Conservation Tillage Systems for Processing Tomato Production

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Abstract. Processing tomatoes (*Lycopersicon esculentum* Mill.) are grown on ≈6000 ha in southwestern Ontario. Field experiments were conducted in 1998 and 1999 at two locations to explore the potential of alternative tillage practices (conventional, disked, zone-till, and no-till) on growth, development, yield and quality of tomatoes. Growth measurements of leaf number, plant height, stem diameter, total aboveground dry weight, and LAI did not differ with tillage system. Rye (*Secale cereale* L.) used as a cover crop did not influence tomato growth or development. Yield differences ($P < 0.05$) were not observed for red and green tomato fruit harvested in the conventional, disked or zone-tillage treatments. Yield reductions ($P < 0.05$) were observed however, for both red and green fruit with no-tillage. The delay in crop maturity associated with no-till reduced the potential for the application of this tillage practice for tomato production. Tomato postharvest quality did not differ among tillage systems. Zone-tillage was found to be a viable alternative to the moldboard plow as a primary tillage practice for the production of processing tomatoes.

Processing tomatoes are grown on ≈120,000 ha in the United States (U.S. Dept. of Agriculture, 2000). In 1998, more than 6000 ha of tomatoes were grown for processing in Ontario with a total yield of 510,000 MT and gross farm value of \$59 million (OVGMB, 2000). Horticultural practices used for tomato production rely upon intensive use of tillage. As many as four to six tillage passes are often employed to prepare the seedbed for transplanting. These practices include moldboard plowing, multiple passes with a disk and/or field cultivator and raised bed formation prior to transplanting. The adverse effect of excessive tillage practices on soil structure, erosion and nutrient leaching have been well documented (Opoku et al., 1997; Singh and Sainju, 1998; Wraith and Wright, 1998).

Conservation tillage systems need to be implemented in vegetable production systems to address these concerns. Soil structural, organic matter breakdown and nutrient leaching problems will continue to plague the vegetable industry unless tillage conservation techniques are adopted. Conservation tillage practices have been practiced successfully in numerous field crops including corn, soybean, and cereal production. Adoption of these alternative tillage practices in tomato production has not been widely accepted.

Numerous studies have been reported on the potential of conservation tillage practices for fresh market (Abdul-Baki and Teasdale, 1993; Doss et al., 1981; Drost and Price, 1991; Mwaja et al., 1996; Price and Baughan, 1987; Sainju et al., 2000; Shelby et al., 1988) and processing tomato production (Creamer et al., 1996; Johnson, 1998; Louws et al., 1996; McKeown et al., 1998; Swanton et al., 1997), and variable yield results were reported. Shelby et al. (1988) found yields of fresh-market tomatoes were comparable under no-tillage and conventional tillage treatments. In a recent paper, Sainju et al. (2000) explored the effect of three tillage systems, including no-till, chisel plow, and moldboard plow, on tomato yield and nitrogen uptake. Their results suggested that chisel plow was a viable alternative to moldboard plow and in one out of three years of the study they found a reduction in stem and leaf dry weights, nitrogen uptake, and fruit yield with no-tillage. None of these studies, however, has examined the role of zone tillage as an alternative tillage practice.

Hooker (2000) examined the use of fall zone-tillage as a management option for use on two different fine-textured soils for corn following soybean. Soil characteristics, including soil moisture and in-row bulk density, were comparable under the fall zone-tillage and moldboard plow systems. Corn yield was not reduced under the zone-tillage compared with the conventional moldboard plow system. This work suggested that zone-tillage

was a viable alternative to conventional tillage and traditional no-till practices.

Only one study has been published on the potential of zone-tillage for use in processing tomato production. Louws et al. (1996) found that zone-tillage did not affect marketable yield when compared with yields from the moldboard plow treatment. In this study, however, tomatoes were planted in single rows, the zone of disturbance was 35 cm deep, and rye was allowed to grow to a height of 1.0 to 1.2 m before being desiccated. No quality analyses of the tomato fruit were performed. They suggested that zone-tillage and rye as a cover crop could be used to enhance the sustainability of the tomato industry. In a preliminary report, Swanton et al. (1997) reported yields of 117 MT/ha for zone-tillage compared with 110 MT/ha of tomatoes grown under conventional management practices. Both studies demonstrated the potential of alternative tillage practices for processing tomato production.

