03-197

Environment Canada
Water Science and Technology Directorate

Direction générale des sciences et de la technologie, eau
Environnement Canada

Water table management, tillage practice and compost application influence on farm water quality

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WATER TABLE MANAGEMENT, TILLAGE PRACTICE AND COMPOST APPLICATION INFLUENCE ON FARM WATER QUALITY

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NWRI Contribution No. 03-197

Water table Management, Tillage Practie and Compost Application Influence on Farm Water Quality

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Abstract

The influence of controlled drainage (CD) and compost (CP) treatments associated with conventional tillage (CT) and no-tillage (NT) was studied for agricultural tile drainage water quality by comparing with free drainage treatment (FD). The study covered two phases. The phase 1 study from May 1995 to September 1998 included controlled drainage and tillage treatment, whereas the phase 2 study from October 1998 to October 2001 included compost and tillage treatment.

The results of Phase 1 study showed that the CD associated with CT (CD-CT) treatment promoted reduction of geometric mean concentration (GMC) for all nutrients (NH_3-N, NO_3-N, TN and TP), major ions (Cl, Na, Ca, and Mg) and trace elements (Fe, Mo and Sr). The reduction of GMC under CT (CD-CT) treatment ranged from the highest of Mo (34%) to the lowest of Fe (0.3%). The CD associated with NT (CD-NT) treatment also promoted reduction of GMC for all nutrients. The reduction of GMC ranges from NH_3-N by 81.1% to TP by 8.0%. Conversely, the CD-NT treatment promoted increase of GMC for all major ions (Cl, K, Na, Ca and Mg) and trace elements (Mo and Sr). The increase of GMC ranges from K (24.2%) to Mg (4.7%) compared with FD-NT treatment. The CD-CT treatment promoted reduction of cumulative loss for most of the studied constituents, except K, Cu and Pb. The reduction of the cumulative loss ranges from Mo (54%) to Zn (5.3%). Similarly, the CD-NT treatment also promoted reduction of cumulative loss for all nutrients and trace elements except Mo and Sr. The reduction of cumulative loss ranges from the highest of Ni (66.3%) to the lowest of NO_3-N (19.9%) compared with FD-NT treatment. Conversely, the CD-NT treatment promoted increase of cumulative loss for all major ions.

The results of Phase 2 study showed that the CP-CT treatment promoted increase of GMC for all nutrient parameters, major ions including trace elements of Ba, Cu, Mo, Ni and Sr. The increase of GMC ranges from K (67.9%) to Ni (15.2%) compared with FD-CT treatment. Conversely, the CP-CT treatment promoted reduction of GMC for Al, Be, Cr, Fe, Li, Mn, Pb, V and Zn. The reduction of GMC ranges from the Al (251%) to Zn (20.5%) compared with CP-CT treatment. The CP-NT treatment had similar results as CP-CT treatment to promote the increase of GMC of nutrients and major ions as well as to promote reduction of GMC of Al, Be, Cr, Fe, Li, Mn, Pb, V and Zn. The increase of GMC ranges from NH_3 N (79.9%) to Ba (10.8%) where the reduction of GMC ranges from Al (154 %) to Zn (0.16%) compared with FD-NT treatment. The CP-CT treatment promoted increase of cumulative loss for all the studied constituents except Al, Be, Cr, Fe, and V. The increase of cumulative loss ranges from 80.7% for K to 2.7% for Pb compared with FD-CT treatment. The CP-NT treatment promoted increase cumulative loss for nutrients and major ions including trace elements of Ba, Cu, Mo and Sr compared with FD-NT treatment. The

increase of cumulative loss ranges from for NH_3 N (83.3%) to Ba (9.1%) compared with FD-NT treatment. In contrast, the CP-NT treatment promoted decrease of cumulative loss for Al, Be, Cr, Fe, Li, Mn, Ni, Pb, V, and Zn. The decrease of cumulative loss ranges from Al (182%) to Zn (4.8%) compared with FD-NT treatment.

NWRI RESEARCH SUMMARY

Plain language title

NWRI and Agriculture and Agri-Food Canada in Harrow, Ontario are assessing the on-farm water quality under the influence of combined water table control, compost application and tillage practices.

What is the problem and what do sicentists already know about it?

Farming practices promoted erosion and leaching, which carry potential pollutants from farmland into surface and subsurface water. The major pollutants carried by water from farmland are sediment, nutrients, pesticides, bacteria and salts. Assessing and controlling these effects is complicated by the difficulty in tracing chemicals back to sources such as diversity of farms, soil types and farming practices. There is a time lag between the time of substance application to the farmland and the time when its effects on the environment may become evident.

Why did NWRI do this study?

To find out what are the best management practices in order to reduce or minimize the adverse effects on the receiving waters.

What were the results?

The researchers found that controlled drainage (CD) associated with conventional tillage (CT) reduced geometric mean concentration (GMC) for nutrients, major ions and a few trace elements (Fe, Mo and Sr) compared to the free drainage (FD) associated with CT. The CD associated with no-tillage (NT) treatment decreased the GMC for all nutrients by up to 81% for NH3-N, 14 % for NO3-N and 8% for TP compared to the GMC under FD-NT treatment. Conversely, CD-NT treatment increased GMC for all major ions, Mo and Sr compared with the GMC under FD-NT treatment. The CD-CT treatment reduced the cumulative loss for all the studied constituents, except K, Cu and Pb compared to the loss under FD-CT treatment. Similarly, the CD-NT treatment reduced cumulative loss for all the nutrients, major ions and trace elements except for Mo and Sr. On the compost (CP) treatment, the researchers found that CP-CT as well as the CP-NT treatment increased GMC for all nutreints, major ions and some trace elements (Ba,Cu, MO, Ni and Sr) compared to the GMC under FD-CT treatment. The CP-NT treatment decreased GMC for Al, Be, Cr, Fe,Li, Mn,Pb, V, and Zn. The CP-CT increased cumulative loss for all constituents except Al, Be, Cr, Fe and V compared to the loss under FD-CT treatment. The CP-NT treatment also increased cumulative loss for all the nutrients and major ions including Ba, Cu, Mo and Sr.

How will these results be used?

The results support the Great Lakes Water Quality Program for nutrient management practices that help farmers implementing on-farm drainage control measures to improve the Great Lakes' water quality by minimizing nutrient loss from agricultural areas in the Great Lakes Basin.

Who were our main partners in the study?

Agriculture and Agri-Food Canada

Impact de la gestion de la nappe phréatique, du travail du sol et d'un apport de compost sur la qualité de l'eau en milieu agricole

H.Y.F. Ng, C.S. Tan, C.F. Drury, W.D. Reynolds, T.Q. Zhang et J.D. Gaynor

Résumé

Nous avons étudié l'impact d'un traitement avec système de drainage contrôlé (DC) et d'un traitement au compost (CO), combinés à un travail classique du sol (TC) ou sans travail du sol (ST), pour évaluer, par rapport au système de drainage libre (DL), la qualité de l'eau de drainage agricole. L'étude a été effectuée en deux étapes. L'étape 1, de mai 1995 à septembre 1998, portait sur le traitement avec système de drainage contrôlé et le travail classique du sol, tandis que l'étape 2, d'octobre 1998 à octobre 2001, portait sur le traitement au compost et à nouveau le travail classique du sol.

