EFFECT OF CONTROLLED DRAINAGE AND SUBIRRIGATION ON SUBSURFACE TILE DRAINAGE NITRATE LOSS AND CROP YIELD AT THE FARM SCALE

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C.S. Tan,[1] C.F. Drury,[1] H.Y.F. Ng[2] and J.D. Gaynor[1]

Abstract

An on-farm evaluation of controlled drainage and subirrigation systems can raise farmer awareness and acceptance of these innovative technologies. A four hectare field experiment was established on sandy-loam soil near Harrow in Essex County, Ontario. The field was modified to allow the implementation of two water table-management treatments, controlled drainage with subirrigation (CDS) and free outlet tile drainage (DR). Volume of tile drainage, nitrate concentration and loss in the tile drainage water and crop yields were measured. The objectives of the study were to provide on-farm demonstrations of controlled drainage and subirrigation systems, and to determine their effect on crop yields and environmental benefits.

The CDS system reduced flow weighted mean nitrate concentration in tile drainage water by 38% and total nitrate loss by 37% compared to the DR system from May 1995 to April 1997. The CDS system increased marketable tomato yields by 11% in 1995. The average marketable tomato yields were 58.4 t ha^{-1} for DR system and 64.9 t ha^{-1} for CDS system. The CDS system also increased corn yields by 64% in 1996. The average corn yields were 6.7 t ha^{-1} for DR system and 11.0 t ha^{-1} for CDS system. Thus, the CDS system effectively reduced total nitrate loss and improved yields of both processing tomatoes and grain corn on a sandy loam soil.

Résumé

Une étude menée à la ferme sur les systèmes de drainage contrôlé et d'irrigation souterraine peut contribuer à faire connaître ces techniques innovatrices et à les faire accepter par les agriculteurs. En effet, l'étude présente les résultats d'une expérience réalisée dans un champ de sable limoneux de quatre hectares, près de Harrow, dans le comté d'Essex, en Ontario. Le champ a été modifié de manière à permettre l'installation de deux systèmes de gestion de la nappe phréatique, soit un système de drainage contrôlé avec irrigation souterraine (CDS) et un système de drainage libre par tuyaux vers un collecteur (DR). On a mesuré le volume du drainage par tuyaux, la concentration de nitrate et sa perte dans les eaux drainées par tuyaux, ainsi que le rendement des cultures. L'objet de l'étude était de faire la démonstration des techniques de drainage contrôlé et d'irrigation souterraine, et de cerner leurs effets sur le rendement des cultures et sur l'environnement en général.

Entre mai 1995 et avril 1997, le système CDS a permis de réduire de 38 % la concentration de nitrate moyenne pondérée dans les eaux de drainage par tuyaux et de 37% la perte totale de nitrate par opposition au système DR. Parallèlement, le système CDS a entraîné une augmentation de 11 % de la production de tomates commercialisables en 1995. En moyenne, le rendement des tomates commercialisables s'élevait à 58,4 t par hectare avec le système DR et à 64,9 t par

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[1] Agriculture and Agri-Food Canada, Greenhouse and Processing Crops Research Centre, Harrow, ON
[2] National Water Research Institute, Environment Canada, Burlington, ON

hectare avec le système CDS. Pour le maïs, les chiffres étaient de 6,7 t par hectare et de 11,0 t par hectare respectivement pour les deux systèmes. On peut donc dire que le système CDS a permis de réduire la perte totale de nitrate et d'augmenter le rendement des cultures de tomates et de maïs en terre limoneuse.

Introduction

Results of research conducted at the Agriculture and Agri-Food Canada research facility under the Great Lakes Water Quality Project suggest that an integrated management system which incorporates controlled drainage and subirrigation and reduced tillage is a sustainable management practice (Tan *et al.*, 1993; Drury *et al.*, 1996). Water table management regulates tile discharge to provide storage of rainfall received after herbicide and fertilizer N application. Water and NO_3^- that would otherwise have been lost with tile drainage can be used by the crop during dry periods in the growing season. The system also improves the fertilizer use efficiency of the crop and therefore reduces the NO_3^- available for loss in drainage water over the fall and spring.

