Environment Canada Environnement Canada

Canada

THE INFLUENCE OF CONTROLLED DRAINAGE AND FREE DRAINAGE ON AGRICULTURAL PRIMARY NUTRIENTS

AQUATIC ECOSYSTEM MANAGEMENT RESEARCH BRANCH

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

NWRI Contribution No. 02-209

NATIONAL WATER RESEARCH INSTITUTE
INSTITUT NATIONAL DE RECHERCHE SUR LES EAUX

THE INFLUENCE OF CONTROLLED DRAINAGE AND FREE DRAINAGE ON AGRICULTURAL PRIMARY NUTRIENTS

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

Aquatic Ecosystem Management Research Branch
National Water Research Institute
Burlington, Ontario L7R 4A6
Canada

NWRI Contribution Number 02-209

Abstract

The influence of controlled drainage and free drainage on agricultural primary nutrients

The effects of controlled drainage and free drainage treatments on agricultural primary nutrients NO_3-N, TP and K were investigated on sandy loam and clay loam soils located in Southwestern Ontario. The investigation was conducted over a period from May 8, 1995 to July 14, 1998. The purpose of this investigation was to compare tile drainage volume, nutrient mean concentration and nutrient loss between the controlled drainage treatment (CD) and the free drainage treatment (FD). The results of this study showed that both CD and controlled drainage combined with subirrigation (CDS) treatments produced less tile drainage volume compared with FD treatment. At the sandy loam site of Bicrel the CDS treatment produced less tile drainage volume by 5.3% compared with FD treatment, and at the clay loam sites of Chevalier and Shanahan respectively, the CD treatment produced less tile drainage volume by 12.2% and 2.9% compared with FD treatment. CD treatment and CDS treatment promoted reduction of NO_3-N mean concentration, respectively by 38.6%, 13.1% and 12.8% at the Bicrel, Chevalier and Shanahan sites over the study period. Contrary, both CD and CDS treatments promoted an increase in K mean concentration by 40.6%, 19.2% and 11.6 % respectively, at Bicrel, Chevalier and Shanahan sites compared with FD treatment. The CD and CDS treatment reduced TP mean concentration marginally at Chevalier site by 6.9% and at Shanahan site by 1.3%, whereas at the Bicrel site, the CDS treatment increased TP mean concentration by 21.9% compared with the FD treatment. Both CD and CDS treatments reduced NO_3-N and TP loss respectively, by 13.4% and 6.7% at Bicrel site, by 13.2% and 7.1% at Chevalier site and by 16.3% and 25% at Shanahan site compared with FD treatment. In contrast, both CD and CDS treatments increased K loss at Bicrel, Chevalier and Shanahan sites, respectively by 5.2%, 5.5% and 28.1% compared with FD treatment.

NWRI RESEARCH SUMMARY

Plain language title

NWRI and Agriculture and Agri-Food Canada are studying the effect of controlled drainage and subsurface irrigation on primary nutrients.

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

Nitrogen, phosphorus and potassium are essential to plant growth. Too much of a good thing can cause environmental problems. Nutrients, in particular nitrogen and phosphorus, stimulate the growth of algae, including toxic algae, in both fresh and coastal waters. Algae cause odour and taste problems in drinking water taken from lakes and reservoirs.

Why did NWRI do this study?

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

What were the results?

The researchers found that both controlled drainage and controlled drainage/ subsurface irrigation technologies uniquely reduced nitrate and phosphorus loss compared with conventional drainage. Contrary, both controlled drainage and controlled drainage/subsurface irrigation increased potassium loss, especially under no-tillage practice.

How will these results be used?
The results supported the Great Lakes Water Quality Program for nutrient management practices that help farmers protect the Great Lakes' water quality by reducing nutrient loss from agricultural areas in the Great Lakes Basin.

Who were our main partners in the study?
Agriculture and Agri-Food Canada

Résumé

Effets du drainage contrôlé et du drainage libre sur les macroéléments en agriculture

Les effets des systèmes de drainage contrôlé et de drainage libre sur l'azote sous forme de nitrates, le phosphore total et le potassium (macroéléments) dans un contexte d'agriculture ont été étudiés en sols sablo-argileux et en sols à limon argileux à des sites du sud-ouest de l'Ontario. L'étude a débuté le 8 mai 1995 et s'est terminée le 14 juillet 1998; elle avait pour but de comparer le système de drainage contrôlé (DC) et le système de drainage libre (DL) au chapitre du volume de drainage, de la concentration moyenne des éléments nutritifs et du lessivage des nutriments. Les résultats de l'étude ont montré que, dans le cas du DC comme dans celui du drainage contrôlé combiné à l'irrigation souterraine (DCIS), le volume de drainage était moins grand qu'avec le drainage libre. À la ferme Bicrel, site où le sol est sablo-argileux, le système de DCIS a produit un volume de drainage de 5,3 % inférieur à celui engendré par le système de DL. Aux sites dont le sol est de limon argileux, soit les fermes Chevalier et Shanahan, le DC a permis de réduire le volume de drainage respectivement de 12,2 % et de 2,9 % par rapport au système de drainage libre. Pendant l'étude, les systèmes de DC et de DCIS ont été à la source d'une diminution de la concentration moyenne de NO_3-N dans tous les cas : à Bicrel, diminution de 38,6 %; à Chevalier, de 13,1 %; à Shanahan, de 12,8 %. À l'inverse, si on les compare au DL, ces deux systèmes ont fait augmenter la concentration moyenne de K et ce, de 40,6 % à Bicrel, de 19,2 % à Chevalier et de 11,6 % à Shanahan. Le DC et le DCIS ont amené une légère réduction de la concentration moyenne de PT aux sites de Chevalier et de Shanahan (respectivement de 6,9 % et de 1,3 %); par contre, le DCIS a engendré, toujours par rapport au DL, une hausse de la concentration moyenne de PT égale à 21,9 % au site de la ferme Bicrel. Les systèmes de DC et de DCIS ont tous deux permis de diminuer le lessivage de NO_3-N et de PT par rapport aux résultats du drainage libre. Pour chacun de ces macroéléments, la réduction a respectivement été de 13,4 % et de 6,7 % au site Bicrel, de 13,2 % et de 7,1 % au site Chevalier, et de 16,3 % et de 25 % au site de Shanahan. En revanche, le drainage contrôlé comme le drainage contrôlé combiné à l'irrigation souterraine ont provoqué, en comparaison du drainage libre, une augmentation du lessivage du K : de 5,2 % à Bicrel, de 5,5 % à Chevalier et de 28,1 % à Shanahan.

Sommaire des recherches de l'INRE

Titre en langage clair
L'INRE et Agriculture et Agroalimentaire Canada étudient les effets du drainage contrôlé et de l'irrigation souterraine sur les macroéléments.

Quel est le problème et que savent les chercheurs à ce sujet?
L'azote, le phosphore et le potassium sont essentiels à la croissance des plantes. Mais abuser de ces bonnes choses peut causer des problèmes environnementaux. Les éléments nutritifs, en particulier l'azote et le phosphore, stimulent la prolifération des algues, dont certaines sont toxiques, dans les eaux douces et côtières. Ces plantes aquatiques peuvent altérer le goût et l'odeur de l'eau potable tirée des lacs et des réservoirs.

Pourquoi l'INRE a-t-il effectué cette étude?
Déterminer quelles sont les pratiques de gestion optimales pour réduire les incidences néfastes sur les eaux réceptrices.

Quels sont les résultats?
Les chercheurs ont constaté que les techniques de drainage contrôlé et de drainage contrôlé combiné à l'irrigation souterraine réduisaient d'une manière incomparable le lessivage des nitrates et du phosphore par rapport aux systèmes conventionnels de drainage. Par contre, ces deux techniques accroissaient le lessivage du potassium, surtout dans le cas des cultures sans travail du sol.

Comment ces résultats seront-ils utilisés?
Les résultats appuient le Programme concernant la qualité de l'eau dans les Grands Lacs puisqu'ils proposent des pratiques de gestion des éléments nutritifs qui aident les agriculteurs à protéger la qualité de l'eau dans les Grands Lacs en réduisant le lessivage des nutriments dans les régions agricoles du bassin des Grands Lacs.

