RESEARCH SUB-PROGRAM

EFFECT OF CONTROLLED DRAINAGE / SUB-IRRIGATION ON TILE DRAINAGE WATER QUALITY AND CROP YIELDS AT THE FIELD SCALE

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FORWARD

This report is one of a series of **COESA** (Canada-Ontario Environmental Sustainability Accord) reports from the Research Sub-Program of the Canada-Ontario Green Plan. The **GREEN PLAN** agreement, signed Sept. 21, 1992, is an equally-shared Canada-Ontario program totalling $64.2 M, to be delivered over a five-year period starting April 1, 1992 and ending March 31, 1997. It is designed to encourage and assist farmers with the implementation of appropriate farm management practices within the framework of environmentally sustainable agriculture. The Federal component will be delivered by Agriculture and Agrifood Canada and the Ontario component will be delivered by the Ontario Ministry of Agriculture and Food and Rural Assistance.

From the 30 recommendations crafted at the Kempenfelt Stakeholders conference (Barrie, October 1991), the Agreement Management Committee (AMC) identified nine program areas for Green Plan activities of which the three comprising research activities are (with Team Leaders):

1. **Manure/Nutrient Management and Utilization of Biodegradable Organic Wastes** through land application, with emphasis on water quality implications
   - **A.** Animal Manure Management (nutrients and bacteria)
   - **B.** Biodegradable organic urban waste application on agricultural lands (closed loop recycling) (Dr. Bruce T. Bowman, Pest Management Research Centre, London, ONT)

2. **On-Farm Research**: Tillage and crop management in a sustainable agriculture system. (Dr. Al Hamill, Harrow Research Station, Harrow, ONT)

3. **Development of an integrated monitoring capability** to track and diagnose aspects of resource quality and sustainability. (Dr. Bruce MacDonald, Centre for Land and Biological Resource Research, Guelph, ONT)

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EFFECT OF CONTROLLED DRAINAGE/SUBIRRIGATION ON TILE DRAINAGE WATER QUALITY AND CROP YIELDS AT THE FIELD SCALE

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1. EXECUTIVE SUMMARY

Controlled drainage and subirrigation have been recommended as a sustainable agricultural management practice. Controlled drainage regulates tile discharge to provide storage of rainfall and minimize tile discharge losses of nitrogen and other agricultural chemicals. Stored water and nitrate can also be used by the crop during dry periods in the growing season which would otherwise leach from the crop root zone. Controlled drainage combined with subirrigation have been shown to improve corn and soybean yields. The system however needs to be evaluated at the farm scale for its impacts on sustainable agriculture and environmental quality. A large farm scale evaluation of this new water management system on producer land raises farmer awareness and acceptance of these innovative technologies. In Southwestern Ontario, three field scale "on-farm" demonstration sites were established in cooperation with three producers. A controlled drainage (CD) system was established on two clay loam sites in a paired watershed (no-tillage versus conventional tillage), whereas a controlled drainage and subirrigation (CDS) system was established on a sandy loam site. 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.

On two clay loam sites, soil structure, organic matter content and water storage in the soil profile were improved with no-tillage (NT) compared to conventional tillage (CT). No-tillage also increased earthworm populations. No-tillage was found to have higher tile drainage volume and nitrate loss which were attributed to an increase in soil macropores from earthworm activity. The controlled drainage system (CD) reduced nitrate loss in tile drainage water by 14% on CT site and 29 % on NT site compared to the corresponding free drainage system (DR) from May, 1995 to December, 1996. No-tillage farming practices are definitely enhanced by using a controlled drainage system for preventing excessive nitrate leaching through tile drainage. Average soybean yields for CT site were about 12 to 14% greater than the NT site in 1995 and 1996. However, both CT and NT treatments had little effect on soybean yields, between free drainage and controlled drainage systems in 1995 and 1996 due to extremely dry growing seasons.

On a sandy loam site, the controlled drainage and subirrigation (CDS) system reduced flow weighted mean nitrate concentration in tile drainage water by 31% and total nitrate loss by 24% compared to the free drainage (DR) system from May, 1995 to December, 1996. The controlled drainage and subirrigation 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.

SOMMAIRE

Le drainage contrôlé et l'irrigation souterraine sont considérés comme des moyens de gestion agricole durable et recommandés. Le drainage contrôlé assure la régulation du taux d'écoulement de l'eau par les tuyaux et permet de conserver l'eau de pluie et de réduire le plus possible le dégagement d'azote et d'autres substances agrichimiques. De plus, l'eau et les nitrates emmagasinées peuvent servir à irriguer les cultures par temps sec pendant la période de croissance; autrement, celles-ci seraient lessivées à partir de la rhizosphère. Il a été démontré que le drainage contrôlé combiné à l'irrigation souterraine améliore le rendement des cultures de maïs et de soja. Toutefois, il faut déterminer en plein champ les incidences du système sur l'agriculture durable et la qualité de l'environnement. Une évaluation à grande échelle de ce nouveau système de gestion de l'eau sur des terres en production permet de promouvoir ces nouvelles technologies auprès des agriculteurs. On a établi trois sites de démonstration en plein champ en collaboration avec trois producteurs dans le sud-ouest de l'Ontario. On a installé un système de drainage contrôlé à deux sites au sol à limon argileux dans un bassin hydrographique sous deux régimes différents (culture sans travail du sol et culture avec labour traditionnelle) et un système de drainage contrôlé et d'irrigation souterraine (DCIR) à un site au sol sablo-argileux. L'étude avait pour but de faire des démonstrations à la ferme de systèmes de drainage contrôlé et d'irrigation souterraine et de déterminer leur effet sur le rendement des cultures et l'environnement.

Aux deux sites au sol à limon argileux, la culture sans travail du sol (CST) a augmenté la teneur en matières organiques et la capacité d'emmagasinement de l'eau du sol par rapport à la culture traditionnelle (CT). Elle a également augmenté le nombre de vers de terre. De plus, on a enregistré une augmentation du volume de drainage et du dégagement de nitrates avec cette pratique, phénomène qu'on a attribué à l'augmentation du nombre de macropores du sol sous l'action des vers. De mai 1995 à décembre 1996, le système de drainage contrôlé a réduit le dégagement de nitrates dans l'eau de drainage de 14 % au site CT et de 29 % aux sites CST en comparaison du système de drainage libre (DL). Il est évident que l'utilisation d'un système de drainage contrôlé prévenant le lessivage excessif de l'azote dans le sol améliore les pratiques culturales sans travail du sol. En 1995 et en 1996, les rendements moyens en soja étaient supérieurs d'environ 12 à 14 % au site CT par rapport aux sites CST. Toutefois, comme on a enregistré du temps extrêmement sec pendant les périodes de croissance de 1995 et de 1996, les traitements ont eu peu d'effet sur les rendements en soja avec ou sans drainage contrôlé.

Au site au sol sablo-argileux, de mai 1995 à décembre 1996, le système DCIR a réduit de 31 % la concentration moyenne pondérée selon le débit de nitrates dans l'eau de drainage et de 24 % les pertes totales de nitrates en comparaison du système DL. En 1995, le système DCIR a augmenté de 11 % les rendements en tomates de calibre marchand. Les rendements moyens en tomates de calibre marchand étaient de 58,4 t/ha^{-1} pour le système DL et de 64,9 t/ha^{-1} pour le système DCIR. De plus, ce dernier système a fait augmenter les rendements en maïs de 64 % en 1996. Les systèmes DL et DCIR ont produit des rendements

en maïs se chiffrant respectivement à 6,7 et 11,0 t/ha^{-1}. Le système DCIR a donc réduit les pertes totales en nitrates et augmenté les rendements en tomates de transformation et en maïs-grain dans le sol sablo-argileux.

2. 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/subirrigation, reduced tillage and intercropping 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^- can then be used by the crop during dry periods in the growing season that would otherwise have been lost with tile drainage. 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/ 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/subirrigation treatments. Gilliam *et al.* (1978) showed that controlled drainage reduced nitrate transport by nearly 50 per cent compared to conventional drainage practices. Lalonde *et al.* (1996) showed that controlled drainage had a significant effect on drainage flow quality and quantity. Conservation tillage in combination with controlled drainage/subirrigation reduced annual nitrate loss by 49% (Drury *et al.* 1996).

Controlled drainage and subirrigation systems have also improved crop yields in some years compared to free drainage treatment in the 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 conventional drainage. This system used in conjunction with various crops on different soils has the potential for significant economic returns at the plot scale. The system however needs to be expanded to the farm scale to evaluate its economic and environmental benefits. A large scale study of this nature will raise producer awareness and acceptance of innovative technologies. In Southwestern Ontario, three field scale "on- farm" demonstration sites were established in cooperation with three producers. A controlled drainage system was established on two clay loam sites (Chevalier and Shanahan Farms) in a paired watershed (no-tillage versus conventional tillage), while a controlled drainage/subirrigation system was established on a sandy loam site (Bicrel Farm). The objectives of the study on two clay loam sites were to determine: (1) the effect of tillage on soil structure and water quality and (2) the effect of a controlled drainage on nitrate loss in tile drainage water at the farm scale. The objectives of the study on the sandy loam site were to determine the effect of controlled drainage /subirrigation system on crop yields and its impacts on the nitrate loss in tile drainage water at the farm scale.

3. MATERIALS AND METHODS

3.1 Experimental sites

Three field sites each of approximately four hectares were selected for the experiments. Two sites were located on Brookston clay loam soil and are within 0.5 km of each other. One site (Chevalier Farm) has been under conventional tillage (CT) for four years, and the second site (Shanahan Farm) under no tillage (NT) for six years. The third site (Bicrel Farm) was located on a sandy loam soil under conventional tillage for four years. Each site consisted of two plots, controlled drainage (CD) and free tile drainage (DR) at Chevalier and Shanahan Farms. Each plot was about 46 m wide by 494 m long and contained 5 subsurface tile drains with an average spacing of 9.3 m and average tile drain depth of 0.65 m. The field at the Bicrel Farm was modified to allow the implementation of two water table management treatments, controlled drainage/subirrigation (CDS) and free tile drainage (DR). Each plot was about 67 m wide by 284 m long and contained 10 subsurface drains with spacing of 6 m between drains at an average drain depth of 0.6 m.

3.2 Controlled drainage and subirrigation systems

On two clay loam sites (Chevalier and Shanahan Farms), INNOTAG control drainage units were installed to control the volume of drainage water from the field. These units are equipped with two main components, the flap gate and a float. The float is attached to the rubber flap of the gate by a string and acts as a level regulator for the water table. When the water table reaches the float level inside the riser column, the float opens the rubber flap gate to allow drainage of excess water. On a sandy loam site (Bicrel Farm), an INNOTAG Subirrigation system (OASIS unit) was installed. The structure regulated drainage from the tile lines in the spring, and allowed subirrigation in dry periods during the growing seasons. The system included a water table level sensor that is directly connected to the piezometric head control of the OASIS unit. When the water table sensor measures a 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 on a sandy loam site (Bicrel Farm) was 40 cm below soil surface. In all three sites, controlled drainage units were only disengaged during the planting and harvesting periods.

