INTEGRATED SOIL, CROP AND WATER MANAGEMENT SYSTEM TO ABATE HERBICIDE AND NITRATE CONTAMINATION OF THE GREAT LAKES: NITRATE

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RATIONALE AND OBJECTIVES

Soil and crop management practices have changed dramatically within the Great Lakes basin during the last decades. Livestock-forage based farming has been replaced with monoculture cash-cropping and there has been an accompanying increase in the use of fertilizers, pesticides and large machinery. However, these changes have resulted in soil compaction and structural deterioration and, therefore, increased surface runoff, erosion and decreased productivity. Application of increased chemical inputs to counter decreased productivity, in conjunction with increased erosion and runoff has resulted in contamination of surface and ground water by nutrients and pesticides.

The development and implementation of an integrated soil, crop and water management system shows promise as a means to manage agricultural chemicals within the root zone and maintain soil structure while sustaining crop production. Current research indicates that conservation tillage alone will not reduce pesticide (Gaynor *et al.,* 1992; Issensee *et al.,* 1990; Sauer and Daniel, 1987) or NO_3^- pollution of tile drainage water (Drury *et al.*, 1993) which eventually discharges into the Great Lakes. Some studies suggest most pollutants are discharged during the first stages of runoff events after herbicide and fertilization applications, thus retention of early runoff events (Jury *et al*., 1985) may also significantly reduce field losses of pesticides and nutrients (Gillam *et al*., 1979). Improving soil structure and managing nutrient uptake and release through intercropping, cover crops and enhancement of root uptake efficiency may also significantly reduce runoff for nutrients and pesticides (Smith, 1982).

In this study, the integrated management system incorporates water table control, reduced tillage and intercropping as sustainable soil management practices. Water table management regulates tile discharge to provide storage of rainfall water received after herbicide and fertilizer N application. Water and NO_3^- can then be used by the crop during dry periods in the growing season which would otherwise have leached out of the root zone. Therefore, this system should reduce herbicide and NO_3^- concentrations in drainage water. The water table control management can also be used for subirrigation during low rainfall periods.

METHODOLOGY

Site characteristics. The experimental site is located at Eugene F. Whelan Experimental Farm (Agriculture Canada, Woodslee, Ontario). The dominant soil series is Brookston clay loam, a poorly drained soil (Orthic Humic Gleysol). The soil at the experimental field has a 30 cm deep dark brown, clay loam A_p horizon with 2.5% organic matter. The B horizon has a clay texture and extends to a depth of 1.5 m.

Experimental design. The experiment was initiated in the spring of 1991. A four by two factorial randomized complete block design was used with four crop/tillage management treatments and two water management treatments. The crop/tillage management treatments were moldboard plow tillage (MP), moldboard plow tillage with annual ryegrass (Lolium multiflorum Lam.) intercrop (MP-IC), soil saver (SS) and soil saver with annual ryegrass intercrop (SS-IC). Water management treatments were drainage only and water table control. All experimental plots received the same pesticide and fertilizer application. When a main plot effect was significant without any interactions, a least squares difference test (LSD) was used to determine differences among treatments. Unless otherwise noted, statistical significance is reported at the 0.05 level. Whenever a significant interaction occurred, a least squares means procedure was used to test for differences between preplanned comparisons.

Field layout and installation. The layout of the experimental field is shown in Fig. 1. It consists of sixteen plots each 15 m wide by 67 m long with an area of 1005 m^2. Each plot contains two 104 mm diameter tile drains. Drains are installed at 7.5 m spacing and 0.6 m depth in the west-east direction. Experimental plots are isolated by: (1) double layer 4 mil thick plastic barrier from the surface to a depth of 1.2 m to prevent leakage and subsurface interaction between the adjacent treatments; (2) a 7.5 m wide by 67 m long buffer area with a single drain to prevent cross contamination between plots; and (3) surface ridges surrounding each plot to contain surface runoff.

Water table in the irrigated plots is controlled with water level control structures (Fig. 2). These structures are built such that, when the bottom drain plug is closed the water rises to desired levels in the structure creating a pressure head which forces the water into the tile drains for subirrigation. When the bottom plug is opened water drains freely from the plots. The water level in these structures can be maintained at a given height by means of a float valve during irrigation. An overflow pipe permits drainage to proceed when the water table rises above the pre-set level. These structures are used for subirrigation and/or controlled drainage during the growing season and controlled drainage during fall, winter and spring. The source of water is an irrigation pond located at the north-west corner of the experimental field (Fig. 1). Irrigation water is pumped and conveyed to the water table control structures via an underground 50 mm diameter polyethylene pipe. Water meters located at the control structures record the total volume of irrigation water delivered to each plot.

Tile drains from each individual plot are intercepted at the east border of each plot and routed to a central instrumentation building at the north-east corner of the experimental field via 104 mm corrugated non-perforated drain pipes. Each plot has a 0.5 m diameter surface catch basin at its east boundary to collect the surface runoff. The surface catch basins are also connected to the central instrumentation building through underground non-perforated drain pipes. The 6 m by 8 m instrumentation building is equipped with an electrical circuit breaker panel, heater, fan, telephone line, data acquisition facilities and a backup generator to provide power to the system when electrical failures occur.

Surface and tile flow measurements. Surface and tile drainage water from the sixteen experimental plots, delivered to the instrumentation building are collected in 32 polyethylene sumps (500 mm diameter by 750 mm deep). Each sump is equipped with an electrical, float activated effluent pump. Surface runoff and subsurface drainage from each individual plot flowing into the respective sumps are pumped through water meters to an outlet drain. Each water meter has the capability of recording drainage volumes mechanically as well as sending analog and digital pulse signals. A multi-channel datalogger utilizes the analog signal of the water meters to monitor, measure and store water volumes on a continuous basis (Soultani *et al*., 1993). The data stored in the datalogger are automatically transmitted 32 km to an IBM PC computer at the Harrow Research Station (HRS) via modem every 24 hours.

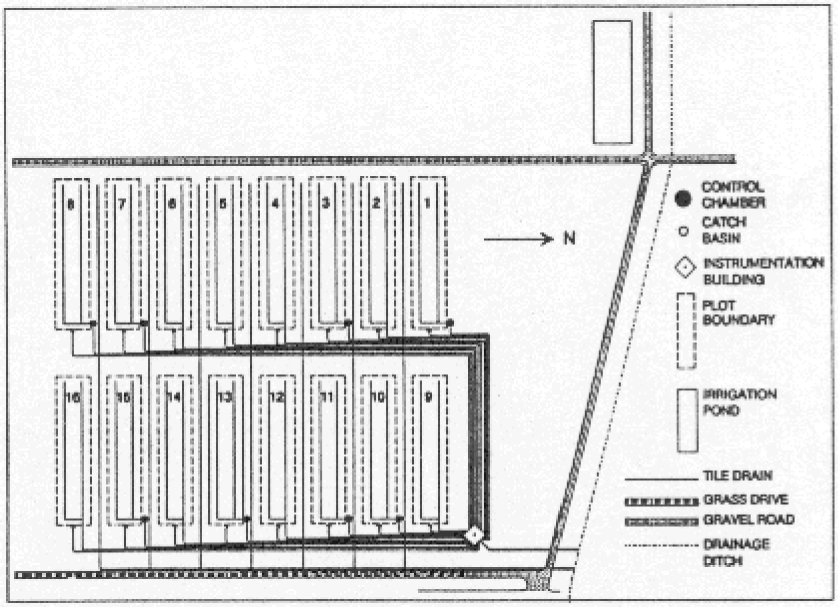

Figure 1. Experimental plot layout showing instrumentation building, drainage system and underground conveyance drain pipes.