Les résultats de l'étape 1 montrent que le DC combiné au TC (DC-TC) tendait à faire diminuer la moyenne géométrique de la concentration (MGC) de tous les nutriments (N-NH_3, N-NO_3, NT et PT), des ions principaux Cl, Na, Ca et Mg ainsi que des microéléments Fe, Mo et Sr. Sous un traitement TC (DC-TC), la diminution de la MGC allait de 0,3 % pour le Fe à 34 % pour le Mo. Le traitement DC sans travail du sol (DC-ST) diminuait la MGC de tous les nutriments. Cette diminution allait de 8,0 % pour le PT à 81,1 % pour le N-NH_3. Inversement, le DC-ST augmentait la MGC de tous les ions principaux (Cl, K, Na, Ca et Mg) ainsi que la MGC des microéléments Mo et Sr. Cette augmentation allait de 4,7 % pour le Mg à 24,2 % pour le K, par rapport au traitement DL-ST. Le traitement DC-TC réduisait la perte cumulative de la plupart des constituants étudiés, à l'exception du K, du Cu et du Pb. Cette réduction allait de 5,3 % pour le Zn à 54 % pour le Mo. De façon similaire, le traitement DC-ST réduisait la perte cumulative de tous les nutriments et de tous les microélements à l'exception du Mo et du Sr. Cette réduction allait de 19,9 % pour le N-NO_3 à 66,3 % pour le Ni, par rapport au traitement DL-ST. Inversement, le traitement DC-ST augmentait la perte cumulative de tous les ions principaux.

Les résultats de l'étape 2 de l'étude montrent que le traitement CO-TC tendait à faire augmenter la MGC de tous les nutriments (N-NH_3, N-NO_3, NT et PT) et ions principaux ainsi que des microéléments Ba, Cu, Mo, Ni et Sr. Cette augmentation allait de 15,2 % pour le Ni à 67,9 % pour le K, par rapport au traitement DL-TC. Inversement, le traitement CO-TC diminuait la MGC des Al, Be, Cr, Fe, Li, Mn, Pb, V et Zn. Cette diminution allait de 20,5 % pour le Zn à 251 % pour le Al, par rapport au traitement CO-TC. Les traitements CO-ST et CO-TC ont donné des résultats similaires, augmentant la MGC des nutriments et des ions principaux tout en diminuant la MGC des Al, Be, Cr, Fe, Li, Mn, Pb, V et Zn. L'augmentation de la MGC allait de 10,8 % pour le Ba à 79,9 % pour le N-NH_3, tandis que la diminution allait de 0,16 % pour le Zn à 154 % pour le Al, par rapport au traitement DL-ST. Le traitement CO-TC augmentait la perte cumulative de tous les constituants étudiés, à l'exception des Al, Be, Cr, Fe et V. Cette augmentation allait de 2,7 % pour le Pb à 80,7 % pour le K, par rapport au traitement DL-TC. Le traitement CO-ST augmentait la perte cumulative des nutriments et des ions principaux ainsi que des microéléments Ba, Cu, Mo et Sr, par rapport au traitement DL-ST. Cette augmentation allait

de 9,1 % pour le Ba à 83,3 % pour le N-NH_3. En revanche, le traitement CO-ST diminuait la perte cumulative des Al, Be, Cr, Fe, Li, Mn, Ni, Pb, V et Zn. Cette diminution allait de 4,8 % pour le Zn à 182 % pour le Al, par rapport au traitement DL-ST.

Sommaire des recherches de l'INRE

Titre en langage clair

L'INRE ainsi qu'Agriculture et Agroalimentaire Canada à Harrow (Ontario) évaluent l'impact de diverses combinaisons de contrôle de la nappe phréatique, d'un apport en compost et de travail du sol sur la qualité de l'eau à la ferme.

Quel est le problème et que savent les chercheurs à ce sujet?

Les pratiques culturales favorisent l'érosion et le lessivage, qui transportent des polluants potentiels des terres agricoles vers les eaux de surface et les eaux souterraines. Les principaux polluants sont les sédiments, les nutriments, les pesticides, les bactéries et les sels. Il est difficile d'évaluer et de limiter ces effets, car il faut retracer l'origine de chaque substance chimique et prendre en considération la diversité des terres agricoles, des types de sols et des pratiques culturales. Il faut s'attendre à ce qu'une certaine période de temps s'écoule entre l'introduction d'une substance sur les terres agricoles et l'observation de ses effets sur l'environnement.

Pourquoi l'INRE a-t-il effectué cette étude?

Choix des meilleures pratiques de gestion permettant de réduire les effets nuisibles des polluants sur les eaux réceptrices.

Quels sont les résultats?

Les chercheurs ont constaté qu'un système de drainage contrôlé (DC) combiné à un travail classique du sol (TC) diminuait la moyenne géométrique de concentration (MGC) des nutriments, des ions principaux ainsi que de certains microéléments (Fe, Mo et Sr), par rapport au drainage libre (DL) combiné au TC. Le traitement DC sans travail du sol (ST) diminuait la MGC de tous les nutriments de 8 % pour le PT à 14 % pour le N-NO_3 et à 81 % pour le N-NH_3, par rapport au traitement DL-ST. Inversement, le traitement DC-ST augmentait la MGC de tous les ions principaux, du Mo et du Sr, par rapport au traitement DL-ST. Le traitement DC-TC réduisait la perte cumulative de tous les constituants étudiés, à l'exception des K, Cu et Pb, par rapport à la perte sous un traitement DL-TC. De façon similaire, le traitement DC-ST réduisait la perte cumulative de tous les nutriments et ions principaux ainsi que des microéléments à l'exception du Mo et du Sr. Sous traitement au compost (CO), le traitement CO-TC aussi bien que le traitement CO-ST augmentaient la MGC de tous les nutriments, des ions principaux et de certains microéléments (Ba, Cu, Mo, Ni et Sr), par rapport au traitement DL-TC. Le traitement CO-ST diminuait la MGC des Al, Be, Cr, Fe, Li, Mn, Pb, V, et Zn. Le traitement CO-TC augmentait la perte cumulative de tous les constituants à l'exception des Al, Be, Cr, Fe et V, par rapport au traitement DL-TC. Le traitement CO-ST augmentait également la perte cumulative de tous les nutriments et ions principaux ainsi que des Ba, Cu, Mo et Sr.

Comment ces résultats seront-ils utilisés?

Ces résultats servent d'appui pour le Programme sur la qualité de l'eau des Grands Lacs en ce qui concerne les pratiques de gestion des nutriments qui aident les agriculteurs à mettre en place des mesures de drainage contrôlé à la ferme afin d'améliorer la qualité de l'eau des Grands Lacs en réduisant au minimum la perte des nutriments des zones agricoles du bassin des Grands Lacs.

Quels étaient nos principaux partenaires dans cette étude?
Agriculture and Agroalimentaire Canada

Introduction

Effects of agricultural activities on water quality have been studied extensively for the past several decades in North America and elsewhere around the world. The results of study concluded that farming practices promoted erosion and leaching, which carry potential pollutants from farmland into surface and subsurface water. The major pollutants carried by water coming from farmland are sediment, nutrients (especially nitrogen, phosphorus and potassium), pesticides (including fungicides, insecticides, and herbicides), bacteria and salts.

Assessing and controlling these effects, particularly related to water quality, is complicated by the difficulty in tracing chemicals back to sources such as diversity of farms, soil types, and farming practices. There is a time lag between the time of substance application to the farmland and the time when its effects on the environment may become evident. With the identification of the critical role of potential pollutants, control and reduction of inputs of agricultural chemicals is an essential option. Studies have shown that water table control (Bergstorm, 1987; Kalita and Kanwar, 1993; Drury et al., 1996; Masse et al., 1996; Gaynor et al., 2001; Ng et al., 2002) and tillage practices (Tan et al., 2002) have pronounced effects on water quantity and quality. To evaluate control and reduction of inputs of agricultural chemicals, an on-farm study associated with compost, water table control and tillage practices was conducted. The report that follows covered two phases of study. The Phase 1 study covered a period from May 1995 to September 1998 and was designed to investigate water table control and tillage practice. The Phase 2 study was devised to investigate compost associated with tillage practices for a period from October 1998 to October 2001. The purpose of this study focused on the water quality under the influence of water table control, compost and tillage practices. The studied water quality parameters included nutrients, major ions and trace metals for a total of 23 parameters.