3.3 Data collection

Subsurface drains are intercepted at the lower border of each field and rerouted to an instrument shed (Fig 1). The 2.3 metre diameter and 4 metre deep manhole in the instrument shed receives the drainage discharge from each plot. Six tipping buckets were custom fabricated from stainless steel and two were installed to measure drainage discharge continuously at each site. Each of the six tipping buckets was calibrated to determine the relationship between flow rate and tip rate (Fig. 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) at each location. 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 4EC before analyses for nitrate. Tile water samples filtered through a 0.45-um 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 December 23, 1996) divided

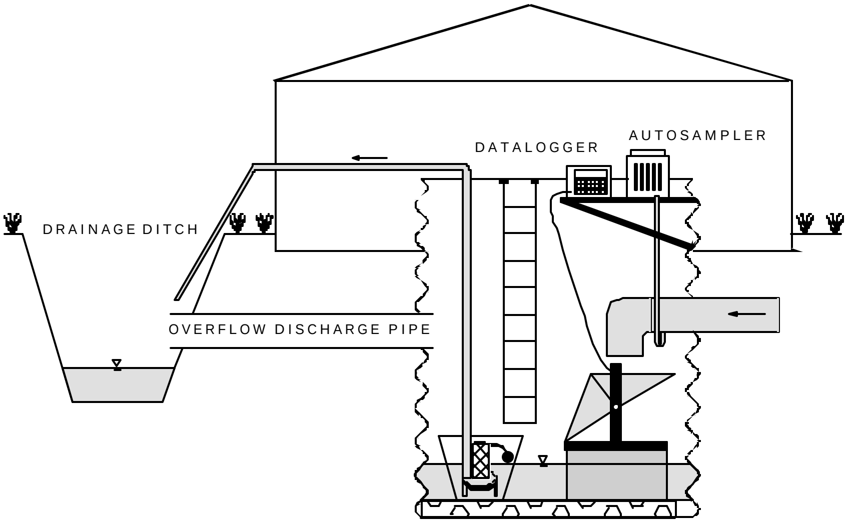

Fig. 1 - Side view of an instrument shed showing flow device, autosampler and datalogger.

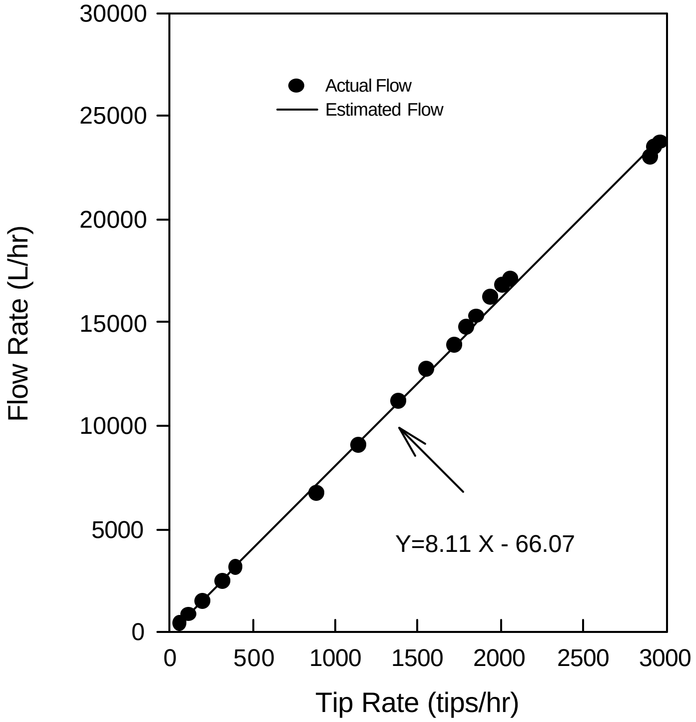

Fig. 2 - The relationship between the flow rate (L/hr) and bucket tip rate (tips/hr)

by the sum of the total flow volume (Baker and Johnson, 1981).

Representative soil samples were collected from all three sites at depths of 0-30 cm and 30-60 cm for particle size, wet aggregate stability (WAS) and mean weight diameter (MWD) analyses. Soil particle size was determined by the standard pipet method (Gee and Bauder 1986). Wet aggregate stability (WAS) was determined on 0.25 mm to 4.69 mm air dry aggregates wetted by immersion using the method described by Kemper and Roseau (1986). The size distribution of aggregates was characterized by determining the mean weight diameter (MWD; Kemper and Roseau 1986). Earthworm samples were collected from conventional tillage (Chevalier Farm) and no-tillage (Shanahan Farm) sites in late October 1996. Sampling was accomplished by the methods described by Tomlin and Gore (1974). Earthworms were collected using a worm expellant (50 ml of 40% V/V formaldehyde per 9 L of water) poured from a garden watering can inside a 0.36 sq. metre wooden quadrat placed on the soil. Before the formalin solution was applied, the sampling area was cleared of thatch or plant residue using a fan rake. Worms were collected for a period of 12 minutes from the time of application of the expellant and placed into mason jars containing a 70% alcohol solution. Earthworms were collected from 6 samples each for both free drainage and controlled drainage plots on conventional tillage and no-tillage sites.

Six 50.8 mm diameter perforated PVC pipes , wrapped in filter material were installed to a depth of 180 cm over and between the tile lines at each plot from all three sites. 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 from all three sites. The measurements were taken twice per week during the growing season.

3.4 Agronomy

Soybeans (Northrup King 2492, 1995 and Tecumseh, 1996) were seeded at a rate of 580,000 seeds ha^{-1} in 38 cm wide rows between second and third weeks of May on two clay loam sites (Chevalier and Shanahan Farms) in 1995 and 1996. On a sandy loam site (Bicrel Farm) in 1995, tomato seedlings (Ohio 8245) were transplanted on June 1 at a population of 31,000 plants ha^{-1} (twin rows), the spacing between twin rows was 30.5 cm, the centres of twin rows were 182.8 cm apart, with 30.5 cm between plants. At the Bicrel Farm in 1996, corn (Pioneer 3751) was seeded at a rate of 74,000 seeds/ha in 76.2 cm wide rows on May 31. At the Chevalier Farm, fertilizer (0-18-36) was broadcasted at a rate of 224 kg ha^{-1} and incorporated during the fall of 1994 and 1995. At the Shanahan Farm, fertilizer (6-36-18) was banded beside the seed at a rate of 185 kg ha^{-1} in 1995 and 1996. At the Bicrel Farm, 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}. Weeds on the Chevalier and Shanahan Farms were controlled by postemergence application of imazethapyr (34 to 68 g a.i. ha^{-1}) and postemergence application of bentazon (0.5 to 1.0 kg a.i. ha^{-1}). 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. 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 at the Bicrel Farm. Marksman (dicamba/atrazine, 1:2) applied June 15, 1996 at 1.5 kg a.i. ha^{-1} provided control of weeds in corn at the Bicrel Farm.

Machine harvest yields were taken over the entire experimental field from all three sites. Harvested materials from the combine were dumped into a weighwagon and weighed. In the case of tomatoes , yields were weighed when tomatoes were delivered to the Canning Factory.

3.5 Climatic measurement

Weather data for Chevalier Farm was collected from a weather station within 0.5 km of the site. Weather data for Shanahan and Bicrel Farms were recorded at the experimental fields.

4. RESULTS AND DISCUSSION

4.1 Effect of tillage and controlled drainage on soil structure and tile water quality on two clay loam sites (Chevalier and Shanahan Farms).

The precipitation was similar for both CT (Chevalier Farm) and NT (Shanahan Farm) sites in 1995 and 1996, except for the month of September in 1996 (Table 1). The 1995 and 1996 growing seasons were very dry with total precipitation from May to August being 80 mm and 136 mm, respectively below long-term average. In 1996, a total of 198 mm of precipitation fell in September at the CT site, whereas only 74.6 mm of precipitation fell in September at the NT site.

A comparison of the CT and NT sites for 0-30 cm and 30-60 cm soil depths showed differences in soil properties. The CT site had a higher sand content and lower clay content than the NT site (Fig. 3). No-tillage increased mean weight diameter (MWD) in the 0-30 cm soil depths compared to CT (Fig. 4). No-tillage also improved wet aggregate stability (WAS) in the 0-30 cm soil depths (Fig. 4). There was no difference in WAS at the deeper 30-60 cm soil depths. Stone and Heslop (1987) measured wet aggregate stability and organic carbon in a 3 year corn-soybean-corn rotation comparing ridge and conventional tillage. They reported that organic carbon and wet aggregate stability were greater under ridge tillage. The average earthworm population and average earthworm weight at the NT site were significantly greater than at the CT site (Fig. 5). There were only small differences in average earthworm population and weight between the CD and DR treatments.

Table 1. Monthly precipitation (mm) in 1995, 1996 and 30-yr long-term average at three experimental sites.

	Bicrel Farm		Chevalier Farm		Shanahan Farm		
Month	1995	1996	1995	1996	1995	1996	Long-term avg (30 yr)
	. . . . Precipitation (mm)						
Jan.	4.0	24.5	50.0	28.5	50.0	28.5	51.2
Feb.	4.5	22.5	4.8	27.8	4.8	27.8	45.7
Mar.	35.5	16.5	33.8	44.5	33.8	44.5	70.1
Apr.	87.5	76.6	65.8	75.8	76.3	75.5	80.4
May	76.1	78.6	66.3	68.3	60.4	75.9	72.7
June	55.5	55.8	38.0	67.0	29.1	58.9	97.4
July	79.6	52.0	96.5	53.5	109.1	49.9	88.6
Aug.	71.0	17.0	54.0	17.8	69.3	17.9	82.1
Sept.	53.1	238.5	35.5	198.0	29.7	74.6	80.7
Oct.	57.1	50.5	83.0	58.0	81.6	41.7	52.2
Nov.	71.0	21.5	67.5	60.2	67.2	60.2	74.1
Dec.	8.5	56.0	12.5	42.0	12.5	42.0	80.3
Seasonal Total (May-August)	282.2	203.4	254.8	206.6	267.9	202.6	340.8

