Nitrate Leaching as Affected by Tillage and Winter Cover Cropping

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Introduction

Heavy use of N resources in corn *(Zea mays* L.) production has been implicated as an extensive source of nitrate (NO_3-) delivered to ground and surface waters in the eastern United States (Hallberg, 1989). Since soil and crop management exert strong influence over NO_3- leaching (Russelle and Hargrove, 1989; Thomas et al., 1989), there is great need to assess NO_3- leaching losses under new corn production systems that are gaining acceptance. Research was undertaken to evaluate the effects of tillage [conventional tillage (CT) vs. no-tillage (NT)] and winter cover cropping (fallow vs. rye) on NO_3- leaching from land devoted to corn production.

Materials and Methods

The study is located at the USDA-ARS Southern Piedmont Conservation Research Center near Watkinsville, GA, The site consists of 12 instrumented, tile-drained plots located on nearly level (0-2% slope) Cecil sandy loam soil (clayey, kaolinitic, thermic Typic Kanhapludults). Each plot (32.8 feet wide 98.4 feet long) is underlain by five tile drains spaced 8.2 feet apart, which are installed on a 1% grade at a depth of approximately 3.3 feet. The border of each plot is enclosed with polyethylene sheeting that extends from the soil surface to the depth of the drain lines.

The volume of water drained from a plot is measured by tipping bucket, and recorded digitally with a datalogger. A small portion of the drainage flow ($<$ 3%) is removed by a sampling slot located between tipping-bucket halves. Drainage samples are collected and stored under refrigeration (35 °F) in the field by Isco Model 3700 FR sequential waste water samplers (Isco, Lincoln, NE). Tile effluent is analyzed for NO_3-.

During the summer of 1991, all plots were fertilized with 150 lb/A of N and conventionally tilled corn was grown. On Oct. 18, 1991, six plots were no-till planted to rye *(cv.* 'Wheeler'; 100 lb seed/A). The remaining six plots were left fallow. Rye dry matter production and N uptake were measured with samples taken on April 23, 1992, immediately prior to killing the rye, and imposing tillage treatments. CT plots were mowed, moldboard plowed and disked. NT plots were mowed, sprayed with paraquat, and left untilled. On April 24, 1992, plots were planted to corn (cv. 'DeKalb 689') in 30-inch rows at the rate of 24,390 kernels/acre. Fertilizer N (150lb N/A as NH_4NO_3) was broadcast 3 days later. On Oct. 7, 1992, corn grain was harvested and corn stover samples were taken from the two center rows of each plot. Corn tissue was dried, weighed, and analyzed for N. Years 2 and 3 began when rye was planted (cv. Wheeler; 100 lb seed/A) on Oct. 30, 1992 and Sept. 29, 1993, respectively. Rye was sampled and killed on April 12, 1993 (year 2) and April 20, 1994 (year 3). Conventional tillage was performed on April 13, 1993 (year 2) and April 19, 1994 (year 3). Corn (cv. DeKalb 689) was planted on all plots on April 14, 1993 (year 2) and April 20, 1994 (year 3), as it had been previously, and fertilizer N (150 lb N/A as NH_4NO_3) was broadcast immediately after planting. Corn was harvested and sampled as before for N analysis on Sept. 14, 1993 (year 2) and Sept. 13, 1994 (year 3). Year 3 concluded on Oct. 14 1994.

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Results and Discussion

Winter 1991

Unusually dry fall conditions (Table 1) delayed soil moisture recharge, and prevented appreciable tile drainage until the end of December 1991 (Figure 1). Winter drainage was essentially complete by the end of February 1992. From then on, lower than normal spring rainfall (Table 1) and increasing evapotranspiration prevented significant drainage for the rest of the fallow period. Cumulative drainage was consistently less under rye than it was under fallow (Figure 1). By late April when the rye was killed, the difference in drainage volumes was considerable and significant ($P < 0.03$).

The concentration of NO_3-N in the drainage effluent was also consistently lower with the rye cover crop (Figure 1). Under rye, the average NO_3-N concentration of tile flow was 8.7 ppm NO_3-N, just below the U.S. Public Health Service's drinking water standard (10 ppm NO_3-N). In contrast, the average NO_3-N concentration measured under fallow was significantly greater (22.7 ppm NO_3-N; $P < 0.01$).