Previous research has shown that the volume of water that flowed through the soil was a primary factor responsible for N loss (Tan *et al.*, 1993; Drury *et al.*, 1996). A controlled drainage and subirrigation system reduced annual tile drainage volume by 24% over a 3-year period (Drury *et al.*, 1996). Flow weighted mean nitrate concentration was reduced by 25% with controlled drainage/subirrigation compared with the free drainage treatments. The average annual nitrate loss was reduced by 43%, from 25.8 kg N ha^{-1} for the free drainage treatment to 14.6 kg N ha^{-1}, for the controlled drainage with subirrigation treatment.

Controlled drainage and subirrigation systems have also improved crop yields in some years compared to the free drainage treatment in clay loam and sandy loam soils (Tan *et al.*, 1993; Tan *et al.*, 1996). Cooper *et al.* (1992) observed a 2-year average yield increase of 43% in subirrigated soybeans in Ohio. Madramootoo *et al.* (1995) obtained an average soybean yield increase of 35% with a controlled water table of 0.6 m, over that of sites with conventional drainage. This system used in conjunction with various crops on different soils has shown potential for significant economic returns from tests at the plot scale. However, the system needs to be expanded to the farm scale to evaluate its economic and environmental benefits. A large scale study will raise producer awareness and acceptance of innovative technologies. The objectives of the study were to determine the effect of controlled drainage and subirrigation system on crop yields and its impacts on the nitrate loss in tile drainage water at the farm scale.

Materials and Methods

Experimental Site

A four hectare field was selected for the experiment. The field was located on a sandy loam soil with flat topography, shallow impermeable layer at around 2.5 m, and an abundant supply of water which from the lake was pumped to a ditch for subirrigation. The field was modified to allow the implementation of two water table management treatments; controlled drainage with subirrigation (CDS) and free outlet tile drainage (DR). The experimental layout consisted of two plots each 67 m wide by 284 m long with an area of 1.9 ha. Each plot contained 10 subsurface drains with spacing of 6 m between drains at an average drain depth of 0.6 m.

Controlled Drainage and Subirrigation Systems

An INNOTAG OASIS subirrigation system (INNOTAG Inc., Quebec, Canada) was installed for the CDS treatment. The structure regulated drainage from the tile lines in the spring, and allowed subirrigation in dry periods during the growing season. The system included a water table sensor that is directly connected to the piezometric head control of the OASIS unit. When the sensor measures a water table level lower than the setting, the float in the piezometric head column activates the control mechanism to the irrigation mode. When the water table reaches the desired level, the float causes the automatic valve to shut off, which terminates irrigation. When the water table exceeds the desired level, the float continues to rise and opens the rubber flap gate to initiate drainage. The target water table during the growing season for CDS treatment was 40 cm below soil surface. The controlled drainage unit was only disengaged during the planting and harvesting periods. The source of water for subirrigation comes from a lake. Irrigation water is pumped to a ditch and conveyed to subirrigation structure via an underground 152.4 mm diam. PVC pipe.

Data Collection

Subsurface drains are intercepted at the lower border of each field and rerouted to an instrument shed (Figure 1). The 2.3 m diameter and 4 m deep manhole in the instrument shed receives the drainage discharge from each plot. Two tipping buckets were custom fabricated from stainless steel and installed to measure drainage discharge continuously. Each of the two tipping buckets was calibrated to determine

