Nitrate Leaching Under Corn Is Not Well Related to Choice of Conservation Tillage System

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Introduction

In Kentucky, row crop agriculture's contribution to impaired water quality is controversial, especially as regards nitrate nitrogen (nitrate-N). The nitrogen cycle is affected by many agronomic management practices, including tillage. There is some concern that continued use of N containing inputs will result in elevated levels of nitrate-N in Kentucky's surface and ground waters. Nitrogen fertilizer is heavily used in corn *(Zea mays* L.) production and that crop is often planted on well-drained soils in the state.

Well-drained soils are a special challenge in water quality research. Water moves both through the soil (as leachate) and across the soil surface (as runoff) during a precipitation event of sufficient intensity. Tillage can affect the partitioning between infiltration and runoff. In many soils, no-tillage (NT) management preserves macroporosity that enhances infiltration and retards runoff.

The evidence that the greater infiltration of water under NT is necessarily associated with greater nitrate leaching is conflicting. In Kentucky, initial reports found that nitrate leaching under NT corn was often greater than that observed under moldboard plow (MP) corn, especially early in the summer (Thomas et al. 1973; Tyler and Thomas, 1977). Later work, on the same soil, suggested that there was no difference in nitrate leaching between these two tillage systems (Kitur et al., 1984). In Iowa, Kanwar et al. (1985) reported greater removal of nitrate from the surface 30 cm of the MP soil, as compared to the NT soil, after simulated precipitation. Randall and Kelley (1986) did find greater quantities of nitrate in 4 years of tile flow under NT corn, but the difference was small (ave. 2.7 kg/ha/yr).

There are several reasons for the different effects of tillage on nitrate leaching. First, any additional infiltration may not result in similar increases in leaching potential. The greater infiltration of water may permit greater water use by the crop, from more replenished stores of soil moisture. Water used is not available to transport solutes deeper in the soil profile. Greater crop water use is also associated with greater crop yield and greater nitrogen removal from the soil. This would reduce the amount of nitrate available for leaching. Second, there is evidence that solute-soil water interactions (or lack thereof) play a large role in whether solutes move when water flows through macropores. If the solute in entrained in micropore water contained within soil aggregates, then water moving through macropores might "bypass" considerable quantities of the solute. If the solute has not had time to dissolve and diffuse into these intraaggregate volumes, then macropore water will "wash" larger quantities of solute through a well-drained soil.

Many important well-drained corn soils are formed in limestone residuum in Kentucky. Because karst topography is often associated with limestone soils, leachate and runoff waters can be mixed to some degree. The issue of tillage and nitrate leaching remains of interest in the region, as evidenced by our ongoing studies (reported here) and those in Tennessee (Wilson et al., 1994). The focus of our research was on the quality of water leaving the root zone. We assumed this depth to be about 90 cm (3 ft), under corn, and that soil biology would not further modify the chemical character of leachate beyond this point.

Methodology

We have used zero tension pan lysimeters (Tyler and Thomas, 1977) to collect leachate samples at a depth of 90 cm in the soil profile at two locations under continuous corn production. One was on a Crider silt loam (Ultic Paleudalf) near Glasgow, Kentucky, and the other was on a Maury silt loam (Typic Paleudalf) near Lexington, Kentucky. Pan dimensions were 60 x 60 cm on the Crider soil and 90 x 60 cm on the Maury soil. We looked for effects oftillage, fertilizer nitrogen (N) rate (168 vs. 252 kg N ha) and weed control strategy on agrichemical leaching at the Glasgow site, and similarly at tillage, fertilizer N rate (0, 84 and 168 kg N/ha, but only the 0 and 168 kg N/ha rates were instrumented with lysimeter pans) and dairy manure at the Lexington site. This report will focus on the elements common to both experiments, tillage and fertilizer N rate. The experimental design was a split plot at both locations, with tillage system as the main plot and fertilizer N rate as the subplot. Four replications of each conservation tillage treatment (NT vs. chisel plow (CH)) were used on the Crider soil, while eight lysimeter pans were located under each tillage system (NT vs. CH) used on the Maury soil.

Tillage plot size was 3.7 m (4 rows) wide by 27.4 m long on the Maury soil and 5.5 m *(6* rows) wide by ***36.6*** m long on the Crider soil. Subplots were of similar width, but were only 9.1 m long. Chisel plowing was done between middle April and middle May of each year, to a depth of 20 cm, using twisted, 10 cm wide shovels on 30 cm centers. Secondary tillage consisted of disking twice. Corn was planted at a 91 cm row spacing using a John Deere 7000 Max-Emerge no-till corn planter. The seeding rate was 57,100 seed/ha. Nitrogen fertilizer (ammonium nitrate) was broadcast at planting on the Crider soil and over the top of the crop 4 wk after planting on the Maury soil. The subplots were hand harvested and a random set of **5** ears was retained from each for grain N analysis.