Total N03-N loss in tile flow was less under rye (3.0 lb N/A) than under fallow (10.9 lb N/A; P < 0.01), though measured NO; leaching losses were small for both winter cover treatments. Reduction in N03-leaching by cover crops was related to their use of both water and N. Rye topgrowth averaged 2.47 tons/A when it was killed, and it contained 84 lb N/A.

Summer 1992

Despite below-normal rainfall for March, April, and May, above average amounts from June through September 1992

Table 1. Monthly rainfall from October 1991 through October 1994, and long-term (1884-1991) average monthly rainfall at Watkinsville, GA.

Year	Month	Measured monthly rainfall at site	Long-term average monthly rainfall*	Rainfall deficit (-) or surplus (+)
		(in)	(in)	(in)
1991	October	0.14	2.98	−2.84
	November	0.72	3.07	−2.35
	December	3.16	4.35	−1.19
1992	January	3.41	4.68	−1.27
	February	4.80	4.75	+0.05
	March	4.00	5.29	−1.29
	April	1.58	3.88	−2.30
	May	1.68	3.80	−2.12
	June	6.51	3.91	+2.60
	July	5.71	4.99	+0.72
	August	8.09	4.23	+3.86
	September	7.65	3.37	+4.28
	October	2.43	2.98	−0.55
	November	7.98	3.07	+4.91
	December	5.26	4.35	+0.91
1993	January	3.73	4.68	−0.95
	February	5.87	4.75	+1.12
	March	7.31	5.29	+2.02
	April	2.94	3.88	−0.94
	May	2.21	3.80	−1.59
	June	0.74	3.91	−3.17
	July	1.97	4.99	−3.02
	August	1.16	4.23	−3.07
	September	3.28	3.37	−0.09
	October	4.38	2.98	+1.40
	November	3.22	3.07	+0.15
	December	2.90	4.35	−1.45
1994	January	3.74	4.68	−0.94
	February	2.78	4.75	−1.97
	March	5.17	5.29	−0.12
	April	2.08	3.88	−1.80
	May	2.07	3.80	−1.73
	June	11.41	3.91	+7.50
	July	7.42	4.99	+2.43
	August	6.54	4.23	+2.31
	September	4.20	3.37	+0.83
	October	6.48	2.98	+3.50
Total		154.72	150.88	+3.84

* Measured 3 miles from site.

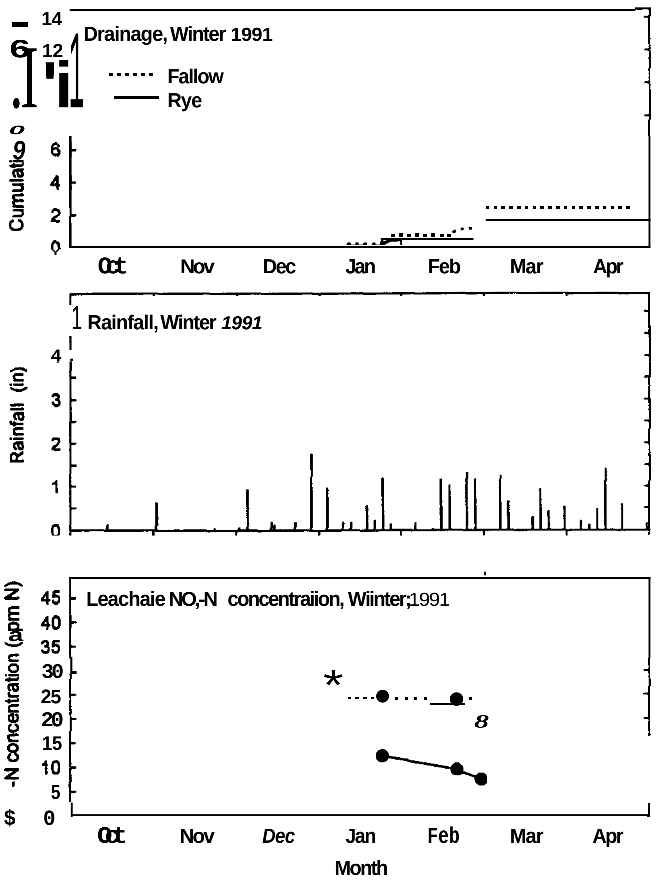


Figure 1. Cumulative drainage, rainfall, and leachate N03-N concentration for winter 1991.

