Agriculture, Ecosystems and Environment 137 (2010) 267–275

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Seasonal and crop rotational effects of manure management on nitrate–nitrogen leaching in Nova Scotia

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ARTICLE INFO

Article history:
Received 5 October 2009
Received in revised form 19 February 2010
Accepted 24 February 2010
Available online 1 April 2010

Keywords:
Tile drainage
Nitrate leaching
Crop rotations
Nitrate concentrations
Nitrate loads
Liquid dairy manure
Tillage practices

ABSTRACT

High nitrate–nitrogen (NO_3–N) concentrations and loads in tile drainage waters in response to crop fertility and other land management practices are a major cause of concern to the health of humans, animals and the environment. The study, conducted at Kentville, Nova Scotia (NS), examined the effect of renovating fallowed land with the introduction of either manure amended permanent forage (PF) or manure amended corn (*Zea mays* L.) – soybean (*Glycine max* L.) – wheat (*Triticum aestivum* L.) Corn–soybean–wheat (CSW) rotations on growing season (GS) and non-growing season (NGS) nitrate (NO_3–N) concentrations and loads of tile drainage water. Treatments included (i) PF rotation established with conventional tillage (CT) practices; (ii) CSW-CT rotation; (iii) minimum tillage in a CSW rotation (CSW-MT) and (iv) zero tillage in a CSW rotation (CSW-ZT). NGS drainage was significantly higher and flow-weighted NO_3–N concentrations significantly lower in all years when compared with GS. There were no consistent differences observed in GS or NGS NO_3–N concentrations and loads between the three levels of tillage in the CSW rotation with loads ranging between 7.1 and 28.2 kg N L^{-1} and 18.7 and 77.0 kg N L^{-1} for GS and NGS, respectively. PF rotation was significantly more efficient in N utilization when compared with a CSW rotation, resulting in significantly lower loads. Decreasing nitrate loads over time appeared to be related to increasing evapo-transpiration and N uptake as the forage matured. Although differences in the amount of N removed by corn, soybean and spring wheat in the CSW rotation were observed, these were not significant in determining the magnitude of NO_3–N loads. The correlation between LDM application and NO_3–N losses in tile water under this rotation in a particular season proved difficult to define. The study showed that the biological response time of the manured, soil system for NO_3–N loading is longer than one seasonal cycle and demonstrates the need to evaluate the long-term impacts of these rotations.

1. Introduction

High nitrate–nitrogen (NO_3–N) concentrations in ground and surface water systems continue to be a cause for concern. The Canadian Council of Ministers of the Environment have identified elevated NO_3–N levels as risk to the health of humans, animals and the environment (Chambers et al., 2002). A major source of this NO_3–N is from the use of fertilizers for crop production.

In Nova Scotia (NS), a significant proportion of agricultural land has been tile drained over the past three decades. This has helped to greatly enhance soil trafficability and crop rooting environments by lowering water table levels during the planting period in spring and the harvest period in the fall (Madani and Brenton, 1995). Higgins (1973) reported that 1300 km of tile drains were installed in NS prior to 1970. In the 1980s, as much as 1300 km was installed annually under government supported land improvement programs, most at 12 m spacing (Cochrane, 2007, personal communication). This equates to approximately 1400 ha y^{-1} of improved land.

A wide range in NO_3–N concentrations from the drainage from agricultural land have been reported. For corn, as an example, these concentrations range from <5 mg L^{-1} (Mkhabela et al., 2008), 5–15 mg L^{-1} (Milburn and Richards, 1994; Gordon et al., 2000) and 15–25 mg L^{-1} (Stoddard et al., 2005). In addition, Hatfield et

Abbreviations: CSW, corn–soybean–spring wheat; CT, conventional tillage; *D*, drainflow; LDM, liquid dairy manure; MT, minimum tillage; NO_3–N, nitrate–nitrogen; *P*, precipitation; PF, permanet forage; ZT, zero tillage.

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doi:10.1016/j.agee.2010.02.012

al. (1999) suggested that approximately 95% of root zone NO_3–N is intercepted by tile lines. Furthermore, agricultural land in NS receives in excess of 1000 mm of annual precipitation (*P*), (Webb and Marshall, 1999). In addition, based on the work of Astatkie et al. (2001) and Mkhabela et al. (2008), also in Nova Scotia, it can be estimated that between 15% and 40% of annual *P* can be redirected to surface water bodies via tile drainage. Drainage systems are therefore an integral component of the hydrological continuum and an avenue for release of NO_3–N into the environment.

