INFLUENCE OF TILLAGE AND COVER CROPPING ON NITRATE LEACHING

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INTRODUCTION

The contamination of water resources by nitrate (NO_3) is a major health and environmental quality issue confronting the U.S. today. Domestic, municipal, industrial, and agricultural sources all contribute to NO_3 loading of streams and aquifers, although the severity of the problem and the source of the NO_3 vary greatly from location to location. Land use and management, biological activity, geology, and climate interact to control how much NO_3 reaches our water supplies and its concentration there.

Heavy use of N resources in corn *(Zea mays* L.) production has been implicated as an extensive source of NO_3 delivered to ground and surface waters in the eastern U.S. (Hallberg, 1989). Since NO_3^- leaching is strongly influenced by soil and crop management (Thomas et al., 1989; Russelle and Hargrove, 1989), there is great need to assess NO_3 leaching losses in the new corn production systems that are gaining farmer acceptance.

No-tillage is a relatively new practice that has undergone widespread adoption in many corn-producing regions of the country (Mannering et al., 1987). Because it profoundly affects the soil moisture regime and soil porosity (Phillips, 1984; Blevins et al., 1984), no-tillage can be expected to impact NO_3 leaching, though often in ways that are not readily predictable Schepers, 1987).

Cover cropping with non-leguminous winter annuals, such as rye *(Secale cereale* L.), is an old practice with great potential for renewed use. Not only does rye help control soil loss during otherwise fallow winter periods, use of a rye cover crop may significantly reduce NO_3 leaching during the fall, winter, and early spring.

Research was undertaken to evaluate the effects of tillage [conventional (CT) vs. no-tillage (NT)] and winter cover cropping (fallow vs. rye) on NO_3 leaching from land devoted to corn production. This report presents first year results of a proposed multi-year study.

MATERIALS AND METHODS

Field Site

This continuing study is being conducted at the USDA-ARS Southern Piedmont Conservation Research Center near Watkinsville, Georgia. The study area is located on Cecil sandy loam soil (clayey, kaolinitic, thermic Typic Kanhapludults), and consists of 12 instrumented, tile-drained plots, each measuring 10 m wide x 30 m long. Each plot is underlain by five 30 m long drain lines spaced 2.5 m apart. Drain lines consist of 10-cm diameter, flexible, slotted PVC pipe installed on a 1% grade. At the lower plot edge, the depth of each drain line is 1 m from the soil surface. To exclude subsurface lateral flow, plot borders are 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 is 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 (1.7°C) in the field by lsco Model 3700 FR sequential waste water samplers Isco Inc., Lincoln, NE 68501-3531). Drainage samples are analyzed for NO_3^- by the Griess-Ilosvay method (Keeney and Nelson, 1982), following reduction by Cd to NO_3^-.

Field Operations, Sampling, and Analysis

In preparation for this experiment, conventionally tilled corn, fertilized with 168 kg N ha^{-1}, was grown during the summer of 1991 on the entire plot area. After grain harvest, corn stalks were mowed.

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On 18 October 1991, six plots were no-till planted to rye (cv. Wheeler) at the rate of 112 kg seed ha^{-1}. The remaining six plots were left fallow for the winter.

To assess the inorganic N content of the soil profile, plots were sampled to 90 cm in 15-cm increments on **6** November 1991 and 14 April 1992. Soil was extracted with 2 M KCI (20 g soil:100 mL solution), and soil extracts were analyzed for NH_4-N by the indophenol-blue method (Keeney and Nelson, 1982) and for NO_3-N by the Griess-Ilosvay method (Keeney and Nelson, 1982).

To estimate dry matter production and N uptake by the rye, aboveground tissue samples were taken on **23** April 1992. Rye samples were dried **(65°C),** ground **(< 1** mm), and digested (Nelson and Sommers, 1973); digest N concentrations were determined colorimetrically by the indophenol-blue reaction (Keeney and Nelson, 1982).

On 23 April 1992, the rye was killed, and tillage treatments were imposed: conventional tillage plots were mowed, moldboard plowed and disked; no-tillage plots were mowed, sprayed with paraquat (1,l'-dimethyl-4,4'-bipyridinium ion), and left untilled.