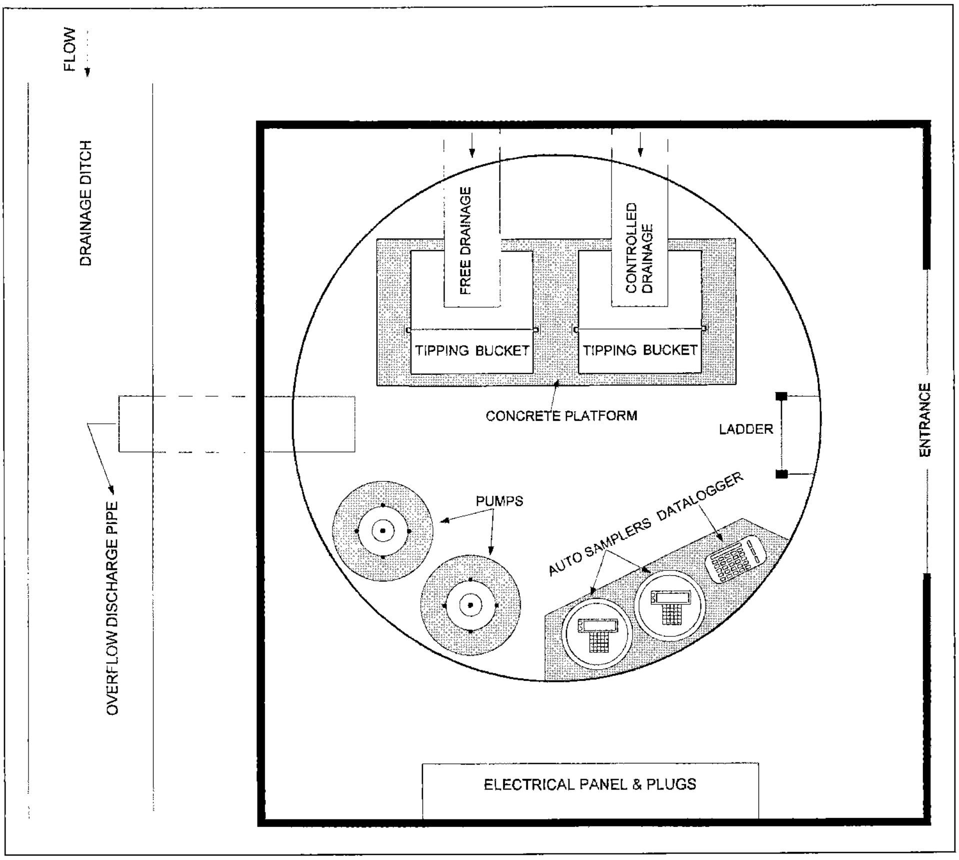

Figure 1: Top View of an Instrument Shed Showing Flow Device, Autosampler and Datalogger

the relationship between flow rate and tip rate (Figure 2). A magnetic reed switch (normally open) is mounted on each bucket, so that every tip produces a switch closure detected by a multichannel datalogger. The datalogger counts and stores these signals for further processing on a continuous basis. Samples of drainage water were collected automatically with two autosamplers (ISCO Model 2900, Lincoln, Nebraska, USA).

Each autosampler contains twenty-four 500 mL bottles. The autosamplers were activated by a signal from the pre-set numbers of tips using a tipping bucket flow device. Sample collection was based on flow volume with collection volumes varying upon the time of year and expected runoff volumes. Water samples were stored in glass bottles at 4°C before analyses for nitrate Tile water samples filtered through a 0.45-µm filter (Gelman GN-6, Gelman Science, MI) were analyzed on a TRAACS 800 autoanalyzer (Bran + Leubbe, Buffalo Grove, IL) for nitrate using the cadmium reduction method (Tel and Heseltine, 1990). Flow weighted mean nitrate concentrations were calculated from the sum of the nitrate loss over the period (May 1,1995 to April 30, 1997) divided by the total flow volume (Baker and Johnson, 1981).

Six 50.8 mm diameter perforated PVC pipes, wrapped in filter material were installed to a depth of 180 cm next to and between the tile lines at each plot. Automative capacitive water level probes (Dataflow Systems, Wesdata, Queensland, Australia) were inserted inside the PVC pipes for monitoring water table depths. Soil water content measurements were made using a neutron scattering technique (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.

Agronomy

In 1995, tomato seedlings (Ohio 8245) were transplanted in twin rows on June 1 at a population of 31,000 plants ha^{-1}. The spacing between the twin rows was 30.5 cm, the