Methods

Field plots description

The Chevalier farm (42° 12' 15" N, 82° 44' 50" W) was subdivided into a 2.0 ha plot installed with a controlled drainage device (CD) and a 2.4 ha plot (Figure 1, Site 2) installed with a free drainage device (FD). Similarly, the Shanahan farm (42° 12' 15" N, 82° 45' 58"W) was subdivided into a 2.4 ha plot installed with a CD device and a 2.2 ha (Figure 1, Site 3) plot installed with a FD system. The tillage on the Chevalier farm was conventional tillage (CT) whereas the Shanahan farm was under no-tillage (NT). Each plot at the Chevalier and Shanahan sites was served by 5 subsurface tiles with an average spacing of 8.7 m. The average depth of tiles was 0.6 m below the soil surface for all plots. The lengths of tiles of 104 mm in diameter were 538 m and 450 m, respectively, for Shanahan and Chevalier. The average gradient of tile was 0.05%.

Measurements and sample analysis

Measurements - A calibrated tipping bucket measured the tile discharge volume from CD and FD systems by counting the number of bucket tippings. The ISCO model 2900 automatic samplers, each with 24-sample bottles of 500 ml, were used to collect tile drainage samples from the CD and FD plots. The automatic samplers were activated by a signal from the preset flow volume. The pre-set flow volume for CD and FD plots at the Chevalier site was 10,000 L throughout the two study periods from May 8, 1995 to November 14, 2001. At the Shanahan site, the pre-set volumes for the CD plot corresponding to starting and ending dates respectively, were 24,490 L (May 8, 1995 to July 31, 2000), 25,000 L (August 1, 2000 to September 25, 2000) and 20,000 L (September 26, 2000 to November 14, 2001) whereas for the FD plot, the pre-set volumes corresponding to starting and ending dates respectively, were 10,000 L (May 8, 1995 to December 16, 1996), 24,490 L (December 17, 1996 to April 25, 2000), 25,000 L (April 26 to September 25, 2000) and 20,000 L (September 26, 2000 to November 14, 2001). The frequency of sample pick up from the sampler depended on the magnitude of rainfall and the number of sequential samples collected by a sampler. The water samples were transferred to glass bottles and kept at 4°C until the laboratory analysis started.

A hand held auger of 2.5 cm in diameter was used to collect soil samples. The soil sample was taken at a ratio of 0.13, 0.25, 0.5 and 0.88 m of the total distance starting at the mid point of the edge of the plot running from east toward west across the center of the plot. Soil samples were taken at two depths between 0-30 cm and 30-60 cm.

Precipitation data for Chevalier and Shanahan sites were collected from the weather station located at Woodslee Experimental Station at 0.5 km from the study sites.

Analytical methods - All water samples were unfiltered. Several sequential samples collected from a given sampler were combined into one sample for analysis of chemical compositions. Cadmium Reduction Method and Colorimetric Method respectively were used for analysis of the nitrate nitrogen (NO_3-N) and total phosphorus (TP). The Flame Emission Photometric Method or Atomic Absorption Method, respectively was used for analysis of potassium (K) for 1995/96 samples and for 1997/98 samples. Inductively coupled plasma-mass spectrometer (ICP-MS) was employed for trace metals and atomic absorption spectroscopy was used for major ion analysis. The analytical procedures can be found in the Manual of Analytical Methods (Environment Canada, 1994 (revised)).

Tillage, agronomy, fertilization and weed control

Phase 1 **- May 1995 to September 1998**

Tillage -The tillage and cropping on Chevalier and Shanahan farms were reported elsewhere (Tan et al., 2002). Throughout the study periods, the Chevalier farm was under conventional tillage (CT) whereas the Shanahan farm was under no-tillage (NT) practices.

Agronomy - Soybeans were seeded at a rate of 580,000 seeds ha^{-1} in 38 cm wide rows on CT and NT farms between second and third weeks of May in 1995, 1996 and 1998. In 1997, both CT and NT farms were seeded with field corn at a rate of 72,000 seeds ha^{-1} in 76.2 cm rows in late May and early June.

Fertilization - At the CT site, fertilizer (0-18-36) was broadcast at a rate of 224 kg ha^{-1} during the fall of 1994 and 1995. At the NT site, fertilizer (6-36-18) was banded beside the seed row at a rate of 185 kg ha^{-1} during the spring of 1995, 1996 and 1998.

In the 1997 cropping season, fertilizer (18-18-12) was banded during planting at a rate of 196 kg ha^{-1} and anhydrous ammonia (180 kg ha^{-1}) was injected at 20 cm depth at the four-leaf stage at the CT site. At the NT site, fertilizer (18-12-18) was banded during planting at a rate of 207 kg ha^{-1} and aqua ammonia (157 kg N ha^{-1}) was injected at mid-row position (6-7 cm depth) at the four-leaf stage.

Weed control - In 1995, 1996 and 1998 cropping seasons, weeds were controlled at both CT and NT sites using imazethayr (34 to 68 g active ingredient (a. i.) ha^{-1}) and bentazon (0.5 to 1.0 kg a. i. ha^{-1}), which were applied before planting. Soybean oil (2.5 L ha^{-1}) was added to the bentazon spray to enhance activity of the herbicide. When required, glyphosate (0.6 to 1.0 kg a. i. ha^{-1}) was applied before planting to control perennial and early-emerging annual weeds.

In the 1997 cropping season, weeds were controlled at the CT site by post-emergence application of 2,4-D/dicamba/ mecoprop (0.45 kg a. i. ha^{-1}) and atrazine (1.26 kg a. i. ha^{-1}). Weeds were controlled at the NT site by pre-emergence application of metolachlor (2.16 kg a. i. ha^{-1}). When required, glyphosate (0.84 kg a. i. ha^{-1}) was also applied to the NT site.

Phase 2 **- October 1998 to October 2001**

The controlled drainage devices on CD plots at both CT and NT sites were deactivated. The yard waste leaf compost was applied to the CD plot, designated as CP plot.

Tillage - The same tillage practices used in Phase 1 were implemented on the CT and NT sites throughout the study period.

Agronomy - Soybeans (Pioneer 9305) were seeded at 103 kg ha^{-1} (566,500 plants ha^{-1}) at CT site in 38 cm wide rows on May 7, 1999 and 105.3 kg/ha (579,040 plants ha^{-1}) at NT site in 38 cm wide rows on May 12, 1999. Field corn was seeded at 72,000 seed ha^{-1} in 76.2 cm wide rows between early May and early June in 2000 on the CT and NT sites. Soybeans (Pioneer 9305) were seeded 100.9 kg ha^{-1} (554,819 plants ha^{-1}) at 38.1 cm on May 4 2001 at the CT site where soybeans (Pioneer 9305) were seeded at a rate of 105.3 kg ha^{-1} (579,000 plants ha^{-1}) at 38.1 cm between rows on May 12, 2001 at the NT site.

