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NWRI Contribution No. 98-042

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MANAGEMENT PERSPECTIVE

This work reported results on an on-farm study on the influence of water table control and subirrigation on nitrate concentration in the tile drainage, soil water and on plant transpiration dynamics.

The results showed that water table control and subirrigation is technological advancement in soil and water management. These methods enable farmers to reduce nitrate contamination of drainage water and to minimize the effect of dry period on crop growth. These methods should be useful for agricultural water management practices.

SOMMAIRE À L'INTENTION DE LA DIRECTION

Les auteurs rendent compte d'une étude agronomique en plein champ portant sur l'influence de la régulation de la nappe phréatique et de l'irrigation souterraine sur la teneur en nitrates du réseau de drainage souterrain et de l'eau du sol ainsi que sur la dynamique de la phytotranspiration.

Les résultats de cette étude montrent que la régulation de la nappe phréatique et l'irrigation souterraine constituent un progrès technologique sur le plan de la gestion des sols et de l'eau. Ces méthodes permettent aux agriculteurs de réduire la contamination de l'eau de drainage par les nitrates et de réduire considérablement l'effet de la période de sécheresse sur la croissance des cultures. Elles devraient être utiles au chapitre de l'hydraulique agricole.

ABSTRACT

Water table control and subirrigation have been recommended for agricultural practice to manage agricultural water quality and improve crop yields. An on-farm study was conducted to evaluate the influence of water table control and subirrigation on a sandy loam soil. A farm was divided into two plots of equal area of 1.9 ha each. One of the plots was installed with a free drainage (FD) system, and the other was installed with a controlled drainage and subirrigation (CDS) system. Both plots were planted with corn. The data results were monitored from Julian days of 122 (May 1) to 306 (November 1), 1996. The cumulative volume of drainage water from the CDS plot was larger compared with the FD plot by 20%, for the same period. The soil moisture content in the CDS plot was 15% higher compared with the FD plot. The water table of the FD plot was 61% deeper from soil surface compared with the CDS plot. The cumulative nitrate loss of 29.1 kg in drainage water of the FD plot was twice the amount of 14.6 kg for the CDS plot. The nitrate loading in rainwater accounted for 14% and 28%, respectively, of the cumulative nitrate losses in tile drainage water of the FD and CDS plots. The subirrigation water accounted for 1% (2 kg) of the nitrate loss in drainage water of the CDS plot. Flow weighted mean nitrate concentration of the drainage water was reduced 44% from 19.1 mg/L for FD plot to 10.8 mg/L for the CDS plot. The average rates of leaf transpiration and stomatal conductance, respectively, were 33% and 11% higher at 47.4 mg/m^2/s and 0.73 cm/s for the CDS plot, compared to 31.7 mg/m^2/s and 0.65 cm/s for the FD plot. The average corn yields were 11.0 t/ha from the CDS plot and 6.7 t/ha from the FD plot. The CDS plot had 64% higher corn yields than the FD plot.

Key Words

Nitrate, subirrigation, water table, corn

RÉSUMÉ

La régulation de la nappe phréatique doublée d'une irrigation souterraine a été recommandée comme pratique agricole aux fins de gérer la qualité des eaux agricoles et d'améliorer le rendement des cultures. Une étude agronomique en plein champ a été réalisée dans le but d'évaluer l'influence de cette formule sur un sol de loam sableux. Une exploitation agricole a été divisée en deux parcelles d'une superficie de 1,9 ha chacune. Une des parcelles a été dotée d'un système de drainage libre (DL) et l'autre d'un système de drainage contrôlé et d'irrigation souterraine (DLIS). Du maïs a été planté dans les deux parcelles. Les résultats ont été relevés entre le 122e (1er mai) et le 306e (1er novembre) jour julien de l'année 1996. Le volume cumulé de l'eau de drainage de la parcelle DLIS était de 20 % de plus que celui de la parcelle DL pour la même période. La teneur en eau du sol de la parcelle DLIS était de 15 % supérieure à celle de la parcelle DL. Le niveau de la nappe phréatique de la parcelle DL se trouvait à une plus grande distance (61 %) de la surface du sol que celui de la parcelle DLIS. La perte cumulée de nitrates dans l'eau de drainage de la parcelle DL, qui était de 29,1 kg, représentait le double de celle de la parcelle DLIS, qui s'établissait à 14,6 kg. La charge en nitrates des eaux de pluie représentait respectivement 14 % et 28 % des pertes cumulées de nitrates dans les réseaux de drainage souterrain des parcelles DL et DLIS. Les eaux attribuables à l'irrigation souterraine représentaient 1 % (2 kg) de la perte de nitrates dans l'eau de drainage de la parcelle DLIS. La concentration moyenne pondérée des nitrates en fonction du débit de l'eau de drainage avait diminué de 44 %, passant de 19,1 mg/l pour la parcelle DL à 10,8 mg/l pour la parcelle DLIS. Les taux moyens de transpiration foliaire et de conductance stomatique étaient respectivement de 33 % et de 11 % supérieurs, se situant à 47,4 mg/m^2/s et à 0,73 cm/s pour la parcelle DLIS, en comparaison de 31,7 mg/m^2/s et 0,65 cm/s pour la parcelle DL. La production moyenne de maïs était de 11 t/ha pour la parcelle DLIS et de 6,7 t/ha pour la parcelle DL. Celle de la parcelle DLIS était supérieure de 64 % à celle de la parcelle DL.

