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Nitrate Losses in Runoff and Subsurface Drain Effluent from Controlled-Water-Table Plots

G. H. Willis, L. M. Southwick, J. L. Fouss, C. E. Carter, J. S. Rogers

USDA-ARS, Soil and Water Research Unit, 4115 Gourrier Avenue, Baton Rouge, in cooperation with the Louisiana Agricultural Experiment Station, Louisiana State University Agricultural Center, Baton Rouge, Louisiana 70808, USA

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Nitrate movement into surface and ground waters has become a concern for both environmental (eutrophication) and health (methemaglobia) reasons. Nitrate losses in surface runoff are usually less than leaching losses, but are important because of the minimal concentrations (0.3 mg/L: Sawyer, 1947) required to support eutrophication. Transport of nitrates to ground water is more likely to occur when the aquifer is closely coupled to the soil surface (karst areas, alluvial aquifers) or where the overlying soil is coarse. For many regions, major recharge of aquifers occurs during snowmelt/spring rain and fall/early winter rain seasons. Evapotranspiration demands account for most rain during the summer/plant growth seasons.

High rainfall and/or irrigation on well-drained agricultural soils, especially sandy soils, can lead to extensive nitrate movement below the plant root zone (Hubbard et al., 1989). The longer the time interval between nitrogen fertilizer application and the intial rain or irrigation, the more likely nitrate will diffuse into the soil micropores and become less available to leach (McLay et al., 1991). Leaching losses can range from <5 to 40 kg/ha/year (Owens et al., 1991; Bottcher et al., 1981; Gold and Loudon, 1989; Kladivko et al., 1991). In a comprehensive survey of wells in the Midwest, nitrate-N concentrations exceeded the drinking water standard of 10 mg/L in 3.4% of the wells (Richards et al., 1996).

Extensive use of tile drains in the Midwest has helped avert high nitrate concentrations in ground water (Spaulding and Exner, 1993). However, conventional subsurface drainage tends to increase nitrate losses (increased nitrification and less denitrification) when effluent is returned to surface waters (Breve et al., 1992). In a survey of Midwestern end Northeastern soils (conventional tillage), nitrate losses ware 10 to 40% of applied, with average tile effluent concentrations in the 10 to 60 mg/L range (Owens, 1994).

Controlled drainage is a technique for reducing nitrate losses in subsurface outflow (Gilliam, 1987; Thomas et al., 1992). Raising the water table increases the volume of stored water, thereby decreasing concentration, and can be used to reduce total drainage outflow. Controlled subdrainage and subsurface irrigation can be used in like manner (Gilliam, 1987; Campbell et al., 1985; Thomas et al., 1991).

Correspondence to: G. H. Willis

This paper reports the concentrations and loads of nitrate in runoff and subsurface drain effluent from controlled-water table plots located on alluvial soil in southern Louisiana.

MATERIALS AND METHODS

The study was conducted on sixteen 0.21-ha plots on the Louisiana Agricultural Experiment Station's Ben Hur Farm near Baton Rouge from April, 1995 till mid-March, 1996. The plots are located on a Commerce silt loam soil (fine-silty, mixed, nonacid, thermic, Aeric Fluvaquents). The plot and field instrumentation layout is described in detail in Willis et al. (1991). Briefly, each plot is hydraulically isolated with 45-cm high levies and 6-mil plastic sheeting that was installed beginning at 30 cm below the soil surface and extending down 180 cm around the perimeter of each plot. Three subsurface drain lines were installed 1.2 m below the soil surface. Field instrumentation included microprocessor-controlled water table management (subdrainage and/or subirrigation), automated measuring and sampling of runoff and drain line effluent, and refrigerated storage of samples.

Four replications of four water table management treatments were imposed on the plots: (1) surface drainage only (SUR), (2) conventional subsurface drainage at 1.2 m or more below the soil surface (DRN), (3) controlled water table depth at 45 cm below the soil surface (CWT45), end (4) controlled water depth table at 75 cm below the soil surface (CWT75). For a more detailed discussion of water table management *on* these plots refer to Fouss and Willis (1994). Briefly, the underlying philosophy for the treatment selections *was* to use the top meter of soil as a reservoir with an adjustable capacity. Capacity adjustments can be made depending on management needs throughout the growing season. For example, if agrochemicals have recently been applied to the soil surface, and significant rainfall is predicted, the water tables can be lowered to enhance infiltration and reduce surface runoff losses. Conversely, if agrochemicals have been applied and are distributed in the plant root zone ,i.e., no large amounts present on the soil surface, the water table could be raised to a height just below the root zone to restrict leaching below that zone.