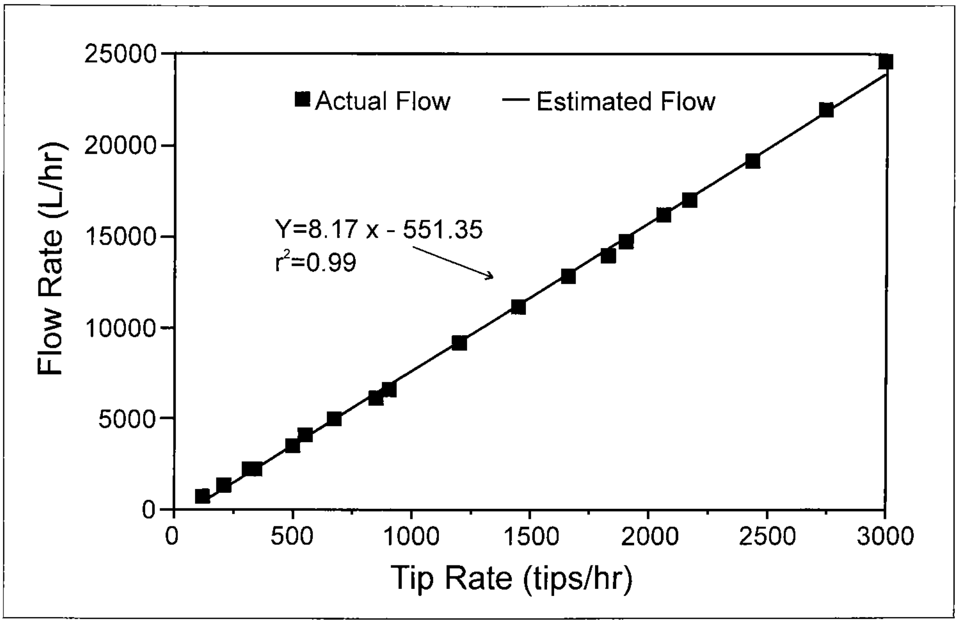

Figure 2: The Relationship Between the Flow Rate (L/hr) and Bucket Tip Rate (tips/hr)

centres of twin rows were 182.8 cm apart, with 30.5 cm between plants. In 1996, corn (Pioneer 3751) was seeded at a rate of 74,000 seeds ha^{-1} in 76.2 cm wide rows on May 31. Fertilizer was applied as a preplant application for tomatoes in 1995 at 78 kg N ha^{-1}, 117 kg P_2O_5 ha^{-1} and 403 kg K_2O ha^{-1}. In addition, sidedress N was applied on June 20 at 56 kg N ha^{-1}. In 1996, fertilizer was applied preplant to corn at 12.5 kg N ha^{-1}, 58 kg P_2O_5 ha^{-1} and 202 kg K_2O ha^{-1}. Anhydrous ammonia was added as a sidedress application on June 26 at 202 kg N ha^{-1}. Metolachlor (2.64 kg a.i. ha^{-1}) and metribuzin (0.3 kg a.i. ha^{-1}) were applied June 1, 1995 for weed control in tomato. Marksman (dicamba/atrazine, 1:2) applied on June 15, 1996 at 1.5 kg a.i. ha^{-1} provided weed control in corn.

Machine harvest yields were taken over the entire experimental field for tomatoes on October 1, 1995 and for corn on October 28, 1996. Harvested materials from the combine were transferred to a weigh wagon and fresh weights obtained. Grain yield was reported at 15.5% moisture content. In the case of tomatoes, yields were calculated from weights recorded at the canning factory.

Climatic Measurement

Weather data were recorded at the experimental field. These measurements included maximum and minimum air temperature, solar radiation, rainfall amount and intensity, wind speed and direction and relative humidity.

Results and Discussion

Table 1 shows that there was 282.2 mm of precipitation in 1995 and 203.4 mm in 1996 between May and August, 58.6 mm below the normal for the growing season in 1995 and 137.4 mm below normal in 1995. Subirrigation for CDS treatment was initiated on June 15 and terminated on September 13, 1995 with a total of

Table 1: Monthly Precipitation (mm) in 1995, 1996, 1997 and 30-yr Long-term Average at the Experimental Site

Month	1995	1996	1997	Long-term avg (30 yr)
	Precipitation (mm)			
Jan.	4.0	24.5	19.5	51.2
Feb.	4.5	22.5	71.5	45.7
Mar.	35.5	16.5	48.5	70.1
Apr.	87.5	76.6	17.5	80.4
May	76.1	78.6		72.7
June	55.5	55.8		97.4
July	79.6	52.0		88.6
Aug.	71.0	17.0		82.1
Sept.	53.1	238.5		80.7
Oct.	57.1	50.5		52.2
Nov.	71.0	21.5		74.1
Dec.	8.5	56.0		80.3
Seasonal Total (May-August)	282.2	203.4		340.8

78.5 mm of subirrigation water added. In 1996, subirrigation for the CDS treatment was initiated on July 8 and terminated on September 6 with a total of 183.9 mm of subirrigation water added. The total soil water in the top 120 cm depth for both CDS and DR treatments during the 1996 growing season was lower than the 1995 growing season (Figure 3). The total soil water with the CDS treatment was consistently

