectare per day for ditches). The tile drain site where sludge is applied had a median nitrate-nitrogen concentration of 10.5 milligrams per liter and a median instantaneous nitrate-nitrogen yield of 93 grams of nitrogen per hectare per day, which were intermediate to those of the conventional and spray tile drain sites. Results from this study indicate that nitrogen loadings and subsequent edge-of-field nitrate-nitrogen yields through tile drains and ditches were significantly higher at sites receiving applications of swine lagoon effluent compared to sites receiving commercial fertilizer.

Introduction

In North Carolina, about 40 percent of the cropland requires drainage improvements to increase agricultural production in poorly drained soils (Evans and others, 1991; Gilliam and others, 1997). A common practice for increasing drainage in poorly drained soils is to install ditches and subsurface tile drains to lower the water table beneath agricultural fields. These drainage improvements increase the amount of land available for cultivation; however, the process of redirecting shallow ground water beneath agricultural fields through tile drains to ditches can alter the quality of drainage water exiting the fields to receiving streams. Nitrate-nitrogen concentrations ranging from about 5 to 50 milligrams per liter (mg/L) in tile drainage water have been noted in various studies (Baker and others, 1975; Gast and others, 1978; David and others, 1997; Jaynes and others, 2001; Randall and Mulla, 2001).

In eastern North Carolina, excessive nutrient loadings have contributed to the degradation of surface-water quality in the Neuse River basin. The North Carolina Environmental Management Commission adopted rules in 1997 to reduce nitrogen loads to the Neuse River by 30 percent to support the Neuse River Nutrient Sensitive Waters Management Strategy (North Carolina Division of Water Quality, 2002). For agricultural land, several combinations of best-management practices (BMPs), including nutrient management, controlled drainage, forested riparian buffers, and vegetative filter strips, were proposed for reducing nutrient loads. Because tile drains and ditches are constructed channels that artificially intercept the water table, they can allow ground water containing agricultural chemicals beneath cultivated fields to bypass natural streamside buffers and organic carbon-rich streambeds that normally would reduce nitrate in the ground water before it discharges to streams (Gilliam and others, 1997; Spruill and others, 1998; Spruill, 2001). Subsurface tile drains are considered an important pathway for nitrate-nitrogen transport to surface water in some agricultural watersheds (Soenksen, 1996; David and others, 1997; Randall and Mulla, 2001).

Nutrient transport, especially nitrate-nitrogen, from agricultural fields with drainage improvements has been the focus of much research (Baker and others, 1975; Gast and others, 1978; Skaggs and Gilliam, 1981; David and others, 1997). The overall transport of nitrate-nitrogen from a tile or ditch is controlled by the quantity of nitrate-nitrogen in the water and the volume of discharged water. Some of the factors that influence nitrate-nitrogen concentrations at a site include the timing and amounts of fertilizer applications, crop types having different uptake efficiencies, and denitrification (Gambrell and others, 1975a; Baker and Johnson, 1981; Gilliam and others, 1997; Jaynes and others, 2001). Water flow from a site is influenced by various factors, such as rainfall intensity and frequency, antecedent soil-moisture conditions, land slope and drainage characteristics, depth and spacing of tile drains and ditches, and lateral ground-water inflow to ditches from fields (Baker and others, 1975; Gambrell and others, 1975b; Skaggs and Gilliam, 1981; Gilliam and others, 1997; Randall and Mulla, 2001; Calhoun and others, 2002).

The purpose of this report is to characterize the quality of drainage water in tile drains and ditches with respect to different agricultural settings in a low-gradient, organic-rich, Coastal Plain watershed. The study approach was to periodically sample 11 tile drains and 7 ditches for 1 year to evaluate water-quality conditions in relation to different nitrogen fertilization practices used in the study area. Information obtained from this study is intended to provide a better understanding of the effects of land-management practices on nitrogen loading associated with artificially drained farmland and to assist water-resource managers in determining priorities for effective management of nutrient-reduction strategies.

Acknowledgments

This report is based on work conducted cooperatively by the U.S. Geological Survey, Raleigh, North Carolina, and the North Carolina Department of Environment and Natural Resources, Division of Water Quality, Groundwater Section. The authors thank Ted Mew and Ray Milosh of the North Carolina Department of Environment and Natural Resources, Division of Water Quality, Groundwater Section, in Raleigh for their help and support in this project. Our appreciation is extended to the private landowners in Greene and Pitt Counties who graciously participated in this study, and the staffs of the U.S. Department of Agriculture, Natural Resources Conservation Service offices in Greene and Pitt Counties, especially Don White who assisted in locating tile drains and ditches for the investigation.

Study Area

The study was conducted in the Middle Swamp watershed (13,634 hectare [ha]) of the Neuse River basin in the North Carolina Coastal Plain physiographic province (fig. 1). Sandy Run and Middle Swamp are the two major streams forming the watershed. Geology in the area is primarily sedimentary rock and unconsolidated sediment layers. The hydrogeology of the area consists of the unconfined surficial aquifer, which is underlain by several deeper confined aquifers; the uppermost confined aquifer over much of the area is the Yorktown aquifer. The surficial aquifer is about 5 to 10 meters (m) thick, and the underlying confining layer ranges from about 6 to 15 m thick. Depth to water near hilltops generally ranges from less than 1 m during the winter to more than 3 m during the summer growing season. The saturated thickness of the unconfined aquifer at most sites generally was less than 6 m, and the lower boundary of the surficial aquifer generally was less than 8 m below land surface. First order streams, tile drains, and ditches generally drain the soils overlying the surficial aquifer in the uplands. Based on hydrograph separation of data from other streams in the Coastal Plain, shallow aquifers contribute more than 50 percent of the annual streamflow (McMahon and Lloyd, 1995). Precipitation at Kinston, N.C., during August 2000–August 2001 was 130.2 centimeters (cm), similar to the 1966–2004 average of 137.5 cm for the same months (Southeast Regional Climate Center, 2004). During the project period (August 2000–August 2001), however, rainfall was below the 1966–2004 average (72.03 cm) for every month beginning in October through May and totaled 43.53 cm. These months, when vegetation is dormant, are typically when most aquifer recharge, runoff, and nonpoint-source nutrient transport occurs in North Carolina.

Based on 1998 land-use information (Ross Lunetta, U.S. Environmental Protection Agency, written commun., April 10, 2000), the Middle Swamp watershed primarily is agricultural (51 percent), with the remaining area in forests (32 percent), wetland (12 percent), and urban areas (5 percent). About 72 percent of the agricultural land is used for row crops, and 28 percent is used for pasture and hay. Cotton, soybeans, corn, and wheat were the major crops grown in 2001 and 2002 in the northern Coastal Plain counties (including Greene, Pitt, and Wilson Counties) (North Carolina Department of Agriculture and Consumer Services, 2004), where the Middle Swamp watershed is located. Animal production in the watershed is substantial—hog production in North Carolina increased from about 2 million hogs in 1990 to more than 10 million hogs by 1998 (Mallin, 2000); more than 90 percent of these facilities are located in the Coastal Plain (Mallin and Cahoon, 2003). In 1998, there were about 100,000 hogs in the Middle Swamp watershed, with 92 percent in the Sandy Run basin (fig. 1; Ross Lunetta, U.S. Environmental Protection Agency, written commun., April 10, 2000).