Fertilization - In the 1999 cropping season, at the CT site, the CP plot received yard waste leaf compost at 100 metric tonnes ha^{-1} on December 10, 1998 in addition to the soybean crop residue from 1998 whereas the FD plot received only soybean crop residue from 1998. Commercial fertilizer was not applied to both CD and FD plots. At the NT site, the CP plot received yard waste leaf compost at 100 metric tonnes ha^{-1} on December 12, 1998 in addition to the soybean crop residue from 1998. Fertilizer at 22.92 kg N ha^{-1}, 47.28 kg P_2O_2 ha^{-1}, and 11.83 kg K_2O_2 ha^{-1} was applied to both the CP and FD plots on May 12, 1999.

In the 2000 cropping season, the CP plot at CT and NT sites, respectively, received yard waste leaf compost at 100 metric tonnes ha^{-1} on October 21, 1999 and October 28, 1999. On May 8, 2000, additional fertilizer at 29.4 kg N ha^{-1}, 29.4 kg P_2O_2 ha^{-1} and 43.2 kg K_2O ha^{-1} was applied on both CP and FD plots at the CT site, banded at 5 cm beside row at a depth of 5 cm. In addition, 185 kg ha^{-1} of actual N in the form of anhydrous ammonia was knifed in at a depth of 20 cm between corn rows on May 20, 2000. On May 8, 2000, additional fertilizer at 4.46 kg N ha^{-1}, 17.83 kg P_2O_2 ha^{-1} and 4.46 kg K_2O ha^{-1} was applied on both CP and FD plots at the NT site. In addition, 156.9 kg of N ha^{-1} with 28% Aqua ammonia was injected in mid spacing of the row about 6-7 cm on May 24, 2000.

In the 2001 cropping season, the CP plot at the CT and NT sites, respectively, received yard waste leaf compost at 100 metric tonnes ha^{-1} applied on December 8, 2000. Commercial fertilizer was not applied to both CP and FD plots in 2001 except field corn stubble and trash residue left from 2000.

Weed control - In the1999 cropping season, weeds were controlled at both CT and NT sites using Dual II magnum (1.05 kg a. i. ha^{-1}), Lexone (0.5 kg a. i. ha^{-1}) and Pursuit (0.75 kg a. i. ha^{-1}) before planting except at the NT site, where additional Roundup (0.84 kg a. i. ha^{-1}) was applied before planting for weeds burnoff. In the 2000 cropping season, weeds were controlled at both CT and NT sites by applying Dual II magnum (1.05 kg a. i. ha^{-1}); atrazine (1.1 kg a. i. ha^{-1}) except at NT site, and additional Roundup (0.84 kg a.i. ha^{-1}) was applied for weed burnoff. In the 2001 cropping season, weeds were controlled by using Dual II magnum (1.05 kg a. i. ha^{-1}) and Senco (0.5 kg a. i. ha^{-1}) at both CT and NT sites before planting. In addition, Roundup (0.84 kg ha^{-1}) was also used at the NT site for weed burnoff.

Results and discussion

Soil type - The major soil type is clay loam soil (Table 1). The soil textures between 0-30 cm and 30-60 cm for CD and FD plots have been reported earlier (Ng, et al., 2002). The average percentage of clay soil between the 0-30 cm depth at the NT site is 16% higher than at the CT site, whereas the percentage of clay soil between the 30-60 cm depth at the NT site is 13% higher than the CT site.

Table 1. Soil types

Soil Type	0-30 cm				30-60 cm			
	CT site		NT site		CT site		NT site	
	CD	FD	CD	FD	CD	FD	CD	FD
Sand (%)	40.7	35.1	31.7	28.0	35.4	31.4	25.8	27.1
Silt (%)	27.3	27.3	31.2	31.7	28.5	31.0	31.8	30.5
Clay (%)	32.0	33.9	38.1	40.4	36.2	37.6	42.5	42.4

Phase 1 **- May 1995 to September 1998**

Precipitation and tile drainage volumes - From May 1995 through September 1998 each of the FD and CD plots at CT and NT sites received total precipitation of 2466.7 mm (Table 2 and Figure 2). It follows that the tile drainage volumes per unit area for the FD and CD plots, respectively, and 1.5×10^3 L ha^{-1} mm^{-1} and 1.6×10^3 L ha^{-1} mm^{-1} at the CT site. The unit area of tile drainage volume for FD and CD plots respectively, were 2.3×10^3 L ha^{-1} mm^{-1} and 2.1×10^3 L ha^{-1} mm^{-1} at the NT sites. The FD plot at the NT site (FD-NT) produced greater tile drainage volume by 35% from 2.3×10^3 L ha^{-1} mm^{-1} for FD-NT compared to 1.5×10^3 L ha^{-1} mm^{-1} for FD-CT. Similarly, the CD plot at the NT site produced greater tile drainage volume by 24% from 2.1×10^3 L ha^{-1} mm^{-1} for CD-NT compared to 1.6×10^3 L ha^{-1} mm^{-1} for CD-CT treatment. Patni et al. (1996) reported similar results had 46% increase in tile drainage volume for NT practices for a 40 months period. Tan et al. (2002) also reported similar results had 48% increase in tile drainage volume for a 60-month period. These results suggested that long-term NT practices enhanced soil moisture content.

Geometric mean concentration (GMC) of tile drainage water quality - A total of 23 water quality parameters out of 26 had GMCs greater than detection limits. The Ag, Cd and Co had GMC below the detection limit and were eliminated from study. The GMC of the 23 parameters varies substantially for both CD-CT and FD-CT treatments (Table 3). At the CT site, the GMC ranges from Ca (67.6 mg/L) to Mo (0.002 mg/L) for the CD treatment whereas the GMC ranges from Ca (82.6 mg/L) and Mo (0.003 mg/L) for FD treatment. Similarly, at the NT site, the GMC respectively, ranges from Ca (76.2 mg/L) to Mo (0.002 mg/L) for the CD treatment and the GMC ranges from Ca (67.9 mg/L) to Mo (0.002 mg/L) for FD treatment. The percentile of change of GMC between CD and FD treatments at the CT and NT sites is shown in Figures 4 and 5. The CD-CT treatment (Figure 4) showed a reduction of GMC for most of the nutrient, major ions, Fe, Mo and Sr compared to FD-CT treatment. The reduction of GMC ranges from 34.9% for Mo to 0.3% for Fe. Similarly, the CD-NT treatment (Figure 5) showed a reduction of GMC for most of the nutrients, Al, Ba, Be, Cr, Cu, Fe, Li, Mn, Ni, V, and Zn except K compared to the FD-NT treatment. The reduction of GMC ranges from 81.1% for NH_3-N to 8.0% for TP. Conversely, the CD-NT treatment had increased GMC for all major ions including Mo and Sr compared to FD-NT treatment. The increase of GMC ranges from 24.2% for K to 4.7% for Mg.

Cumulative loss of constituent in tile drainage – The cumulative loss of constituent in tile drainage water was calculated as a product of GMC and the tile drainage volume (Tables 3 & 5, and Figures 2 & 3). The percentile of change of cumulative loss between CD and FD treatments at the CT site is shown in Figure 6. The CD-CT treatment had reduced the cumulative loss for almost all the constituents except K, Cu and Pb. The reduction of cumulative loss ranges from the highest of 54% for Mo to the lowest of 5.3% for Zn. The CD-NT treatment (Figure 7) showed a reduction of cumulative loss for all nutrients and trace metals except Mo and Sr. In contrast the CD-NT treatment (Figure 7) had increased cumulative loss for all major ions including two trace metals (Mo and Sr). The reduction of cumulative loss under CD-NT treatment ranges from the highest of 66% for Ni to the lowest of 19.9% for NO_3-N whereas the increase of cumulative loss for major ions including two metals ranges from the highest of 20% for K to the lowest of 6.4% for Mg. The results suggested that CD-CT treatment promoted reduction of cumulative loss for nutrients, major ions and trace elements, except K, Cu and Pb. In contrast, the CD-NT treatment promoted reduction of cumulative loss for nutrients and trace metals (except Mo and Sr), but CD-NT treatment had promoted increase of cumulative loss for all nutrients. It is noted that both CD-CT or CD-NT treatments had increased cumulative loss for K. The increase of cumulative loss for K may have been the results from soil reserve and surface application since K is abundant in the soil reserve (Ontario Ministry of Agriculture 1994).