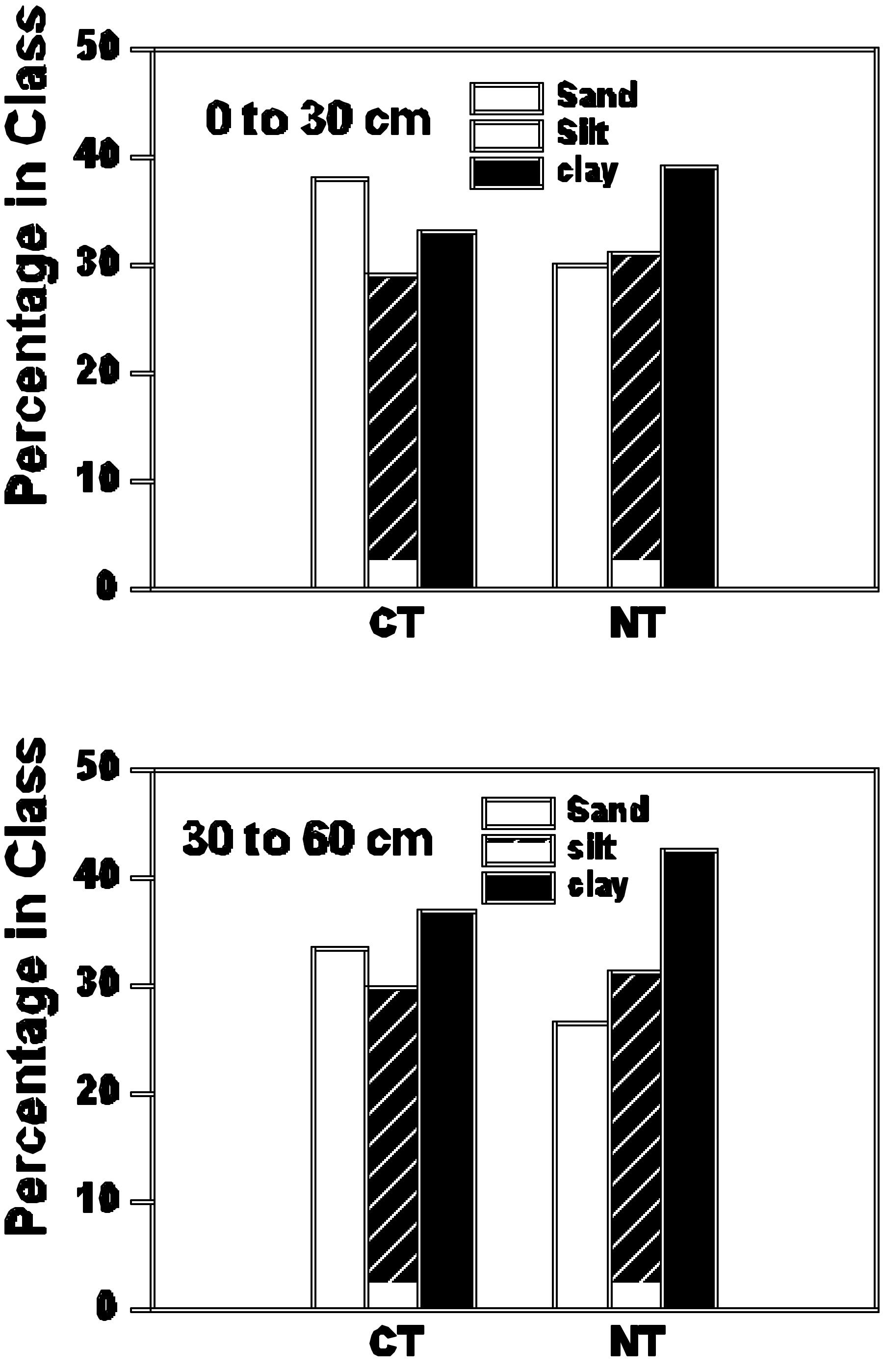

Fig. 3. Soil texture between 0-30 cm and 30-60 cm depths for conventional tillage (CT) and no-tillage (NT) sites.

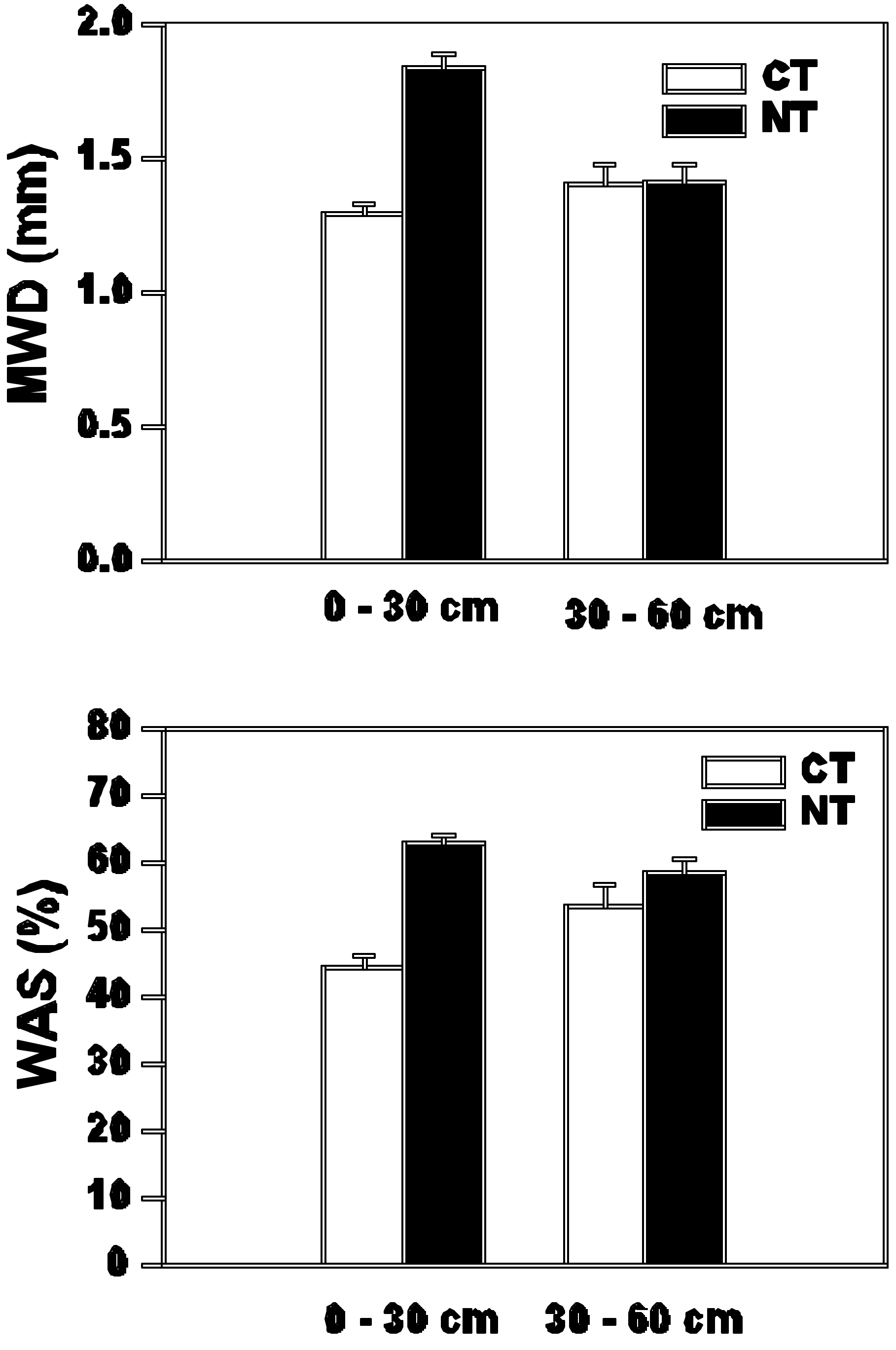

Fig. 4. Mean weight diameter (MWD) and wet aggregate stability (WAS) between 0-30 cm and 30-60 cm soil depths for conventional tillage (CT) and no-tillage (NT) sites. The vertical bars are standard errors (n=10).

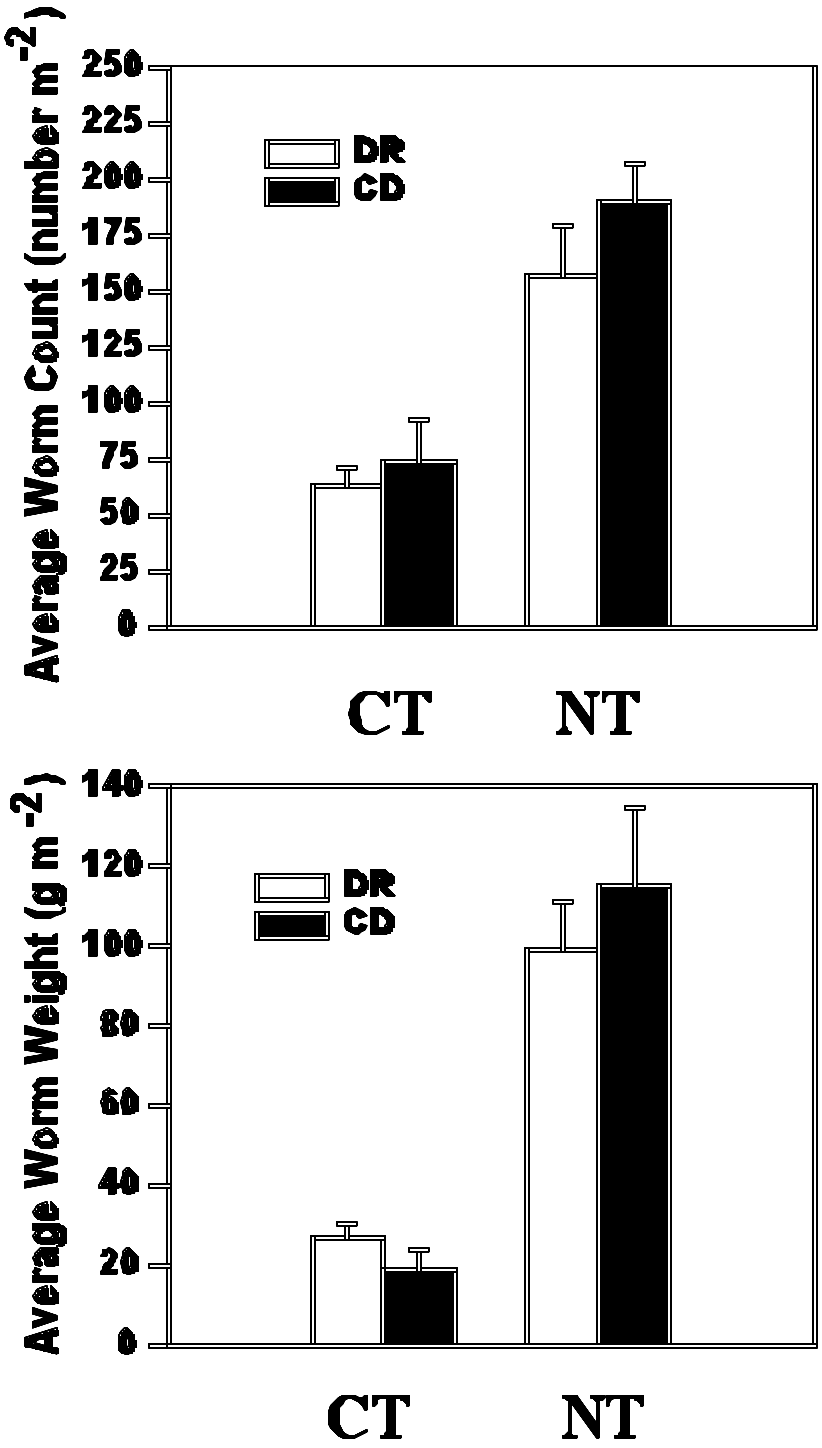

Fig. 5. Average worm count and average worm weight for the drainage (DR) and controlled drainage (CD) treatments at the conventional tillage (CT) and no-tillage (NT) sites. The vertical bars are standard errors (n=6).