On 24 April 1992, plots were planted to corn (cv. DeKalb 689) at the rate of 60250 kernels ha^{-1}, in rows 0.76 m apart. Fertilizer N (168 kg N ha^{-1} as NH_4NO_3) was broadcast 3 days later. To control weeds, plots were sprayed on 28 April 1992 with atrazine [2-chloro-4-(ethylamino)-6-(isopropylamino)-s-triazine] and alachlor [2-chloro-2',6'-diethyl-N-(methoxymethyl) acetanilide], both applied at the rate of 2.24 kg ai ha^{-1}. Corn on the no-tillage rye plots was replanted on 21 May 1992 because of extensive bird damage.

On 7 October 1992, corn grain was harvested, and corn stover samples were taken from the two center rows of each plot. Corn tissue was analyzed for N as rye tissue had been (described above). The first year of the experiment was concluded on **30** October 1992.

Experimental Design and Statistical Procedures

The experiment was laid out as a split plot design in randomized blocks with three replications. The main plot is tillage (conventional or no-tillage), and the subplot is winter cover crop (fallow or rye). Analysis of variance was performed using SAS (SAS Institute, 1985).

RESULTS AND DISCUSSION

Winter 1991

Drainage. Unusually dry fall conditions (Table 1) delayed soil moisture recharge and virtually eliminated tile drainage until the last days of December 1991 (Figure **1**). By the end of February 1992, winter drainage essentially had ceased. From then on, lower than normal spring rainfall (Table 1) and increasing evapotranspiration combined to prevent significant drainage during the rest of the cover crop/winter fallow period.

Table 1. Monthly rainfall from October 1991 through October 1992 and long-term (1884-1991) average monthly rainfall at Watkinsville, Georgia.

Year	Month	Monthly rainfall at site (mm)	Long-term average monthly rainfall† (mm)	Rainfall deficit (-) or surplus (+) (mm)
1991	October	3.4	75.7	-72.3
	November	17.0	78.0	-61.0
	December	81.5	110.5	-29.0
1992	January	88.2	118.9	-30.7
	February	121.9	120.6	+1.3
	March	101.6	134.4	-32.8
	April	40.1	98.6	-58.5
	May	43.7	96.5	-52.8
	June	165.3	99.3	+66.0
	July	145.1	126.7	+18.4
	August	205.5	107.4	+98.1
	September	194.3	85.6	+108.7
	October	61.7	75.7	-14.0
	Total	1269.3	1327.9	-58.6

† measured 5 kvm from site.

Cumulative drainage was consistently less under rye than it was under winter fallow (Figure **1**). By late April when the rye was killed, the difference in drainage volumes was considerable (41 mm under rye, 60 mm under fallow).

Nitrate Concentrations. 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 8.8 mg

NO_3-N L^{-1}, just below the **U.S.** Public Health Service's maximum allowable concentration for drinking water (**10** mg NO_3-N L^{-1}). In contrast, the average NO_3-N concentration measured under winter fallow (**21.6** mg NO,-N L^{-1}) was roughly two times the Health Service limit.

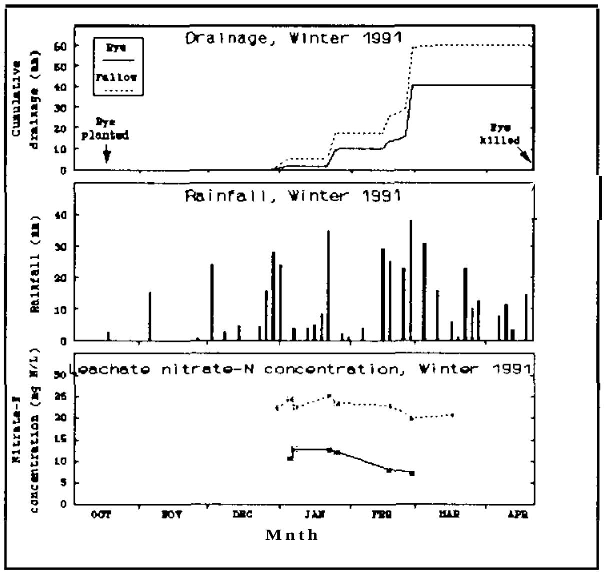

Figure **1.** Cumulative drainage, rainfall, and leachate NO_3-N concentration for winter **1991.**

Nitrate Losses. Measured NO_3 leaching losses were small for both winter cover treatments (Table 2). However, we do not know how completely the tile drains intercepted water leaching through the plots or how much these values underestimate actual NO; leaching losses. Incomplete drainage water inter-ception is suggested by the drainage response of a storm in February. This storm occurred less than a day after drainage from the previous storm had ceased and during a time of year when evapotranspiration was minimal. Thus, the soil was near saturation when the storm began, and under these conditions, tile interception of water draining through the plots should be maximal. For this storm, we calculated that tile drains intercepted an average of 742% (std. dev. 12.8%) of the rainfall. It should be noted, however, that this estimate of tile drain capture efficiency did not take into account the possibility that runoff losses were significant. Runoff was not measured in this study.