(Table 1) generated considerable summer drainage (Figure 2). During summer 1992, cumulative drainage was greater where rye had been grown (7.8 inches for rye, 6.1 inches for fallow (P 0.08). However, during the same period, tillage had no significant effect on cumulative drainage (7.6 inches for NT, 6.3 inches for CT (P<0.35). Overall, the trend was greater summer drainage where surface coverage was greatest—on NT plots that possessed a mulch of both rye and corn residues (Figure 2).

Leachate NO3-N concentrations were higher soon after drainage began in the summer, and lower at the end of the corn growing season (Figure 2). This trend probably reflects the seasonal pattern of N use by corn, and the fact that **N** fertilizer was applied in a single application at the beginning of the growing season. In addition, leachate NO3-N concentrations during the first half of the summer period tended to be higher with NT than with CT (Figure 2). This tillage effect may be due to the presence of more macropores continuous with the soil surface under NT. Macropores can conduct large amounts of water and nitrate rapidly through root zone and deep into the profile, or beyond. The NO_3-N concentration of tile flow averaged across the entire summer tended to be higher with NT (16.9 ppm) than with CT (14.2 ppm; P<0.11).

In general, NO3-N concentrations of the tile flow during summer were lower where rye had been grown (Figure 2). NO3-N concentrations of tile flow averaged across the entire summer were lower for rye (13.2 ppm NO_3-N) than for fallow (18.0 ppm NO,-N; $P<0.05$). These results probably reflect less NO3-N present in the root zone of rye plots at the beginning of the corn growing season. Immobilization of N associated with the decomposition of rye residues also may have limited the amount of NO3-N available for leaching under corn.

Unexpectedly, total NO3-N losses in the tile flow were much greater during the corn growing season than they had been during the preceding winter period. This can be attributed to above average rainfall from June through September, and the leaching of fertilizer N applied for corn. During summer 1992, the trend was for greater NO3-N leaching loss with NT (28 lb/A NO_3-N) than with CT (19 lb/A NO3-N; P<O.13). However, there was no effect of previous cover crop on total N03-N leaching losses (24 lb/A NO3-N for rye, and 24 Ib/A NO3-N fallow; $P<0.83$). Similarly, the interaction of tillage and previous cover crop had no significant effect on measured NO3-N leaching losses during this period ($P\sim0.23$).

There were no significant effects of tillage ($P<0.71$), cover cropping ($P<0.45$) or their interaction ($P<0.99$) on corn N uptake (89 Ib N/A for NT rye, 86 lb N/A for CT rye, 85 lb N/A for NT fallow, and 82 lb N/A for CT fallow). Similarly, there were no significant effects of tillage (P<O.72), cover cropping ($P<0.13$) or their interaction ($P<0.98$) on corn grain yield (102 bu/A for NT rye, 100 bu/A for CT rye, 111 bu/A for NT fallow, and 108 bu/A for CT fallow).

Winter 1992

The trend for above average rainfall during summer 1992 persisted through much of the subsequent winter season (Table 1). As a result significant drainage began about 6 weeks earlier than it did in winter 1991, and drainage occurred more or less continuously until the rye was killed (Figure 3). However, neither tillage ($P<0.45$), cover cropping ($P<0.36$), or their interaction ($P<0.52$) significantly affected total drainage during winter 1992.