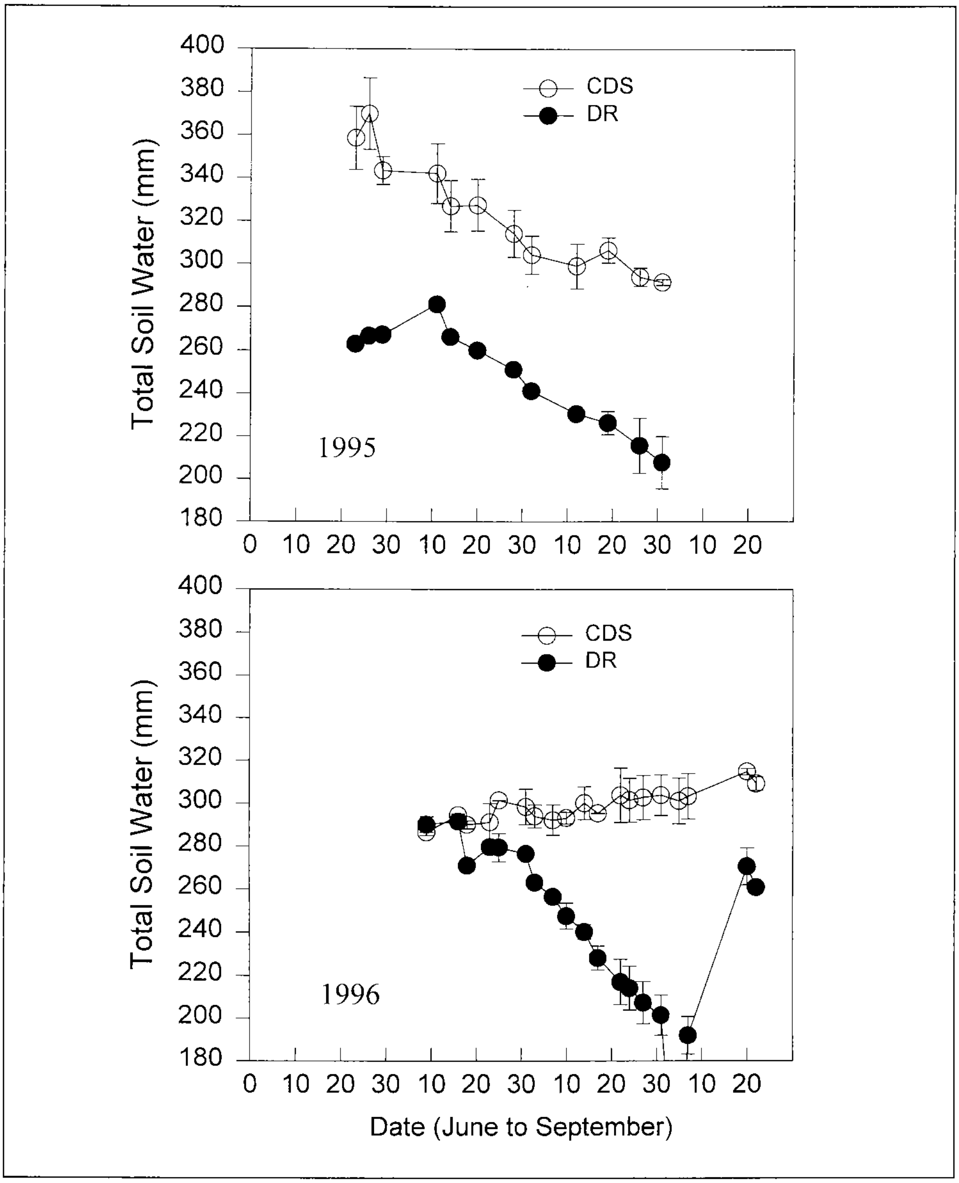

Figure 3: Total Soil Water in the Soil Profile from 0 to 120 cm for the Drainage (DR) and Controlled Drainage/Subirrigation (CDS) Treatments During 1995 and 1996 Growing Seasons. The Vertical Bars are Standard Errors (n=2)

higher than with the DR treatment during the entire 1995 and 1996 growing season (Figure 3). A similar trend was also observed for water table depths (Figure 4).