A "starter" application of ammonium nitrate was applied at 56 kg N/ha on April 19 (day O) and was tilled into the top 7.5 to 10 cm of soil. Corn *(Zea mays* L.) was planted on April 27 (day 8). A side-dress N application (84 kg N/ha) was made on May 17 (day 27). On June 28 (day 69) a third application (84 kg N/ha) was applied by aircraft; no tillage occurred. The water table treatments were imposed on the day of planting and maintained until day 146 (Sept. 13), one day before corn harvest. sampling of runoff began on day O and continued until day 197 (Nov. 1); sampling of drain line effluent continued until day 328 (March 14, 1996). Rainfall was measured at two sites within the plot area and electronically recorded. Tillage treatments were the same for all plots throughout the study.

For each plot, surface runoff was routed through an H-flume where the volume was measured and recorded electronically and samples collected (50 mL for each 2000 L of flow) by a refrigerated, automated liquid sampler. After each runoff event, the collected samples were taken to the laboratory where a flow-weighted composite sample was prepared for analysis.

Drain line effluent was routed from the drains into a sump where it was then pumped into a ditch outlet system. During pumping the volume was measured and a 0.2% aliquot was split into a 10-L container housed in a small refrigerator. The refrigerated aliquot was then transferred to the lab for analysis.

The runoff and drain line effluent samples were filtered in the laboratory (0.45 µm mixed celluose ester membrane filters) and analyzed by ion chromatography (USEPA Method 353.2; USEPA, 1979) . The lower limit of detection was 0.05 mg/L nitrate-N.

RESULTS AND DISCUSSION

The major loss of NO_3-N in surface runoff occurred on day 3 (Table 1) . Approximately 25 mm of rain fell on day 1, producing no runoff; approximately 50 mm of rain fell on day 3. Since the water table treatments were not imposed until day 8 (to help ensure that the soil remained dry enough for corn planting and pesticide

Table 1. Cumulative NO_3-N losses and runoff and subdrainage volumes during 197 days following initial N-fertilizer application.

	Treatment[a]			
Item	SUR	DRN	CWT45	CWT75
Surface runoff, m^3/ha	3458	3158	3379	3201
Surface runoff, mm[b]	346	316	338	320
NO_3-N in runoff, kg/ha	44.1	31.1	33.2	44.9
during days 1-3	(23.2)	(19.8)	(17.7)	(28.2)
during days 4-197	(20.9)	(11.3)	(15.5)	(16.7)
Subdrain effluent, m^3/ha	-	104	100	85
NO^3-N in effluent, kg/ha	-	6.6	6.5	7.8

[a]SUR = surface drainage only, DRN = conventional subsurface drainage at 1.2 m or more, CWT45 = controlled water table at 45 cm, CWT75 = controlled water table at 75cm. [b]Total rain during 197 days was 743 mm.

application), the differences in losses on day 3 were the result of site, tillage (incorporation), and application variabilities. The mean water table depths during days 1 through 3 were: SUR, 78 cm; DRN, 107 cm; CWT45, 103 cm; and CWT75, 101 cm.

As expected, after the water table treatments were imposed, the greatest NO_3-N losses in runoff occurred from the SUR plots, and least from the DRN plots. Similarly, surface runoff volume was greatest from the SUR plots and least from the DRN plots. NO_3-N losses and drain volumes in subsurface drain effluent during the first 197 days were similar for the three water table treatments. Surface runoff was 46.5%, 42.5%, 45.5%, and 43.1% of the total rainfall for the SUR, DRN, CWT45, and CWT75 plots, respectively. NO_3-N losses in surface runoff were equal to 20%, 14%, 15%, and 20% of the amount added as fertilizer to the SUR, DRN, CWT45, and CWT75 plots, respectively. Because of high variability within treatments, none of the mean losses or mean volumes were statistically different ($p = 0.05$).

Rain, cumulative mean runoff volume, and cumulative mean NO_3-N losses in runoff for the CWT45 plots are shown in Fig. 1. Even though a log-scale is used to present NO_3-N losses, the major contribution of the losses on day 3 to the total loss Is readily apparent. The impacts of additional N-fertilizer applications on days 28 and 70 to runoff losses were minimal. Those applications occurred during periods of rapid plant growth and times when runoff-producing rainfall events were infrequent. Cumulative runoff and NO_3-N loss patterns were similar for all treatments.