The concentrations of NO_3-N in the drainage effluent were low relative to those measured for winter 1991 and summer 1992. Low NO_3-N concentrations during winter 1992 are attributable to good growth and N uptake by corn in response to abundant, well-distributed summer rain. NO_3-N concentrations averaged across the entire winter season were significantly affected by tillage (4.5 ppm for NT, 6.2 ppm for

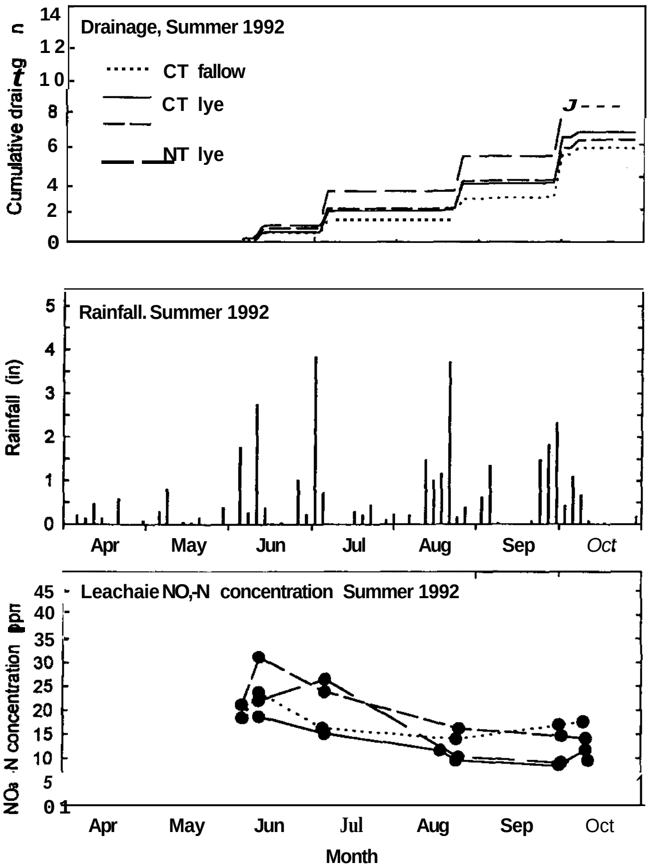


Figure 2. Cumulative drainage, rainfall, and leachate N03-N concentration for summer 1992.

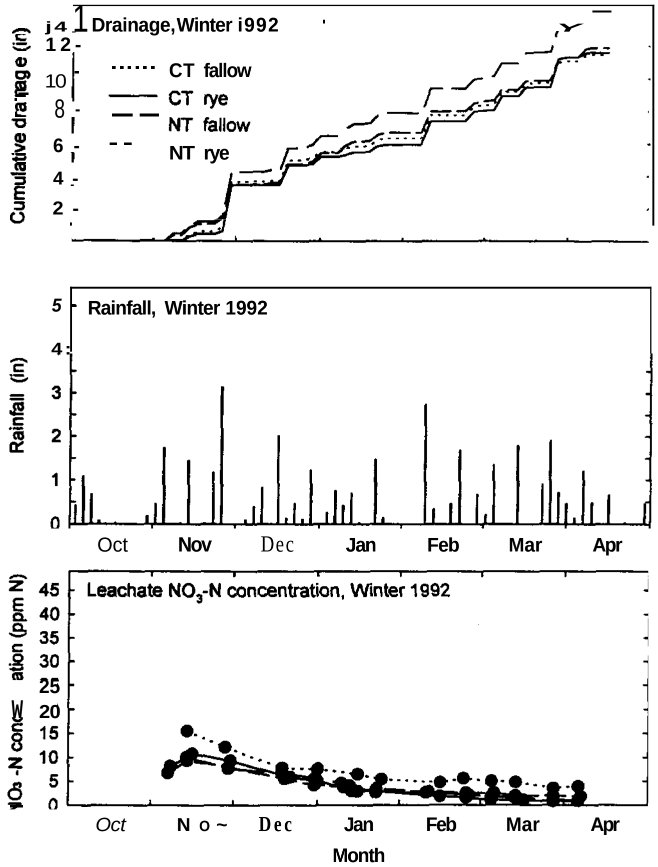


Figure 3. **Cumulative d r a i n a** rainfall, **and leachate N03-N concentration for winter 1992.**

CT; $P<0.07$), cover cropping (4.6 ppm for rye, 6.1 ppm for fallow; $P<0.01$), and their interaction (4.6 ppm for NT rye, 4.6 ppm for CT rye, 4.4 ppm for NT fallow, 7.8 ppm for CT fallow; $P<0.01$).