Mots clés

nitrate, irrigation souterraine, niveau phréatique, maïs

INTRODUCTION

The environmental significance of nitrogen to aquatic life and to human and animal health has been well documented (Kincheloe et al., 1979; Forman et al., 1985; Haynes et al., 1986; Sittig, 1991). Nitrate is a very soluble ion and is relatively mobile in soil. If not taken up by the crop or denitrified, nitrate can be lost by runoff or leaching to the deeper soil zone and contaminate groundwater or adjoining receiving water systems. Nitrate itself is not toxic. Nitrate can be reduced to nitrite in the gastrointestinal tract of the human infant and in the rumens of animals (Lewis, 1951; Shearer et al., 1972) such as cattle and sheep. This occurs when nitrite oxidizes hemoglobin in the blood, forming methemoglobin, a compound unable to transport oxygen. The World Health Organization and European Community (Council of the European Communities, 1980) set a limit of 50 mg NO^-_3/L (11 mg NO^-_3 N/L) in potable water. Similarly, in North America, the Environmental Protection Agency (EPA), USA and the Water Quality Branch, Canada (Water Quality Branch, 1995) set a limit of 44 mg NO^-_3 /L (10 mg NO^-_3 N/L) as the maximum safe level in drinking water.

Nitrate has been recognized as one of the most common agricultural sources of contamination to ground water. In the North American context, the regional studies indicated that the elevated nitrate concentrations in groundwater in the agricultural areas were partly due to over application of nitrogen (Hallberg, 1986). For example, Wall and Magner, 1988 reported that the increased nitrate level in groundwater in Minnesota was related to the increased intensity of agricultural production. Jones and Schwab (1993) reported that nitrate concentrations of drinking water in Kansas often exceeded the EPA's maximum contaminant level. In Manitoba, nitrate concentrations were found up to 20 mg N/L in the shallow, non-farmstead wells located in irrigated areas overlying the Assiniboine Delta Aquifer (Harker, et al., 1997). In Alberta, a three-year study on tile drainage water from 20 sites, found that 25% of tile drainage water were above the Canadian Water Quality Guidelines for drinking water (Harker, 1982; Paterson, 1992). In Ontario, 1300 domestic and 140 field wells were sampled for groundwater quality (Agriculture Canada, 1993) during the winter and the following summer, and 15% of domestic and 25 % of field wells had average nitrate concentrations above drinking water guidelines. In New

Brunswick, Milburn and Richards (1994) monitored subsurface drainage discharge from continuously cropped corn field year-round with annual nitrogen inputs of about 90 kg/ ha. They found that maximum mean summer nitrate concentration was 13.4 mg N/L.

There has been considerable attention directed toward understanding of the mechanisms involved in contamination of receiving water systems with N from agricultural production. A common conclusion reported by many researchers indicated that proper fertilizer, crop, water and soil management can minimize leaching of nitrates and increase crop yields (Bergstrom, 1987; Kalita and Kanwar, 1993). Recently, regional authorities had focused on reducing farm chemical impacts on the water quality of the Great Lakes and the St. Lawrence lowlands. In Quebec, the Government introduced provision on the protection of soils and water. The provision outlined on the timing of spreading fertilizers; manure spreading to be 30 m from a drinking water source and manure storage facilities to be 300 m from a public water source (The Canadian Society for Engineering in Agricultural, Food, and Biological Systems, 1997). In Ontario, there is increasing demand for on-farm studies to supply information to help minimize nitrogen losses to the environment (Goss et al., 1995). Controlled drainage and subsurface irrigation have been demonstrated by plot scale and green house studies as a viable technology to reduce nitrate loss and improve crop yields (Wright, et al., 1992; Madramootoo, et al., 1995). The objective of this study is to evaluate the influence of water table control and subsurface irrigation on soil-plant-water system, nitrate loss and crop yields.

