Project Title: **Optimizing application of phosphorus and potassium to processing tomatoes under drip-irrigation to maximize quality and yield while minimizing adverse impacts on water quality**

(Annual report for year 2007)

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Interpretive Summary

Processing tomatoes, a major high-value crop in Ontario, are high in nutrient demands. The nutrient needs can further increase with drip-irrigation/fertigation due to the enhanced yield potential. Our studies in the past five years showed that the fertilizer nitrogen (N) rate required for processing tomato production with drip fertigation can be as high as 270 to 300 kg N ha^{-1}, about 3 times the previous recommendation. With increased needs for fertilizer N, other nutrients, such as phosphorus (P) and potassium (K), must be supplied accordingly in sufficient amounts to provide a balanced nutrient source and to develop the maximum yield potential. On the other hand, over-application of nutrients, especially P, can cause build-up in soil that may consequently contaminate water resources, as P is a key element controlling eutrophication of water bodies. In addition, more and more demands on quality (soluble solids, lycopene, and vitamin C) of processing tomatoes have become an emerging issue to producers from both processors and consumers. Application of fertilizer P and K for processing tomatoes must be optimized in a way that minimizes adverse effects on water quality, while improving product quality and maximizing marketable yield.

The long-term objectives of this study are 1) to develop the optimum rates of P and K with drip irrigation under Ontario conditions, that meet the needs for maximum economic yield and quality, while minimizing the potential for P losses; and 2) to determine P and K removals. The short-term objectives for 2007 were 1) to determine the relationships between fertilizer P and K and yield and quality of processing tomatoes under drip-irrigation in accordance with the newly developed N rate in Ontario; 2) to determine crop nutrient (N, P, K) uptake and removals; and 3) to evaluate the potential leaching losses of soil P and N.

The experiment was conducted in a sandy loam soil at GPCRC, Harrow, ON. The treatments applied beginning in 2006? included four fertilizer P rates ranging from 0 to 90 kg P ha^{-1}, four fertilizer K rates ranging from 0 to 600 kg K ha^{-1}, and two water management regimes including natural rainfall (non-irrigation) and natural rainfall enhanced with drip-irrigation to best satisfy crop physiological needs in an optimum manner. The experiment was arranged in a split-plot design, with four blocks and a total of 128 plots. The two water management regimes were assigned to the main plots, with P and K treatment combinations assigned to the subplots. The 16 P and K treatment combinations were completely randomized within each main plot.

The major yield results drawn from the 2007 growing season are as follows.

Yields: Drip-irrigation increased the marketable fruit yield by 181% through the increase of total fruit yield (by 62%) and the decrease of green fruit yield at harvest (by 86%), when compared with the non-irrigation. Drip-irrigation did not affect stover biomass. Fertilizer P rates had no effects on total and marketable fruit yields, although it increased stove biomass. Fertilizer K increased total and marketable fruit yields, regardless of drip-irrigation. A rate of 360 kg K ha^{-1} was required to produce the maximum marketable

yield when drip-irrigation was applied, while marketable yield increased linearly with increasing fertilizer K rate with non-irrigation.

Fruit quality: Adequate water and timely nutrient supplies with drip-irrigation enlarged both source and sink; consequently, they increased fruit size by 28%. However, high fruit production with drip-irrigation diluted soluble solids and caused a decrease by 19%. The reduction of soluble solids with drip-irrigation can be compensated with addition of fertilizer K, as increase of fertilizer K increased soluble solids content. Fertilizer K should be sufficiently supplied when drip-irrigation is applied to maximize the marketable yield with improved quality.

Fertilizer P had no effects on fruit quality such as soluble solids content, fruit size, and lycopene content. Lycopene content was not affected by any experimental factors or the interactions between them. However, this needs to be confirmed with additional studies. Why?

Nutrient use: Processing tomato utilized N much more economically and efficiently with drip-irrigation than without irrigation, as stover N uptake was 13% higher, but fruit N removal was 160% lower without irrigation. Drip-irrigation also increased plant P and K uptakes due to higher production: 11% for stover P uptake, 166% for fruit P removal, 13% for stover K uptake, and 145% for fruit K removal. Fertilizer P application did not affect plant K uptake, but increased stover and fruit P uptake. Fertilizer P application enhanced stover N uptake. Addition of each kg P led to a stover N uptake increment of 0.0315 kg. Fertilizer K application significantly affected stover N, stover P, and plant (stover and fruit) K uptake, but fertilizer K effects on such variables varied with and without drip-irrigation. Fertilizer K application resulted in more N and P translocation from stover to fruit. As a consequence, increased fertilizer K application rate decreased stover N and P uptake, but increased fruit N removal from 59% to 66% and fruit P removal from 68% to 74%. Responses of stover K uptake and fruit K removal to fertilizer K rate followed the same patterns as marketable yield, regardless of irrigation circumstances.

Soil test NPK: Post harvest soil (0-20 cm) test P and K increased linearly with fertilizer P and K rates, respectively. Addition of each kg fertilizer P resulted in soil test P increment of 0.082 and 0.1568 mg kg^{-1} in 2006 and 2007, respectively. Addition of each kg fertilizer K increased soil test K by 0.4411 and 0.2518 mg K_2O kg^{-1} for the non irrigation and irrigation plots in 2006, respectively; the increment was 0.6420 mg K_2O kg^{-1} in 2007. Drip-irrigation decreased soil test K as a result of increased plant K uptake.

Soil profile (0-100 cm) nitrate N was affected by neither fertilizer P nor K application, but decreased under drip-irrigation due to the increased crop N removal relative to non-irrigation. Drip-irrigation increased N use efficiency and thus reduced potential for adverse impacts of soil residual N on environmental quality.

This study is to be continued in 2008.

Introduction

Processing tomatoes, a major high-value crop in Ontario, are high in nutrient demand. The nutrient needs can further increase with drip-irrigation/fertigation, due to the enhanced yield potential. Our studies in the past 5 years showed that the nitrogen (N) rate required for processing tomato production with drip-irrigation/fertigation should be as much as 300 kg N ha^{-1}, which is about 3 times previous provincial recommendation. Our result has recently been approved as an official recommendation for processing production in Ontario. As implicated by the "Law of the Minimum", with increased needs for fertilizer N, other nutrients, such as phosphorus (P) and potassium (K), must be supplied accordingly in sufficient amounts to develop the maximum yield potential.

On the other hand, over-application of P can cause build-up in soil, and consequent contamination of water resource, as P is a key element controlling eutrophication of water bodies. Over-applied K may result in crop luxury K uptake without profitable economic return. Balanced NPK fertilization can increase crop productivity, while reducing environmental contamination by decreasing nutrient losses to water systems. Application of fertilizer P and K for processing tomatoes must be optimized in a way that minimizes adverse effect on water quality, while improving product quality and maximizing marketable yield. The provincial government of Ontario has made the protection of source water as one of its top priorities, and passed the Nutrient Management Act (ON. REG. 267/03) in 2002. The regulation restricts land application of nutrients and encourages adoption of BMPs to mitigate the potential impacts on water quality. The OMAFRA NMAN series of nutrient management computer programs have been developed to assist producers with nutrient management planning. Optimum fertilizer rates along with crop nutrient removal are the key variables of NMAN. However, data on P and K is not available for processing tomatoes with drip-irrigation, and have to be developed for the Ontario conditions.

More and more demands on quality of processing tomatoes have become an emerging issue to processors and consumers. The major food quality variables related to processing tomatoes include soluble solids, lycopene, and vitamin C. Potassium is a well-known element highly related to crop quality and has been linked with tomato yield and quality. However, information on the roles of P and K in the formation of these food quality variables are limited and often in controversy, depending on the soil and weather conditions. The data available in Ontario on the interactive roles of P and K are very limited, especially under drip-irrigation/fertigation.

The industries (OTRSC - Ontario Tomato Research and Service Sub-Committee; Ontario Soil Management Research and Services Committee, Sub-Committee for Horticultural Crops; IPNI – International Plant Nutrition Institute) have identified optimization of P and K application for processing tomatoes to maximize yield and quality in an environmentally responsible manner as a high research priority.

Objectives

1) To determine the relationships between fertilizer P and K and yield and quality of processing tomatoes under drip-irrigation in accordance with the newly developed N rate in Ontario;
2) To determine crop nutrient (N, P, K) uptake and removals;
3) To evaluate the potential leaching losses of soil P and N; and
4) To develop the optimum rates of P and K under Ontario conditions, that meet the needs for maximum quality and economic yield while minimizing the potential for P losses.

Activities Related to Field Year 2007

1) April - May, 2007: transplant preparation,; large field soil sampling using a grid approach and soil test P and K analysis for site selection; plot allocation;
2) May: plot layout, fertilization, transplanting; drip line installation and checking
3) June-September: field management, soil moisture monitoring; drip-irrigation; field tours for visitors from industries, universities, and governments, plant tissue sampling
4) September: plant tissue sampling; harvesting; and yield and quality measurements
5) October: soil sampling; plant N, P, and K analyses
6) November – January 08: soil sample N, P, and K analyses; report preparation

Materials and Methods

The experiment was conducted in a sandy loam soil at GPCRC, Harrow, ON. The treatments included four fertilizer P rates (0, 30, 60, 90 kg P ha^{-1}), four fertilizer K rates (0, 200, 400, and 600 kg K ha^{-1}), and two water management regimes (non-irrigation, drip-irrigation to best satisfy crop physiological needs in an optimum manner). The treatments were applied annually, starting in 2006, in order to find the optimum combination of P and K rates for long-term continuous tomato production. They were arranged in a split-plot design, with four blocks and a total of 128 plots. The water management regimes were assigned to the main plots, with the P and K treatment combinations assigned to the sub-plots. All fertilizer P and K was pre-transplant broadcasted and incorporated. All plots received 270 kg N ha^{-1} fertilizer N. Need information on when the N was applied - % preplant incorporated, fertigated, side-dressed??? Other plot management followed the local practices.