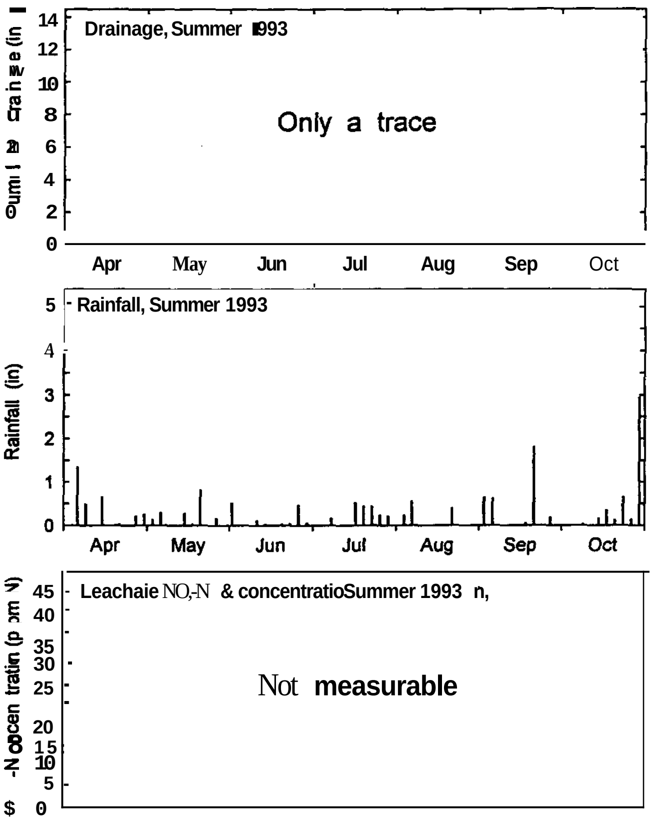
Total NO_3-N loss in tile flow was affected by tillage (13.0 lb/A for NT, 16.1 lb/A for CT; $P<0.05$) and the interaction of tillage with cover cropping (14.5 lb/A for NT rye, 12.2 lb/A for CT rye, 11.5 lb/A for NT fallow, 19.9 lb/A for CT fallow; $P<0.01$). The trend was for greater NO_3-N loss with fallow than with rye (13.4 lb/A for rye, 15.7 lb/A for fallow; $P<0.13$). Above-ground dry matter production by rye was less with NT than with CT (0.42 ton/A for NT, 0.61 tons/A for CT; $P<0.03$). Similarly, the N content of rye topgrowth was less with NT than with CT (15.8 lb/A for NT, 23.4 lb/A for CT; $P<0.02$).

Summer 1993

This corn growing season was one of the driest on record (Table 1, Figure 4). Only traces of drainage occurred, which provided insufficient sample volumes for NO_3-N analysis. Because of drought, corn N uptake was also greatly reduced, relative to uptake the previous summer season. Corn above-ground N content at harvest was not affected significantly by tillage (56 lb N/A for NT, 43 lb N/A for CT; $P<0.40$) and cover cropping (54 lb N/A for rye, 45 lb N/A for fallow; $P<0.18$) had no significant effect on corn N uptake. However, the interaction of tillage and cover cropping did affect corn N content at harvest significantly (66 lb N/A for NT rye, 43 lb N/A for CT rye, 47 lb N/A for NT fallow, and 43 lb N/A for CT fallow; $P<0.07$). Greater N uptake by corn with NT rye was probably due to greater moisture conservation by the heavier mulch of this treatment. However, corn grain yields on all treatments were extremely low, and not significantly affected by tillage (11 bu/A for NT, 16 bu/A for CT; $P<0.51$), cover cropping (13 bu/A for rye, 13 bu/A for fallow; $P<0.99$), or their interaction (10 bu/A for NT rye, 16 bu/A for CT rye, 12 bu/A for NT fallow, 15 bu/A for CT fallow; $P<0.60$).