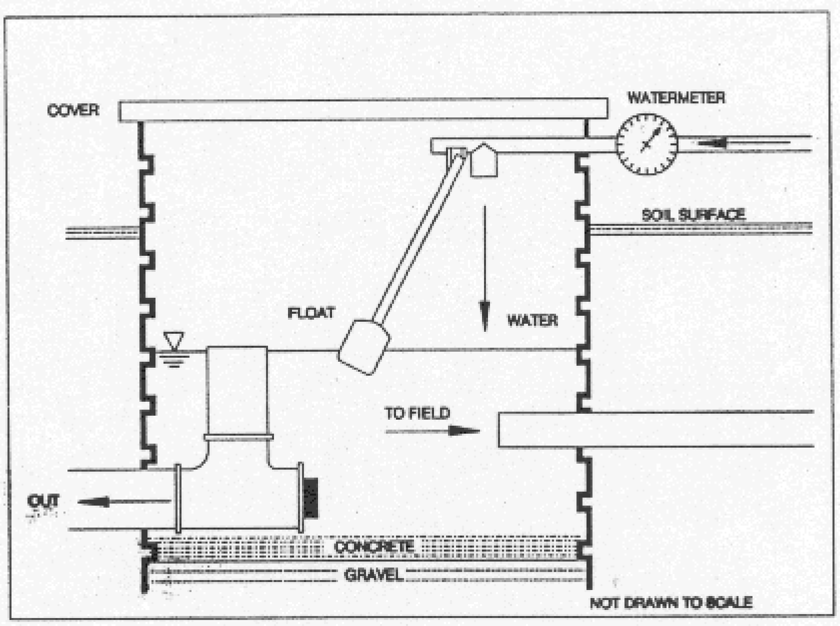

Figure 2. Schematic diagram of the water table control structure.

Water quality sampling and frequency. Samples of surface runoff and tile drainage water for nitrate analyses were collected automatically with 32 autosamplers (CALYPSO 2000S, Buhler Gmbh & Co.) stationed in the instrumentation building. Each autosampler contains 24 one-litre bottles. The autosampler is activated by digital signals from the water meter. Sample collection was based on flow volume with collections at 500 to 3000 L depending upon the time of year and expected runoff volumes. Water samples were stored in glass bottles at 4EC prior to analyses.

Nitrate analysis. Surface and tile water samples filtered through a 0.45 um filter were analyzed on a TRAACS 800 autoanalyzer (Bran + Leubbe, Buffalo Grove, IL) for NO_3^- using the cadmium reduction method (Tel and Heseltine, 1990). Total volumes, nitrate concentrations and nitrate losses were determined from November 1991 to December 1993.

Agronomy. Corn (*Zea mays* L., Pioneer 3573) was seeded at a rate of 65,000 seed ha^{-1} in 75 cm wide rows with a Kinze 4 row planter. Fertilizer (8-32-16) was banded beside the seed at a rate of 132 kg ha^{-1}. Urea (46-0-0) was applied with a brush applicator at the 6 leaf stage at a rate based on the average nitrate soil test. In 1991, a total of 125 kg N ha^{-1} was applied (including the preplant application) as 55 kg N ha^{-1} credit was given to account for the N release from the previous alfalfa crop. In 1992 and 1993, the total N rates were 152 kg N ha^{-1} and 200 kg N ha^{-1}. Annual ryegrass intercrop was seeded in the interrow with a Brillion seeder at a rate of 12 kg ha^{-1}. Atrazine was applied at 550 g ha^{-1}, metribuzin at 250 g ha^{-1} and metolachlor at 840 g ha^{-1}.

Water table depth. Water table depths in each plot were monitored by eleven 25.4 mm diam. perforated PVC pipes, wrapped in filter material. Three pipes were installed midway between the tiles and three pipes were installed adjacent to each tile. The other two pipes were installed midway between the tile drains and the plastic barrier on each side. Water table depth was monitored every second day during the growing season and on a weekly basis during the off season.

Climatic measurement. Weather data was collected from a nearby automated weather station. These data include maximum and minimum air temperature, solar radiation, rainfall intensity and amount, wind speed and direction and relative humidity.

Yields. Grain was harvested by both hand harvest and machine harvest with a 3-row Gleaner combine. Each plot contained 20 rows with the centre 12 rows harvested for yield determination. The cobs were shelled in the field and the grain moisture content was determined with a Dickey-John (Gow Mac III) moisture meter. Grain yield was reported at 15.5% moisture content. Grain samples were dried at 80 ^{0}C, ground with a Wiley mill fitted with a 40 mesh sieve and weighed (0.2 g) into a 75 mL tube and a Kjeldahl digestion performed in a Technicon digestion block. Ammonium sulfate solutions and a blank were similarly digested. The digests were analyzed on a TRAACS 800 autoanalyzer for NH_4^+ as described previously except that NaOH was added to the EDTA solution to neutralize the excess acid in the digests. Total nitrogen uptake in grain was calculated as the product of grain yield and grain nitrogen concentration.

FINDINGS

Water table depth. The 1991 growing seasons (May 1 - September 30) were very dry as there was only 250.5 mm of rain whereas the average growing season rainfall (1960 to 1992) is 411 mm. Subirrigation was initiated on July 14 and stopped on September 4.