Fruits from the central two rows of each plot were hand harvested at the 80% fruit ripening (or peak ripening) stage and graded into marketable, green, blossom end-rot and cull, and weights recorded. Total and assorted fruit yields were calculated. Fruit soluble solids and fruit size were measured. Fruit and stover samples were taken and analyzed for N, P, and K contents. Total N, P and K uptake of processing tomato were calculated according to the biomass yields and nutrient contents. Fruit vitamin C and lycopene analyses are to be completed.

Soil profile samples (0-20, 20-40, 40-60, 60-80, and 80-100 cm depths) were taken shortly after harvesting and analysed for NO_3- and NH_4-N to evaluate the leaching potential of soil N as a function of fertiliser P and K rates and water regimes. Soil samples are also to be analyzed for water extractable P to determine the soil P loss potential.

Data of soil profile NO_3-N were analyzed using the repeated measures procedure, with others analyzed using Proc Mixed in SAS. When the treatment effects were significant ($P<0.1$), means comparisons were completed by generating letter groupings at a 5% level of significance.

Results and Discussion

Fruit yields

Both fertilizer K addition and drip-irrigation affected total, marketable, green, and blossom end rot (BER) fruit yields, except for BER yield that was not affected by the addition of fertilizer K (Table 1). Interactions between fertilizer K addition and drip-irrigation were also found on marketable and green yields. However, there were neither fertilizer P effects nor interactions of fertilizer P with fertilizer K and drip-irrigation observed on any of the fruit yields.

Drip-irrigation increased total fruit yield by 52 Mg ha^{-1}, an equivalent of 62%, relative to the non-irrigation (Fig. 1). Blossom end rot fruit yield was higher for the drip-irrigation treatment than for the non-irrigation treatment (Fig. 2). However, the percentage of blossom end rot was largely identical, 2.3% for both non-irrigation and drip-irrigation treatments.

The percentages of green fruits were 39% and 3% without and with drip-irrigation, respectively (**Fig. 3**). Drip-irrigation decreased green fruit yield by 87%, compared with the non-irrigation treatment. Fertilizer N was applied at the same rate in both drip-irrigated and non-irrigated plots. The natural rainfall events occurred unevenly during the growing season, with more in August (**Fig. 4**). Sufficient N supply along with the delayed arrival of large amount of rainfall might have resulted in greater proportion of green fruits in the non-irrigated treatment. Processing tomato fruits under non-irrigation circumstances started to mature earlier but lasted much longer than those under drip-irrigation circumstances. Uneven ripening of processing tomato fruits in non-irrigation treatments was a serious problem and another important reason for high green fruit yield. In contrast, fruits matured very evenly when drip-irrigation was applied.

Fertilizer K addition increased linearly the total fruit yield (**Fig. 5**). A calculated value of 0.02 Mg of total fruit yield was produced with each kg of K applied. The linear relationship between total fruit yield and fertilizer K rate indicates that there appeared additional potential for yield increase, at least with this variety, if additional fertilizer K is applied. However, conversion of fruits to marketable yield remains as an issue.

Consequently, marketable fruit yield responded to fertilizer K applied, but the response curves varied between non-irrigation and drip-irrigation (**Fig. 6**). For the non- irrigation treatments, marketable yield increased linearly with K rate. Each kg of fertilizer K added caused an increase of 0.0148 Mg of marketable fruits. Marketable fruit yield for the drip-irrigated treatments responded quadratically to fertilizer K rate, with its maximum produced at 360 kg K ha^{-1} added. This suggests that fertilizer K added above the rate required for maximum marketable yield might have simply produced additional green fruits at the late season, since the total fruit yield linearly increased with fertilizer K rate.

Stover yield

Addition of both fertilizer P and K affected stover yield (Table 1). There was also a significant irrigation by fertilizer K interaction on stover yield. However, stover yield was not influenced by the single factor of drip-irrigation.

Stover yield across all fertilizer K rate treatments with and without drip-irrigation increased linearly with fertilizer P rate, ranged from 2.49 Mg ha^{-1} when zero P was applied to 2.76 Mg ha^{-1} when fertilizer P was added at 90 kg P ha^{-1} (**Fig. 7**).

Effects of fertilizer K on stover yield varied depending on irrigation circumstances (**Fig. 8**). While stover yield was not influenced by the addition of fertilizer K when non-irrigation was applied, it responded quadratically to the addition of fertilizer K when drip-irrigation was applied. Stover yield for the drip-irrigated treatment increased with the increase of fertilizer K rate and reached its maximum with fertilizer K added at 348 kg K ha^{-1}. The fertilizer K rate was similar to that was required for the production of maximum marketable yield, suggesting that fertilizer K supplied was efficiently used for the formation of marketable fruits, rather than simply a luxury crop uptake.

High economic yield was not only affected by total photosynthetic assimilates, but also by the assimilate partitioning between vegetative and reproductive organs of the crop. Drip-irrigation results in high soil moisture and timely K availability to plants; K could improve assimilate transportation from the source (i.e. leaf) to sink (i.e. fruit) and consequently enhance the formation of fruit yield. This experiment showed that there were substantial differences in total and marketable yields between non-irrigated and drip-irrigated treatments, although no stover biomass difference was observed. This suggests that K availability was lower and affected the assimilate translocation from stover to fruits for the non-irrigation treatment, thus resulted in a substantially lower fruit yield.

The lack of response of stover yield to drip-irrigation might have been caused by the enhanced vegetative growth resulted from the increased natural rainfall in the late season, although small canopy was observed during the early to middle stages for the non-irrigation treatment.

Fruit Quality

Drip-irrigation influenced significantly both soluble solids content and fruit size (Table 1). Fertilizer K addition also affected soluble solids content, but not the fruit size.

However, fertilizer P addition had no effects on either soluble solids content or fruit size. In addition, none of the experimental factors including drip-irrigation and fertilizer K and P addition affected the lycopene contents of fruits in either 2006 or 2007.

Drip-irrigation decreased soluble solids content by 19% (**Fig. 9**), but increased fruit size by 28% (**Fig. 10**), compared with non-irrigation. Irrigation determines, to some extent, the amounts of water available to the plant and the water in fruits. However, increased total yield with drip-irrigation might have diluted the synthesized solids, thus lowering solids content. As mentioned earlier, increased fruit yield with drip-irrigation (62% higher) can compensate the decreased soluble solids content, such that total production of soluble solids is higher. Nutrient use efficiency, as discussed below, was improved with drip-irrigation. Therefore, sufficient water and timely nutrient supplies in the drip-irrigation treatment were the main reasons for enlarging both source and sink, resulting in larger average fruit weight.

Soluble solids content had a linear relationship with fertilizer K rate (**Fig. 11**), and application of each kg of fertilizer K resulted in soluble solids increment of 0.0005%. It is worth pointing out that high yield may be associated with low soluble solids content due to the dilution effects. This may explain why there is only a slight increase in soluble solids with increased levels of fertilizer K. However, the significance of this increase can be greatly meaningful, since quality is maintained or improved along with a large yield increase, especially with drip-irrigation.

Tomato lycopene content did not show significant differences among treatments in either 2006 or 2007 (Table 1). Variety is an important factor determining lycopene content, and lycopene content in the selected variety (H9478) may not be sensitive to management practices. Interactions amongst variety, fertilizer P and K, and drip irrigation remain to be determined.

Stover nutrient (N, P, and K) uptake and fruit nutrient removals

Nitrogen:

Stover N uptake was significantly affected by drip-irrigation and addition of fertilizer P and K (Table 1). There were also interactions between drip-irrigation and fertilizer K addition on stover N uptake.

Fertilizer P application increased linearly the stover N uptake (**Fig. 12**). Addition of each kg of fertilizer P could increase 0.0315 kg stover N uptake. This may be related to plant vigor growth as a result of the positive P effect on plant root growth.

There were quadratic relationships between stover N uptake and fertilizer K addition, but the curveships varied depending on the irrigation treatment (**Fig. 13**). With drip-irrigation, stover N uptake increased with the increase of fertilizer K rate, with the maximum stover N uptake reached at a fertilizer K rate of 194 kg K ha^{-1}. Further increase K rate resulted in a decrease of stover N uptake. This implies that large percentage of plant N could be translocated to fruits with increased supply of available K. Stover N uptake with non-irrigation decreased with the increase of fertilizer K rate and reached the lowest at a fertilizer K rate of 485 kg K ha^{-1}. As a result, over application of fertilizer K resulted in the decrease in stover N uptake, regardless of irrigation circumstances, although the curveships varied.

On the other hand, fruit N removal responded only to drip irrigation (Table 1). Fruit N removal was 160% higher in the drip-irrigation than the non-irrigation treatment, due to the increased fruit yield (**Fig. 14**).