Tile drainage for the two year period (Figure 5) was similar for the CDS treatment (3,421 m^3 ha^{-1}) and the DR treatment (3,403 m^3 ha^{-1}). Over the two six month non-cropping periods (between November 1 and April 31), 59 and 65% of the tile

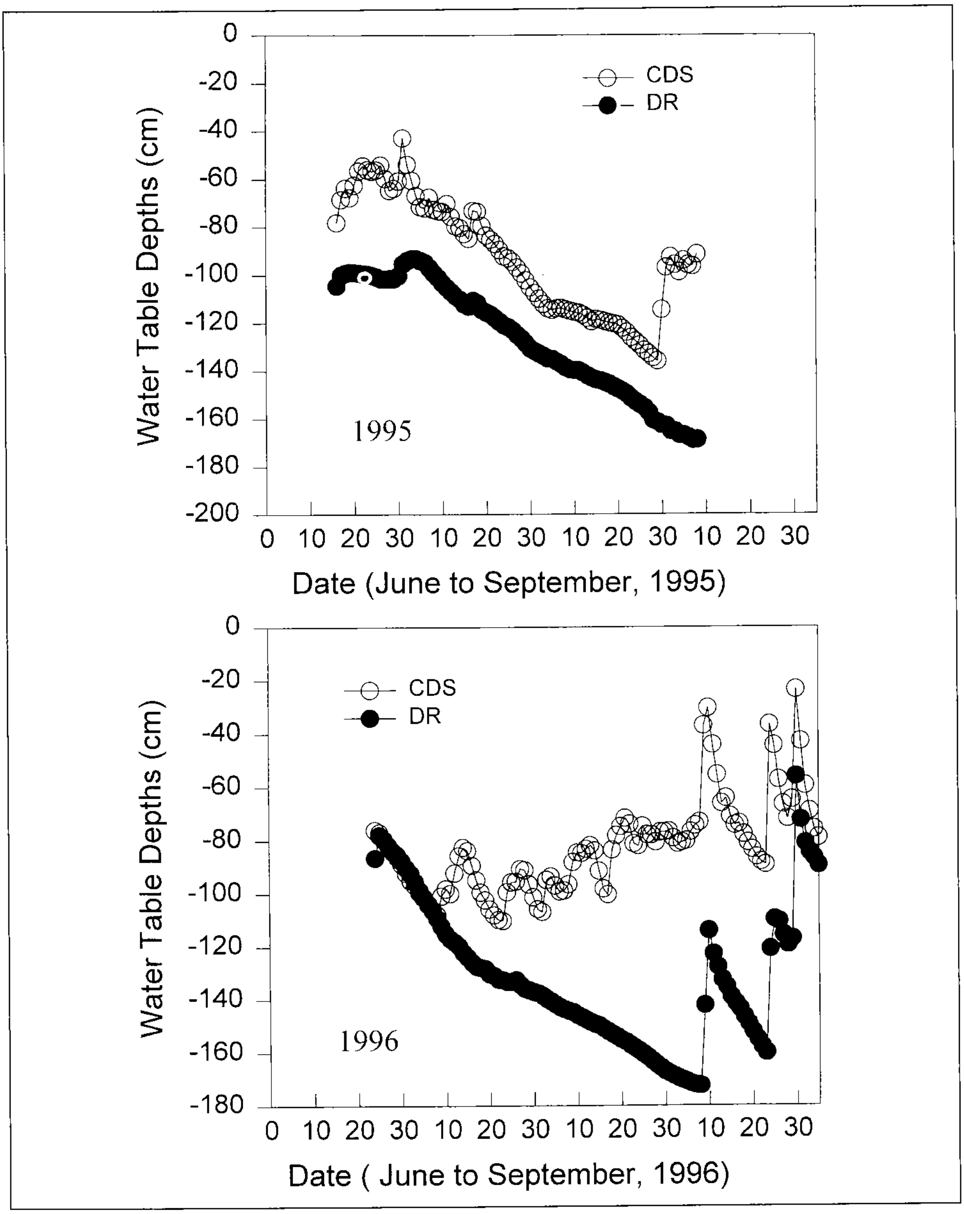

Figure 4: Water Table Depths for the Drainage (DR) and Controlled Drainage/ Subirrigation (CDS) Treatments During 1995 and 1996 Growing Seasons

drainage water was lost from the CDS and DR treatments respectively. In particular, the DR treatment (2,228 m^3 ha^{-1}) had 9% more water loss through tile drainage than the CDS treatment (2,019 m^3 ha^{-1}). In contrast, during the cropping period, there was 19% more tile drainage from the CDS treatment (1,402 m^3 ha^{-1}) than the DR treatment (1,175 m^3 ha^{-1}). This increase with the CDS treatment was due to the reduced storage capacity of available water in the soil as there was greater input of water through both rainfall and subirrigation with the CDS treatment compared to rainfall only with the DR treatment. The greater tile drainage volume in the CDS treatment in the fall of 1996 (Figure 5) was attributed to the high antecendent water content (Figure 3) and high water table depth (Figure 4) prior to heavy precipitation (238.5 mm) in September, 1996 (compared to a 30 year average of 80.7 mm for September). Soils in the DR treatment were much drier and were able to store 120 mm more water in the soil profile than the CDS treatment (Figure 3)