The potential of zone tillage as an alternative tillage system for tomato production has not been thoroughly explored. Therefore the objective of this study was to determine the effect of zone tillage on growth, development, yield and postharvest quality of processing tomatoes.

Materials and Methods

Experiments were conducted in 1998 and 1999 at Simcoe and Harrow, Ont. At Simcoe, the soil was a Wilsonville sand (Brunisolic Gray Brown Luvisol) with 66% sand, 28% silt and 6% clay, 1.5% organic matter, and pH 6.4 in 1998 and was a Wattford fine sandy loam (Brunisolic Gray Brown Luvisol) with 70% sand, 24% silt and 6% clay, 1.7% organic matter, and pH 5.8 in 1999. At Harrow, the soil was a Fox sandy loam (Brunisolic Gray Brown Luvisol: Hapludolf Subgroup) with 83% sand, 5% silt and 13% clay, 2.6% organic matter, and pH 6.5 in 1998 and 1999.

The experiment was designed as a randomized complete block, replicated four times at Simcoe and three times at Harrow. Rye was seeded in 20-cm rows at 180 kg·ha⁻¹ in mid-Oct. 1997 and 1998. Glyphosate [N-(phosphonomethyl) glycine] at 0.9 kg·ha⁻¹ a.i. was applied in 300 L·ha⁻¹ of water at a pressure of 200 kPa using a tractor-mounted sprayer in April of the following spring to all plots when rye was 40–50 cm in height. Three reduced-tillage systems (disk, zone-till, and no-till) were compared with conventional moldboard tillage. Conventional tillage consisted of moldboard plowing, followed by disking and cultivation to prepare the seedbed for transplanting. The “disking” treatment consisted of one pass with a tandem disk in one direction, at a depth of ≈10–15 cm. “Zone tillage” consisted of one pass into the standing rye with a “Trans-Till” (Rowtech Inc., Stover, Mich.) to leave a tilled zone (23 cm wide, 15 cm deep) for planting. Rye remained standing in the no-tillage plots prior to planting. All tillage operations were conducted 7 to 10 d after the spring application of glyphosate. Metolachlor [2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-

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methoxy-1-methylethyl)acetamide] at 1.92 kg·ha⁻¹ a.i. plus metribuzin [4-amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4-triazin-5(4*H*)-one] at 0.25 kg·ha⁻¹ a.i. were applied preemergence. Fertilizer was broadcast according to soil test recommendations at 500 kg·ha⁻¹ 10N-10P-10K prior to the tillage operations at Simcoe in 1998 and 1999. No supplemental Ca or Mg was applied.

Each plot was 9 m wide × 17 m long with 10-m alleyways between replications to allow for movement of machinery. Five-week-old tomato plants in 288 cell trays were obtained from a commercial greenhouse. Tomato seedlings (cv. H9478) were planted on 20 May at Simcoe and 26 May at Harrow in 1998 and 1999 with a modified tomato transplanter (RJ Equipment, Blenheim, Ont., Canada). Planters were fitted with heavy duty, down-pressure springs and narrow packing wheels to firmly set plants in reduced tillage plots. Starter fertilizer (10N-34P-0K) was applied at 0.5% v/v in the transplant water. Six twin rows were planted in each plot. Rows were 45 cm apart with tomato transplants spaced 40 cm within the row on 1.5-m centers to give a final plant population of 33,333 plants/ha across all tillage systems. Two weeks after planting, an additional 455 kg·ha⁻¹ of 28% urea ammonium nitrate (UAN) was applied in a band at a depth of 10 cm using a 3-shank applicator. One shank was positioned between the twin rows of tomatoes and the remaining two shanks positioned 23 cm on either side of the two tomato rows. At Harrow, 532 kg·ha⁻¹ of 28% UAN was injected using a similar setup, 3 weeks after transplanting.

