# NITROGEN AND BACTERIA LEACHING IN AGRICULTURAL DRAINAGE WATER

# LESSIVAGE AZOTE ET BACTERIEN DANS L'EAU DE DRAINAGE AGRICOLE

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## *ABSTRACT*

*Zero tillage (ZT) is increasingly adopted in Atlantic Canada due to its soil erosion benefits relative to conventional tillage (CT). However, the impact of ZT on drainage water quality is less known. Two field trials were conducted during 2002-2003 and 2003-2004 to compare ZT and CT on concentration and loads of $NO_3^-$-N and indicator organism (E.coli) in surface and subsurface drainage water. Zero tillage had 30-35% significantly lower concentrations of $NO_3^-$-N in combined drainage water than CT. Nevertheless, $NO_3^-$-N load losses were 17-40% greater under ZT than that of CT. Subsurface drainage contributed greatly to $NO_3^-$-N losses. However, no effect of tillage was observed on E.coli levels in either combined or individual drainage sources. When the nutrient and bacterial contamination risks were considered, no tillage effect was observed.*

**Key words:** *Zero tillage, Conventional tillage, Drainage water, Nitrogen leaching, Nova Scotia.*

## *RESUME*

*La pratique de culture sans labourage (ZT) est adoptée de plus en plus au Canada Atlantique en raison de ses avantages sur l'érosion du sol par rapport au labourage conventionnel (CT). Cependant, il n'existe pas des informations sur l'impact de la ZT sur la qualité de l'eau de drainage. Deux essais sur le terrain ont été menés en 2002-2003 et 2003-2004 pour comparer ZT et CT sur la concentration, les charges de $NO_3^-$-N et l'indicateur de l'organisme (E.coli) dans l'eau de drainage souterrain et l'eau de surface. La culture sans labourage avait des concentrations inférieures de 30-35% de $NO_3^-$-N dans l'eau de drainage combinée par rapport à CT. Cependant, la perte de charge de $NO_3^-$-N était de 17-40% plus élevé en ZT qu'en CT. Le drainage souterrain a hautement contribué aux pertes de $NO_3^-$-N. Cependant,*

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*aucun effet du labourage n'a été remarqué sur les niveaux d'E.coli dans les sources de drainage soit combinées soit individuelles. Aucun effet de labourage n'est remarqué dans le cas des risques de contamination des nutriments et des bactéries.*

**Mots clés :** *Sans labourage, labourage conventionnel, eau de drainage, lessivage azoté, Nouvelle-Écosse.*

# 1. INTRODUCTION

In Canada, farm related activities are well established as non-point sources of water pollution (Weil, 1990). The surface and subsurface transport of nutrients and pathogens is greatly influenced by tillage and drainage practices. Conservation tillage is increasing in popularity due to benefits associated with erosion control (McKyes, 1986), improved soil quality, increased water holding capacity, and greenhouse gas benefits (i.e. carbon sequestration) (Hussain, 1999; Lemke, 1999; Elmi, 2003).

Tillage practices can be categorized into conventional or conservation tillage systems. Conventional tillage (CT) refers to the combined primary and secondary tillage operations performed on agricultural land prior to planting. Primary tillage is usually performed with a moldboard or chisel plow and secondary tillage is typically performed with discs or harrows (Thiagarajan, 2005). As any surface residues are incorporated during CT, the surface remains bare.

Conservation tillage retains at least 30% of the previous crop residue on the soil surface (Unger, 1994). One of the widely adopted forms of conservation tillage is zero tillage (ZT). Seeding under ZT involves using disk coulters without any tillage, thereby retaining much of the previous crop residues on the soil surface (McDowell and McGregor, 1980).

# 2. ARTIFICIAL DRAINAGE SYSTEMS IN NOVA SCOTIA

In addition to having poor natural drainage, Nova Scotia soils annually receive precipitation in excess of potential evapotranspiration (Carter, 1996). Therefore, subsurface drainage systems are often used to improve internal soil drainage and thus crop growth. Water from these systems however, has been found to contain $NO_3^-$-N exceeding the maximum acceptable drinking water concentration (MAC) of 10 mg $L^{-1}$ (Drury, 1993). Although drainage water is not directly used for drinking purposes, it poses a direct threat to surface water and groundwater resources.