As a result, total plant N uptake, including stover N uptake and fruit N removal, was 91.5 kg N ha^{-1}, or 74%, higher under drip-irrigation relative to the non-irrigation

Phosphorus:
Fertilizer P application significantly affected both stover P uptake (**Fig. 15**) and fruit P removal (**Fig. 16**). With addition of each kg of fertilizer P, stover P uptake increased by 0.0123 kg. Fruit P removal responded quadratically to the fertilizer P rate applied. A greater increase in fruit P removal was found when fertilizer P was added above 60 kg P ha^{-1}. Total plant P uptake followed the similar relationship with fertilizer P rate to the fruit P removal (**Fig. 17**).

Fertilizer K did not affect fruit P removal, but significantly influenced stover P uptake (**Fig. 18**). Each kg of added fertilizer K decreased stover P uptake by 0.0014 kg. This implies that fertilizer K might have enhanced the photosynthetic carbonhydrate translocation from stover to fruits, with a result of apparent decrease of stover P uptake.

Drip-irrigation significantly increased fruit P removal, although had no effects on stover P uptake (Table 1). Because of increased tomato production, drip-irrigation increased fruit P removal by 166 % relative to the non-irrigation (**Fig. 19**). Total plant P uptake was 15.5 kg P ha^{-1}, or 108%, higher in drip-irrigation than in non-irrigation treatments.

Potassium:
Drip-irrigation, fertilizer K, as well as the interaction between drip-irrigation and fertilizer K influenced consistently both stover K uptake and fruit K removal, although fertilizer P rate had no effects on plant K uptake (Table 1).

Response of both stover K uptake and fruit K removal to addition of fertilizer K followed the same pattern within the same irrigation category (**Fig. 20** and **Fig. 21**). There were quadratic relationships between stover K uptake or fruit K removal and fertilizer K rate for the drip-irrigation treatment. Stover K uptake and fruit K removal reached the maximums of 66.6 and 297.6 kg ha^{-1} at K rates of 575.5 and 524.1 kg K ha^{-1}, respectively. However, for the non irrigation treatment linear relationships were observed between stover K uptake or fruit K removal and fertilizer K rate. Addition of each kg of fertilizer K resulted in stover K uptake and fruit K removal increments of 0.0234 and 0.0815 kg, respectively. Clearly, K use efficiency was much higher with drip-irrigation before fertilizer K rates reached the optimum application rate. One reason for the linear relationship for the non-irrigation treatment is that plants have a nature of luxury uptake if K is supplied excessively.

With the increase of tomato production, as mentioned previously, drip-irrigation increased stover K uptake and fruit K removal by 13% and 145%, respectively, compared to the non-irrigation. Total plant K uptake in drip-irrigation was 157 kg ha^{-1}, an equivalent of 104%, higher relative to the non-irrigation treatment.

Consequently, a quadratic relationship was found between total plant K uptake and fertilizer K rate (**Fig. 22**). Total plant K uptake would have reached the maximum of 272.3 kg K ha^{-1} at the fertilizer K rate of 650 kg K ha^{-1}.

Post harvest soil test P and K

In 2006, post harvest soil test P in the top soil layer (0-20 cm) was significantly affected by fertilizer P addition (Table 1). However, soil test P was affected neither by drip-irrigation nor fertilizer K application. In 2007, treatments had the similar effects on soil test P (Table 1). Soil test P increased linearly with the increase of P rate in both years (Fig. 23 and **Fig. 24**). Addition of each kg fertilizer P made soil test P increment of 0.082 and 0.1568 mg kg^{-1}, respectively. Since the plots were superimposed in the last two years, application of fertilizer P resulted in a soil P increase in the second year. Soil test P was increased by 20.3% (an equivalent of 9.9 ppm) and 25.8% (an equivalent of 12.5 ppm) across the P fertilized drip irrigation and non-irrigation plots, respectively.

In 2006, post harvest soil test K was significantly affected by added fertilizer K, drip-irrigation, and the interaction between the two factors (Table 1). Soil test K was linearly related to the fertilizer K rate in both drip-irrigated and non-irrigated plots (Fig. 25), but it had a larger increment per kg fertilizer K added in non-irrigated plots (0.441 mg K_2O kg^{-1}), when compared with drip-irrigated plots (0.2518 mg K_2O kg^{-1}). Lower increment in the drip irrigated plots would have been due to high plant K uptake and more leaching losses with irrigation.

In 2007, treatments had the similar effects on soil test K except no fertilizer K by irrigation interaction effects (Table 1). Soil test K was linearly related to the fertilizer K application rate (**Fig. 26**). Addition of each kg fertilizer K made a gain of 0.6420 mg K_2O kg^{-1} post-harvest soil test K. Given the fact of increased tomato production with greater K uptake, drip-irrigation decreased soil test K by 28% relative to non-irrigation treatment (**Fig. 27**).

Repeated application of fertilizer K in the second year dramatically increased soil test K level. Compared with 2006, soil test K in 2007 was increased by 50% (an equivalent of 97 ppm) across the K fertilized drip irrigation plots and 48% (an equivalent of 133 ppm) across the K fertilized non-irrigation plots.

Post harvest soil profile NO_3-N

Compared with the non-irrigation treatment, drip-irrigation reduced soil nitrate N content by 37%, an equivalent of 2 mg N kg^{-1}, due to the increased fruit N uptake, as mentioned previously (**Fig. 28**). Hence, drip-irrigation reduced the potential for nitrate N contamination on water and air. Fertilizer P and K application did not have significant effects on post harvest soil nitrate N content, although the addition increased plant P and K uptake.

Summary

Drip-irrigation increased the marketable fruit yield (by 181%) through the increase of total fruit yield (by 62%) and fruit size (by 28%) and the decrease of green fruit yield at harvest (by 86%). Drip-irrigation increased plant above-ground nutrient uptake (N by 74%, P by 108%, and K by 104%). As a result, drip-irrigation decreased post harvest soil test K (by 28%) and soil profile residual nitrate N (by 36%). The results of decreased soil profile nitrate N with increased crop N and P uptake imply that drip-irrigation could reduce the adverse impacts of soil residual N and P on water and air quality. Drip-irrigation caused a decrease in the content of soluble solids of fruits, which, however, can be compensated partially by the application of fertilizer K, as well as the increased production of total soluble solids.

There were significant irrigation by K interactions on such variables as marketable fruit yield, stover K uptake, and fruit K removal. The best-fitting curves between such response variables and fertilizer K rate were quadratic and linear for the drip-irrigation and non-irrigation treatments, respectively. A rate of 360 kg K ha^{-1} was required to produce the maximum marketable yield when drip-irrigation was applied. Fertilizer K application also enhanced N and P translocation from stover to fruits. Increased fertilizer K application decreased stover N and P uptake, but increased fruit N and P removals, therefore improved N and P use efficiency. Post harvest soil test K in the top layer linearly increased with increased K rates. Increased fertilizer K increased soluble solids content of tomato fruits. Fertilizer K must be sufficiently supplied when drip-irrigation is applied to maximize the marketable yield with improved quality.

Fertilizer P application increased fruit P removal and stover N uptake, thus reduced potential for adverse effects of post-harvest soil residual N and P on water and air quality. Post harvest soil test P was also linearly increased with increased fertilizer P levels. Each kg ha^{-1} added P increase soil test P by 0.1568 mg kg^{-1}.

The study is to be continued in 2008.

Table 1. Statistical significance of drip-irrigation (I), fertilizer phosphorus (P), and fertilizer potassium (K) on processing tomato yield, quality, nutrient uptake, and soil P and K on a sandy loam soil, Harrow, ON, 2007.

Variation source	Total fruit yield	Marketable fruit yield	Green fruit yield	BER fruit yield	Stover biomass	Soluble solids	Fruit size	Lycopene 2006	Lycopene 2007	Stover N uptake	Fruit N removal	Stover P uptake	Fruit P removal	Stover K uptake	Fruit K removal	Soil test P06	Soil test P07	Soil test K06	Soil test K07
Drip-irrigation (I)	**	**	**	*	NS	**	**	NS	NS	*	**	NS	**	†	**	NS	NS	**	**
Fert. P (P)	NS	NS	NS	NS	†	NS	NS	NS	NS	†	NS	**	*	NS	NS	**	**	NS	NS
Fert. K (K)	**	*	†	NS	†	*	NS	NS	NS	**	NS	*	NS	**	**	NS	NS	**	**
I×P	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
I×K	NS	*	**	NS	*	NS	NS	NS	NS	*	NS	NS	NS	**	**	NS	NS	**	NS
P×K	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
I×P×K	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

†, *, and **: significantly different at $P≤0.1$, 0.05, and 0.01 levels, respectively.
NS: not significant at $P≤0.1$ level.

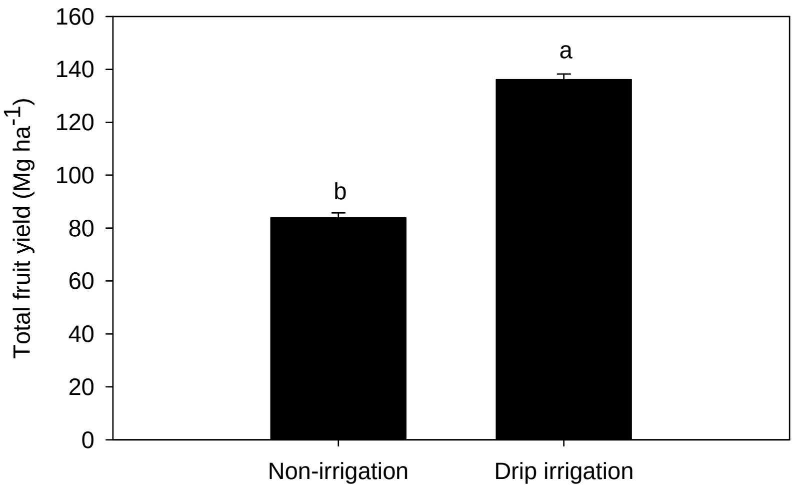

Fig. 1. Response of total fruit yield of processing tomatoes to drip-irrigation on a sandy loam soil, Harrow, ON, 2007. Vertical bars marked with the same letters are not significantly different at the *P*≤5% level.