Drees et. al (1994) reported that earthworm channels were abundant in no-till plots, but absent in conventionally tilled plots.

The total soil water in the top 120 cm depth in the NT site was greater than in the CT site for both DR and CD treatments during the 1995 growing season (Fig. 6). The total soil water content differences between CT and NT sites were small during the 1996 growing season (Fig. 7). The extremely low precipitation in July and August during the 1996 growing season could account for the small differences in soil water content between CT and NT sites (Table 1). A similar trend was also observed for water table depths (Figs. 8 & 9).

The drainage treatments for the NT site had 68% more tile drainage volumes (1993 kL ha^{-1}) than the CT site (1188 kL ha^{-1}). These greater volumes with the NT site were evident throughout the entire year (Fig. 10). Controlled drainage treatment reduced tile drainage volume by 22% in the NT site but only reduced the volume by 13% with the CT site. The CD system was more effective on the NT site because there was a greater volume of tile drainage with this site. Long-term no-tillage resulted in greater preferential flow as a result of increased earthworm populations (Fig. 5) and perhaps improved pore continuity. Edwards et. al. (1993) reported that no-till soils produced the greatest amounts of preferential flow under high intensity storms. The increased preferential flow was attributed to earthworm burrows. For all treatments, most of the tile water (72%-81%) was lost in the 6 month non-cropping period between harvest and planting (Nov. 15 to May 14).

The nitrate concentration of the tile drainage water was greater than the 10 mg N L^{-1} drinking water guidelines for 90% of the water samples from the CT site and was above this guideline for 68% of the sampling events in the NT site (Fig. 10). The nitrate concentration of tile drainage water was particularly high from April to October 1996. The flow weighted mean nitrate concentration of the tile drainage water

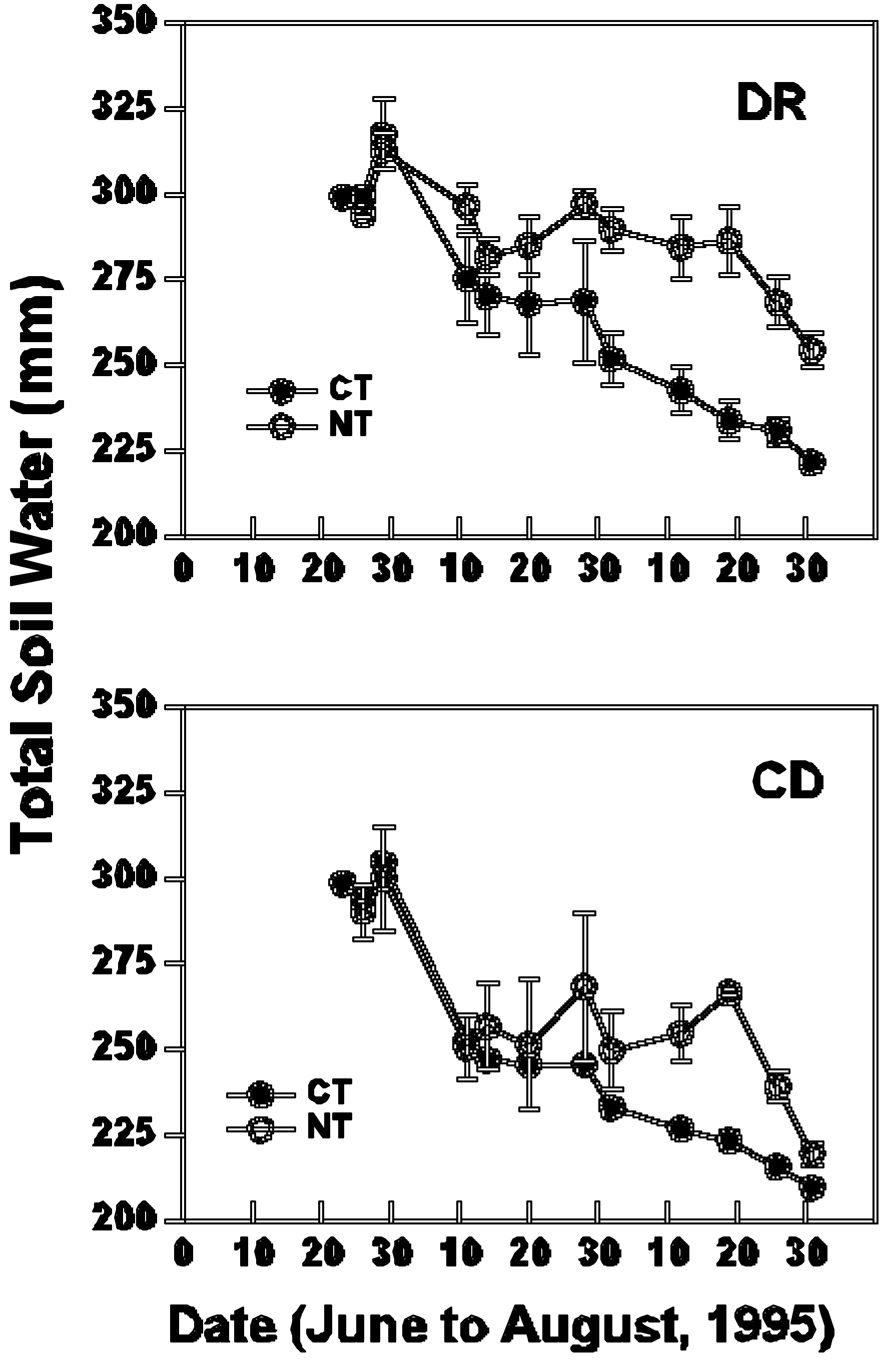

Fig. 6. Total soil water in the soil profile from 0 to 120 cm for the drainage (DR) and controlled drainage (CD) treatments at the conventional tillage (CT) and no-tillage (NT) sites during the 1995 growing season. The vertical bars are standard errors (n=2).

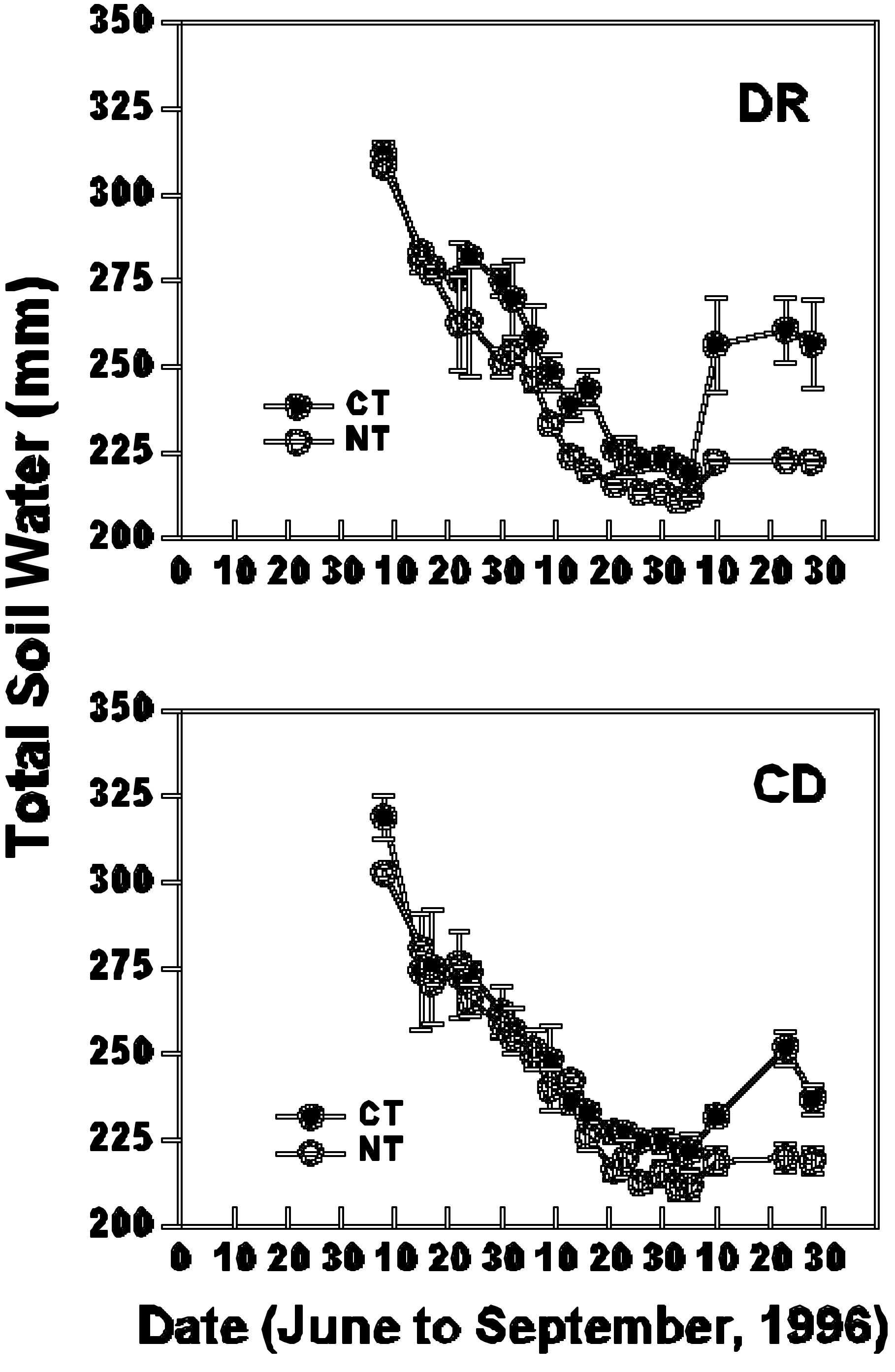

Fig. 7. Total soilwater in the soil profile from 0 to 120 cm for the drainage (DR) and controlled drainage (CD) treatments at the conventional tillage (CT) and no-tillage (NT) sites during the 1996 growing season. The vertical bars are standard errors (n=2).