Flow weighted mean nitrate concentration for the entire two year period (May 1, 1995 to April 30, 1997) for CDS treatment was 10.9 mg N L^{-1} compared to 17.5 mg N L^{-1} for the DR treatment. This represented a 38% reduction in nitrate concentration with the CDS treatment compared to DR treatment. The nitrate concentration in DR treatment exceeded the drinking water guidelines (10 mg N L^{-1}) in 64% of the drainage events, whereas the nitrate concentrations exceeded the guidelines in 16% of the events with the CDS treatment. It should be noted, however, that both 1995 and 1996 growing seasons were very dry until September, 1996 (Table 1) which would have minimized nitrate leaching losses. The nitrate concentrations in tile drainage water varied over seasons with the highest levels in the DR treatment occurring from September 10, 1996 to January 6, 1997. During this period, the flow weighted mean nitrate concentration was 26.7 mg N L^{-1} (range of 20.4 to 40.9 mg N L^{-1}) for the DR treatment compared to 13.9 mg N L^{-1} (range of 6 to 34 mg N L^{-1}) for the CDS treatment (Figure 5). For 92% of the sampling periods, the CDS treatment had lower nitrate concentrations in tile drainage water than the DR treatment.

The CDS treatment reduced the total nitrate loss by 37% compared to the DR treatment over the entire two year period (i.e. from 59.6 kg N ha^{-1} for the DR treatment to 37.5 kg N ha^{-1} for the CDS treatment). These lower nitrate losses with the CDS treatment were primarily due to the reduced nitrate concentrations in tile drainage water, and increased plant uptake by the crops especially for the corn in 1996. During the non-cropping period, 42 and 68% of nitrate losses occurred through tile drainage for the CDS and DR treatments, respectively. Nitrate loss from the DR treatment (40 kg N ha^{-1}) was reduced by 60% compared with the CDS treatment (16 kg N ha^{-1}) in the non-cropping period. Nitrate losses were 16% greater with the CDS treatment (22 kg N ha^{-1}) compared with the DR treatment (19 kg N ha^{-1}) during the two cropping periods. These increases during the cropping period were however offset by the large reductions in nitrate loss that occurred in the non-cropping period.

The nitrate losses reported in this study are comparable with those reported in other studies (Drury *et al.*, 1996; Tan *et al.*, 1993; Drury *et al.*, 1993). In other studies involving controlled drainage systems, denitrification contributed to nitrate removal from soil (Kliewer and Gilliam, 1995). Estimates of denitrification losses and N mineralization were beyond the scope of this study. In a controlled drainage/subirrigation study within 5 km of this site no definitive differences in N_2O emissions were found in a clay loam soil (Drury *et al.*, 1996). The low hydraulic conductivity of the Brookston clay loam soil limited the differences in soil water content in the active denitrification zone (0-10 cm) which minimized the effect on N_2O evolution through denitrification. In a previous greenhouse study, high water tables which resulted from water table management increased