We partitioned our leachate collection into "seasons", based on the hydrologic cycle, for our region. "Spring" ran from middle April to late June (planting/early crop development]. "Summer" went from early July until middle *Octo*ber or November (late crop development/harvest). "Fall" was from middle October or November until late December (soil moisture recharge), and "Winter" began in early January and ended in middle April (soil moisture excess-drainage).

Soil samples were taken between the "summer" and "fall" seasons, and also between the "winter" and "spring" seasons, each year. Soils were sampled (4 cores per plot) to a depth of **90** cm and subdivided into 0-15, 15-30, 30-60, and 60-90 cm depth increments. Soil samples were air dried and crushed to pass a 2 mm screen opening. Soil bulk density was determined across the plot area, at each depth increment, using cores that did not exhibit any compression during sampling.

Grain N concentrations were determined by microKjeldahl digestion (Nelson and Sommers, 1973), with automated N detection by the colorimetric indophenol-blue reaction (Keeney and Nelson, 1982). Soil nitrate was found by extraction with molar KCI (25 mL solution:l0 g soil for 30 min), filtering the extract through Whatman 42 paper, and automated determination of nitrate by the colorimetric Greiss-llosvay method (Keeney and Nelson, 1982) after reduction of nitrate to nitrite by cadmium. Soil nitrate was expressed in kg N/ha after correction of soil nitrate concentrations for the bulk density. Results were then summed across all the depth increments. Nitrate in water samples was determined using the same filtering and colorimetric procedures as for soil nitrate. above.

Results and Discussion

Leachate was collected for three years at Glasgow and two years at Lexington (Table 1) Leachate yield, as a Fraction of precipitation, was generally higher on the Crider soil than on the Maury soil. Leachate distribution among the seasons differed considerably from one year to the next. Usually, greater amounts of leachate were observed in either the fall or the winter season. The 1992/93 growing season was unusually moist at the Crider soil's location and there was more leachate during the spring and summer seasons that year.

The differences in spring and summer rainfall were also reflected in corn yields on the Crider soil (Table 2). The 1992/93 growing season gave higher yields than those observed in the other two years. The greater rate of fertilizer nitrogen did not raise corn yields that year, but did so in the other two years. As expected, fertilizer nitrogen rate had no effect on the amount of leachate that was collected in the year subsequent to fertilization, but both the flow-weighted concentration and total quantity of nitrate-N in the leachate were positively affected.

Chisel tillage resulted in a higher yield than did NT in 1992/93 on the Crider soil (Table 2), but there was no difference between conservation tillage systems in the other two years. The amount of leachate collected over the year following fertilization was always greater under NT soils. Flow-weighted nitrate-N concentrations in the leachate were not influenced by tillage, but the greater amount of leachate under NT resulted in greater quantities of leached nitrate under that system.

Corn grain yields on the Maury soil were positively influenced by N fertilizer rate both years (Figure l). Yields were generally better the first year at this location. There was a significant tillage by fertilizer N rate interaction in the second year. In that year NT corn yielded less than CH corn at the lowest N rate, but more at the two higher rates. Such a response would be expected, given that NT conserves more soil moisture for the crop to use, and that places the crop in a better position to respond to additional fertilizer N. The response at this site contrasts with that observed on the Crider soil, where no benefit of NT to yields in more dry years was found.

Chisel tillage resulted in greater amounts ofleachate than did NT on the Maury soil (Figure 2). These differences occurred largely in the fall and winter seasons (periods 3,4 in 1993/94; periods 7,8 in 1994/95). Again, fertilizer N rate had no effect on leachate quantities (data not shown). Leachate nitrate concentrations (Figure 3) were highest in the fall and winter seasons, and were positively influenced by fertilizer N addition. During these periods, leachate from NT soils was often higher in nitrate-N than leachate from CH soils, but the greater flow under the CH soils resulted in greater quantities of nitrate-N being lost (Figure 4).

When comparing these two sites, it appears that tillage does not contribute a great deal to our ability to predict leachate water quality. On the Maury soil, chisel plowing was associated with greater leachate volume and lower nitrate concentrations, while on the Crider soil, no-tillage was observed to give higher leachate volume, but similar nitrate concentrations. Because of this, we tried other approaches to predicting nitrate concentrations in leachate during the fall and winter seasons, when so much is usually being lost under our conditions.

When we related leachate nitrate concentrations to an above-ground nitrogen budget (fertilizer N applied - N removed in the grain) on the Crider soil (Figure 5), there was a positive relationship, but there was considerable dispersion

Table 1. Rainfall and seasonal leachate collection at the two locations.