Total NO_3-N loss in tile flow was less under rye than under winter fallow (Table 2). Reduction in NO; leaching by cover crops appears related to their use of both water and N (Meisinger et al., 1991). Transpiration by cover crops consumes soil moisture, and this reduces the volume of water available to transport NO; through the root zone. Uptake of N by cover crops removes NO; from the soil solution that otherwise can be leached out of the soil profile.

Table **2.** Total measured leaching loss of NO_3-N during winter, soil profile NO_3-N content on 6 Nov 1991 and 14 Apr 1992, and N content of aboveground rye dry matter on 23 April 1992.

Winter cover	Measured leaching loss of NO_3-N†	Soil profile NO_3-N content‡ **6** Nov **1991**	**14** Apr **1992**	**Rye** N content 23 Apr **1992**
	kg NO_3-N ha^{-1}			
Rye	**3.6(±2.0)a§**	**80(±27)a**	**14(± 6)a**	**94(±13)**
Fallow	**11.8(±3.2)b¶**	**80(±17)a**	**51(±12)b**	**--**

† Total from 18 October 1991 through 23 April 1992.
‡ Sampled to a depth of 90 cm.
§ Where letter postscripts differ within **a** column, means are significantly different (***P*** **< 0.10).**
¶ Values in parenthesis are sample standard deviations.

Nitrogen Balance. Rough N balances were constructed for winter 1991. In early November 1991, 80 kg NO,-N ha^{-1} were found in the root zone of both winter cover treatments (Table 2). By late April 1992, N accounting on the rye plots indicated a total of 112 kg N ha" had been sequestered in rye aboveground dry matter, intercepted by tile drains, or retained within the root zone as NO_3-N (Table 2). Although variability in field measurements was great, the lack of agreement between fall and spring N-balance estimates raises the possibility that soil N mineralization was appreciable between early November and April.

In contrast, roughly half as much N was accounted for in April on the fallow plots, where a total of 63 kg N ha^{-1} had been captured by tile drains or remained in the root zone as NO_3-N (Table 2). This difference in N-balance estimates between the two winter cover treatments suggests that denitrification was greater on the fallow plots. On the cover-cropped plots, competition by rye for NO_3-N may have reduced denitrification losses.

Summer 1992

Drainage. Despite below normal rainfall in March, April, and May, above average amounts from June through September 1992 (Table 1) generated more summer drainage than expected (Figure 2). From the time of corn planting through 30 October 1992, the trend was for greater cumulative drainage where rye had been grown the previous winter (198 mm after rye, 168 mm after fallow, **$P<0.13$).** During the same period, cumulative drainage was greater where no-tillage was used (200 mm for NT, 164 mm for CT, $P<0.06$). These results are consistent with a mulch effect. Killed cover crops and post-harvest crop residues, left as surface mulch by no-tillage, frequently increase leachate volume by encouraging infiltration and slowing evaporative water loss (Phillips, 1984). Not surprisingly, summer drainage was greatest where residue coverage was greatest: on no-tillage plots that possessed a mulch of both rye and corn residues (Figure 2).

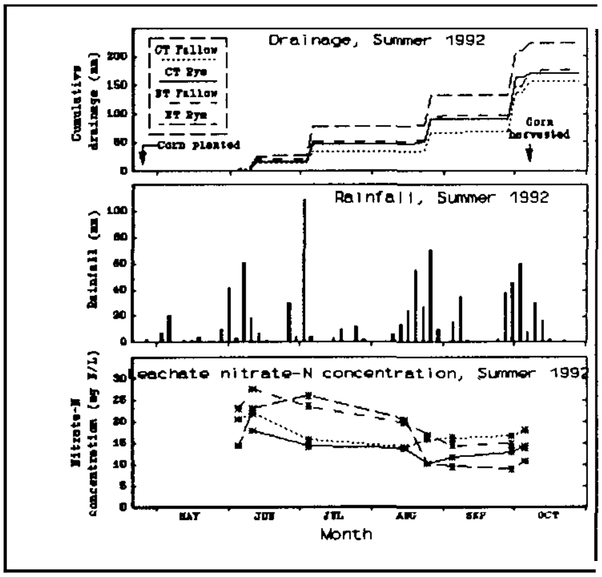

Figure **2.** Cumulative drainage, rainfall, and leachate NO_3-N concentration for summer **1992.**