***Phase 2* - October 1998 to October 2001**

Precipitation and tile drainage volumes - From October 1998 to October 2001, the FD and CP plots at the CT and NT sites, each received a total of 2031.5 mm of precipitation (Table 4 and Figure 3). It follows that the FD-NT treatment had produced greater tile drainage volume per unit area by 29% from 2.1 x 10^3L ha^{-1} mm^{-1} for FD-NT compared to 1.5 x 10^3 L ha^{-1} mm^{-1} for FD-CT treatment. Conversely the CP-NT treatment had produced lesser tile drainage volume by 31% from 1.6 x 10^3 L ha^{-1} mm^{-1} for CP-NT treatment compared to 2.4 x 10^3 L ha^{-1} mm^{-1} for CP-CT treatment. This may suggest that surface applied compost materials may have impeded infiltration rate as opposed to the results without compost materials reported by earlier investigators (Bouma et al., 1982; Patni et al., 1996).

Geometric mean concentration (GMC) of tile drainage water quality – As noted in Phase 1, the parameters Ag, Cd and Co had GMC below the detection limit in the Phase 2 study. They were eliminated from reporting. The GMC of the 23 constituents under CP-CT treatment ranges from the highest of 109.1 mg/L for Ca to the lowest of 0.002 mg/L for Cr (Table 5) whereas the GMC of the 23 constituent under FD-CT treatment ranges from 75.5 mg/L for Ca to the lowest of 0.004 mg/L for Mo

(Table 5). The GMC of the 23 parameters under the CP-NT treatment were similar to the FD-CT treatment. The GMC ranges from the highest of 93.3 mg/L for Ca to the lowest of <0.001 mg/L for Mo, whereas the results of GMC under FD-NT treatment were smaller compared to the results of GMC under CP-NT treatment. The GMC under FD-NT treatment ranges from the highest of 61.9 mg/L for Ca to the lowest of <0.003 mg/L for Mo. The comparison of changes of GMC between CP-CT and FD-CT and between CP-NT and FD-NT treatments is shown in Figures 4 and 5. The CP-CT treatment (Figure 4) showed an increase in GMC for all nutrient parameters, major ions, Ba, Cu, Mo, Ni and Sr compared to FD-CT treatment. Contrary, the CP-CT treatment showed reduction of GMC for Al, Be, Cr, Fe, Li, Mn, Pb, V and Zn ranging from 251% for Al to 20.5% for Zn compared to FD-CT treatment.
The CP-NT treatment (Figure 5) showed similar results as the CP-CT treatment. The CP-NT treatment showed an increase of GMC for all nutrients, major ions, Ba, Cu, Mo, Ni and Sr compared to FD-NT treatment. The CP-NT treatment reduced GMC for Al, Be, Cr, Fe, Li, Mn, Pb, V and Zn ranging from 154 % (Al) to 0.16% (Zn) compared to FD-NT treatment. A significant contrast emerged and indicated that both CP-CT and CP-NT treatments had increased the GMC of nutrients and major ions compared with FD-CT and FD-NT, except for some trace elements.
Cumulative loss of constituents in tile drainage – The calculation of cumulative loss of constituents in the tile drainage has been discussed earlier. The comparison of cumulative loss of constituents in tile drainage between CP-CT and FD-CT treatments is presented in Figures 6 and 7. Figure 6 shows that CP-CT treatment had increased the cumulative loss for almost all the studied nutrients and major ions. Similarly, CP-CT treatment promoted decrease of cumulative loss for some trace metals, Al, Be, Cr, Fe, and V. The increase of cumulative loss ranges from 80.7% for K to 2.7% for Pb, whereas the decrease of cumulative loss for Al, Be, Cr, Fe, and V ranges from the highest of 81.1% for Al to the lowest of 25.9% for Be. The CP-NT treatment (Figure 7) showed an increase of cumulative loss for the entire study period for nutrients and major ions including four trace metals (Ba, Cu, Mo, and Sr). The increase of cumulative loss under CP-NT treatment ranges from the highest NH_3 N (83.3%) to the lowest Ba (9.1 %) whereas the decrease of cumulative loss ranges from the highest Al (182%) to the lowest of Zn (4.8%). The results suggested that CP-NT treatment had increased cumulative loss for all nutrients and major ions including four metals (Ba, Cu, Mo and Sr). Contrary, the CP-NT treatment had also reduced the cumulative loss for metals of Al, Be, Cr, Fe, Li, Mn, Ni, Pb, V and Zn.

Summary and conclusion

This study produced a large volume of information. According to the purpose of this study, summary and conclusion of results in this report are limited to tile drainage volume, concentration and cumulative loss of constituents in tile drainage.

Tile drainage volume - The FD-CT treatment produced greater tile drainage volume by 20.6% for the *Phase 1* compared to *Phase 2*, which resulted from higher precipitation received in *Phase 1* (18%) compared to *Phase 2*. The CD-CT treatment produced lesser tile drainage volume by 19% for *Phase 1* compared to *Phase 2*. Both FD-NT and CD-NT treatments produced more tile flow volume by 25.2% and 36%, respectively for *Phase 1* compared to *Phase 2*, implying the greater hydraulic conductivity due to more numerous soil macropores under the NT treatment.

The Phase 1 study

Geometric mean concentration: This phase of study demonstrated that the CD-CT treatment promoted reduced GMCs for most of the nutrients and major ions, except K, Fe, Mo and Sr, compared with the FD-CT treatment. The reduction of GMC under CD-CT treatment ranges from the highest of Mo (34.9%) to Fe (0.3%). The CD-NT treatment was more efficient in reduction of GMC for nutrients and trace elements except Mo and Sr. The reduction of ranges from the highest for NH_3-N (81.1%) to TP (8.0%). In contrast the CD-NT treatment promoted increased GMC for all major ions, Mo and Sr, compared with the FD-NT treatment. The increase of GMC of major ions ranges from the highest of K (24.2%) to the lowest Mg (4.7%) compared with the FD-NT treatment.

Cumulative loss of constituents in tile drainage: The CD-CT treatment promoted reduction of the cumulative loss for most of the studied constituents except K, Cu and Pb, compared with FD-CT treatment. The reduction of cumulative loss ranges from the highest of Mo (54%) to the lowest of Zn (5.3%) compared with the FD-CT treatment. The CD-NT treatment promoted further reduction of cumulative loss. The reduction of cumulative loss ranges from the highest of Ni (66.3%) to NO_3-N (19.9%) compared with FD-NT treatment. In contrast, the CD-NT treatment promoted increase cumulative loss for all major ions including Mo and Sr compared with the FD-NT treatment. The increase of cumulative loss ranges from the highest of K (24.2%) to the lowest of Mg (4.7%).

