ROLE OF ADOPTING REDUCED TILLAGE PRACTICES TO SATISFY GOVERNMENT MANDATES IN THE NEUSE RIVER BASIN AND OTHER SENSITIVE WATERSHEDS IN NORTH CAROLINA

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ABSTRACT

Fish kills and the identification of *Pfiesteria piscicida* spurred environmental regulations of point and nonpoint source nitrogen (N) pollution in the Neuse River Basin. The majority of the producers selected to join a Local Area Plan to document best management practice (BMP) implementation and N reductions. Documentation required the development of a tracking tool, Nitrogen Loss Estimation Worksheet (NLEW). In determining N reduction coefficients for BMPs, the committee developing NLEW developed the following literature review on the efficacy of no-till. Since the majority of nitrogen lost from agricultural systems in the South is through the soil into the shallow groundwater, only soluble N was considered. The committee determined that cover crops could reduce N loading into shallow ground water but that research conducted on no-till showed no pattern of N reductions: sometimes nitrate loading to the shallow groundwater increased and sometimes it decreased.

INTRODUCTION

The U.S. Environmental Protection Agency (USEPA) has estimated 70 to 80 % of all water pollution is caused by nonpoint sources (NPS) (USEPA, 1998). As a large part of the nonpoint source load, agriculture has been implicated in water quality deterioration of estuarian and ocean resources. Currently USEPA is under court order/consent decree to ensure that Total Maximum Daily Loads (TMDLs) are established in many states (USEPA, 2000a). The suits resulted in proposed revisions to existing regulations for administering the TMDL provisions of the Clean Water Act. On July 13, 2000, the final TMDL Rule was published in the Federal Register (USEPA, 2000b). Under the TMDL Rule, a TMDL will be established for each impaired water resource. Each TMDL specifies the pollutant and the amount by which a pollutant needs to be reduced from a particular source to meet water quality standards.

Specific water quality problems have already prompted passage of some TMDLs. Fish kills and the identification of *Pfiesteria piscicida* spurred environmental regulations of point and NPS nitrogen (N) pollution in the Neuse River (NC DENR, 1997). The intent of these regulations is aimed at improving the water quality of the Neuse River estuary by reducing N loading by 30% within five years. This 30% reduction in N has become the USEPA-approved TMDL (NC DENR, 1999).

Several rules were written to abate agriculturally derived NPS N in the Neuse River. One rule in particular, Rule .0238, requires that agricultural producers either implement mandatory best management practices (BMPs) or that they join a Local Area Plan. Under the mandatory BMP option, producers must utilize one of the following BMPs: 1) a 15-meter riparian buffer (9 meter tree, 6 meter other vegetation), 2) nutrient management and either a 9 meter vegetative buffer or a 6 meter tree buffer, 3) nutrient management and controlled drainage, and 4) controlled drainage and either grass (9 meter) or tree (6 meter) buffers. The local plan allows a local group to determine where the approved BMPs should be implemented to obtain the 30% N reduction. This precludes all producers from installing BMPs on all acres. In addition, the local option provided additional BMP options not specified in the rules.

In exchange for this flexibility, however, the rules mandated accountability in the form of an accounting tool rather than water quality monitoring. Water quality monitoring to demonstrate water quality attainment is expensive, long-term and technically difficult. An accounting tool - Nitrogen Loss Estimation Worksheet (NLEW) - was developed to track changes in N losses and BMPs (Osmond et al., 2000). Development of NLEW required decisions to be made on those BMPs that reduced N besides those mandated by the state. Since NLEW is based on soluble N losses primarily through the soil profile and into the shallow groundwater, we were only considering BMPS that reduce N through that pathway.