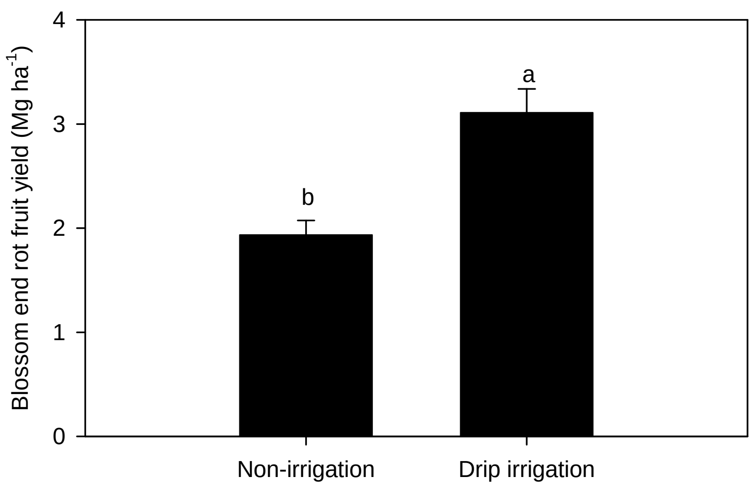

Fig. 2. Response of blossom end rot fruit yield of processing tomatoes to drip-irrigation on a sandy loam soil, Harrow, ON, 2007. Vertical bars marked with the same letters are not significantly different at the *P*≤5% level.

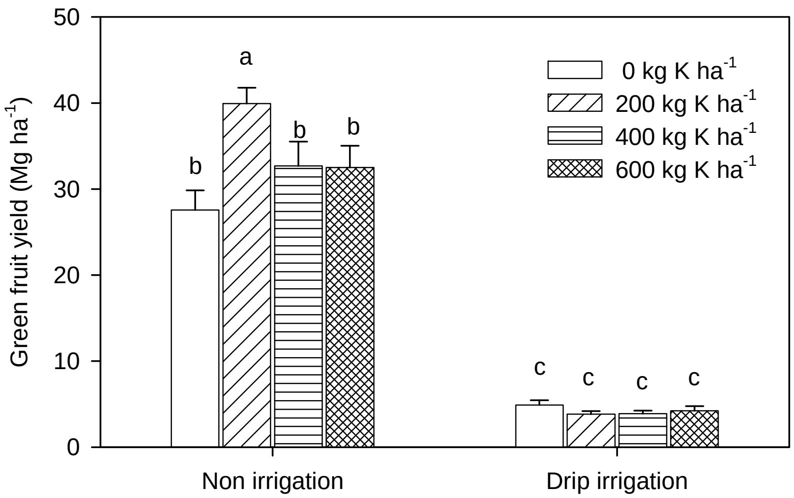

Fig. 3. Response of green fruit yield of processing tomatoes to drip-irrigation and fertilizer K rates on a sandy loam soil, Harrow, ON, 2007. Vertical bars marked with the same letters are not significantly different at the *P*≤5% level.

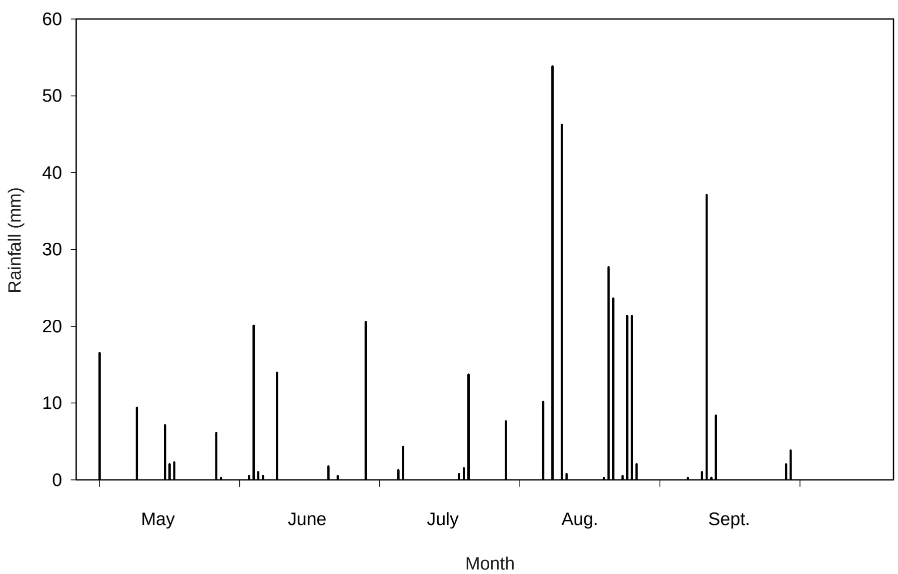

Fig. 4. Monthly precipitation on the experimental site during the growing season, 2007, Harrow, ON.

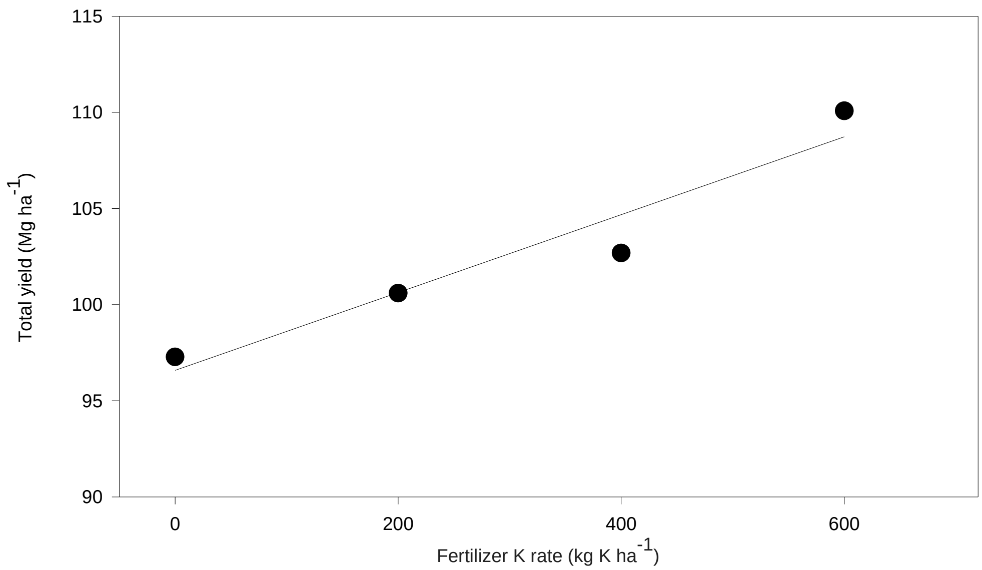

Fig. 5. Response of processing tomato total fruit yield to fertilizer K rates on a sandy loam soil, Harrow, ON, 2007.

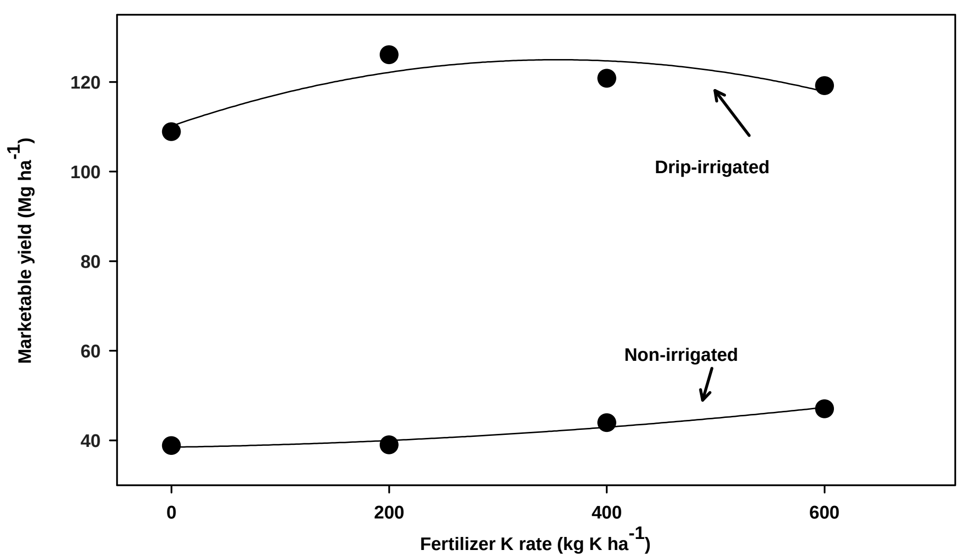

Fig. 6. Response of marketable fruit yield of processing tomatoes to fertilizer K rate with and without drip-irrigation on a sandy loam soil, Harrow, ON, 2007.

