2002-2004

Farm-Scale Processing Tomato Production using Surface and Subsurface Drip Irrigation and Fertigation

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Dave Epp Farm (3E) ~ 16.48 acres

Tomato Variety

-Heinz 9478

Emitter

- Flow rate - 0.25 U.S. gal/min/100'

- Spacing- 12"

Plant spacing - 16"

Row spacing - 20"

Plant density - 13403
plants/acre

Bed Spacing - 60"

33 beds - S,B

15 beds - S,F&SS,F

30 beds - S&B

3 beds per control - C

-----1450 ft-----

-----495 ft-----

C: control, non-irrigation

S: surface drip

SS: sub-surface drip

B: broadcast fertilizer

F: fertigation

B: 3 splits: before planting – 40 lbs N, 80 lbs P, 20 lbs K;
planting – 100 lbs N; sidedress – 40 lbs N, 25 lb K

F: before planting – 40 lbs N, 80 lbs P, 20 lbs K;
planting - 60 lbs N, 25 lbs K; fertigation - 100 lbs N

Ken Epp Farm (4E) ~ 5.11 acres

Tomato Variety

-Heinz 9478

Emitter

- Flow rate - 0.25 U.S. gal/min/100'

- Spacing- 12"

Plant spacing - 15"

Row spacing - 18"

Bed Spacing - 66"

9 beds per drip treatment

3 beds per control treatment

C: control, non-irrigation

S: surface drip

SS: sub-surface drip

B: broadcast fertilizer

F: fertigation

B: 2 splits: before planting – 50 lbs N, 120 lbs P, 30 lbs K;
sidedress (10-14 days post planting), 120 lbs N

F: before planting - 50 lbs N, 120 lbs P, 30 lbs K; Sidedress
(10-14 days post planting), 60 lbs N; fertigation 60 lbs N

2002 OTRI Final Research Report

TITLE: Farm-Scale Processing Tomato Production using Surface and Subsurface Drip Irrigation and Fertigation

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SUMMARY

Processing tomatoes (*Lycopersicon esculentum* Mill.; cultivar, Heinz 9478) were grown on two commercial fields: one comprising about 16 acres on the loamy sand and the other comprising about 5 acres on the clay loam soil. The objectives of this study were to determine the effects of surface and subsurface drip irrigation and fertigation on yield, quality, water and nutrient use efficiency of processing tomatoes on commercial scale. The treatments included the non-irrigated control plots with broadcast fertilizer and surface and sub-surface drip irrigated plots, both with broadcast fertilizer and fertigation (ie. fertilizer applied via drip lines). Surface and sub-surface drip and/or fertigated plots had consistently higher available soil moisture than non-irrigated plots throughout the entire 2002 growing season on both loamy and clay loam soils. Both the leaf petiole sap NO_3^- -N and K concentrations were within sufficiency values during a month before harvest on both soils. On the loamy sand soil, marketable tomato yields were increased by 52.3 % and 60.4 % under surface drip or fertigated (SDI) and sub-surface drip or fertigated (SSDI) plots relative to non-irrigated control (NI) plots (131.8 MT/ha for SDI, 138.8 MT/ha for SSDI, 86.5 MT/ha for NI). Marketable tomato yields under SSDI plots were increased only by 5.3 % relative to SDI plots. There was no significant difference in marketable tomato yields between broadcast fertilizer and fertigation on both SSDI and SDI plots. On the clay loam soil, marketable tomato yields were increased by 86.7 % under SDI plots relative to NI plots (117.1 MY/ha for SDI, 62.7 MT/ha for NI), while tomato yields under SSDI plots were increased by 44.2 % relative to NI plots (90.5 MT/ha for SSDI, 62.7 MT/ha for NI). Marketable tomato yields under SDI plots were increased by 29.5 % relative to SSDI plots. The soluble solids of tomato were higher in the non-irrigated than drip irrigated and/or fertigated plots for both soils. There were no significant differences on soluble solids among surface and sub-surface drip irrigated tomatoes with either broadcast fertilizer or fertigation. Drip irrigated and/or fertigated tomatoes increased water use efficiency by 32 % and 52 % relative to non-irrigated tomatoes on the loamy and clay loam soils, respectively. Both soil profile NO_3^- -N and crop nutrient N and P removals suggested that drip and

/or fertigated tomatoes had higher nutrient N and P use efficiency than the non-irrigated tomatoes. On the loamy sand soil, subsurface drip and /or fertigated tomatoes also had greater nutrient N and P use efficiency than the surface drip and /or fertigated tomatoes. Furthermore, the largest decrease in soil profile $\text{NO}_3\text{-N}$ and the highest crop N and P removals imply that subsurface fertigated tomatoes had the highest nutrient N and P use efficiency.

INTRODUCTION

Increasing incidences of drought and high temperatures in southwestern Ontario have had serious negative effects on processing tomato growth, yield, and quality. These climate extremes are expected to become more frequent as global warming continues.

Researchers from GPCRC and elsewhere have shown that processing tomato responds favorably to both overhead sprinkler and surface drip irrigation (Phene et al., 1992; Dangler and Lacascio, 1990; Tan, 1995). From the standpoint of water and nutrient best management practices, however, drip irrigation/fertigation is superior to sprinkler irrigation because water is applied slowly to the root zone of the tomato plants. This results in less water loss through evaporation, reduced nutrient leaching losses, and greater efficiency with which tomato plants can utilize applied water and nutrients (Lacascio et al. 1997; Dangler and Lacascio, 1990). An additional advantage of drip irrigation/fertigation includes lower labor and operating costs relative to sprinkler systems, e.g. large metal pipes do not have to be moved and drip systems are easily automated.

Plot-scale research on drip irrigation/fertigation has proven its potential to substantially improve the economics of tomato production on coarse-textured soils (Phene et al., 1992; Tan, 1995; Tu et al., 2002). However, farm-scale research needs to be conducted to determine the viability of the system on different soil types and in a commercial environment. Farm-scale studies will also raise producer awareness and acceptance of drip irrigation and fertigation systems. Two commercial scale large farm sites have been identified in southwestern Ontario in cooperation with two Producers. One site comprises about 16 acres on a loamy sand soil, and the other comprises about 5 acres on a clay loam soil.

The objective of this study is to determine the effects of surface and sub-surface drip irrigation and fertigation on: 1) the yield and quality of processing tomato; and 2) the efficiency with which processing tomato utilizes water and nutrients applied via surface and subsurface drip irrigation and/or fertigation.

MATERIALS AND METHODS

The experiments were conducted on two fields owned by cooperating Producers: one comprising about 16 acres on the loamy sand soil (3E), and the other comprising about 5 acres on the clay loam soil (4E). The soil texture and soil water retention characteristics of these two soil types are summarized in Tables 1 & 2. On the loamy sand soil (3E), processing tomatoes (Heinz 9478) were transplanted on May 22, 2002 on double row, 1.52 m raised beds with 40.6 cm plant

spacing and 50.8 cm row spacing at a density of 33,105 plants per hectare. On the clay loam soil (4E), processing tomatoes (Heinz 9478) were transplanted on May 29, 2002 on double row, 1.67 m raised beds with 38.1 cm plant spacing and 45.7 cm row spacing at a density of 31,300 plants per hectare. The experiments consisted of three irrigation management treatments included non-irrigated control plots (NI), surface drip irrigated plots (SDI) and sub-surface drip irrigated plots (SSDI). Fertilizer treatments included both broadcast fertilizer and fertigation applied via the drip lines.

Drip irrigation and fertigation were delivered through lay-flat drip irrigation tubes (Chapin) with emitters spaced 30 cm apart and 0.15 U. S. gallon/emitter/hr flow rates (or 0.25 U.S. gallons/min/100 ft). One drip line was installed in the middle of double row. The irrigation amount and frequency for drip and fertigation treatments were determined using corrected long-term potential evapotranspiration data (Table 3) from near-by weather station and emitter flow rate, along with soil moisture retention characteristics (Table 2) from both loamy sand and clay loam soils.

On the loamy sand soil (3E), broadcast fertilizer treatments had three fertilizer splits (44.8 kg N/ha, 89.7 kg P/ha, 22.4 kg K/ha before planting; 112 kg N/ha at the planting; 44.8 kg N/ha and 28 kg K/ha at the side-dressing). Fertigation treatments had 2 splits broadcast fertilizer (44.8 kg N/ha, 89.7 kg P/ha, 22.4 kg K/ha before the planting; 67.3 kg N/ha, 28 kg K/ha at the planting) and 112 kg N/ha applied through fertigation.

On the clay loam soil (4E), broadcast fertilizer treatments had fertilizer splits (56.1 kg N/ha, 134.5 kg P/ha, 33.6 kg K/ha before planting; 134.5 kg N/ha at the side-dressing). Fertigation treatments had 2 splits broadcast fertilizer (56.1 kg N/ha, 134.5 kg P/ha, 33.6 kg K/ha before planting; 67.3 kg N/ha at the side-dressing) and 67.3 kg N/ha applied through fertigation.

Representative soil samples were collected from both loamy sand (3E) and clay loam (4E) soils at depths of 0-30 cm for soil texture determination, using the pipette method (Gee and Bauder, 1986). Intact soil cores (10 cm diameter by 10 cm long) were collected at three depths (0-10 cm, 10-20 cm and 20-30 cm) on both soils for determination of various soil physical properties. Soil samples were also collected at depths of 0-20, 20-40, 40-60, and 60-100 cm before planting and post-harvest for $\text{NO}_3\text{-N}$, $\text{NO}_4\text{-N}$ and mineral-N determinations.

Time Domain Reflectometer (TDR) was used to measure volumetric soil water content between 5 to 25 cm soil depths. Measurements were made two times per week in all treatments on both soils. Volumetric soil water content data were plotted throughout the growing season to show the differences in wetting and drying patterns between the treatments and the soil types.

Leaf petiole nitrate and potassium measurements were determined using Cardy nitrate and potassium metres (Spectrum Technologies, Plainfield, IL). Thirty-five leaf petiole samples from the 4th leaf of the growing tip were taken from each location in each treatment. The petiole samples were put in a plastic bag and store in the cooler immediately. At the same day, the composite juice from each location was analysed for $\text{NO}_3\text{-N}$ and K in the laboratory. Samples

were obtained once per week in three location in each treatments on the loamy sand soil (3E). Leaf petiole samples were taken only once in all the treatments during the growing season on the clay loam soil (4E).

Weather data were automatically recorded at both experimental fields, using Campbell CR-10 datalogger. These measurements included precipitation, air temperature, solar radiation, relative humidity, vapour pressure deficit, potential evapotranspiration.

Machine harvest yields were taken over the entire experimental fields for tomatoes on August 22, 2002 for loamy sand soil (3E) and for clay loam soil (4E) on September 13, 2002. Fifteen to twenty tomato plants at three separate locations from each treatments were also hand harvested for comparison with machine harvest on both soils. The yields were calculated as metric tonnes of marketable tomatoes per hectare (table 4a) and tons of marketable tomatoes per acre (Table 4b). The soluble solid was measured and expressed as Brix for both machine and hand harvest tomatoes. Plant tissue samples were collected and analysed for N and P contents, and total N and P removals were calculated by integrating with marketable yield.

RESULTS AND DISCUSSION

A late, cold spring delayed planting and crop growth until June, followed by dry, hot growing season had put a crimp in crop production in 2002 growing season. Temperature in May was 1.7 C below normal and June temperature was slightly below normal. Temperatures were high throughout July and August, with average 1.6 C and 1 C above normal, respectively (Table 3). The total precipitation from May to August was 163 mm and 134 mm below 70-yr long-term average for loamy sand (3E) and clay loam (4E) soils, respectively (Table 3). This resulted in 2002 growing season water deficit of 315 mm and 280 mm, respectively for loamy sand and clay loam soils. The precipitation in May, June and July was similar for both loamy sand and clay loam soils except for the month of August. A total of 44.8 mm of precipitation fell in August on the clay loam soil, whereas only 16.2 mm fell in August on the loamy sand soil. Therefore, the plants in non-irrigated treatment on both soils were experiencing high temperatures and a severe water deficit during the most parts of growing season in 2002.