Methods

Agricultural fields with existing ditches and(or) tile drains and in which different sources of nitrogen fertilizer were applied to row crops were selected for study. The types of

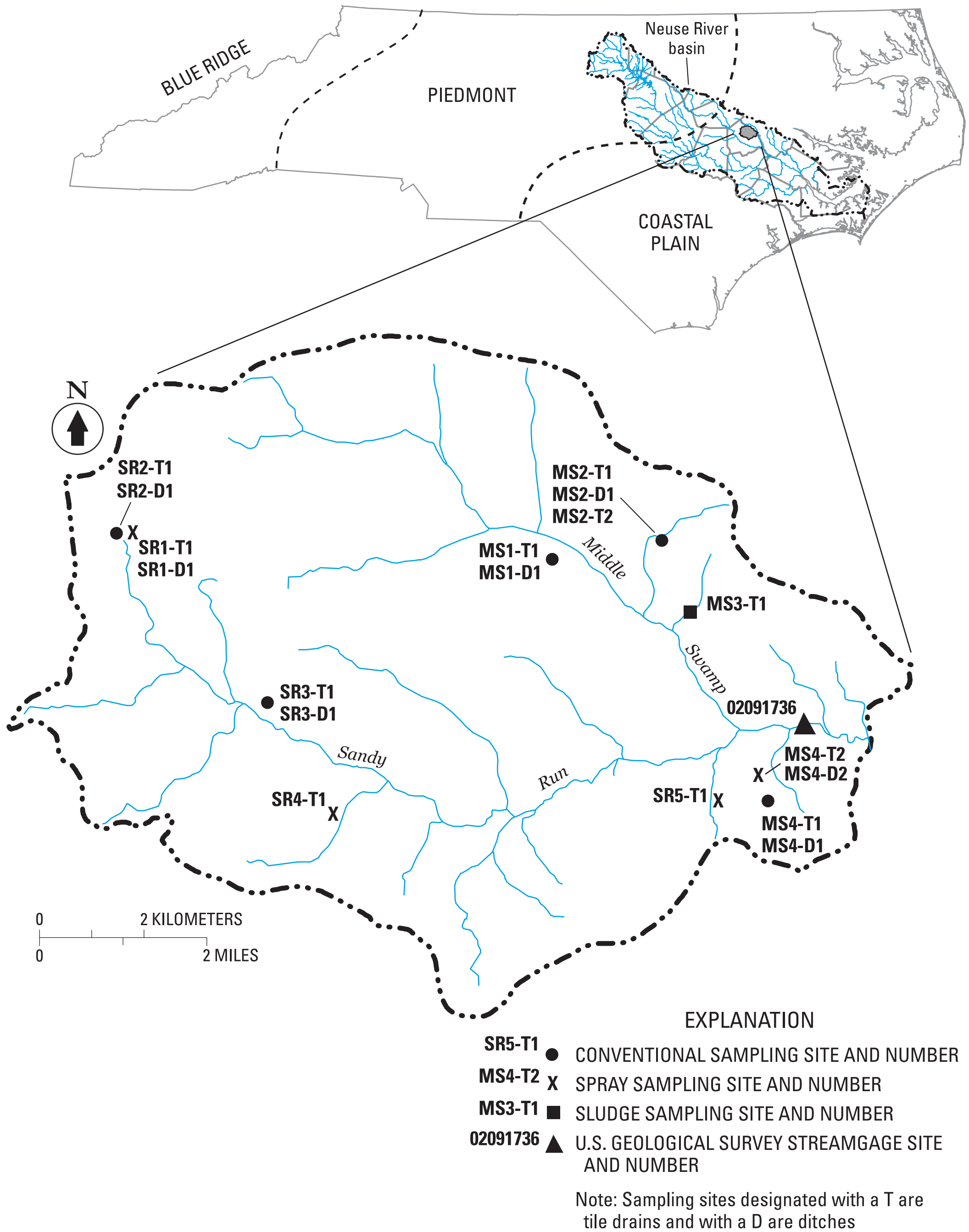

Figure 1. Locations of study sites in the Middle Swamp watershed in the Neuse River basin, North Carolina.

fertilizer applied to study sites include conventional inorganic fertilizer, swine lagoon effluent, and wastewater-treatment plant sludge. In the Middle Swamp watershed, seven study sites consist of a paired tile drain and receiving ditch (fig. 1). Individual tile drains that empty directly into a riparian buffer or swampy flood plain and have no downstream ditch sampling site were studied at four locations.

Study sites where swine lagoon effluent was sprayed onto fields include two paired tile and ditch sites (SR1-T1 and SR1-D1, and MS4-T2 and MS4-D2) and two tile sites (SR4-T1 and SR5-T1), hereafter referred to as spray sites. Sludge from a wastewater-treatment plant was spread onto a field in slurry form at tile location MS3-T1, referred to as the sludge site. The remaining five paired tile and ditch sites (SR2-T1 and SR2-D1, SR3-T1 and SR3-D1, MS1-T1 and MS1-D1, MS2-T1 and MS2-D1, and MS4-T1 and MS4-D1) and individual tile site MS2-T2 received applications of commercial inorganic fertilizer and hereafter are referred to as conventional sites (fig. 1).

Water-quality samples and discharge measurements were collected from August 2000 to August 2001 approximately on a monthly basis; however, selected precipitation events were targeted to obtain data during various flow conditions. During sample collection, field measurements of pH, dissolved oxygen, specific conductance, and temperature were obtained by using a Hydrolab MiniSonde. Field processing of water-quality samples collected from tile-drain outlets and downstream ditch sites at the field edge next to the riparian buffer included sample filtration and preservation. The samples were shipped by overnight delivery to the U.S. Geological Survey (USGS) water-quality analytical laboratory in Ocala, Fla., for chemical analyses of nutrients, anions, and cations. Methods used for chemical analysis by the Ocala laboratory are presented in Fishman and Friedman (1989). The nitrate concentration values presented in this report were measured as nitrite plus nitrate in milligrams per liter as nitrogen. Because nitrite typically constitutes less than 1 percent of the total concentration, the reported values are presented and discussed as nitrate.

Discharge measurements at tile-drain outlets were determined primarily by using volumetric methods (Rantz and others, 1982). A velocity meter was used to determine tile discharge when volumetric methods were not feasible. Discharge measurements at ditch sites also were determined by using a velocity meter (Rantz and others, 1982). In some cases, discharge data obtained with the velocity meter are considered estimated when flow rates were less than about 19 liters per minute (L/min) because of limitations in using the meter at low-flow velocities. For the purpose of this report, the presentation and discussion of data at selected sites do not include sample results when discharge values were estimated to be less than 0.19 L/min. This flow rate is used to represent minimal flow that could not be measured by using available equipment and the point at which the flow of water past the edge of the field by way of drainage ditches is considered to be insignificant. All chemical analytical results and discharge measurements obtained for all sites investigated during this study are presented in Ragland and others (2001; 2002).