One BMP that is increasingly used in North Carolina is no-till. Since not all farmers who practice no-till also practice conservation tillage, we separated the effects of cover crops that received N reduction credit from the effects of tillage. Using research from Wagger (1996), nonfertilized cover crops received the following N reduction: wheat (*Triticum aestivum*) = 5%, oats (*Unicola paniculata*) and barley (*Hordecum vulgare*) = 10%, and rye (*Secale cereale*) and triticale (*Triticosecale spp*.) = 15%. Following is a summary of information about N loss effects resulting from no-tillage production practices. This was our basis for assessment of the N-reducing ability of no-till.

No-till Effects on N Loss Pathways

Agricultural fields lose N primarily through erosion, leaching, denitrification, and volatilization. The two loss pathways that degrade water quality are erosion and leaching. In humid regions, leaching losses of N are generally much greater than surface losses (Smith et al., 1990; Drury et al., 1993). Most mineralized N is in the soluble form and potentially moves through the soil into shallow groundwater, which subsequently moves to drainage ditches and streams (Mitsch et al., 1999; Gilliam et al., 1985). Jacobs and Gilliam (1985) found that in the Coastal Plain of North Carolina, only 6% of the soluble N was lost as surface runoff, whereas 94% of N loss was into shallow groundwater. Nitrate-N (NO_3^-) levels measured in streams and ditches have been found to increase from around 1 mg L^{-1} to 5 mg L^{-1} or more in well-drained agricultural watersheds (Mitsch et al., 1999; Goolsby et al., 1999). Several recent reports or review articles of tillage effects on subsurface N losses have concluded that there is no difference in N losses due to tillage systems (Mitsch et al., 1999; Smith et al., 1990).

A literature review to determine the effectiveness of no-till in reducing leaching losses of N revealed that differences in crop rotations, tillage systems, and other soil and crop management factors complicate the interpretation and comparison of research results. For example, the duration of no-till practices between relevant studies can vary from several years to several decades. In some studies, researchers separate the effects of cover crops from tillage type, whereas in other studies these effects are confounded. For this review, we will consider the cropping practice only by the type of tillage used in establishing a crop stand, exclusive of cover crop. In general, we will use the term "no-till" since many of the studies reviewed did not meet or recognize the conservation tillage standards defined by the Conservation Technology Information Center (CTIC, 2000).

No-till generally increases the macroporosity of the soil through increased aggregation. Changes in pore size generally allow for enhanced infiltration but can cause an increase in bulk density in high-traffic areas. Kamau et al. (1996) studied the effect of tillage and cropping practices on preferential flow through macropores and solute transport. Although these researchers were able to determine that macropore pathways played a major role in leaching losses, there was extreme variability in water and solute flow within plots, and they did not find any differences in solute movement due to tillage treatment. Rasse and Smucker (1999) and Ogden et al. (1999) found that no-till increased flow volume compared to conventional-till. The amount of solute lost in both studies, whether NO_3^- or bromide, was essentially similar even though flow was greater under no-till. Researchers in a recent study from Minnesota demonstrated that minimum tillage systems had higher soluble surface nitrogen losses as well as subsurface losses (Zhao et al, 2001).

Better soil structure and increased porosity that are associated with no-till systems may increase N leaching. Preferential flow of water through larger pores may permit more N and pesticides to move through the soil profile in no-till than in conventional tillage systems. Conversely, preferential flow actually can reduce the amount of NO_3^- lost if the water moves quickly through the pores without equilibrating with the N in the smaller pores. Total mass of N loss is a function of both NO_3^- concentration and volume of water flow. Nitrate-N concentration and water movement both must be considered in order to obtain the total mass of N lost below the root zone. There is often an increase in the amount of water moving through the soil in no-till systems. Although this increase may decrease the N concentration, the total mass of N lost from the no-till system will be similar to that of conventional-till systems.