Soil water content

On the loamy sand soil (3E), drip irrigation treatments were initiated on June 27 and terminated on August 18 with a total of 193.5 mm of water added. Volumetric soil water content at a distance of 10 to 30 cm from emitter between 5 and 25 cm soil depth for either surface or sub-surface drip irrigated treatments were consistently 7 to 13 % (equivalent to about 50 to 80 % available soil moisture) higher than non-irrigated treatments in July and August, 2002 (Fig. 1). Sub-surface drip irrigated treatments also had consistently higher soil water content between 5 and 25 cm soil depth than surface drip irrigated treatments. On the clay loam soil (4E), drip irrigation treatments were initiated on June 19, and terminated in September 3, 2002 with a total of 197.7 mm of water added. A similar consistently higher soil water content for surface and sub-surface drip irrigated treatments was also observed on clay loam soil (Fig. 2).

Wetting patterns

The wetting pattern of surface and sub-surface drip irrigated treatments on the loamy sand soil (3E) was used to evaluate root zone soil water content vs. lateral distance from emitter. The result indicated that for loamy sand soil at the 5 to 25 cm soil profile, volumetric soil water content was greater than 50 % available soil water (ASM) within a distance of 20 cm from drip emitters (Fig. 3). The root zone available soil water at a distance of greater 20 cm from drip emitters dropped below 50 % level. Tan et al. (1981) reported that tomato roots had a greater relative absorption capacity for water uptake in response to the transpiration demand. They suggested that irrigation of only 50 % of the root zone is adequate to produce optimum yield and there is no need to irrigated the entire root system. This would suggested that a single drip line is adequate to irrigate twin row tomatoes at row spacing of 50 cm apart for optimum yield as used on the loamy sand soil by most producers.

Leaf petiole sap nitrate

The leaf petiole sap $\text{NO}_3\text{-N}$ concentration on the loamy sand soil (3E) declined rapidly from 1600 ppm at the early flowing and fruit enlargement period to a level of 700 ppm by pre-harvest (Fig. 4). The similar leaf petiole sap $\text{NO}_3\text{-N}$ concentration values have been established for field grown tomatoes in principal production regions such as California and Florida (Locascio et al., 1997). The increase leaf petiole sap $\text{NO}_3\text{-N}$ concentration at around last week of July corresponding approximately 50 mm of rainfall occurred during that period. The hot and dry weather in June and early July left plenty of unused broadcasting fertilizer at the upper layer of soil. The plant uptake of fertilizer at this layer probably increased due to ample supply of surface water through rainfall. On the other hand, the continuous decrease leaf petiole sap $\text{NO}_3\text{-N}$ concentration for surface drip with broadcasting fertilizer treatments (SB) probably due to a constant surface drip water supply throughout the growing season. Therefore, less surface fertilizer was available for this treatments. The leaf petiole sap K followed the similar patterns as leaf petiole sap $\text{NO}_3\text{-N}$ (Fig. 5). Both the leaf petiole sap $\text{NO}_3\text{-N}$ and K concentrations were within sufficiency values during a month before harvest on the clay loam soil (Figs. 6, 7).

Tomato yields

On loamy sand soil, marketable tomato yields were similar from both hand and mechanical harvesting data. Average surface-broadcast (SB) and surface-fertigated (SF) treatments resulted in 52.3 % yield increase relative to non-irrigated (NI) treatments (Table 4). Average subsurface-broadcast (SSB) and subsurface-fertigated (SSF) treatments increased yield by 60.4 % relative to non-irrigated (NI) treatments. Average subsurface-broadcast (SSB) and subsurface-fertigated (SSF) treatments had only 5.3 % greater yields than the average surface-broadcast (SB) and surface-fertigated (SF) treatments (Table 4). There was no significant difference in yields between broadcast fertilizer and fertigation on both surface and sub-surface drip irrigated treatments. This was expected because there was no evidence of fertilizer leaching and there was ample surface broadcast fertilizer available for plant uptake due to extremely low rainfall during the 2002 growing season as seen in leaf petiole sap $\text{NO}_3\text{-N}$ and K concentrations which were

within sufficiency values for all the treatments (Figs. 4, 5). The soluble solids of tomato were higher in the non-irrigated treatments than in drip and fertigated treatments (Table 5). As was found in other study (Tan, 1995), soluble solids were decreased by drip and sprinkler irrigations on the loamy sand soil. There were no significant differences on soluble solids among surface and sub-surface drip irrigated treatments with either broadcast fertilizer or fertigation.

On the clay loam soil, marketable tomato yields also showed the similar results between hand and mechanical harvesting. Average surface-broadcast (SB) and surface-fertigated (SF) treatments resulted in 86.7 % yield increase relative to non-irrigated (NI) treatments (Table 4). Average subsurface-broadcast (SSB) and subsurface-fertigated (SSF) treatments had 44.2 % greater yields than the non-irrigated (NI) treatments. It is interesting to note that average surface-broadcast (SB) and surface-fertigated (SF) treatments had 29.5 % greater yield than the average subsurface-broadcast (SSB) and subsurface-fertigated (SSF) treatments on the clay loam soil. Observed root intrusion into the sub-surface emitters which prevented uniform water distribution was responsible for the reduction of yields relative to surface drip irrigated treatments. The soluble solids of tomato were higher in the non-irrigated than drip irrigated and fertigated treatments, however, the differences among various treatments on the clay loam soil were small relative to loamy sand soil (Table 5).

Marketable tomato yields under non-irrigated treatments on the loamy sand soil were 23.8 MT/ha (10.6 tons/acre) higher than on the clay loam soil (Table 4). This is because the loamy sand soil have higher plant available water and air-filled capacity than the clay loam soil (Table 2). The soil with high plant available water capacity produced greater tomato yields than the soil with low plant available water capacity was also reported by other study (Liptay et.al., 1997). A soil with the greater plant available water capacity, the longer crops can grow without rainfall before experiencing drought stress. These were evidenced by the TDR field volumetric soil water content measurements during the growing season (Figs.1,2). The clay loam soil also have certain physical property limitations such as an air-filled capacity below 15 % often results in frequent root-zone aeration deficits, which impair root growth and function thereby reduce crop performance.

Water use efficiency

Water use efficiency is defined as crop yield per unit of water transpired by crops. The drip irrigation and fertigation treatments increased water use efficiency by about 32 % and 52.0 % relative to non-irrigation treatments on the loamy sand and clay loam soils, respectively (Table 6). Water use efficiency can be improved through cultural practices (ie. optimum plant density, tillage, drainage etc.) and irrigation timing to match critical stages of crop growth. The maximum efficiency of water use is not always practical because it requires production of the maximum possible yield, which often is unprofitable. For example, the yield may increase with increasing frequency of irrigation, but the yield per unit of water applied may decrease at high rates of irrigation (Tan and Dhanvantari, 1985; Tan, 2002). Water use efficiency is higher for drip irrigation than for sprinkler irrigation (Tan, 2002).

Crop nutrient N and P removal

Tomato removals for N varied from 89 to 224 kg/ha and for P from 11 to 31 kg/ha on the loamy sand soil (Table 7). Drip and /or fertigation increased both N and P removals, in comparison with non-irrigated control. Sub-surface drip irrigation had significant more N and P removals than surface drip irrigation, regardless of the fertilization method, which had similar N and P removals within the same irrigation strategy. In contrast, N and P removals on the clay loam soil were lower than that on the sandy loam soil, primarily due to the lower yield. Although irrigated plots had greater N and P removals than the non-irrigated plots, the N and P removals were similar among the irrigated plots, except for the subsurface-fertigation which had a lower N and P removals due to low yield (Table 4).

Pre-plant and post-harvest soil profile $\text{NO}_3\text{-N}$ and mineral-N

There were significant amounts of soil $\text{NO}_3\text{-N}$ found at pre-planting, indicating the contribution of organic soil N through mineralization during the non-growing season and residual mineral N from previous crop (Fig. 8). The $\text{NO}_3\text{-N}$ remained mainly in the soil layer of 0-40 cm. In comparison with pre-season, soil $\text{NO}_3\text{-N}$ after growing season decreased and the majority of soil $\text{NO}_3\text{-N}$ accumulated on the soil layer of 0-40 cm, an implementation of leaching of $\text{NO}_3\text{-N}$ in soil profile. The decreases were 2.3, 0.9, 2.7, 2.3, and 4.8 mg N/kg soil in the depth of 0-100 cm for the non-irrigated (NI), surface drip irrigated with broadcast (SB), surface fertigated (SF), subsurface drip irrigated with broadcast (SSB), and subsurface fertigated (SSF) plots, respectively. Soil mineral N followed the same pattern as soil $\text{NO}_3\text{-N}$ (Fig. 9).

Nutrient use efficiency

Soil profile $\text{NO}_3\text{-N}$ (Fig. 8) and crop nutrient N and P removals (Tables 7, 8)) suggested that drip and /or fertigated (SB, SF, SSB, SSF) treatments had higher nutrient N and P use efficiency than the non-irrigated (NI) treatments on both soils. On the loamy sand soil, subsurface drip and /or fertigated (SSB, SSF) treatments also had greater nutrient N and P use efficiency than the surface drip and /or fertigated (SB, SF) treatments (Tables 7, 8). Furthermore, the largest decrease in soil profile $\text{NO}_3\text{-N}$ (Fig. 8) and the highest crop N and P removals (Tables 7, 8) on the loamy sand soil imply that subsurface fertigated (SSF) treatments had the highest nutrient N and P use efficiency.

ACKNOWLEDGEMENTS

This research has been supported by grants from the Ontario Tomato Research Institute and the Ontario Processing Vegetable Growers. Appreciation is also expressed for expert technical assistance to Mr. K. Rinas, Mr. B. Hohner, Ms. M. Reeb, and Ms J. Byrne. We also acknowledge the cooperation of Mr. David & Peter Epp of the Lycoland Farms and Mr. Ken Epp of 4E Farm.

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Table 1. Average soil texture at 0-30 cm soil depth on the loamy sand (3E) and clay loam (4E) soils

Soils	Soil Texture (%)		
	Sand	Silt	Clay
Loamy sand (3 E)	89.3	6.0	4.7
Clay loam (4 E)	32.7	30.4	36.9

Table 2. Average soil water retention properties at 0-30 cm depth on the loamy sand (3E) and clay loam (4E) soils

Soils	FC $\text{m}^3 \text{m}^{-3}$	PWP $\text{m}^3 \text{m}^{-3}$	PAWC $\text{m}^3 \text{m}^{-3}$	POR $\text{m}^3 \text{m}^{-3}$	AC $\text{m}^3 \text{m}^{-3}$	BD Mg m^{-3}
Loamy sand	0.209	0.081	0.128	0.480	0.271	1.47
Clay loam	0.379	0.265	0.114	0.463	0.084	1.33

FC: field capacity; PWP: permanent wilting point; PAWC: plant available water capacity; POR: saturated volumetric water content; AC= POR - FC, air-filled capacity; BD: bulk density

Table 3. Total precipitation (P), potential evapotranspiration (PE), water deficit, average air temperature (T_a), vapour pressure deficit (VPD) during the growing season in 2002 on the loamy sand (3E) and clay loam (4E) soils plus 70-yr long-term regional total precipitation and average air temperature.