Metribuzin was applied early postemergence (POST) at 0.15 kg·ha⁻¹ a.i. Plots were kept weed-free by hand weeding. Chlorothalonil (tetrachloroisophthalonitrile) was applied at 1.5 kg·ha⁻¹ a.i. in 725 L·ha⁻¹ of water as required for disease control. Colorado potato beetle was controlled with one application of imidacloprid [1-[6-chloro-3-pyridinyl)methyl]-*N*-nitro-2-imidazolidinimine] at 48 g·ha⁻¹ a.i. applied in 725 L·ha⁻¹ of water. Ethepon (2-chloroethanesulphonic acid) was applied at a rate of 0.9 kg·ha⁻¹ a.i. in 300 L·ha⁻¹ of water when ≈20% of the fruit were red or partly red to promote ripening. No irrigation was used throughout the season at either location.

Growth analyses were performed throughout the growing season at Simcoe only. Total crop heat units (CHU) at each sampling date was calculated using a day base temperature of 10 °C and a night base temperature of 4.4 °C as described by Brown (1978). Five plants were tagged per plot (n = 20) for repeated, nondestructive analyses. Measurements of leaf number per plant, plant height and stem diameter were recorded weekly until mid season and then biweekly thereafter until mid-Aug. 1998 and 1999. Time to 50% of the plants to produce at least one open flower was recorded daily starting at flower initiation. An additional five plants per plot were selected randomly for analyses of leaf area and above ground dry matter. These tomato plants were harvested by hand clipping at the soil surface. Leaves were separated from the main stem.

Fig. 1. Effect of tillage system (conventional) (◆), disked (■), zone-tillage (▲), and no-tillage (●) on tomato leaf number (A), plant height (B), and stem diameter (C) during the growing season. Data are means for each of 2 years (1998 and 1999) at Simcoe.

Leaf area was measured using a LI-COR 3100 area meter (LI-COR, Lincoln, Nebr.). The above ground biomass was then dried at 80 °C to a constant weight. When present, fruit were separated into red and green at each sampling time. Fruit was graded and weighed fresh prior to LAI and dry matter determination. These results were averaged for each plot (n=4). The sampling schedule was identical to the one used for the nondestructive sampling.

Tomatoes were harvested mechanically using a commercial Blackwelder tomato harvester (Blackwelder Manufacturing Co., Rio Vista, Calif.) at Harrow and by hand at Simcoe. Tomatoes were harvested on 31 Aug. 1998 and 15 Sept. 1999 at Simcoe and 1 Sept. 1998 and 27 Aug. 1999 at Harrow. Fruit was separated into red, green, and those with blossom-end rot. Quality parameters were assessed at Simcoe only. A random sample of red fruit were washed, and cut in half. One-half of the tomatoes was blended under vacuum for 40 s. The juice extracted was placed into an Agron E-5M (Agron, Reno, Nev.) apparatus for color determination. The remaining juice from this sample was used to measure pH of the purée and soluble solids (°Brix) was determined using a Palette PR101 digital refractometer (Atago, Tokyo). An additional sample (1.5 L) was placed in a microwave and heated to the hot break point (95 °C) and screened (0.033 size screen) to ensure that no pulp was ejected. The sample was cooled to 20 °C and used to determine a modified Bostwick measurement. The Bostwick consistometer track was 24 cm long with 0.5-cm divisions and equipped with a spring-loaded gate to prevent premature sample flow. The apparatus was leveled to ensure that the relative consistency was based on the distance the purée traveled under its own weight (Loewen, 1997). A 50-mL sample was allowed to run on this track for 30 s and the distance travelled was recorded to determine relative viscosity.