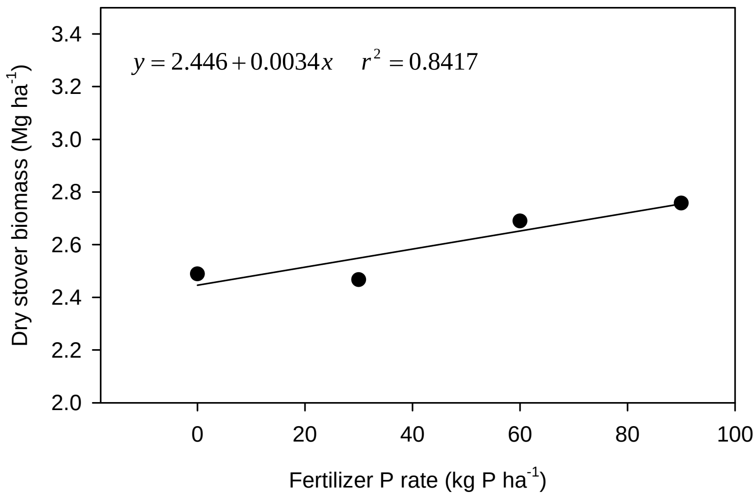

Fig. 7. Response of dry stover biomass of processing tomatoes to fertilizer P rate on a sandy loam soil, Harrow, ON, 2007.

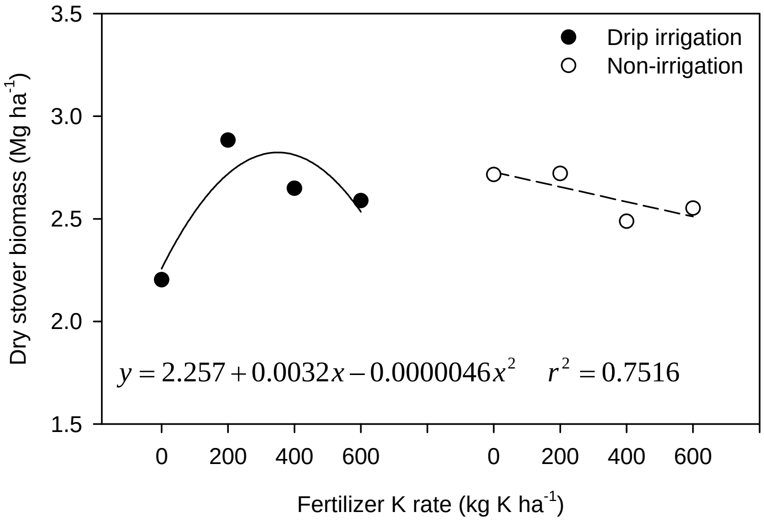

Fig. 8. Response of processing tomato dry stover biomass to fertilizer K rate with and without drip-irrigation on a sandy loam soil, Harrow, ON, 2007.

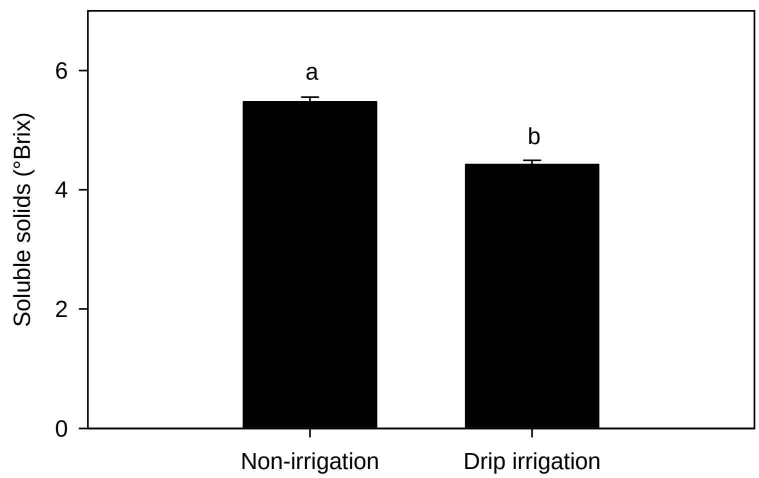

Fig. 9. Response of fruit soluble solids content of processing tomatoes to drip-irrigation on a sandy loam soil, Harrow, ON, 2007. Vertical bars marked with the same letters are not significantly different at the *P*≤5% level.

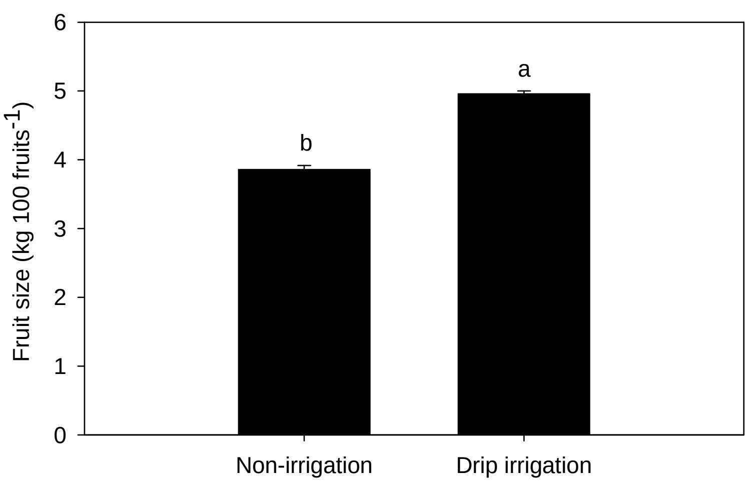

Fig. 10. Response of processing tomato fruit size to drip-irrigation on a sandy loam soil, Harrow, ON, 2007. Vertical bars marked with the same letters are not significantly different at the *P*≤5% level.

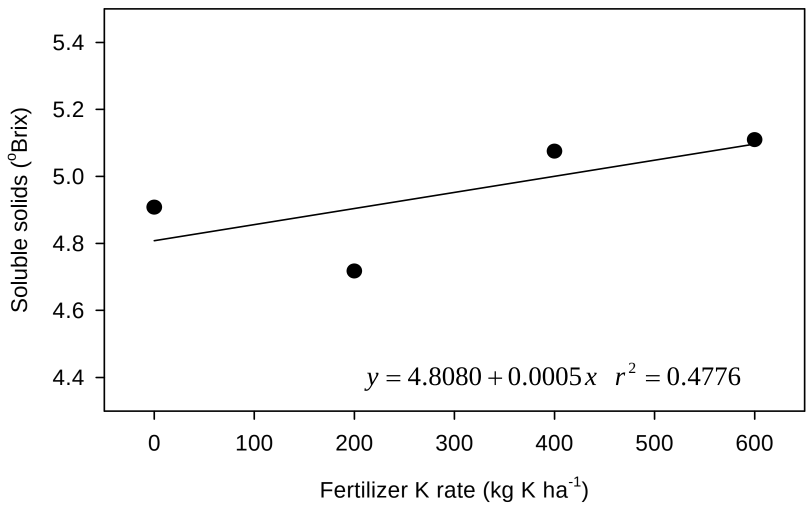

Fig. 11. Response of soluble solids content of processing tomatoes to fertilizer K rate on a sandy loam soil, Harrow, ON, 2007.

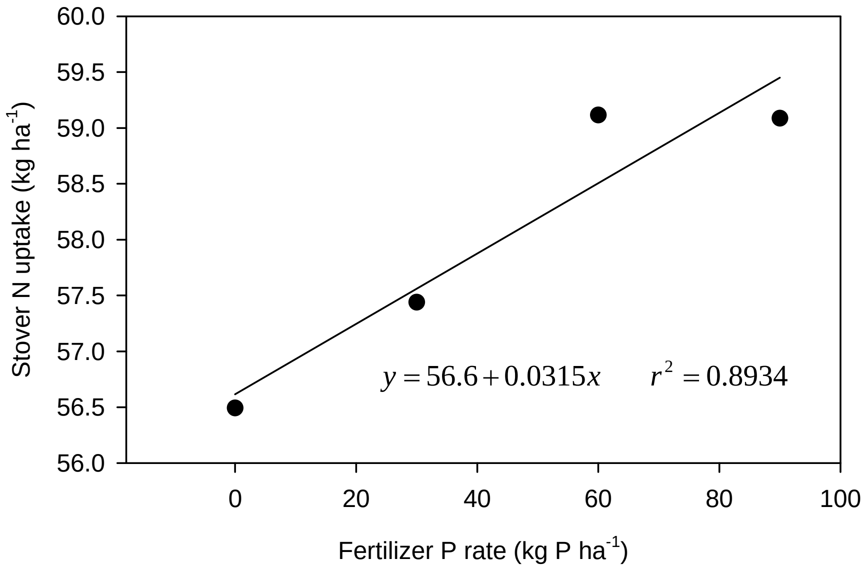

Fig. 12 Response of processing tomato stover N uptake to fertilizer P rates on a sandy loam soil, Harrow, ON, 2007.