Months	Total P			Total PE		Deficit		Average T_a			Avg VPD	
	mm			mm		mm		C			Kpa	
	3E	4E	70-yr	3E	4E	3E	4E	3E	4E	70-yr	3E	4E
May	31.1	25.6	70.4	58.9	58.3	27.8	32.7	12.4	12.6	14.2	0.34	0.35
June	26.3	25.4	75.9	117.7	121.9	91.4	96.5	20.2	20.4	19.5	0.53	0.62
July	62.0	70.0	72.5	150.5	147.9	88.5	77.9	23.4	23.6	21.9	0.62	0.74
August	16.2	44.8	80.0	123.3	117.0	107.1	72.2	21.9	21.8	20.9	0.46	0.42

P: Precipitation; PE: Potential evapotranspiration; T_a : Air temperature;
VPD: Vapour pressure deficit; 3E: Loamy sand soil; 4E: Clay loam soil

Deficit=total P - total PE (deficit=0; if total P $\geq$ total PE)

Table 4a. Effect of various drip irrigation and fertigation treatments on marketable tomato yields(MT/ha) on the loamy sand (3E) and clay loam (4E) soils

Treatments	Marketable yields (MT/ha)	
	Loamy sand (3E)	Clay loam (4E)
Non-irrigated (NI)	86.5	62.7
Surface-broadcast (SB)	130.3	113.7
Surface-fertigated (SF)	133.4	120.5
Subsurface-broadcast (SSB)	138.8	96.8 (104.0 [*])
Subsurface-fertigated (SSF)	138.8	84.1 (101.2 [*])

* Removed sub-surface drip lines that were plugged by roots and re-installed surface drip lines on July 19, 2002

Table 4b. Effect of various drip irrigation and fertigation treatments on marketable tomato yields(tons/acre) on the loamy sand (3E) and clay loam (4E) soils

Treatments	Marketable yields (tons/acre)	
	Loamy sand (3E)	Clay loam (4E)
Non-irrigated (NI)	38.6	28.0
Surface-broadcast (SB)	58.1	50.7
Surface-fertigated (SF)	59.5	53.8
Subsurface-broadcast (SSB)	61.9	43.2 (46.4 [*])
Subsurface-fertigated (SSF)	61.9	37.5 (45.1 [*])

* Removed sub-surface drip lines that were plugged by roots and re-installed surface drip lines on July 19, 2002

Table 5. Effect of various drip irrigation and fertigation treatments on tomato soluble solids (%) on the loamy sand (3E) and clay loam (4E) soils

Treatments	Soluble solids (%)	
	Loamy sand (3E)	Clay loam (4E)
Non-irrigated (NI)	5.6	5.1
Surface-broadcast (SB)	4.5	4.4
Surface-fertigated (SF)	4.2	4.7
Subsurface-broadcast (SSB)	4.4	4.7
Subsurface-fertigated (SSF)	4.2	4.9

Table 6. Marketable yields, accumulated evapotranspiration (ET), water use efficiency (WUE) and percentage increase on water use efficiency of processing tomatoes (cultivar Heinz 9478) for non-irrigated (NI) and drip irrigated and /or fertigated (DI) treatments on both loamy sand (3E) and clay loam (4E) soils.

	Yields (MT/ha)		Accumulated ET (mm)		WUE (kg/ha/mm)		Increase WUE (%)
	DI	NI	DI	NI	DI	NI	DI
Loamy sand	135.3 ^a	86.5	320	270	422.8	320.4	32.0
Clay loam	117.1 ^b	62.7	322	262	363.7	239.3	52.0

^a Combined surface, sub-surface drip and fertigated treatments

^b Combined surface drip and fertigated treatments

Table 7. Effect of various drip irrigation and fertigation treatments on crop nutrient N and P removals on loamy sand (3E) and clay loam (4E) soils.

Treatment	Loamy sand (3E)		Clay loam (4E)	
	N	P	N	P
	----- kg/ha -----			
No-irrigated (NI)	89.0	11.2	75.6	11.4
Surface-broadcast (SB)	148.9	21.1	129.0	23.8
Surface-fertigated (SF)	157.4	22.3	141.9	23.7
Subsurface -broadcast (SSB)	223.9	30.9	133.7	23.7
Subsurface-fertigated (SSF)	215.4	31.0	114.9	18.3

Table 8. Increases in nutrient use efficiency due to irrigation/fertigation applied to processing tomatoes, in comparison with the no-irrigated plots, 2002.

Treatment	Loamy sand (3E)		Clay loam (4E)	
	N	P	N	P
	----- % -----			
Surface-irrigation-broadcast	35.9	72.7	69.8	108.6
Surface-fertigation	34.9	78.1	63.3	86.0
Subsurface -fertigation	79.1	149.4	48.5	55.7
Subsurface-irrigation-broadcast	91.5	148.4	53.2	83.0

Fig.1. Volumetric soil water content measured at a soil depth of 5-25 cm and a distance 5 cm from emitter under non-irrigated (NI), surface drip irrigated with broadcast fertilizer (SB), surface fertigated (SF), sub-surface drip irrigated with broadcast fertilizer (SSB) and sub-fertigated (SSF) plots on the loamy sand soil (3E) during 2002 growing season.

Fig.2. Volumetric soil water content measured at a soil depth of 5-25 cm and a distance of 10 cm from emitter under non-irrigated (NI), surface drip irrigated with broadcast fertilizer (SB), surface fertigated (SF), sub-surface drip irrigated with broadcast fertilizer (SSB) and sub-surface fertigated (SSF) plots on the clay loam (4E) soil during 2002 growing season.

Wetting Pattern (July 19, 2002) East- West Direction

Fig.3. Volumetric soil water content between 5 and 25 cm soil depth vs. lateral distance from emitter for surface drip irrigated (S) and surface drip irrigated (SS) plots on the loamy sand soil (3E) .

Fig. 4. Leaf petiole sap NO₃-N concentration for non-irrigated (NI), surface drip irrigated with broadcast fertilizer (SB), surface fertigated (SF), sub-surface drip irrigated with broadcast fertilizer (SSB) and sub-surface fertigated (SSF) plots on the loamy sand soil (3E) during 2002 growing season.

Fig. 5. Leaf petiole sap K concentration for non-irrigated (NI), surface drip irrigated with broadcast fertilizer (SB), surface fertigated (SF), sub-surface drip irrigated with broadcast fertilizer (SSB) and sub-surface fertigated (SSF) plots on the loamy sand soil (3E) during 2002 growing season.

SAP NO₃-N (4E), August 12, 2002

Fig. 6. Leaf petiole sap NO₃-N concentration for non-irrigated (NI), surface drip irrigated with broadcast fertilizer (SB), surface fertigated (SF), sub-surface drip irrigated with broadcast fertilizer (SSB) and sub-surface fertigated (SSF) plots on the clay loam (4E) on August 12, 2002.

SAP K (4E). August 12, 2002

Fig. 7. Leaf petiole sap K concentration for non-irrigated (NI), surface drip irrigated with broadcast fertilizer (SB), surface fertigated (SF), sub-surface drip irrigated with broadcast fertilizer (SSB) and sub-surface fertigated (SSF) plots on the clay loam soil (4E) on August 12, 2002.

Fig. 8. soil profile $\text{NO}_3\text{-N}$ for non-irrigated (NI), surface drip irrigated with broadcast fertilizer (SB), surface fertigated (SF), sub-surface drip irrigated with broadcast fertilizer (SSB) and sub-surface fertigated (SSF) plots on the loamy sand soil (3E) during 2002 growing season.

Fig. 9. soil profile mineral-N for non-irrigated (NI), surface drip irrigated with broadcast fertilizer (SB), surface fertigated (SF), sub-surface drip irrigated with broadcast fertilizer (SSB) and sub-surface fertigated (SSF) plots on the loamy sand soil (3E) during 2002 growing season.

C: control, non-irrigation
 S: surface drip
 SS: sub-surface drip
 B: broadcast fertilizer
 F: fertigation

B: 3 splits; before planting, 40 lbs N, 120 lbs P, 20 lbs K;
 planting, 100 lbs N; sidedress, 60 lbs N, 25 lb K
 F: before planting, 40 lbs N, 120 lbs P, 20 lbs K;
 Post sidedress, 60 lbs N, 25 lbs K; fertigation, 100 lbs N

~3.06 acres

Emitter flow rate: 0.25 us gal/min/100'

Emitter spacing 12"

16" between plants

20" between rows

60" between beds

Plant density: 13,403 plants/acre

Heinz 9478

796-0840

Dave & Peter Epp
 2003

Final: Apr. 24, 2003

Ken Epp
2003

2003 OTRI Final Research Report

TITLE: Farm-Scale Processing Tomato Production using Surface and Subsurface Drip Irrigation and Fertigation

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SUMMARY

Processing tomatoes (*Lycopersicon esculentum* Mill.; cultivar, Heinz 9478) were grown on two commercial fields: one comprising about 3.1 acres on the sandy loam and the other comprising about 4.6 acres on the sandy clay loam soil. The objectives of this study were to determine the effects of surface and subsurface drip irrigation and fertigation on yield, quality, water and nutrient use efficiency of processing tomatoes on commercial scale. The treatments included the non-irrigated control plots with broadcast fertilizer and surface and sub-surface drip irrigated plots, both with broadcast fertilizer and fertigation (ie. fertilizer applied via drip lines). The 2003 growing season was relative wet. The plants in non-irrigated treatment on both sandy loam (3E) and sandy clay loam (4E) soils were only experiencing small water deficit during the most parts of growing season in 2003. On the sandy loam soil (3E), drip irrigation treatments were initiated on June 27 and terminated on August 13 with a total of 111.9 mm of water added. On the sandy clay loam soil (4E), drip irrigation treatments were initiated on July 2, and terminated in August 8, 2003 with a total of 74.7 mm of water added. Available soil moisture at the top 30 cm of rooting depths for drip and non-irrigated treatments were above 50 % level during the 2003 growing season on both sandy loam and sandy clay loam soils. Leaf petiole sap $\text{NO}_3\text{-N}$ and K concentrations were within sufficiency values during a month before harvest on both soils. On the sandy loam soil, there were only small differences in average marketable tomato yields between drip and non-irrigated treatments. Average marketable tomato yields under sub-surface drip irrigated plots were increased by 13.3 % relative to surface drip irrigated plots. Average marketable tomato yields under broadcast fertilizer were increased by 8.7 % relative to fertigated plots. On the sandy clay loam soil, average marketable tomato yields were increased by 17.8 % under drip irrigated plots relative to non-irrigated plots. Average marketable tomato yields under sub-surface drip irrigated plots were decreased by 7 % relative to surface drip irrigated plots. There were only small differences in average marketable tomato yields between broadcast and fertigated plots. The soluble solids of tomato were higher in the non-irrigated than

drip irrigated and/or fertigated plots on both soil conditions. There were no significant differences in soluble solids between surface and sub-surface drip irrigated tomatoes. However, tomatoes under fertigated plots on the sandy loam soil seemed to have lower soluble solid than tomatoes under broadcast plots. The drip irrigated tomatoes on sandy clay loam soil also have higher soluble solid than tomatoes on sandy loam soil. Drip irrigated and/or fertigated tomatoes increased water use efficiency by 9.2 % relative to non-irrigated tomatoes on the sandy clay loam soils but no difference in water use efficiency between drip irrigated and non-irrigated tomatoes on sandy loam soil. Drip and /or fertigated tomatoes had slightly higher total N and P uptake and removals than the non-irrigated control tomatoes on the sandy loam soil (3 E). However, on the sandy clay loam soil (4 E), all drip and/or fertigation treatments, except for sub-surface drip with broadcast fertilizer (SSB), decreased total N uptake and removal, because of the much reduced N concentrations in both fruits and stover.

INTRODUCTION

Increasing incidences of drought and high temperatures in southwestern Ontario have had serious negative effects on processing tomato growth, yield, and quality. These climate extremes are expected to become more frequent as global warming continues.