Winter 1993

Rainfall for winter 1993 was also less than average, though the deficit was not as large as for summer 1993 (Table 1). Total drainage during winter 1993 was significantly affected by tillage (4.30 inches for NT, 2.68 inches for CT; $P<0.05$). However, neither cover cropping (3.16 inches for rye, 3.82



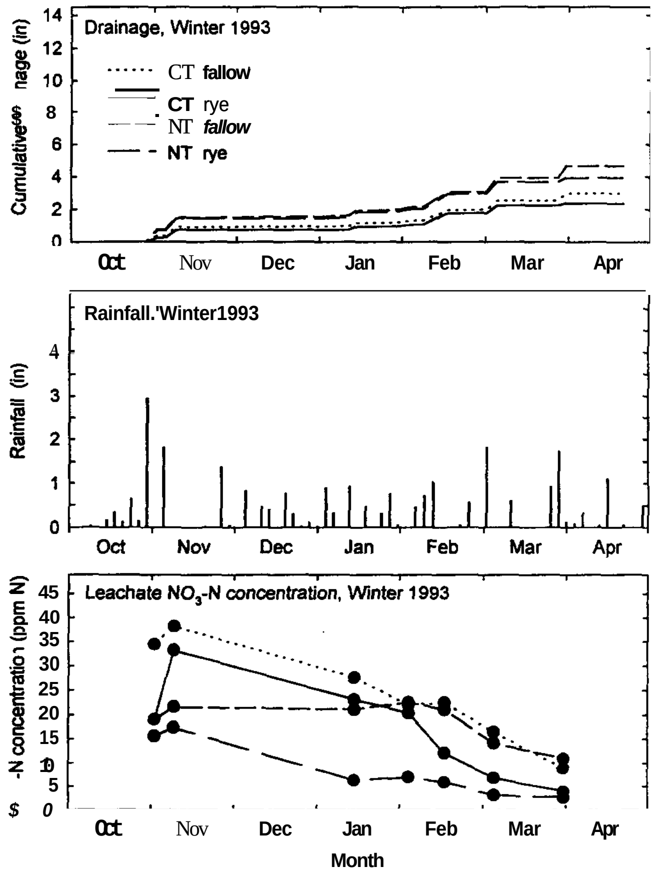


Figure 5. Cumulative *drainage*, rainfall, and leachate NO_3-N concentration for winter 1993.

inches for fallow; P<0.32), or its interaction with tillage (3.94 inches for NT rye, 2.37 inches for CT rye, 4.65 inches for NT fallow, 3.00 inches for CT fallow; P<0.95) had a significant effect on total winter drainage.

The concentrations of NO_3-N in the drainage effluent were relatively high during much of winter 1993 (Figure 5). Winter 1993 followed an exceptionally dry summer growing season, during which corn was unable to utilize applied N fertilizer efficiently, leaving much NO_3-N susceptible to leaching over the winter. NO_3-N concentrations averaged across the entire winter season were significantly affected by tillage (13.6 ppm for NT, 20.3 ppm for CT; P < 0.01), cover cropping (12.9 ppm for rye, 21.0 ppm for fallow; P < 0.01), but not their interaction (9.2 ppm for NT rye, 16.6 ppm for CT rye, 18.0 ppm for NT fallow, 24.0 ppm for CT fallow; P<0.47).

Total NO_3-N loss in tile flow was affected by cover cropping (8.7 lb N/A for rye, 17.7 lb N/A for fallow, P<0.04), but not by tillage (13.6 lb/A for NT, 12.8 lb/A for CT; P < 0.85) or the interaction of tillage and cover cropping (8.2 lb/A for NT rye, 9.2 lb/A for CT rye, 19.0 lb/A for NT fallow, 16.4 lb/A for CT fallow; P < 0.56). Neither above-ground dry matter production by rye (1.62 tons/A for NT, 1.68 tons/A for CT; P<0.48), nor above-ground rye N content (52.7 lb/A for NT, 63.0 lb/A for CT; P < 0.12) was affected significantly by tillage.

Summer 1994

In contrast to summer 1993, this corn growing season was much above average in rainfall (Table 1). Total drainage during summer 1994 was significantly affected by tillage (8.51 inches for NT, 5.80 inches for CT; P <0.01). However, neither cover cropping (P~0.15) or its interaction with tillage (P < 0.39) had a significant effect on total summer drainage.

