This is not a peer-reviewed article.
Pp. 165-168 in Preferential Flow Water: Movement and Chemical Transport in the Environment, Proc. 2nd Intl. Symp. (3-5 January 2001, Honolulu, Hawaii, USA), eds. David Bosch & Kevin King, St. Joseph, Michigan: ASAE. 701P0006

Preferential Flow and its Effects on Nitrate and Herbicide Leaching to Groundwater under Various Tillage Systems

Ramesh S. Kanwar and Allah Bakhsh[1]

Abstract

Tillage practices can affect the formation and persistence of preferential flow paths and their role in transporting portion of the surface applied chemicals to groundwater. Field experiments were conducted to quantify tillage (chisel, moldboard, ridge and no-till) effects on subsurface drain flow and losses of nitrate-nitrogen (NO_3-N), atrazine, and alachlor to shallow groundwater. Rapid increase in subsurface drain flow rates following heavy rains indicate the preferential movements of rain water to subsurface tile drains. The sudden decreases in NO_3-N concentrations and increase in the concentrations of atrazine, and alachlor in subsurface drain water, particularly under no-till and ridge till systems, supports the role of preferential flow paths to carry contaminants to shallow water table depth and its overall effects on groundwater quality.
Keywords. macropores, water quality, tillage

Introduction

Preferential flow paths known as 'macropores' are generally referred as non capillary channels or pores formed in the soil as a result of physical, chemical and biological processes in the soil-air-water environment. Recent studies have shown significant role of these flow paths in water and chemical transport through the soil profile and to the shallow groundwater (Kanwar, 1997; Hillel et al., 1999; Larson and Jarvis, 1999; Brown et al., 1999). A better understanding on the formation of these flow paths and their capacity to transport chemicals is required to develop suitable management practices which can minimize the adverse impacts on groundwater quality (Ahuja et al., 1993; Kanwar et al., 1988).

The formation and persistence of macropores may depend on soil, climate, and management practices. Tillage practices directly affect the soil water properties of surface soil and therefore the leaching characteristics (Kanwar et al., 1988; Brown et al., 1999). Tillage practices can also influence the distribution and continuity of soil macropores that can act as preferential flow paths for rapid movement of water and chemicals to the groundwater. Because of these concerns of nonpoint source pollution, the fate of agricultural chemicals is of considerable interest and importance under different tillage systems, particularly the no-till system. No-tillage system allows more crop residue to accumulate on the surface, preserve macropores, and requires more use of chemicals to control weeds. Also, no-tillage system can increase chemical concentration in surface flow causing preferential flow paths to increase the contamination potential of groundwater resources. Conversely, the conventional tillage destroys macropores continuity at the surface and considerably reduces the entry of overland flow solution into macropores and therefore plays different role in chemical transport through the soil profile when compared with no-till system (Ahuja et al., 1993). The role of preferential flow paths for rapid chemical transport through the soil profile becomes even more important when soils under different tillage systems are underlain by subsurface drainage system network. Therefore, a study was conducted to investigate the effect of four tillage systems (chisel plow (CP), moldboard plow (MB), ridge till (RT), and no-till (NT)) on leaching of NO_3-N and herbicides (atrazine and alachlor) with subsurface drainage water. This study presents data on the variability in chemical concentrations in subsurface drainage water in relation to variable rainfall patterns during the growing seasons of three years (1990-92) study period.

Methods and Materials

The study was conducted at Iowa State University's northeastern research center, Nashua, Iowa. The soils at the site, under continuous corn production with four tillage systems, are Floyd loam (fine-loamy, mixed, mesic Aquic Hapludolls), Kenyon loam (fine-loamy, mixed mesic Typic Hapludolls) and Readlyn loam (fine-loamy, mixed mesic, Aquic Hapludolls) (Kanwar et al., 1997). These silty loam soils are moderately well to poorly drained, lie over loamy glacial till, and have 3-4% organic matter. These soils have seasonally high