Rasse and Smucker (1999), like many other researchers, have found that more total water was lost to subsurface drainage under no-till than conventional systems, but that the NO_3^- concentrations were greater under conventional tillage plots. Total NO_3^- leached in this study was similar to slightly lower for no-till. An 11-year study compared N leaching losses of no-till to conventional tillage corn (Randall and Iragavarapu, 1995). Total flow over the years was greater under no-till, but NO_3^- concentration was greater under conventional tillage. NO_3^- losses were greater for no-till in 6 out of the 11 years. Average flow-weighted NO_3^- concentration for the entire study period was 13.4 mg L^{-1} for the conventional system and 12.0 mg L^{-1} for the no-till system. Most of the difference in total N leaching between the two systems was due to large losses that occurred under conventional tillage in a single year. Grain yields and N removal were significantly higher 6 out of the 11 years for conventionally tilled corn.

Drury et al. (1993) found higher water losses under no-till and ridge-till but greater NO_3^- concentrations for the conventional-till treatments. Total subsurface NO_3^- losses were conventional-till (23.5 mg L^{-1}), no-till (17 mg L^{-1}), ridge-till (17 mg L^{-1}), and continuous bluegrass pasture (2 mg L^{-1}). Surface NO_3^- losses, however, were 1.6 kg N ha^{-1}, 3.3 kg N ha^{-1}, 2.9 kg N $ha^{-1}$and 0.14 kg N ha^{-1} for conventional-till, no-till, ridge-till, and continuous bluegrass pasture, respectively. Corn yields and N removal in plant biomass were greater for the no-till and ridge-till systems in this study than the conventional-tilled system.

Izaurralde et al. (1995) found greater N losses under no-till than conventional-till systems. Other researchers from Canada reported that NO_3^- leaching losses were greater under no-till than conventional systems, whereas another experiment showed that the reverse was true: conventional-tilled systems leached more N (Serem et al., 1997). Although research reports that present data with soil N concentration are useful, care must be taken in interpreting data that only provides soil N concentration information because of the possible differences in the amount of water movement.

Power et al. (2000) summarized research conducted on the Management Systems Evaluation Area Project. Losses of NO_3^- under conventional vs minimum till systems were dependent on the soil properties in differing location. Less NO_3^- was leached under no-till for a site with heavy clay soils in Missouri, whereas more NO_3^- was leached in deep loess soils of western Iowa. At two other locations there was no difference in NO_3^- leaching losses between the tillage systems.

Increased water infiltration can increase available soil moisture. If water is limiting, extra soil water can increase yields. Increased crop yields generally result in greater utilization of fertilizer N, which can reduce the amount of N available for leaching. However, these differences in plant N uptake are frequently so small that the effects on shallow groundwater NO_3^- concentrations are negligible. One reason may be that crops grown under no-till conditions often contain lower N concentrations in the above-ground biomass than conventionally produced crops, probably due to a dilution effect (Rasse and Smucker, 1999; Martens, 2000). In addition, identical rates of N may not have been applied to both systems. For instance, no-till burley tobacco (*Nicotiana tabacum*) generally requires an additional 30 kg N ha^{-1} over the N needs of a conventionally produced tobacco crop (Hoyt, 1991). In another example, agronomists recommend in a conservation tillage guide for cotton (*Gossypium hirsutum*) that an additional 34 kg ha^{-1} of N be applied to no-till cotton crops that are planted into a desiccated wheat cover crop (Reeves et al., 1993). This extra-recommended N is needed to offset the effects of immobilization.

Cropping systems tend to have a greater effect on NO_3^- leaching than tillage systems. Kanwar et al. (1997) examined the effects of tillage on tile drainage water quality in the Midwest (Table 1). Statistically, there were few differences between tillage treatments for subsurface drainage volume and NO_3^- loss in drainage water.

Table 1. Effects of various tillage practices and rotation on NO_3^- losses in drainage water (Kanwar et al., 1997).