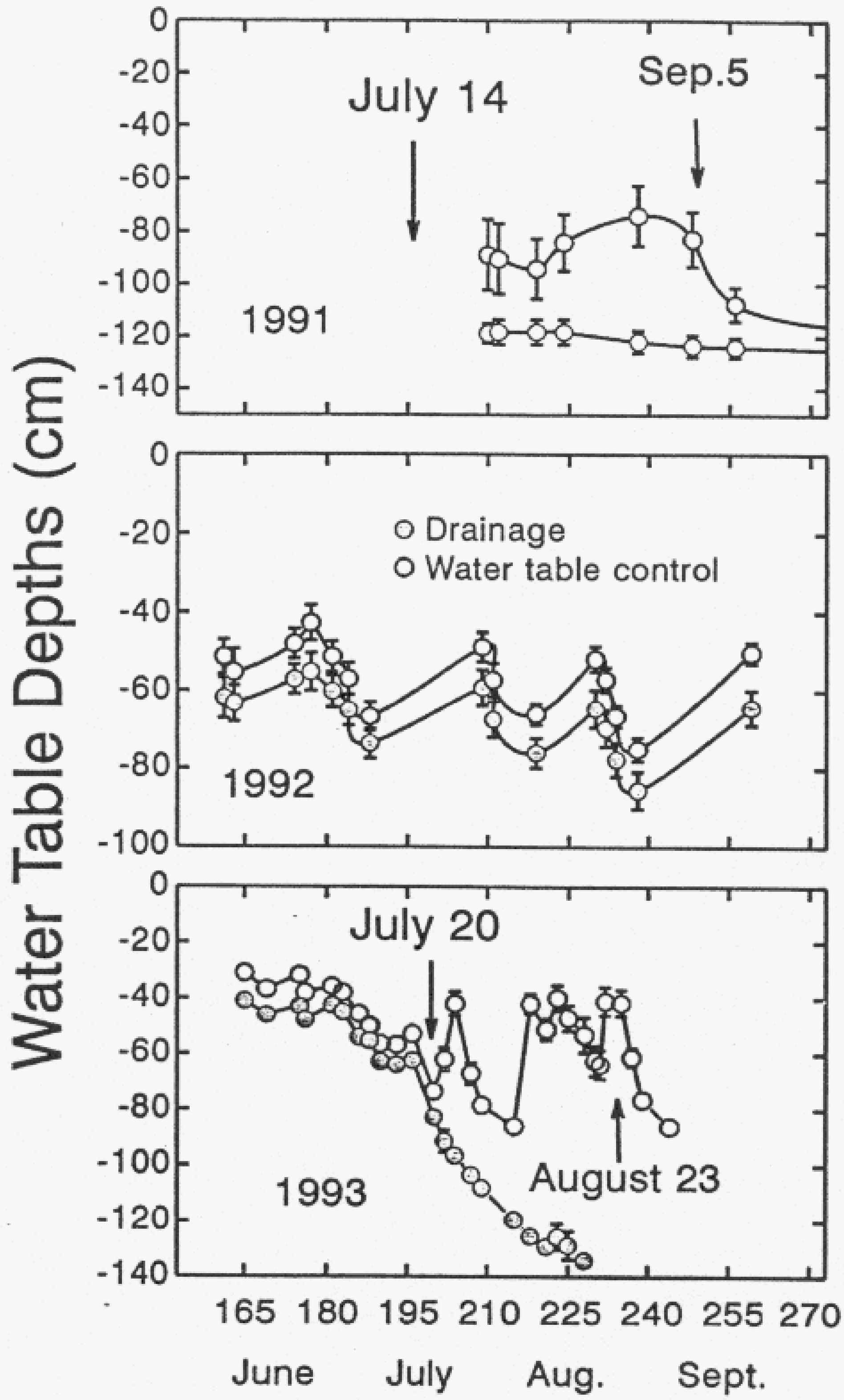

Figure 3. Water table depths for the drainage in the growing seasons

The average water table depth in the controlled drainage/subirrigation plots were about 30 to 50 cm higher than in the drainage plots during the growing season (Fig. 3). There was a considerable amount of rain in the 1992 growing season (497 mm) hence no subirrigation water was applied. However risers (30 cm) were used in the controlled drainage plots to reduce tile drainage. The average water table depth in the controlled drainage/subirrigation plots was about 10 to 15 cm higher than in the drainage plots during the growing season (Fig. 3). The 1993 growing season was dry (342 mm) hence subirrigation was initiated on July 20 and stopped on August 23. The average water table depth in the controlled drainage/subirrigation plots remained at about 40 cm. The water table depth in the drainage plots dropped below 150 cm which was the lowest depth that could be measured with the water table PVC pipes.

Nitrate. The cumulative tile drainage volumes were measured for the crop management and water table control treatments from November 1, 1991 to December 31, 1993 (Fig. 4). Seasonal fluctuations in tile drainage volume were evident especially in the spring periods for 1992 and 1993. The greatest differences in tile drainage volume were for the water table control treatments. Cumulative tile drainage volume was on average 21% greater with the tile drainage treatments compared to the controlled drainage subirrigation system (Table 1). Tile drainage volume was reduced with the controlled drainage/subirrigation treatment even though an average of 125.7mm of water was added through subirrigation in the summer of 1993 as a result of the low amount of rainfall which fell in the growing season (399 mm from May 1 to October 31). In 1992, virtually no subirrigation water was added due to the greater amount of rainfall which fell in the growing season (602 mm).

The nitrate concentration in tile drainage water peaked in the fall of 1991 with a maximum concentration of 74 mg N L^{-1} occurring with the drainage plus moldboard plow tillage and intercropping treatment (Fig. 5). The high levels resulted from dry soil conditions which limited corn yields and N uptake. Controlled drainage/subirrigation treatments increased yields and N uptake and thereby reduced nitrate concentrations in tile drainage water in the fall and winter of 1992. The nitrate concentrations were not as high in the fall of 1992 as the greater rainfall increased corn yields and N uptake which reduced the amount of nitrate available for leaching. The flow weighted mean nitrate concentrations were consistently above the 10 mg N L^{-1} drinking water guidelines for the tile drainage treatments but were below the guidelines for all of the controlled drainage/subirrigation treatments (Table 1). On average the flow weighted mean nitrate concentrations were reduced by 25% from 11.2 mg N L^{-1} for the drainage treatments to 8.5 mg N L^{-1} for the controlled drainage/subirrigation system. The lowest flow weighted mean nitrate concentration occurred with the controlled drainage/subirrigation system with soil saver tillage.

The cumulative tile nitrate loss ranged form 61.4 to 81.2 kg N ha^{-1} for the tile drainage treatments versus 32 to 49.3 kg N ha^{-1} for the controlled drainage/subirrigation treatments (Table 1 and Fig. 6). On an annual basis, the average yearly nitrate loss was reduced by 41% from 32.5 kg N ha^{-1} for the drainage system to 19.1 kg N ha^{-1} for the controlled drainage/subirrigation system (Table 1). Moldboard plow tillage resulted in the lowest nitrate losses through tile drainage for the drainage treatments at 28.3 kg N ha^{-1} whereas the soil saver tillage treatment resulted in the lowest nitrate losses in the controlled drainage/subirrigation system at 14.8 kg N ha^{-1} which was a 48% reduction.

The cumulative volume of surface runoff was greater with the controlled drainage/subirrigation system than tile drainage treatments (Fig. 7). Considerable surface runoff occurred in the fall of 1992 which corresponded to the above average growing season rainfall (602 mm for 1992 as compared to an average of 522 mm for the thirteen year period from 1980 to 1992).