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

The influence of controlled drainage and free drainage on agricultural primary nutrients

INTRODUCTION

Primary nutrients are chemical elements such as nitrogen, phosphorus, and potassium that are needed by plants for growth and yields. Agriculture and urban activities are major sources of P and N to the aquatic ecosystems. Atmospheric deposition further contributes as a source of N (Carpenter, et al., 1998; Ng and Rudra, 2001). Agricultural primary nutrients, specifically P and N have been a concern in past years because of increased use of commercial fertilizers and feed lot manure which have been reported to promote environmental degradation, including eutrophication problems in fresh waters (Carpenter, et al., 1998; Withers, et al., 2000; DeWit et al., 2002). Nutrient control and management plans are needed to protect aquatic life in different water bodies (Environment Canada, 2001) and maintain good water quality for human consumption. In Canada, the federal government instituted the Canadian Environmental Protection Act (CEPA) to regulate nutrients that can cause excessive growth of aquatic plants such as algae and aquatic weeds. In Ontario, the Ontario Government introduced the Nutrient Management Act in June of 2001. The proposed act is intended to provide new standards for all land-applied materials containing nutrients relating to agriculture. There are practical, affordable approaches for improvement of nutrient control to enhance farm soil and nutrient loss (Ontario Ministry of Agriculture, Food and Rural Affairs, 1994); make use of wetland (Sakadevan and Bavor, 1999) for purification, phosphorous recycling, water table control, and so on. Among the approaches, water table control or controlled drainage is an emerging approach for control of nutrient loss. Studies have shown that controlled drainage can produce a significant reduction of nitrate nitrogen concentration in agricultural tile water (Drury et al., 1996; Tan et al., 1998). To facilitate the evaluation of the controlled drainage technology, an on-farm study was conducted for assessing the concentration and loss of the primary nutrients. Three field sites, 4 ha in size and located in Southwestern Ontario, were selected to serve for data acquisition. Two of the field sites, Chevalier and Shanahan, consisted of Brookston clay loam soil, and were each subdivided into two plots. One of the plots was installed with a controlled drainage system and the other without a controlled drainage device. The third field site, Bicrel, consisted of Colwood fine sandy loam soil and was subdivided into two plots. One plot was installed with a controlled drainage-subirrigation system and the other with a free drainage device. Conventional tillage, no-tillage and mould board plough systems associated with crop rotations were incorporated into this study. The study spanned a period from May 8, 1995 to July 14, 1998.

The objective of this study was to compare tile drainage volume, nutrient mean concentration and loss between controlled drainage and free drainage treatments on the clay loam soils and sandy loam soils over a consecutive period of four cropping cycles.

MATERIALS AND METHODS

Study sites. Three field sites (Bicrel farm: 42° 18' 08" N, 82° 29' 56" W; Chevalier farm 42° 12' 15" N, 82° 44' 50"), Shanahan farm 42° 12' 15" N, 82° 45' 58" W) approximately 4 ha each were established in cooperation with the farmers in Southwestern Ontario. Each field was subdivided into 2-ha plots. Controlled drainage (CD) and free drainage (FD) systems were installed at Chevalier and Shanahan farms, and a CD combined with subsurface irrigation device (CDS) and a FD system were installed at Bicrel farm. The tillage on Shanahan was no-tillage (NT) practice, whereas Bicrel and Chevalier farms were under conventional tillage (CT) during the study period. Each field plot at Chevalier and Shanahan contained 5 subsurface tiles with an average spacing of 8.7 m. Each plot at Bicrel contained 10 subsurface tiles at 6 m spacing. The average depth of tile was 0.6 m below soil surface standard for all plots. The lengths of tiles104 mm in diameter were 538 m, 450 m and 284 m long, respectively, for Shanahan, Chevalier and Bicrel and the tiles were installed at an average gradient of 0.05%.

Sampling methods and measurements. A calibrated tipping bucket measured the tile discharge volume from CD, CDS and FD systems. The number of bucket tippings was counted and stored onto a data logger. The ISCO model 2900 automatic samplers collected tile drainage samples. Each sampler contained 24-sample bottles of 500 ml each. The automatic sampler was activated by a signal from the preset numbers of the bucket tips or flow volume. When the flow volume from a plot matched the designated volume, the automatic sampler was activated and a sample was collected. Thus, the collection frequency of a sample was based on the pre-set volume. Throughout the study period, the pre-set flow volume for both CDS and FD at the Bicrel site was 12259 L and the pre-set volume for CD and FD at the Chevalier site was 10000 L. At the Shanahan site the pre-set volume for CD and FD was 10000 L from May 8, 1995 to December 16, 1996, and changed to 24490 L from January 6, 1997 to July 14, 1998. The water samples were collected sequentially up to 24 samples over a period of time. 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. Once picked up, the water samples were transferred to glass bottles and kept at 4°C until laboratory analysis began.

Soil samples were collected using a hand held auger of 2.5 cm diameter from each of the field sites for analysis of soil textures. The sampling point was taken at ratio of 0.13, 0.25, 0.5 and 0.88 to the total length (m) referenced from one side to the other side of the plot, running from east toward west direction across the central point of the plot. Soil samples were taken at a depth between 0-30 cm and 30-60 cm.

Precipitation data for Chevalier and Shanahan sites were collected using a weather station located 0.5 km away whereas precipitation data for the Bicrel site were obtained using an on-site weather station.

Analytical method. All water samples were unfiltered. To reduce the analytical cost, several sequential samples collected from a given sampler were combined into one sample for analysis of nutrient compositions. Cadmium Reduction Method and Colorimetric Method respectively were used for analysis of the nitrate nitrogen (NO_3 -N) and the total phosphorus (TP). Flame Emission Photometric Method and Atomic Absorption Method, respectively were used for analysis of potassium (K) for 1995/96 samples and for 1997/98 samples. The analytical procedures can be found in the Manual of Analytical Methods (The National Laboratory for Environmental Testing, 1994).

Tillage, agronomy, fertilization and weed control.

Tillage. The tillage and cropping on Bicrel, Chevalier and Shanahan sites were reported elsewhere (Ng et al., 2000; Tan et al., 2001). For convenience, they are repeated here. The no-tillage practice was implemented on Shanahan farm, whereas the conventional tillage was used on both Bicrel and Chevalier farms.

Agronomy. Soybeans were seeded at a rate of 580,000 seed ha^{-1} in 38 cm wide rows between second and third weeks of May on Chevalier and Shanahan farms in 1995, 1996 and 1998. Corn was seeded at a rate of 72,000 seed ha^{-1} in 76.2 cm rows in late May and early June in 1997 at both farms.

At Bicrel farm, tomatoes were planted in 1995 at a population of 31,000-plant ha^{-1} in twin rows. The spacing between twin rows was 30.5 cm, with 30.5 cm between plants and the spacing between rows was 183 cm. Corn was seeded at a rate of 74,000 seeds ha^{-1} in 76.2 cm wide rows in 1996. Green snap beans were planted in 1997 at 600,000 seed ha^{-1}, and soybeans were seeded at 137 kg seed ha^{-1} on May 26, 1998.

Fertilization. At the Chevalier site, fertilizer (0-18-36) was broadcast at a rate of 224 kg ha^{-1} during the fall of 1994 and1995. In 1997, 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 Shanahan 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 1997, fertilizer (18-12-18) was banded during planting at a rate of 207 kg ha^{-1} and aqua ammonia (157kg N ha^{-1}) was injected at mid-row position (6-7 cm depth) at the four-leaf stage.

At the Bicrel farm in 1995, fertilizer (78 kg N ha^{-1}, 117 kg P_2O_2 ha^{-1} and 403 kg K_2O ha^{-1}) was applied pre-planted to tomatoes and side-dress N was applied on June 20 at 56 kg N ha^{-1}. In 1996, fertilizer was applied pre-plant to corn (12.5 kg N ha^{-1}, 58 kg P_2O_2 and 202 kg K_2O ha^{-1}), and anhydrous ammonia was added as side-dress on June 26 at 202 kg N ha^{-1}. In 1997, fertilizer (56 kg N ha^{-1}, 112 kg P_2O_2 ha^{-1} and 112 kg K_2O ha^{-1}) was applied for green snap beans during planting on June 9. In 1998, fertilizers (ammonium nitrate (32% N), 112 kg ha^{-1}, mixed fertilizers (11-46-0), 112 kg ha^{-1} (12.3 kg N ha^{-1} and 51.5 kg P_2O_2 ha^{-1}) were broadcast on May 24.

Weed control. In 1995, 1996 and 1998, weeds were controlled at both Chevalier and Shanahan farms 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 in both years of 1995 and 1996. 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 1997, weeds were controlled at the Chevalier 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 Shanahan site by pre-emergence application of metolachlor (2.16 kg a.i.ha^{-1}) and when required, glyphosate (0.84 kg a. i. ha^{-1}) was applied.