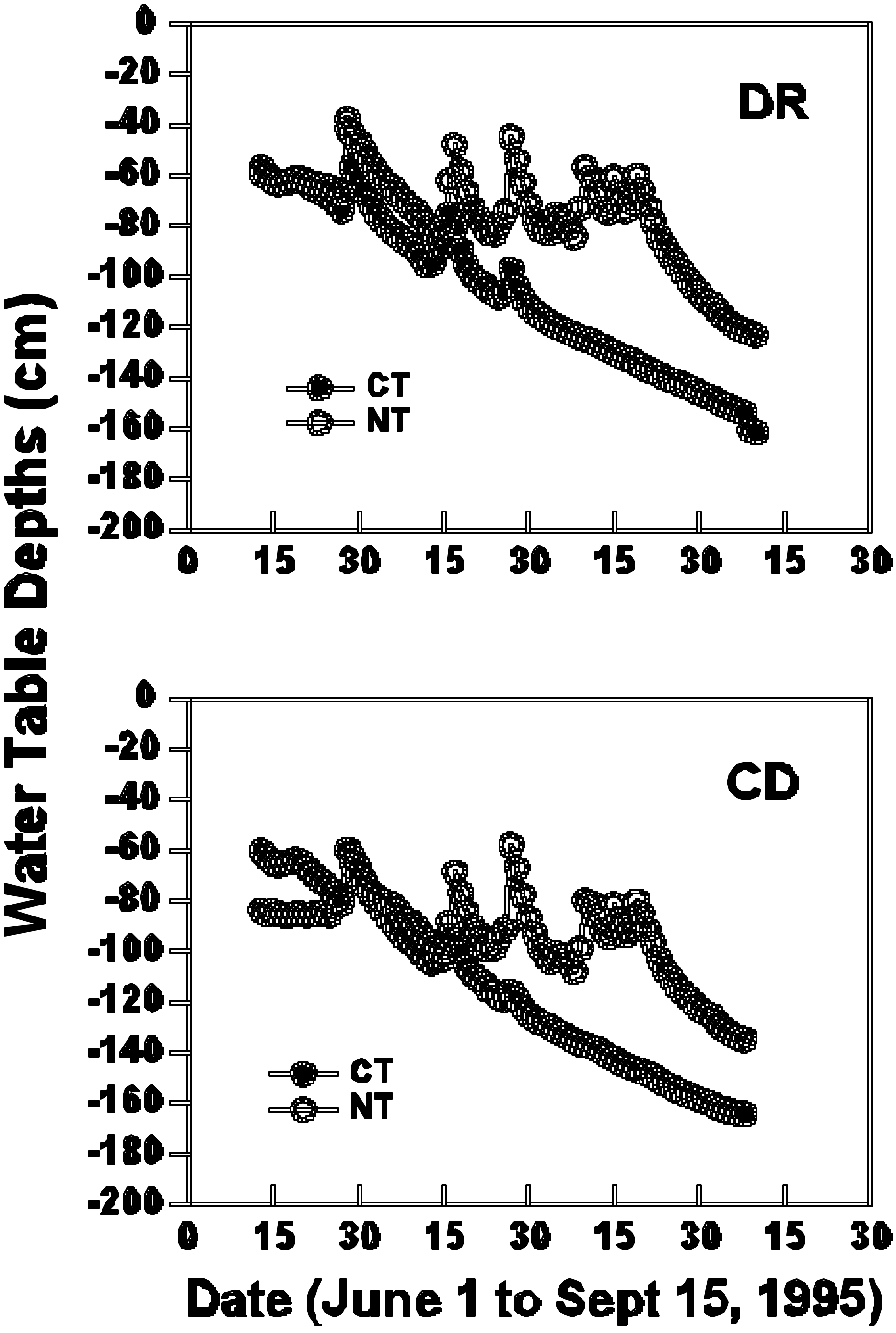

Fig. 8. Water table depths for the drainage (DR) and controlled drainage (CD) treatments at the conventional tillage (CT) and no-tillage (NT) sites during the 1995 growing season.

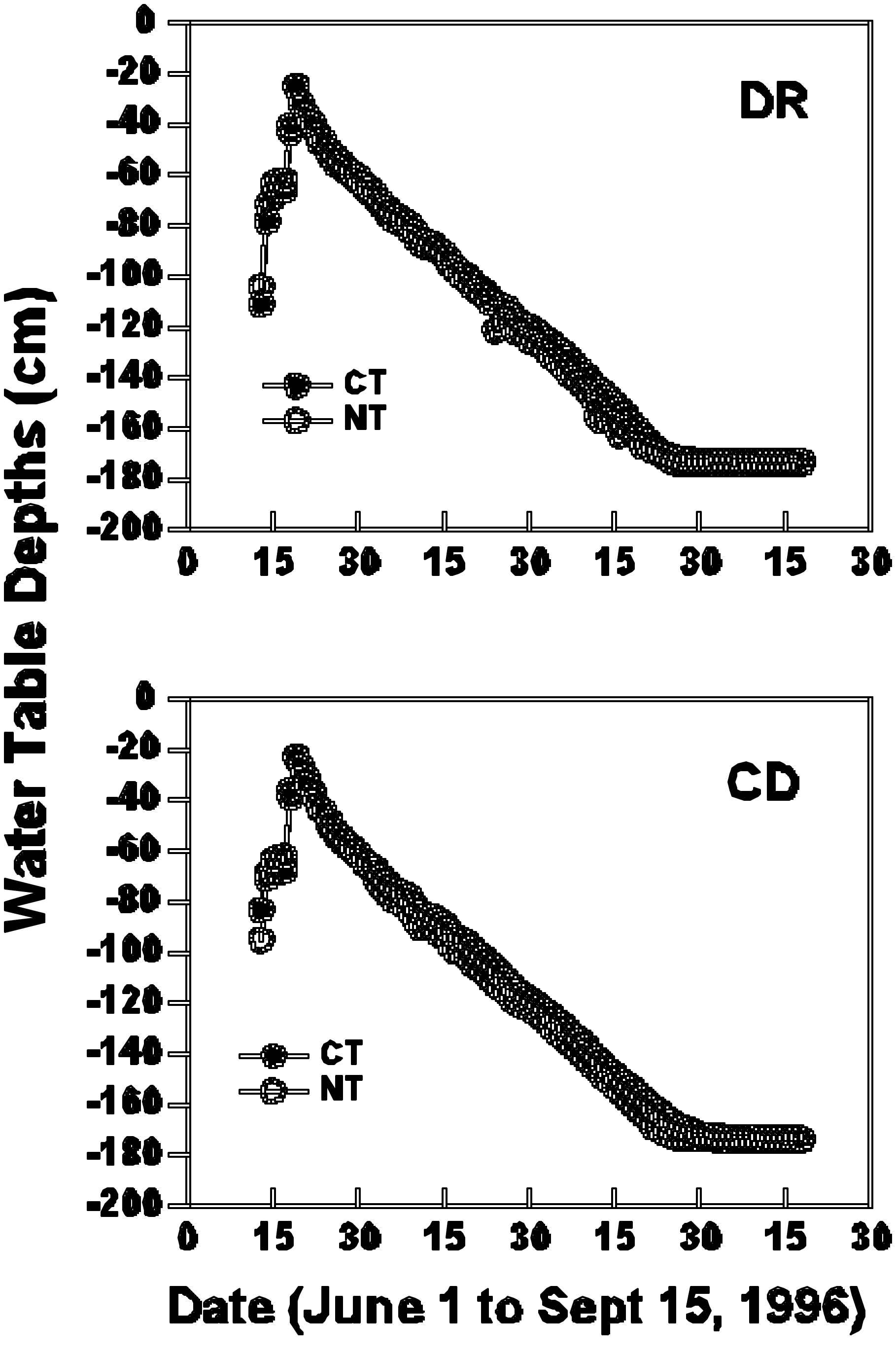

Fig. 9. Water table depths for the drainage (DR) and controlled drainage (CD) treatments at the conventional tillage (CT) and no-tillage (NT) sites during the 1996 growing season.

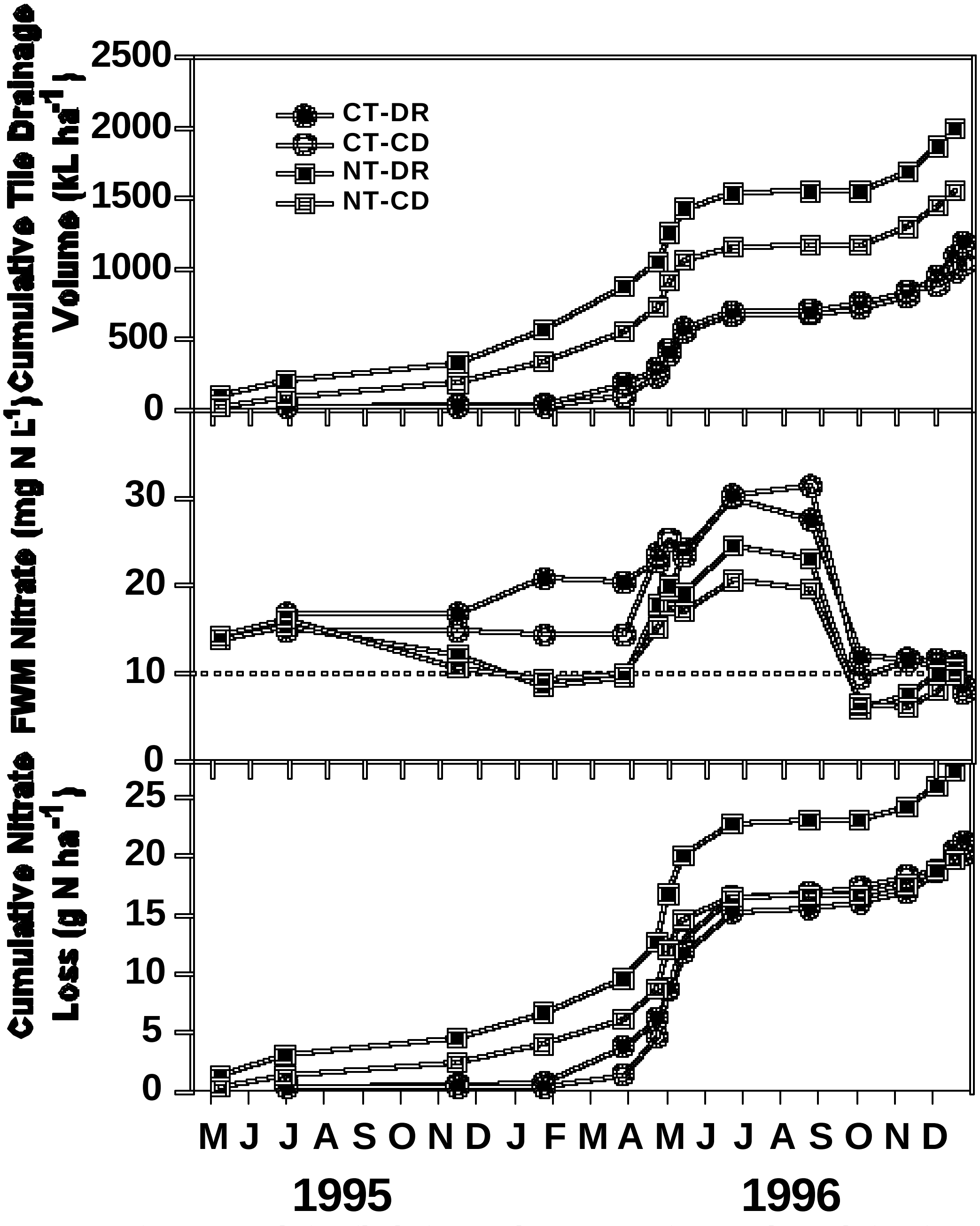

Fig. 10. Cumulative tile drainage volume, FWM nitrate and cumulative nitrate loss for the drainage (DR) and controlled drainage (CD) treatments at the conventional tillage (CT) and no tillage (NT) sites during the period from May,1995 to December, 199

