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Preferential Flow Effects on NO_3-N Losses with Tile Flow

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Abstract

The variation in continuity and geometry of macropores over the growing season can affect subsurface drain 'tile' water and nitrate-nitrogen (NO_3-N) concentrations in tile water. This study analyzes the patterns of tile flows and nitrate-nitrogen (NO_3-N) concentrations in tile water in relation to rainfall events using field measured data as well as invoking the macropore option of the Root Zone Water Quality Model (RZWQM98). The increase in NO_3-N concentration in tile flow during the growing season in comparison with the decrease in NO_3-N concentrations after the crop harvest following heavy rainfalls support the role of dual flow theory, soil matrix flow and preferential flow. These results and model simulations suggest that variation in macropore during the growing season can have significant effect on tile flow and NO_3-N concentrations in tile water for soils similar to the study area.
Keywords. macropores, growing season, water quality

Introduction

The flow of water and solute transport in structured soils is strongly controlled by the occurrence of macropores because of their capacity to enhance chemical mobility and increase groundwater contamination (Ahuja et al., 1993; Harris et al., 1994). The formation and persistence of macropores depend on soil type, climate and management practices. Several studies have reported tillage effects on macropore flow (Kanwar et al., 1997; Brown et al., 1999) but less literature is available to quantify macropores development during and after the growing season. The continuity and geometry of macropores can vary over the growing season due to soil moisture variation and clay mineralogy characteristics particularly for soils having subsurface drainage system. Understanding the temporal transport behavior of macropores on nitrate-nitrogen (NO_3-N) leaching to the tile lines during and after the growing season can help in developing suitable management practices to reduce adverse effects on groundwater quality. Therefore, the specific objectives of this study were to: (1) characterize the temporal effects of macropore flow on NO_3-N concentrations in subsurface drainage water in relation to rainfall events during and after the growing season and (2) estimate the effects of macropore flow on NO_3-N losses with subsurface drainage water using Root Zone Water Quality Model (RZWQM98).

Materials and Methods

The study area is a 22-ha, corn-soybean rotation field, in central Iowa. The soils at the field site are in the Kossuth-Ottosen-Bode Soil Association and are mostly poorly drained. Nine subsurface drain pipes drain nine plots of the study area into individual sumps. Each sump is equipped with an automatic tile flow recording mechanism and collects composite water samples weekly for chemical analysis. Three N-fertilizer treatments, each replicated three times, were applied in a randomized complete block design. Anhydrous ammonia was injected one week before planting corn in 1996 and 32% urea ammonium nitrate solution (UAN) was applied in 1998 three weeks after planting. Fertilizer (actual N) was applied at the rate of 202 kg-N/ha in 1996 and 172 kg-N/ha in 1998 (called high N-treatments), 135 kg-N/ha in 1996 and 115 kg-N/ha in 1998 (medium), and 67 kg-N/ha in 1996 and 57 kg-N/ha in 1998 (low). More detail of the experimental layout and management activities can be found in Bakhsh et al. (2000[a]) and Jaynes et al. (1999). On-site measured daily minimum and maximum temperature, and hourly rainfall data were used to prepare the climatic input data file for RZWQM. Soil physical properties of bulk density, porosity, field capacity (1/3 bar), sand, silt, and clay percentage from 0-1.2-m and organic matter from 0-152-mm depths were measured at 42 sampling sites in the field and were used as input to the model. Detail of these soil attributes measurements can be found in Bakhsh et al. (2000[a]) and detail on the RZWQM calibration process for this site can be found in Bakhsh et al. (2000[b]).