[1] Ramesh S. Kanwar, Professor of Agricultural and Biosystems Engineering and Director of Iowa State Water Resources Research Institute; Allah Bakhsh, Post Doctoral Research Associate, Department of Agricultural and Biosystems Engineering, Iowa State University, Ames, IA 50011. Corresponding author: Ramesh S. Kanwar, 219C Davidson Hall, Ames, Iowa, IA50011; email: <rskanwar@iastate.edu>

water table and benefit from subsurface drainage system. Subsurface drainage system was installed at this site in 1979 at 1.2 m depth and 28.5 m spacing. The site has 36, 0.4 ha plots with fully documented tillage and cropping records for the past 19 years. Each plot has an independent drainage sump with flow meter for measuring flow rates and collecting water samples for chemical analysis. Drain water sampling frequency averaged three times a week during subsurface drainage flows. Water samples were refrigerated until chemical analyses of NO_3-N and herbicides were made at National Soil Tilth Laboratory in Ames, Iowa. Four tillage treatments, each replicated three times, were applied under a randomized complete block design (Bjorneberg et al., 1996). Both CP and MB plow system received fall plowing and spring cultivation before planting corn. Fall plowing was not done in 1991 because of wet weather. All four tillage systems were given field cultivation, during growing seasons for weed control. Corn was planted in 75 cm apart with a six row planter having a 150-cm wheel base. Anhydrous ammonia was knifed into the soil before planting. Corn grain yield for each plot was measured with a combine (Kanwar et al., 1997). Continuous corn plots received N application of 180 kg/ha compared to 168 kg/ha for corn rotated with soybean.

Results and Discussion

Rapid increase in tile flow rates was observed following heavy rainstorms under the no-till system (Fig. 1). On the average, no-till system (NT) resulted in higher tile flow peaks compared to other tillage systems and these variations in hydrograph can be connected to the formation and continuity of macropores in the soil.

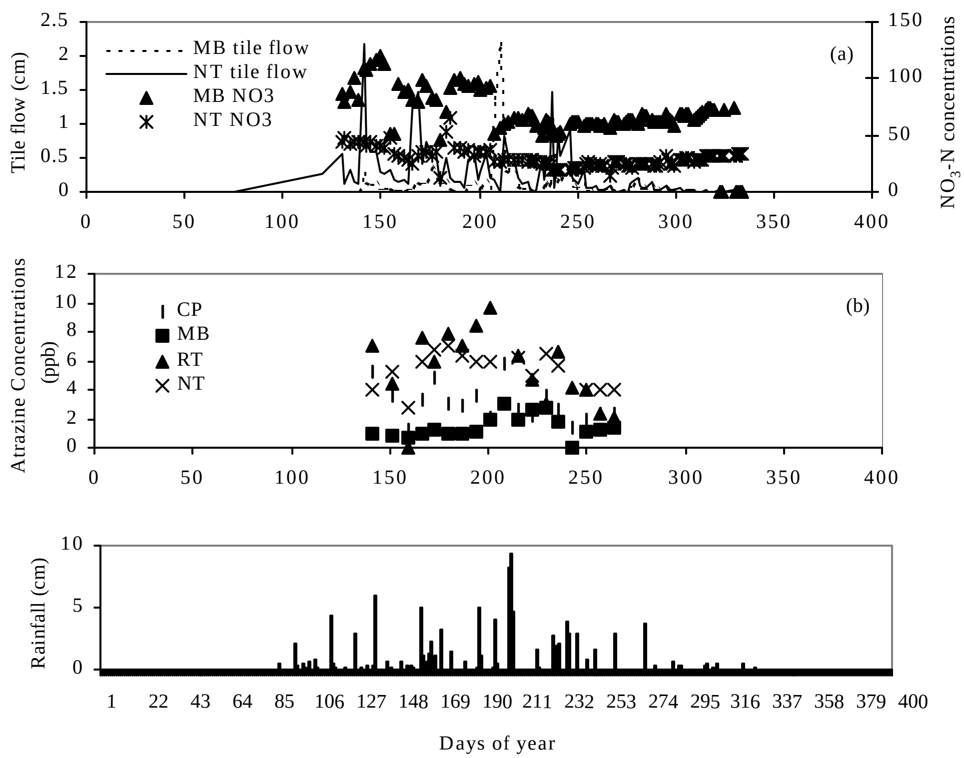

Figure 1-Tillage effects on subsurface drain water quality for 1990.