	Tillage				
Rotation	CP	MBP	RT	NT	Average
	----------------------- NO_3^- losses, kg ha^{-1} ----------------------------				
Corn after corn	65	47	55	64	58
Corn after soybean	36	28	24	24	28
Soybean after Soybean	35	33	25	26	29
Average	45	36	34	38	

CP = chisel plow, MBP = moldboard plow, RT = ridge-till, NT = no-till

In this study, corn (*Zea mais*) in the rotation was more influential than tillage type in determining leaching losses of N. Typically, there were smaller differences between tillage treatments in the total amount of N leached and there was no statistical difference in the amount of NO_3^--N lost. The maximum difference in NO_3^--N losses between tillage treatments were less than 25%. In contrast, there were much larger differences between the amounts of NO_3^--N leached due to crop rotation, with a maximum 52% difference due to cropping system.

Southern Region No-till Studies

Staver and Brinsfield (1998) used a paired agricultural watershed design to study the effects of no-till, conventional-till, and a rye winter cover crop under both forms of tillage on N uptake and subsurface NO_3^- losses in the Coastal Plain of Maryland. They also examined the effect of planting date on the N-reducing effectiveness of a rye cover crop. Shallow groundwater NO_3^- concentrations were similar between tillage treatments when there was no cover crop (Staver and Brinsfield, 1998). Following inclusion of a rye cover crop, the following 5-year period depicted lower groundwater NO_3^- concentrations under no-till. After this period, NO_3^- concentrations were similar for both tillage treatments. Because of the changes that occur during the transition to no-till, it is important to monitor long-term experiments on no-till to separate the establishment phase from the semi-equilibrium phase. Based on their results, they concluded that a winter cover crop was much more effective in reducing soil NO_3^- leaching than no-till.

Sharpley and Smith (1994) compared conventional and no-till winter wheat systems in a paired-watershed experiment in Oklahoma. They used conventional tillage in two watersheds and found shallow groundwater concentrations of NO_3^- averaged 4 mg L^{-1} prior to converting one field to no-till. The NO_3^- concentration of the shallow groundwater under the conventional-tilled watershed varied between 2 and 4 mg L^{-1} of NO_3^- during the next 6 years of the experiment, whereas the NO_3^- concentration of the shallow groundwater under the no-till system increased immediately and rose as high as 25 mg L^{-1}. The increased NO_3^- concentration was attributed to poorer wheat yields from the inability to incorporate fall-applied fertilizer N into the no-till wheat.

Crop yields following a cover crop can be higher or lower than a non-cover crop system, depending on the environment. Yield has sometimes been used as an estimate of treatment affects on N leaching. When using yield as a surrogate, caution must be taken because higher yield does not always indicate lower leaching losses.

In a 3-year study conducted on a Norfolk sandy loam, Reeves and Touchton (1991) showed that corn yields were lower following a rye cover crop than following fallow (no cover crop) at N rates from 0 to 150 kg N ha^{-1}. At the highest N rate (150 kg N ha^{-1}), yields were similar. In the Georgia Coastal Plain, Neely et al. (1987) compared sorghum yields produced on a Greenville sandy clay loam over 2 years. Grain sorghum yields were greater after fallow than after a wheat cover crop at N rates ranging from 0 to160 kg N ha^{-1}. A long-term study of 10 years in Maryland (Poplar Hill) reported no statistical difference in yield between no-till and conventional-till plots (Coale, 1999) for corn and soybean (*Glycine max*). Early data from these same experiments demonstrated that conventional tillage had a slight (but not statistically significant) yield advantage at 0 and 80 kg N ha^{-1}. No-till had a slight, but not statistically significant, corn yield advantage at 120 and 160 kg N ha^{-1} (Bandel, 1986).

In Kentucky, Frye (1986) developed a N budget for a Maury silt loam by measuring N uptake and losses (Table 2). At lower N fertilizer rates, more N was translocated to the grain and less was immobilized in the soil in conventional tillage than no-till systems. Approximately the same proportion of N was lost under all tillage treatments and N rates.