Researchers from GPCRC and elsewhere have shown that processing tomato responds favorably to both overhead sprinkler and surface drip irrigation (Phene et al., 1992; Dangler and Lacascio, 1990; Tan, 1995). From the standpoint of water and nutrient best management practices, however, drip irrigation/fertigation is superior to sprinkler irrigation because water is applied slowly to the root zone of the tomato plants. This results in less water loss through evaporation, reduced nutrient leaching losses, and greater efficiency with which tomato plants can utilize applied water and nutrients (Lacascio et al. 1997; Dangler and Lacascio, 1990). An additional advantage of drip irrigation/fertigation includes lower labor and operating costs relative to sprinkler systems, e.g. large metal pipes do not have to be moved and drip systems are easily automated.

Plot-scale research on drip irrigation/fertigation has proven it's potential to substantially improve the economics of tomato production on coarse-textured soils (Phene et al., 1992; Tan, 1995; Tu et al., 2002). However, farm-scale research needs to be conducted to determine the viability of the system on different soil types and in a commercial environment. Farm-scale studies will also raise producer awareness and acceptance of drip irrigation and fertigation systems. Two commercial scale large farm sites have been identified in southwestern Ontario in cooperation with two Producers. One site comprises about 16 acres on a loamy sand soil, and the other comprises about 5 acres on a clay loam soil.

The objective of this study is to determine the effects of surface and sub-surface drip irrigation and fertigation on: 1) the yield and quality of processing tomato; and 2) the efficiency with which processing tomato utilizes water and nutrients applied via surface and subsurface drip irrigation and/or fertigation.

MATERIALS AND METHODS

The experiments were conducted on two fields owned by cooperating Producers: one comprising about 3.1 acres on the sandy loam soil (3E), and the other comprising about 4.6 acres on the sandy clay loam soil (4E). The soil texture and soil water retention characteristics of these two soil types are summarized in Tables 1 & 2. On the sandy loam soil (3E), processing tomatoes (Heinz 9478) were transplanted on May 14, 2003 on double row, 1.52 m raised beds with 40.6 cm plant spacing and 50.8 cm row spacing at a density of 33,105 plants per hectare. On the sandy clay loam soil (4E), processing tomatoes (Heinz 9478) were transplanted on May 22, 2003 on double row, 1.67 m raised beds with 38.1 cm plant spacing and 45.7 cm row spacing at a density of 31,300 plants per hectare. The experiments consisted of three irrigation management treatments included non-irrigated control plots (NI), surface drip irrigated plots (SDI) and sub-surface drip irrigated plots (SSDI). Fertilizer treatments included both broadcast fertilizer and fertigation applied via the drip lines.

Drip irrigation and fertigation were delivered through lay-flat drip irrigation tubes (Chapin) with emitters spaced 30 cm apart and 0.15 U. S. gallon/emitter/hr flow rates (or 0.25 U.S. gallons/min/100 ft). One drip line was installed in the middle of double row. The irrigation amount and frequency for drip and fertigation treatments were determined using corrected long-term potential evapotranspiration data (Table 3) from near-by weather station and emitter flow rate, along with soil moisture retention characteristics (Table 2) from both sandy loamy and sandy clay loam soils.

On the sandy loam soil (3E), broadcast fertilizer treatments had three fertilizer splits (44.8 kg N/ha, 89.7 kg P/ha, 22.4 kg K/ha before planting; 112 kg N/ha at the planting; 44.8 kg N/ha and 28 kg K/ha at the side-dressing). Fertigation treatments had 2 splits broadcast fertilizer (44.8 kg N/ha, 89.7 kg P/ha, 22.4 kg K/ha before the planting; 67.3 kg N/ha, 28 kg K/ha at the planting) and 112 kg N/ha applied through fertigation.

On the sandy clay loam soil (4E), broadcast fertilizer treatments had fertilizer splits (56.1 kg N/ha, 134.5 kg P/ha, 33.6 kg K/ha before planting; 134.5 kg N/ha at the side-dressing). Fertigation treatments had 2 splits broadcast fertilizer (56.1 kg N/ha, 134.5 kg P/ha, 33.6 kg K/ha before planting; 67.3 kg N/ha at the side-dressing) and 67.3 kg N/ha applied through fertigation.

Representative soil samples were collected from both sandy loam (3E) and sandy clay loam (4E) soils at depths of 0-30 cm for soil texture determination, using the pipette method (Gee and Bauder, 1986). Intact soil cores (10 cm diameter by 10 cm long) were collected at three depths (0-10 cm, 10-20 cm and 20-30 cm) on both soils for determination of various soil physical properties. Soil samples were also collected at depths of 0-20, 20-40, 40-60, and 60-100 cm before planting and post-harvest for $\text{NO}_3\text{-N}$, $\text{NO}_4\text{-N}$ and mineral-N determinations.

Time Domain Reflectometer (TDR) was used to measure volumetric soil water content between 5 to 25 cm soil depths. Measurements were made two times per week in all treatments on both soils. Volumetric soil water content data were plotted throughout the growing season to show the

differences in wetting and drying patterns between the treatments and the soil types.

Leaf petiole nitrate and potassium measurements were determined using Cardy nitrate and potassium metres (Spectrum Technologies, Plainfield, IL). Thirty-five leaf petiole samples from the 4th leaf of the growing tip were taken from each location in each treatment. The petiole samples were put in a plastic bag and store in the cooler immediately. At the same day, the composite juice from each location was analysed for NO₃-N and K in the laboratory. Samples were obtained once per week in three location in each treatments on the sandy loam soil (3E). Leaf petiole samples were taken only once in all the treatments during the growing season on the sandy clay loam soil (4E).

Weather data were automatically recorded at both experimental fields, using Campbell CR-10 datalogger. These measurements included precipitation, air temperature, solar radiation, relative humidity, vapour pressure deficit, potential evapotranspiration.

Machine harvest yields were taken over the entire experimental fields for tomatoes on September 1, 2003 for sandy loam soil (3E) and for sandy clay loam soil (4E) on September 6, 2003. Fifteen to twenty tomato plants at three separate locations from each treatments were also hand harvested for comparison with machine harvest on both soils. The yields were calculated as metric tonnes of marketable tomatoes per hectare. The soluble solid was measured and expressed as Brix for both machine and hand harvest tomatoes. Plant tissue samples were collected and analysed for N and P contents, and total N and P removals were calculated by integrating with marketable yield. On the sandy loam (3 E) site, the effect of various drip irrigation and fertigation treatments on fruit disease severity and fruit firmness was evaluated. On August 26, 100 fruits per sample were selected at random and checked for bacterial spot or speck. The tomato fruits were divided into five classes: class 0= no spot; class 1= 1-2 spots per fruit; class 2= 3-5 spots per fruit; class 3= 6-10 spots per fruit; class 4= 11-15 spots per fruit; class 5= 16 or more spots per fruit. The disease severity value was calculated by summing the product of percent fruit in each class times the rating class. Eg. If 75 fruit in class 0 (no spot) and 5 fruit in each of other classes then the disease severity would be $(75*0) + (5*1) + (5*2) + (5*3) + (5*4) + (5*5) = 75$. Fruit firmness was determined with penetrometer puncture test 20 red fruit per sample using a 10 mm diameter cone shaped tip (68 degree angle).

RESULTS AND DISCUSSION

The 2003 growing season was relative wet, especially at the sandy loam (3 E) soil site (Table 3). The total precipitation during the growing season was 114.4 and 20.9 mm above 70-yr average at the sandy loam (3 E) and sandy clay loam (4 E) sites, respectively. The plants in non-irrigated treatment at the sandy loam (3 E) soil was only experiencing small water deficit during the most parts of growing season in 2003. On the sandy loam soil (3E), drip irrigation treatments were initiated on June 27 and terminated on August 13 with a total of 111.9 mm of water added. Volumetric soil water contents at a distance of 10 to 30 cm from emitter between 5 and 25 cm soil depth for surface and sub-surface drip irrigated treatments were consistently above 50 % available soil moisture during the entire growing season in 2003 (Fig. 1). Even the non-irrigated

treatment, the volumetric soil water content at the upper 30 cm soil depth was above 50 % available soil moisture during the most part of growing season, only a few brief dry periods, the available soil moisture was dropped below 50 %. On the sandy clay loam soil (4E), drip irrigation treatments were initiated on July 2, and terminated in August 8, 2003 with a total of 74.7 mm of water added. A consistently higher soil water contents for surface, sub-surface drip irrigated and non-irrigated treatments were observed on sandy clay loam soil (Fig. 2).

The wetting pattern of surface and sub-surface drip irrigated treatments on the sandy loam (3 E) and clay loam soils (4E) was used to evaluate root zone soil water content vs. lateral distance from emitter (Figs 3a, b). The result indicated that for both sandy loam and sandy clay loam soils at the 5 to 25 cm soil profile, volumetric soil water content was greater than 50 % available soil moisture (ASM) within a distance of 20 cm from drip emitters (Fig. 3a, b). However, the available soil moisture under surface drip irrigated plots at the sandy loam (3 E) soil was above 100 % level within a distance of 20 cm from drip emitters (Fig. 3a). This suggested that some of roots in the plant probably experienced too high soil moisture content at the sandy loam (3 E) soil during the 2003 growing season. Tan et al. (1981) reported that tomato roots had a greater relative absorption capacity for water uptake in response to the transpiration demand. They suggested that maintaining the root zone available soil moisture level of 50 % above is adequate to produce optimum yield. There is no need to maintain root zone available soil moisture above 100 % level.

The leaf petiole sap $\text{NO}_3\text{-N}$ concentration on the sandy loam soil (3E) declined rapidly between 1500 and 2500 ppm at the early flowing and fruit enlargement period to a level of 700 ppm by pre-harvest (Fig. 4). The similar leaf petiole sap $\text{NO}_3\text{-N}$ concentration values have been established for field grown tomatoes in principal production regions such as California and Florida (Locascio et al., 1997). The leaf petiole sap K followed the similar patterns as leaf petiole sap $\text{NO}_3\text{-N}$ (Fig. 5). On the sandy clay loam soil (4 E), the leaf petiole sap $\text{NO}_3\text{-N}$ and K concentrations were measured on August 7, 2003. The surface and sub-surface fertigated tomatoes had the lower leaf petiole sap $\text{NO}_3\text{-N}$ concentration than the non-irrigated , surface and sub-surface broadcast fertilizer tomatoes (Fig. 6). However, tomatoes under sub-surface fertigated plots had the higher leaf petiole sap K concentration than all other plots (Fig. 7).

On the sandy loam (3 E) soil, average surface-broadcast (SB) and surface-fertigated (SF) treatments resulted in only 2.3 % tomato yield increase relative to non-irrigated (NI) treatments during the 2003 wet year (Table 4). Average subsurface-broadcast (SSB) and subsurface-fertigated (SSF) treatments increased yield by 8.7 % relative to non-irrigated (NI) treatments. Average subsurface-broadcast (SSB) and subsurface-fertigated (SSF) treatments had 13.3 % greater yields than the average surface-broadcast (SB) and surface-fertigated (SF) treatments (Table 4). It is also interesting to note that average surface-broadcast (SB) and sub-surface broadcast (SSB) drip irrigated treatments had about 8.7 % greater yields than the average surface-fertigated (SF) and sub-surface fertigated (SSF) treatments. The soluble solids of tomato were higher in the non-irrigated treatments than in drip and fertigated treatments (Table 5). As was found in other study (Tan, 1995), soluble solids were decreased by drip and sprinkler irrigations on the loamy sand soil. The soluble solids of tomato were also found lower in the fertigated

treatments than in the broadcast drip irrigated treatments at the sandy loam (3 E) soil. The effect of various drip irrigation and fertigation treatments on fruit disease severity and fruit firmness was evaluated on the sandy loam soil (Table 6). The fertigated plots had more fruit with bacterial disease and more spots per fruit compared to the non-irrigated control and drip with broadcast fertilizer plots. The fertigated and non-irrigated control plots had softer fruit compared to the broadcast plots.