Glasgow			Lexington		
Season	Rainfall	Leachate	Season	Rainfall	Leachate
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	1991/92			1993/94	
Spring	161	8	spring	269	25
Summer	188	2	summer	467	18
Fall	300	216	Fall	144	88
Winter	344	106	winter	427	178
Total	993	331	Total	1307	309
	1992/93				
Spring	357	144	spring	209	55
Summer	412	150	summer	343	2
Fall	208	10	Fall	126	14
Winter	376	108	winter	255	83
Total	1352	412	Total	933	154
	1993/94				
Spring	153	10			
Summer	214	1			
Fall	328	198			
Winter	640	373			
Total	1334	582			

Table 2. Effect of fertilizer N rate and tillage on corn grain yield and water and nitrate-N losses on the Crider soil.

Year	Fert. N Rate	Tillage System	Grain Yield	Leachate	Flow-Weighted Nitrate Conc.	Nitrate Flux
	kg/ha		Mg/ha	mm	mg N/L	kg N/ha
			Main Effect of Fertilizer N Rate			
91/92	168		7.28b*	347a	18.1b	62.8b
	252		7.72a	316a	23.9a	75.6a
92/93	168		10.30a	418a	14.0b	58.5b
	252		10.53a	406a	18.0a	72.9a
93/94	168		8.55b	573a	9.8b	56.3b
	252		9.14a	591a	13.5a	80.1a
			Main Effect of Tillage System			
91/92		NT†	7.50a	378a	19.0a	71.7a
		CH	7.50a	284b	23.5a	66.6a
92/93		NT	9.60b	474a	16.6a	78.4a
		CH	11.24a	351b	15.1a	53.0b
93/94		NT	8.90a	631a	12.2a	76.9a
		CH	8.78a	533b	11.2a	59.5b

* Means followed by the same letter are not significantly different at the 95% level of confidence

† NT = no-tillage; CH = chisel plow.

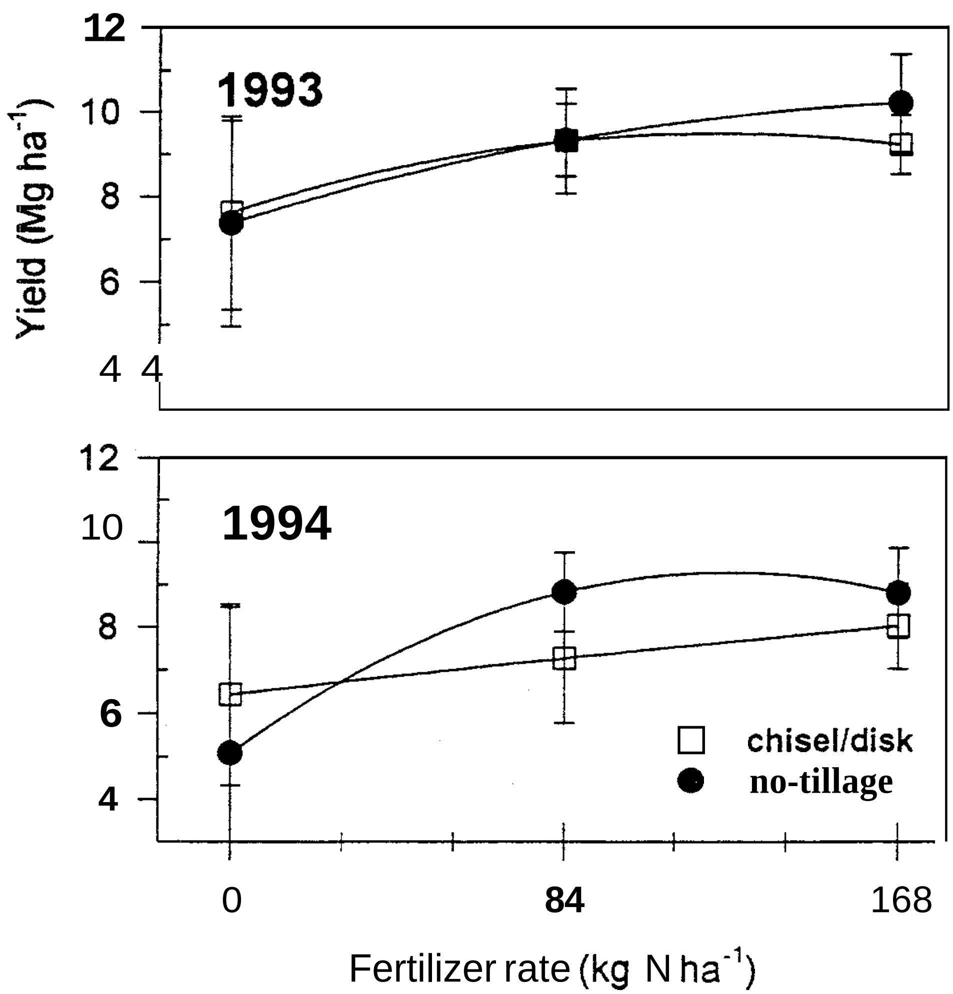

Figure 1. Corn grain yield response to fertilizer nitrogen on the Maury soil. Error bars are+/- one standard deviation.