over the entire period was 19 mg N L^{-1} for the CT site whereas it was 13 mg N L^{-1} for the NT site. Controlled drainage did not affect flow weighted mean nitrate concentrations compared to free drainage for either CT or NT sites. Nitrate losses were greatest during the non-cropping period ranging from 72 to 80% across the tillage and water table control treatments (Fig. 10). Averaged across the two water table control treatments, the NT site had 14% more nitrate lost (23.6 kg N ha^{-1}) through tile drainage than the CT site (20.7 kg N ha^{-1}). Controlled drainage (CD) treatments reduced tile nitrate loss by 27% in the NT site (from 27.3 kg N ha^{-1} to 19.8 kg N ha^{-1}) and by 4% in the CT site (from 21.2 to 20.3 kg N ha^{-1}) compared to the corresponding DR treatments (Fig.11). The differences in nitrate loss between the NT and CT sites were due primarily to the larger volumes of tile drainage water lost from the NT site compared to the CT site. Smaller nitrate concentration was found in the tile drainage water from the NT than the CT site because of dilution from the larger drainage volumes. Thus the differences in nitrate loss were smaller than the differences in tile drainage volume between these two sites. This relationship of increased nutrient losses with increased drainage volumes has also been reported by Bolton *et al.* (1970) and by Drury *et al.* (1996). Drury *et al.* (1993) reported that conservation tillage treatments reduced tile drainage volume, nitrate concentration of tile drainage water and therefore total nitrate loss compared to conventional tillage treatments. Perhaps the differences in drainage volume loss and total nitrate loss between these two studies is related to the increased earthworm populations with the no-till treatments in this study (Fig. 5). The NT treatments in this study probably had greater preferential flow which facilitated the greater amount of nitrate lost through tile drainage compared to the NT treatments in the continuous corn study reported by Drury *et al.* (1993).

Both CT and NT sites had little difference in yield between DR and CD treatments in 1995 and 1996 (Fig. 12). This was mainly due to a dry growing season for both years. However, the average yield for CT site was about 14% and 12 % greater than the NT site in 1995 and 1996, respectively.

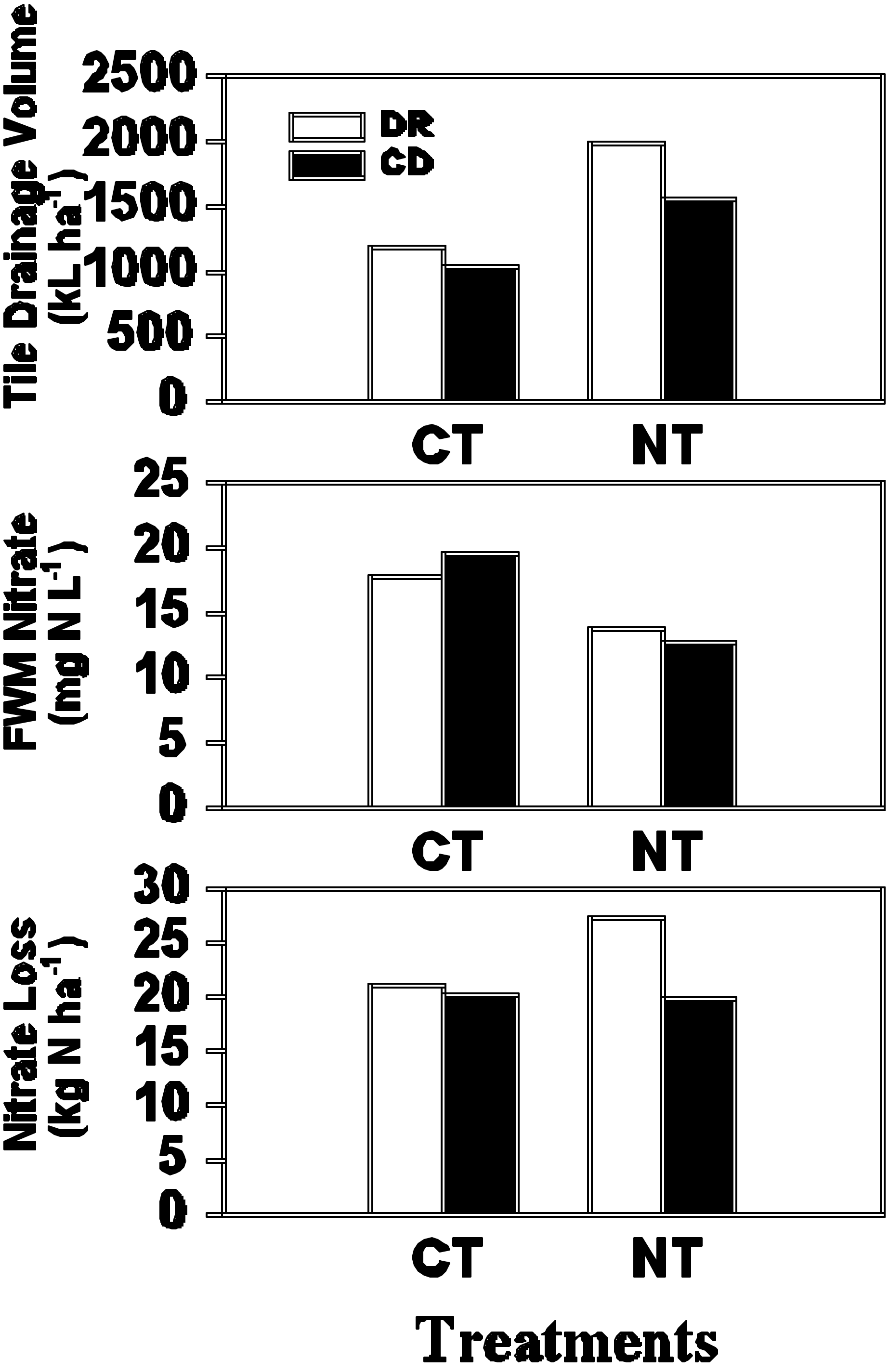

Fig. 11. Total tile drainage volume, FWM nitrate and total nitrate loss for the drainage (DR) and controlled drainage (CD) treatments at the conventional tillage (CT) and no-tillage (NT) sites from May, 1995 to December, 1996.

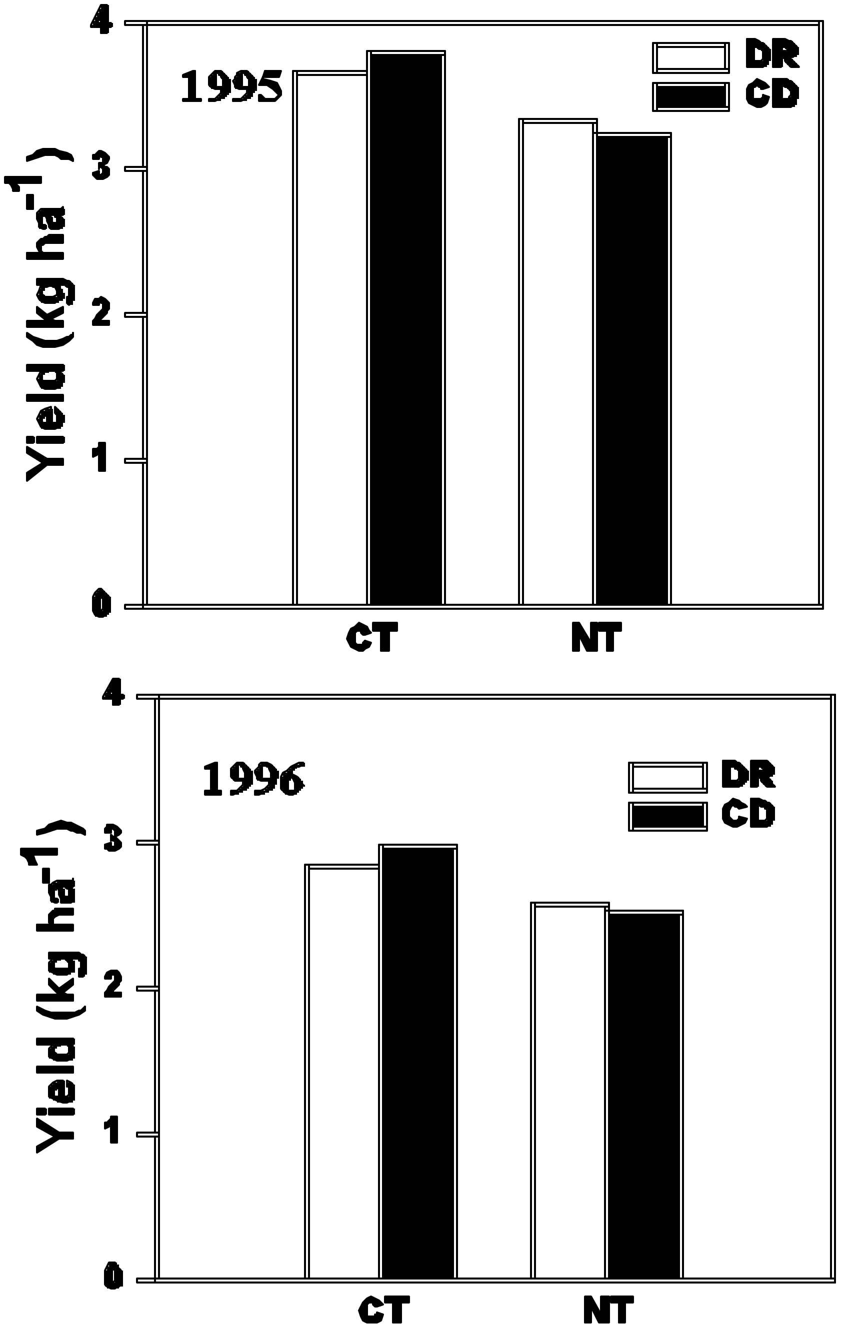

Fig. 12. Soybean yield for the drainage (DR) and controlled drainage (CD) treatments at the conventional tillage (CT) and no-tillage (NT) sites in 1995 and 1996.