All data were subjected to analysis of variance (ANOVA) using the MIXED and GLM procedures of SAS ver. 6.12 (SAS Institute, Cary, N.C.) to detect tomato response due to tillage system. Data were $\log_{10}$ transformed, where necessary, to normalize and distribute the residuals to satisfy the assumptions of ANOVA. Destructive and nondestructive growth measurements were regressed over time (CHU) using repeated measures. Year $\times$ tillage interactions were nonsignificant for any tomato plant growth parameters measured, including leaf area index (LAI), total aboveground dry matter accumulation, stem diameter, plant height, and leaf number, so these variables were pooled across years. Tomato yields were reported by location to account for a significant location $\times$ tillage interaction. A significant year $\times$ tillage interaction was also observed for tomato yields at Harrow and Simcoe. Studentized residuals were determined for all data and individual measurements were rejected if the critical value was greater than |3.4| (Lund, 1975). Treatment means were separated using the least square means test where appropriate. The Type I error rate for this experiment was 0.05.

Results and Discussion

Growth and development

Leaf number, plant height, and stem diameter did not differ with tillage system. A single growth curve was generated for each variable (Fig. 1A–C). A quadratic curve provided the best fit to the data for each variable. Maximum leaf number, plant height, and stem diameter were 16 leaves, 64 cm, and 13 mm, respectively, based on back-transformed means where the slope was zero, recorded between 1536 CHU and 1757 CHU after transplanting. Our results were comparable to Creamer et al. (1996) who found no difference in tomato plant height and stem diameter 5 weeks after transplanting among four tillage systems which included no-till. In a 3-year study, Doss et al. (1981) observed no difference in plant height

for fresh market tomatoes when rye was used as a cover crop in a strip till or no-till system. In addition, Drost and Price (1991) also found no reduction in plant height associated with no-tillage. Other studies, however, have reported a delay in tomato growth under reduced tillage systems. For example, Price and Baughan (1987) observed reduced growth rates in no-tillage plots for the first 40 d following transplanting.

Total aboveground dry weight and LAI did not differ with tillage system (Fig. 2A and B). One growth curve per parameter was generated to explain the relationship between tillage, tomato dry weight accumulation and LAI over the season. Maximum aboveground dry matter accumulation and LAI was 227 g·m⁻² and 1.7 cm²·cm⁻², respectively, based on back transformed means at the inflection points, recorded at 1722 CHU and 1630 CHU after

Fig. 2. Effect of tillage system (conventional) (◆), disked (■), zone-tillage (▲), and no-tillage (●) on tomato (vegetative) plant aboveground dry matter accumulation (A) and LAI (B) during the growing season. Data are means for each of 2 years (1998 and 1999) at Simcoe.

transplanting. Soon after transplanting, LAI increased rapidly to the flowering stage of tomato development, ≈ 1000 CHU after transplanting. This was followed by a decrease in dry weight and LAI per plant as fruit production was maximized.

At fruit set, most of the dry matter accumulated by the tomato plant would be imported from the leaves to assist in the development of the fruit (Ho and Hewitt, 1986). This transfer of photosynthetic assimilates from vegetative growth to reproductive development would result in a reduction of dry matter and leaf area per plant. As the tomato fruit continues to grow, the accumulation of water in the fruit would also result in an overall reduction in dry matter (Ho and Hewitt, 1986). In addition, the reduction in dry matter and LAI and the associated increase in leaf senescence was enhanced by the use of ethephon.

Table 1. Effect of tillage system on time to 50% flower of tomatoes at Simcoe in 1998 and 1999.^z

Treatment	Time to 50% flower	
	DAT ^y	CHU
Conventional	33.1	659
Disking	32.6	654
Zone tillage	32.8	655
No tillage	32.6	653
Standard error ^x	NS	NS
P value	0.9675	0.9983
Year		
1998	29.5 a	534 a
1999	36.1 b	777 b
Standard error ^x	0.57	16.5
P value	0.0036	0.0009

^zData were pooled across years (1998 and 1999).

^yDAT = days after transplanting; CHU = crop heat units accumulated after transplanting.

^xStandard error was based on nontransformed data within columns, where NS represents nonsignificant at $P = 0.05$.