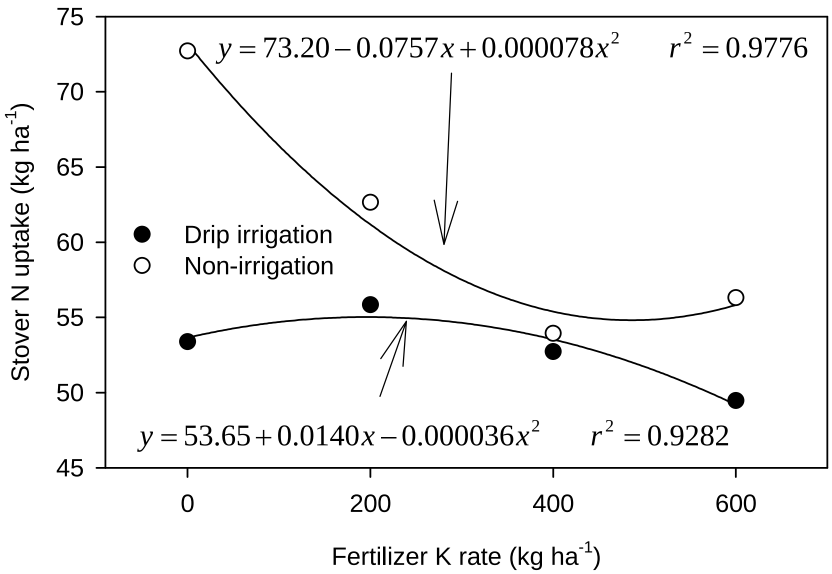

Fig. 13. Response of stover N uptake of processing tomatoes to fertilizer K rate with and without drip-irrigation on a sandy loam soil, Harrow, ON, 2007.

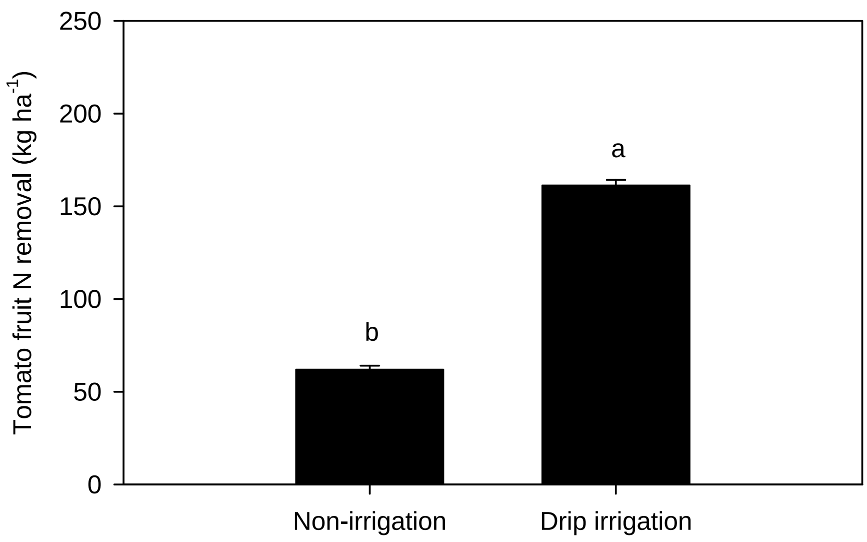

Fig. 14. Response of fruit N removal of processing tomatoes to drip-irrigation on a sandy loam soil, Harrow, ON, 2007. Vertical bars marked with the same letters are not significantly different at the $P \leq 5\%$ level.

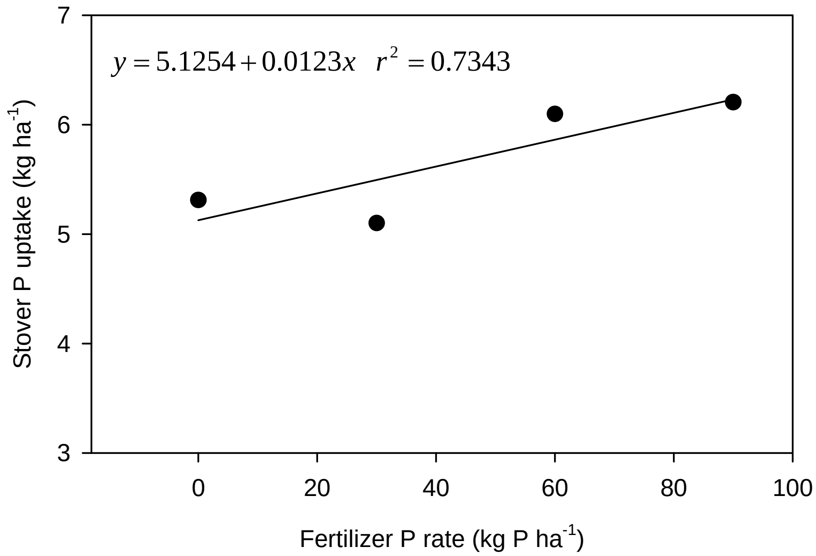

Fig. 15. Response of stover P uptake of processing tomatoes to fertilizer P rate on a sandy loam soil, Harrow, ON, 2007.

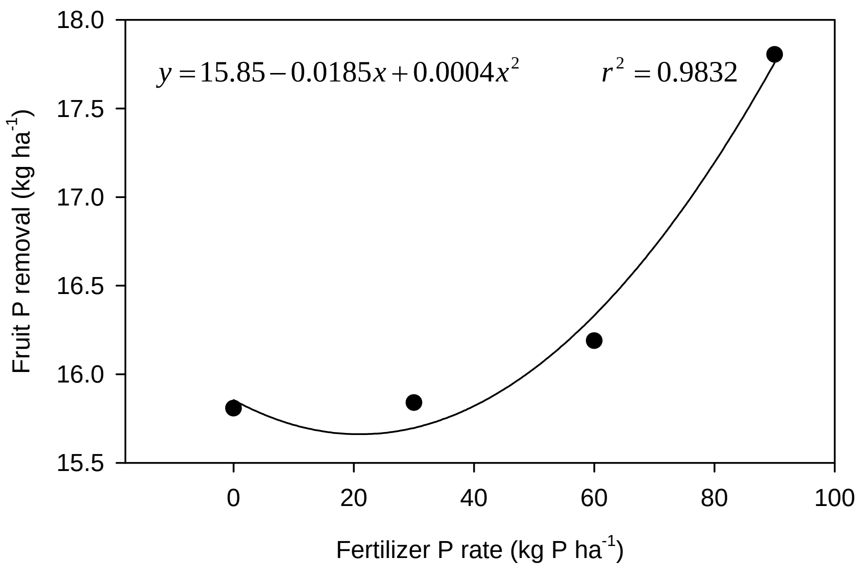

Fig. 16. Response of fruit P removal of processing tomatoes to fertilizer P rate on a sandy loam soil, Harrow, ON, 2007.

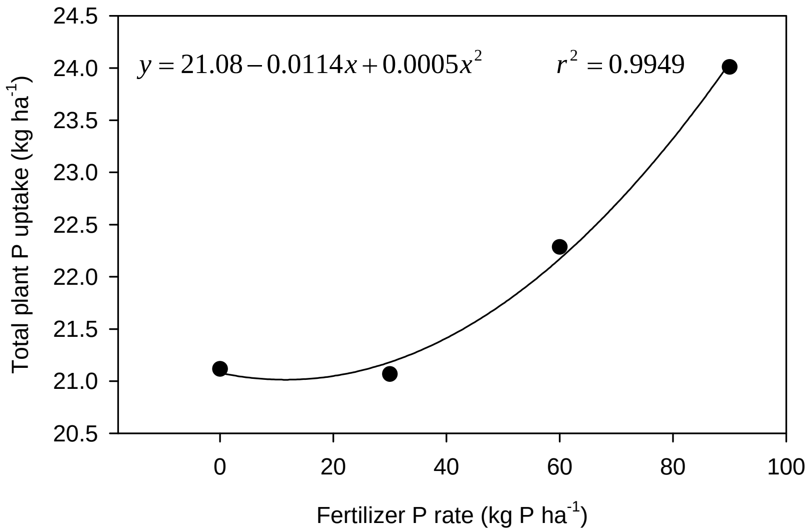

Fig. 17. Relationship between processing tomato total P uptake and fertilizer P rate on a sandy loam soil, Harrow, ON, 2007.

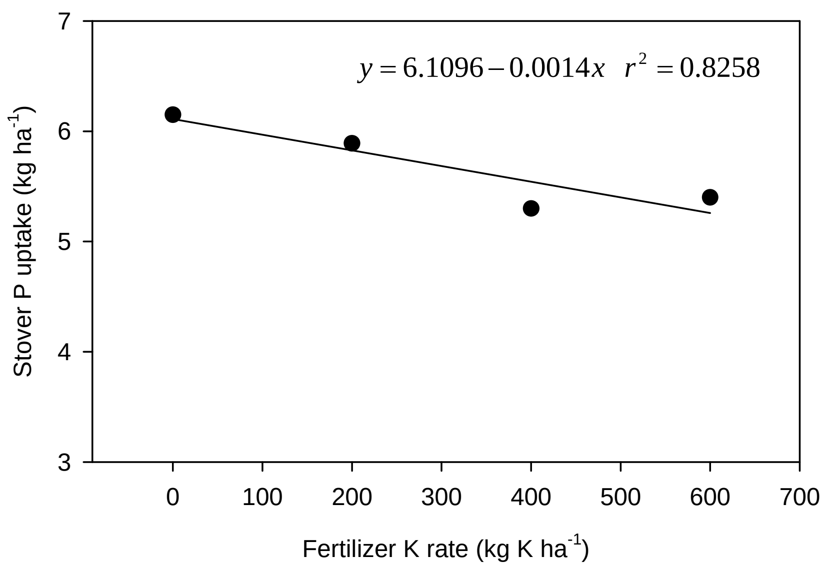

Fig. 18. Response of stover P uptake of processing tomatoes to fertilizer K rates on a sandy loam soil, Harrow, ON, 2007.