On the sandy clay loam(4 E) soil, average surface-broadcast (SB) and surface-fertigated (SF) treatments resulted in 17.8 % yield increase relative to non-irrigated (NI) treatments (Table 4). Average subsurface-broadcast (SSB) and subsurface-fertigated (SSF) treatments had 10.1 % greater yields than the non-irrigated (NI) treatments. Average surface-broadcast (SB) and surface-fertigated (SF) treatments had 7 % greater yield than the average subsurface-broadcast (SSB) and subsurface-fertigated (SSF) treatments on the sandy clay loam soil. The soluble solids of tomato were higher in the non-irrigated than drip irrigated and fertigated treatments. However, there were only small differences among various drip irrigated and fertigated treatments.

Marketable tomato yields under non-irrigated treatments on the sandy clay loam (4 E) soil were 7.3 MT/ha (3.3 tons/acre) higher than on the sandy loam(3 E) soil (Table 4). This is because the sandy clay loam soil have higher plant available water than the sandy loam soil (Table 2). The soil with high plant available water capacity produced greater tomato yields than the soil with low plant available water capacity was also reported by other study (Liptay et.al., 1997).

Water use efficiency is defined as crop yield per unit of water transpired by crops. There were only small differences in water use efficiency among various drip, fertigated and non-irrigated treatments on the sandy loam (3 E) soil (Table 7). However, on the sandy clay loam (4 E) soil, the drip irrigation and fertigation treatments increased water use efficiency by about 9.2 % relative to non-irrigation treatments (Table 7).

Nitrogen removed by fruit harvest ranged from 145 to 170 kg N ha⁻¹ at the sandy loam soil (3E). Compared with the non-irrigation treatments, all the irrigated or fertigated treatments increased crop N removal, with sub-surface drip (SSB) or fertigated (SSF) having the highest N removal (Table 8a). Similarly, all irrigated or fertigated treatments increased total nitrogen uptake, except for surface-fertigation (SF) which decreased total N uptake due to the decreased N concentrations in stover. In general, all treatments with drip or fertigation decreased the N concentrations in the stover, compared with the non-irrigated control. As a result, drip irrigation or fertigation increased only slightly the N use efficiency compared to the non-irrigated control (Table 9). Surface or sub-surface fertigation reduced the N use efficiency due to the largely reduced N concentrations in stover.

At the sandy clay loam soil (4E), the N uptake and removal patterns were much different from those at the sandy loam site (Table 8b). All the irrigated/fertigated treatments, except for subsurface-irrigation broadcast (SSB), decreased total N uptake and removal, because of the much reduced N concentrations in both fruits and stover, although the fruit yields were increased. This resulted in an up to 26% reduction in N use efficiency relative to the non-irrigated control

(Table 9).

On the other hand, all the irrigated/fertigated treatments increased phosphorus removal and total phosphorus uptake on both soils (Tables 8a,b). In comparison with the non-irrigated control treatment, phosphorus use efficiency with drip or fertigation increased by up to 39% on the sandy loam (3E) soil and up to 18% on the sandy clay loam (4E) soil. Clearly, drip or fertigation enhanced phosphorus movement in soil through diffusion.

On the sandy loam soil (3E), post-harvest soil $\text{NO}_3\text{-N}$ contents in the fertigation treatments, both surface and subsurface, were largely similar to the non-irrigated control (Fig. 8). However, post-harvest soil $\text{NO}_3\text{-N}$ contents in the 0-20cm soil depth of the fertilizer broadcasted treatments were increased by 1.7 and 3 mg kg^{-1} in surface and subsurface irrigation broadcast, respectively. It seems that fertilizer broadcast prevented the $\text{NO}_3\text{-N}$ from leaching through percolation water in soil profile.

On the sandy clay loam soil(4E), all the irrigation/fertigation treatments decreased $\text{NO}_3\text{-N}$ content up to 40 cm soil depth compared to the non-irrigated treatments(Fig. 9). Post-harvest soil mineral N followed the same patterns as soil $\text{NO}_3\text{-N}$ at both soils.

ACKNOWLEDGEMENTS

This research has been supported by grants from the Ontario Tomato Research Institute and the Ontario Processing Vegetable Growers. Appreciation is also expressed for expert technical assistance to Mr. K. Rinas, Mr. B. Hohner, Ms. M. Reeb, and Ms J. Byrne. We also acknowledge the cooperation of Mr. David & Peter Epp of the Lycoland Farms and Mr. Ken Epp of 4E Farm.

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Table 1. Average soil texture at 0-30 cm soil depth on the sandy loam (3E) and sandy clay loam (4E) soils.

Soils	Soil Texture (%)		
	Sand	Silt	Clay
Sandy loam	72.2	13.8	14
Sandy clay loam	53.6	22.2	24.2

Table 2. Average soil water retention properties at 0-30 cm depth on the sandy loam (3E) and sandy clay loam (4E) soils.

Soils	FC $\text{m}^3 \text{m}^{-3}$	PWP $\text{m}^3 \text{m}^{-3}$	PAWC $\text{m}^3 \text{m}^{-3}$
Sandy loam	0.20	0.11	0.09
Sandy clay loam	0.26	0.11	0.15

FC: field capacity; PWP: permanent wilting point; PAWC: plant available water capacity;

Table 3. Total precipitation (P), potential evapotranspiration (PE), water deficit, average air temperature (T_a), vapour pressure deficit (VPD) during the growing season in 2003 on the sandy loamy (3E) and sandy clay loam (4E) soils plus 70-yr long-term regional total precipitation and average air temperature.

Months	Total P			Total PE		Deficit		Average T_a			Avg VPD	
	mm			mm		mm		C			Kpa	
	3E	4E	70-yr	3E	4E	3E	4E	3E	4E	70-yr	3E	4E
May	107.2	109.0	70.4	90.4	91.2	0	0	12.1	12.2	14.2	0.17	0.19
June	63.0	66.3	75.9	117.8	118.9	54.8	52.6	18.2	18.5	19.5	0.37	0.45
July	124.0	73.3	72.5	129.7	130.5	5.7	57.2	21.5	21.4	21.9	0.41	0.42
August	119.0	71.1	80.0	119.6	112.3	0.6	41.2	21.5	21.1	20.9	0.31	0.24

P: Precipitation; PE: Potential evapotranspiration; T_a : Air temperature;
 VPD: Vapour pressure deficit; 3E: Sandy loam soil; 4E: Sandy clay loam soil
 Deficit=total P - total PE (deficit=0; if total P>= total PE)

Table 4. Effect of various drip irrigation and fertigation treatments on marketable tomato yields(MT/ha) on the sandy loam (3 E) and sandy clay loam (4 E) soils.

Treatments	Marketable yields (MT/ha)	
	Sandy loam (3 E)	Sandy clay loam (4 E)
Non-irrigated (NI)	96.9	104.2
Surface-broadcast (SB)	95.3	123.3
Surface-fertigated (SF)	90.6	122.1
Subsurface-broadcast (SSB)	110.8	115.7
Subsurface-fertigated (SSF)	99.8	113.6

Table 5. Effect of various drip irrigation and fertigation treatments on tomato soluble solids (%) on the sandy loam (3 E) and sandy clay loam (4 E) soils.

Treatments	Soluble solids (%)	
	Sandy loam (3 E)	Sandy clay loam (4 E)
Non-irrigated (NI)	5.1	5.0
Surface-broadcast (SB)	4.4	4.6
Surface-fertigated (SF)	3.9	4.5
Subsurface-broadcast (SSB)	4.3	4.8
Subsurface-fertigated (SSF)	3.9	4.6

Table 6. Effect of various drip irrigation and fertigation treatments on fruit disease severity and fruit firmness on the sandy loam soil.

Treatment	% fruit with bacterial spot or speck	Disease severity value	Fruit firmness (kg)
Non-irrigated (NI)	20.5 $\pm$ 10.5	33.8 $\pm$ 25.5	2.36 $\pm$ 0.16
Surface-broadcast (SB)	20.3 $\pm$ 8.1	32.0 $\pm$ 12.8	2.54 $\pm$ 0.26
Subsurface-broadcast (SSB)	19.7 $\pm$ 1.5	27.7 $\pm$ 1.5	2.64 $\pm$ 0.18
Surface-fertigation (SF)	36.7 $\pm$ 5.1	69.0 $\pm$ 2.6	2.39 $\pm$ 0.20
Subsurface-fertigation (SSF)	29.0 $\pm$ 10.1	53.0 $\pm$ 26.2	2.33 $\pm$ 0.15

Mean $\pm$ standard deviation.

Table 7. Marketable yields, accumulated evapotranspiration (ET), water use efficiency (WUE) and percentage increase on water use efficiency of processing tomatoes (cultivar Heinz 9478) for non-irrigated (NI) and drip irrigated and /or fertigated (DI) treatments on both sandy loam (3 E) and sandy clay loam (4 E) soils.

	Yields (MT/ha)		Accumulated ET (mm)		WUE (kg/ha/mm)		Increase WUE (%)
	DI	NI	DI	NI	DI	NI	DI
Sandy loam	99.1 ^a	96.9	326	315	304.0	307.6	-1.2
Sandy clay loam	118.7 ^a	104.2	310	297	382.9	350.8	9.2

^a Combined surface, sub-surface drip and fertigated treatments

Table 8a. Effect of various drip irrigation and fertigation treatments on nutrient removals (kg/ha) on a sandy loam soil(3 E), 2003.

	N removal	Total N uptake	P removal	Total P uptake
Non-irrigated (NI)	145.3	194.6	20.5	24.6
Surface-broadcast (SB)	149.8	216.7	20.7	24.9
Surface-fertigated (SF)	151.1	183.1	28.3	34.2
Subsurface-broadcast (SSB)	170.4	208.2	27.9	32.2
Subsurface-fertigated (SSF)	163.7	197.7	26.1	29.1

Table 8b. Effect of various drip irrigation and fertigation treatments on nutrient removals (kg/ha) on a sandy clay loam soil (4 E), 2003.

	N removal	Total N uptake	P removal	Total P uptake
Non-irrigated (NI)	170.6	226.5	20.6	25.0
Surface-broadcast (SB)	156.8	199.8	23.0	28.0
Surface-fertigated (SF)	173.3	175.9	25.5	29.5
Subsurface-broadcast (SSB)	183.6	245.4	22.4	27.3
Subsurface-fertigated (SSF)	129.5	167.0	23.1	28.7

Table 9. Increases in nutrient use efficiency due to irrigation/fertigation applied to processing tomatoes, in comparison with the no-irrigated plots, 2003.

Treatment	Sandy loam(3E)		Sandy clay loam (4E)	
	N	P	N	P
	----- % -----			
Surface-broadcast (SB)	11.4	1.2	-11.7	12
Surface-fertigation (SF)	-5.9	39	-22.3	18
Subsurface -broadcast (SSB)	7.0	30.9	8.3	9.2
Subsurface-fertigated (SSF)	1.6	18.3	-26.3	14.8

Fig. 1. Volumetric soil water content (%) measured at a soil depth of 5-25 cm and a distance of 10-30 cm from emitter under non-irrigated (NI), surface drip irrigated with broadcast fertilizer (SB), surface fertigated (SF), sub-surface drip irrigated with broadcast fertilizer (SSB) and sub-surface fertigated (SSF) plots on the sandy clay loam soil (3 E farm) during 2003 growing season.

Fig. 2. Volumetric soil water content (%) measured at a soil depth of 5-25 cm and a distance of 10-30 cm from emitter under non-irrigated (NI), surface drip irrigated with broadcast fertilizer (SB), surface fertigated (SF), sub-surface drip irrigated with broadcast fertilizer (SSB) and sub-surface fertigated (SSF) plots on the sandy clay loam soil (4 E farm) during 2003 growing season.

Fig. 3a. Volumetric soil water content between 5 and 25 cm soil depth vs. lateral distance from emitter for surface drip irrigated (S) and sub-surface drip irrigated (SS) plots on the sandy loam soil (3 E).

Fig. 3b. volumetric soil water content between 5 and 25 cm soil depth vs. lateral distance from emitter for surface drip irrigated (S) and sub-surface drip irrigated (SS) plots on the sandy clay loam soil (4 E).