Moreover, tile flow response seems variable under no-till system over the growing season (Fig. 1a), which can be associated with variable cracks patterns due to changes in soil moisture, root development and raindrop impacts (Ghidey et al., 1999). No-till system showed higher peaks in tile flows in early and later parts of the growing season compared with middle season because field cultivation applied to all plots to control weeds may have clogged the pores at the surface. Higher evapotranspiration requirement during middle part of the season can also affect the preferential flow process. The effect of tillage on NO_3-N concentrations in subsurface drainage water was found to be significant (P=0.05) and this difference is also shown in Fig. 1(a). Moldboard plow system resulted in significantly (P=0.05) higher NO_3-N concentrations (Table 1) in comparison with the no-till system (64 mg/L vs 39 mg/L). The lower value of flow weighted average NO_3-N concentrations for NT showed that infiltrating water through macropores might have bypassed the soil matrix (rather than the concept

Table 1. Tillage effects on subsurface drain water quality under continuous corn production system

Tillage	Variables	1990	1991	1992	Average
	Rainfall (mm)	1050	970	750	923
Chisel Plow	Tile flow (mm)	183b	272a	128	194a
	NO_3-N loss (kg-N ha^{-1})	100a	76a	19a	65a
	NO_3-N conc. (mg L^{-1})	54b	28b	15a	32ab
	Atrazine loss (g ha^{-1})	7.67	7.35	0.78	5.3
	Alachlor loss (g ha^{-1})	0.29	0.004	0.002	0.10
Moldboard Plow	Tile flow (mm)	90c	185b	111	209a
	NO_3-N loss (kg-N ha^{-1})	58a	63a	19a	62a
	NO_3-N conc. (mg L^{-1})	64a	34a	16a	38a
	Atrazine loss (g ha^{-1})	2.2	1.7	0.43	1.4
	Alachlor loss (g ha^{-1})	0.06	1.5	0.002	0.5
Ridge Tillage	Tile flow (mm)	191ab	326a	104	207a
	NO_3-N loss (kg-N ha^{-1})	83a	68a	11a	54a
	NO_3-N conc. (mg L^{-1})	44c	21c	11a	25c
	Atrazine loss (g ha^{-1})	11	9.8	1.1	7.3
	Alachlor loss (g ha^{-1})	0.30	0.74	0.00	0.5
No-till	Tile flow (mm)	275a	336a	178	263b
	NO_3-N loss (kg-N ha^{-1})	107a	63a	20a	63a
	NO_3-N conc. (mg L^{-1})	39c	19c	11a	23bc
	Atrazine loss (g ha^{-1})	18	11	1.6	10.2
	Alachlor loss (g ha^{-1})	0.33	0.6	0.00	0.5

Variables with different letters show significant tillage difference (P=0.05) for the same year