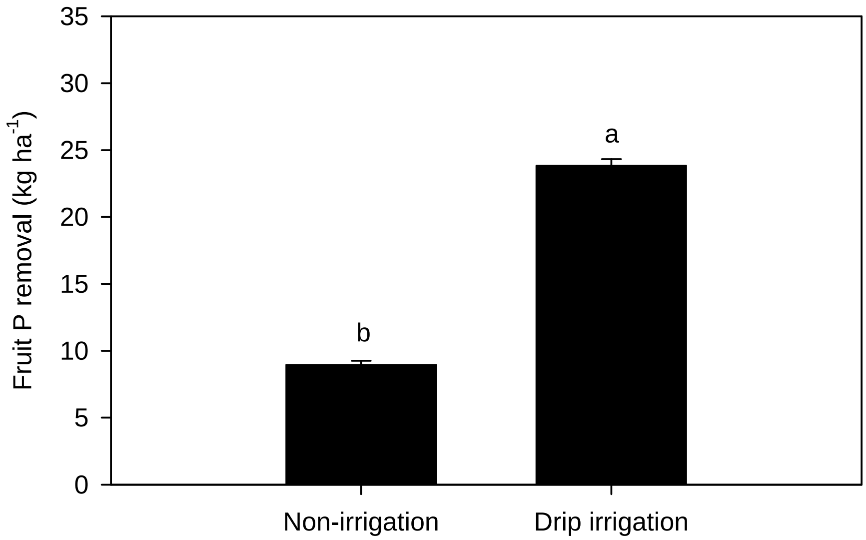

Fig. 19. Response of fruit P removal of processing tomato to drip-irrigation on a sandy loam soil, Harrow, ON, 2007. Vertical bars marked with the same letters are not significantly different at the P≤5% level.

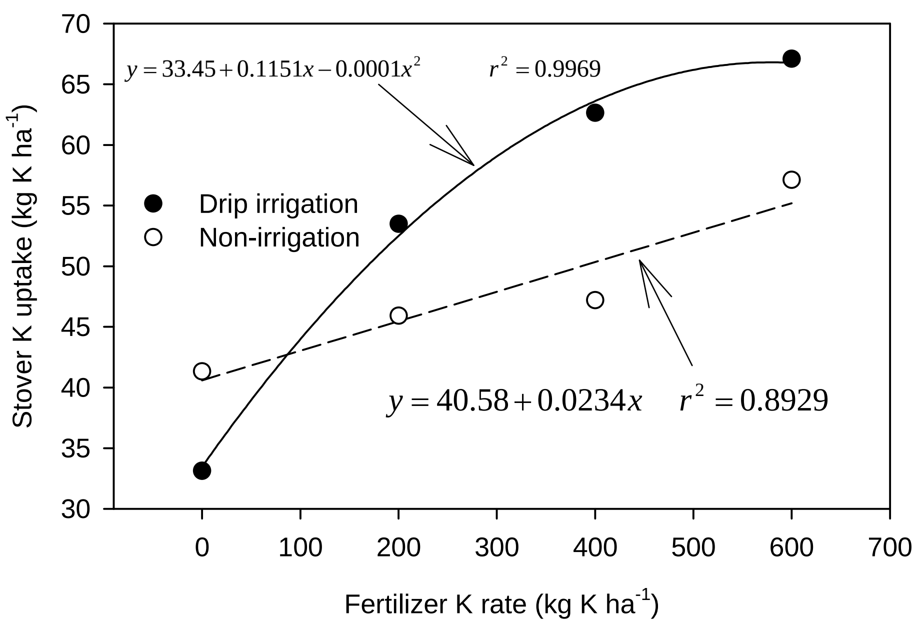

Fig. 20. Response of stover K uptake of processing tomatoes to fertilizer K rates with and without drip-irrigation on a sandy loam soil, Harrow, ON, 2007.

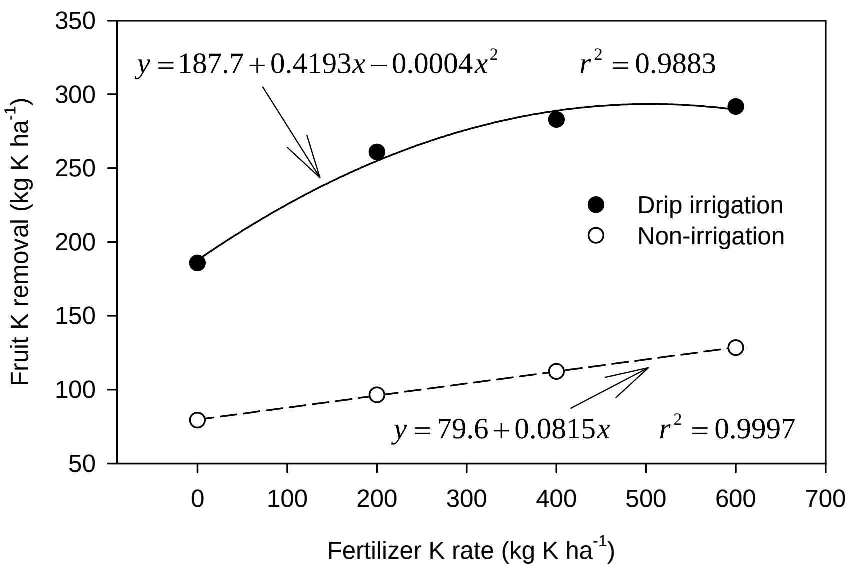

Fig. 21. Response of fruit K removal of processing tomatoes to drip-irrigation and fertilizer K rate on a sandy loam soil, Harrow, ON, 2007.

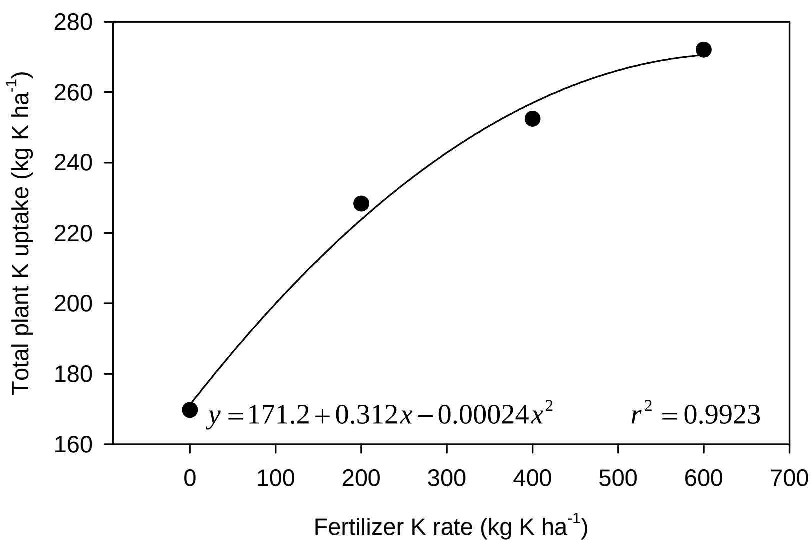

Fig. 22. Relationship between processing tomato total K uptake and fertilizer K rate on a sandy loam soil, Harrow, ON, 2007.

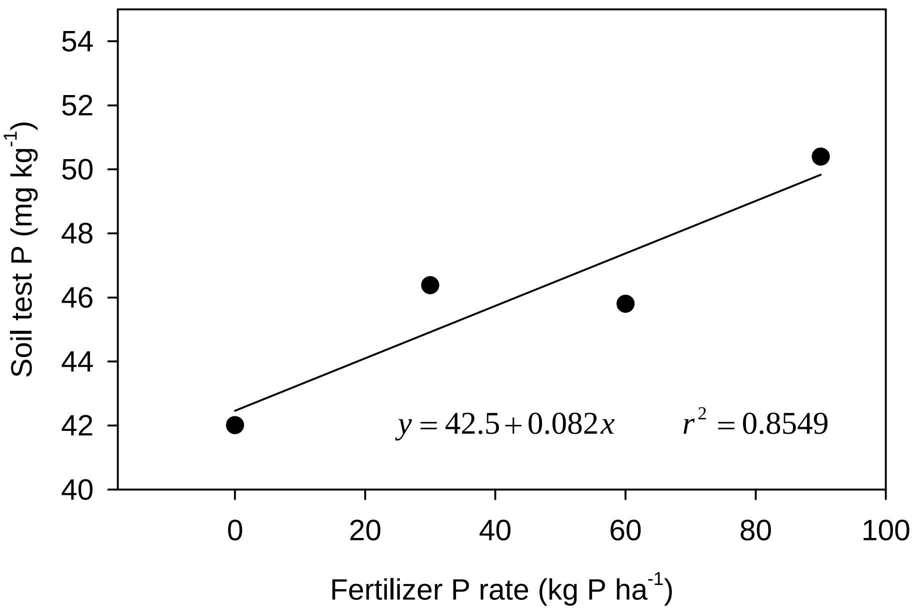

Fig. 23. Response of post-harvest soil test P (0-20 cm) to fertilizer P rates on a sandy loam soil, Harrow, ON, 2006