In estimating the drainage area of a tile drain, previous investigators (Baker and Johnson, 1981; Jaynes and others, 2001) assumed the drainage area to be equal to the tile length multiplied by the tile-spacing interval. Most tile systems in this study consisted of a main line with multiple, parallel lateral lines with spacing intervals of about 30.5 m. Several tile systems had a single lateral line that had a perpendicular or angled connection to the main line. The drainage areas for tile sites were estimated by developing a drainage perimeter, or boundary, around each tile system. Determination of the drainage areas for tile sites was treated equally in that the drainage perimeter for each tile system was assumed to extend outward 61 m, or twice the tile-spacing interval of 30.5 m. Although a factor of 1 times the spacing interval was used in the previous investigations, a more conservative factor of 2 times the spacing interval was used in this study to account for potential ground-water inflows from adjacent areas. Ditch drainage areas were estimated by using land-surface elevation data contoured at 0.6-m intervals. Drainage areas ranged from 1.81 to 5.31 ha for tile sites and from 5.66 to 99.26 ha for ditches (table 1).

The tile and ditch study sites not only represent locations with different fertilizer source types but also hydrologic-soil groups with varying degrees of drainage capacity. Hydrologic-soil group data for the Middle Swamp watershed were compiled from the U.S. Department of Agriculture (1974, 1980, and 1995). Within the drainage area of each site, soils classified as hydrologic-soil groups A and(or) B were combined to represent the areal percentage of soil that is excessively to moderately well drained. Soils classified as hydrologic-soil groups C, D, and(or) B/D were combined to represent the areal percentage of soil that is somewhat poorly drained to very poorly drained (table 1).

Nitrate-nitrogen yields at tile and ditch sites were determined by first coupling the discharge measurements with the dissolved nitrate concentration data to obtain nitrate-nitrogen loads for each sampling date. The nitrate-nitrogen loads were normalized to the drainage area at each site to compute instantaneous nitrate-nitrogen yields. The calculated nitrate-nitrogen yields represent an instantaneous yield at the time of sample collection and not an annual cumulative loss of nitrate-nitrogen. Because of the limited (1 year) sampling period and relatively low rainfall amounts experienced during times when runoff transport normally occurs, it was determined that valid site comparisons could reasonably be made among sites, even though annual loads comparisons could not. For discussion purposes, the instantaneous yield values are expressed on a daily basis as grams of nitrogen per hectare per day (g N/ha/d). Nitrate-nitrogen yields were computed for each site with the exception of MS4-D1 (fig. 1; table 1), which had the smallest ditch drainage area and a high degree of uncertainty associated with discharge measurements. Thus, this site was not used in the evaluation of nitrate-nitrogen yields.

Table 1. Drainage area and soil characteristics for study sites in the Middle Swamp watershed in the Neuse River basin, North Carolina.

[ha, hectare]

Site number[a] (fig. 1)	Drainage area (ha)	Hydrologic-soil group: Groups A and(or) B (percent)	Hydrologic-soil group: Groups C, D, and(or) B/D (percent)	Drainage classification[b]
Conventional sites				
SR2-T1	2.09	46	54	Mixed
SR2-D1	99.26	39	61	Mixed
SR3-T1	2.63	0	100	Poor
SR3-D1	9.41	16	84	Poor
MS1-T1	2.51	100	0	Well
MS1-D1	37.37	25	75	Poor
MS2-T1	3.63	4	96	Poor
MS2-D1	9.88	30	70	Poor
MS2-T2	5.31	88	12	Well
MS4-T1	1.82	97	3	Well
MS4-D1	5.66	86	14	Well
Spray sites				
SR1-T1	1.81	47	53	Mixed
SR1-D1	15.11	78	22	Well
SR4-T1	1.84	100	0	Well
SR5-T1	1.85	100	0	Well
MS4-T2	3.81	16	84	Poor
MS4-D2	11.15	76	24	Well
Sludge site				
MS3-T1	4.92	0	100	Poor

[a]Sites designated with a T are tiles; sites designated with a D are ditches.

[b]Well-drained sites are dominated by hydrologic-soil groups A and(or) B. Poorly drained sites are dominated by hydrologic-soil groups C, D, and(or) B/D. Sites with mixed drainage have a mixture of hydrologic-soil groups.

Ionic Composition of Water from the Tile Drains and Ditches

The general ionic composition of water samples from the tile drains and ditches was examined by using Piper diagrams (Piper, 1944) to evaluate possible chemical differences as a result of fertilizer source type. Piper diagrams are useful for discerning clusters of samples that exhibit similar chemical characteristics, where chemical composition is indicated by the relative percentage of cations and anions totaling 100 percent (Hem, 1985). Piper diagrams typically include the cations calcium, magnesium, sodium, and potassium and the anions chloride, nitrate, bicarbonate, and sulfate. Sulfate, bicarbonate, and nitrite plus nitrate normally are represented on each axis of the trilinear portion for anions; however, for this report, sulfate and bicarbonate were grouped on the same axis to obtain better separation between fertilizer categories that were investigated.

Potential differences in ionic composition of the drainage water initially were evaluated for conventional tile and ditch sites (fig. 2A) and spray tile and ditch sites (fig. 2B). The ionic composition of tile water and ditch water is more variable at the conventional sites compared to the spray sites. In general, the principal ions composing tile water at the conventional sites include, in decreasing proportions, the cations calcium and magnesium and the anions chloride, nitrate, and sulfate. The principal ions composing ditch water at the conventional sites include, in decreasing proportions, the cations calcium and magnesium and the anions chloride and sulfate. At conventional tile site SR2-T1 and conventional ditch site MS1-D1 (fig. 2A), a shift in the cationic composition reflects a higher percentage of sodium than calcium relative to the other conventional tile and ditch sites. Although inorganic fertilizers are applied to crops at SR2-T1 and MS1-D1, the strong shift to sodium in the cations in drainage water from these sites may indicate an additional source of nutrients.

In applying tree-based classification methods for identifying sources of nitrate contamination in groundwater samples from shallow Coastal Plain aquifers in North Carolina, Spruill and others (2002a) noted that sodium-potassium ratios greater than 3.2 were indicative of septic wastes as a source of nitrate. Samples from tile site SR2-T1 and ditch site MS1-D1 have median sodium-potassium ratios of 3.1 and 4.1, respectively, whereas the remaining conventional tile and ditch sites have median sodium-potassium ratios that are less than or equal to 2.2. The higher sodium-potassium ratios may indicate that septic wastes influence the chemical composition of drainage water at conventional tile site SR2-T1 and ditch site MS1-D1. Potential sources of septic wastes at these two sites include a septic drain field from a farmhouse located near SR2-T1 and a residential neighborhood located in the headwater drainage of MS1-D1.

The ionic compositions of drainage water from tile and ditch spray sites (fig. 2B) fall in fairly tight clusters and exhibit less chemical variability compared to the conventional sites. The principal ions composing tile water at the spray sites include, in decreasing proportions, the cations calcium and sodium and the anions nitrate and chloride. The principal ions composing ditch water at the spray sites include, in decreasing proportions, the cations calcium, sodium, and magnesium and the anions chloride and nitrate. No notable difference was observed in cation chemistry between tile water and ditch water at the spray sites (fig. 2B). Similarly, there was a uniform distribution of cations between tile water and ditch water at the conventional sites if tile site SR2-T1 and ditch site MS1-D1 were not considered (fig. 2A).