Nitrate Concentrations. In general, leachate NO_3-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 (Magdoff, **1991)** and the fact that N fertilizer was applied in a single application at the beginning of the growing season.

For three of the four treatment combinations, NO_3-N concentrations appeared to increase slightly late in the summer season (Figure 2). These increases may be due to the combined effect of diminished N uptake by corn as it matured and to continuing mineralization of soil organic N (Magdoff, 1991).

In general, leachate NO_3-N concentrations tended to be higher with no-tillage than with conventional tillage during the first half of the summer period (Figure 2). This tillage effect may be due to the presence of more large soil pores (macropores) that are continuous with the soil surface under no-tillage (Tyler and Thomas, 1977). Macropores can conduct large amounts of water and nitrate rapidly through the root zone, deep into the profile, or beyond (Thomas and Phillips, 1979). Intense storms, like the one on 4 July 1992 (Figure 2), usually produce the most macropore flow.

The NO_3-N concentration of the tile flow during the summer was affected by winter management practices. In general, summer NO_3-N concentrations tended to be lower where rye had been grown the previous winter than where the land had been left fallow (Figure 2). When averaged across the summer season, the NO_3-N concentration of tile flow was lower ***($P<0.05$)*** after rye (13.9 mg NO_3-N **L^{-1})** than after fallow **(17.6** mg NO_3-N **L^{-1}).** These differences in summer NO_3-N concentration reflect the difference between the two winter cover treatments in profile NO_3-N at about the time the corn growing season began (Table 2). In addition, N immobilization associated with the decomposition of rye residues could have limited the amount of NO_3-N susceptible to summer leaching.

Nitrate Losses. Total NO_3-N losses during the corn growing season were much greater than they had been during the preceding winter fallow/cover crop period. This can be attributed to above average rainfall from June through September and to the leaching of fertilizer N applied for corn. Between corn planting and 30 October 1992, significantly **($P<0.07$)** more NO_3-N was lost in tile flow with no-tillage **(34 kg** NO_3-N ha^{-1}) than was lost with conventional tillage (25 kg NO_3-N ha^{-1}). Despite tillage differences in measured NO_3-N leaching loss and the fact that corn was replanted on the no-tillage rye plots, there was no significant effect of tillage, cover cropping or their interaction on corn N uptake (99 kg N ha^{-1} for NT rye, **97 kg** N ha^{-1} for CT rye, **95 kg** N ha^{-1} for NT fallow, **92** kg N ha^{-1} for CT fallow).

Winter management did not significantly affect the total quantity of NO_3-N leached during the summer season (29 kg NO_3-N ha" after rye, and 30 kg NO_3-N ha^{-1} after winter fallow). Similarly, the interaction of tillage and previous cover crop had no significant effect on measured NO_3-N leaching losses during the summer season (35 kg NO_3-N ha^{-1} for NT rye, 23 kg NO_3-N ha" for CT rye, 34 kg NO_3-N ha^{-1} for **NT** fallow, 27 kg NO_3-N ha^{-1} for CT fallow).

CONCLUSIONS

In climates like Georgia's that possess mild humid winters, use of a rye cover crop appears to have utility for control of NO,' leaching from cropland. First year results of this study indicate that a rye cover crop significantly limited NO,' leaching loss by reducing both the volume and the NO_3-N concentration of water that leached through the root zone. While quantities of NO_3-N in the drainage were small during both winter and summer, NO_3-N concentrations generally remained above 10 mg NO_3-N L^{-1}, except in winter where a rye cover crop was growing.

Since no-tillage conserves soil moisture from evaporation and promotes macroporosity, it is not surprising that NO; leaching losses were greater with no-tillage corn than with conventional tillage corn. These preliminary results suggest that use of no-tillage in the Southern Piedmont may necessitate a higher level of management if stringent control of NO,' leaching is required.

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