The presence of a rye cover crop, which was present in the disked, zone till, and no-till treatments, did not influence tomato growth and development. In a 1-year study, Drost and Price (1991) observed that the presence of rye mulch in a no-tillage tomato production system had no adverse effect on plant height of fresh-market tomatoes. The number of flower trusses produced per plant, however, was reduced in the no-till rye covered plots during the early part of the growing season. Doss et al. (1981) noted that a rye cover crop may deplete soil moisture prior to planting, especially in a dry year. Depletion of the soil water was most evident if the rye was not properly controlled or if allowed to grow too late into the season. Careful management of the rye cover crop was critical for the success of transplant establishment and the continued growth and development of tomato.

The time required for 50% of the plants to initiate one open flower per plant did not differ among tillage systems, but varied with year (Table 1). In 1999, an additional 243 CHU was required for 50% of the plants to develop an open flower compared with 1998. Tomato plants will flower earlier when grown under stress (Atherton and Harris, 1986). In May and June of 1999, a total of 134 mm precipitation was recorded compared with 79 mm in 1998 (Table 2). In 1998, high temperatures and $<50\%$ of average rainfall in May and June resulted in a premature onset of flowering across all tillage systems.

Yield

Yield differences were nonsignificant for red and green tomato fruit harvested in the conventional, disked, or zone-tillage treatments at either location in 1998 and 1999 (Table 3).

Yield reductions were observed for both red and green fruit in the no-tillage treatments. For example, at Harrow in 1998, the yield of red fruit in the no-tillage treatment was 41.3 MT/ha compared with an average of 61.9 MT/ha for all other tillage systems. In 1999, green fruit yield was 5.7 MT/ha in the no-tillage treatment compared with an average of 3.3 MT/ha for all other tillage treatments. A similar response in 1999 was recorded at Simcoe for green fruit. This increase in green fruit associated with no-tillage suggested a delay in crop maturity compared with conventional, disked and zone-tillage. Several studies have reported a delay in crop maturity attributed to lower soil temperatures associated with no-till when compared with conventional tillage (Griffith et al., 1988; Kaspar et al., 1990). In a 3-year study conducted in Ontario, Hooker (2000) found no difference in spring soil temperatures measured to a depth of 5 cm in moldboard plow, fall chisel plow, and fall zone tillage treatments.

Although no differences were detected in terms of aboveground growth and development, increased green fruit in the no-tillage plots might be accounted for by belowground root distribution. Singh and Sainju (1998) reported that the number of tomato roots/cm² was 65% higher in a conventional plowed system compared with a no-tillage system at depths of 19.5 to 58.5 cm. Hooker (2000) showed that corn root length was greater in moldboard plow plots compared with no-tillage in most years of the study. This was attributed to a higher bulk density in the no-till system. His results validated reports that no-till corn was more sensitive to the level of soil moisture, or lack thereof, compared with other tillage systems (Betz et al., 1998; Griffith et al., 1988). Hooker (2000) suggested that the

Table 2. Mean monthly air temperatures and precipitation at Simcoe and Harrow in 1998 and 1999.

Month	Simcoe						Harrow					
	Temp (°C)			Precipitation (mm)			Temp (°C)			Precipitation (mm)		
	1998	1999	Avg (1962–86)	1998	1999	Avg (1962–86)	1998	1999	Avg (1961–90)	1998	1999	Avg (1961–90)
May	16.9	15.1	12.6	43	55	74	17.9	16.4	14.3	22	31	80
June	18.7	20.0	17.8	36	79	82	20.5	21.4	19.7	27	33	81
July	20.9	23.5	20.4	132	35	77	22.6	24.9	22.1	55	49	92
August	21.1	19.5	19.5	21	145	80	22.2	20.7	21.1	88	28	82
September	17.8	17.2	15.5	49	173	89	19.8	18.5	17.4	17	23	85
Mean/Total	19.1	19.1	17.2	281	487	402	20.6	20.4	18.9	209	164	420

Table 3. Marketable yield of 'H-9478' tomatoes grown under four tillage systems at Simcoe and Harrow in 1998 and 1999.