# 3. TILLAGE EFFECT ON NITRATE-N LEACHING

Tillage influences N cycling processes in soil and thus affects $NO_3^-$-N leaching losses (Malhi, 2001). Research findings on the effect of tillage systems on $NO_3^-$-N leaching is however contradictory. Goss (1993) found that CT increased $NO_3^-$-N leaching losses by 20% over direct drilling (ZT). They suggested that decreased $NO_3^-$-N content under ZT was due to increased denitrification losses. Others (Gilliam and Hoyt, 1987; Drury, 1993) have observed greater $NO_3^-$-N losses under ZT. They attributed this to the presence of soil macropores and slower mineralization rates. From the perspective of soil $NO_3^-$-N availability, Angle (1993) and Patni

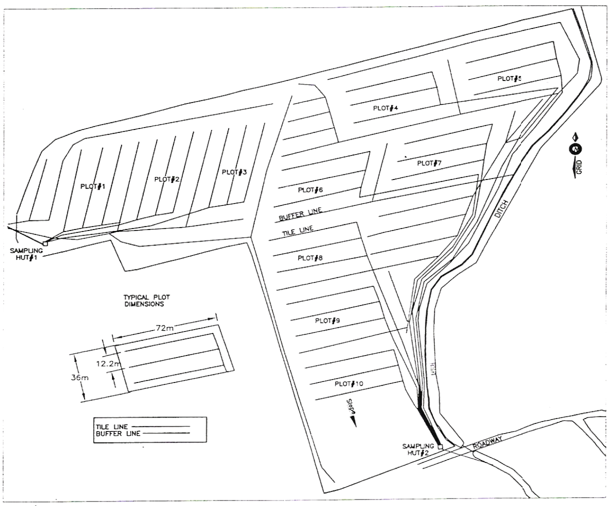
(1996) found that ZT allowed for lower soil $NO_3^-$-N than CT due to enhanced denitrification and slower mineralization. Ultimately, they suggested ZT as a best management practice for reducing surface and subsurface nutrient losses. Similar results were found by Dou (1995) in the 0 to 120 cm depth of the soil profile. From the above research findings it is evident that the effect of ZT on the transport of $NO_3^-$-N is not completely understood. Therefore research with the overall goal of comparing the drainage water quality from CT and ZT systems was initiated. This paper will present $NO_3^-$-N and *E. coli* losses from two research sites with different soils, crop rotations; and manure applications. Both sites have plots under CT and ZT, allowing comparisons to be made between tillage systems.

# 4. MATERIAL AND METHODS

## 4.1 Site Descriptions

### 4.1.1 BEEC Site

The BEEC drainage research site (45° 22° N 63° 16° W) (Fig. 1) is a 6.0 ha field located in Bible Hill Nova Scotia, Canada. Soils are predominately of the Pugwash and Debert series, typified by melanic brunisols, with sandy loam to fine sandy loam textures (Webb and Langille, 1996). The field has ten drainage plots (Fig.1). Since 2001, five plots have been under CT, and five plots ZT. Subsurface tile drains (100 mm diameter) are located at an approximate depth of 80 cm, with 12 m spacing. Buffer drains are placed between plots to hydrologically separate them from each other. The drains flow into two heated sampling huts (Fig. 1). Flows from each plot were monitored using separate calibrated tipping buckets wired to CR10 dataloggers (Campbell Scientific, Edmonton, AB, Canada). All flow volumes were initially measured in litres, and then normalized to the plot area and expressed as an equivalent depth of water.




CT Plots 2, 3, 5, 8, 9
ZT Plots 1, 4, 6, 7, 10

Fig. 1. Schematic diagram of the Bio-Environmental Engineering Centre field showing the plot layouts, location of tile drains and sampling huts, as well as treatment details.