At the Bicrel farm, metolachlor (2.64 kg a. i. ha^{-1}) and metribuzin (0.3 kg a. i. ha^{-1}) were applied on June 1, 1995 for weed control in tomato. Marksman (1.5 kg a. i. ha^{-1}) of dicamba / atrazine at 1:2 ratio was applied on June 15, 1996 to provide control of weeds in corn. In 1997, pesticide DUAL (1.73 L ha^{-1}), weed killer BASAGRAM (low rate) and insecticide LARGON (low rate) were all applied on June 9 to control weeds and leaf hopper on green snap beans. In 1998, ROUNDUP (5.0 L ha^{-1}) was applied on May 13, DUAL (2.25 L ha^{-1}) and Sencor (1 L ha^{-1}) were both applied on May 25 at the Bicrel farm for weed control in soybeans.

RESULTS AND DISCUSSION

Soil textures. The analytical results of soil textures between 0 and 30 cm depths and 30 to 60 cm for the field sites are summarized in Table 1.

Table 1. Soil type of the field sites.

	0-30 cm						30-60 cm					
Soil	Bicrel		Chevalier		Shanahan		Bicrel		Chevalier		Shanahan	
Type	CDS	FD	CD	FD	CD	FD	CDS	FD	CD	FD	CD	FD
Sand (%)	59.9	60.5	40.7	35.1	31.7	28.0	61.3	64.1	35.4	31.4	25.8	27.1
Silt (%)	18.2	16.9	27.3	31.0	31.2	31.7	18.3	15.3	28.5	31.0	31.8	30.5
Clay (%)	21.9	22.6	32.0	33.9	38.1	40.4	20.4	20.6	36.2	37.6	42.5	42.4

As seen from Table 1, the soil type for Bicrel site can be characterized as a sandy loam and both Chevalier and Shanahan sites are characterized as clay loam soils.

Precipitation. Precipitation is the main factor for determination of the tile drainage volume as well as the nutrient loss at the farm. The total precipitation received at Bicrel site was 2086.2 mm, 10.2% less than the 2299.7 mm received by each of the Chevalier and Shanahan sites during the study period, from May 8 1995 to July 14 1998 (Figure 1). It should be noted that starting from July 8 to September 6, 1996, the Bicrel site received additional 184 mm of subsurface irrigation water in addition to the precipitation bringing the total sum to 2270.2 mm. Thus, the moisture supplies to the three field sites were almost equal.

Tile Drainage Volume. The total tile drainage volume for CD, CDS and FD from the three sites are summarized in Table 2. Included in Table 2 is the ratio between free drainage and the controlled drainage. The ratio shown in Table 2 was unique in that all values were greater than 1, indicating that free drainage treatment produced greater tile drainage volume than the controlled drainage. Over the study period, the free drainage treatment produced larger tile drainage volume by 5.6%, 13.8% and 2.9% respectively, at Bicrel, Chevalier and Shanahan sites compared with the controlled drainage treatment. The tile drainage volumes for controlled drainage treatment and free drainage treatment were evident throughout the entire study period (Figure 1).

Table 2. Tile drainage volume for controlled drainage and free drainage systems

	Tile drainage volume (KL)			
	CDS	CD	FD	Ratio (FD/CDS; FD/CD)
Bicrel	9690		10230	1.056
Chevalier		7807.9	8887.8	1.138
Shanahan		12396.9	12764.0	1.030

Nutrient mean concentration. The analytical results were reduced to mean concentrations for each of the pick-up periods using an arithmetic method. The arithmetic mean concentration of NO_3-N, TP and K for Bicrel, Chevalier and Shanahan sites respectively, were plotted in Figures 2, 3 and 4. The arithmetic mean concentration of NO_3-N, TP and K in tile drainage water for the three study sites are summarized in Table 3. Included in Table 3, are the maximum and minimum concentrations.

Table 3. Maximum, minimum and mean concentration of NO_3-N, TP and K.

Period May 8 1995 to July 14 1998						
	Bicrel		Chevalier		Shanahan	
Concentration	CDS	FD	CD	FD	CD	FD
Max. NO_3-N (mg/L)	15.900	25.600	24.400	24.898	35.100	21.900
Min. NO_3-N (mg/L)	0.100	0.140	3.530	6.060	2.040	4.720
Mean NO_3-N (mg/L)	6.008	9.782	11.600	13.351	10.719	12.295
Max. TP (mg/L)	0.577	0.441	0.645	1.430	0.334	0.638
Min. TP (mg/L)	0.003	0.003	0.033	0.011	0.020	0.071
Mean TP (mg/L)	0.178	0.146	0.283	0.304	0.152	0.154
Max. K (mg/L)	11.000	5.500	5.470	4.300	3.820	5.130
Min. K (mg/L)	0.720	0.250	0.600	0.560	0.930	0.640
Mean K (mg/L)	1.934	1.376	2.258	1.894	2.154	1.930

The NO_3-N, TP and K mean concentration in tile drainage water (Table 3) were used to compare the effects between controlled drainage and free drainage treatments in terms of percentage increase or reduction of mean concentration of the studied nutrients. An expression of (CDS-FD/FD) x100% was used for the Bicrel site and the (CD-FD/FD) x100% was used for the Chevalier and Shanahan sites. The results are presented in Table 4. The positive or negative sign shown beside the value in Table 4 indicates an increase or a reduction in mean concentration.

Table 4. Comparison of NO_3-N, TP and K mean concentration between controlled drainage and free drainage.

Study period from May 8,1995 to July 14, 1998			
	Bicrel (CDS-FD/FD) x100	Chevalier (CD-FD/FD) x100	Shanahan (CD-FD/FD) x100
NO_3-N	- 38.6%	-13.1%	-12.8%
TP	+ 21.9%	- 6.9%	- 1.3%
K	+ 40.6%	+19.2%	+ 11.6%

A significant contrast emerged in Table 4. The CD and CDS treatments reduced NO_3-N mean concentration in tile drainage water on all three-study sites. The same results were observed by Drury et al. (1996). The reduction of NO_3 -N mean concentration ranged from 12.8% at Shanahan farm to 38.6% at Bicrel farm implying that controlled drainage managed adequate soil moisture and promoted NO_3-N uptake by plant. As long as a plant is taking up water, NO_3-N will move to the roots since it is very soluble in water. In contrast, the controlled drainage increased K mean concentration on all three sites suggesting that soils generally have large reserves of K. Many clay loam soils contain an abundance of K. Sandy soils are low in K and K does not absorb to sandy soil tightly enough to resist removal by leaching. K ion is also very soluble. Under favourable moisture supply to the soils by controlled drainage, these reserves together with input from fertilizer application enhanced K cation exchange and leaching (Ministry of Agriculture and Food, 1990).

From Table 4, the controlled drainage treatment also increased the P mean concentration at the Bicrel site by almost 22% compared with free drainage treatment suggesting that P is not held by sandy soil particles for uptake by plant. Thus excessive P is lost from soil in soluble form through larger pore space of sandy soil. Contrary, controlled drainage reduced P mean concentration by about 7% at the Chevalier site and barely reduced P by 1% at the Shanahan site implying that P is strongly attached to clay soil particles. Only a small amount remains in soil solution. Much of the P remains in a reserve form and is released into solution to replenish what has been removed by plants (Ontairo Ministry of Agriculture, Food and Rural Affairs, 1994).

Nutrient loss and percentage of loss between controlled drainage and free drainage. The losses of NO_3-N, TP and K were calculated as a product of mean concentration and the tile drainage volume. The cumulative losses of NO_3-N, TP and K over the study period were depicted in Figures 5, 6 and 7. The ratio of loss between controlled drainage and free drainage for each nutrient was presented in Figure 8 and summarized in Table 5.

Table 5. NO_3-N, TP and K loss between controlled drainage and free drainage treatments.

Study period from May 8, 1995 to July 14, 1998									
	Bicrel		Increase or reduction	Chevalier		Increase or reduction	Shanahan		Increase or reduction
Loss	CDS	FD	(%)	CD	FD	(%)	CD	FD	(%)
NO_3-N (kg ha^{-1})	49.2	56.8	-13.4	46.8	53.9	-13.2	50.9	60.8	-16.3
TP (kg ha^{-1})	1.4	1.5	-6.7	1.3	1.4	-7.1	0.6	0.8	-25.0
K (kg ha^{-1})	10.1	9.6	+5.2	9.6	9.1	+5.5	15.5	12.1	+28.1

Note: minus sign indicated reduction and plus sign indicated increase.