The Phase 2 study

Geometric mean concentration: The CP-CT treatment promoted increased of GMCs for all nutrients as well as major ions including Ba, Cu, Mo, Ni and Sr, compared with the FD-CT treatment. The increase in GMC ranges from the highest of K (67.9%) to the lowest of Ni (15.2%). In contrast, the CP-CT treatment promoted reduction of GMC for Al, Be, Cr, Fe, Li, Mn, Pb, V and Zn. The reduction of GMC ranges from the highest of Al (251%) to the lowest of Zn (20.5%) compared with the FD-CT treatment. The CP-NT treatment had similar results as the CP-CT treatment. The CP-CT treatment had increased GMC for all nutrient constituents, major ions, Ba, Cu, Mo, Ni and Sr compared with the FD-CT treatment. Conversely, the CP-CT treatment had reduced GMC for Al, Be, Cr, Fe, Li, Mn, Pb, V and Zn, ranging from the highest Al (154 %) to the lowest of Zn (0.16%) compared with the FD-CT treatment.

Cumulative loss of constituents in tile drainage: The CP-CT treatment promoted the cumulative loss for most of the studied constituents except Al, Be, Cr, Fe, and V compared with the FD-CT treatment. The increase of cumulative loss ranges from the highest of K (80.7%) to the lowest of Pb (2.7%). Conversely, the CP-CT promoted decreased cumulative loss for the five trace elements (Al, Be, Cr, Fe, and V). The decrease of cumulative loss ranges from the highest of Al (81.1%) to the lowest of Be (25.9%). The CP-NT treatment promoted increased cumulative loss for all the studied nutrients and major ions including four trace elements (Ba, Cu, Mo and Sr). The increase of cumulative loss ranges from the highest of NH_3 N (83.3%) to the lowest of Ba (9.1%). The CP-NT also promoted decrease of cumulative loss for some trace elements (Al, Be, Cr, Fe, Li, Mn, Ni, Pb, V and Zn). The decrease of cumulative loss ranges from the highest of Al (182%) to the lowest of Zn (4.8%).

Acknowledgements

This research has been supported by the Great Lakes Water Quality Program, grants from the Canada-Ontario Agriculture Green Plan Program, and the Agriculture and Agri-Food Canada Matching Investment Initiative. Appreciation is expressed to Mr. K. Rinas, Mr. Soultani, Dr. T.Oloya, Miss. J. Sifton, Ms. J. St. Denis, Mr. D. Pohlman and Ms. J. Gignac for their expert technical assistance. The cooperation of farm operators, Mr. Chevalier and Mr. Shanahan is gratefully acknowledged.

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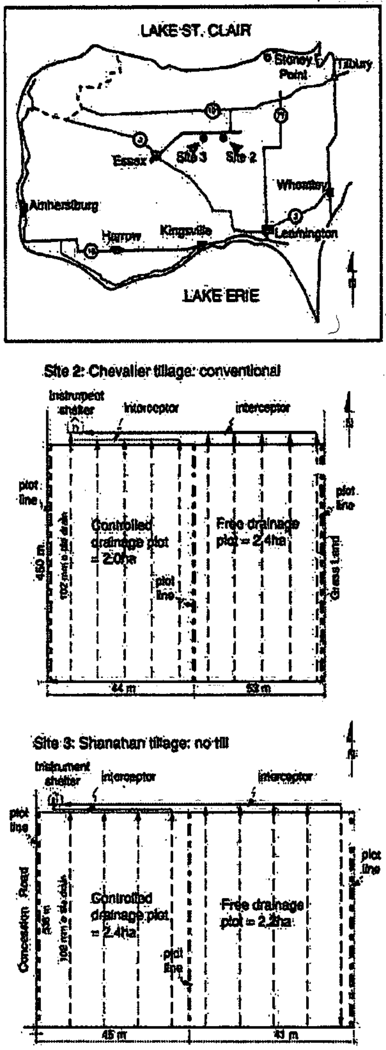
Figure 1. Location Map and Plot Layout.



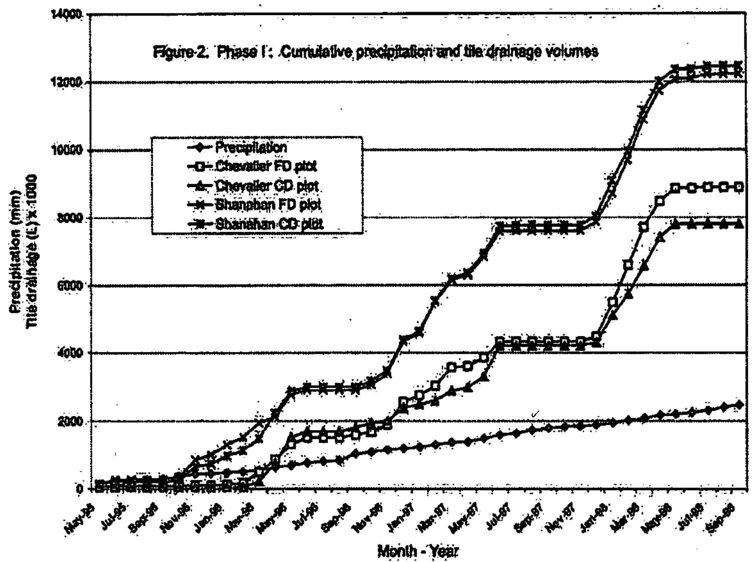


Figure 2. Phase I: Cumulative precipitation and tile drainage volumes

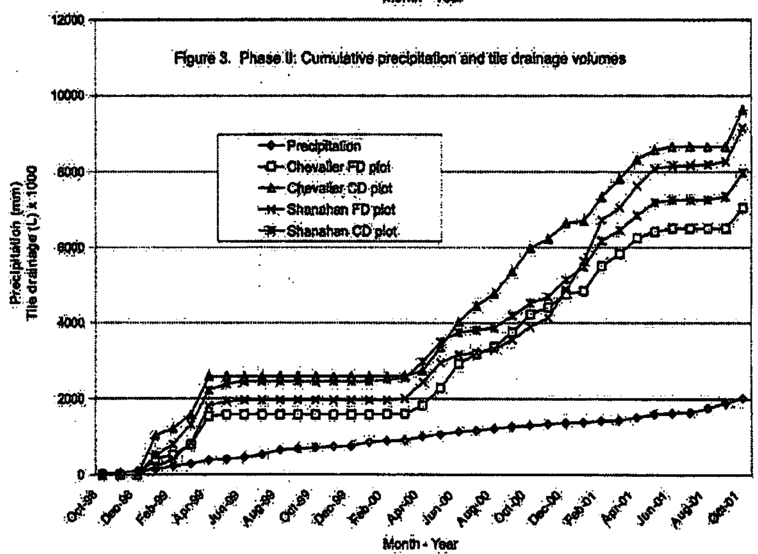


Figure 3. Phase II: Cumulative precipitation and tile drainage volumes

Figure 4. Comparison of chemical mean concentration under the influence of CD, CP and FD treatments at Chevalier farm