METHODS AND MATERIALS

Experimental site and drainage system layout

A field site designated as Bicrel Farm (42° 18′ 08″ N, 82°29′ 56″ W) located on a sandy loam soil was divided into two plots (Figure 1a). One of the plots was installed with a free drainage (FD) system, and the other one was installed with a controlled drainage and subsurface irrigation (CDS) system. Each plot was 67 m wide by 284 m long (1.9 ha). The averaged field slope was 0.05%. Each plot contained 10 subsurface tile drains of 102 mm in diameter each, spaced at 6.1m between tiles at an average drain depth of 0.6m below the soil surface. The average slope of the tile was 0.08%. A subsurface irrigation unit and a controlled drainage unit manufactured by Innotag Inc., Montreal, Quebec, Canada were installed on the CDS plot (Figure 1 b). The units regulated drainage from the tile lines in the wet periods, and allowed water for subsurface irrigation in dry periods during the growing seasons. The subsurface tile drains of the CDS and FD plots were connected to a separate, 152 mm diameter subsurface interceptor located at the lower border of the plot (Figure 1 c).

Agronomic practices

Both CDS and FD plots were mouldboard ploughed. The corn (*Zea mays L.),* the Pioneer 3751, was seeded at a rate of 74,000 seeds/ha in a 76.2 cm wide rows and 50.8 cm spacing on May 31, 1996. The fertilizer was applied pre-planting at the following rates: 12.5 kg N/ha, 59 kg P_2O_5 /ha, and 202 kg K_2O/ ha. The anhydrous ammonia at 204 kg N/ha was applied on June 26 as side dressing. Herbicide of Marksman (dicamba: atrazine, ratio = 1:2) was applied on June 15, at 1.5 kg a.i./ha to control weeds.

Soil samples, water table and soil moisture measurements

Twenty soil samples from each of FD and CDS plots were collected, prior to planting. The soil samples were collected at a central location of 37m, 71m, 142 m, and 250 m from the edge of the plot through the field on east - west direction. The samples were taken at depths of 0-30 cm and 30-60 cm, two samples from each position through the field. Six perforated PVC pipes of 50.8 mm diameter, were installed to a depth of 180 cm over and between tile lines at each plot. Automative capacitive water level probes (Dataflow Systems, Wesdata, Queensland, Australia) were inserted inside the PVC pipes to measure the water table depth. Soil water content measurements were made using a neutron scattering techniques (Model CPN 503, Campbell Pacific, Martinez, Calif.). Two aluminum access tubes were inserted to a depth of 120 cm at each plot. The measurements were taken twice per week during the growing season.

Tile drainage flow measurement and sample collection

A 2.3 m diameter by 4 m deep manhole inside the instrument shed (Figure 1 c) received the tile drainage outflow from the plots. Two fabricated stainless steel tipping buckets (Tan, et al., 1997) were installed in the manhole to measure the flow rate, respectively, from FD and CDS plots. The tipping buckets were calibrated to determine the relationship between flow rate and the tipping rate, $Y = 8.11\ X - 66.07$, ($r^2 = 0.99$), where Y is the flow rate, in L/hr., and X is the bucket tipping rate, in number of tips/hr. A dataloger counts and stores the number of bucket tips and converts the records into drainage volume. Two ISCO model 2900 autosamplers, one for each of the CDS and the FD systems, were used to collect drainage water samples. Each sampler contains twenty-four 500 ml bottles. The autosamplers were activated by a signal from the pre-set numbers of the bucket tips. The water samples from tile drainage were stored in bottles at 4 °C prior to analyses for concentration of nitrate on a TRAACS 800 autoanalyzer.

Rainwater, surface runoff and irrigation water sampling

The rainwater samples were collected by connecting a tygon tubing through the base of the rain gage to a 4L glass jar located inside the instrument shed (Figure 1 a-3). The surface runoff event samples were collected using a Sigma Model Series 702 automatic sampler. The activation of the automatic sampler to start collecting samples was based on the number of bucket tips (10 tips for this study) of the rain gauge together with the water level rise above a reference level at the stilling well. The purpose of using this combined measure was to eliminate the effect of backfill water to the open drain from the conveyance channel (Figure 1 a-1). A grab sample was taken approximately once in every two weeks, at the irrigation water pump house for determination of the nitrate level of the irrigation water.

Climatic, soil temperature and surface runoff measurements

The air temperature, wind speed and direction, relative humidity, total solar radiation, photosynthesis active region (PAR) and UVB were measured at the experimental site (Figure 1 a-

3), using the National Water Research Institute's standard protocol of the meteorological measurement. All the climatic sensors were installed at 4 m above the ground level. The amount of precipitation was measured by a thermostat controlled heated rain-snow gage. The flow rate of the open drain (Figure 1 a-3) was measured by using a 90° V-notch weir. The surface runoff volume was calculated by using the depth of flow of the weir. For partial flow condition, the equation of $Q = 1.34\ H^{2.48}$ was used. Under full flow condition, the equation of $Q = 1.49\ (AR^{0.667}\ S^{0.5})\ /n$ was used. Where: Q is the flow rate, H is the depth of flow of the V-weir, A is the area of flow, R is the hydraulic radius, S is the slope of the culvert and n is the Manning's roughness. Soil temperatures were measured at depths of 5, 15 and 30 cm near the instrumentation site, using a temperature probe. The outputs of the measurements were stored onto a Campbell Scientific 21 XL dataloger and were downloaded weekly via a Campbell Scientific modem DC112 through a telephone data line to a computer located at the National Water Research Institute.