SAP · NO₃-N, 3E, 2003

Fig. 4. Leaf petiole sap NO₃-N concentration for non-irrigated (NI), surface drip irrigated with broadcast fertilizer (SB), surface fertigated (SF), sub-surface drip irrigated with broadcast fertilizer (SSB) and sub-surface fertigated (SSF) plots on the loamy sand soil (3E) during 2003 growing season.

SAP - K, 3E, 2003

Fig. 5. Leaf petiole sap K concentration for non-irrigated (NI), surface drip irrigated with broadcast fertilizer (SB), surface fertigated (SF), sub-surface drip irrigated with broadcast fertilizer (SSB) and sub-surface fertigated (SSF) plots on the sandy loam soil (3E) during 2003 growing season.

SAP NO₃-N, Blythwood, Aug. 7, 2003

Fig. 6. Leaf petiole sap NO₃-N concentration for non-irrigated (NI), surface drip irrigated with broadcast fertilizer (SB), surface fertigated (SF), sub-surface drip irrigated with broadcast fertilizer (SSB) and sub-surface fertigated (SSF) plots on the sandy clay loam soil (4E) during 2003 growing season.

SAP K, Blythwood, Aug. 7, 2003

Fig. 7. Leaf petiole sap K concentration for non-irrigated (NI), surface drip irrigated with broadcast fertilizer (SB), surface fertigated (SF), sub-surface drip irrigated with broadcast fertilizer (SSB) and sub-surface fertigated (SSF) plots on the sandy clay loam soil (4E) during 2003 growing season.

Fig 8. Post-harvest soil profile $\text{NO}_3\text{-N}$ and mineral-N for non-irrigated (NI), surface drip irrigated with broadcast fertilizer (SB), surface fertigated (SF), sub-surface drip irrigated with broadcast fertilizer (SSB) and sub-surface fertigated (SSF) plots on the sandy loam soil (3E) during 2003 growing season.

Fig. 9. Post-harvest soil profile NO₃-N and mineral-N for non-irrigated (NI), surface drip irrigated with broadcast fertilizer (SB), surface fertigated (SF), sub-surface drip irrigated with broadcast fertilizer (SSB) and sub-surface fertigated (SSF) plots on the sandy clay loam soil (4E) during 2003 growing season.

control, non-irrigation
 surface drip
 sub-surface drip
 broadcast fertilizer
 fertigation

B: 3 splits; before planting, 40 lbs N, 120 lbs P, 20 lbs K;
 planting, 100 lbs N; sidedress, 60 lbs N, 25 lb K
F: before planting, 40 lbs N, 120 lbs P, 20 lbs K;
 Post sidedress, 60 lbs N, 25 lbs K; fertigation, 100 lbs N

Emitter flow rate:
 0.25 us gal/min/100'

Emitter spacing: 12"

16" between plants
 20" between rows
 60" between beds

Plant Density:
 13,403 plants/acre

Heinz 9478

**Dave &
 Peter Epp
 2004**

796-0840

Final: June 8, 2004

C: control, non-irrigation
 S: surface drip
 SS: sub-surface drip
 B: broadcast fertilizer
 F: fertigation

B: 2 splits; before planting, 50 lbs N, 120 lbs P, 30 lbs K;
 sidedress (10-14 days post planting), 120 lbs N

F: before planting, 50 lbs N, 120 lbs P, 30 lbs K; Sidedress (10-14 days post planting), 60 lbs N; fertigation, 60 lbs N

~ 6 acres

Ken Epp
 2004

796-4381
 1919 Con. 8

Emitter flow rate:
 0.25 us gal/min/100'

Emitter spacing: 12

15" between plants
 18" between rows

66" bed

Variety:
 Heinz 9553 (Rows 1-36)
 Heinz 2401 (Rows 36-42)

Final: June 15, 2004

2004 OTRI Final Research Report

TITLE: Farm-Scale Processing Tomato Production Using Surface and Subsurface Drip Irrigation and Fertigation

INSTITUTION: Agriculture and Agri-Food Canada, Research Branch, Greenhouse and Processing Crops Research Centre, Harrow, Ontario N0R 1G0

RESEARCHERS: Dr. C. S. Tan, Soil Water Management (Project leader)
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Dr. C. F. Drury, Soil Biochemistry
Mr. John Warner, Vegetable Specialist

SUMMARY

The 2004 growing season was extremely wet in May, about 132 mm above long-term average. The rest of the growing season (June, July and August) was close to the long-term average. The plants in the non-irrigated treatment of both soils experienced moderate water deficits during most parts of growing season in 2004. On the loamy sand soil (3E), drip irrigation treatments were initiated on July 6 and terminated on August 26 with a total of 126.8 mm of water added. On the sandy clay loam soil (4E), drip irrigation treatments were initiated on July 3, and terminated in September 14, 2004 with a total of 185.6 mm of water added. On the loamy sand soil, drip irrigated and fertigated treatments had consistently higher available soil moisture (ASM) in the top 30 cm depth than non-irrigated treatments during July and August. On the sandy clay loam soil, the ASM levels in the top 30 cm depth for non-irrigated treatments were lower than drip irrigated and fertigated treatments, however, the ASM levels for all drip, fertigated and non-irrigated treatments were above 50 % during the growing season. Leaf petiole sap $\text{NO}_3\text{-N}$ and K concentrations were within sufficiency values during the month before harvest on the loamy sand soil. However, leaf petiole sap $\text{NO}_3\text{-N}$ concentrations during the month before harvest on the sandy clay loam soil were low, especially for the fertigated plots. On the loamy sand soil (3 E), marketable tomato yields in 2004 were increased by 60.9 % and 65.7 % under surface drip or fertigated (SDI) and sub-surface drip or fertigated (SSDI) plots relative to non-irrigated control (NI) plots (129.4 tonnes/ha for SDI, 133.2 tonnes/ha for SSDI, 80.4 tonnes/ha for NI). There was no significant difference in marketable tomato yields among surface drip, sub-surface drip, broadcast fertilizer and fertigation treatments. Three-year average (2002-2004), marketable tomato yields on the loamy sand were increased by 41 % for drip irrigation and fertigation relative to no irrigation. On the sandy clay loam soil (4E), average marketable tomato yields on the drip irrigated and fertigated plots were increased by 12 % relative to non-irrigated plots. Average marketable tomato yields under broadcast drip irrigated plots were increased by 23 % relative to fertigated and non-irrigated plots. There were only small differences in average marketable tomato yields between fertigated and non-irrigated plots. The low marketable yields

for fertigated plots in 2004 were due to nitrogen deficiency as indicated by low leaf petiole sap $\text{NO}_3\text{-N}$ concentrations. Three-year average (2002-2004), marketable tomato yields on the sandy clay loam were increased by 25 % for drip irrigation and fertigation relative to no irrigation. On the loamy sand, tomato soluble solids were higher for no irrigation than for drip irrigation and fertigation. There were no significant differences in soluble solids among all drip or fertigated tomatoes. On the sandy clay loam soil, the drip irrigated tomatoes have similar soluble solid than the non-irrigated tomatoes. Drip irrigation and fertigation increased water use efficiency by 45% and 7% relative to no irrigation on the loamy sand and sandy clay loam, respectively. Drip irrigated and fertigated tomatoes on the loamy sand (3E) had much greater fruit N, P removals and total uptakes than the non-irrigated tomatoes, causing the nutrient N and P use efficiency to be greater by 56 % and 69 %, respectively, relative to no irrigation. However, on the sandy clay loam (4E), all the fertigated tomatoes decreased fruit N removals and total N uptakes, causing the N use efficiency to be reduced as much as 27 % relative to non-irrigated tomatoes.

INTRODUCTION

Increasing incidences of drought and high temperatures in southwestern Ontario have had serious negative effects on processing tomato growth, yield, and quality. These climate extremes are expected to become more frequent as global warming continues.

Researchers from GPCRC and elsewhere have shown that processing tomato responds favorably to both overhead sprinkler and surface drip irrigation (Phene et al., 1992; Dangler and Lacascio, 1990; Tan, 1985, 1995, 2002). From the standpoint of water and nutrient best management practices, however, drip irrigation/fertigation is superior to sprinkler irrigation because water is applied slowly to the root zone of the tomato plants. This results in less water loss through evaporation, reduced nutrient leaching losses, and greater efficiency with which tomato plants can utilize applied water and nutrients (Lacascio et al. 1997; Dangler and Lacascio, 1990). An additional advantage of drip irrigation/fertigation includes lower labor and operating costs relative to sprinkler systems, e.g. large metal pipes do not have to be moved and drip systems are easily automated.

Plot-scale research on drip irrigation/fertigation has proven its potential to substantially improve the economics of tomato production on coarse-textured soils (Phene et al., 1992; Tan, 1995, 2002; Tu et al., 2002). However, farm-scale research needs to be conducted to determine the viability of the system on different soil types and in a commercial environment. Farm-scale studies will also raise producer awareness and acceptance of drip irrigation and fertigation systems. Two commercial scale large farm sites have been identified in southwestern Ontario in cooperation with two Producers. One site locates on a loamy sand soil, and the other on a clay loam soil.

The objective of this study is to determine the effects of surface and sub-surface drip irrigation and fertigation on: 1) the yield and quality of processing tomato; and 2) the efficiency with which processing tomato utilizes water and nutrients applied via surface and subsurface drip irrigation and/or fertigation.

MATERIALS AND METHODS

The experiments were conducted on two fields owned by cooperating Producers: one comprising about 2.5 acres on the loamy sand soil (3E), and the other comprising about 5.7 acres on the sandy clay loam soil (4E). The soil texture and soil water retention characteristics of these two soil types are summarized in Tables 1 & 2. On the loamy sand soil (3E), processing tomatoes (Heinz 9478) were transplanted on May 28, 2004 on double row, 1.52 m raised beds with 40.6 cm plant spacing and 50.8 cm row spacing at a density of 33,105 plants per hectare. On the sandy clay loam soil (4E), processing tomatoes (Heinz 9553) were transplanted on June 5, 2004 on double row, 1.67 m raised beds with 38.1 cm plant spacing and 45.7 cm row spacing at a density of 31,300 plants per hectare. The experiments consisted of three irrigation management treatments included non-irrigated control plots (NI), surface drip irrigated plots (SDI) and sub-surface drip irrigated plots (SSDI). Fertilizer treatments included both broadcast fertilizer and fertigation applied via the drip lines.

Drip irrigation and fertigation were delivered through lay-flat drip irrigation tubes (Chapin) with emitters spaced 30 cm apart and 0.15 U. S. gallon/emitter/hr flow rates (or 0.25 U.S. gallons/min/100 ft). One drip line was installed in the middle of double row. The irrigation amount and frequency for drip and fertigation treatments were determined using corrected long-term potential evapotranspiration data (Table 3) from near-by weather station and emitter flow rate, along with soil moisture retention characteristics (Table 2) from both loamy sand and clay loam soils.

On the loamy sand soil (3E), broadcast fertilizer treatments had three fertilizer splits (44.8 kg N/ha, 89.7 kg P/ha, 22.4 kg K/ha before planting; 112 kg N/ha at the planting; 44.8 kg N/ha and 28 kg K/ha at the side-dressing). Fertigation treatments had 2 splits broadcast fertilizer (44.8 kg N/ha, 89.7 kg P/ha, 22.4 kg K/ha before the planting; 67.3 kg N/ha, 28 kg K/ha at the planting) and 112 kg N/ha applied through fertigation.

On the sandy clay loam soil (4E), broadcast fertilizer treatments had fertilizer splits (56.1 kg N/ha, 134.5 kg P/ha, 33.6 kg K/ha before planting; 134.5 kg N/ha at the side-dressing). Fertigation treatments had 2 splits broadcast fertilizer (56.1 kg N/ha, 134.5 kg P/ha, 33.6 kg K/ha before planting; 67.3 kg N/ha at the side-dressing) and 67.3 kg N/ha applied through fertigation.