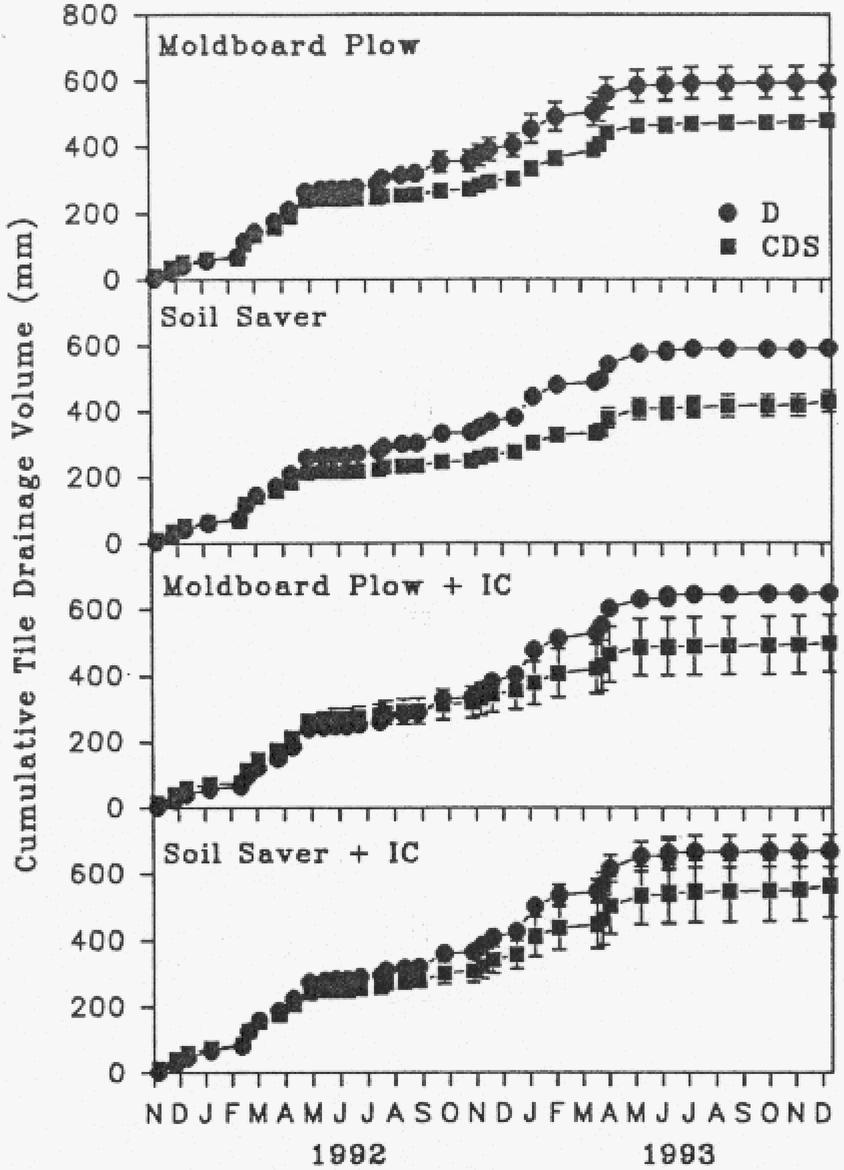

Figure 4. Cumulative tile drainage volume for the soil and crop (moldboard plow and soil saver tillage with/without annual ryegrass intercrop (IC)) and water management (tile drainage (D) and controlled drainage/subirrigation (CDS)) treatments from November 1, 1991 to December 31, 1993.

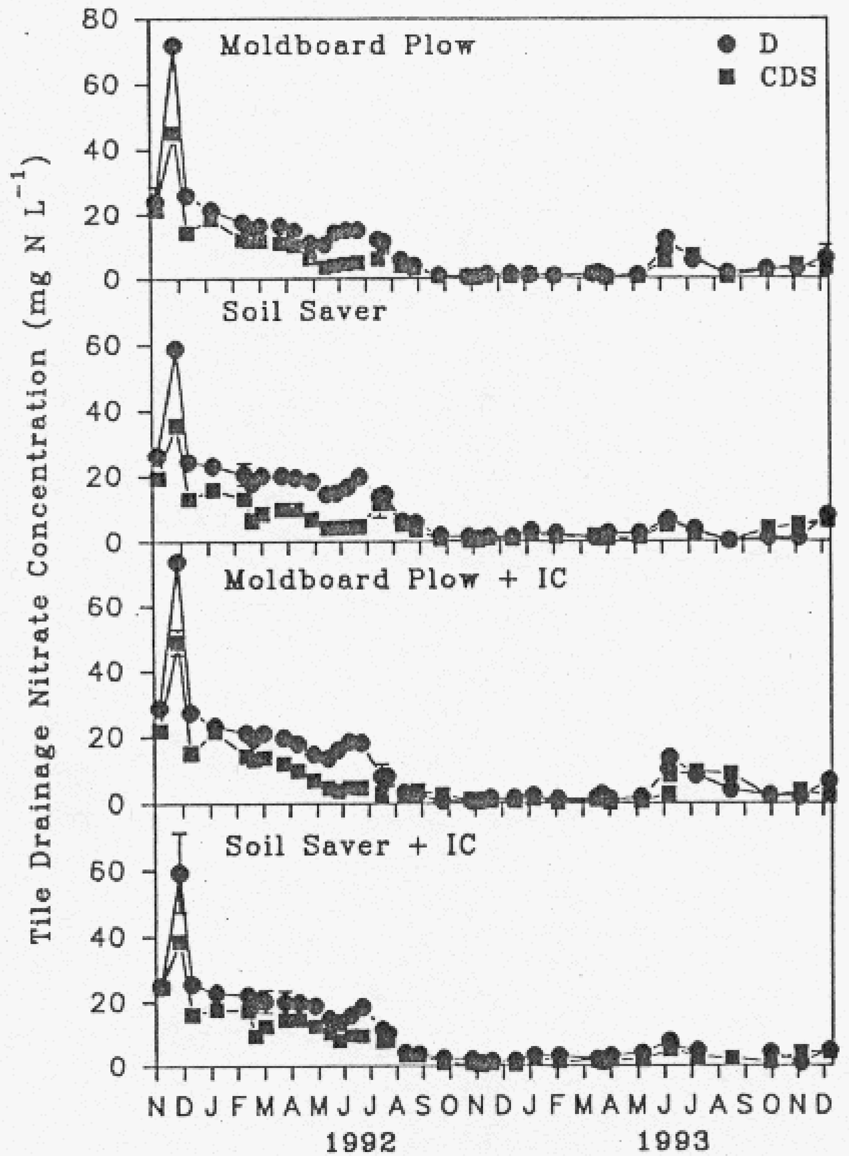

Figure 5. Nitrate concentration of tile drainage water for the soil and crop (moldboard plow and soil saver tillage with/without annual ryegrass intercrop (IC)) and water management (tile drainage (D) and controlled drainage/subirrigation (CDS)) treatments from November 1, 1991 to December 31, 1993.

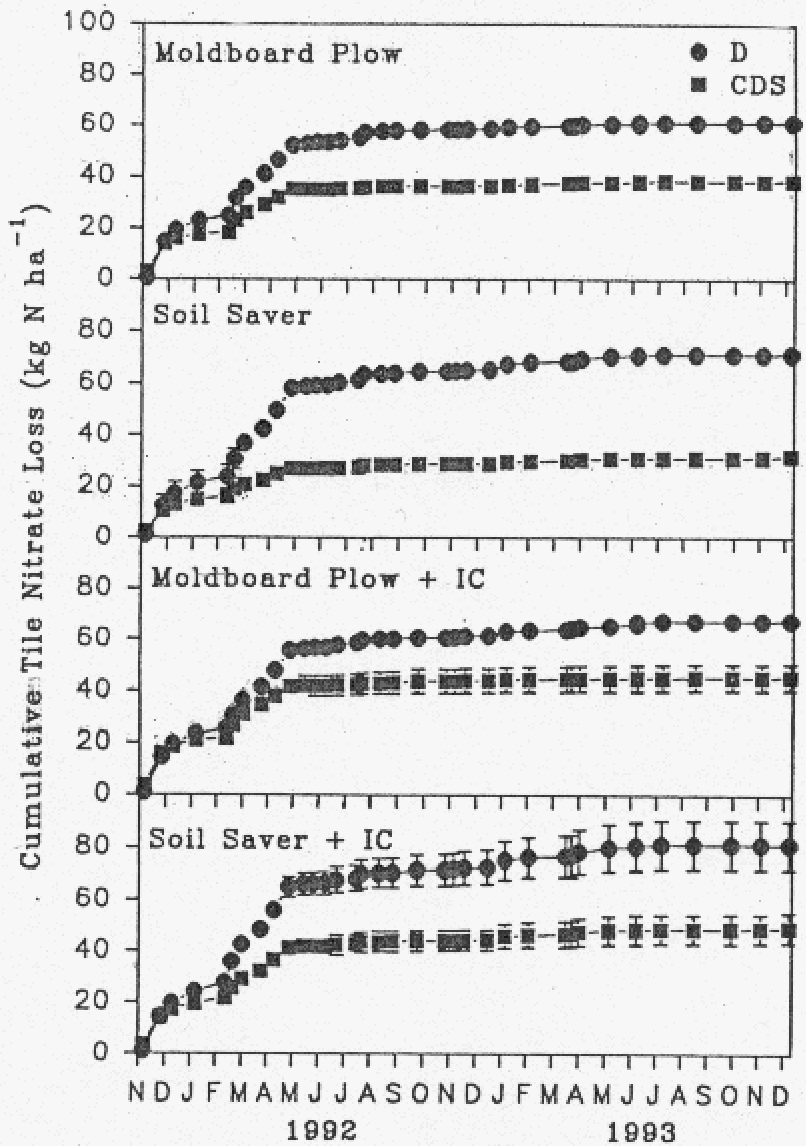

Figure 6. Nitrate loss from tile drainage for the soil and crop (moldboard plow and soil saver tillage with/without annual ryegrass intercrop (IC)) and water management (tile drainage (D) and controlled drainage/subirrigation (CDS)) treatments from November 1, 1991 to December 31, 1993.

