Project Title: **Agronomic and Environmental Consequences of Applying Fertilizer Nitrogen and Phosphorus to Processing Tomatoes and Green Peppers under Drip Fertigation**

(Report of the year 2005)

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Funding Sources: **Ontario Agri-Business Association**
Phosphate & Potash Institute of Canada
Canadian Fertilizer Institution
Ontario Tomato Research Institute
Ontario Processing Vegetable Growers
A & L Canada Laboratories East, Inc.
Agriculture and Agri-Food Canada

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December, 2005

Interpretative summary

Processing tomatoes and green peppers are high nutrient-demand crops, and the requirements can be further increased with increased yield potential resulted from improved water supply. Irrigation, especially drip irrigation/fertigation, has been largely adopted in southwestern Ontario for processing tomatoes and green peppers to overcome the frequent incidences of drought stress. However, excessive nutrient supply can have adverse impacts on water quality through surface runoff and leaching (nitrogen and phosphorus) and to air quality through gaseous emissions. New fertilization techniques must be developed for irrigated crops to maximize farmers' profits and to sustain or improve the environmental quality.

The long-term objectives of this study are 1) to develop optimum rates of fertilizer nitrogen and phosphorus for processing tomatoes and green peppers under drip fertigation, which are both economically and environmentally sound, 2) to determine the amounts of nitrogen and phosphorus required for each tonne production of processing tomatoes and green peppers, and 3) to determine the threshold values of petiole NO_3-N for processing tomatoes under Ontario conditions. The short-term objectives for 2005 were 1) to determine the relationships between fertilizer nitrogen and phosphorus rates and yield and quality of processing tomatoes and green peppers; 2) to determine crop nitrogen and phosphorus removals; and 3) to evaluate the potential leaching losses of soil NO_3-N.

The experiment was conducted in a Granby sandy loam soil in Harrow, ON. Treatments for processing tomatoes included 4 fertilizer nitrogen rates ranging from 0 to 360 kg N ha^{-1} and 3 fertilizer P rates ranging from 0 to 200 kg P_2O_5 ha^{-1}). For green peppers, treatments included 4 fertilizer N rates ranging from 0 to 240 kg N ha^{-1} and 3 fertilizer phosphorus rates ranging from 0 to 200 kg P_2O_5 ha^{-1}. Both trials were arranged in a factorial randomized completely block design, with 4 replicates.

Green peppers: The marketable yield was maximized at 38.5 tonne ha^{-1} with fertilizer nitrogen added at 203 kg N ha^{-1} (current OMAF recommendation: 70 kg N ha^{-1}). The result is consistent to what was obtained in 2003 (200.7 kg N ha^{-1}) and 2004 (277 kg N ha^{-1}). Green peppers require an increased nitrogen supply under drip fertigation.

An optimized combination of nitrogen (240 kg N ha^{-1}) and phosphorus (125 kg P_2O_5 ha^{-1}) was necessary, if large size of fruits are desired.
Fruit nitrogen removal ranged from 21 to 60 kg N ha^{-1}. Total above-ground nitrogen uptake ranged from 29 to 84 kg N ha^{-1}. Green peppers used 26% of nitrogen added with the production of maximum marketable yield, and thus have a low nitrogen use efficiency.

Amount of nitrogen required to produce each tonne of marketable yield varied from 0.28 to 5.2 kg N $tonne^{-1}$, depending on the level of target yield. When the maximum marketable yield is considered, the amount of fertilizer nitrogen required across the three years (2003-2005) was from 5.2 to 6.5 kg

N tonne^{-1}.

Total above-ground phosphorus uptake ranged from 7.6 to 15.4 kg P ha^{-1}, with fruit phosphorus removal ranging from 5.2 to 11.3 kg P ha^{-1}. Both phosphorus removal and total uptake fell respectively into the same range as in 2004, and responded quadratically to nitrogen rate. This also applies to the relationship between total potassium uptake and fertilizer nitrogen rate.

Post-harvest soil NO_3-N increased with increases in fertilizer nitrogen rate in soil layer up to 100cm, a reflection of leaching that have occurred in the growing season. Prevention of nitrogen leaching loss is necessary for green peppers under drip fertigation/irrigation.