The concentrations of NO_3-N in the drainage effluent were relatively low during summer 1994 (Figure 6). NO_3-N concentrations averaged for the summer were significantly affected by cover (4.39 ppm for rye, 5.52 ppm for fallow; P<0.01), but not by tillage (4.98 ppm for NT, 4.92 ppm for CT; P < 0.0.95), or the interaction of tillage and cover cropping (4.39 ppm for NT rye, 4.38 ppm for CT rye, 5.56 ppm for NT fallow, 5.47 ppm for CT fallow; P<0.83).

Total NO_3-N loss in tile flow during summer 1994 was not affected by cover cropping (8.1 lb N/A for rye, 7.6 lb N/A for fallow; P<0.77), tillage (9.6 lb N/A for NT, 6.1 lb N/A for CT; P<0.17), or their interaction (8.8 lb/A for NT rye, 7.3 lb/A for CT rye, 10.3 lb/A for NT fallow, 4.9 lb/A for CT fallow; P < 0.30). The combined N content of corn grain and stover at harvest was affected significantly by tillage (136 lb N/A for NT, 144 lb N/A for CT; P < 0.01) and cover cropping (125 lb N/A for rye, 155 lb N/A for fallow; P<0.06), but not by the interaction of tillage and cover cropping (128 lb N/A for NT rye, 121 lb N/A for CT rye, 143 lb N/A for NT fallow, 166 lb N/A for CT fallow; P<0.25). Corn grain yield was significantly affected by cover cropping (151 bu/A for rye, 174 bu/A for fallow; P<0.03), and the interaction

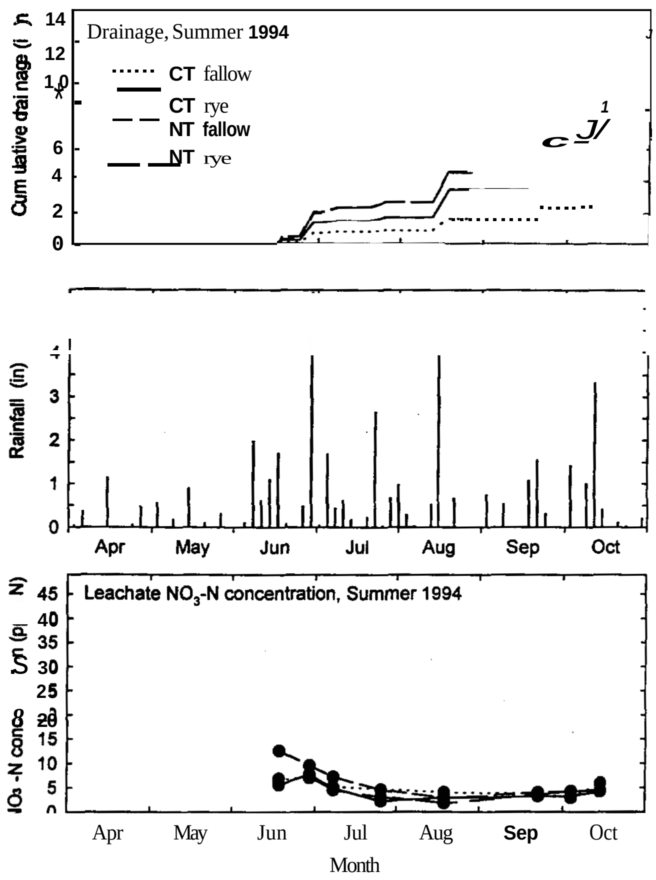


Figure 6 Cumulative drainage, rainfall, **and leachate NO_3-N concentration for summer 1994.**

of cover cropping and tillage (162 bu/A for NT rye, 140 bu/A for CT rye, 160 bu/A for NT fallow, 188 bu/A for CT fallow; P < 0.02), but not by tillage (160 bu/A for NT, 164 bu/A for CT; P < 0.61).

In climates like Georgia's that possess mild, humid winters, cover cropping with rye has utility for control of NO_3^- leaching from cropland. Rye cover crops consistently reduced leachate NO_3-N concentrations, and limited NO_3-N leaching losses during winter. Our results indicate no consistent differences between NT and CT in their effect on NO_3^- leaching, and suggest that choice of tillage method on upland soils of the Southern Piedmont will have minor impact on groundwater quality.

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