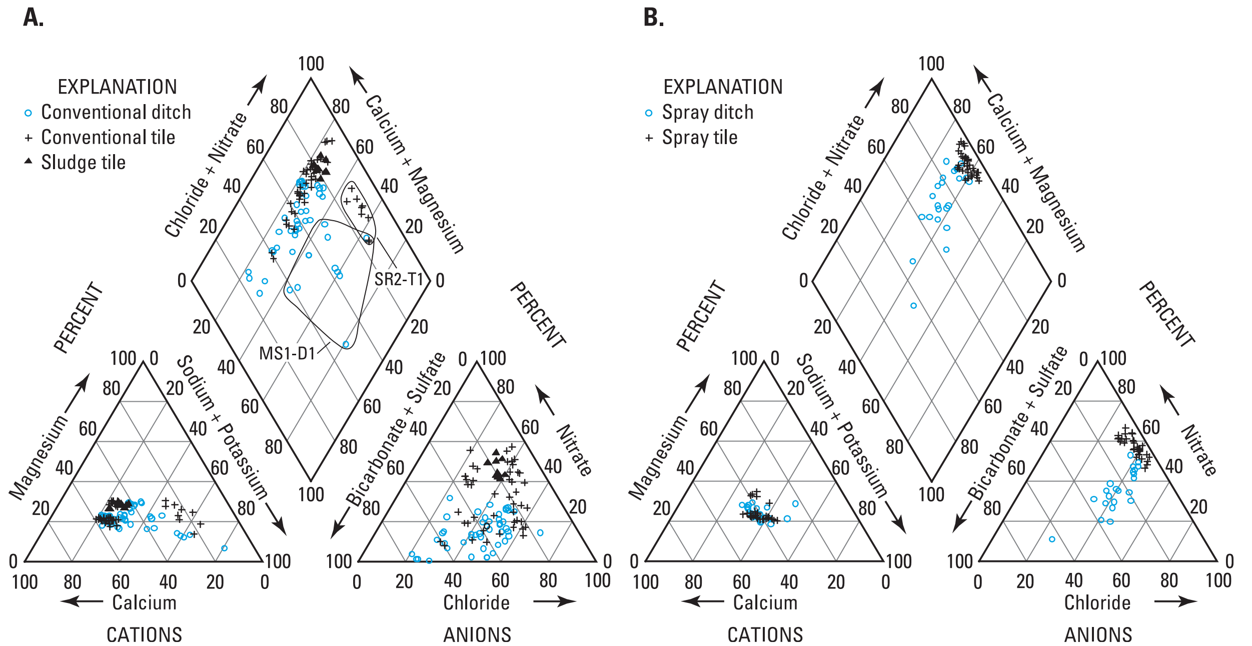

Figure 2. Piper diagrams showing ionic composition of water grouped by (A) conventional ditches and tiles, and the sludge tile, and (B) spray ditches and tiles in the Middle Swamp watershed.

The most notable difference between tile water and ditch water at the conventional and spray sites was in the anion chemistry, where the ditch water had a higher percentage of bicarbonate and sulfate and a lower percentage of nitrate compared to tile water (fig. 2). Although bicarbonate is combined with sulfate on the Piper diagrams, bicarbonate was a major constituent in ditch water and essentially is absent in tile water having pH values usually less than 4.5. The ionic composition of water in the ditches is influenced not only by tile drainage inputs but also by receiving overland runoff and ground-water discharge. The lower percentage of nitrate in the ditches relative to the tiles likely reflects dilution and denitrification processes.

Potential chemical differences at ditch and tile locations resulting from fertilizer source type were evaluated further by grouping the ionic compositions of water from conventional ditches and spray ditches (fig. 3A) and conventional tiles, spray tiles, and the sludge tile (fig. 3B) for comparison. This

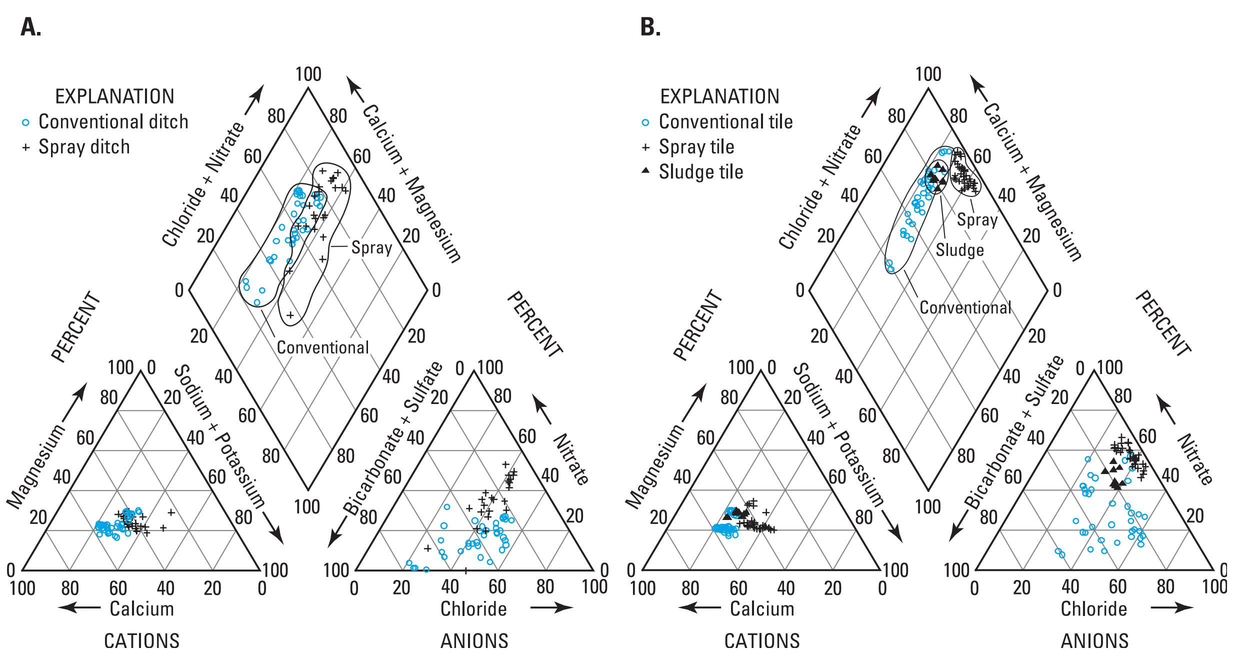

Figure 3. Piper diagrams showing ionic composition of water grouped by (A) conventional ditches and spray ditches, and (B) conventional tiles, spray tiles, and the sludge tile in the Middle Swamp watershed.

comparison did not include conventional ditch site MS1-D1 and conventional tile site SR2-T1 because of the potential influence of septic wastes at these sites. Ditch and tile waters differed in chemical composition depending on fertilizer type (fig. 3). For both ditches and tiles, the spray sites had a higher percentage of sodium than calcium relative to the conventional sites, reflecting the greater predominance of sodium in animal wastes compared to inorganic fertilizer (Spruill and others, 2002a). Also, there was a shift in the anionic composition of water at spray ditches and spray tiles. This shift reflects a higher percentage of nitrate than sulfate at the spray ditch and tile sites relative to the conventional ditch and tile sites. The higher percentage of nitrate in water at the spray sites likely reflects higher nitrate loadings at the spray sites compared to the conventional sites; this is discussed further in the evaluation of the nitrate concentration and yield data.