Over the study period, the controlled drainage reduced NO_3-N and TP loss in tile drainage water at all three sites compared with free drainage treatment (Table 5). The controlled drainage reduced NO_3-N with losses ranging from 13.2% at Chevalier site to 16.3% at Shanahan site. Similarly, controlled drainage also reduced TP loss in tile drainage water by 6.7%, 7.1% and 25% respectively at Bicrel, Chevalier and Shanahan sites compared with free drainage treatment. The reduction of NO_3-N and TP loss in tile drainage water suggested that controlled drainage promoted uptake of NO_3-N and P by plants. In contrast, controlled drainage increased K loss in tile drainage water at all three sites compared with free drainage treatment (Table 5). This suggests that K is abundant in soil reserves and K ion is very soluble in water and can leach since controlled drainage improved soil moisture content.

SUMMARY

Tile drainage volume. The controlled drainage treatment produced less tile drainage volume at Bicrel site by 5.3%, at Chevalier site by 12.2% and at Shanahan site by 2.9% compared with the free drainage treatment for the study period from May 8, 1995 to July 14, 1998. This indicated that controlled drainage treatment was unique in retaining water in the soil zone. The magnitude of tile drainage volumes produced by either controlled drainage or by free drainage treatment depends on the precipitation characteristics.

Mean concentration. Controlled drainage treatment reduced NO_3 -N mean concentration significantly compared with the free drainage treatment (Figure 9). The highest reduction of mean concentration, 38.6% occurred at the sandy loam site of Bicrel. On the clay loam sites, the reduction of mean concentration was almost equal, 13.1% at Chevalier and 12.8% at Shanahan site, regardless of fertilizer input rates. Controlled drainage treatment reduced TP mean concentration slightly when compared to free drainage treatment. At Chevalier the reduction was 7% and at Shanahan 1% compared to with free drainage treatment. At the Bicrel site, controlled drainage with subirrigation treatment increased TP mean concentration by 21.9% compared with free drainage treatment, suggesting that P is not being strongly attached to sand particles and is removed from soil solution quickly. Controlled drainage treatment increased K mean concentration substantially at all three sites. The mean concentration of K increased by 40.6% at Bicrel site, 19.2% at Chevalier site and 11.6% at Shanahan site compared with free drainage treatment.

Nutrient loss. A unique result revealed through this study was that the controlled drainage treatment reduced both NO_3-N and TP loss (Figure 10). The NO_3-N loss at both Bicrel and Chevalier sites were similar, 13.4% at Bicrel site and 13.2% at Chevalier site and a slightly higher at Shanahan site by 16.3% compared with the free drainage treatment. Similarly, controlled drainage treatment reduced TP loss at Bicrel site by 6.7% and 7.1% at Chevalier site and much higher by 25% at Shanahan site compared with free drainage treatment. Contrary, controlled drainage increased K loss in small percentage for both Bicrel (5.2%) and Chevalier (5.5%) sites except at Shanahan site by 28% compared with free drainage treatment. The high percentage reduction of NO_3 -N and TP loss and the high percentage increase in K loss under controlled drainage treatment at the Shanahan site would have been the result of no-tillage practices. No-tillage practices increased tile drainage volume (Tan, et al. 2001) since the nutrient loss is the result of nutrient concentration and tile drainage volume.

ACKNOWLEDGMENTS

The funding of this study has been supported by the Great Lakes Water Quality Program, the Canada-Ontario Agriculture Green Plan Program and the Agriculture and Agri-Food Canada Matching Investment Initiative. Thanks for technical assistance are also extended to Mr. K. Rinas, Dr. T. Oloya, Ms. J. St. Denis, E. Smith, R. Roswel and Miss. Jennifer Sifton. The weather data at the Chevalier and Shanahan sites were provided by Mr. P. Hermans, Essex Regional Conservation Authority. The cooperation of producers, Mr. Chevalier, Mr. Shanahan and Mr. Bicrel, is gratefully acknowledged.

REFERENCES

DeWit, M., H. Behrendt, G. Bendoricchio, W. Bleuten, P. van Gaans. 2002. The contribution of agriculture to nutrient pollution in three European rivers, worth reference to European nitrates directive. European Water Management Online, Official Publication of the European Water Association (EWA 2002).

Carpenter, S. R., N.F. Caraco, D.L. Correll, R.W. Howarth, A.N. Sharpley, and V.H. Smith. 1998. Nonpoint pollution of surface waters with phosphorus and nitrogen. Ecological Application. 8(3). pp 559-568.

Drury, C.F., C.S. Tan, J.D. Gaynor, T.O. Oloya, and T.W. Welacky, 1996. Influence of controlled-subirrigation on surface and tile drainage nitrate loss. J. Environ. Qual. 25:317-324.

Environment Canada. 2001. Threat to sources of drinking water and aquatic ecosystem health in Canada. National Water Research Institute, Burlington, Ontario. NWRI Scientific Assessment Report Series No. 1, 72 p.

National Laboratory for Environmental Testing. 1994. Manual of Analytical Methods.

Ng, H.Y.F., C.S. Tan, C.F. Drury, J.D. Gaynor. 2000. Perspective of controlled drainage and subsurface irrigation technologies for agricultural water management: A Case Study. In Proceedings of Agri-Food 2000 Conference, July 15-19, Winnipeg, Manitoba. AFL21. p. 221. NWRI Contribution # 00-014.

Ng, H.Y.F. and R. P. Rudra. 2001. Baseline of nitrate nitrogen in tile drainage water from field plots. Paper presented at the 2001 ASAE Annual International Conference - July 30-August 1, Sacramento, California, USA. NWRI Contribution # 01-210.

Ontario Ministry of Agriculture and Food. 1990. An introduction to soil fertility. AGDEX 530. January.

Ontario Ministry of Agriculture, Food and Rural Affairs.1994. Nutrient Management. ISBN 0-7778-2684-4. 69 pp.

Sakadevan, K. Bavor, H. J. 1999. Nutrient removal mechanisms in constructed wetlands and sustainable water management. Wat. Sci. Tech. Vol 40, No. 2. pp 121-128.

Tan, C.S., Drury, C.F., Soultani, M., van Wesenbeeck, I.J., Ng, H.Y.F., Gaynor, J.D. and Welacky, T.W. 1998. Effect of controlled drainage and tillage on soil structure and tile drainage nitrate loss at the field scale. Wat. Sci. Tech. Vol. 38, No. 4-5, pp 103-110.

Tan, C.S., C.F. Drury, W.D. Reynolds, J.D. Gaynor , T. Q. ZHANG and H.Y.F. Ng. 2001. Effect of long-term conventional tillage and no-tillage systems on soil and water quality at the field scale. Proceeding of IWA 2nd World Water Congress - October 15-19, 2001 conference on Efficient Water Management Making It Happen. Berlin, Germany. Available in CD-ROM.

Withers, Paul J.A., I.A. Davidson, and R.H. Foy. 2000. Prospects for controlling nonpoint phosphorous loss to water: A UK. Perspective. J. Environ. Qual. 29:167-175. pp 167-175.

List of Figures.