Corn heat unit (CHU)

Using on-site temperature and radiation data, the corn heat units (CHU) were calculated according to equation (1) (Brown and Bootsma (1993))

$$CHU = (1.80\ (T_{min} - 4.4) + 3.33\ (T_{max} - 10) - 0.084\ (T_{max} - 10)^2) \times 0.5 \qquad (1)$$

Where: T_{min}, T_{max} = minimum and maximum temperature (°C). The CHU was cumulated from the date of seeding (May 31, 1996) until the date of corn physiological maturity (October 28, 1996).

The potential evapotranspiration (PE)

The potential evapotranspiration (PE) was calculated by using equation (2) for southwestern Ontario (Sanderson, 1974, Tan and Fulton, 1981).

$$PE = 1.26 \times (0.48 + 0.01\ Ta) \times (0.341 \times Rs - 0.039) \qquad (2)$$

Where: PE is in mm/day, Ta is the average daily air temperature (^{o}C) and Rs is the average daily solar radiation (KJ/m^2 /day).

Leaf transpiration, stomatal conductance

The rates of leaf transpiration and stomatal conductance were measured at 48, 60, 68, 69, 75, 76, 81, 82, 92, 101, and 126 days after seeding by using a Delta-T AP4 Porometer. Prior to each episode of measurement, the porometer was calibrated at the field environment by using the Delta-T supplied calibration plate. The measurement was performed by clamping the porometer's automatic reading cup on the abaxial surface of the sample leaf. When the acceptable value is reached, a 'beep' from the porometer is sounded. The accepted value is stored in the porometer's memory.

During each of the measurements, three topmost matured leaves of the plant were measured, and 21 plants on each of the CDS and FD plots were randomly selected for measurement. The time courses of measurement were between 08-10, 10-12, 12-14, 14-16, and 16-18 hours. The average values of the three leaves and 21 plants were used to calculate the rates of leaf transpiration and stomatal conductance.

Mean concentration and load of nitrate

Flow weighted nitrate concentrations were calculated from the sum of nitrate loss, a product of concentration and flow volume, over the collection period (May 1 to Nov. 1) divided by the sum of the total flow volume (Baker and Johnson, 1981).

RESULTS AND DISCUSSION

Environmental factors and monthly climatic characteristics

Previous crops grown on the plots were soybeans in 1992 and tomatoes from 1993 to 1995. The soil samples collected in 1995 after harvest were analyzed for soil types (Duncan and LaHaie, 1979), nitrate nitrogen (NO_3^--N), organic carbon (OC), inorganic carbon (IC), organic matters (OM), conductivity (Cond.) and pH. The results of soil analysis for CDS and FD plots are listed in Table 1. As shown in Table 1, the sand constituted the majority of the soil type. There was no significant difference of soil type between the two plots except the organic matters and the NO_3^--N at the top 30 cm of the CDS plot were higher than the FD plot, respectively, by 20 % and 15%. The acidity of soil of both plots was within the preferred pH ranges (5.4 -7.0) for corn (Ontario Ministry of Agriculture, Food and Rural Affairs, 1994).

Table 1. Soil particle size distribution, NO_3^--N, OC, IC, TOC (OC+IC), organic matter, conductivity and pH

Plot	Zone (cm)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	NO_3^--N (ppm)	OC (%)	IC (%)	TOC (%)	OM (%)	Cond. (µm/cm)	pH
CDS	0-30	0.0	59.9	18.3	21.8	11.6	1.22	0.79	2.01	5.26	3.0	5.8
	0-60	0.0	61.3	18.3	20.4		0.44	0.84	1.28			
FD	0-30	0.0	56.7	21.2	22.1	9.3	1.61	0.48	2.09	4.48	3.2	6.2
	0-60	0.0	58.7	14.5	26.8		0.52	0.28	0.80			

Note: TOC = OC + IC

The climatic factors were measured year round at the experimental site. For the purpose of this study, only the monthly (May to October) climatic characteristics were summarized in Table 2. The temperature in May was fairly cool. The planting was started late on May 31. The average air temperature from June to August was 21.8 °C after planting. This temperature was close to the preferred ranges (22 °C - 27 °C) for corn growth from germination to grain filling. The average relative humidity from June to October was 76.4 %. It was also within the preferred ranges (72 - 80 %).