Animal-derived wastes were used as a source of nutrients at both the sludge tile site and the spray tile sites; however, the ionic composition of tile water at the sludge site was intermediate to that of spray tiles and conventional tiles (fig. 3B). Tile water at the sludge site and spray sites had nitrate and chloride as the primary anions, whereas chloride, nitrate, and sulfate were the primary anions at the conventional sites. The primary cations in tile water at the sludge site and conventional sites were calcium and magnesium, whereas calcium and sodium were the primary cations at the spray sites. Although the sludge tile site received applications of animal wastes that were anthropogenic in nature, they differed from the hog wastes in that the treated sludge could contain large amounts of calcium, thereby decreasing the relative percentage of sodium in water at the sludge tile site.

Nitrate Concentrations and Yields

Nitrate-nitrogen concentration and yield data for individual study sites (table 2) were used to examine potential differences based on site type (tile and ditch) and fertilizer source type (conventional, spray, and sludge). Temporal plots of nitrate-nitrogen concentrations and yields for representative tile and ditch sites having applications of conventional fertilizer and applications of swine lagoon effluent are provided in figures 4A and 4B, respectively. Although the data set obtained during this 1-year study may be too limited to sufficiently

Table 2. Discharge and nitrate data at study sites in the Middle Swamp watershed, August 2000 to August 2001.

[L/min, liter per minute; mg/L as N, milligram per liter as nitrogen; g N/ha/d, grams of nitrogen per hectare per day; —, no data]

Site number (fig. 1)	Number of samples	Range in discharge (L/min)	Median discharge (L/min)	Range in nitrate concentration (mg/L as N)	Median nitrate concentration (mg/L as N)	Median nitrate yield (g N/ha/d)
			Conventional sites			
SR2-T1	10	0.4 – 43.8	7.3	8.4 –15	11	52
SR2-D1	10	4.2 – 1,730	43.1	0.2 – 5.9	4.0	4
SR3-T1	9	0.4 – 102.5	2.6	4.0 – 9.6	5.8	14
SR3-D1	11	5.6 – 322.3	15.6	0.8 – 5.4	3.7	8
MS1-T1	4	19.2 – 81.0	47.6	9.4 –15	12.5	377
MS1-D1	10	2.0 – 1,199	116.5	0.3 – 4.7	2.1	5
MS2-T1	9	0.3 – 50.3	16.8	1.5 – 5.1	2.7	13
MS2-D1	8	6.8 – 153.7	46.1	1.7 – 4.2	2.1	17
MS2-T2	6	1.1 – 49.6	13.7	1.6 – 4.3	2.8	8
MS4-T1	9	0.8 – 63.6	6.7	6.4 –11	7.0	43
MS4-D1	7	—	—	0.1 – 5.6	2.4	—
			Spray sites			
SR1-T1	5	1.8 – 96.0	6.4	20 – 25	22	118
SR1-D1	9	6.6 – 186.6	21.0	1.2 –13	8.2	16
SR4-T1	12	1.0 – 160.0	15.2	27 – 58	37	424
SR5-T1	9	0.6 – 66.5	4.7	30 – 46	35	169
MS4-T2	7	25.3 – 102.1	53.4	29 – 35	30	606
MS4-D2	14	3.9 – 143.2	32.1	3.5 – 21	8.8	61
			Sludge site			
MS3-T1	10	2.2 – 160.1	29.4	9.2 – 20	10.5	93

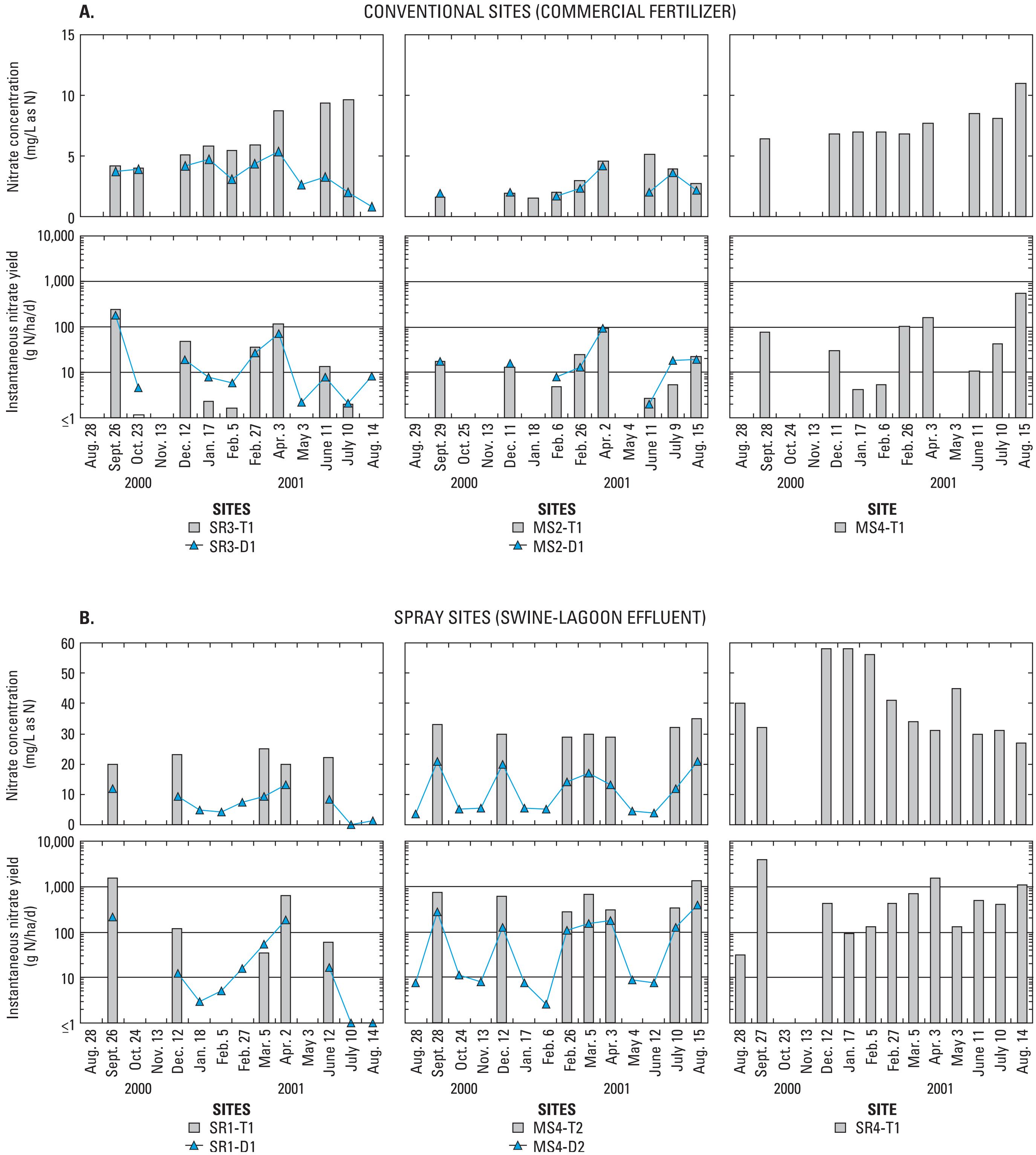

Figure 4. Temporal distribution of nitrate concentrations and instantaneous yields at selected (A) conventional sites and (B) spray sites in the Middle Swamp watershed. Note: Gaps in data represent dates when samples were not collected because of no-flow conditions.

characterize seasonal trends in nitrate concentrations and yields at the study sites, the data provide useful insights regarding the use of different fertilizers in the study area and the effect of tile drainage on ditch water quality.