In recent years there has been a shift by producers to reduced tillage systems to minimize soil erosion, increase carbon sequestration and improve soil health (Moebius et al., 2007; Idowu et al., 2008). However best agricultural practices for reducing erosion, gaseous emissions and surface run-off losses of nitrogen (and other contaminants) are not always necessarily compatible with those for minimizing NO_3–N leaching losses. In this regard, environmental tradeoffs (Mkhabela et al., 2008) can only be made if they are based on quantified data from specific soil–crop–climate associations.

A further issue in NS is land-use change in response to fluctuating markets, change in ownership as well as government incentive programs directed towards agricultural land use. Fields are often taken out of production for a number of years before being brought back into production. Limited research has been conducted to examine the impact of these land-use changes on water quality. Fuller et al. (2001) reported an increase in tile drainage NO_3–N concentration from 0.3 to 2.55 mg L^{-1} when a stable orchard system was removed and converted to ryegrass (*Lolium italicum* L.).

This 10 y field study was conducted to examine the impact of land use and various management practices on NO_3–N concentrations and loads in tile drainage discharge. Specific objectives include: (i) understanding the impact of renovating fallowed land; (ii) assessing the impact of corn–soybean–wheat and permanent forage (PF) rotations with liquid dairy manure; (iii) evaluation of different tillage systems; (iv) quantifying differences between growing season (GS) and non-growing season (NGS) NO_3–N loads.

2. Materials and methods

This research was conducted between 1998 and 2007 in Kentville, NS (45°03′51″N; 64°29′03″W; 65 m) on a 1.6 ha tile drainage research site at the Kentville Agriculture and Agri-Food Canada (AAFC) Research Station. The site has a uniform, 1–2% slope. The soil type is a Gleyed Sombric Brunisol (Agriculture Canada Expert Committee on Soil Survey, 1987), locally known as Debert (Holmstrom and Thompson, 1989). These soils are imperfectly drained with a friable, coarse loamy upper soil material and a saturated hydraulic conductivity (K_{sat}) of 30.4 cm h^{-1}. The lower soil material (>50 cm) is a firm, coarse loamy, glacial till (Holmstrom and Thompson, 1989). Soil properties are provided in Table 1. The drainage system was installed between 1978 and 1985 and consists of 12 parallel, rectangular plots, 100 m in length and ∼13 m wide (range: 12.0–13.9 m). Each ∼1300 m^2 plot was drained by a 10 cm diameter perforated tile line which ran centrally down the plot length at 120 cm depth. Buffer tile drains installed around the experimental site prevented lateral movement of water into the experimental area. In September 2001, hydrological separation of treatment plots was achieved using a trenching machine (“ditch witch”) to cut a narrow (15 cm) trench, 100 m long and 1.2 m deep, midway between adjacent tile drains. The polyethylene curtain was dropped to the bottom of the 1.2 m trench which was then backfilled. In the spring of 2002, a small, narrow berm was raised immediately above the plastic barrier to divert occasional surface water off at the lower end of each plot. This action coincided with the introduction of tillage treatments (see Section 2.1) to nine of the 12 drainage plots (PF, CSW-CT and CSW-MT).

Table 1
Soil properties at Kentville prior to implementation of treatments in 2002.

Agronomic properties

Depth (cm)	pH	OM (%)	C (%)	N (%)	C:N (ratio)	P_2O_5 (kg ha^{-1})	K_2O (kg ha^{-1})	Ca (kg ha^{-1})	Mg (kg ha^{-1})	Cl (kg ha^{-1})	CEC (100 g^{-1})[a]	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Cu (mg kg^{-1})	Zn (mg kg^{-1})	B (mg kg^{-1})
0–25	5.8	3.54	1.71	0.14	12.53	432	241	1946	362	5.9	11.0	298	39.7	2.3	1.0	0.3

Depth (cm)	Sand (%)	Silt (%)	Clay (%)	% M	% M	Hydraulic conductivity (cm h^{-1})		
				0.2 bar	15 bar	Mean	Median	Range
0–25	63.1	23.9	13.0	22.8	7.1	30.4	8.3	0–313
25–50	55.3	23.3	21.4	12.1	6.7	2.2	0.8	0–11
50–120[b]	52.0	34.0	14.0	–	–	1.4	–	0–2.1

[a] Cation exchange capacity (meq 100 g^{-1}).
[b] Based on Holmstrom and Thompson (1989) and Langille (1986).