The cumulative surface drainage volumes were considerably lower than tile drainage volumes (Table 1). The cumulative surface runoff volumes ranged from 91 to 153 mm for the tile drainage treatments versus 214 to 326 mm for the controlled drainage/subirrigation treatments.

Nitrate concentrations in surface runoff were considerably lower than in tile drainage water (Figs. 5 and 8). Nitrate concentrations in surface runoff peaked in runoff events following nitrogen sidedress applications (Fig. 8). The flow weighted mean nitrate concentrations for surface runoff water were less than 3 mg N L^{-1} for all treatments (Table 1). Controlled drainage/subirrigation treatments reduced the flow weighted mean nitrate concentration by 19% compared to the tile drainage treatments. Intercropping resulted in 13% lower flow weighted mean nitrate concentrations in surface runoff water than in the non-intercropping treatments.

The cumulative nitrate loss in surface runoff was greater with the controlled drainage/subirrigation treatments than the corresponding tile drainage treatments (Fig. 9). There was between 2.9 to 5.6 kg N ha^{-1} lost in surface runoff water from the controlled drainage/subirrigation treatments as compared to a range of 1.5 to 2.9 kg N ha^{-1} lost from the tile drainage treatments from November 1, 1991 to December 31, 1993 (Table 1). Nitrate loss through surface runoff was considerably lower than nitrate loss through tile drainage (Table 1). The annual loss of nitrate through surface runoff was on average 1.1 kg N ha^{-1} with the tile drainage treatments versus 1.86 kg N ha^{-1} with the controlled drainage/subirrigation treatments. The additional 0.76 kg N ha^{-1} nitrate loss through subirrigation/controlled drainage was considerably smaller than the 13.4 kg N ha^{-1} savings of nitrate from tile drainage with the controlled drainage/subirrigation system (Table 1).

Yields. Rainfall and temperature had a strong impact on yield and plant growth parameters in each year. In 1991, there was a shortage of rain in the growing season (250.5 mm rain between May 1 and September 30) and the controlled drainage/subirrigation treatments resulted in higher total biomass production (Table 2). Above average rainfall in the 1992 growing season (497 mm) increased yields, biomass production and N uptake in grain for the drainage treatments (Table 2). Tillage treatments did not affect yields but competition with the annual ryegrass intercrop decreased total corn production on the controlled drainage/subirrigation treatments. In 1993, rainfall was below average (342 mm) and the controlled drainage/subirrigation treatments increased corn grain yield and biomass production by 8%, and increased grain N uptake by 7% (Table 2). Moldboard plow tillage produced 15% higher grain yields and greater plant biomass than the soil saver treatments. Soil saver treatments had significantly more surface organic residues than the moldboard plow treatments and they also had better annual ryegrass intercrop production in both 1992 and 1993 (data not presented).

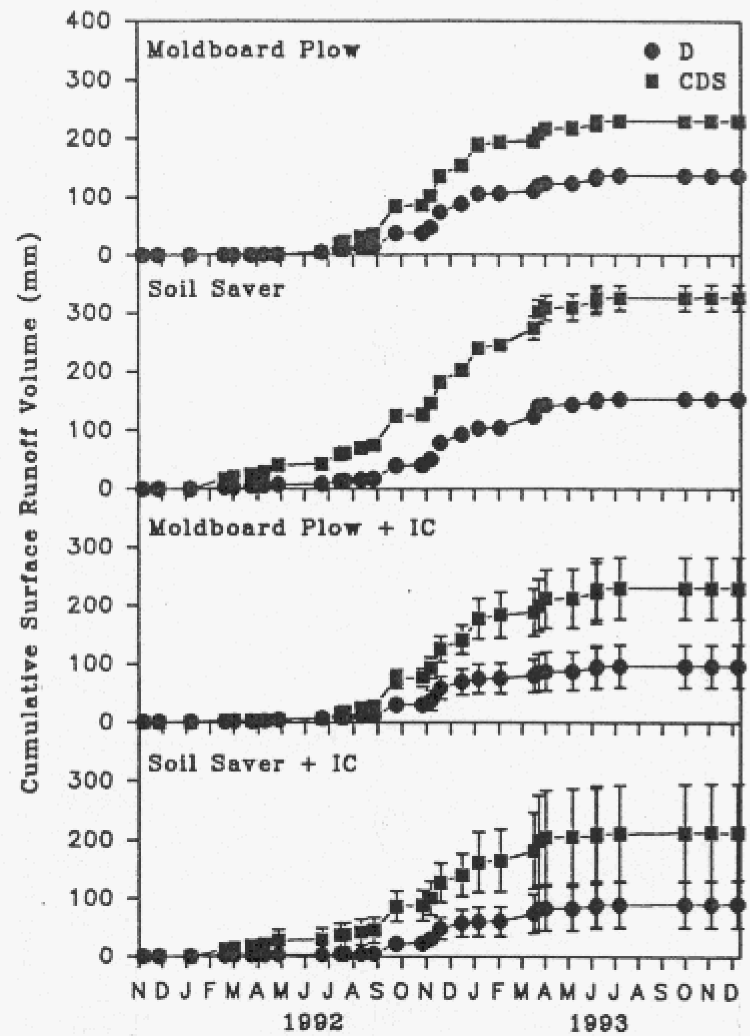

Figure 7. Cumulative surface runoff volume for the soil and crop (moldboard plow and soil saver tillage with/without annual ryegrass intercrop (IC)) and water management (tile drainage (D) and controlled drainage/subirrigation (CDS)) treatments from November 1, 1991 to December 31, 1993.