Examination of sites with different fertilizer use indicates that median nitrate-nitrogen concentrations were nearly always higher at spray sites than conventional sites (table 2; fig. 4). This is illustrated at paired spray sites SR1-T1 (22 mg/L) and SR1-D1 (8.2 mg/L), paired spray sites MS4-T2 (30 mg/L) and MS4-D2 (8.8 mg/L), paired conventional sites SR3-T1 (5.8 mg/L) and SR3-D1 (3.7 mg/L), and paired conventional sites MS2-T1 (2.7 mg/L) and MS2-D1 (2.1 mg/L). The data further indicate that, regardless of fertilizer source type, median nitrate-nitrogen concentrations at paired tile and ditch sites were higher for tiles relative to the ditches.

At conventional sites, nitrate-nitrogen concentrations generally were highest in the spring and summer, which may be a result of nitrogen fertilizer applications during the growing season. Nitrogen fertilizer applications in the study area typically occur in the spring from about March to May. The fertilizer application generally is split so that part of the fertilizer is applied to the crop at the time of planting in early spring and the remaining amount is applied during the growing period and increased crop uptake. At paired conventional tile site MS2-T1 and ditch site MS2-D1, as well as conventional tile site MS4-T1, nitrate-nitrogen concentrations typically were highest from April to August 2001 (fig. 4A). This pattern also is observed for conventional tile site SR3-T1; however, the lowest observed nitrate-nitrogen concentrations for corresponding ditch site SR3-D1 occurred during this same period, likely as a result of lower yields from the tile (fig. 4A).

Nitrate-nitrogen concentrations at spray tile and ditch sites were more variable than at the conventional sites and exhibited no consistent temporal pattern. For example, spray tile site SR4-T1 exhibited significant temporal variability in nitrate-nitrogen concentrations (ranging from 27 to 58 mg/L), with the highest values occurring from December 2000 to early February 2001 (fig. 4B). The cause of the higher nitrate-nitrogen values in the winter months at this spray site is unknown but is likely associated with spraying needed to provide nutrients to cover crops or to reduce the volume of wastes held in the lagoon. With similar crops grown at individual study sites, the timing of nitrogen fertilizer applications of either conventional fertilizer or swine wastes to meet crop requirements occurs during the same general period. Unlike the conventional sites, however, the spray sites are subject to climatic conditions in which excessive rainfall may impose the need to spray wastes at any time of the year to reduce the volume of wastes held in the lagoon. As noted in previous studies (Baker and Johnson, 1981; Jaynes and others, 2001), some of the temporal differences in nitrate-nitrogen concentrations observed between the conventional sites and spray sites likely reflect differences in the timing and amounts of fertilizer applications at the different site types.

Examination of instantaneous nitrate-nitrogen yields indicates differences in nitrate-nitrogen export from tile and ditch sites having different fertilizer source types. Spray tile and ditch sites typically had higher median nitrate-nitrogen yields than the conventional tile and ditch sites (table 2), as illustrated by paired spray sites SR1-T1 (118 g N/ha/d) and SR1-D1 (16 g N/ha/d) and paired conventional sites SR3-T1 (14 g N/ha/d) and SR3-D1 (8 g N/ha/d). For a given site, nitrate-nitrogen yields varied in relation to changes in nitrate-nitrogen concentration and discharge. Comparison of nitrate-nitrogen concentration and discharge data indicates no correlation between concentration and discharge at the conventional and spray tile sites (fig. 5A) and the conventional ditch sites (fig. 5B). At each site type, nitrate-nitrogen concentrations usually varied by less than an order of magnitude, and instantaneous discharge varied by more than two orders of magnitude, indicating that variations in nitrate-nitrogen yield for the conventional tile and ditch sites and spray tile sites were influenced primarily by changes in water discharge compared to changes in nitrate-nitrogen concentration. A more positive correlation between nitrate-nitrogen concentration and discharge can be noted for the spray ditches (fig. 5B) where the higher nitrate-nitrogen concentrations in the spray ditches during periods of higher flow reflect larger contributions of high nitrate-nitrogen concentration in water from the spray tiles. This information suggests that changes in nitrate-nitrogen concentrations have a more pronounced effect on nitrate-nitrogen yield variability at spray ditch sites relative to conventional ditch sites.

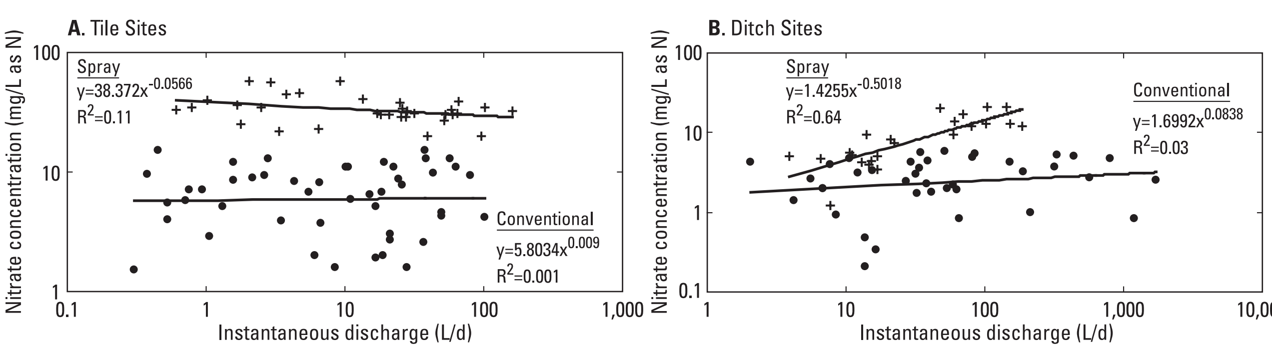

Figure 5. Relation of nitrate concentration and discharge at (A) tile sites and (B) ditch sites in the Middle Swamp watershed.

Although no consistent temporal pattern in nitrate-nitrogen yields is noted among the study sites (fig. 4), nitrate-nitrogen yields at paired tile and ditch sites typically exhibit similar patterns in that the ditch yield increases or decreases with a corresponding increase or decrease in nitrate-nitrogen inputs from the tile. The effect that tile drainage has on the edge-of-field transport of nitrate-nitrogen through ditches is illustrated with paired spray tile and ditch sites MS4-T2 and MS4-D2 (fig. 4B). The nitrate-nitrogen concentrations at MS4-D2 averaged 4.7 mg/L, and nitrate-nitrogen yields were less than or equal to about 10 g N/ha/d when tile site MS4-T2 was dry and contributed no water to the ditch. When water was flowing at tile site MS4-T2, nitrate-nitrogen concentrations in the ditch averaged 16.8 mg/L, or 3.6 times greater than when the tile was dry, and nitrate-nitrogen yields at ditch site MS4-D2 increased to more than 100 g N/ha/d.