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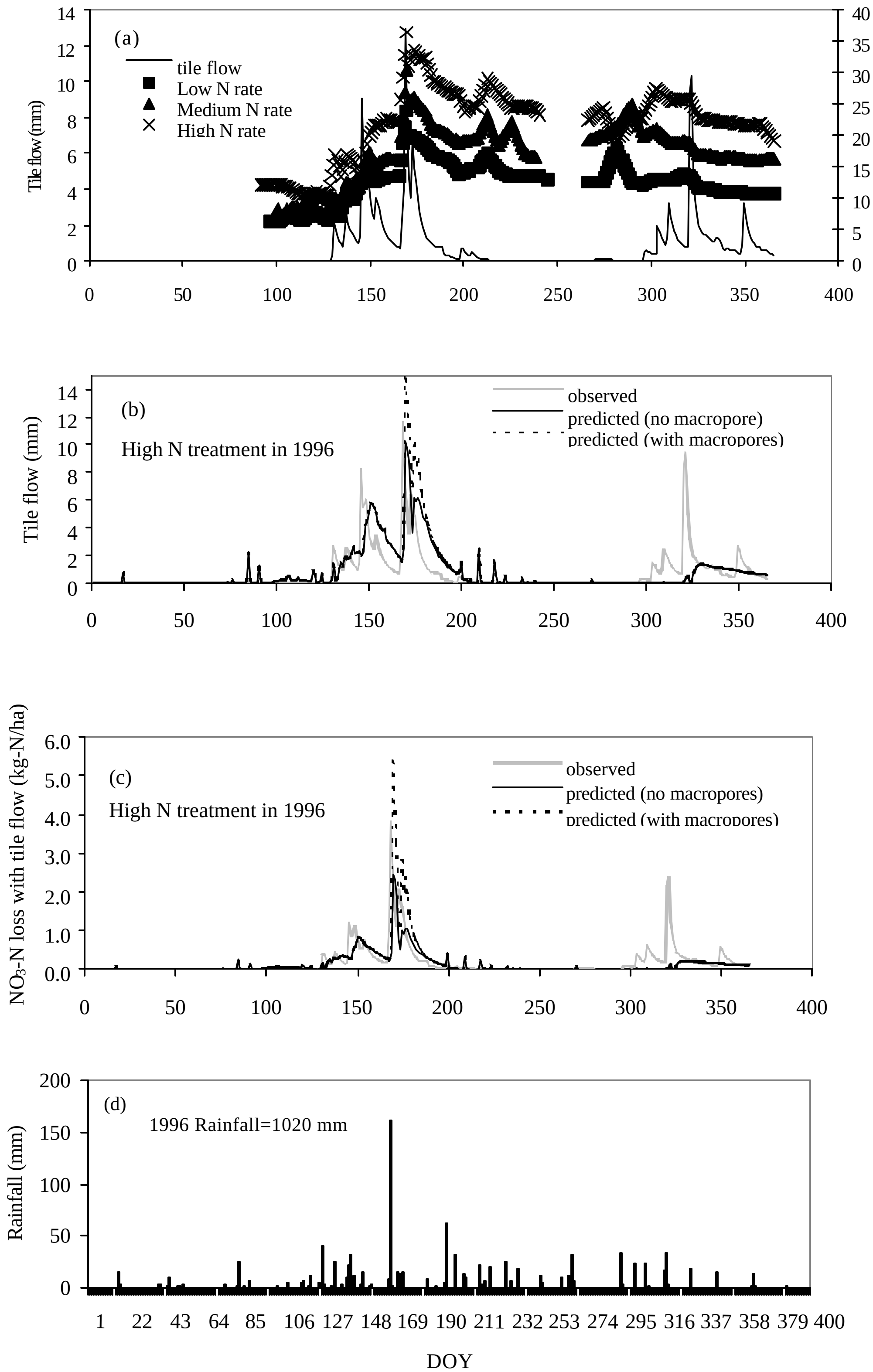

Figure 1-Nitrogen fertilizer treatment effects and RZWQM predictions on NO_3-N concentrations and NO_3-N losses with subsurface drainage 'tile' water.

Results and Discussion

The variable temporal patterns in tile flow and its NO_3-N concentrations following heavy rains in 1996 (total rainfall of 1020-mm), corn year, indicate the possibility of soil matrix flow during the crop growing season and preferential flow after the growing season. The peak tile flow of 12.9 mm was observed during the growing season following a heavy rainfall of 161mm on 168 day of year (DOY) compared to another peak tile flow of 10.3 mm after a rainfall of 49 mm on DOY 320 and 321 (Evapotranspiration requirements can be different considerably for these two events) (Figs. 1a-1d). The NO_3-N concentrations in tile flow increased from 25 mg/L to 36 mg/L for the high N-treatment (Fig. 1a) in response to rainfall event on DOY of 168, flushing NO_3-N from the soil profile probably due to the concept of piston flow. But the NO_3-N concentrations decreased from 26 mg/L to 22 mg/L in response to rainfall event on DOY 320. All the N-fertilizer treatments showed a similar trend of increasing NO_3-N concentrations on DOY 168 and decreasing NO_3-N concentrations on DOY 320 (Fig. 1a). These trends can be explained with the concept that soil matrix flow leached NO_3-N from the entire soil profile and resulted in increased NO_3-N concentrations while the preferential flow on DOY 320 bypassed the soil matrix and decreased the NO_3-N concentrations due to dilution effect. Also, the spring cultivation might have destroyed surface macropores which resulted in soil matrix flow during the crop growing season in comparison with preferential flow after the growing season. This on and off growing season analysis on tile flow and NO_3-N concentrations in tile water support the phenomenon of more macropores after the crop growing season resulting in decreased NO_3-N concentrations in tile water. The rainfall pattern in 1998 (rainfall of 897-mm), corn year, was different than 1996 and tiles did not flow much after the growing season like they did in 1996. Soybean was grown in 1997 and 1999.