### 4.1.2 Streets Ridge

The Streets Ridge site (Fig. 2) (45° 42° N 63° 41°W) is 5.4 ha, has a 4% slope and was originally established to determine the effect of drain spacing on subsurface drainage performance (Madani and Brenton, 1995). The predominant soil series at this site is an imperfectly drained Queens soil with a shallow fine loam top layer, over a highly compacted basil till. The site has six (83 x 96 m each) drainage plots (Fig. 2), lined with tile drains (100 mm in diameter) located at a depth of 80 cm. Drains were placed at a systematic spacing of 3, 6 and 12 m within each plot. In addition to subsurface drains, each plot has a surface drainage ditch with a hickenbottom surface inlet at its lower end to collect surface runoff water. Buffer drains hydrologically separate all plots from one another. All twelve drains (6 surface and 6 subsurface) flow into a heated sampling hut (Fig. 2). Separate calibrated tipping buckets, wired to a Zeno datalogger (Coastal Environmental Systems Inc., Seattle, WA, USA), were utilized to measure flow rates from surface and subsurface drains. All flow volumes were initially measured in litres, and then normalized to the plot area and expressed as an equivalent depth of water.

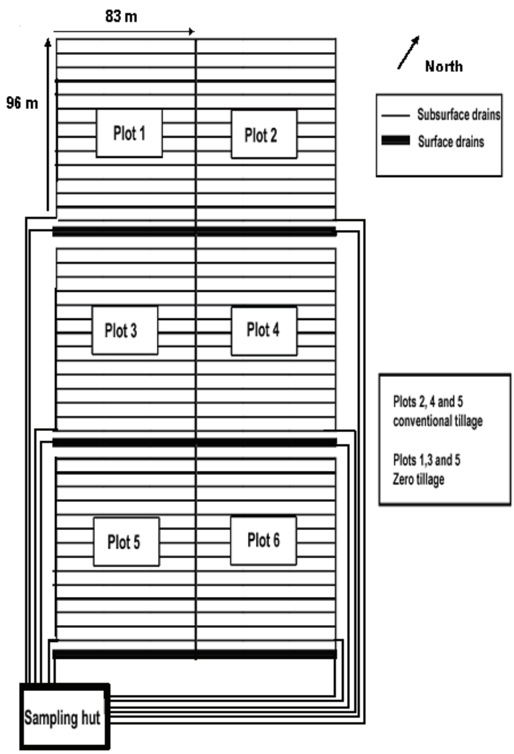



Fig. 2. Schematic diagram of the Streets Ridge site showing the plot layout with drainage and treatment details.

## 4.2 Manure Application and Field Activities

At both sites, manure and inorganic fertilizer application rates were based on crop N needs, assuming a 50% N availability from the manure applied during the current year, soil nutrient status and nutrient credits from previous manure applications (Langman, 1991). Manure and inorganic fertilizer application rates are provided in Tables 1 and 2 for BEEC and Streets Ridge, respectively moldboard plowing, followed by disc harrowing. Manure applied to ZT plots was left unincorporated on the surface. The field was under a 3-year cropping rotation (barley-spring wheat-soybeans). All crops were seeded using a Tye seeder. Cropping details for the BEEC site are provided in Table 1.

Table 1: Crop, manure application rates and chemical fertilizer doses at the Bio-Environmental Engineering Centre field.

| Year | Crop | Manure Application Rate (T $ha^{-1}$)[1] | Top Dress Chemical Fertilizer Dose (kg $ha^{-1}$)[2] |
|---|---|---|---|
| 2002-2003 | Spring wheat | 40 | 100 (17-17-17) |
| 2003-2004 | Soybean | 25 | NA[3] |
| 2004-2005 | Barley | 65 | NA |
| 2005-2006 | Spring wheat | 85 | NA |

1 Liquid dairy manure was applied in the spring prior to planting.
2 Chemical composition of fertilizer is provided in parentheses (%N-%P-%K).
3 NA: Not applied.

Table 2: Manure and chemical fertilizer applications rates at Streets Ridge for conventional and zero tillage plots.[1]

| Year | Fall Manure Application Rate (T $ha^{-1}$)[2] | Basal Chemical Fertilizer Dose (kg $ha^{-1}$)[3] | Top Dress Chemical Fertilizer Dose (kg $ha^{-1}$)[3] |
|---|---|---|---|
| 2002-2003 | 44 | 200 (18-46-0) | 150 (34-0-0) |
| 2003-2004 | 39 | 200 (12-24-24) | 250 (18-46-0) |
| 2004-2005 | 50 | 200 (18-46-0) | 250 (19-19-19) |
| 2005-2006 | 50 | 200 (18-46-0) | 200 (40-10-0) |

1 Corn was the crop each year.
2 Solid beef manure was applied.
3 Chemical composition of fertilizer is provided in parentheses (%N-%P-%K).