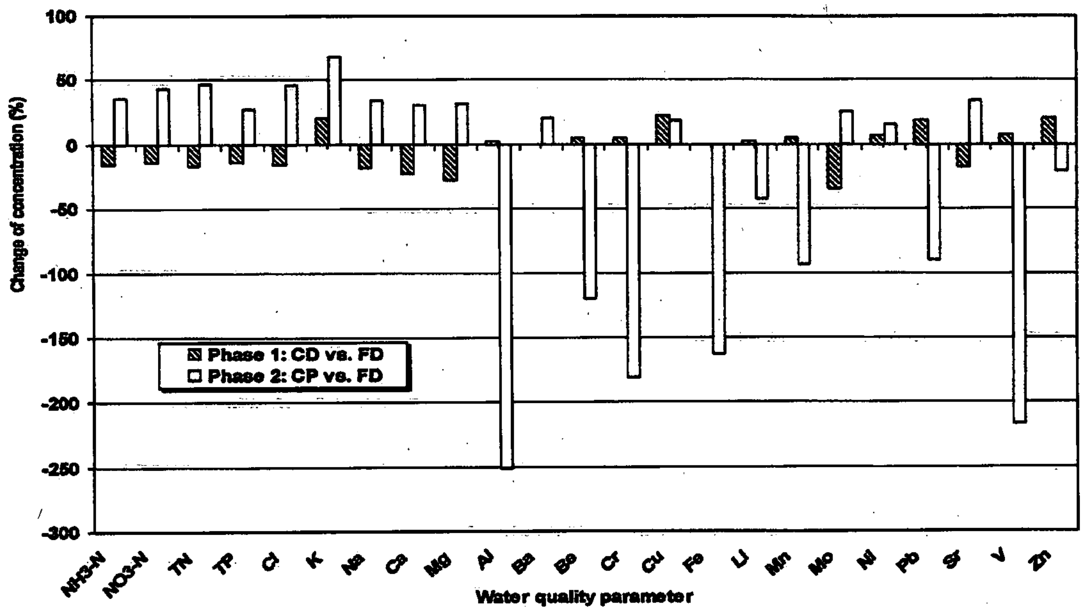


Figure 5. Comparison of chemical mean concentration under the influence of CD, CP and FD treatments at Shanahan farm

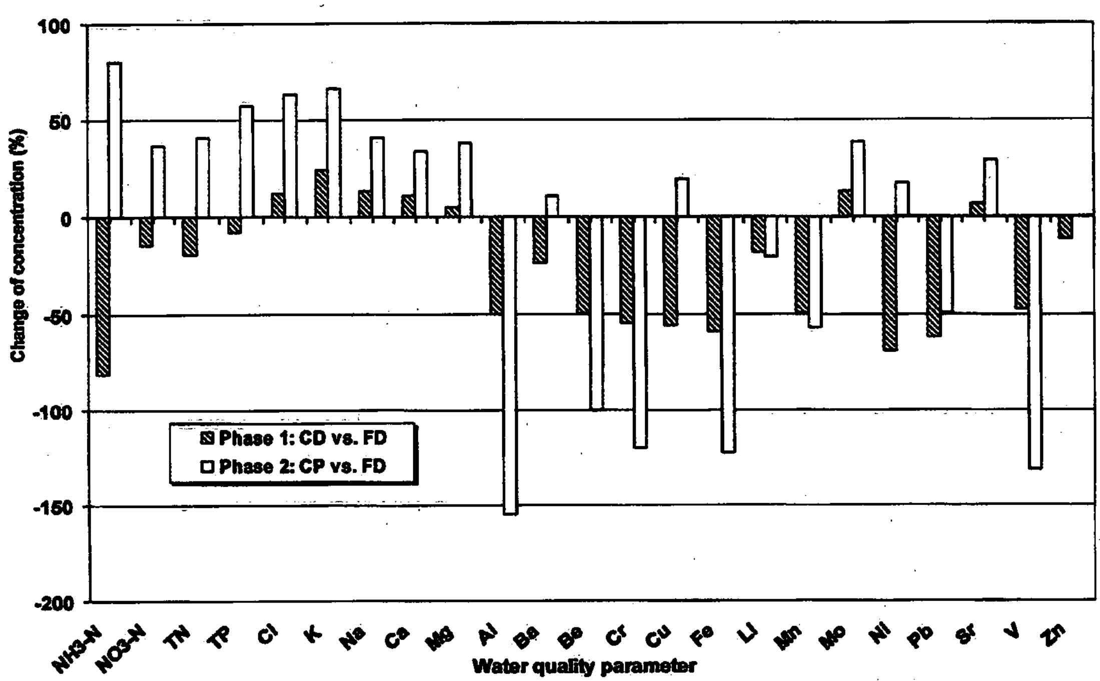


Figure 6. Comparison of loss of constituent under the influence of CD, CP and FD treatments at Chevalier farm

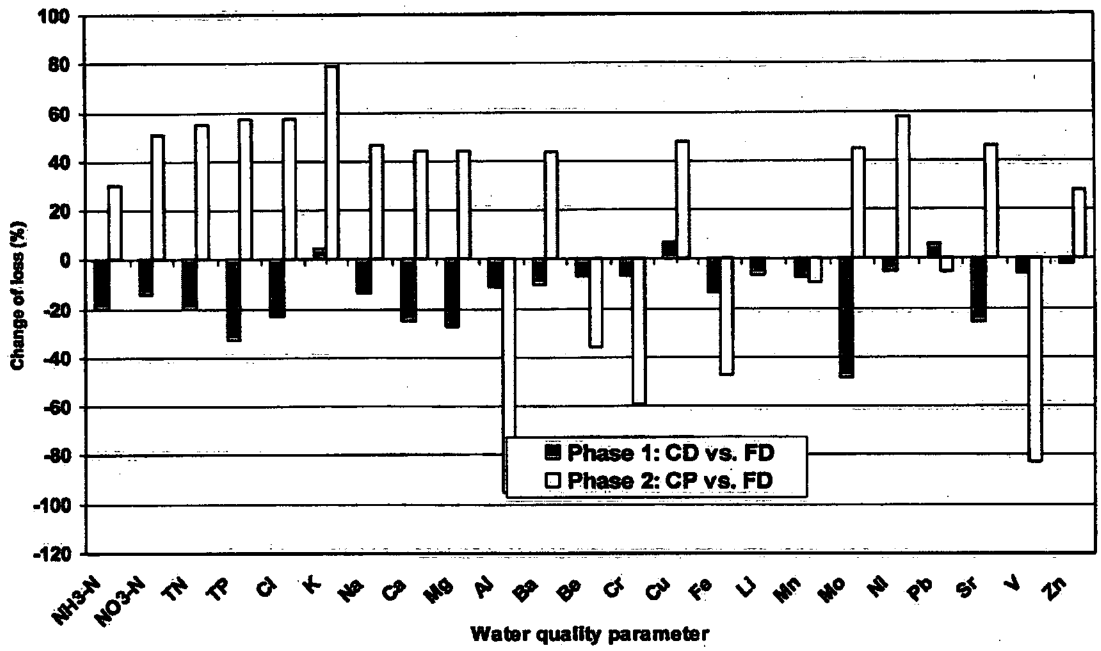


Figure 7. Comparison of loss of constituent under the influence of CD, CP and FD treatments at Shanahan farm