Mean NO_3-N concentrations in runoff are shown in Fig. 2. Concentrations ranged as high as 79 mg/L. In general the concentrations were highest for the runoff events following the first two fertilizer applications. Concentrations in the runoff from the DRN plots following the second N-fertilizer application were substantially less than those for the other plots. It is possible that more of the rain infiltrated the soil surface (at least during the first part of the storm) and transported more NO_3-N into the soil, thereby restricting its loss in runoff. After about day 40, NO_3-N concentrations in runoff were below the drinking water standard (10 mg/L). The N-fertilizer application on day 70 did not result in high NO_3-N concentrations in subsequent runoff.

Rain, cumulative effluent volume, and cumulative NO_3-N losses in subsurface drain water from the CWT45 plots for 328 days following the initial N-fertilizer application are shown in Fig. 3. Cumulative effluent volume and NO_3-N loss patterns were similar for the other treatments. Slow, but steady loss, during the late fall and winter months (ea. days 190-340) are not unexpected since the soils are biologically active all year (Megonigal et al. 1996). Total drain volumes and NO_3-N losses for all the subdrainage treatments are given in Table 2. Effluent volumes equaled 13.9%, 12.7%, end 13.1% of the total rainfall for the DRN, CWT45, and CWT75 plots, respectively. NO_3-N losses in subsurface drain effluent from the DRN, CWT45, and CWT75 plots were each equal to about 3% of the amounts applied as N-fertilizer.

Mean NO_3-N concentrations in subdrainage effluent are shown for the three water table treatments in Fig. 4. Again, concentrations

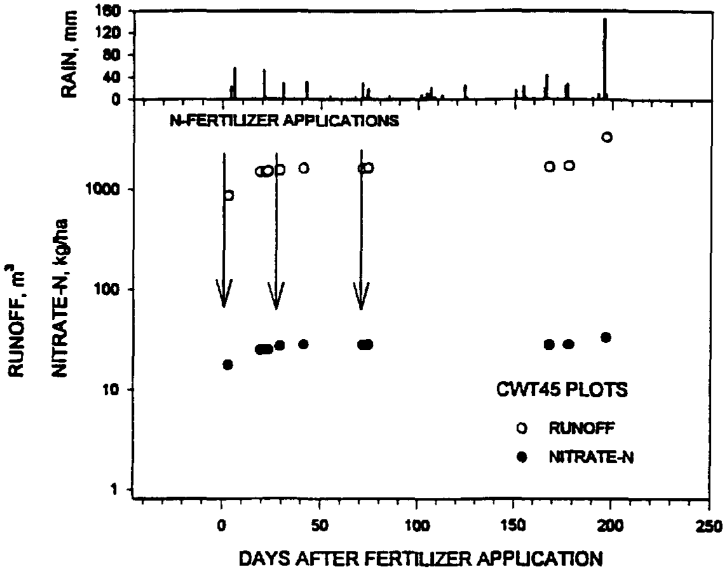

Figure 1. Rain and cumulative runoff volume and NO_3-N losses in surface runoff.

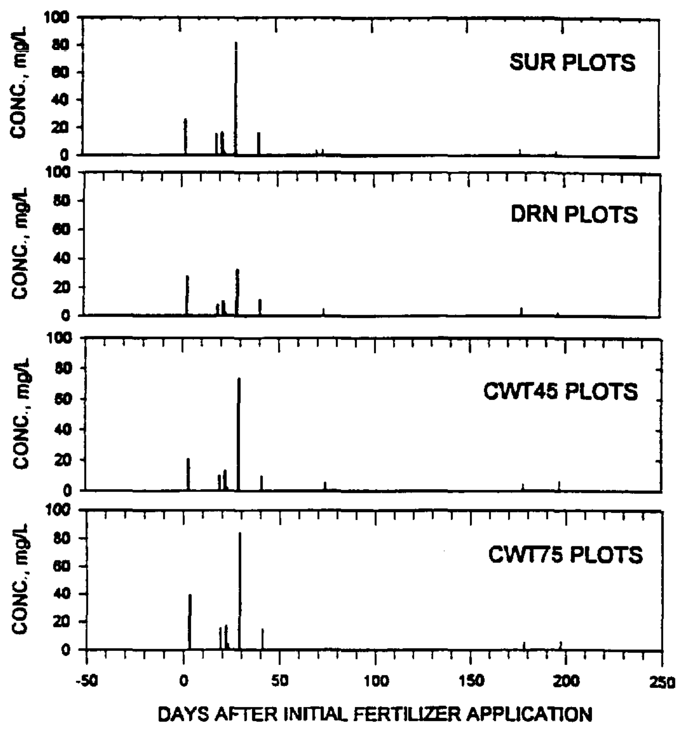

Figure 2. Mean NO_3-N Concentrations in surface runoff.