Processing tomatoes: Both total and marketable yields responded quadratically to nitrogen application. A maximum marketable yield of 112 tonne ha^{-1} was produced with 305 kg N ha^{-1} fertilizer nitrogen applied. This was consistent with the results obtained in 2003 (216 kg N ha^{-1}) and 2004 (292 kg N ha^{-1}). Processing tomatoes under fertigation requires more nitrogen than the current recommendation (90-120 kg N ha^{-1} for the soil under study) to develop the maximum yield potential and to obtain the highest profits.

Fruit nitrogen removal ranged from 63 to 185 kg N ha^{-1}, and total nitrogen uptake from 97 to 251 kg N ha^{-1}. Both nitrogen removal and total nitrogen uptake were related quadratically to fertilizer nitrogen rate.

Values of fertilizer nitrogen required for each tonne of marketable yield production ranged from 0.12 to 2.7 kg N tonne^{-1}, depending on the level of target yield. The values are similar, but bracket those obtained from past two years (2003 and 2004). The amount of nitrogen required for the maximum yield across three years ranged from 1.7 to 2.7 kg N tonne^{-1}.

Total phosphorus uptake ranged from 24.8 to 44 kg P ha^{-1} (57 to 100.8 kg P_2O_5 ha^{-1}), and responded quadratically to nitrogen rate. A coordinate supply of nitrogen and phosphorus is important to best meet crop needs.

Marketable yield was related to petiole NO_3-N concentrations at various stages from first blooming to fruit set, but levels of petiole NO_3-N at the early blooming stage (July 06) accounted for the majority of nitrogen contribution to yield. Nitrogen fertilization should be performed right before full blooming.

The threshold value of petiole NO_3-N at the early blooming stage was 2020 mg N kg^{-1}, which is consistent with the value of 1934 mg N kg^{-1} in 2003.

Post-harvest soil profile NO_3-N contents increased with fertilizer nitrogen rate, especially above the rate required for maximum marketable yield production. Any excessive nitrogen applied would pose significant potential for losses, if not used by the crop during the growing season.

The optimized fertilization techniques are essential to maximize crop marketable yield, while minimizing adverse effects on environmental quality.

Addendum:

Background soil test levels were 82.7ppm for P and 215.2 ppm for K for processing tomatoes. For green peppers, soil test P was 97.5ppm and soil test K was 209.1ppm

Introduction

Field vegetables are often short season but high nutrient demanding crops. Sufficient and timely supply of nutrients is essential to produce high yield and quality. For processing tomatoes, production with yields of 74-125 t ha^{-1} removes 185-375 kg N ha^{-1}, 37-100 kg P_2O_5 ha^{-1}, and 277-750 kg K_2O ha^{-1} (calculated based on values from IFA World Fertilizer Use Manual). Similarly, for green peppers, production with yields of 35-50 t ha^{-1} removes 180-400 kg N ha^{-1}, 45-120 kg P_2O_5 ha^{-1}, and 250-675 kg K_2O ha^{-1}. The amount of nutrients required by each crop can be highly variable depending on soil type, variety, and climatic conditions.

On the other hand, excessive nutrient supply can have negative impacts on water quality through surface runoff and leaching (N and P) and to air quality through gaseous emissions (N_2O). As a result, legislation has being applied to various crops in various parts of the world to prevent over-application of fertilizers. Ontario is one of the provinces in Canada which is currently implementing nutrient management plans. In the Ontario's NMAN planning software, nutrient management standards are regulated based on the criteria of application rate in comparison with crop removal. While there is a lack of information on nutrient removals by various crops for the current Ontario conditions, the recommendations in the OMAF publication may be considered (such as 70 kg N/ha for peppers). Compared with the current production potential with new hybrids or the nutrient requirement mentioned above, these recommendation rates are often not sufficient to develop maximum economic yield. For instance, a farm for processing tomato production in Leamington area has a soil test P value of 145 mg P_2O_5 kg^{-1} soil and fertilizer P is still added at 80 kg P ha^{-1} due to the potential profit that the farmer believes will result based on his experience, while the Publication 363 considers >60 mg P kg^{-1} soil test P as excessive and no fertilizer P is recommended. A study in California has shown a 19% increase in marketable yield with added fertilizer P from 56 to 152 kg ha^{-1} and a 53% increase with added N from 151 to 302 kg ha^{-1}. There is lack of information on nutrient removal and the optimum fertilization rate which maximizes crop yield and quality, while minimizing the adverse impacts on water quality.