At the BEEC site, seeding each year was performed approximately four days following manure application. At Streets Ridge, manure was applied to all plots in the fall. Manure applied to CT plots was incorporated by moldboard plowing (~20 cm deep), while manure applied to ZT plots was left unincorporated on the surface. Prior to seeding CT plots were disc harrowed to 10 cm. A no-till corn planter equipped with disc coulters was used to seed silage corn on all plots at the Streets Ridge site. Silage corn was grown continuously at this site starting in the spring of 2003.

## 4.3 Water Sample Collection and Analysis

Water samples were collected from drainage water discharging into the tipping buckets using 250 mL high density polyethylene bottles. From August 2002 to July 2003 samples were collected manually. Since August 2003, samples were collected using ISCO model 6700 auto-samplers (Isco, Lincoln, NE). Sampling frequency was based on the duration and intensity of individual flow events. Water samples were stored at 4°C until analysis. Nitrate-N was quantified by ion chromatography according to Standard Methods for the Examination of Water and Wastewater Method 4110 (Clesceri, 1998). Water samples were always analyzed within 24 hours of collection for *E. coli* analysis. Samples were analyzed using the procedure described by Clesceri (1998).

# 5. RESULTS AND DISCUSSION

## 5.1 Hydrology

### 5.1.1 BEEC Site

Hydrological data for the BEEC site are provided in Table 3. The average ratio of annual subsurface drainage flow to annual precipitation was 0.16 and 0.33 for CT and ZT system, respectively. Higher subsurface flows from ZT plots may be due to the presence of soil macropores, which are known to be more abundant in ZT systems. Despite receiving similar precipitation during the growing season (GS) and non-growing season (NGS), on average (all years), 76 and 68% of flow occurred during the NGS for CT and ZT systems, respectively (data not shown). Increased NGS flows are likely due to decreased evapotranspiration caused by the lack of crop cover, cooler air temperatures and decreased solar radiation.

Table 3: Annual precipitation and subsurface drainage flow volumes under conventional (CT) and zero tillage (ZT) at the Bio-Environmental Engineering Centre.[1]

| | Precipitation (mm) | CT Flow (mm)[2] | ZT Flow (mm)[2] |
|---|---|---|---|
| 2002-2003 | 1133 | 172 (22) | 424 (88) |
| 2003-2004 | 888 | 172 (20) | 313 (82) |
| 2004-2005 | 1318 | 169 (21) | 359 (111) |
| 2005-2006 | 1392 | 251 (27) | 473 (138) |
| Average | 1183 | 191 | 392 |

1 Table values are means with the standard error in parentheses.
2 Rainfall equivalent.

### 5.1.2 Streets Ridge Site

At Streets Ridge both surface and subsurface drainage were measured. Annual precipitation, and combined surface and subsurface drainage flow volumes are presented in Fig. 3. Table 4 provides surface and subsurface flows from CT and ZT plots. The average ratios of annual combined drainage to precipitation were 0.37 and 0.40 for CT and ZT plots, respectively. As observed at BEEC, despite receiving similar precipitation during the GS and NGS, on average (all years), 75% of combined drainage flow occurred during the NGS for both tillage systems (data not shown). The high proportion of flow occurring during the NGS suggests that systems, regardless of tillage, must be managed carefully during the NGS. Higher NGS flows increases the risk of losing nutrient inputs (e.g. fall manure application) to either surface or subsurface flow. By managing tillage however, this risk may be mitigated.