In studying the effect of soil drainage on nitrate-nitrogen losses from agricultural fields in the North Carolina Coastal Plain, Gambrell and others (1975b) noted that the loss of nitrate-nitrogen from poorly drained soil having a relatively high water table was less than that from moderately well-drained soil. Although not a primary focus of this study, the soil-drainage class at individual tile sites was qualitatively examined to determine if there could be a relation between median nitrate-nitrogen yields and soil-drainage characteristics (fig. 6). In comparing these few sites, no discernible difference in nitrate-nitrogen yields was apparent between the different drainage classes. When fertilizer source type is taken into account, there was an insufficient number of sites within each drainage class to fully evaluate a possible relation between median nitrate-nitrogen yield, soil-drainage class, and fertilizer source type. Four of the five highest observed median nitrate-nitrogen yields (fig. 6), however, are associated with the spray tiles, suggesting that the effect of fertilization practices (conventional as opposed to spray) on nitrate-nitrogen yields at tile sites may be a more important factor than soil-drainage class.

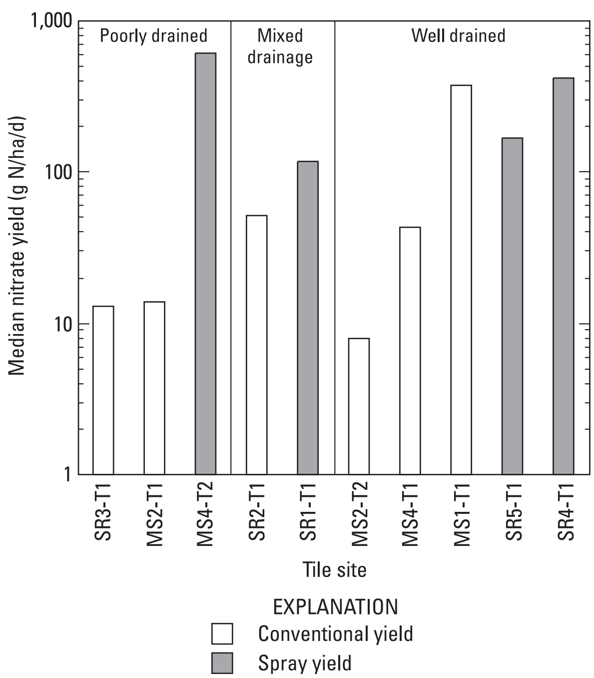

Figure 6. Relation of median nitrate yield and soil-drainage class for tile sites in the Middle Swamp watershed.

Relation of Fertilizer Type and Site Type in the Middle Swamp Watershed

The nitrate-nitrogen concentration data were grouped on the basis of site type and fertilizer type and statistically analyzed to characterize the overall influence of fertilizer type on nitrate-nitrogen concentrations and instantaneous yields at study sites throughout the Middle Swamp watershed (table 3; fig. 7). Conventional ditch site MS4-D1 was excluded from this evaluation because nitrate-nitrogen yield data were unavailable at this site. Statistical analysis of the data was conducted with a Kruskall Wallis rank test (Conover, 1980) to determine significant differences ($\alpha = 0.05$) in nitrate-nitrogen concentrations, nitrate-nitrogen yields, and discharge (table 3).

Evaluation of the grouped nitrate data was based on comparisons of median values of nitrate concentrations and yields. These comparisons indicate that nitrogen loadings and subsequent edge-of-field nitrate yields through tiles and ditches are significantly higher ($p = < 0.001$) at study sites receiving applications of swine lagoon effluent compared to sites receiving conventional fertilizer (table 3; fig. 7). The median nitrate-nitrogen concentration for spray tiles (32 mg/L) is 4.7 times greater than conventional tiles, and the median nitrate-nitrogen concentration for spray ditches (8.2 mg/L) is 3.0 times higher than conventional ditches. These results are in general agreement with findings reported by Spruill and others (2002b) who found a 5-fold increase in nitrate-nitrogen in ground water from 10 mg/L to 50 mg/L at a site that changed from receiving applications of conventional fertilizer to applications of swine lagoon effluent. Although significant differences ($p = 0.402$) in median discharge values were not observed between the conventional tiles and spray tiles or the conventional ditches and spray ditches, the median instantaneous nitrate-nitrogen yield for spray tiles was significantly higher ($p = 0.024$), by a factor of 16.8, than the conventional tiles, and the median instantaneous nitrate-nitrogen yield at spray ditches was 1.9 times higher than at conventional ditches (table 3; fig. 7). The only tile site (MS3-T1) investigated that received applications of sludge from a wastewater-treatment plant had a median nitrate-nitrogen concentration and yield that was intermediate to that of the conventional tiles and spray tiles. Regardless of fertilizer type, the tile sites had higher median nitrate-nitrogen concentrations and yields compared to the ditch sites.

Previous studies have indicated that increasing nitrogen fertilizer rates generally result in higher nitrate-nitrogen concentrations and transport in subsurface tile drainage (Baker and Johnson, 1981; Evans and others, 1984; Randall and others,

Table 3. Summary of nitrate and discharge data by site type and fertilizer type in the Middle Swamp watershed, August 2000 to August 2001.

[mg/L as N, milligrams per liter as nitrogen; g N/ha/d; grams of nitrogen per hectare per day; L/min, liter per minute; —, no data; <, less than]

Analysis (unit)	Tiles		p value	Ditches		p value
	Conventional	Spray		Conventional	Spray	
Number of sites	6	4	—	4[a]	2	—
Number of samples	47	33	—	39	23	—
Median nitrate concentration (mg/L as N)	6.8	32.0	< 0.001	2.7	8.2	< 0.001
Median nitrate yield (g N/ha/d)	25	420	< .001	8.1	15.6	.024
Median discharge (L/min)	10.6	20.8	.102	38.0	21.0	.402

[a]Conventional ditch site MS4-D1 was not included in the statistical summary because of insufficient discharge information for this site.