Representative soil samples were collected from both loamy sand (3E) and sandy clay loam (4E) soils at depths of 0-30 cm for soil texture determination, using the pipette method (Gee and Bauder, 1986). Intact soil cores (10 cm diameter by 10 cm long) were collected at three depths (0-10 cm, 10-20 cm and 20-30 cm) on both soils for determination of various soil physical properties. Soil samples were also collected at depths of 0-20, 20-40, 40-60, and 60-100 cm before planting and post-harvest for $\text{NO}_3\text{-N}$, $\text{NO}_4\text{-N}$ and mineral-N determinations.

Time Domain Reflectometer (TDR) was used to measure volumetric soil water content between 5 to 25 cm soil depths. Measurements were made two times per week in all treatments on both

soils. Volumetric soil water content data were plotted throughout the growing season to show the differences in wetting and drying patterns between the treatments and the soil types.

Leaf petiole nitrate and potassium measurements were determined using Cardy nitrate and potassium metres (Spectrum Technologies, Plainfield, IL). Thirty-five leaf petiole samples from the 4th leaf of the growing tip were taken from each location in each treatment. The petiole samples were put in a plastic bag and store in the cooler immediately. At the same day, the composite juice from each location was analysed for NO₃-N and K in the laboratory. Samples were obtained once per week at three locations in each treatment on the loamy sand soil (3E). Leaf petiole samples were taken only once in all the treatments during the growing season on the sandy clay loam soil (4E).

Weather data were automatically recorded at both experimental fields, using a Campbell CR-10 datalogger. These measurements included precipitation, air temperature, solar radiation, relative humidity, vapour pressure deficit, and potential evapotranspiration.

Machine harvest yields were taken over the entire experimental fields for tomatoes on September 9, 2004 for the loamy sand soil (3E) and for the sandy clay loam soil (4E) on September 27, 2004. Fifteen to twenty tomato plants at three separate locations from each treatments were also hand harvested for comparison with machine harvest on both soils. The yields were calculated as metric tonnes of marketable tomatoes per hectare (Table 4). The soluble solid was measured and expressed as Brix for both machine and hand harvest tomatoes. Plant tissue samples were collected and analysed for N and P contents, and total N and P removals were calculated by integrating with marketable yield.

RESULTS AND DISCUSSION

The 2004 growing season was extremely wet in May, about 132 mm above long-term average (Table 3). The rest of the growing season (June, July and August) was close to the long-term average. The plants in the non-irrigated treatment of both soils experienced moderate water deficit (172 mm and 141 mm, respectively for loamy sand and sandy clay loam soils) during most parts of growing season in 2004. On the loamy sand soil (3E), drip irrigation treatments were initiated on July 6 and terminated on August 26 with a total of 126.8 mm of water added. On the sandy clay loam soil (4E), drip irrigation treatments were initiated on July 3, and terminated in September 14, 2004 with a total of 185.6 mm of water added. On the loamy sand soil, drip irrigated and fertigated treatments had consistently higher available soil moisture (ASM) in the top of 30 cm depth than non-irrigated treatments in July and August during the 2004 growing season (Fig. 1). On the sandy clay loam soil, the ASM levels in the top 30 cm depth for non-irrigated treatments were lower than drip irrigated and fertigated treatments, however, the ASM levels for all drip, fertigated and non-irrigated treatments were above 50 % during the growing season (Fig. 2).

The leaf petiole sap NO₃-N concentration on the loamy sand soil (3E) declined rapidly between 1800 and 3200 ppm at the early flowing and fruit enlargement period to a level of 1000 ppm by

pre-harvest (Fig. 3). The similar leaf petiole sap $\text{NO}_3\text{-N}$ concentration values have been established for field grown tomatoes in principal production regions such as California and Florida (Locascio et al., 1997). The large drop in leaf petiole sap $\text{NO}_3\text{-N}$ concentration at around last week of July for surface drip with broadcasting fertilizer treatments (SB) probably due to heavy rainfall (58 mm) occurred during that period and a constant surface drip water supply throughout the growing season. The leaf petiole sap K increased from early season up to around last week of July and decreased thereafter (Fig. 4). Both the leaf petiole sap $\text{NO}_3\text{-N}$ and K concentrations were within sufficiency values during a month before harvest. On the sandy clay loam soil (4 E), the leaf petiole sap $\text{NO}_3\text{-N}$ and K concentrations were measured on August 23, 2004. The surface and sub-surface fertigated (SF, SSF) tomatoes had much lower leaf petiole sap $\text{NO}_3\text{-N}$ concentrations than the non-irrigated (NI), surface and sub-surface drip irrigated with broadcast fertilizer (SB, SSB) tomatoes (Fig. 5). The heavy rainfall (68 mm) occurred between last week of July and first week of August had delayed nitrogen application to all fertigated treatments. Therefore, the tomatoes under surface and subsurface fertigated treatments showed symptoms of nitrogen deficiency as indicated by extremely low leaf petiole sap $\text{NO}_3\text{-N}$ (Fig. 5). Tomatoes under sub-surface fertigated plots also had the lower leaf petiole sap K concentration than all other plots (Fig. 6).

On the loamy sand soil, average surface drip-broadcast (SB) and surface-fertigated (SF) treatments resulted in 60.9 % yield increase relative to non-irrigated (NI) treatments (Table 4a). Average subsurface drip-broadcast (SSB) and subsurface-fertigated (SSF) treatments increased yield by 65.7 % relative to non-irrigated (NI) treatments. There was no significant difference in yields among surface drip-broadcast (SB), surface-fertigated (SF), subsurface drip-broadcast (SSB) and subsurface-fertigated (SSF) treatments (Table 4a). Three-year average (2002-2004), marketable tomato yields were increased by 41 % under drip irrigated or fertigated plots relative to non-irrigated plots (Table 4b). The soluble solids of tomato were higher in the non-irrigated treatments than in drip and fertigated treatments (Tables 5a,5b). As was found in other study (Tan, 1995), soluble solids were decreased by drip and sprinkler irrigations on the loamy sand soil. There were no significant differences on soluble solids among surface, sub-surface drip and fertigated treatments.

On the sandy clay loam soil, average surface drip-broadcast (SB) and surface-fertigated (SF) treatments resulted in 9.9 % yield increase relative to non-irrigated (NI) treatments (Table 4a). Average subsurface drip-broadcast (SSB) and subsurface-fertigated (SSF) treatments had 14.2 % greater yields than the non-irrigated (NI) treatments. It is interesting to note that average surface drip-broadcast (SB) and subsurface drip-broadcast (SSB) treatments had 21.7 % greater yield than the average surface-fertigated (SF) and subsurface-fertigated (SSF) treatments on the sandy clay loam soil. The low marketable tomato yields for fertigated treatments were due to nitrogen deficiency as indicated by extremely low leaf petiole sap $\text{NO}_3\text{-N}$ (Fig. 5). Three-year average (2002-2004), marketable tomato yields were increased by 25 % under drip irrigated and fertigated plots relative to non-irrigated plots (Table 4b). The soluble solids of tomato were higher in the non-irrigated than drip irrigated and fertigated treatments, however, the differences among various treatments on the sandy clay loam soil were small relative to the loamy sand soil (Tables 5a,5b).

Water use efficiency is defined as crop yield per unit of water transpired by crops. The drip irrigation and fertigation treatments increased water use efficiency by about 45 % and 7 % relative to non-irrigation treatments on the loamy sand and sandy clay loam soils, respectively (Table 6).

On the loamy sand soil (3E), nitrogen removed by fruit harvest ranged from 133 to 226 kg N ha⁻¹ and phosphorus removal from 18 to 31 kg P ha⁻¹ (Table 7a). Compared with the non-irrigation treatments, all the irrigated or fertigated treatments increased crop N, P removal and uptake. On the sandy clay loam soil (4E), nitrogen removed by fruit harvest ranged from 107 to 182 kg N ha⁻¹ and phosphorus removal from 20 to 23 kg P ha⁻¹ (Table 7b). The non-irrigated control treatments had higher N removal and uptake than the irrigated and fertigated treatments except the sub-surface drip with broadcast fertilizer (SSB), which had the highest N removal and uptake. The low N removal and uptake on the sandy clay loam soil for surface and sub-surface fertigated treatments (Table 7b) is primarily due to the low yields (Table 4a) caused by nitrogen deficiency as indicated by low leaf petiole sap NO₃ -N (Fig. 5).

On the loamy sand (3E), crop nutrient N and P removals and total uptakes (Table 7a) suggested that drip and fertigated (SB, SF, SSB, SSF) treatments had much higher nutrient N and P use efficiency than the non-irrigated (NI) treatments (Table 8). On the sandy clay loam (4E), all the fertigated treatments decreased crop N removal and total uptake (Table 7b). Therefore, the nitrogen use efficiency for all the fertigated tomatoes was reduced as much as 27 % relative to the non-irrigated control (Table 8). However, the total P uptake (Table 7b) and phosphorus use efficiency (Table 8) were increased slightly for all drip and fertigated treatments.

ACKNOWLEDGEMENTS

This research has been supported by grants from the Ontario Tomato Research Institute and the Ontario Processing Vegetable Growers. Appreciation is also expressed for expert technical assistance to Mr. K. Rinas, Mr. B. Hohner, Ms. M. Reeb, and Ms J. Byrne. We also acknowledge the cooperation of Mr. David & Peter Epp of the Lycoland Farms and Mr. Ken Epp of 4E Farm.

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Table 1. Average soil texture in the top 30 cm depth on the loamy sand (3E) and sandy clay loam (4E) soils

Soils	Soil Texture (%)		
	Sand	Silt	Clay
Loamy sand (3 E)	83.2	11.8	5
Sandy clay loam (4 E)	52.8	24.8	22.4

Table 2. Average soil water retention properties in the top 30 cm depth on the loamy sand (3E) and sandy clay loam (4E) soils.

Soils	FC $\text{m}^3 \text{m}^{-3}$	PWP $\text{m}^3 \text{m}^{-3}$	PAWC $\text{m}^3 \text{m}^{-3}$
Loamy sand	0.19	0.07	0.12
Sandy clay loam	0.27	0.135	0.135

FC: field capacity; PWP: permanent wilting point; PAWC: plant available water capacity;

Table 3. Total precipitation (P), potential evapotranspiration (PE), water deficit, average air temperature (T_a), and vapour pressure deficit (VPD) during the growing season in 2004 on the loamy sand (3E) and sandy clay loam (4E) soils plus 70-yr long-term regional total precipitation and average air temperature.

Months	Total P			Total PE		Deficit		Average T_a			Avg VPD	
	mm			mm		mm		C			Kpa	
	3E	4E	70-yr	3E	4E	3E	4E	3E	4E	70-yr	3E	4E
May	207.0	197.5	70.4	91.1	97.5	0	0	14.9	14.7	14.2	0.19	0.17
June	39.5	73.3	75.9	116.2	119.1	76.7	45.8	19.1	19.0	19.5	0.38	0.39
July	66.7	75.0	72.5	122.6	122.6	55.9	47.6	21.0	21.0	21.9	0.33	0.40
August	69.4	58.2	80.0	108.4	105.4	39.0	47.2	19.5	19.5	20.9	0.25	0.30

P: Precipitation; PE: Potential evapotranspiration; T_a : Air temperature;
VPD: Vapour pressure deficit; 3E: Loamy sand; 4E: Sandy clay loam

Deficit=total P - total PE (deficit=0; if total P>= total PE)

Table 4a. Effect of various drip irrigation and fertigation treatments on marketable tomato yields(tonnes/ha) on the loamy sand (3 E) and sandy clay loam (4 E) soils in 2004.