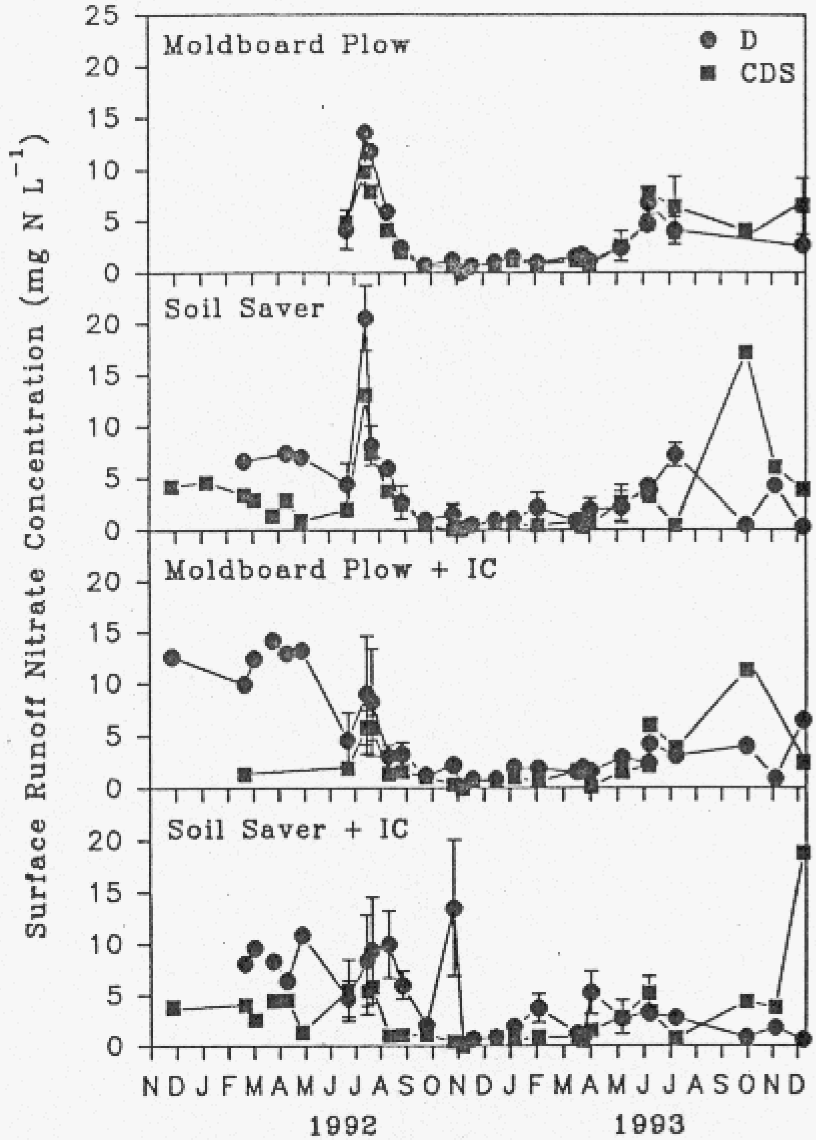

Figure 8. Nitrate concentration of surface runoff water for the soil and crop (moldboard plow and soil saver tillage with/without annual ryegrass intercrop (IC)) and water management (tile drainage (D) and controlled drainage/subirrigation (CDS)) treatments from November 1, 1991 to December 31, 1993.

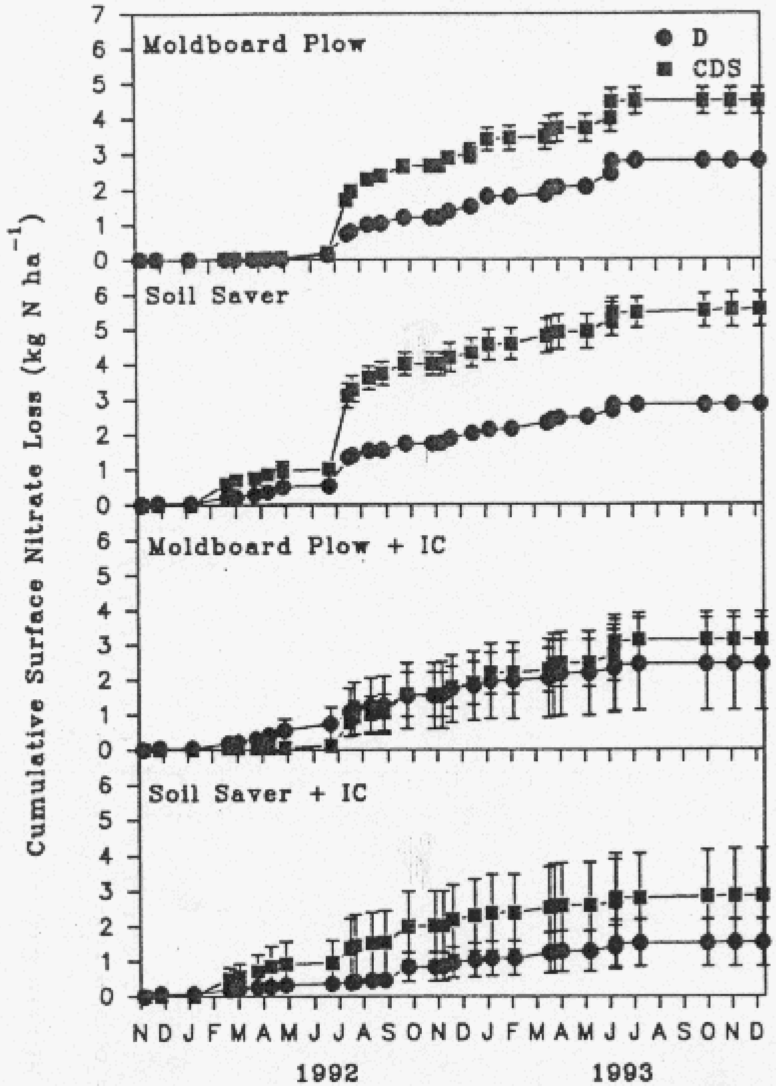

Figure 9. Nitrate loss from surface runoff for the soil and crop (moldboard plow and soil saver tillage with/without annual ryegrass intercrop (IC) and water management (tile drainage (D) and controlled drainage/subirrigation (CDS)) treatments from November 1, 1991 to December 31, 1993.

STUDY CONCLUSIONS

Nitrate leaching through the soil profile and contamination of groundwater has become a serious environmental and economic problem (loss of fertilizer) for intensive agricultural systems. Nitrates in drinking water in excess of 10 mg N L^{-1} can lead to blue-baby syndrome (methaemoglobinaemia) and stomach cancer. Previous research has indicated that the volume of water that flowed through the soil was the primary factor responsible for N loss. In this study a controlled drainage/subirrigation systems was used to manage drainage water and reduce tile drainage volume by 21%. Flow weighted mean nitrate concentration was reduced by 25% from 11.2 mg N L^{-1} for the drainage treatments to 8.5 mg N L^{-1} for the controlled drainage/subirrigation system. The average yearly nitrate loss was reduced by 41% from 32.5 kg N ha^{-1} for the drainage system to 19.1 kg N ha^{-1} for the controlled drainage/subirrigation system. Moldboard plow tillage resulted in the lowest nitrate losses through tile drainage for the drainage treatments at 28.3 kg N ha^{-1} whereas the soil saver tillage treatment resulted in the lowest nitrate losses in the controlled drainage/subirrigation system at 14.8 kg N ha^{-1}. Therefore controlled drainage subirrigation system combined with soil saver tillage reduced nitrate loss by 48% to the conventional moldboard plow tillage. Annual loss of nitrates through surface runoff with drainage treatments was 1.1 kg N ha^{-1} which is only 3% of the total nitrate loss. Annual nitrate loss through surface runoff was increased to 1.9 kg N ha^{-1} with the controlled drainage/subirrigation systems, but this loss was minor compared to losses incurred through tile drainage.

The controlled drainage/subirrigation system reduced nitrate concentration by 25% and in combination with soil saver tillage effectively reduced the nitrate loss in tile drainage water by 48%. This system improved nitrogen fertilizer efficiency for corn production systems. The controlled drainage/subirrigation system is a technological breakthrough as it enables farmers to increase nitrogen fertilizer efficiency, reduce nitrate contamination of drainage water, and provide their crops with water during dry periods in the summer.

NEW TECHNOLOGIES AND BENEFITS

New Technology. The introduction of an integrated management system which incorporates controlled drainage/subirrigation, conservation tillage and intercrop as sustainable production management practices.