The RZWQM has the macropore option and the calibrated model for the study area (Bakhsh et al., 2000[b]) was also run to see the effect of macropore flow on tile flow and NO_3-N losses with tile flow (Figs 1b, 1c). Invoking the macropore option of the model resulted in 23% higher tile flow compared to the measured (323 vs 262 mm) and only 11% higher flow with no macropore option (290 vs 262 mm) (Table 1). The macropore option, using constant cracks, slightly overestimated the peak tile flow rates during the growing season of 1996 but no difference in tile flow or NO_3-N loss with tile flow was predicted after the growing season because the

Table 1. RZWQM simulations with/without macropore flow option

Years	Variables	Nitrogen application rates								
		Low			Medium			High		
			predicted			predicted			predicted	
		obs.*	no mac	with mac	obs.*	no mac	with mac	obs.*	no mac	with mac
1996	Tile flow (mm)	261.5	289.6	323.6	244.5	286.0	321.6	253.6	282.7	319.1
	(standard deviation)	(29)			(25)			(69)		
	FWANC (mg/L)	14.3	14.8	15.3	18.7	15.5	17.2	24.2	15.9	18.7
	NO_3-N loss (kg/ha)	37.4	42.8	49.6	45.6	44.3	55.4	61.4	44.9	59.8
1997	Tile flow (mm)	135.7	126.4	134.9	134.8	127.1	135.1	143.9	126.8	135.5
	(standard deviation)	(20)			(11)			(57)		
	FWANC (mg/L)	9.2	16.5	16.2	12.5	20.9	21.8	18.1	29.0	25.2
	NO_3-N loss (kg/ha)	12.5	20.9	21.8	16.9	25.3	28.0	25.7	29.1	34.1
1998	Tile flow (mm)	325.9	225.2	229.5	304.1	221.8	225.5	317.6	221.3	225.7
	(standard deviation)	(12)			(26)			(76)		
	FWANC (mg/L)	11.4	14.9	13.6	13.7	20.8	18.9	18.1	29.0	26.9
	NO_3-N loss (kg/ha)	37.2	33.7	31.3	41.7	46.2	42.6	57.5	64.3	60.9
1999	Tile flow (mm)	318.3	305.9	303.6	306.1	303.5	305.8	318.7	303.6	305.5
	(standard deviation)	(32)			(21)			(78)		
	FWANC (mg/L)	9.3	12.7	12.4	11.3	17.2	16.3	15.4	25.0	23.7
	NO_3-N loss (kg/ha)	29.8	38.9	37.7	34.6	52.1	49.7	49.1	75.9	72.4

Low = 67 kg-N/ha for 1996 and 57 kg-N/ha for 1998; Medium= 135 kg-N/ha for 1996 and 115 kg-N/ha for 1998;High= 202 kg-N/ha for 1996 and 172 kg-N/ha for 1998; No N-fertilizer was applied to soybean in 1997 and 1999; FWANC= flow weighted average nitrate concentrations (mg/L); NO_3-N loss=NO_3-N loss with subsurface drainage water; obs.= observed; no mac= without macropore option; with mac= with macropore option; * means of treatments model does not support the variable cracking patterns (Ghidey et al., 1999). However, model simulations of NO_3-N losses with tile flow, as a function of N-application rates, were improved with macropore option particularly for 1996 when compared with no macropore option. Model predicted NO_3-N losses with tile flow adequately for high N-treatment using macropore option and difference between measured and predicted was <5% (61.4 vs 59.8 kg-N/ha) in comparison to difference of 27% (61.4 vs 44.9 kg-N/ha) with no macropore option. The trend of prediction of NO_3-N losses with tile flow in 1996 improved using macropore option. Overall, the constant crack option slightly improved the model prediction for 1997, 1998 and 1999 (Table 1). These simulations suggest that for better predictions of macropore effects on tile flow and NO_3-N losses with tile flow may require induction of subroutine which can take into account the variability in macropores over the growing season as a result of soil type, climate and management practices. The field measured data and RZWQM simulations using constant cracking suggest that macropores can develop during the growing season and can affect the patterns of tile flow and the corresponding NO_3-N losses with tile flow.

Summary

Field experiments were conducted on a corn-soybean rotation field in Central Iowa to determine the effects of N-application rates on NO_3-N concentrations and NO_3-N losses with subsurface drainage 'tile' water. Tile flow data were collected and analyses were made to determine the effect of heavy rainfall events on tile flow and the resulting NO_3-N concentrations in tile flow by comparing tile flow patterns during and after the growing season. The analysis of data on tile flow and NO_3-N concentrations revealed that NO_3-N concentrations increased sharply for all N-treatments in response to rainfall event during the growing season while the NO_3-N concentrations decreased rapidly after the growing season. These trends suggest the possibility of soil matrix flow during the growing season and preferential flow after the growing season probably due to variation in geometry and continuity of macropores during the growing season. Moreover, the RZWQM simulations, using constant crack macropore option, slightly improved the model predictions of tile flow peaks and NO_3-N losses with tile flow during the growing season. But the model did not simulate tile flow and NO_3-N losses with tile flow adequately after the growing season in 1996 because current version of the model does not support the variability in cracks. The model may include a subroutine which can simulate the variability in cracks as a function of soil type, climate and management practices for better prediction of macropore effects on tile flow and NO_3-N losses with tile flow. These results suggest that macropore geometry can vary over the growing season and can affect the tile flow and NO_3-N concentrations in tile flow.

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