In addition, increasing incidences of drought and high temperature in southwestern Ontario have had serious negative effects on yield and quality of both processing tomatoes and green peppers. These climate extremes are expected to become more frequent as global warming continues. Producers are adopting more and more irrigation practices, especially drip irrigation and fertigation. The expansion of drip irrigation and fertigation has been substantially enhanced with the $2 million grant awarded through the OMAF Health Environment Program. Timely satisfactory provision of soil moisture required by crops can greatly increase crop yield, and thus the nutrient requirement.

Since nitrogen (N) and phosphorus (P) are the two environmentally concerned nutrients and both processing tomatoes and green peppers are the two major field vegetable crops, with a farm gate value of about $75 million in Ontario (OMAF, 2002), research is necessary to document the negative effects of insufficient N and P supply on yield and quality, to assess the environmental impacts of higher application rates, and finally to develop optimum rates which maximize farmers' profit and sustain or improve the environmental quality. Research on nutrient management has been ranked as the top priority by Horticultural industry and the Ontario Soil Research and Service Committee (OMAF, 2002).

Objectives

The long-term objectives of this study is to develop optimum rates of fertilizer N and P for processing tomatoes and green peppers under drip fertigation, which are both economically and environmentally sound, 2) to determine the amounts of nutrients N and P required for each ton production of processing tomatoes and green peppers, and 3) to determine the threshold values of petiole NO_3-N and K for processing tomatoes under drip fertigation for Ontario conditions.

The short-term objectives of this study for 2005 were 1) to determine the relationships of fertilizer N and P rates and yield and quality of processing tomatoes and green peppers under drip fertigation; 2) to determine crop N and P uptake and removals; and 3) to evaluate the potential leaching losses of soil NO_3-N.

Activities conducted in 2005

1. April - May: renovation of Fertigation Manager and the filed fertigation systems, site selection and preparation, pre-plant soil sampling and analysis
2. May: plot layout, fertilization, planting
3. May: drip line installation
4 June-September: field management, fertigation application, multiple-time green pepper harvesting, processing tomato harvesting, yield and quality measurements, field trips to growers, and other industry personals delegations from Canada and USA.
5. October - Nov.: continuous green pepper harvesting, plant tissue and post-harvest soil sampling
4) Nov. - Dec.: Plant and soil sample analyses
5) Jan. - Mar./05: completion of plant and soil sample analyses, reporting

Materials and Methods

The experiments in 2005 were conducted in a Granby sandy loam soil at GPCRC, Harrow, ON. The experiment design was consistent with that in 2003 and 2004, but on a different site each year. In brief, for processing tomatoes, treatments included 4 fertilizer N rates ranging from 0 to 360 kg N ha^{-1} and 3 fertilizer P rates ranging from 0 to 200 kg P_2O_5 ha^{-1}. For green peppers, treatments included 4 fertilizer N rates ranging from 0 to 240 kg N ha^{-1} and 3 fertilizer P rates ranging from 0 to 200 kg P_2O_5 ha^{-1}. For both crops, the plots were arranged in a factorial randomized completely block design, with 4 replicates for a total 96 plots. All fertilizer P and 40% of fertilizer N were pre-transplant broadcasted and the remaining fertilizer N drip-fertigated. Drip fertigation was applied to all plots using a computerized Fertigation Manager System. Weeds were controlled with Treflan + Dual Magnum + Sencor pre-plant incorporation. All other plot managements followed the local practices.

For processing tomatoes, fruits from the central rows of each plot were harvested at the 80% fruit ripening (or peak ripening) stage and graded into processing ripe (marketable), green, blossom end-rot and cull, and weights recorded. Total and assorted fruit yield was calculated. Fruit soluble solids were measured. Fruit and stover were sampled and analysed for N, P and K contents. Total N, P and K uptake and removals were calculated in combination with fruit and stover yields.

Leaf petiole nitrate (NO_3-N) and potassium measurements were conducted using Cardy nitrate and potassium metre (Spectrum Technologies, Plainfield, IL). Thirty-five leaf petiole samples from the 4th leaf of the complete growing tip were taken from each plot once in a week for a consecutive five weeks from first bloom to fruit set stages. The petiole samples were put in a plastic bag and stored in a cooler immediately. The samples are transported to the laboratory in one hour. At the same day, the composite juice from each plot was analysed for NO_3-N and K in the laboratory.

For green peppers, fruits were harvested once in a week or when applicable (6 harvests during the season). Fruit were ranked as marketable and non-marketable yields, of which both count and weight were determined. Fruit and stover were sampled and analysed for moisture, nitrogen and phosphorus contents. Total nitrogen and phosphorus uptake and removals were calculated in combination with fruit and stover yields. Nitrogen and phosphorus requirements for each tonne production of green peppers were calculated.