## 5.2 Nitrate-N Losses

### 5.2.1 BEEC Site

Nitrate-N subsurface drainage flow weighted average (FWA) concentrations, and annual loads at BEEC are provided in Table 5. Although FWA concentrations tended to be lower from ZT plots, loads from ZT systems were consistently higher. Higher flows from ZT plots (Table 3) may have caused dilution, resulting in lower concentrations. This demonstrates the importance of considering loading data when evaluating how tillage impacts $NO_3^-$-N losses. Higher loadings from ZT plots may be the result of increased macropore flow promoting $NO_3^-$-N transport to the tiles.

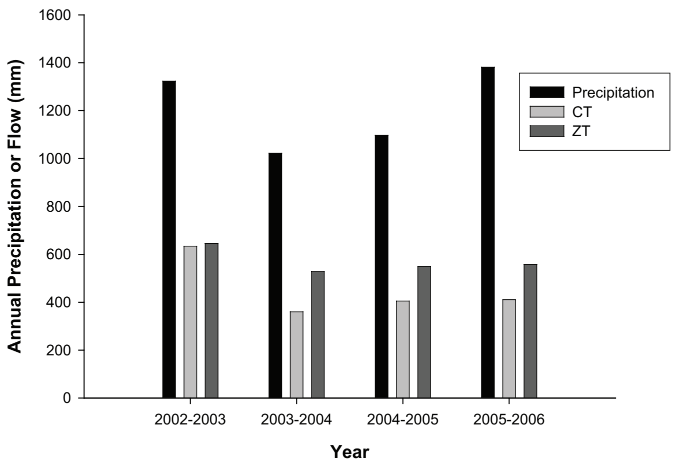



Fig. 3. Annual precipitation (mm) and combined drainage flows (mm) for conventional tillage (CT) and zero-tillage (ZT) systems at Streets Ridge.

Table 4: Annual surface and subsurface drainage flow volumes from conventional (CT) and zero tillage (ZT) systems at Streets Ridge.[1]

| Period | CT Flow | | ZT Flow | |
|---|---|---|---|---|
| | Surface (mm)[2] | Subsurface (mm)[2] | Surface (mm)[2] | Subsurface (mm)[2] |
| 2002-2003 | 282 (78) | 445 (81) | 216 (9) | 534 (47) |
| 2003-2004 | 208 (33) | 242 (91) | 213 (12) | 250 (23) |
| 2004-2005 | 231 (28) | 277 (100) | 182 (20) | 365 (25) |
| 2005-2006 | 196 (17) | 215 (66) | 147 (35) | 319 (28) |
| Average | 229 | 295 | 190 | 367 |

1 Table values are means with the standard error in parentheses.
2 Rainfall equivalent

Table 5: Annual $NO_3^-$-N flow weighted average concentrations and loads in subsurface drainage water from conventional (CT) and zero tillage (ZT) systems at the Bio-Environmental Engineering Centre.

| | CT | | ZT | |
|---|---|---|---|---|
| | Concentration (mg $L^{-1}$) | Load (kg $ha^{-1}$ $y^{-1}$) | Concentration (mg $L^{-1}$) | Load (kg $ha^{-1}$ $y^{-1}$) |
| 2002-2003 | 6.95 | 12.77 | 5.03 | 19.05 |
| 2003-2004 | 7.01 | 9.98 | 5.13 | 12.94 |
| 2004-2005 | 10.54 | 18.19 | 6.91 | 22.38 |
| 2005-2006 | 11.06 | 27.88 | 8.04 | 36.13 |
| Average | 8.89 | 17.21 | 6.28 | 22.63 |

### 5.2.2 Streets Ridge Site

Nitrate-N flow weighted average concentrations, and annual loads in combined drainage at Streets Ridge are provided in Table 6. Table 7 provides $NO_3^-$-N flow weighted average concentrations and annual loads found in surface and subsurface drainage at Streets Ridge. The majority of $NO_3^-$-N losses were through leaching to subsurface flow (Table 7), which was expected. Nitrate-N concentrations were however; generally < the drinking water guideline of 10 mg $L^{-1}$. Average concentrations in combined drainage were often near or > the guideline for the protection for aquatic life (3 mg $L^{-1}$), demonstrating a potential threat to aquatic life.