4.2 Effect of controlled drainage and subirrigation on crop yield and tile water quality on a sandy loam site (Bicrel Farm).

There was 282.2 mm of precipitation in 1995 and 203.4 mm in 1996 between May and August (Table 1). The precipitation was 58.6 mm and 137.4 mm below normal during 1995 and 1996 growing seasons, respectively. Subirrigation for CDS treatment was initiated on June 15 and terminated on September 13, 1995. A total of 78.5 mm of subirrigation water was added to the CDS treatment during the 1995 growing season. Subirrigation for CDS treatment was initiated on July 8 and terminated on September 6, 1996. A total of 183.9 mm of subirrigation water was added to the CDS treatment during the 1996 growing season. The total soil water in the top 120 cm depth with the CDS treatment was consistently higher than with the DR treatment during the entire 1995 and 1996 growing season (Fig. 13). A similar trend was also observed for water table depths (Fig. 14).

Over the period between May, 1995 and September, 1996, the CDS treatment reduced tile drainage volume by about 45% (from 872 kL ha^{-1} to 479 kL ha^{-1}), even though a tremendous amount of water was supplied to the crops through subirrigation (Fig. 15), with 78.5 mm in 1995 and 183.9 mm in 1996. Subirrigation supplied 22% of the total water input for the 1995 growing season and 47% of the water input for the 1996 growing season. During the period Sept. 10, 1996 to Dec. 23, 1996, the CDS treatment produced 46% more tile drainage volume than the DR treatment (1789 kL ha^{-1} vs. 1223 kL ha^{-1}). The greater tile drainage volume in the CDS treatment over this short duration was attributed to the high soil water content (Fig. 13) and water table depth (Fig. 14) prior to heavy precipitation (238.5 mm) in September, 1996 (compared to a 30 year average of 80.7 mm). 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 (Fig. 13).

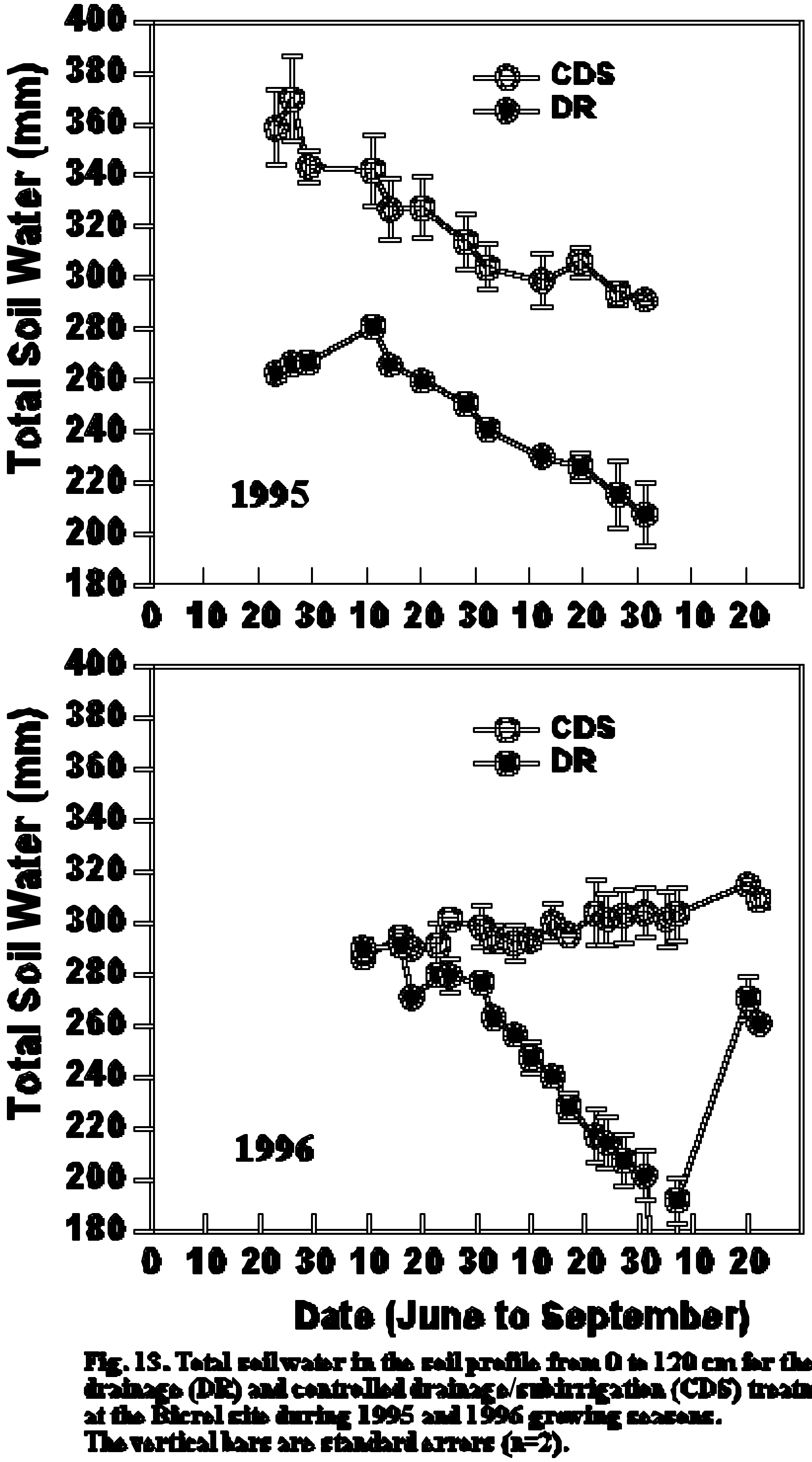

Fig. 13. Total soil water in the soil profile from 0 to 120 cm for the drainage (DR) and controlled drainage/subirrigation (CDS) treatments at the Bicrel site during 1995 and 1996 growing seasons.
The vertical bars are standard errors (n=2).

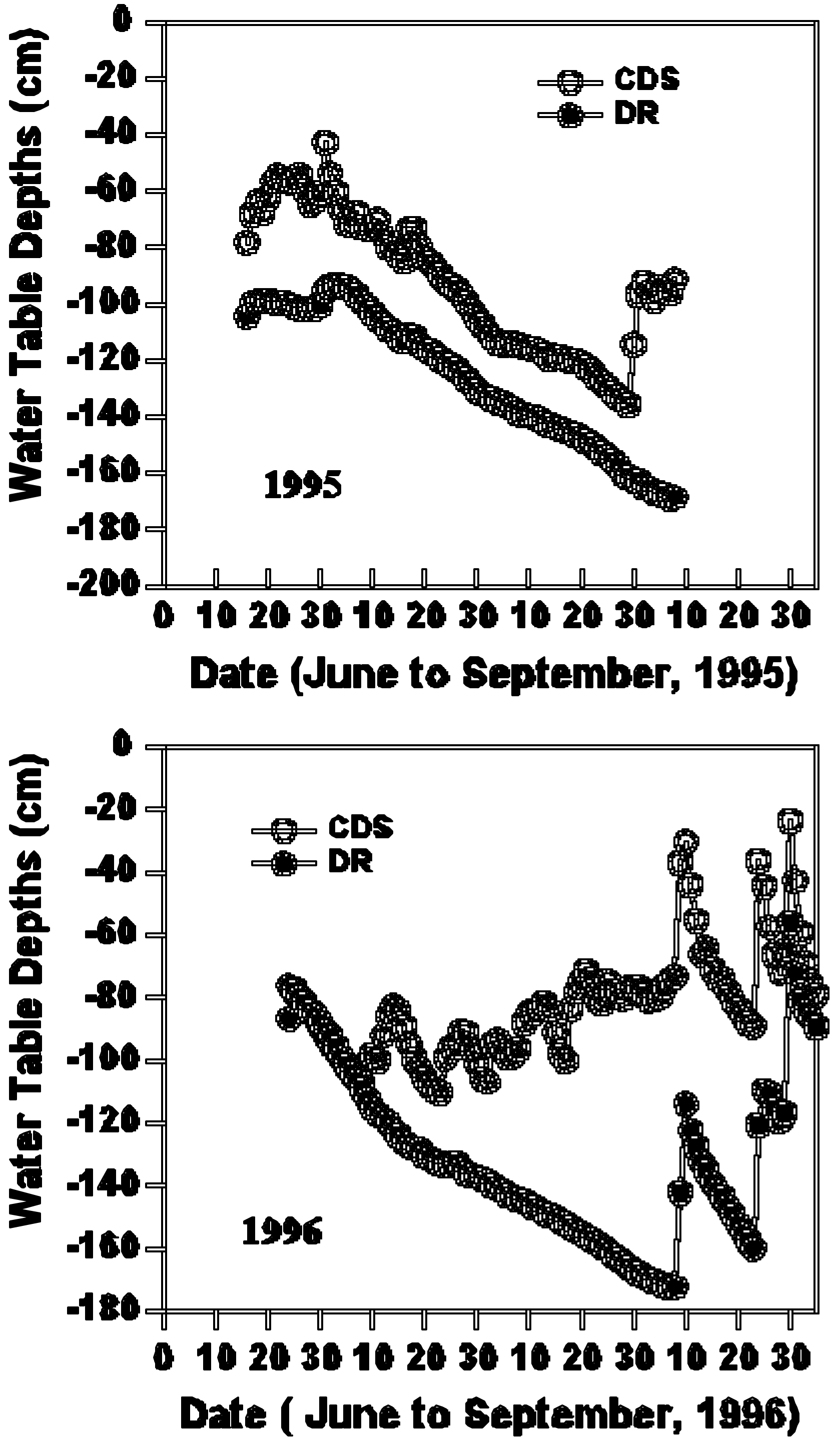

Fig. 14. Water table depths for the drainage (DR) and controlled drainage and subirrigation (CDS) treatments at the Bicrel site during 1995 and 199 growing seasons.