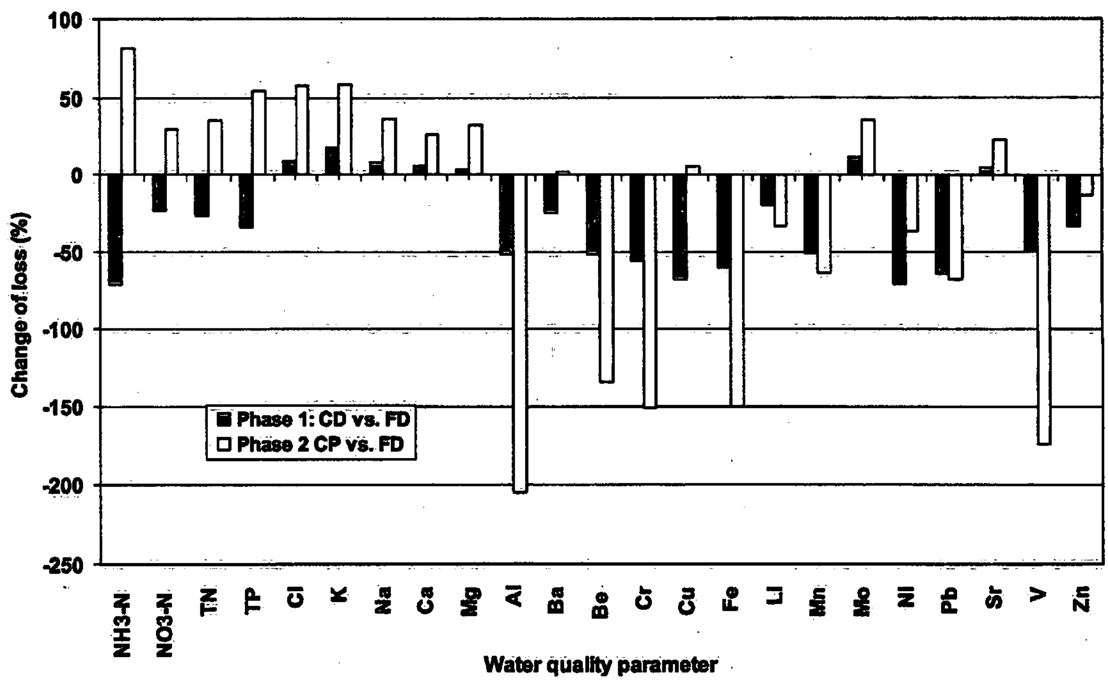


Table 2. Phase 1: Statistics of monthly precipitation and tile drainage volume

	Precipitation	Conventional tillage		No-tillage	
	(mm)	FD (L) x 10^3	CD (L) x 10^3	FD (L) x 10^3	CD (L) x 10^3
Cumulative	2466.7	8888.7	7808.3	12232.8	12458.2
Average	60.2	216.8	190.4	298.4	302.7
Maximum	198.0	1120	900.4	1200.1	1205.9
Minimum	12.5	0.0	0.0	0.0	0.0

Table 3. Phase I - Mean concentration of tile drainage water quality (mg/L) for CP and FD plots at conventional tillage and no-tillage sites

	Conventional tillage				No-tillage			
	CD (n = 31)		FD (n = 32)		CD (n =35)		FD (n = 34)	
Parameter	G.mean	Std. error	G.mean	Std. error	G.mean	Std. error	G.mean	Std. error
NH_3-N	0.022	0.004	0.026	0.004	0.013	0.001	0.024	0.005
NO_3-N	12.315	0.885	14.017	0.968	11.049	0.955	12.618	0.856
TN	11.452	0.524	13.367	0.784	10.948	1.011	13.084	0.655
TP	0.288	0.026	0.328	0.043	0.129	0.019	0.139	0.016
Cl	31.947	0.863	36.950	1.173	18.029	0.896	15.903	0.704
K	2.275	0.213	1.815	0.152	3.452	1.430	2.617	0.291
Na	4.664	0.231	5.520	0.281	6.290	0.289	5.449	0.264
Ca	67.554	2.550	82.607	3.693	76.172	3.157	67.923	2.804
Mg	17.597	0.766	22.428	1.066	20.586	0.819	19.615	0.780
Al	3.922	0.253	3.825	0.267	2.242	0.141	3.363	0.207
Ba	0.049	0.001	0.049	0.001	0.033	0.001	0.041	0.001
Be	0.209	0.012	0.199	0.011	0.121	0.006	0.181	0.010
Cr	0.005	0.000	0.005	0.000	0.003	0.000	0.005	0.000
Cu	0.068	0.005	0.053	0.002	0.047	0.007	0.073	0.003
Fe	5.129	0.323	5.143	0.379	2.898	0.181	4.591	0.277
Li	0.010	0.000	0.010	0.000	0.008	0.000	0.010	0.000
Mn	0.024	0.002	0.023	0.002	0.015	0.001	0.023	0.001
Mo	0.002	0.000	0.003	0.000	0.002	0.000	0.002	0.000
Ni	0.007	0.000	0.007	0.000	0.004	0.000	0.007	0.000
Pb	0.009	0.000	0.007	0.000	0.004	0.000	0.007	0.000
Sr	0.180	0.006	0.212	0.004	0.167	0.005	0.157	0.004
V	0.009	0.001	0.008	0.001	0.005	0.000	0.007	0.000
Zn	0.075	0.009	0.060	0.006	0.048	0.006	0.053	0.005

Note: n = number of samples, Std. = standard, G.= geometrical

Table 4. Phase 2: Statistics of monthly precipitation and tile drainage volume

	Precipitation	Conventional tillage		No-tillage	
	(mm)	FD (L) x 10^3	CD (L) x 10^3	FD (L) x 10^3	CD (L) x 10^3
Cumulative	2031.5	7060.2	9640.9	9151.3	7972.8
Average	54.9	190.8	267.8	247.33	215.5
Maximum	145.6	745.6	1030.6	1084.6	897.8
Minimum	13.0	0.0	0.0	0.0	0.0

Table 5. Phase II - Mean concentration of tile drainage water quality (mg/L) for CP and FD plots at conventional tillage and no-tillage sites

	Conventional tillage				No-tillage			
	CP (n = 26)		FD (n = 34)		CP (n = 26)		FD (n = 24)	
Parameter	G.mean	Std. error	G.mean	Std. error	G.mean	Std. error	G.mean	Std. error
NH_3-N	0.078	0.042	0.136	0.097	0.172	0.095	0.035	0.005
NO_3-N	29.425	4.368	16.651	1.845	17.717	1.922	11.239	1.246
TN	34.297	3.349	18.152	1.871	21.378	1.910	12.620	1.248
TP	0.361	0.053	0.263	0.021	0.592	0.107	0.254	0.032
Cl	62.518	1.270	33.965	0.545	55.485	2.215	20.345	1.147
K	7.546	1.023	2.423	0.385	15.711	3.757	5.308	0.799
Na	8.971	0.112	5.911	0.303	11.523	0.548	6.773	0.633
Ca	109.121	4.431	75.527	1.985	93.328	3.828	61.946	3.533
Mg	33.155	0.852	22.669	0.898	29.941	1.372	18.509	1.195
Al	1.232	0.315	4.326	1.223	1.634	0.619	4.158	0.965
Ba	0.055	0.002	0.044	0.003	0.051	0.003	0.046	0.004
Be	0.096	0.014	0.211	0.045	0.111	0.029	0.222	0.040
Cr	0.002	0.000	0.005	0.001	0.003	0.001	0.006	0.001
Cu	0.070	0.007	0.058	0.006	0.066	0.003	0.053	0.002
Fe	1.462	0.377	3.840	0.804	2.208	0.901	4.912	1.008
Li	0.007	0.000	0.010	0.002	0.009	0.001	0.010	0.001
Mn	0.010	0.002	0.020	0.004	0.021	0.006	0.032	0.007
Mo	0.005	0.000	0.004	0.000	0.005	0.000	0.003	0.000
Ni	0.007	0.001	0.006	0.001	0.006	0.001	0.008	0.001
Pb	0.003	0.001	0.006	0.001	0.005	0.001	0.007	0.001
Sr	0.314	0.010	0.208	0.007	0.262	0.010	0.186	0.017
V	0.003	0.001	0.011	0.003	0.004	0.001	0.010	0.002
Zn	0.044	0.005	0.053	0.007	0.058	0.006	0.059	0.005

Note: n = number of samples, Std. = standard, G.= geometrical

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