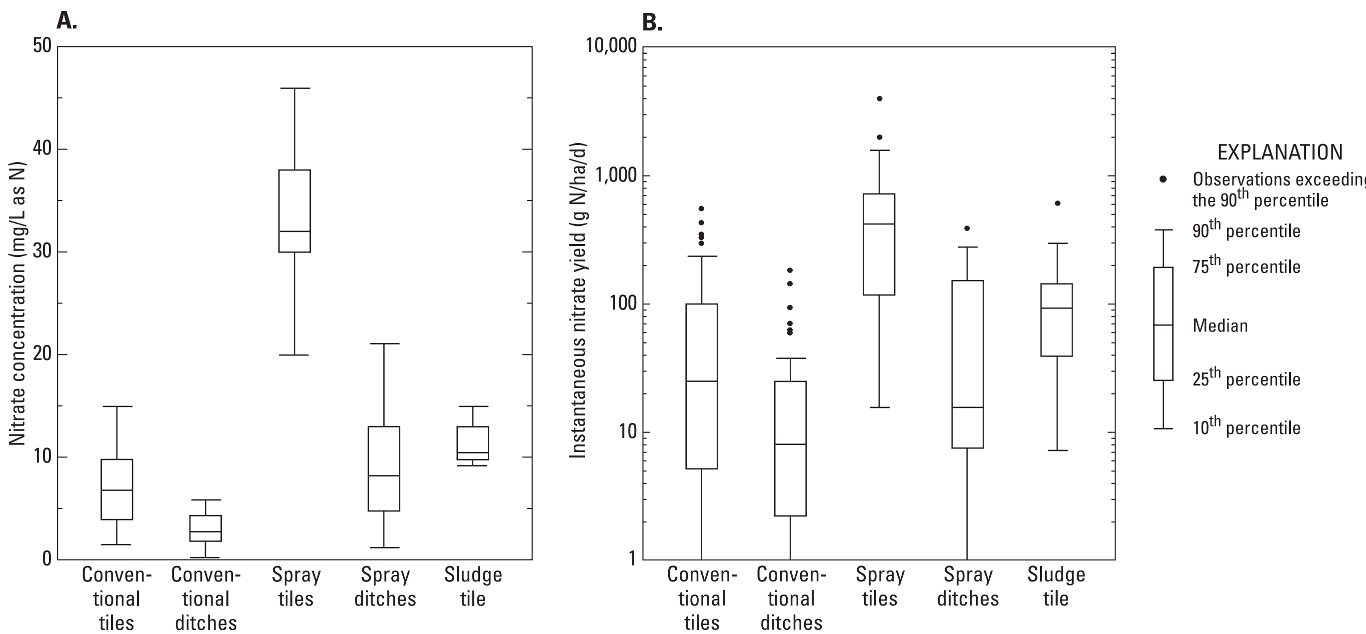

Figure 7. (A) Nitrate concentrations and (B) instantaneous yields grouped by site and fertilizer type in the Middle Swamp watershed.

2000; Jaynes and others, 2001). Results of these studies were based on applications of conventional fertilizers (urea, anhydrous ammonia) and(or) animal wastes (swine lagoon effluent and dairy manure). Randall and others (2000) applied dairy manure and urea at equivalent rates of available nitrogen to different plots over a 4-year period and found no differences in nitrate-nitrogen concentrations and losses in subsurface tile drainage. Irrigation systems involving applications of swine lagoon effluent are designed such that the total nitrogen applied can be used during crop growth to avoid runoff or excessive leaching; however, problems can result from adverse weather conditions or application rates that exceed crop uptake (Evans and others, 1984; Smith and Evans, 1998).

Study results indicate that for agricultural fields with similar crop types, crop fertilization needs, soil drainage, and water discharge, there are significantly higher nitrate-nitrogen concentrations and instantaneous nitrate-nitrogen yields for tiles and ditches at sites receiving swine lagoon effluent as a fertilizer source compared to sites receiving applications of conventional fertilizer. This difference suggests that more total nitrogen is applied to the spray sites relative to the conventional sites, which may indicate that the agronomic rates developed for fields fertilized with swine lagoon effluent may be inappropriate or that the prescribed agronomic rates for each spray site may not be practical because of extreme precipitation events and capacity limitations of the waste lagoons.

Study results also indicate that regardless of fertilizer source type, tile drainage increases the edge-of-field nitrate-nitrogen yields in surface drainage ditches, which subsequently may increase the amount of nitrate-nitrogen transported through the watershed. Controlled drainage techniques have been used in ditches and canals in the lower and tidewater Coastal Plain regions to reduce offsite loss of nitrogen from agricultural fields with subsurface tile drainage; however, this approach may not be practical for field ditches located in the middle Coastal Plain because more moderately sloping land is present in this region (Gilliam and others, 1979; Gilliam and others, 1997). The use of riparian buffers combined with nutrient management is considered to be more appropriate for reducing nitrogen losses in the middle Coastal Plain (Gilliam and others, 1997). This approach, however, may be vulnerable to nitrate losses through tile-drainage water that bypasses the riparian buffers through the field ditches. Water-control structures have been used at tile outlets to reduce water flow through tile lines, which decrease the amount of nitrate lost by the tiles (Gilliam and others, 1979). Additional work is needed in middle Coastal Plain areas with moderately sloping agricultural land to determine if flow from tile drains can be regulated to achieve beneficial nitrate-nitrogen reductions.

Summary

Water-quality data collected periodically during a 1-year study (August 2000–August 2001) from 11 tile drains and 7 ditches in the Middle Swamp watershed in the North Carolina Coastal Plain indicated significant differences among sites receiving applications of different types of nitrogen fertilizer. The focus of the study was on sites where applications of nitrogen to row crops were derived from locally available conventional fertilizer (conventional sites) or from field spraying swine lagoon effluent (spray sites). The use of wastewater-treatment plant sludge at one tile location (sludge site) also was examined.

Drainage water from tile drains and field ditches differed in ionic composition depending on the type of fertilizer applied. The principal ions composing tile and ditch water included calcium and magnesium at conventional sites and calcium and sodium at the spray sites. The higher percentage of sodium than calcium at the spray sites relative to the conventional sites reflects the greater predominance of sodium in animal wastes compared to inorganic fertilizers. The most notable difference between tile water and ditch water at conventional sites and spray sites was in the anion chemistry, which varied from chloride-dominated to nitrate-dominated in the following sequence: conventional ditches, conventional tiles, spray ditches, and spray tiles. Water from ditches also typically had higher concentrations of sulfate and bicarbonate compared with water from tile drains.

Results from the study indicate significant differences in nitrate-nitrogen concentrations and yields at tile and ditch sites having different fertilizer sources. Tile and ditch sites that received applications of swine lagoon effluent had higher median nitrate-nitrogen concentrations and median instantaneous nitrate-nitrogen yields than tile and ditch sites that received applications of commercial fertilizer. Some of the temporal differences in nitrate-nitrogen concentrations observed between the conventional sites and spray sites likely reflect differences in the timing and amounts of fertilizer applied. In general, variations in instantaneous nitrate-nitrogen yields for a given site type were influenced primarily by changes in water discharge compared to changes in nitrate-nitrogen concentration. No discernible difference in nitrate-nitrogen yields was noted between tile sites with poorly drained soils and tile sites with well-drained soils. The effect of fertilizer source type on tile nitrate yields may be a more important factor than soil-drainage class where the highest yields are associated with the spray tiles.

The nitrate-nitrogen data for the 18 study sites in the watershed were aggregated and evaluated on the basis of site type and fertilizer type, and the nitrogen loadings and subsequent edge-of-field nitrate yields through tiles and ditches were significantly higher at sites receiving applications of swine lagoon effluent compared to sites receiving commercial fertilizer. The results and findings presented in this report are based on the periodic collection of water-quality and discharge data for a 1-year study from August 2000 to August 2001. The collection of continuous discharge data and flow-weighted nitrate-nitrogen loads from tiles and field ditches over longer periods of time and under more experimental control could provide a better understanding of nutrient management practices, temporal and spatial trends, and cumulative annual nitrate-nitrogen losses associated with agricultural fields in which different sources of nitrogen fertilizer are used.

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