Soil profile samples (0-20, 20-40, 40-60, 60-80, and 80-100 cm depths) were taken before planting and shortly after harvesting and analysed for NO_3-N and NH_4-N to evaluate the leaching potential of soil N as a function of fertiliser rates. Because of the very low contents of soil NH_4-N, the results were not included in the report.

Impacts of fertilizer nitrogen and phosphorus on yield, quality, nitrogen and phosphorus uptake and removal, and potential losses of soil N and P were analysed and quantified using the SAS program.

Results and Discussions

Green Peppers

Yields and quality:

<u>Yields:</u> Addition of fertilizer nitrogen affected both total and marketable yields of green peppers (Table 1). However, neither fertilizer phosphorus nor interaction between fertilizer nitrogen and phosphorus was found on either total or marketable yield. The results were consistent with those from 2004, but slightly different than what from 2003 in which application of fertilizer phosphorus also affected both total and marketable yields.

Similar to 2003 and 2004, total yield of green peppers across all rates of fertilizer phosphorus in 2005 increased quadratically with fertilizer nitrogen rate (Fig. 1). The maximum total yield of 44.5

tonne ha^{-1} was obtained with fertilizer nitrogen applied at 202.6 kg N ha^{-1}.

Similarly, a quadratic relationship was found between the marketable yield of green peppers and fertilizer nitrogen rate (Fig. 2). The marketable yield was maximized at 38.5 tonne ha^{-1} with fertilizer nitrogen added at 203.1 kg N ha^{-1}, which was about 3 times as much as the rate, 70 kg N ha^{-1}, recommended by the OMAF publication 363. The results are consistent to what was obtained in past two years, in which 200.7 and 277 kg N ha^{-1} fertilizer nitrogen was required to maximize the marketable yield of 30.2 and 44.8 tonne ha^{-1} in 2003 and 2004, respectively. Green peppers require an increased nitrogen supply under drip fertigation.

Fruit size:
Fruit size was 76.6 g $fruit^{-1}$ in the control plots (Fig. 3). Added fertilizer nitrogen alone increased fruit size up to 106.2 g $fruit^{-1}$, while added phosphorus alone increased fruit size up to 101.4 g $fruit^{-1}$. However, the largest fruit size (109.4 g $fruit^{-1}$) was only obtainable with application of both fertilizer nitrogen (240 kg N ha^{-1}) and phosphorus (125 kg P_2O_5 ha^{-1}). Hence, an optimized combination of nitrogen and phosphorus was necessary, if big fruits are desired.

Nutrient (nitrogen and phosphorus) uptake and removal:
Stover nitrogen and phosphorus uptake: Stover uptake of nitrogen and phosphorus was only related to the fertilizer nitrogen rate applied (Table 1). This was the same as the results found in 2003, but slightly different from what was found in 2004, in which stover uptake of nitrogen and phosphorus were related to application of both fertilizer nitrogen and phosphorus. Interactions between nitrogen and phosphorus were not found on stover uptake of either nitrogen or phosphorus.

Stover nitrogen uptake ranged from 8 to 26 kg N ha^{-1}, and followed quadratic curveship with fertilizer nitrogen rate added (Fig. 4). Stover phosphorous uptake ranged from 2.1 to 4.3 kg P ha^{-1}, and increased also quadratically with increases in fertilizer nitrogen (Fig. 5). The increase of stover nitrogen uptake with increases in fertilizer nitrogen rate can be explained primarily by the increases in stover biomass production (Fig. 6) and the nitrogen concentration (Fig. 7). However, the increase of stover phosphorus uptake with increase in fertilizer nitrogen rate was the consequence of negative effect of nitrogen on phosphorus concentration (Fig. 8) integrated with its positive effect on dry matter production.

In addition, interaction between nitrogen and phosphorus was found on stover yield (Fig. 6). Increased fertilizer phosphorus rate increased stover yield, when no nitrogen was applied, but the effective phosphorus rate for production of the highest stover yield decreased with increases in nitrogen rate. It appeared that high phosphorus enhanced the dry matter accumulation of stover, when soil was low in nitrogen, or that high nitrogen enhanced the dry matter accumulation of stover, when soil was low in phosphorus. The significance of this result is the potential for that we would develop a new technique to increase nitrogen use efficiency through phosphorus application, especially in soils with high organic nitrogen. Bio-availability of organic nitrogen is often low in the early season due to the low mineralization rate, but can substantially increase when soil is warmed up in the middle to late season. Phosphorus can be applied to minimize nitrogen loss from un-necessary application, while maximizing vegetative growth.