Tillage method	Yield											
	Simcoe ^z						Harrow					
	1998			1999			1998			1999		
	Red	Green	Total	Red	Green	Total	Red	Green	Total	Red	Green	Total
	t·ha ⁻¹											
Conventional	54.0	0.6	54.7	29.9	19.0 a	49.0	63.6 a	6.7	70.3 a	93.3	3.5 a	96.9
Disking	60.6	0.8	61.4	24.0	20.3 a	44.3	63.3 a	9.6	72.9 a	98.7	3.7 a	102.4
Zone tillage	54.6	0.8	55.4	24.0	22.2 a	46.2	58.7 a	9.3	68.0 a	112.3	2.8 a	115.1
No-tillage	59.3	1.3	60.6	23.6	27.0 b	50.6	41.3 b	8.2	49.5 b	101.7	5.7 b	107.4
Standard error ^y	NS	NS	NS	NS	1.79	NS	2.54	NS	2.87	NS	0.62	NS
P value	0.5891	0.2964	0.5328	0.2842	0.0272	0.4720	0.0001	0.1987	0.0001	0.3488	0.0438	0.3539

^zMachine and hand sampled yield was pooled at Simcoe in both years. Yield obtained by machine is reported at Harrow within years.

^yStandard error was based on nontransformed data within columns, where NS represents nonsignificant at $P = 0.05$.

optimum range of soil moisture content for corn growth was narrower for no-till than other tillage systems. These variables may have contributed similarly to a reduction in root growth and the resulting increase in green fruit observed in no-till tomato.

Tomato yields differed significantly between locations. Highest yields were obtained in 1999 at Harrow. Yields from the Simcoe location were lower than the expected commercial yields for southwestern Ontario. Yields were similar to other studies reported in the literature (Creamer et al., 1998; Doss et al., 1981; Drost and Price, 1991; Sainju et al., 2000) and also comparable to previous research conducted at the same location (McKeown et al., 1998). Tomato yields from Simcoe in 1999 were reduced by a severe outbreak of blossom-end rot on the first fruit set. Tomato fruit affected by blossom-end rot can act as a sink for photosynthetic assimilates and nutrients thereby inhibiting the ripening of later developing fruit (Ho and Hewitt, 1986). Lack of moisture during the fruiting period may have also influenced adversely the development of the first fruit set. Tan and Dhanvantari (1985) reported an increase in blossom-end rot in tomatoes when irrigation was withheld.

Postharvest quality

Tomato postharvest quality did not differ among tillage systems (Table 4). All measured parameters were within acceptable processing standards and were comparable to values obtained from other Ontario based research (Loewen, 1997). Creamer et al. (1996) also observed no differences in tomato quality characteristics, such as purée pH and Agron with tillage system.

In summary, tomatoes can be grown under selected conservation tillage systems without a decrease in growth, marketable yield, or postharvest quality. The zone tillage or single disking treatments were the most promising reduced tillage systems compared with conventional tillage. No-tillage tomato production was more variable in crop maturity and marketable yield. Sustainable tomato production practices need to be developed to ensure the long-term viability of the tomato industry. Our study has shown that the potential exists for alternative tillage practices for use in the processing tomato industry.

Table 4. Effect of four tillage systems on postharvest quality of 'H-9478' tomatoes.^a

Quality parameter	Tillage system ^b				Significance	P value
	CT	DISK	ZT	NT		
Agron (no units)	21.8	21.4	20.5	21.8	NS	0.4701
Bostwick (cm)	6.0	5.7	5.6	5.6	NS	0.7227
Purée pH	4.32	4.33	4.35	4.36	NS	0.2990
Soluble solids (%)	5.9	6.1	5.3	5.9	NS	0.1445

^aParameters were pooled across years (1998 and 1999) at Simcoe.

^bCT = conventional tillage; DISK = disked; ZT = zone-till; NT = no-till.

^cNS=Non-significant ($P = 0.05$) across rows.

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