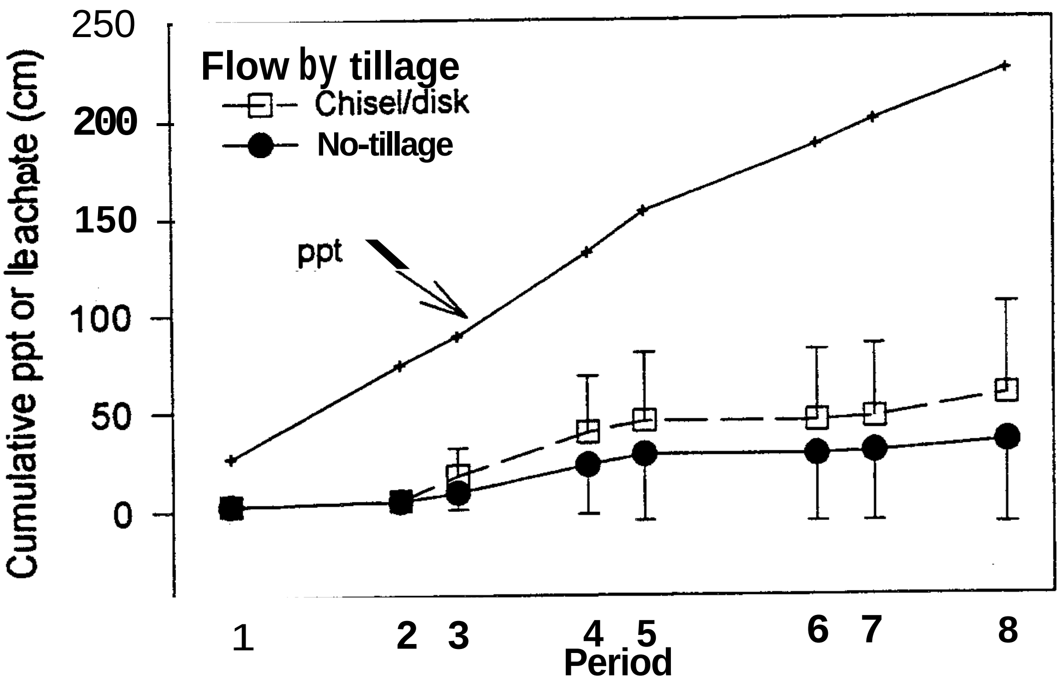

Figure 2. Cumulative precipitation (ppt) and leachate, by season, as affected by tillage on the Maury soil. Error bars are +/- one standard deviation, with center portions removed for clarity.