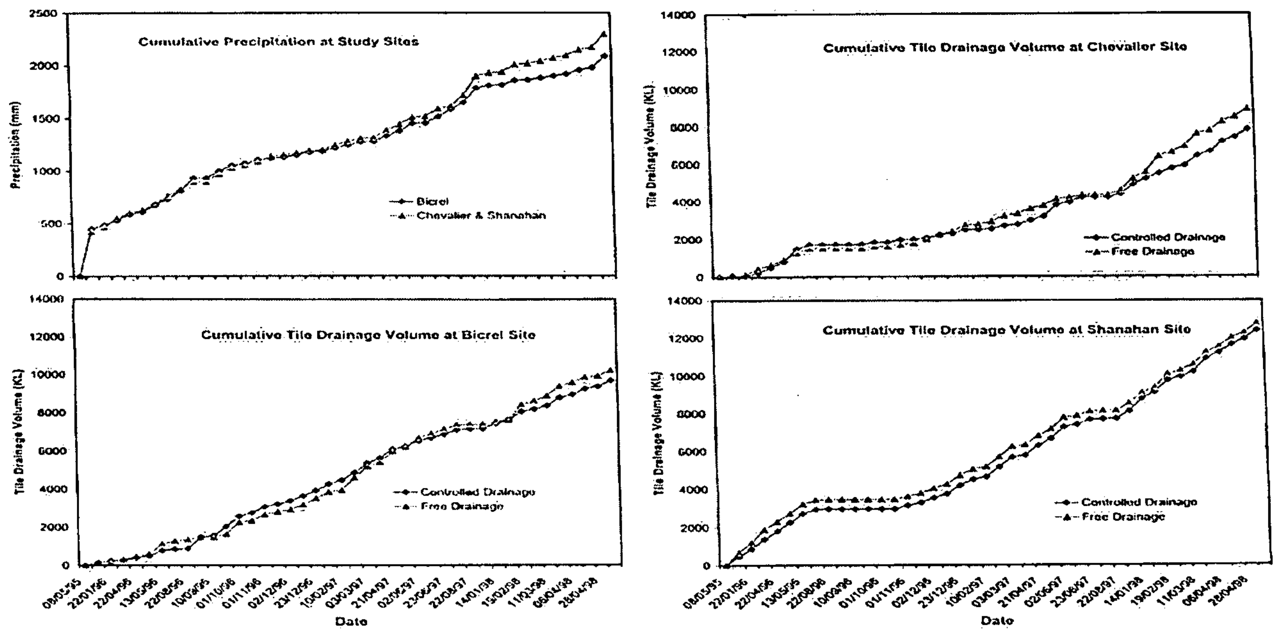


Figure 1. Precipitation and tile drainage volumes at Bicrel, Chevalier and Shanahan sites.

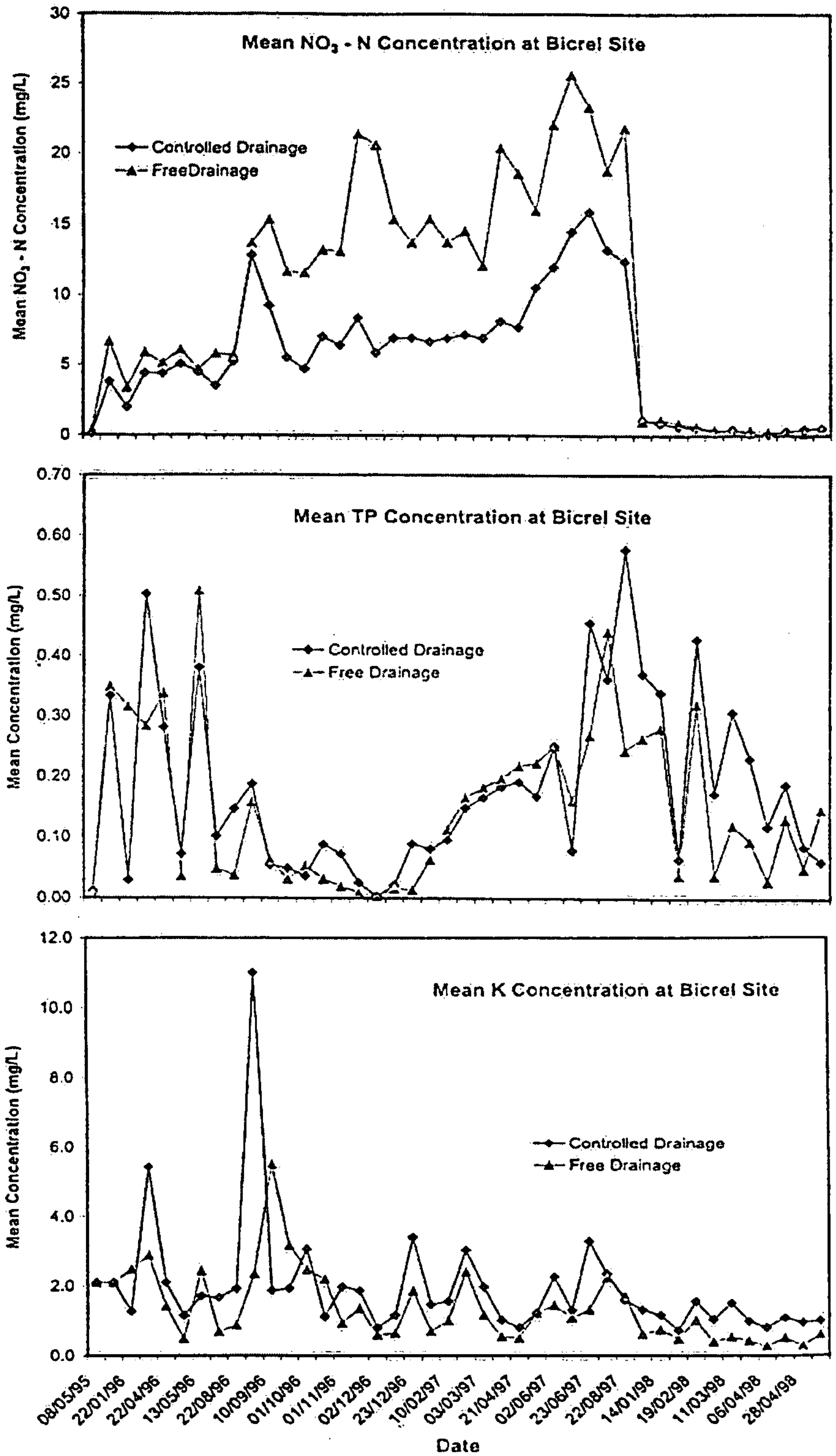


Figure 2. Mean concentration of NO_3-N, TP and K at Bicrel site.

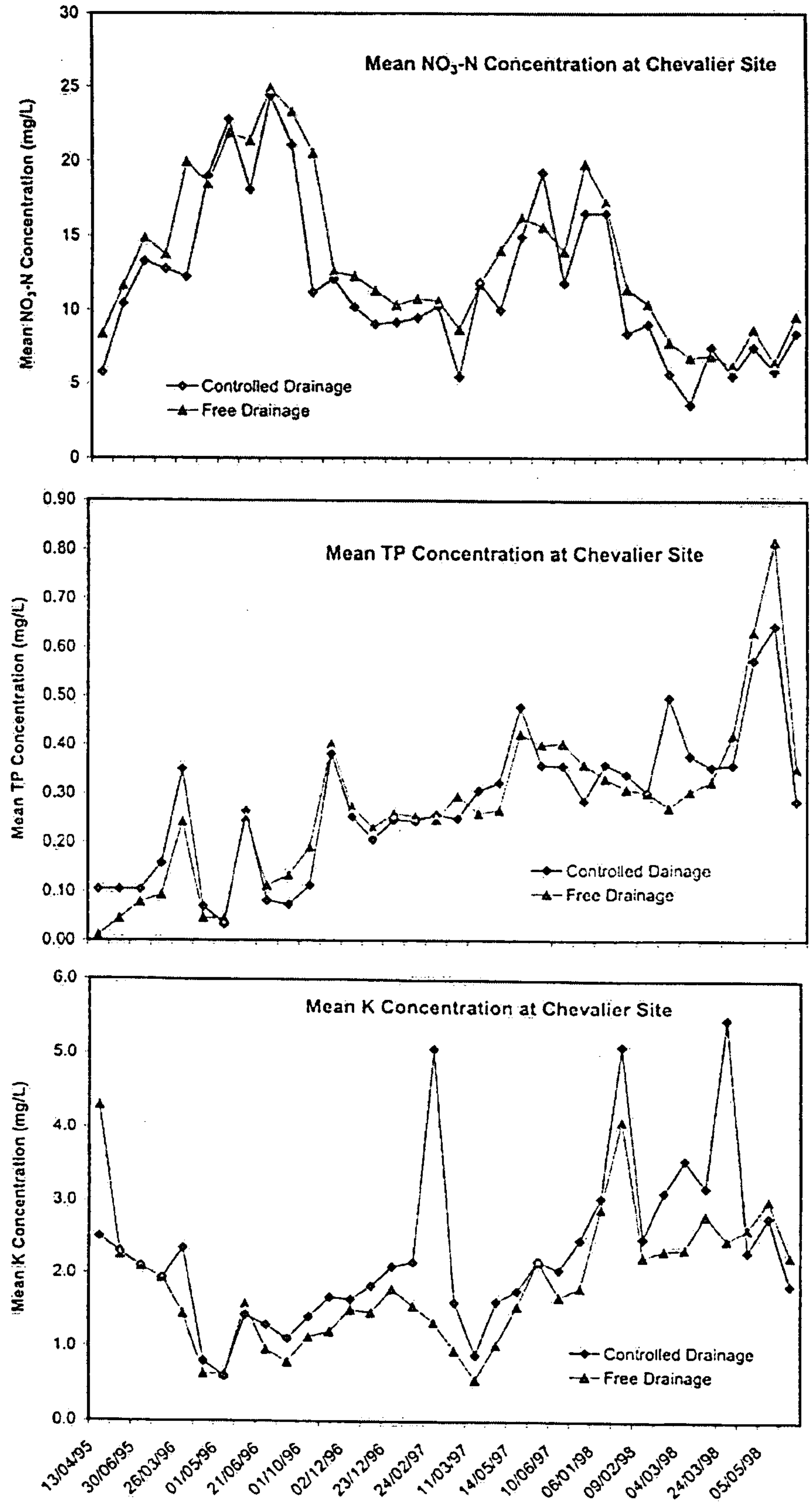


Figure 3. Mean concentration of NO_3-N, TP and K at Chevalier site.