Treatments	Marketable yields (tonnes/ha)	
	Loamy sand (3 E)	Sandy clay loam (4 E)
Non-irrigated (NI)	80.4	110.7
Surface-broadcast (SB)	125.9	137.2
Surface-fertigated (SF)	132.8	106.1
Subsurface-broadcast (SSB)	133.5	135.1
Subsurface-fertigated (SSF)	132.8	117.6

Table 4b. Effect of various drip irrigation and fertigation treatments on marketable tomato yields(tonnes/ha) on the loamy sand (3 E) and sandy clay loam (4 E) soils average over 3-year (2002-2004).

Treatments	Marketable yields (tonnes/ha)	
	Loamy sand (3 E)	Sandy clay loam (4 E)
Non-irrigated (NI)	86.7	92.5
Surface-broadcast (SB)	117.2	125.0
Surface-fertigated (SF)	118.9	116.3
Subsurface-broadcast (SSB)	127.7	115.8
Subsurface-fertigated (SSF)	123.8	105.1

Table 5a. Effect of various drip irrigation and fertigation treatments on tomato soluble solids (%) on the loamy sand (3 E) and sandy clay loam (4 E) soils in 2004.

Treatments	Soluble solids (%)	
	Loamy sand (3 E)	Sandy clay loam (4 E)
Non-irrigated (NI)	6.0	5.0
Surface-broadcast (SB)	4.9	5.1
Surface-fertigated (SF)	5.1	4.9
Subsurface-broadcast (SSB)	4.8	5.1
Subsurface-fertigated (SSF)	4.7	4.6

Table 5b. Effect of various drip irrigation and fertigation treatments on tomato soluble solids (%) on the loamy sand (3 E) and sandy clay loam (4 E) soils average over 3-year (2002-2004).

Treatments	Soluble solids (%)	
	Loamy sand (3 E)	Sandy clay loam (4 E)
Non-irrigated (NI)	5.6	5.0
Surface-broadcast (SB)	4.6	4.9
Surface-fertigated (SF)	4.5	4.7
Subsurface-broadcast (SSB)	4.6	4.9
Subsurface-fertigated (SSF)	4.4	4.8

Table 6. Marketable yields, accumulated evapotranspiration (ET), water use efficiency (WUE) and percentage increase on water use efficiency of processing tomatoes (cultivar Heinz 9478 for 3E, Heinz 9553 for 4E) for non-irrigation (NI), drip irrigated and fertigated (DI) treatments on both Loamy sand (3 E) and sandy clay loam (4 E) soils in 2004.

	Yields (tonnes/ha)		Accumulated ET (mm)		WUE (kg/ha/mm)		Increase WUE (%)
	DI	NI	DI	NI	DI	NI	DI
Loamy sand	131.3 ^a	80.4	306	272	429	296	45
Sandy clay loam	124.0 ^a	110.7	307	292	404	379	7

^a Combined surface, sub-surface drip and fertigated treatments

Table 7a. Effect of various drip irrigation and fertigation treatments on nutrient N, P removals and total uptakes (kg/ha) on the loamy sand soil (3 E) in 2004.

	N removal	N uptake	P removal	P uptake
Non-irrigated (NI)	133.4	216.9	18.2	25.6
Surface-broadcast (SB)	175.0	258.9	30.2	41.7
Surface-fertigated (SF)	220.1	338.1	31.0	43.2
Subsurface-broadcast (SSB)	219.2	308.4	29.7	38.0
Subsurface-fertigated (SSF)	226.1	315.0	30.2	39.2

Table 7b. Effect of various drip irrigation and fertigation treatments on nutrient N, P removals and total uptakes (kg/ha) on the sandy clay loam soil (4 E) in 2004.

	N removal	N uptake	P removal	P uptake
Non-irrigated (NI)	160.6	206.3	20.0	24.7
Surface-broadcast (SB)	148.3	200.8	21.7	27.1
Surface-fertigated (SF)	107.3	150.5	19.7	25.1
Subsurface-broadcast (SSB)	182.1	221.8	23.1	27.0
Subsurface-fertigated (SSF)	123.6	168.5	21.7	27.2

Table 8. Increases in nutrient use efficiency due to irrigation and fertigation applied to processing tomatoes, in comparison with the no-irrigated plots in 2004.

Treatment	Loamy sand (3E)		Sandy clay loam (4E)	
	N	P	N	P
	----- % -----			
Surface-broadcast (SB)	19.4	62.9	-2.7	9.7
Surface-fertigation (SF)	55.9	68.8	-27.0	1.6
Subsurface -broadcast (SSB)	42.1	48.4	7.5	9.3
Subsurface-fertigation (SSF)	45.2	53.1	-18.3	10.1

Fig.1. Volumetric soil water content measured at a soil depth of 5-25 cm and a distance of 10-30 cm from emitter under non-irrigated (NI), surface drip irrigated with broadcast fertilizer (SB), surface fertigated (SF), sub-surface drip irrigated with broadcast fertilizer (SSB) and sub-surface fertigated (SSF) plots on the loamy sand soil during 2004 growing season.

Fig.2. Volumetric soil water content measured at a soil depth of 5-25 cm and a distance of 10-30 cm from emitter under non-irrigated (NI), surface drip irrigated with broadcast fertilizer (SB), surface fertigated (SF), sub-surface drip irrigated with broadcast fertilizer (SSB) and sub-surface fertigated (SSF) plots on the sandy clay loam soil during 2004 growing season.

SAP - NO₃-N, 3E, 2004

Fig. 3. Leaf petiole sap NO₃-N concentration for non-irrigated (NI), surface drip irrigated with broadcast fertilizer (SB), surface fertigated (SF), sub-surface drip irrigated with broadcast fertilizer (SSB) and sub-surface fertigated (SSF) plots on the loamy sand soil (3E) during 2004 growing season.

SAP - K, 3E, 2004

Fig. 4. Leaf petiole sap K concentration for non-irrigated (NI), surface drip irrigated with broadcast fertilizer (SB), surface fertigated (SF), sub-surface drip irrigated with broadcast fertilizer (SSB) and sub-surface fertigated (SSF) plots on the loamy sand soil (3E) during 2004 growing season.

SAP NO₃-N, 4E, Aug. 23, 2004

Fig. 5. Leaf petiole sap NO₃-N concentration for non-irrigated (NI), surface drip irrigated with broadcast fertilizer (SB), surface fertigated (SF), sub-surface drip irrigated with broadcast fertilizer (SSB) and sub-surface fertigated (SSF) plots on the sandy clay loam soil (4E) during 2004 growing season

SAP K, 4E, Aug. 23, 2004

Fig. 6. Leaf petiole sap K concentration for non-irrigated (NI), surface drip irrigated with broadcast fertilizer (SB), surface fertigated (SF), sub-surface drip irrigated with broadcast fertilizer (SSB) and sub-surface fertigated (SSF) plots on the sandy clay loam soil (4F) during 2004 growing season.

Farm-Scale Processing Tomato Production using Surface and Subsurface Drip Irrigation and Fertigation

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Study Objectives

Surface and sub-surface drip and fertigation on yield and quality of processing tomatoes

Surface and sub-surface drip and fertigation on nutrient and water usage of processing tomatoes

Impacts/Benefits for Ontario Processing Tomato Industry

Development of best water and nutrient management practices for increasing tomato yield and quality and reducing nitrogen and phosphorus leaching to groundwater

Increasing producer awareness and acceptance of new tomato production technologies through farm-scale studies on cooperator fields

Installation of subsurface drip lines

Installation of surface drip lines

Soil sampling for N, P, K measurements (0- 100 cm depths)

Water level in the early spring

Water level in the late summer

Average Soil Texture (%) at 0-30 cm depth

Sites	Sand	Silt	Clay
Loamy Sand (3 E)-2002	89.3	6.0	4.7
Sandy Loam (3 E)-2003	72.2	13.8	14.0
Loamy Sand (3E)- 2004	83.2	11.8	5.0
Clay Loam (4 E)-2002	32.7	30.4	36.9
Sandy Clay Loam (4 E)-2003	53.6	22.2	24.2
Sandy Clay Loam (4E)-2004	52.8	24.8	22.4

Precipitation (mm)--3 E Farm

Precipitation (mm)--4 E Farm

Water Deficit (mm)--3 E Farm

Water Deficit (mm)--4E Farm

Wetting Pattern (July 19, 2002)

East- West Direction

Wetting Pattern (Aug. 14, 2003)- 3 E

Wetting Pattern (August 14, 2003)- 4 E

Marketable Yields (t/ha)--3 E 3-years Average

Marketable Yields (ton/acre)--3 E 3-years Average

Soluble Solids (% Brix)--Sandy Loam

Marketable Yields (ton/acre)--4E Farm 3-years Average

Marketable Yield (t/ha)- 4E Farm 3-years Average

Soluble Solids (% Brix)--4E Farm

% Increase in WUE (Broadcast DI vs NI)
Average over 2002-2004

Advantages of Sub-surface Drip IRRIGATION

- ✱ **No need to remove drip lines prior to harvest**
- ✱ **Fewer problems for weed control**
- ✱ **Less susceptible to being damaged by machinery or animals and to being blown away on windy days**
- ✱ **Reduce risk of tomato fruit rots due to direct contact of a wet soil surface**

Disadvantages of Sub-surface Drip IRRIGATION

- * Higher costs of laying and retrieving dripper-lines
- * Possible of plugging emitters
- * Dripper-lines have to be buried deep enough to avoid cultivation damage

Acknowledgements

- ✱ **Ontario Tomato Research Institute**
- ✱ **Ontario Processing Vegetable Growers**
- ✱ **Mr. David & Peter Epp (Lycoland Farm)**
- ✱ **Mr. Ken Epp (4E Farm)**

Acknowledgements

- ★ Technical assistance to Mr. K. Rinas, Mr. B Hohner, Ms. M Reeb and Ms. J Byrne

Farm-Scale Processing Tomato Production using Surface and Subsurface Drip Irrigation and Fertigation

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3-year Summary (2002-2004)

Processing tomato (Heinz 9478) was grown on two commercial fields: one on light soil (ie. sandy loam or loamy sand) and the other on heavy soil (ie. clay loam or sandy clay loam). The objective of this study was to determine the effects of surface and subsurface drip irrigation and fertigation on yield, quality, and water-nutrient use efficiency of processing tomato grown at the commercial field scale. The treatments included: i) non-irrigated control plots with broadcast fertilizer; ii) surface drip irrigated plots with broadcast fertilizer; iii) surface drip irrigated plots with fertigation; iv) sub-surface drip irrigated plots with broadcast fertilizer; and v) sub-surface drip irrigated plots with fertigation. On the light soil, average marketable tomato yields over a 3-year period (2002-2004) were increased by 36 % and 45 % under the surface drip or fertigated (SDI) and sub-surface drip or fertigated (SSDI) treatments relative to the non-irrigated control (NI) treatments (118.1 tonnes/ha for SDI, 125.8 tonnes/ha for SSDI, 86.7 tonnes/ha for NI). Average marketable tomato yields under SSDI were increased only by 6.5 % relative to SDI. There was no significant difference in average marketable tomato yields between broadcast fertilizer and fertigation for both SSDI and SDI treatments. On the heavy soil, average marketable tomato yields over a 3-year period (2002-2004) were increased by 31 % under SDI relative to NI treatments (120.7 tonnes/ha for SDI, 92.5 tonnes/ha for NI), while tomato yields under SSDI were increased by 19.5 % relative to NI treatments (110.5 tonnes/ha for SSDI, 92.5 tonnes/ha for NI). Average marketable tomato yields under SDI were increased by 9 % relative to SSDI. The soluble solids of tomato were higher in the non-irrigated than drip irrigated and/or fertigated plots under both soil conditions. However, the reduction on soluble solids due to irrigation was much larger for the light soil than for the heavy soil. There were no significant differences on soluble tomato solids among SDI broadcasting, SDI fertigation, SSDI broadcasting, and SSDI fertigation. Drip irrigated and/or fertigated tomatoes increased water use efficiency by 25 % and 17 % relative to non-irrigated tomatoes for the light and the heavy soils, respectively.