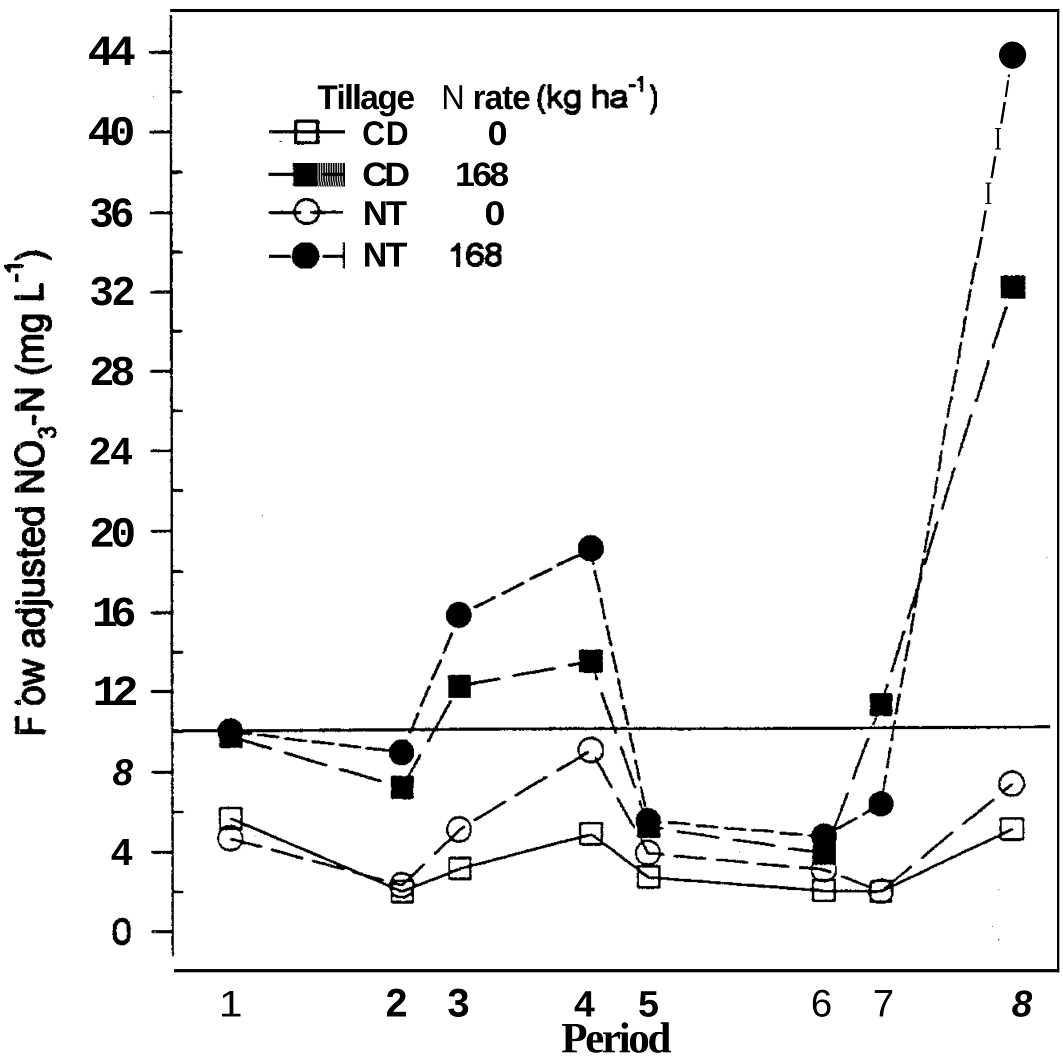

Figure 3. Flow-weighted nitrate concentrations, by season, as affected by tillage (CD = chisel/disk, NT = no-tillage) and fertilizer N rate on the Maury soil.

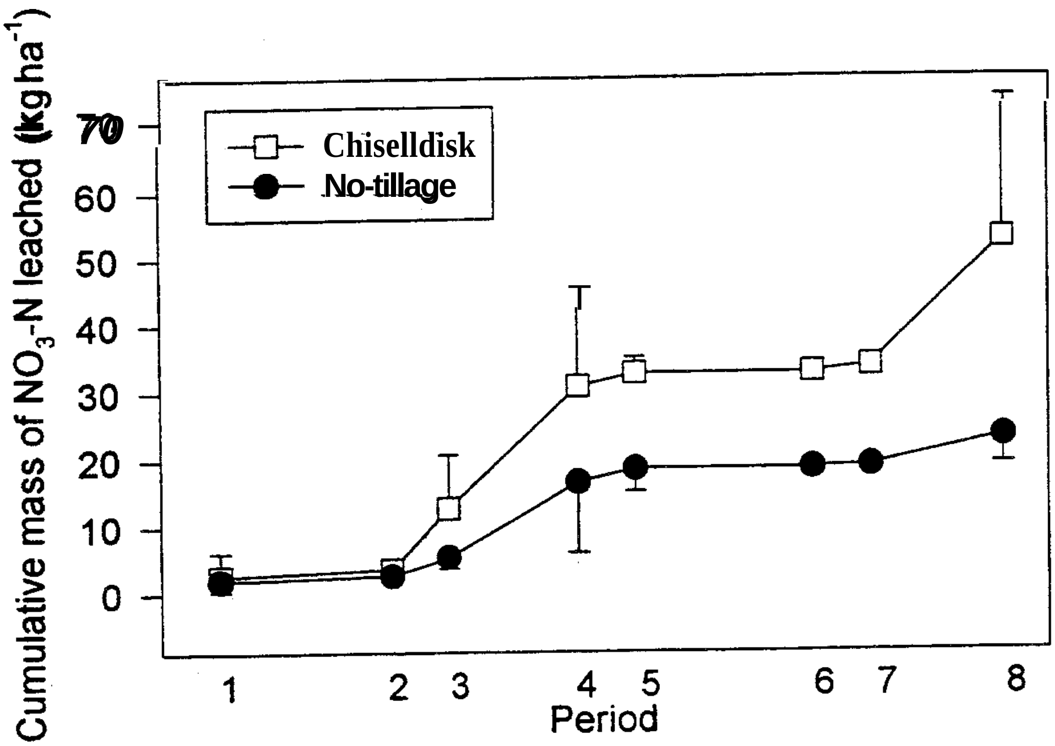

Figure 4. Cumulative quantity of nitrate-N leached, by season, as affected by tillage on the Maury soil. Error bars are +/-one standard deviation, with center portions removed for clarity.