Table 6: Annual $NO_3^-$-N flow weighted average concentrations and loads in combined drainage water from conventional (CT) and zero tillage (ZT) systems at Streets Ridge.

| | CT | | ZT | |
|---|---|---|---|---|
| | Concentration (mg $L^{-1}$) | Load (kg $ha^{-1}$ $y^{-1}$) | Concentration (mg $L^{-1}$) | Load (kg $ha^{-1}$ $y^{-1}$) |
| 2002-2003 | 2.41 | 17.46 | 1.87 | 17.84 |
| 2003-2004 | 3.47 | 14.46 | 1.92 | 9.25 |
| 2004-2005 | 3.50 | 18.08 | 3.58 | 21.66 |
| 2005-2006 | 7.54 | 37.88 | 7.75 | 51.94 |
| Average | 4.23 | 21.97 | 3.78 | 25.17 |

Table 7: Annual $NO_3^-$-N flow weighted average concentrations and loads in surface and subsurface drainage water from conventional (CT) and zero tillage (ZT) systems at Streets Ridge.

| | CT | | | | ZT | | | |
|---|---|---|---|---|---|---|---|---|
| | Surface | | Subsurface | | Surface | | Subsurface | |
| | Conc.[1] | Load[2] | Conc.[1] | Load[2] | Conc.[1] | Load[2] | Conc.[1] | Load[2] |
| 2002-2003 | 1.79 | 3.65 | 3.03 | 13.82 | 0.57 | 1.24 | 3.16 | 16.6 |
| 2003-2004 | 2.61 | 5.13 | 4.34 | 9.33 | 1.02 | 2.15 | 2.83 | 7.10 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 2004-2005 | 3.10 | 7.17 | 3.91 | 10.91 | 2.50 | 4.61 | 4.65 | 17.05 |
| 2005-2006 | 7.14 | 16.98 | 7.93 | 20.90 | 4.92 | 9.52 | 10.58 | 42.42 |
| Avg. | 3.66 | 8.23 | 4.80 | 13.74 | 2.25 | 4.38 | 5.31 | 20.79 |

1 $NO_3^-$-N Concentrations reported as mg $L^{-1}$
2 $NO_3^-$-N Load reported as kg $ha^{-1}y^{-1}$

# 6. E. COLI IN DRAINAGE WATER

## 6.1 BEEC Site

The *E.coli* concentrations during each year are presented in Table 8. The total number of samples analyzed for this site were 830. The *E.coli* concentrations were log transformed to achieve normality. The statistical results demonstrated that tillage had no significant effect on *E.coli* concentrations during study period. However, the *E.coli* concentrations under ZT were approximately 2x higher during the first year and this, coupled with the greater flow increased the E. coli load for ZT by 3.5x compared with CT during 2002-2003.

Table 8. Annual flow weighted averages (CFU 100 $mL^{-1}$) and loads (CFU $ha^{-1}$ $y^{-1}$) of E.coli in subsurface drainage water during 2002-2003 and 2003-2004 under conventional and zero tillage systems*

| Period | CT | | ZT | |
|---|---|---|---|---|
| | E.coli Concentrations (CFU 100 $mL^{-1}$) | Load ($10^{10}$ CFU $ha^{-1}$ $y^{-1}$) | E.coli Concentrations (CFU 100 $mL^{-1}$) | Load ($10^{10}$ CFU $ha^{-1}$ $y^{-1}$) |
| 2002-2003 | 1891 (891) | 0.34 (0.15) | 3690 (2371) | 1.22 (0.51) |
| 2003-2004 | 745 (202) | 0.12 (0.03) | 4734 (2148) | 1.88 (1.30) |
| Average (2 yr.) | 1318 | 0.23 | 4212 | 1.55 |

*Table values are means with the standard error in parentheses.

## 6.2 Streets Ridge Site

The annual flow weighted average (AFWA) concentration and loads of *E.coli* in combined drainage water and in surface and subsurface drainage water were calculated and are presented in Tables 9 and 10. The results were based on the *E.coli* enumeration done from 1080 samples during the entire study period. The *E.coli* data met normality assumptions and the statistical results for each year. No significant effects of tillage, drainage source or the tillage * drainage interaction on *E.coli* concentrations in combined drainage during both 2002-2003 and 2002-2003 were found. During 2003- 2004, the effect of the tillage*drainage interaction on E.coli discharged in surface and subsurface drainage water was alone.