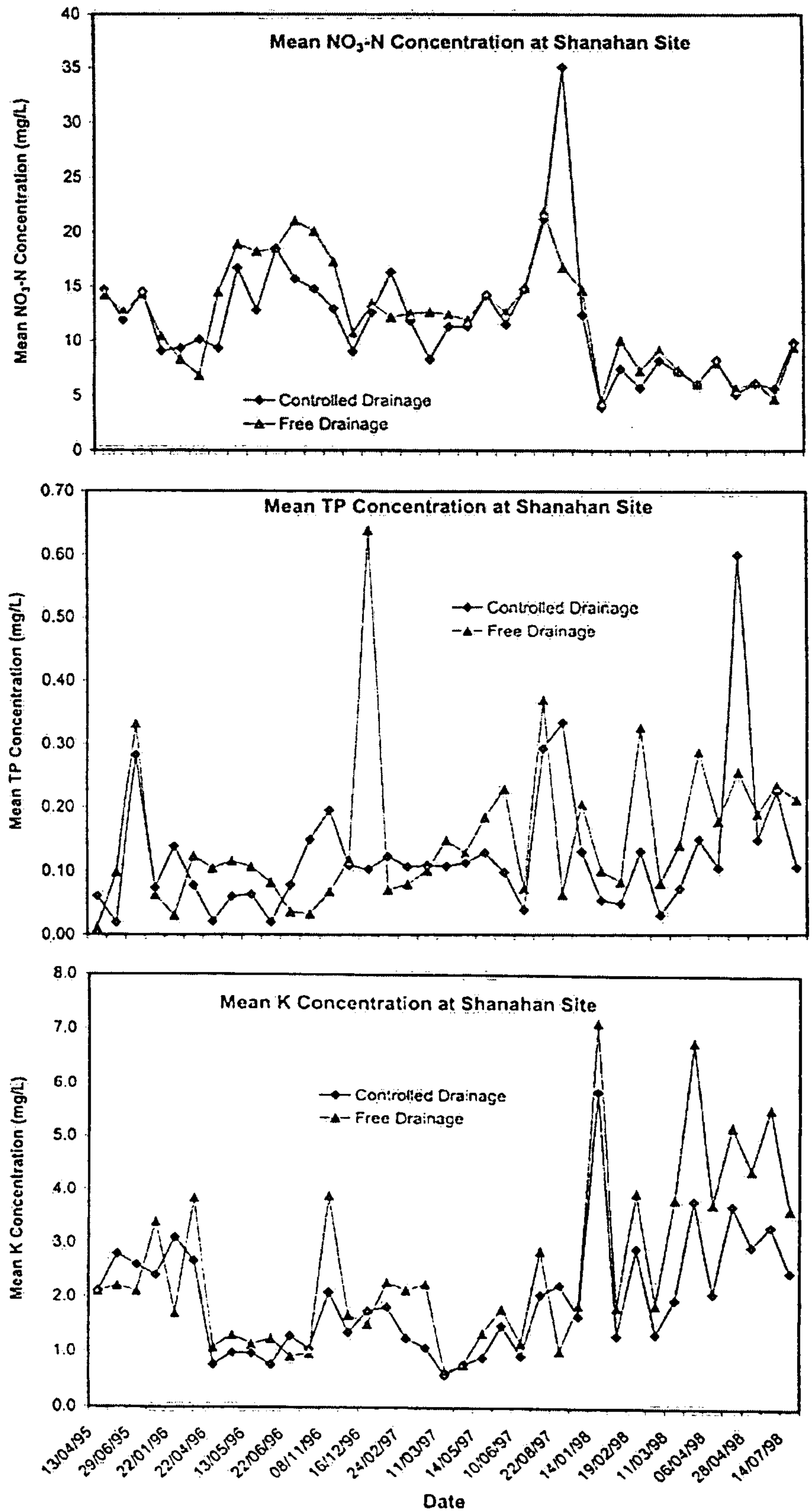


Figure 4. Mean concentration of NO_3-N, TP and K at Shanahan site.

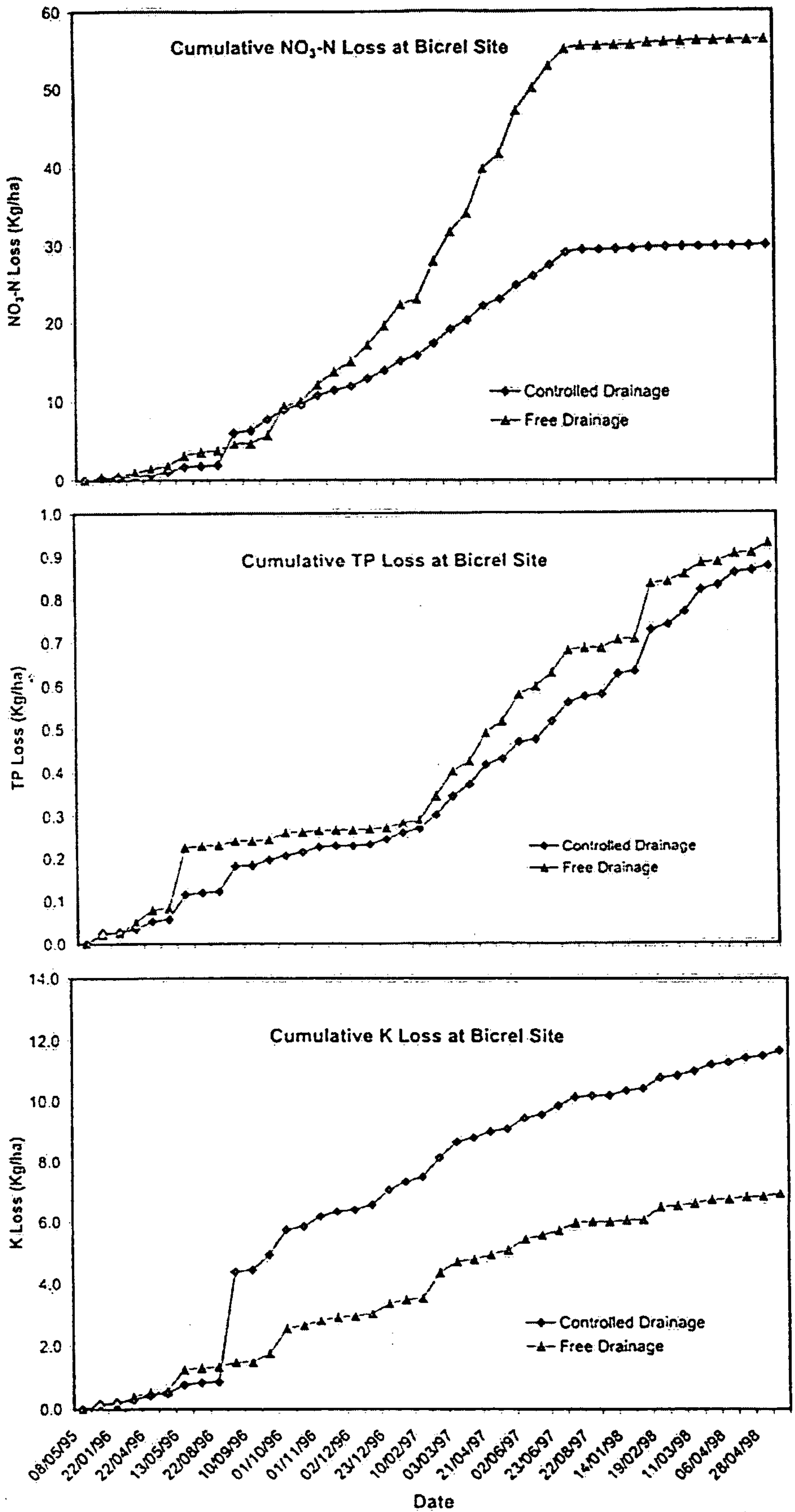


Figure 5. Cumulative loss of NO_3-N, TP and K at Bicrel site.