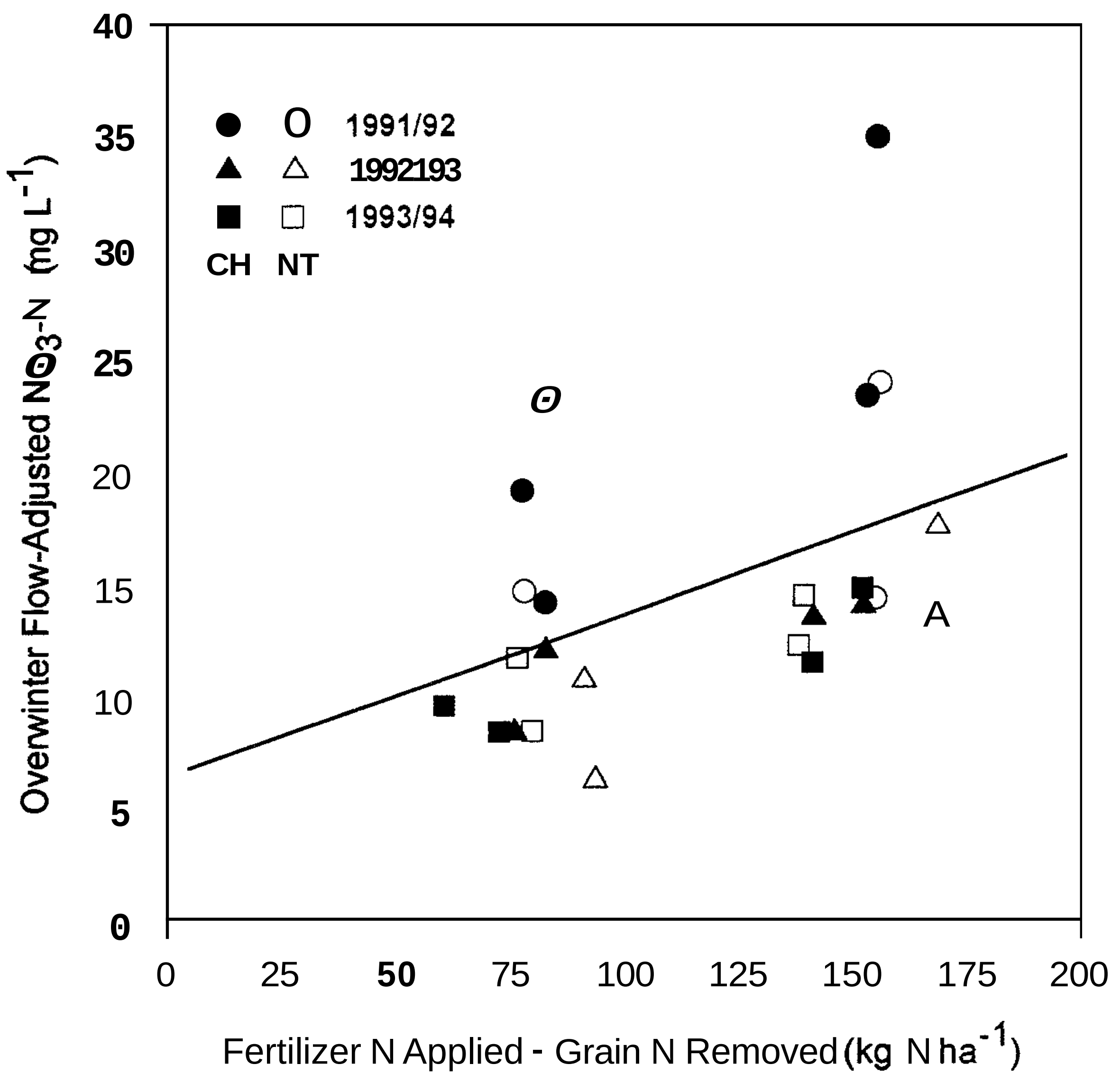

Figure 5. Overwinter (November-April) flow-weighted nitrate concentrations, for three years, as related to the above-ground N budget for continuous corn grown on the Crider soil.