The sum of the rainfall from June to October was 413.7 mm which was slightly higher compared with the long-term average (401.0 mm), by 3 %. The rainfall was not evenly distributed during the growing period. The rainfall in September alone was more than double the sum of rainfall received for the months of June, July, August and October (Table 2). Thus, subsurface irrigation was initiated on the CDS plot on July 8 and continued until September 6. A total of 183.9 mm of irrigation water was used. With respect to corn plant, May-June is a period of germination and vegetation growth, while July-August is a period of flowering and grain filling. During these periods, the climatic factors play an important role of crop growth and yields coupled with optimum nutrient supply. There was sufficient solar energy during the growing season. The months of June, July and August (Table 2) received the highest solar heating. The average PAR from June to October was 242 MJ/m^2 (Table 2). The highest UV values for June, July and August were less than 0.0002% of the total radiation. Its effects on the plant life, and especially crop yields were considered to be negligible. The sum of CHU from January to December was 3372, which was slightly higher than the long-term average of 3344 (Drury and Tan, 1994).

Table 2. Monthly climatic characteristics at the experimental site, 1996.

Parameters	May	June	July	August	September	October
Air temperature (°C)	13.7	21.2	21.8	22.4	18.5	12.4
Relative humidity (%)	74.0	77.1	72.0	77.2	78.8	76.5
Soil temperature (°C): 0-30 cm	13.5	21.0	23.0	25.2	20.2	13.1
Radiation (MJ/m^2)	523.8	549.2	613.3	581.0	359.3	243.7
PAR (MJ/m^2)	262.9	282.3	308.2	291.2	190.6	135.9
UV (mJ/m^2)	590.0	885.0	926.0	654.0	155.0	14.0
PAR/Radiation (%)	50.1	51.4	50.2	50.1	53.0	55.8
UV/Radiation (%)	0.0001	0.0002	0.0002	0.0001	0.00001	0.000001
Evapotranspiration (mm)	96.4	113.2	126.6	121.0	70.7	51.7
Rainfall (mm), 1996	78.6	55.8	52.0	17.0	238.5	50.5
Rainfall (mm), long term*	72.7	97.4	88.6	82.1	80.7	52.2
Cumulative (CHU)	425	637	675	694	557	386

Note: M = mega; m = milli; * = 1960-93 at Eugene Whelan Experimental Farm (20 km from the experimental site), Woodslee, Ontario.

Quantification

Within the context of a systematic study of several components of the soil-plant-water and nitrate from the FD and CDS systems, it is desirable to express the result of the individual parameter of a component on a time scale during the study period from planting to harvest. This facilitates a comparison of parameter values between the CDS and the FD plots. The studied parameters are soil water content, water table depth, cumulative tile drain volumes, nitrate concentrations and losses, plant leaf transpiration and the stomatal conductance. The crop growing period considered in here was from May 1 to November 1. The results of soil moisture content, water table depth, tile drain volume, nitrate concentration and loss, stomatal conductance and leaf transpiration were plotted on a normalized time X-axis by 306 days (Figure 2 (A), (B), (C), (D), (E) and (F)).

Comparison of the effect of water table control and subirrigation between CDS and FD plots

To evaluate the effect of water table control and subirrigation between the CDS and FD plots can be difficult because of the inconsistency of the times series data (Figure 2) of field parameters. To this end, evaluation of the effects was done by comparing a ratio of the field parameters between FD and CDS plots (Table 3). The ratio of soil water content in the soil profile between FD and CDS plot was 0.85 which suggested that the CDS plot contained 15% more of soil moisture for the crop to consume during the growing period compared with the FD plot. Conversely, the ratio of the water table depth between FD and CDS plots was 1.61 indicating that the water table of the FD plot was 61 % deeper from the soil surface compared with the CDS plot. The tile drainage volume was 20 % larger from the CDS plot compared with the FD plot suggesting that supplemental subirrigation water (183.9 mm) satisfied the water losses from the soil profile through evapotranspiration (Table 2). Thus, subsurface irrigation increased the moisture storage of the soil column of the CDS plot compared with the FD plot (Table 3). The rate of leaf transpiration under the CDS plot was 33% higher compared with the FD plot suggesting that there was sufficient moisture supply under the CDS plot. Similarly, the rate of stomatal conductance under the CDS plot also showed an 11% faster compared with those under the FD plot. This may suggest that moisture supply at the root zone of plant grown on CDS plot are readily available without stress for the transpiration processes of the plant leaf. The transpiration processes are beyond the scope of this study.