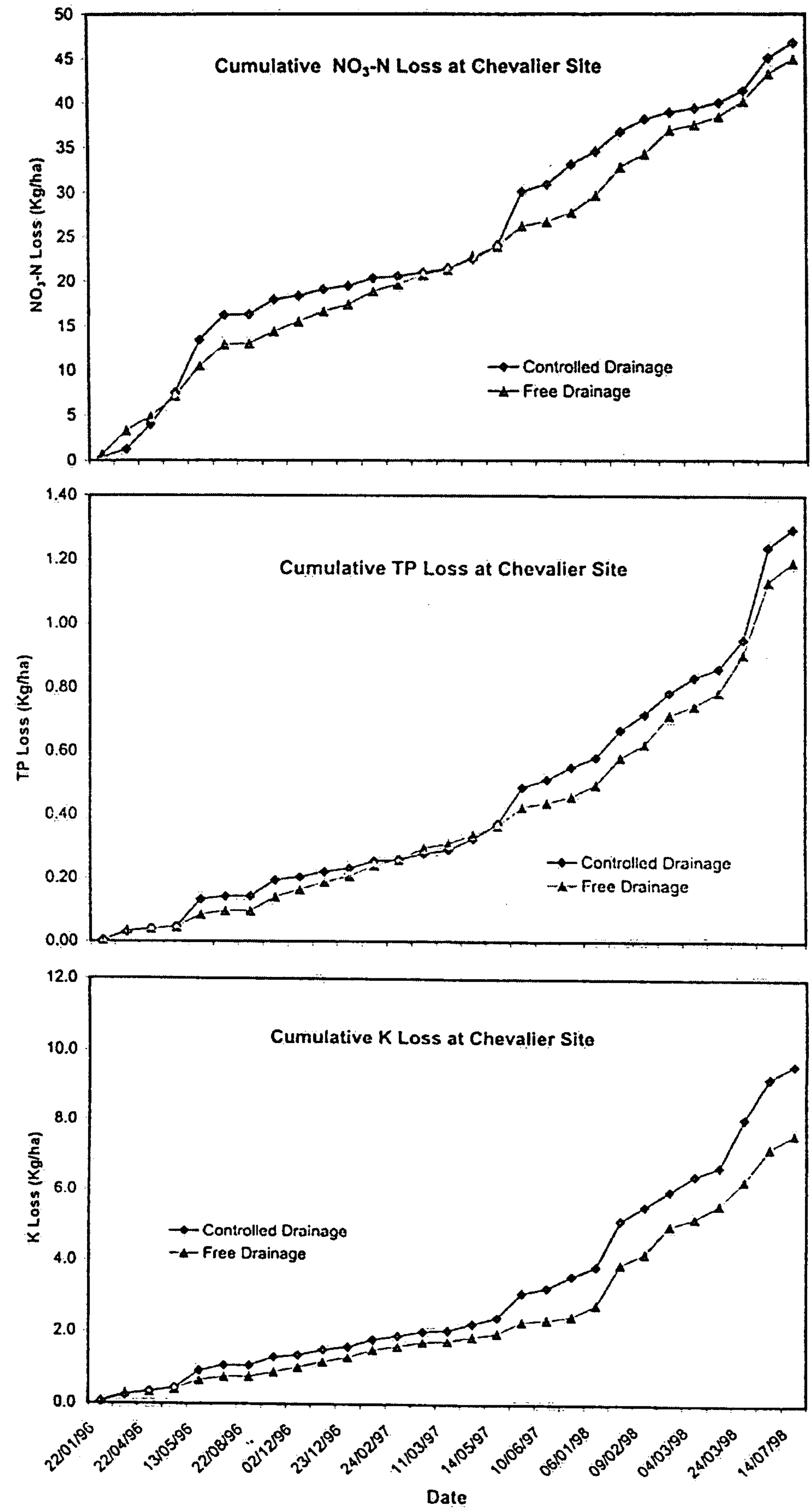


Figure 6. Cumulative loss of NO_3-N, TP and K at Chevalier site.

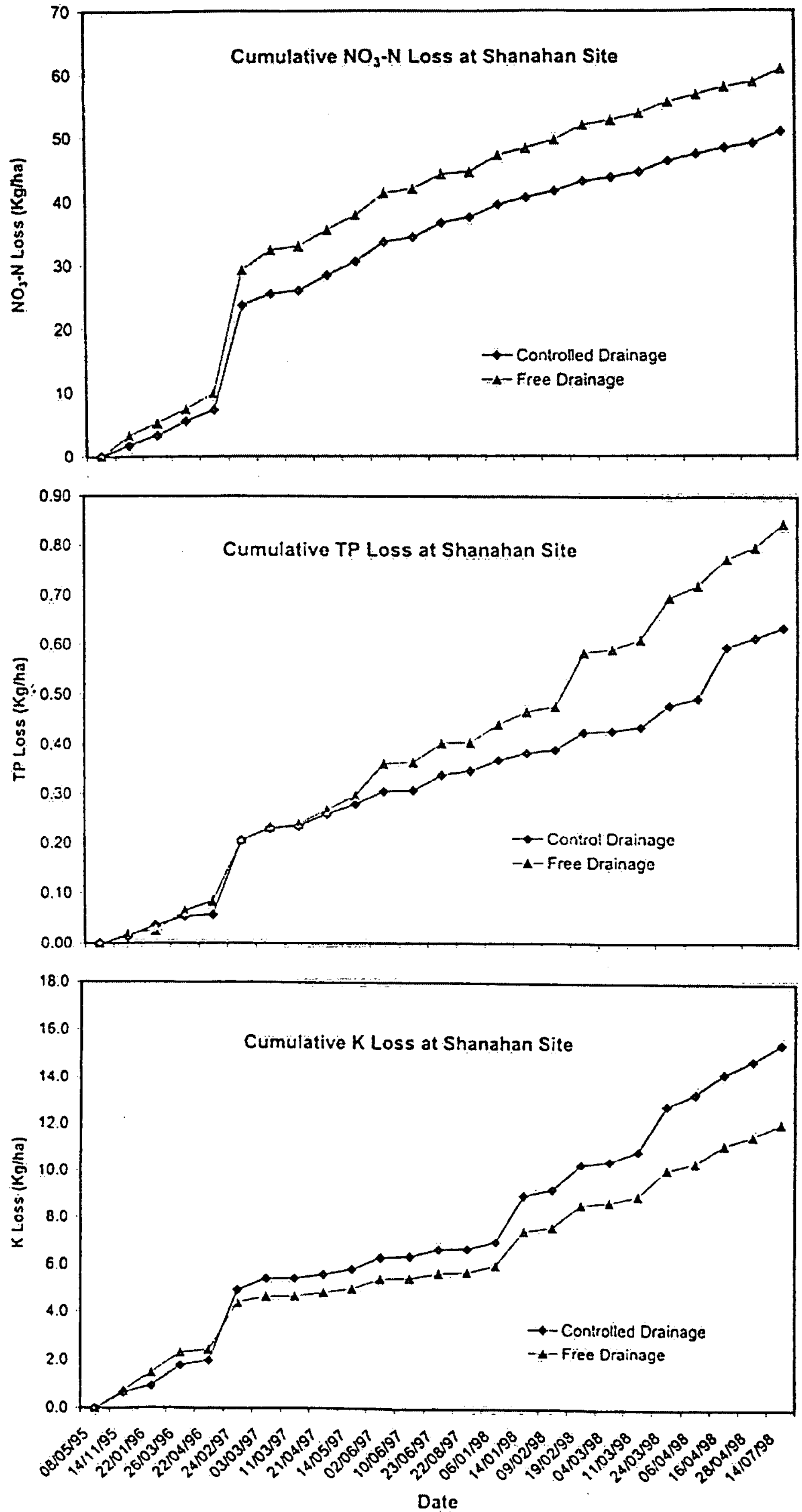


Figure 7. Cumulative loss of NO_3-N, TP and K at Shanahan site.