Table 2. N Loss Budget

		Fertilizer N		
N Rate	Tillage	In grain	Immobilized	Lost
kg ha^{-1}		%		
84	No-tillage	23	42	29
84	Conventional	40	27	26
168	No-tillage	29	39	25
168	Conventional	28	37	27

Another long-term study was conducted in Tennessee, where researchers compared corn yields from different tillage systems for 11 years. Corn yields were higher in the conventional-tilled plots for 5 of the 11 years, with similar yields in the other 6 years (Howard, 2000). In spite of the yield differences, no-till remains an extremely important tool to reduce soil erosion on the highly erodible, sloping silt-loam soils in this area of Tennessee.

Researchers in Texas found that N applied to no-till wheat was more effective in improving grain yield than conventional treatments at all but the 100 kg N ha^{-1} rate (Hons et al., 1985). Conversely, grain sorghum yields were significantly higher for conventional tillage at all N rates, including the no N treatment. Cropping sequence had a more pronounced influence on yield, however, than tillage type.

Mullins and Mitchell (1989) examined wheat production on a Dothan loam fertilized at 120 and 180 kg N ha^{-1}. At both N rates, wheat yields were greater in conventional tillage than in reduced tillage. Camp et al. (1984) reported no difference in corn or soybean yields between conventional and minimum tillage with subsoiling in a 3-year study on Bonneau and Norfolk soil in the Coastal Plain of South Carolina. More recently, researchers in South Carolina found no consistent differences in yields of corn, wheat, and cotton, or in plant populations; or crop biomass between conventional tillage and no-tillage systems (Hunt et al., 1990; 1997). They did report differences among cultivars in seed cotton yield between the two tillage systems. Averaged over 3 years, three of the six cotton cultivars produced greater yields under conservation tillage management, compared to only one cultivar with higher yields under conventional tillage. In a related study, Bauer and Busscher (1996) reported slightly lower lint yield in conservation tillage compared to conventional tillage, but the difference was not significant. In another study, Torbert and Reeves (1994) evaluated cotton production under several tillage systems produced on three Hapludults: Wickham, Cahaba, and Bassfield. They found that strip-tillage increased lint yield by 14% over conventional tillage, but there was no difference in total N uptake.

The effects of tillage and cover crops at different fertilizer rates were studied for tomato (*Triticolsecale esculentum*) (Sainju et al., 1999). Nitrate-N losses were significantly greater for no-till (129 kg ha^{-1}) than either chisel-plow (54.8 kg ha^{-1}) or moldboard (55.6 kg ha^{-1}). As expected, nitrate losses increased with increasing fertilizer N rate.

Thomas (1992) found that cumulative NO_3^- losses between October and May were similar (100 kg ha^{-1}) for conventional and no-tilled corn. For no-till soybean, however, nitrate-N losses were twice as great as for this crop produced under conventional tillage.(30 kg ha^{-1} vs 15 kg ha^{-1}).

SUMMARY

During a national conference on no-till, it was concluded that no-till had little effect on increasing or decreasing N movement into shallow groundwater (Logan, 1987). Additional data since then continues to support this conclusion: the type of tillage, when considered alone and separately from cover crop practices, has little effect on N movement into the shallow groundwater, and may in fact increase N leaching.

From this review of the effectiveness of various BMPs in reducing N losses, we concluded that no-till, if considered separately from use of small grain cover crops, does not reduce soluble N losses in Coastal Plain cropping systems. We did, however, allow some reduction in N losses for no-till corn produced in the Piedmont since yields are immediately and significantly increased with no-till systems. Data from the Mountains do not support crediting N due to no-till. Cover crops in any physiographic region, however, will give some N-reducing credit.

Increasingly, as tools such as NLEW are developed to track NPS reduction in regulated watersheds or river basins, the scientific community will be asked to answer questions about BMPs such as "What pollutants do individual BMPs affect?" and "How effective are BMPs in reducing a particular pollutant?" Not all states will have the research data necessary to answer these questions and as a consequence, we must rely on the substantial body of scientific knowledge that already exists. Future research in conservation tillage will be most useful if experimental questions are carefully developed and research reports indicate the limitations of the data and results.

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