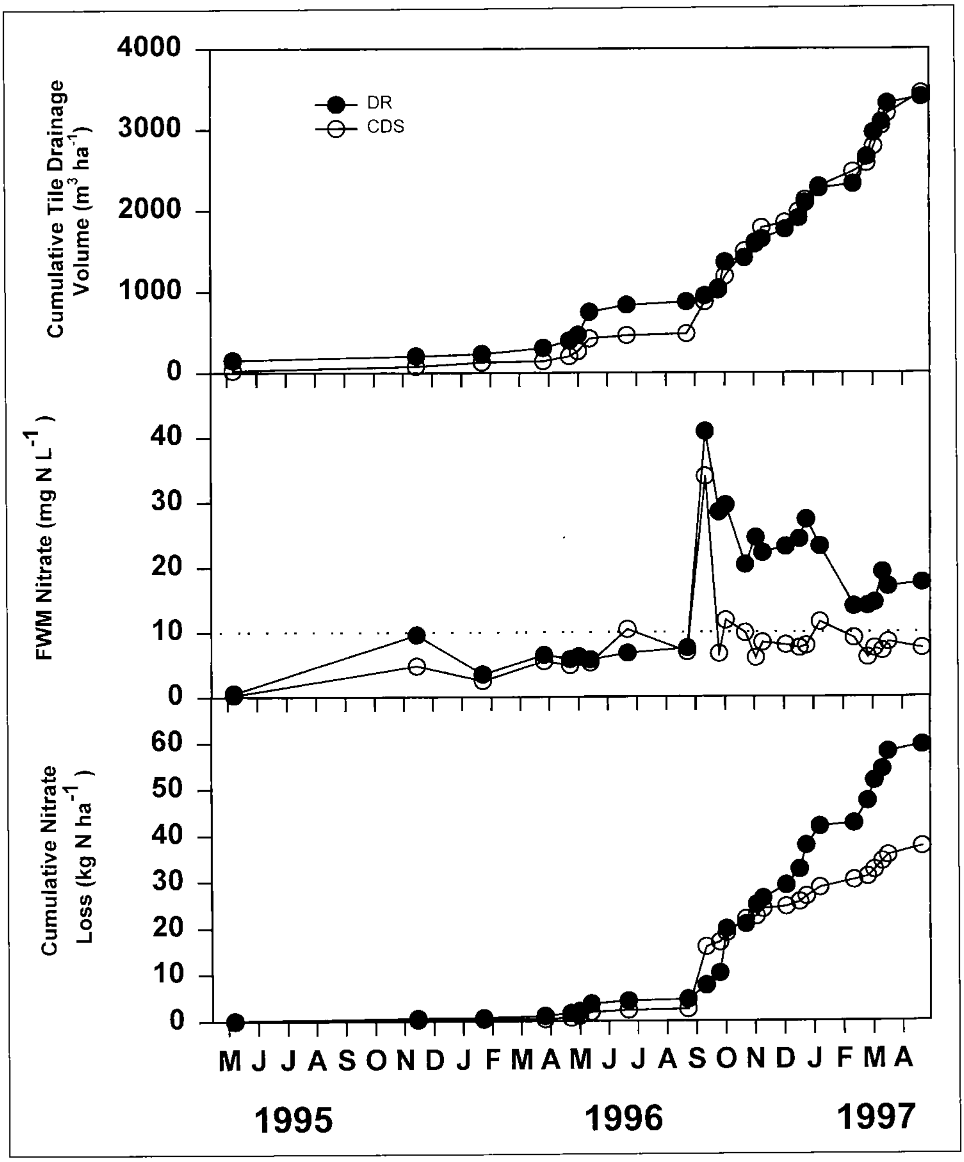

Figure 5: **Cumulative Tile Drainage Volume, FWM Nitrate Concentration and Cumulative Nitrate Loss for the Drainage (DR) and Controlled Drainage/ Subirrigation (CDS) Treatments from May 1, 1995 to April 30, 1997**

N_2O losses from a sandy loam soil (Drury *et al.*, 1997). Hence nitrate losses by denitrification with water table management may have contributed to some of the nitrate removal observed in this study.

The CDS treatment increased marketable tomato yields by 11% in 1995. The average marketable tomato yields were 58.4 t ha^{-1} for DR treatment and 64.9 t ha^{-1} for CDS treatment. Tomato fruits matured earlier in the CDS treatment. The potential marketable yields could have been 15%

larger if the crops had been harvested earlier to account for the large amounts of over-ripe tomatoes in the late harvest of the CDS treatment. The CDS treatment had significantly higher corn yields than the DR treatment. The CDS treatment increased corn yields by 64% in 1996 with grain yields of 6.7 t ha^{-1} for the DR treatment and 11.0 t ha^{-1} for the CDS treatment.

Conclusions

The CDS system reduced total nitrate loss by 37% compared to the DR system (from 59.6 kg N ha^{-1} to 37.5 kg N ha^{-1}) over two years with two different crops. The CDS system also reduced flow weighted mean (FWM) nitrate concentration by 38% compared to the DR system (from 17.5 mg N L^{-1} to 11.0 mg N L^{-1}). The CDS system increased marketable tomato yields by 11% in 1995 and corn grain yields by 64% in 1996. Thus, a field scale trial of the CDS system effectively demonstrated that this technology will reduce total nitrate loss and improve yields of processing tomatoes and grain corn.

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