Benefits. All or part of the integrated management system can be adopted depending upon farmer acceptance and cost. The extent of adoption will determine the extent of improvement on water quality. The controlled drainage/subirrigation will reduce nitrate loss through tile drainage and increase water and nitrate use efficiency.

The integrated management system should result in improved water quality by reducing nitrate loss and increased crop yields (ie. improve soil water regimes by controlled drainage/subirrigation) and lower input costs (ie. improve N fertilizer efficiency). Therefore, the integrated management system being developed at Harrow should be able to address both environmental quality and agricultural production issues in a balanced way.

IMPLICATIONS FOR GREAT LAKES ECOSYSTEM

The integrated management system being developed at Harrow provides technology to reduce non-point contributions of herbicide, nitrate and phosphorus to the Great Lakes ultimately improving the lakes' ecosystem. Also, reduced herbicide and nitrate input will decrease potential for leaching to the groundwater.

TECHNOLOGY TRANSFER POTENTIAL

Components of the integrated management system are 1) controlled drainage/subirrigation, 2) conservation tillage and 3) intercrop. The integrated management system is based on existing farming structures (ie. tile drains). The existing drainage structures with minor modification can be converted to a controlled drainage/subirrigation system for better management of water and nutrients. Furthermore, the controlled drainage/subirrigation system incorporated with intercrop proves to be a dramatic means of reducing nitrate losses because of reductions in tile drainage volumes and nitrate concentrations in tile drainage water which result in improved nitrogen fertilizer efficiency.

Part or all of the integrated management system can be easily adopted and implemented as a sustainable agricultural management system which minimize use and transport of agricultural chemicals.

GAPS NEEDING FUTURE RESEARCH

(1) Determine the effect of controlled drainage (i.e. without subirrigation) on water quality and crop performance. This is important for farms which do not have a supply of water fro subirrigation and/or cannot afford to install a subirrigation system.

(2) Determine the effectiveness of controlled drainage (with/without subirrigation) in a no-till system on water quality and crop performance.

(3) Determine the effectiveness of the controlled drainage/subirrigation on nitrate and herbicide losses on other crops, crop rotations and soils.

(4) The emphasis of the GLWQ project centres on surface and subsurface runoff water quality. The ground water quality and the migration and dissipation of herbicide and nitrogen in soil from the integrated management system needs to be studied further.

(5) Determine the effect of the integrated management system on soil organic matter, soil structure and microbial biomass activity.

(6) Determine the relative contributions of drainage outflow over tile and between tile area in the integrated management system using a non-reactive tracer (results could impact management practices by changing fertilizer/herbicide placements, use of intercrop over tiles or direction of planting etc.; results should also provide a useful database for model calibration).

(7) Utilize our field and climatic data to verify and/or develop models for estimating herbicide and nitrate transport (ie. surface runoff, subsurface drainage, leaching and dissipation).

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Table 1.

Cumulative tile drainage volume and surface runoff, flow weighted mean nitrate concentration and nitrate loss from moldboard plow, soil saver, moldboard plow and annual rye grass, soil saver and annual rye grass treatments with/without controlled drainage/subirrigation from November 1, 1991 to December 31, 1993.

Water Management Treatments	Soil & Crop Management Treatments	Drainage Volume -- mm --	Flow Weighted Mean Nitrate Concentration mg N L^{-1}	Cumulative Nitrate Loss kg N ha^{-1}	Annual Nitrate Loss kg N ha^{-1}
		Tile Losses			
Tile drainage	MP	596 (25)	10.4 (0.7)	61.4 (0.5)	28.3 (0.2)
	SS	592 (8)	12.1 (0.2)	71.4 (0.5)	33.0 (0.2)
	MP + IC	649 (9)	10.4 (0.2)	67.3 (0.4)	31.1 (0.2)
	SS + IC	671 (25)	12.0 (0.5)	81.2 (47)	37.5 (2.2)
Controlled drainage/ subirrigation	MP	478 (12)	8.1 (<0.1)	38.8 (0.9)	17.9 (0.4)
	SS	430 (16)	7.5 (0.4)	32.0 (0.4)	14.8 (0.2)
	MP + IC	497 (43)	9.3 (0.6)	45.4 (2.5)	21.0 (1.2)
	SS + IC	565 (47)	8.9 (0.5)	49.3 (2.9)	22.8 (1.3)
		Surface Losses			
Tile drainage	MP	137 (14)	2.08 (0.14)	2.80 (0.11)	1.29 (0.05)
	SS	153 (8)	1.87 (0.09)	2.85 (0.02)	1.32 (0.01)
	MP + IC	97 (37)	2.09 (0.59)	2.44 (1.33)	1.13 (0.61)
	SS + IC	91 (41)	1.68 (0.01)	1.53 (0.68)	0.71 (0.31)
Controlled drainage/ subirrigation	MP	230 (11)	1.95 (0.07)	4.49 (0.37)	2.07 (0.17)
	SS	326 (22)	1.70 (0.04)	5.56 (0.50)	2.57 (0.23)
	MP + IC	230 (53)	1.35 (0.03)	3.13 (0.79)	1.45 (0.36)
	SS+IC	214 (82)	1.24 (0.13)	2.87 (1.31)	1.33 (0.61)

* Numbers in parenthesis are standard error (n=2)

Table 2.
Corn grain yield, grain N uptake and plant biomass (excluding grain) from the moldboard plow, soil saver, moldboard plow and annual rye grass, soil saver and annual rye grass treatments with/without controlled drainage/subirrigation from 1991 to 1993.

Water Management Treatments	Soil & Crop Management Treatments	Grain Yield $t\ ha^{-1}$	Grain N uptake $kg\ N\ ha^{-1}$	Plant Biomass $t\ ha^{-1}$
		1991		
Tile drainage	MP	7.57 (0.11)*		
	SS	8.16 (0.58)		
	MP + IC	7.69 (0.41)		
	SS + IC	7.60 (0.24)		
Controlled drainage/ subirrigation	MP	8.56 (0.29)		
	SS	8.20 (0.14)		
	MP + IC	7.76 (0.12)		
	SS + IC	8.53 (0.13)		
		1992		
Tile drainage	MP	9.63 (0.56)	86.4 (1.3)	8.44 (0.43)
	SS	9.93 (0.53)	99.9 (9.8)	8.49 (0.46)
	MP + IC	9.29 (0.25)	96.2 (11.8)	8.80 (0.51)
	SS + IC	8.50 (0.74)	78.5 (8.0)	8.81 (0.52)
Controlled drainage/ subirrigation	MP	7.55 (0.19)	64.3 (0.6)	7.98 (0.29)
	SS	6.79 (0.27)	54.7 (2.1)	7.60 (0.28)
	MP + IC	6.69 (0.25)	52.9 (2.2)	6.59 (0.23)
	SS+IC	6.70 (0.63)	49.8 (3.9)	7.36 (0.76)
		1993		
Tile drainage	MP	9.93 (0.10)	75.8 (2.1)	7.12 (0.22)
	SS	7.99 (0.62)	56.8 (3.0)	5.83 (0.29)
	MP + IC	9.68 (0.53)	72.0 (4.4)	7.56 (0.32)
	SS + IC	8.29 (0.03)	60.1 (1.6)	6.73 (0.34)
Controlled drainage/ subirrigation	MP	10.27 (0.33)	78.6 (4.5)	7.98 (0.29)
	SS	9.96 (0.01)	73.1 (0.6)	7.60 (0.28)
	MP + IC	10.15 (0.22)	73.9 (2.5)	6.59 (0.23)
	SS+IC	8.52 (0.20)	57.1 (0.8)	7.36 (0.76)

* Numbers in parenthesis are standard error (n=2).