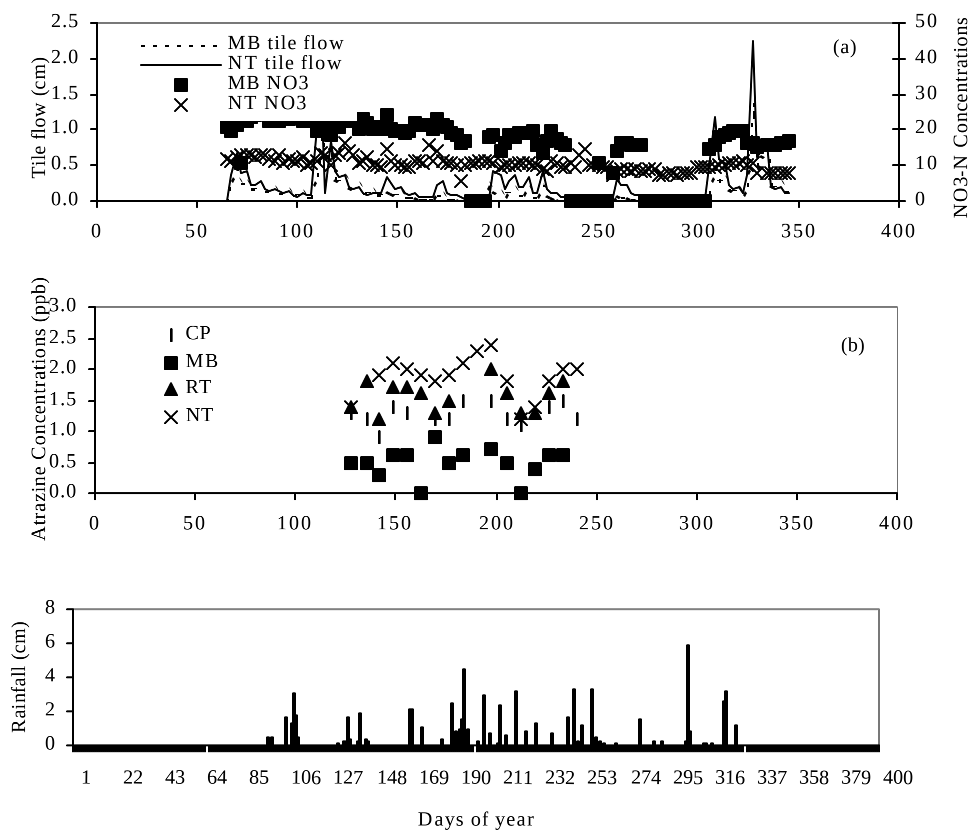

Figure 2-Tillage effects on subsurface drain water quality for 1992

of piston flow) when compared with MB system. Moreover, the detail analysis shown in Fig. 1(a) shows that on 180 DOY, there is a sharp decrease in NO_3-N concentrations from 65 mg/L to 11 mg/L in relation to rainfall event on that day. Such an abrupt change can be associated with preferential flow of water, which might have decreased NO_3-N concentration due to dilution effect. The effect of ridge tillage on herbicide concentrations in subsurface drainage water was closer to that observed under no-till system because both the systems were not given fall plowing and both the systems might have maintained similar preferential flow path ways (Table 1). Tillage effects on herbicide concentrations in tile flow were more noticeable in relation to heavy rainfall events because herbicides were surface sprayed and their solution in overland flow might have followed the preferential flow paths resulting in higher concentrations in tile flow. No-till and ridge till resulted in significantly higher atrazine concentrations in tile flow compared with chisel plow and moldboard systems (Fig. 1b). This difference can be due to better connected network of macropores in NT and RT systems compared to that with CP and MB systems.

Similar trends of tillage effects on NO_3-N concentrations in subsurface drainage water were observed in 1992 (Fig. 2a). Sharp peaks in tile flow and the corresponding NO_3-N concentrations in tile flow under NT system correspond very well to the rainfall pattern showing the role of macropore flow on solute transport through the soil profile. This fact is also supported with atrazine concentrations in tile flow which showed peak concentration of 2.4 ppb on DOY of 198 in relation to rainfall event of 4.45 cm on DOY of 195. The highest atrazine concentrations in tile flow were observed under NT system and the lowest concentration was observed under MB system (Fig. 2b). These results clearly suggest that formation and persistence of preferential flow paths as a result of tillage practices have significant effect on the transport of NO_3-N and herbicides to subsurface drain water.

References

Ahuja, L. R., D. G. DeCoursey, B. B. Barnes, and K. W. Rojas. 1993. Characteristics of macropore transport studied with the ARS root zone water quality model. *Transactions. of the ASAE*. 36:369-380.

Bjorneberg, D. L., R. S. Kanwar and S. W. Melvin. 1996. Seasonal changes in flow and nitrate-N loss from subsurface drains. *Transactions. of the ASAE* 39(3):961-976.

Brown, C. D., V. L. Marshall, A. Deas, A. D. carter, D. Arnold and R. L. Jones. 1999. Investigation into the effect of tillage on solute movement to drains through a heavy class soil II: Interpretation using a radio scanning technique , dye tracing and modeling. *Soil Use Manage*. CABI International 15(2):94-100.

Ghidey. F., E. E. Alberts and N. R. Kitchen. 1999. Evaluation of the Root Zone Water Quality Model using field measured data from the Missouri MSEA. *Agron. J*. 91(2): 183-192.

Hillel, A. R., J. M. Buttle and D. Goodyear. 1999. Nitrogen chemistry of subsurface storm runoff on forested Canadian Shield hillslopes. *Water Resour. Res*. Am. Geo. Phys. Union, 35(3):811-821.

Kanwar, R. S., J. L. Baker, and D. G. Baker. 1988. Tillage and split N-fertilizer effects on subsurface drainage water quality and crop yields. *Transactions of the ASAE* 31(2):453-460.

Kanwar, R. S., T. S. Colvin and D. L. Karlen. 1997. Ridge, moldboard, chisel, and no-till effects on tile water quality beneath two cropping system. *J. Prod. Agric*. 10(2):227-234.

Larson, M. H. and N. J. Jarvis. 1999. Evaluation of a dual porosity model to predict field scale solute transport in a macro-porous soil. *J. Hydrol*. 215(1/4):153-171.