Table 9. Annual flow weighted average E.coli concentrations (CFU 100 mL$^{-1}$) and E.coli loads (CFU ha$^{-1}$ y$^{-1}$) in combined drainage water during 2002-2003 and 2003-2004 under conventional (CT) and zero tillage (ZT) systems*.

| Period | CT | | ZT | |
|---|---|---|---|---|
| | E.coli Concentration (CFU 100 mL$^{-1}$) | E.coli Load ($10^{10}$ CFU ha$^{-1}$ y$^{-1}$) | E.coli Concentration (CFU 100 mL$^{-1}$) | E.coli Load ($10^{10}$ CFU ha$^{-1}$ y$^{-1}$) |
| 2002-2003 | 973 (87) | 5.5 | 961 (116) | 4.9 |
| 2003-2004 | 1224 (249) | 4.1 | 1476 (224) | 4.4 |
| 2002-2004 | 1099 | 4.8 | 1219 | 4.7 |

*Table values are means with the standard error in parentheses.

Table 10. Annual flow weighted average E.coli concentration (CFU 100 mL$^{-1}$) and E.coli loads (CFU ha$^{-1}$ y$^{-1}$) in surface and subsurface drainage water during 2002-2003 and 2003-2004 under conventional (CT) and zero tillage (ZT) systems*

| Period | CT | | | | ZT | | | |
|---|---|---|---|---|---|---|---|---|
| | Surface drainage | | Subsurface drainage | | Surface drainage | | Subsurface drainage | |
| | E.coli Conc**. (CFU 100 mL$^{-1}$) | E.coli Load ($10^{10}$ CFU ha$^{-1}$ y$^{-1}$) | E.coli Conc**. (CFU 100 mL$^{-1}$) | E.coli Load ($10^{10}$ CFU ha$^{-1}$ y$^{-1}$) | E.coli Conc**. (CFU 100 mL$^{-1}$) | E.coli Load ($10^{10}$ CFU ha$^{-1}$ y$^{-1}$) | E.coli Conc**. (CFU 100 mL$^{-1}$) | E.coli Load ($10^{10}$ CFU ha$^{-1}$ y$^{-1}$) |
| 2002-2003 | 825.3 (273.1) | 1.5 (0.3) | 1122.5 (142.7) | 4.0 (0.9) | 1259.5 (300.6) | 2.2 (0.5) | 662.2 (70.2) | 2.7 (0.2) |
| 2003-2004 | 1297.5 (471.6) | 2.0 (0.7) | 1151.4 (39.4) | 2.1 (0.7) | 801.2 (50.8) | 1.3 (0.1) | 2150.1 (403.2) | 4.1 (0.3) |
| 2002-2004 | 1061.4 (265.6) | 1.8 (0.3) | 1136.9 (665.0) | 3.1 (0.7) | 1030.3 (170.6) | 1.7 (0.3) | 1406.2 (379.7) | 3.4 (0.3) |

*Table values are means with the standard error in parentheses;**Concentration

# 7. SUMMARY

Despite reducing the concentrations of nutrient in drainage water, several disadvantages such as, greater nutrient load losses and higher bacterial discharge rates were associated with ZT when compared with CT. Apart from the tillage systems, the drain discharge volume, concentrations and loads of nutrients and pathogens were affected by several factors such as, soil type, annual precipitation, manure incorporation practices and the tillage system. Under tile drained soils, manure application followed by rainfall periods resulted in higher bacterial levels under ZT soils than under CT. Consequently the risk of bacterial leaching under ZT soils is high. Nevertheless, the risk of bacterial water contamination cannot be overlooked under both tillage systems. Conventional tillage systems potentially reduced the nutrient and pathogen load losses when compared to ZT. On the other hand, ZT reduced concentrations of nutrients in drainage water, minimized soil erosion losses, increased the water holding capacity, lower residual soil N and therefore resulted in higher yields when compared with CT. However, the increased drainage flow under ZT resulted in greater nutrient load losses when compared with CT. In order to minimize the load losses of the nutrients and to reduce the environmental risk through nutrient enrichment, CT appears to be more effective than ZT.

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