The results of the field parameter and the results of the ratio between FD and CDS plots are summarized in Table 3. The value of the ratio is to indicate which of the field parameter in the FD plot is greater or smaller than that of the CDS plot. As shown in Table 3, the cumulative nitrate loss in tile drainage water from the FD plot was almost doubled of that in the CDS (Figure 2 (D)). The mean nitrate concentration in the FD plot (Table 3) accounted for about 77% compared with the CDS plot. Nitrate loading in rainwater, surface runoff, and subirrigation water, respectively, was 4.1 kg, 1.7 kg and 2.0 kg. Expressing the nitrate loading of the rainwater to the nitrate losses in tile drainage water from CDS and FD plots, the rainwater accounted for 28% and 14%, respectively, of the total nitrate losses from the CDS and FD plots. This may suggest that rainwater contributed sufficient amount of nitrate in the drainage water of the CDS and FD plots.

The nitrate mean concentrations ranged from 4.1 to 41.0 mg NO^-_3 N/L of the FD plot. Within the ranges, the occurrences of the concentration in the samples had exceeded the Canadian Water Quality Guidelines (CWQG) (1995) of drinking water (10 mg NO^-_3 N/L) by 50% of time during the study period. These corresponded to sampling periods from Julian days 261 through 306. The nitrate mean concentrations ranged from 2.8 to 34.0 mg NO^-_3 N/L for the CDS plot. The occurrences of the concentration in the samples had also exceeded the CWQG drinking water guidelines by 21% of time during the study period. These corresponded to the sampling periods on Julian days; 173, 261 and 275. Estimation of the mass balance of nitrate loss was not conducted because of the components of nitrification (Baker et al., 1975), and denitrification (Addiscott, et al., 1992) were not observed and it was beyond the scope of the current study.

Table 3. Average values of field parameters and its ratio between FD/CDS plots.

Parameter field	FD	CDS	FD/CDS
Mean soil water content, depth: 0-120 cm (mm)	262.0	310.0	0.85
Mean water table depth (cm)	129.0	80.0	1.61
Cumulative tile drain volume (mm)	109.7	137.3	0.80
Cumulative nitrate loss in tile drain water (Kg)	29.1	14.6	1.99
Mean nitrate concentration of tile drain water (mg/L)	19.1	10.8	1.77
Leaf transpiration ($mg/m^2/s$)	31.7	47.4	0.67
Stomatal conductance (cm/s)	0.65	0.73	0.89

Corn yields

Corn was machine harvested on October 28, 1996 and yields were loaded into a weigh wagon and weighed. The average yields of corn were 11.0 t/ha from the CDS plot and 6.7 t/ha from the FD plot. The CDS plot had increased corn yields by 64%compared to the FD plot.

CONCLUSIONS

The results of an on-farm study demonstrated that CDS had the ability to store soil moisture and reduce the nitrate concentration as well as losses to the tile drainage water and increase corn yields compared to the FD plot. The nitrate loss in tile drainage water of the FD plot was double than that in the CDS plot. The water table control and subirrigation system also increased rates of leaf transpiration and stomatal conductance.

ACKNOWLEDGMENTS

The funding of this research was supported by the Great Lakes Water Quality Program and the Canada-Ontario Agriculture Green Plan. Appreciation is also extended to specialized technical assistance of Mr. K.Rinas, Dr. T. Oloya, Mr. E. Smith, Mr. R. Rowsell, Ms. J. St. Denis and the farm owner Mr. G. Bicrel.