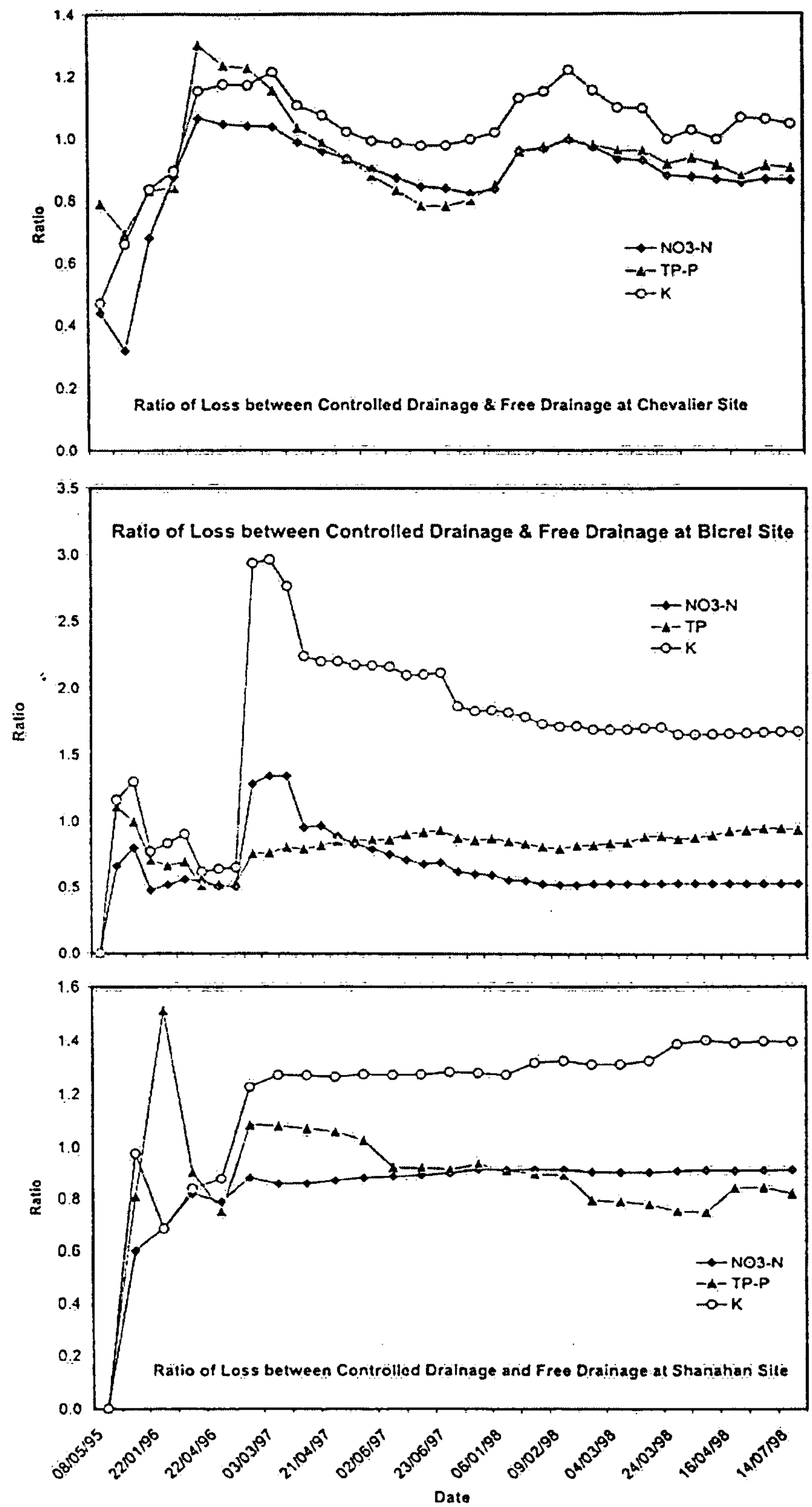
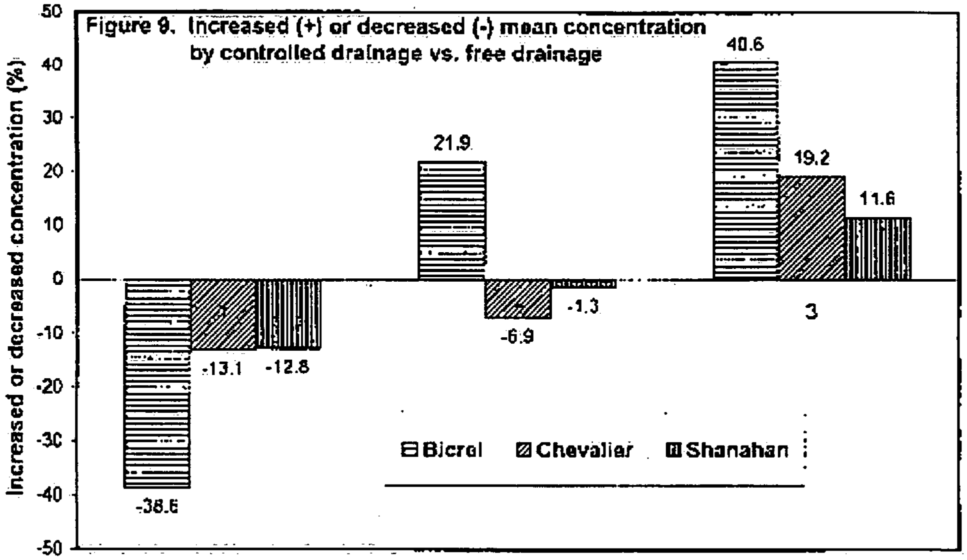
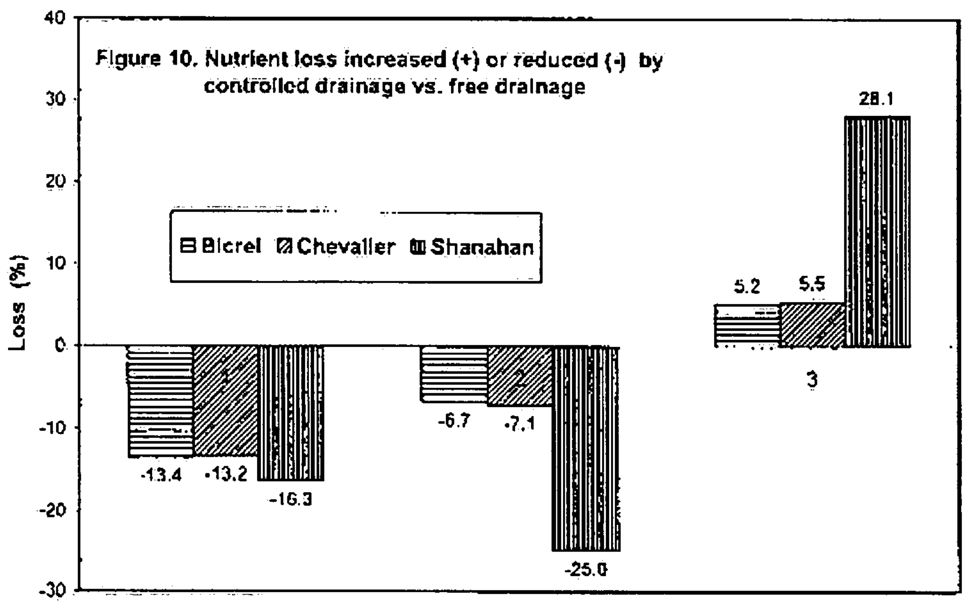


Figure 8. Ratio of loss of NO_3-N, TP and K between controlled drainage and free drainage at Chevalier, Bicrel and Shanahan sites.



Category: 1 = NO_3-N, 2 = TP and 3 = K



Category: 1 = NO_3-N, 2 = TP & 3 = K

PRINTED IN CANADA
IMPRIMÉ AU CANADA
ON RECYCLED PAPER
SUR DU PAPIER RECYCLÉ

National Water Research Institute
Environment Canada
Canada Centre for Inland Waters
P.O. Box 5050
867 Lakeshore Road
Burlington, Ontario
L7R 4A6 Canada

National Hydrology Research Centre
11 Innovation Boulevard
Saskatoon, Saskatchewan
S7N 3H5 Canada

NATIONAL WATER RESEARCH INSTITUTE
INSTITUT NATIONAL DE RECHERCHE SUR LES EAUX

Institut national de recherche sur les eaux
Environnement Canada
Centre canadien des eaux intérieures
Case postale 5050
867, chemin Lakeshore
Burlington, Ontario
L7R 4A6 Canada

Centre national de recherche en hydrologie
11, boul. Innovation
Saskatoon, Saskatchewan
S7N 3H5 Canada

Environment Canada Environnement Canada

Canada