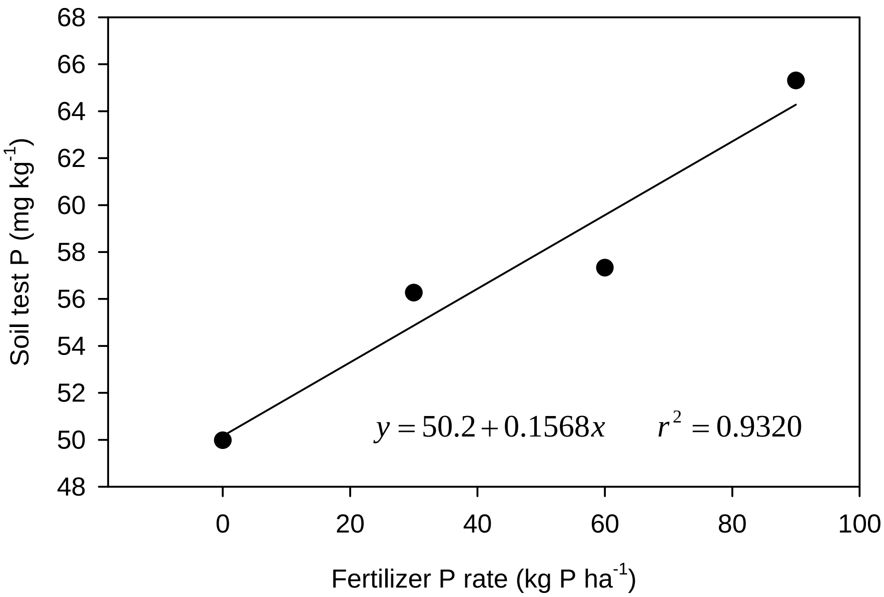

Fig. 24. Response of post-harvest soil test P (0-20 cm) to fertilizer P rates on a sandy loam soil, Harrow, ON, 2007.

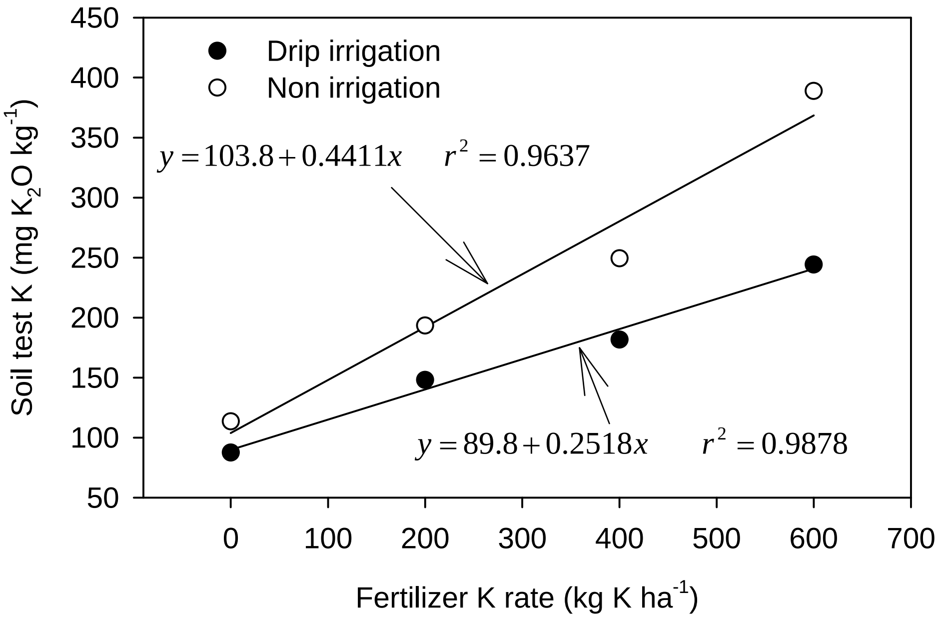

Fig. 25. Response of post-harvest soil test K (0-20 cm) to fertilizer K rates on a sandy loam soil, Harrow, ON, 2006.

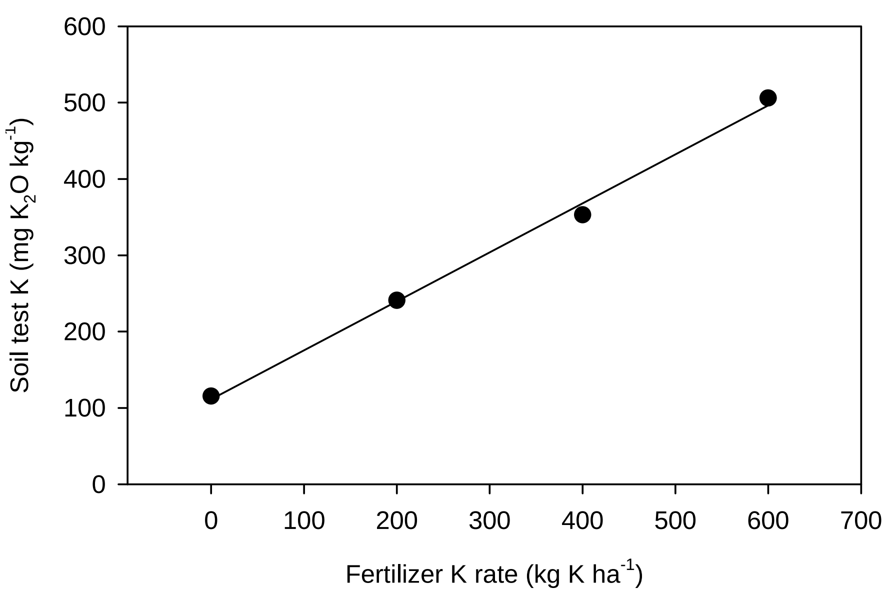

Fig. 26. Response of post-harvest soil test K (0-20 cm) to fertilizer K rates on a sandy loam soil, Harrow, ON, 2007.

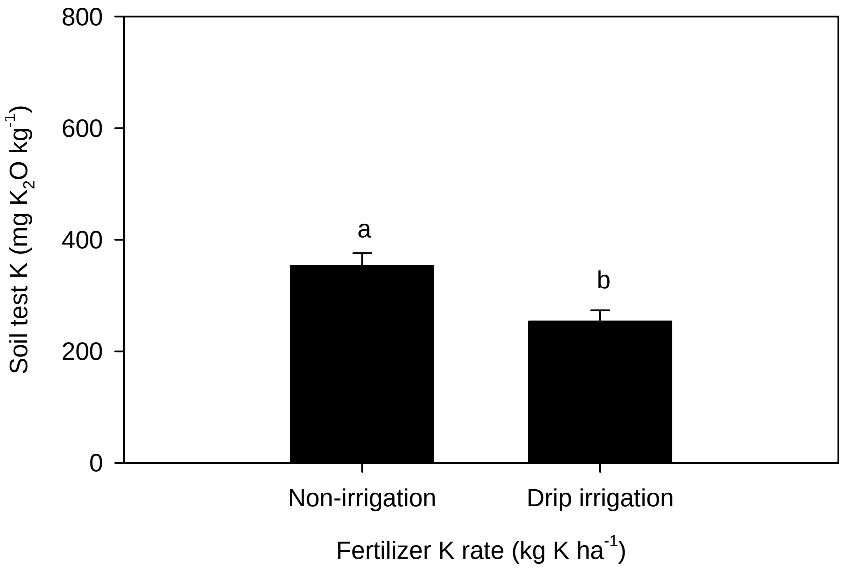

Fig. 27. Response of post-harvest soil test K (0-20 cm) to drip-irrigation on a sandy loam soil, Harrow, ON, 2007. Vertical bars marked with the same letters are not significantly different at the *P*≤5% level.

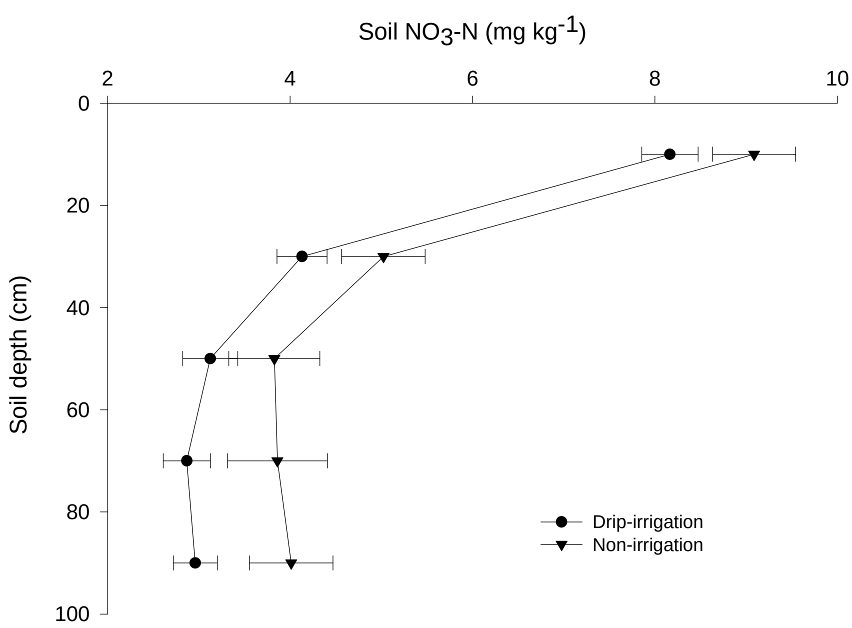

Fig. 28. Post-harvest soil profile nitrate N (0-100 cm) as affected by drip-irrigation under processing tomatoes on a sandy loam soil, Harrow, ON, 2007.