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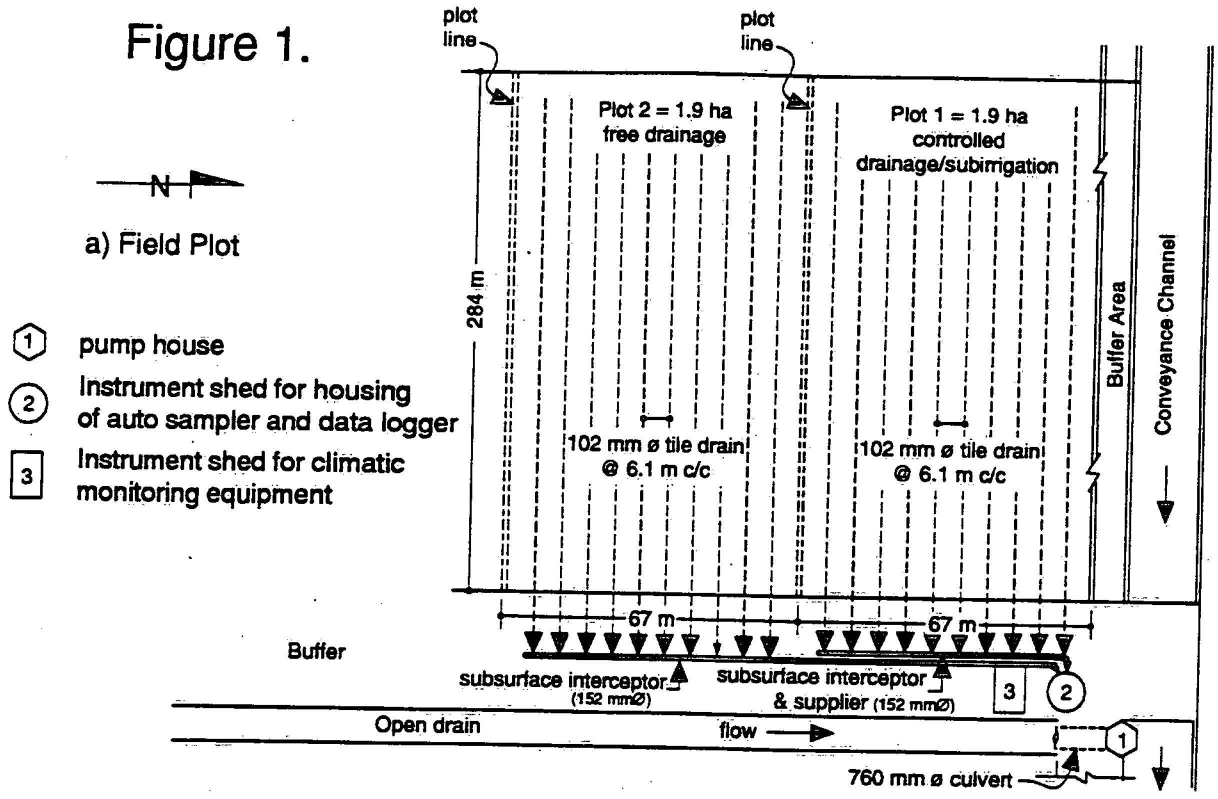
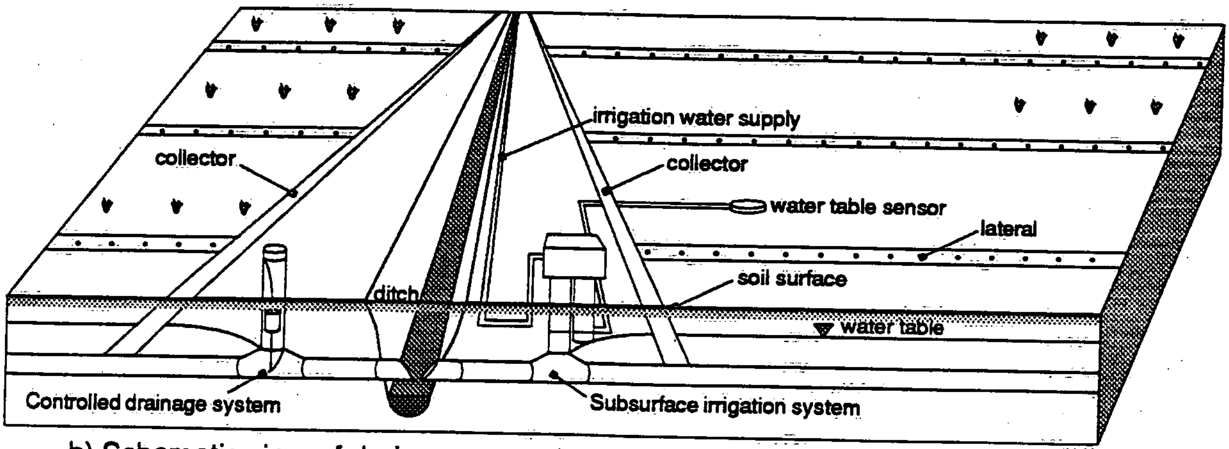
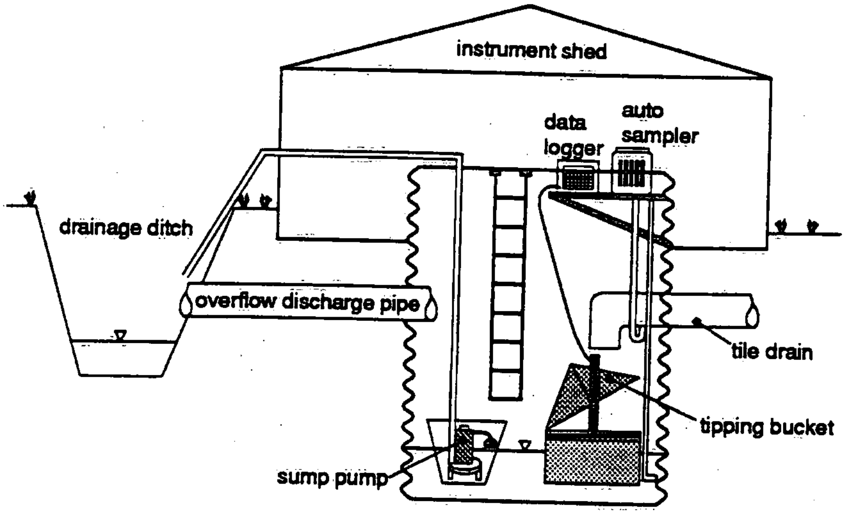
Figure 1.