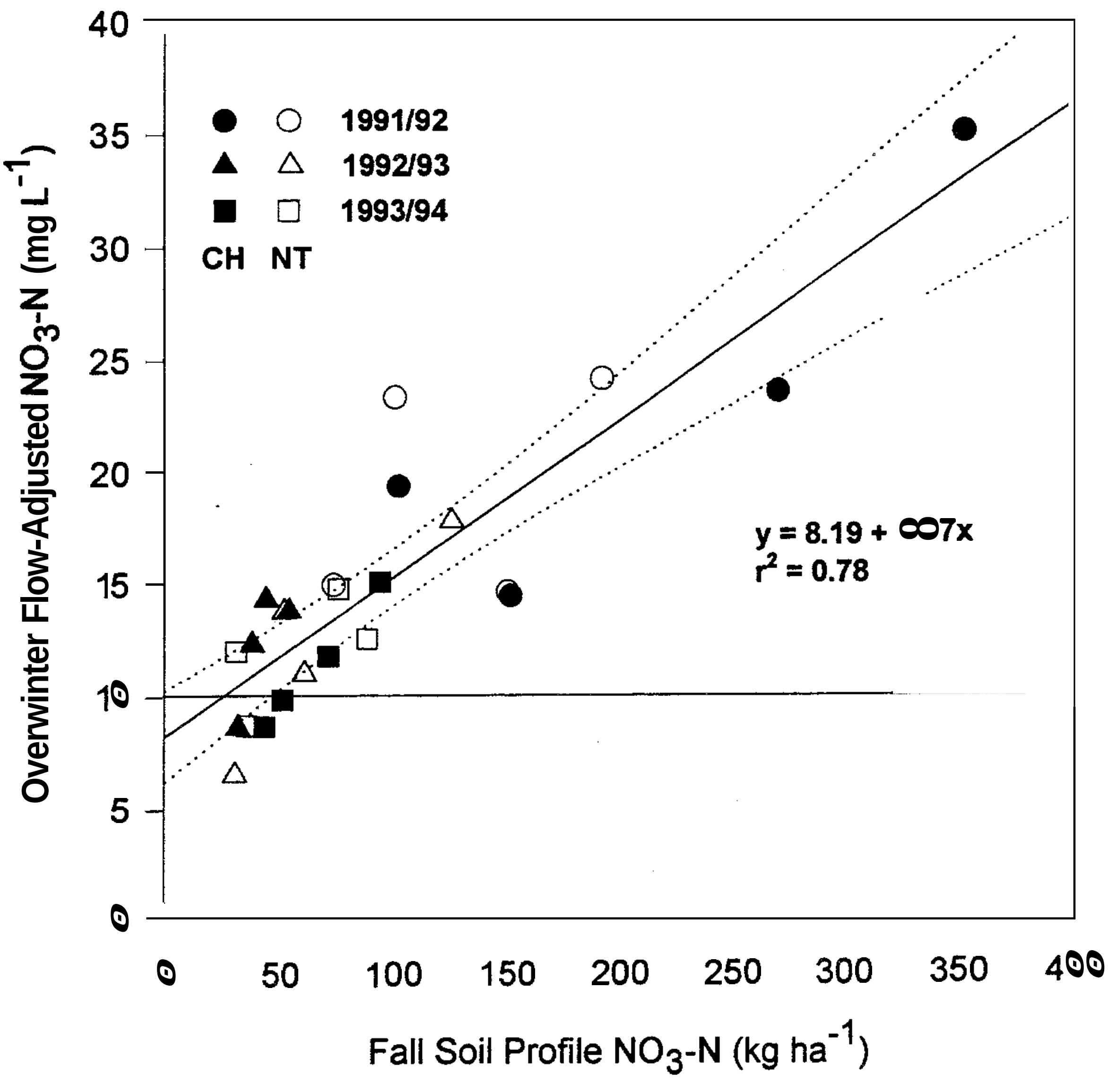

Figure 6. Overwinter (November-April) flow-weighted nitrate concentrations, for three years, as related to quantities of nitrate-N in the soil profile after corn harvest on the Crider soil. Dashed lines represent 95% confidence limits on the regression relationship.