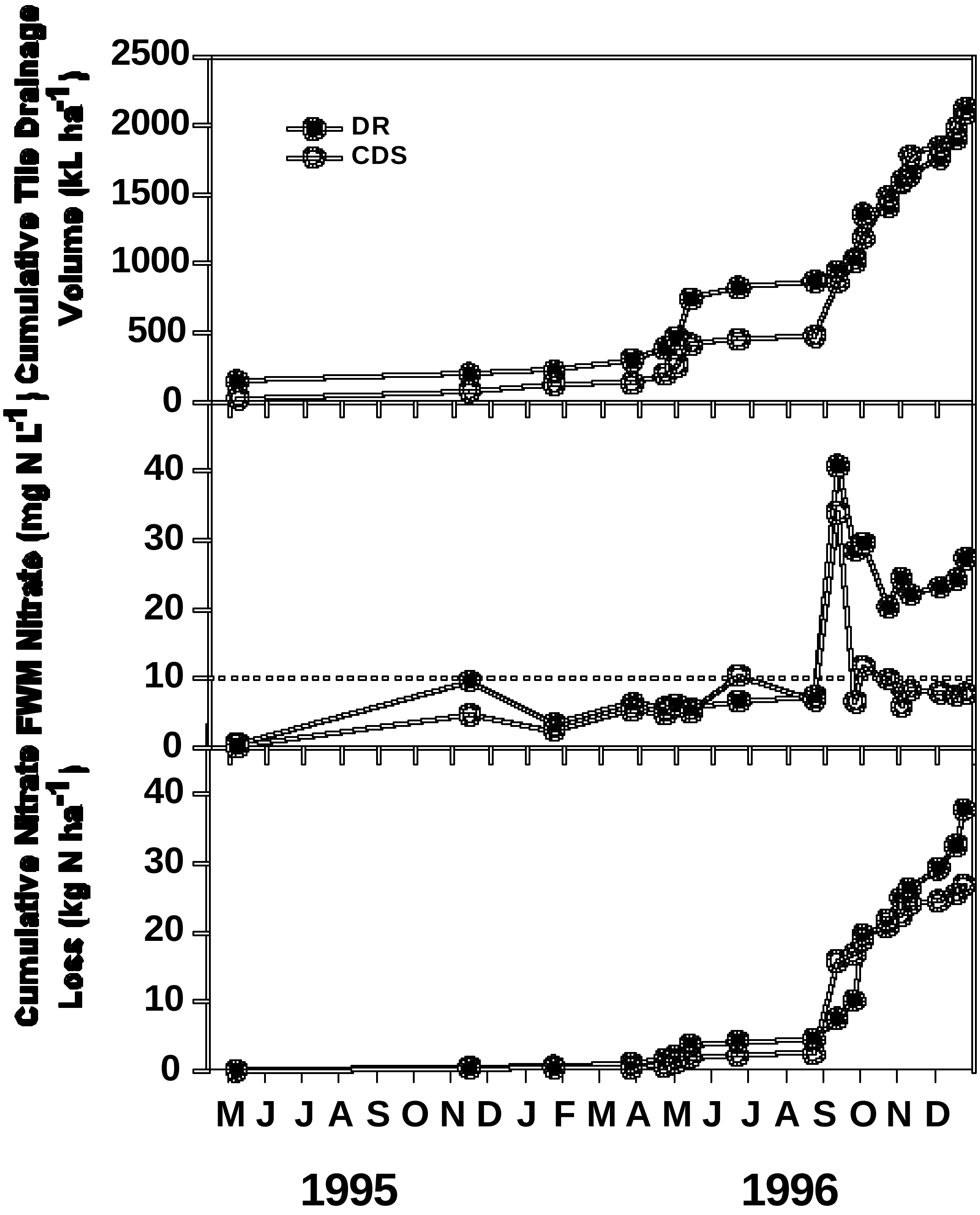

Fig. 15. Cumulative tile drainage volume, FWM nitrate concentration and cumulative nitrate loss for the drainage (DR) and controlled drainage and subirrigation (CDS) treatment from May, 1995 to December, 1996.

Flow weighted mean nitrate concentration for the entire period (May 1,1995 to December 23, 1996) for CDS treatment was 12.5 mg N L^{-1} compared to 18.0 mg N L^{-1} for the DR treatment. This represented a 31% 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 50% of the drainage events, whereas the nitrate concentrations exceeded the guidelines in 22% of the events with the CDS treatment. It should be noted, however, that both 1995 and 1996 growing seasons were very dry (Table 1) which would have minimized nitrate leaching losses for the DR treatment. The nitrate concentrations in tile drainage water varied over seasons with the highest levels in the DR treatment occurring from September 10, 1996 to December 31, 1996. During this period, the nitrate concentration ranged from 20.4 to 40.9 mg N L^{-1} for the DR treatment compared to 6 to 34 mg N L^{-1} for the CDS treatment (Fig. 15). For 94% 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 24% compared to the DR 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. Nitrate loss was largest in runoff events from September 10, 1996 to December 23, 1996. In particular, about 88% of the total nitrate lost from the DR treatment and 91% from the CDS treatment was lost in these sampling periods.(Fig. 15). These losses are comparable with those reported in other studies (Drury *et al.,* 1996, Tan *et al.,* 1993, Drury *et al.,* 1993). Since both 1995 and 1996 had dry growing seasons, nitrate losses were lower especially with the DR treatment. 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. However in a controlled drainage/subirrigation study within 1 km of this site no definitive differences in N_2O emissions were found in this 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. When we measured N_2O losses from a sandy loam soil, high water tables which resulted from water table management increased N_2O losses from soil (Drury et al., 1997). Hence N losses from soil vary with soil type and water table management.

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. The average corn yields were 6.7 t ha^{-1} for DR treatment and 11.0 t ha^{-1} for CDS treatment.

5. CONCLUSIONS

Three large field scale “on-farm” demonstration sites were established in cooperation with three producers in Southwestern Ontario. A controlled drainage (CD) system was established on two clay loam sites in a paired watershed (no-tillage versus conventional tillage), whereas a controlled drainage and subirrigation (CDS) system was established on a sandy loam site.

On two clay loam sites (Chevalier and Shanahan Farms), no-tillage (NT) increased mean weight diameter (MWD) of soil aggregates, improved wet aggregate stability (WAS) and soil water storage compared to conventional tillage (CT) . The total nitrate lost from May 1995 to December, 1996 was 23.6

kg N ha^{-1} for the NT site and 20.7 kg N ha^{-1} for the CT site. The NT site had 68% more tile drainage volume (1993 kL ha^{-1}) than the CT site (1188 kL ha^{-1}). The flow weighted mean (FWM) nitrate concentration of the tile drainage water over the entire period was 19 mg N L^{-1} for the CT site whereas it was 13 mg N L^{-1} for the NT site. Controlled drainage (CD) system reduced tile nitrate loss by 27% in the NT site (from 27.3 kg N ha^{-1} to 19.8 kg N ha^{-1}) and by 4% in the CT site (from 21.2 kg N ha^{-1} to 20.3 kg N ha^{-1}) compared to the corresponding drainage (DR) system. The controlled drainage system reduced tile drainage volume by 22% in the NT site but only reduced the volume by 13 % with the CT site. Thus, the combination of no-tillage and controlled drainage improves soil structure and prevents excessive nitrate leaching through the tile drainage water.

On a sandy loam site (Bicrel Farm), the CDS system reduced total nitrate loss by 24 % compared to the DR system (from 37.8 kg N ha^{-1} to 28.7 kg N ha^{-1}). The CDS system also reduced flow weighted mean (FWM) nitrate concentration by 31% compared to the DR system (from 18 mg N L^{-1} to 12.5 mg N L^{-1}). The CDS system increased marketable tomato yields by 11% in 1995 and corn yields by 64% in 1996. Thus, the CDS system effectively reduced total nitrate loss and improved yields of processing tomatoes and grain corn.

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7. REFERENCES

Baker, J. L. and Johnson, H. P. 1981. Nitrate-nitrogen in tile drainage as affected by fertilization. J. Environ. Qual. 10:519-522.

Bolton, E. F., Aylesworth, J. W. and Hore, F. R. 1970. Nutrient losses through tile drains under three cropping systems and two fertility levels on Brookston clay soil. Can. J. Soil Sci. 50:275-279.

Cooper, R. L., Fausey, N. R. And Streeter, J. G. 1992. Effect of water table level on the yield of soybean grown under subirrigation/drainage. J. Prod. Agric. 5:180-184.

Drees, L. R., Karathanasis, A. D., Wilding, L. P. And Blevins, R. L. 1994. Micromorphological characteristics of long-term no-till and conventionally tilled soils. Soil Sci. Soc. Am. J. 58:508-517.

Drury, C. F., Mckenny, D. J., Findlay, W. I. and Gaynor, J. D. 1993. Influence of tillage on nitrate loss in surface runoff and tile drainage. Soil Sci. Soc. Am. J. 57:797-802.

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

Drury, C. F., Tan, C. S., Gaynor, J. D., Oloya, T. O., van Wesenbeeck, I. J. and McKenney, D. J. 1997. Water table control effects on nitrate leaching, denitrification and corn production. Soil Sci. Soc. Am. J. (In press)

Edwards, W. M., Shipitalo, M. J., Owens, L. B. And Dick, W. A. 1993. Factors affecting preferential flow of water and atrazine through earthworm burrows under continuous no-till corn. J. Environ. Qual. 22:453-457.

Gee, G. W. and Bauder, J. W. 1986. Particle-size analysis. In A. Klute, ed. Methods of soil analysis, Part 1. American society of Agronomy, Madison, Wis.

Gilliam, J.W., Skaggs, R.W. and Weed, S.B. 1978. An evaluation of the potential for using drainage control to reduce nitrate loss from agricultural fields to surface waters. Report No, 128. Water Resource Research Institute of the University of North Carolina. Raleigh, N.C.

Kemper, W. D. and Roseau, R. C. 1986. Aggregate stability and size distribution. In A. Klute, ed. Methods of soil analysis, Part 1. American society of Agronomy, Madison, Wis.

Kliewer, B. A. and Gilliam, J. W. 1995. Water table management effects on denitrification and nitrous oxide evolution. Soil Sci. Soc. Am. J. 59:1694-1701.

Lalonde, V., Madramootoo, C. A., Trenholm, R. S. and Broughton, R. S. 1996. Effects of controlled drainage on nitrate concentrations in subsurface drain discharge. Agricultural Water Management 29:187-199.

Madramootoo, C. A., Broughton, S. R. and Dodds, G. T. 1995. Watertable managementstrategies for soybean production on a sandy loam soil. Canadian Agricultural Engineering 37:1-7.

Stone, J. A. and Heslop, L. C. 1987. Blade cultivator, ridge, and moldboard plow tillage comparison on poorly drained soil. Trans. ASAE 30:61-64.

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

Tan, C. S., Drury, C. F., Gaynor, J. D., van Wesenbeeck, I. J. and Soultani, M. 1996. Effect of water-table management and nitrogen supply on yield, plant growth and water use of corn in undisturbed soil columns. Can. J. Plant Sci. 76:229-235.

Tel, D. A. and Heseltine, C. 1990. The analyses of KCL soil extracts for nitrate, nitric and ammonium using TRAACS 800 analyzer. Commun. Soil Sci. Plant Anal. 21:1681-1688.

Tomlin, A. D. And Gore, F. L. 1974. Effect of six insecticides and a fungicide on the numbers and biomass of earthworms in pasture. Bull. Environ. Contam. Tox. 12:487-492.