a) Field Plot





b) Schematic view of drainage control and subsurface irrigation systems (after Innotag, 1996)



c) Schematic view of flow device, auto sampler and data logger in an instrument shed (after Tan et al., 1997)

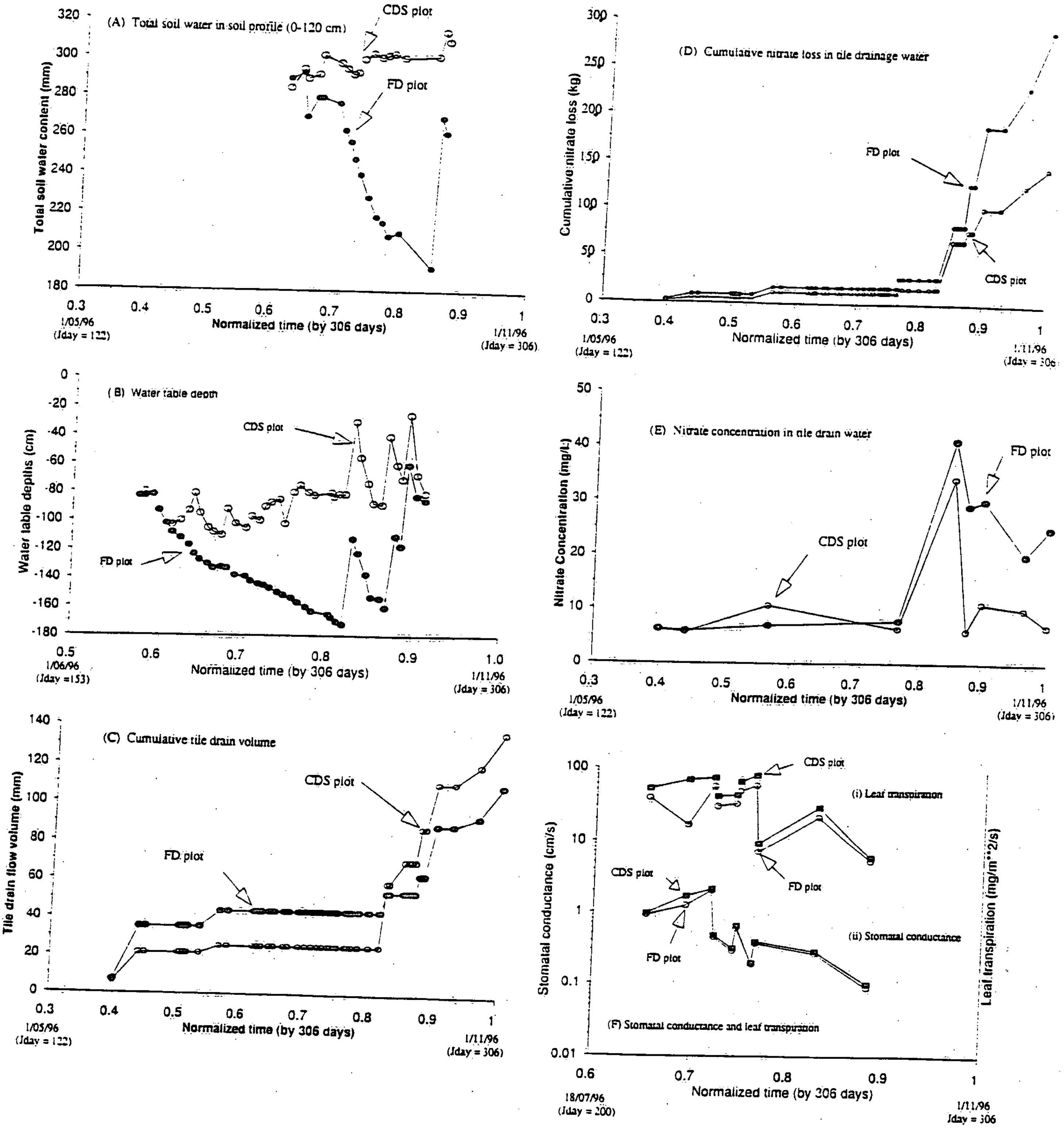


Figure 2. (A) Total soil water in soil profile, (B) Water table depth, (C) Cumulative tile drain volume, (D) Cumulative nitrate loss in tile drainage water, (E) Nitrate concentration in tile drain water and (F) Stomatal conductance and leaf transpiration.

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