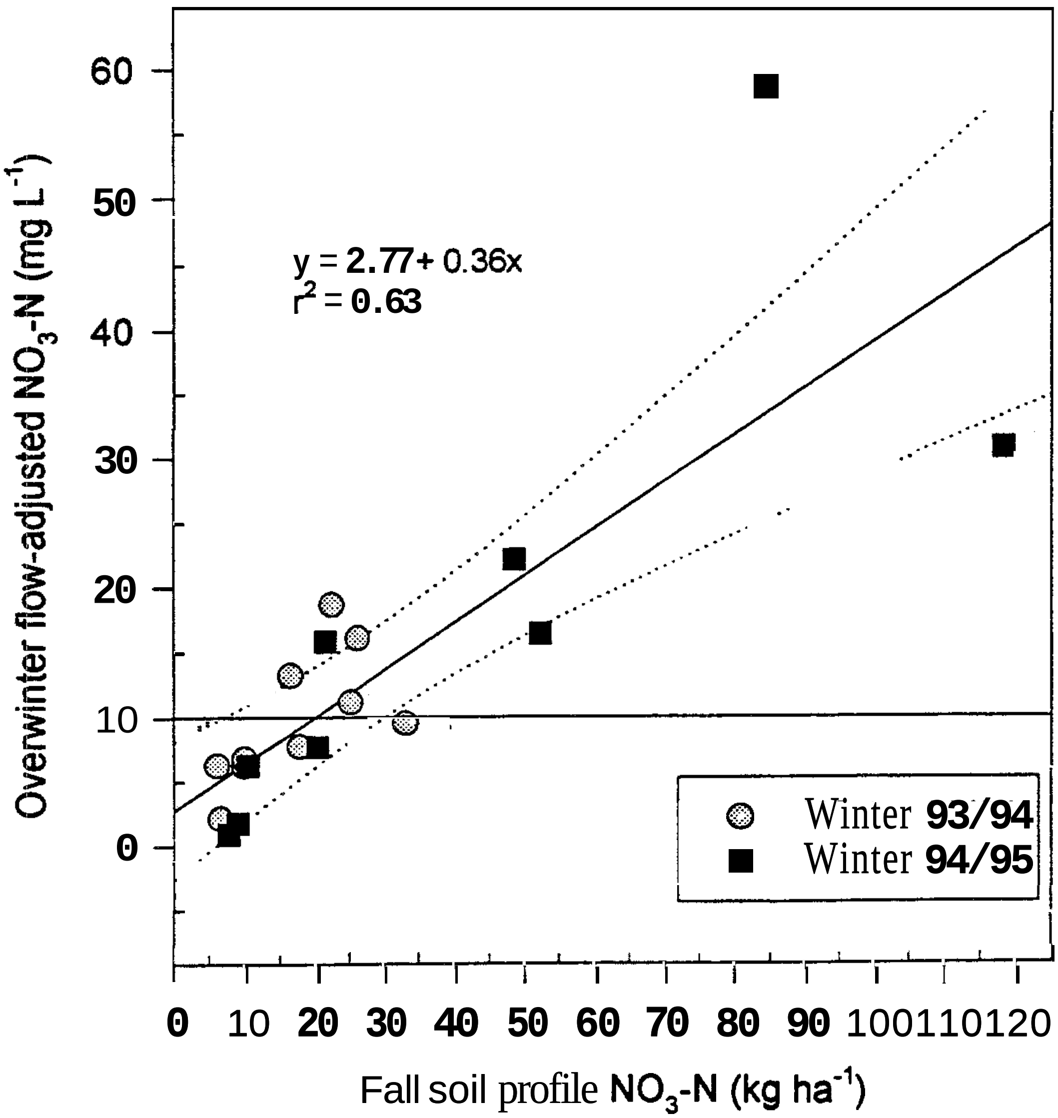

Figure 7. Overwinter (November-April) flow-weighted nitrate concentrations, for two years, as related to quantities of nitrate-N in the soil profile after corn harvest on the Maury soil. Dashed lines represent 95% confidence limits on the regression relationship.

about the region defined by each of the two N rates used in the study. A stronger relationship over the three years was observed when we related leachate nitrate concentration to the quantity of nitrate-N found in the soil profile after corn harvest (Figure 6), though there are fewer than desired data points for soil profile nitrate levels greater than 150 kg N/ha.

On the Maury soil, an above-ground budget was not attempted because of the complication of the addition of N as dairy manure to some of the plots. Still, when leachate nitrate concentrations were related to fall soil profile nitrate over the two years, a relationship, similar in strength to that observed for the Crider soil, was observed (Figure 7). Our analysis suggests that fall soil profile nitrate, regardless of tillage, is a much better predictor of leachate nitrate concentrations. Though continuous corn was grown at both locations, and though these soils are quite similar in many profile characteristics, the difference in slope between the two regression lines does suggest that more knowledge is needed if we are to predict the potential for nitrate leaching in well-drained soils in Kentucky.

References

Kanwar, R.S., J.L. Baker, and J.M. Laflen. 1985. Nitrate movement through the soil profile in relation to tillage system and fertilizer application method. Trans. ASAE 28:173 1-1735.

Keeney, D.R., and D.W. Nelson. 1982. Nitrogen: Inorganic forms. In A.L. Page et al. (eds) Methods of Soil Analysis, 2nd ed. Agronomy 9:643-698.

Kitur, B.K., M.S. Smith, R.L. Blevins, and W.W. Frye. 1984. Fate of N-depleted ammonium nitrate applied to no-tillage and conventional tillage corn. Agron. J. 76:240-242.

Nelson, D.W., and L.E. Sommers. 1973. Determination of total nitrogen in plant material. Agron. J. 65:109-112.

Randall, G.W., and P.L. Kelly. 1986. Nitrogen loss to tile lines as affected by tillage. In A report on filed research in soils. Univ. Minnesota Agric. Exp. Stn. Misc. Pub. 2 (rev). p. 125-127.

Thomas, G.W., R.L. Blevins, R.E. Phillips, and M.A. McMahon. 1973. Effect of a killed sod mulch on nitrate movement and corn yield. Agron. J. 65:736-739.

Tyler, D.D., and G.W. Thomas. 1977. Lysimeter measurements of nitrate and chloride losses from soil under conventional and no-tillage corn. J. Environ. Qual. 6:63-66.

Wilson, G.V., D.D. Tyler, N.J. Storck, M.E. Essington, and T.C. Mueller. 1994. Tillage effects on agrichemical movement through the vadose zone. Tenn. Farm Home Sci. (Winter Issue) p.34-39.