PUBLICATIONS

(a) Refereed Journals

1. Soultani, M., C.S. Tan, J.D. Gaynor, R. Neveu and C.F. Drury. 1993. Measuring and sampling surface runoff and subsurface drain outflow volume. Applied Engineering in Agriculture 9(5):447-450.

2. Tan, C.S., C.F. Drury, J.D. Gaynor and T.W. Welacky. 1993. Integrated soil, crop and water management system to abate herbicide and nitrate contamination of the Great Lakes. Wat. Sci. Tech. 28:497-507.

(b) Conference Proceedings

1. Tan, C.S., C.F. Drury, M. Soultani, T. Oloya, J.D. Gaynor and T.W. Welacky. 1992. Evaluation of an integrated soil, crop and water management system to abate nitrate loss. Workshop proceeding on Agricultural Nitrate and Impacts on Water Quality in Ontario (in press).

(c) Other

1. Soultani, M., C.S. Tan, J.D. Gaynor, C.F. Drury and T.W. Welacky. 1991. Integrated management system for abatement of herbicide and nitrogen loss. ASAE No. 91-2584.

2. Soultani, M., C.S. Tan, J.D. Gaynor and C.F. Drury. 1993. An automated system for runoff measurement and water quality assessment. ASAE No. 93-2136.

3. Tan, C.S., J.D. Gaynor, C.F. Drury and T.W. Welacky. 1993. Tillage and water table management to abate herbicide and nitrate loss in surface runoff and tile drainage water. ASAE No. 93-2081.

4. Drury, C.F., Tan, C.S., J.D. Gaynor, T.O. Oloya and T.W. Welacky. 1994. Influence of controlled drainage/subirrigation on nitrate loss from Brookston clay loam soil. ASAE No. 94-2068.

(d) Abstracts

1. Soultani, M., C.S. Tan, J.D. Gaynor, C.F. Drury and T.W. Welacky. 1991. Integrated management system for abatement of herbicide and nitrogen loss. Paper presented at ASAE Winter Meeting.

2. Gaynor, J.D., C.S. Tan, C.F. Drury, T.W. Welacky and A.S. Hamill. 1992. Integrated soil, crop and water management system to abate herbicide and nitrate contamination of the Great Lakes. Paper presented at Weed Science Society of America Annual Meeting

3. Gaynor, J.D., C.S. Tan, C.F. Drury and T.W. Welacky. 1993. Assessment of water quality employing intercrop, water table control and tillage management for corn production with band application of atrazine, metribuzin and metolachlor. Paper presented at American Chemical Society Annual Meeting.

4. Tan, C.S., C.F. Drury, J.D. Gaynor and T.W. Welacky. 1993. Integrated soil, crop and water management system to abate herbicide and nitrate contamination of the Great Lakes. Paper presented at the International Workshop on sustainable Land Management for the 21st Century.

5. Tan, C.S., C.F. Drury, J.D. Gaynor and T.W. Welacky. 1993. Tillage and water management system to abate herbicide and nitrate contamination of the Great Lakes. Paper presented at 1st International Conference on Diffuse (Nonpoint) Pollution: Sources, Prevention, Impact and Abatement.

6. Soultani, M., C.S. Tan, J.D. Gaynor and C.F. Drury. 1993. An automated system for runoff measurement and water quality assessment. Paper presented at ASAE International Summer Meeting.

7. Tan, C.S., J.D. Gaynor, C.F. Drury and T.W. Welacky. 1993. Tillage and water table management to abate herbicide and nitrate loss in surface runoff and tile drainage water. Paper presented at ASAE International Summer Meeting.

8. Drury, C.F., C.S. Tan, T.O. Oloya, J.D. Gaynor and T.W. Welacky. 1993. Influence of subirrigation/controlled drainage and intercropping systems on nitrate loss through surface runoff and tile drainage. Paper presented at American Society of Agronomy Annual Meeting.

9. Gaynor, J.D., C.S. Tan, C.F. Drury, I.J. Van Wesenbeeck and T.W. Welacky. 1994. Atrazine concentration and losses in subsurface runoff as affected by tillage, band application, intercrop and water table control. Paper presented at 29th Central Canadian Symposium on Water Pollution Research.

10. Gaynor, J.D., C.S. Tan, C.F. Drury, T.W. Welacky, and I. van Wesenbeeck. 1994 Herbicide loss in surface runoff from corn plots: Effects of tillage, water table control, intercrop and banding. Paper presented at the 207th American Society Meeting, San Diego, CA.

11. Tan, C.S., C.F. Drury, J.D. Gaynor and T.W. Welacky. 1994. Influence of control drainage/subirrigation on nitrate loss from Brookston clay soil. Paper presented at ASAE International Summer Meeting.

12. Tan, C.S., J.D. Gaynor, C.F. Drury and T.W. Welacky. 1994. Tillage, corn cropping practices and controlled drainage/subirrigation systems on water quality. I. Field design and automated runoff measurement. Paper presented at the Northeast AG/BIO Engineering Conference and International Great Lakes Research Conference.

13. Gaynor, J.D., C.S. Tan, C.F. Drury and T.W. Welacky. 1994. Tillage, corn cropping practices and controlled drainage/subirrigation on water quality. II. Herbicide loss. Paper presented at the Northeast AG/BIO Engineering Conference and International Great Lakes Research Conference.

14. Drury, C.F., C.S. Tan, J.D. Gaynor, T.W. Welacky and T.O. Oloya. 1994. Tillage, corn cropping practices and controlled drainage/subirrigation systems on water quality. III. Nitrate loss. Paper presented at the Northeast AG/BIO Engineering Conference and International Great

Lakes Research Conference.

15. Welacky, T.W., C.F. Drury, C.S. Tan and J.D. Gaynor. 1994. Tillage, corn cropping practices and controlled drainage/subirrigation systems on water quality. IV. Crop performance and yield. Paper presented at the Northeast AG/BIO Engineering Conference and International Great Lakes Research Conference.

16. Tan, C.S., C.F. Drury, J.D. Gaynor and I. Van Wesenbeeck. 1994. Water table control and N-supply effects on water quality in undisturbed soil columns. I. Plant growth and water use. Paper presented at the Northeast AG/BIO Engineering Conference and International Great Lakes Research Conference.

17. Drury, C.F., C.S. Tan, J.D. Gaynor and I. Van Wesenbeeck. 1994. Water table control and N-supply effects on water quality in undisturbed soil columns. II. Nitrate. Paper presented at the Northeast AG/BIO Engineering Conference and International Great Lakes Research Conference.

18. Gaynor, J.D., C.S. Tan, C.F. Drury and I. Van Wesenbeeck. 1994. Water table control and N-supply effects on water quality in undisturbed soil columns. III. Herbicide. Paper presented at the Northeast AG/BIO Engineering Conference and International Great Lakes Research Conference.

19. Van Wesenbeeck, I., C.S. Tan, J.D. Gaynor and C.F. Drury. 1994. Comparison of DRAINMOD simulation of a tile drainage and controlled drainage/subirrigation system with field data in S.W. Ontario. Paper presented at the Northeast AG/BIO Engineering Conference and International Great Lakes Research Conference.

20. Drury, C.F., C.S. Tan, T.O. Oloya, J.D. Gaynor and T.W. Welacky. 1994. The influence of water table management on surface and tile nitrate loss for corn production. Paper presented at American Society of Agronomy Annual Meeting.