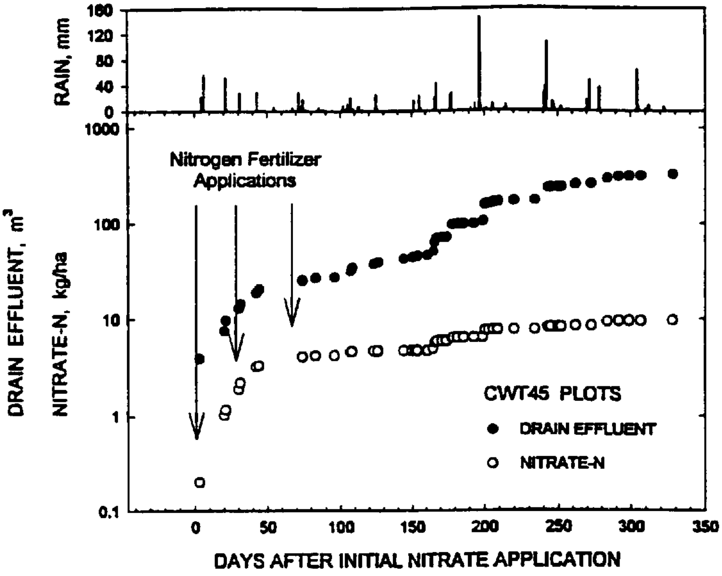

Figure 3. Rain and cumulative effluent volume and NO_3-N losses in subsurface drain water.

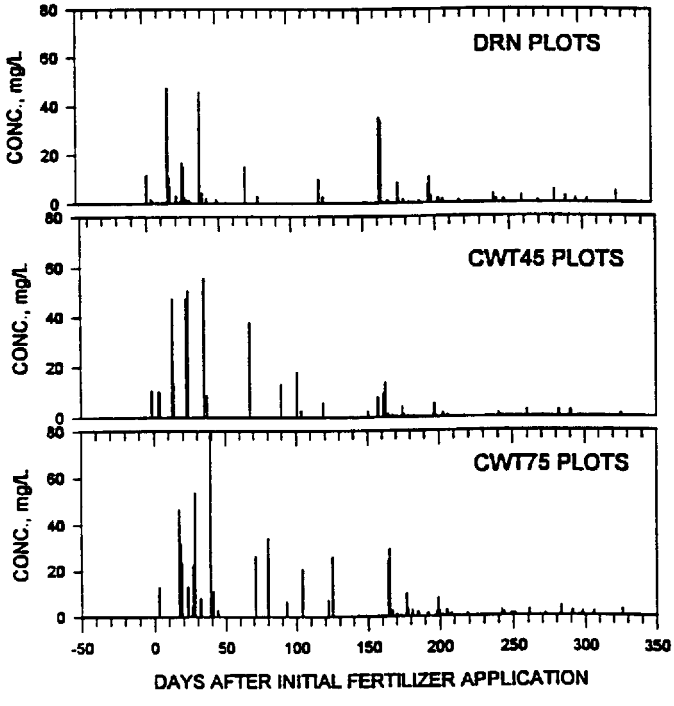

Figure 4. Mean NO_3-N concentrations in subsurface drainage effluent.

ranged to about 80 mg/L. Several major concentration peaks in excess of 10 mg/L occurred during the first 40 days. Several additional peaks also occurred between days 60 and 170, but the frequency was less, perhaps because of lower rainfall. Although NO_3-N concentrations were high on numerous occasions, the drain volumes were small, resulting in low total amounts lost in subsurface drain effluent.

Table 2. Cumulative NO_3-N losses and effluent volume in subsurface drain water during 327 days following Initial N-fertilizer application.

	Treatment[a]		
Item	DRN	CWT45	CWT75
Effluent volume, m^3/ha	357	325	335
Effluent volume, mm[b]	167	152	157
NO_3-N in drain effluent, kg/ha	12.3	9.7	12.6

[a]DRN = conventional subsurface drainage at l.lm or more, CWT45 = controlled water table at 45 cm, CWT75 = controlled water table at 75 cm. [b]Total rainfall during the 320 days was 1200 mm.

The reported results are for a single growing season. The results suggest that water table control is a promising tool for managing soil water to reduce agrochemical loads in surface and ground waters on high-water-table soils. However, several more years of data under variable weather regimens, and dynamic adjustments to water table depths during the growing season, will be required before the full utility of the process can be evaluated.

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