<u>Fruit nitrogen and phosphorus removal:</u> Similar to the fruit yield of green peppers, the fruit removal of both nitrogen and phosphorus followed a quadratic curveship with fertilizer nitrogen rate (Figs. 9 &10). The fruit nitrogen removal ranged from 21.3 to 60 kg N ha^{-1}, while the fruit phosphorus removal ranged from 5.2 to 11.3 kg P ha^{-1}. The maximum nitrogen and phosphorus removal was obtained with fertilizer nitrogen added at 220.8 and 206.4 kg N ha^{-1}, respectively. Thus, the nitrogen rate at which fruit nitrogen and phosphorus removals maximized were consistent with that was required to produce the maximum marketable yield, as discussed earlier.

<u>Total nitrogen and phosphorus uptake and amount of nitrogen required for each tonne production of green peppers:</u> Total above-ground nitrogen uptake, the sum of stover uptake and fruit nitrogen removal, followed the same pattern as stover and fruit yield (Fig. 11). Total nitrogen uptake ranged from 29.3 to 83.7 kg N ha^{-1}. A calculated value of 260 kg N ha^{-1} was needed to maximize the total nitrogen uptake. The nitrogen use efficiency with the production of maximum marketable yield was 26.1%. Clearly, green peppers have a low nitrogen use efficiency, which is as low as half of that for the field crops, such as grain corn.

Amount of nitrogen required to produce each tonne of marketable green pepper yield varied depending on the level of target yield (Fig. 12). Calculated values of fertilizer nitrogen required to produce each tonne of marketable yield ranged from 0.28 to 5.2 kg N $tonne^{-1}$. The values are comparable with those obtained in 2003 (0.3 to 6.2 kg N $tonne^{-1}$) and 2004 (0.4 to 6.7 kg N $tonne^{-1}$). When the maximum marketable yield is considered, the amount of fertilizer nitrogen required across the three years was from 5.2 to 6.5 kg N $tonne^{-1}$.

Total phosphorus uptake ranged from 7.6 to 15.4 kg P ha^{-1} and responded quadratically with nitrogen rate (Fig. 13). The total phosphorus uptake falls into the same range as in 2004. This also applies to the relationship between total potassium uptake and fertilizer nitrogen rate (Fig. 14).

Soil residual NO_3-N after harvest:
Soil profile (0-100 cm) NO_3-N after harvest increased with increases in fertilizer nitrogen rate (Fig. 15). In addition to the top soil layer of 0 to 20 cm, fertilizer rate effect was found in the entire soil profile determined. Levels of soil nitrate nitrogen increased substantially with fertilizer nitrogen at 240 kg N ha^{-1}, while it increased slightly with fertilizer nitrogen at 160 kg N ha^{-1}, indicating that any nitrogen added not taken by crops would have remained in soil profile. The high levels of nitrate nitrogen found in both surface and deep (80-100cm) soil layers imply that significant leaching of soil NO_3-N occurred during the growing season, if not absorbed immediately by crops. As a result, prevention of nitrogen leaching loss through increased use efficiency become a serious issue for green pepper production under drip fertigation/irrigation.

Processing tomatoes

Yields and quality:
Addition of fertilizer nitrogen affected significantly the yields of fruit (both total and marketable) and stover of processing tomatoes (Table 2). However, there were no significant effect of added

fertilizer phosphorus and its interactions with fertilizer nitrogen on either fruit or stover yield. These are identical to what were found in 2004. In addition, the curveship between fruit yield were also identical to those found in 2004.

Total yield of processing tomatoes across three fertilizer phosphorus rates was related quadratically to fertilizer nitrogen rate, with the maximum total yield of 137 tonne ha^{-1} obtained with fertilizer nitrogen applied at 322.4 kg N ha^{-1} (Fig. 16).

Responses of marketable yield to the application of fertilizer nitrogen followed the same pattern as did the total yield (Fig. 17). A maximum marketable yield of 112.2 tonne ha^{-1} was produced with 304.7 kg N ha^{-1} fertilizer nitrogen applied. Thus, an amount of 18 kg N ha^{-1} of excessive fertilizer nitrogen produced an additional of 18 tonne ha^{-1} of green or culled fruits, both of which were not marketable at the harvesting stage. It has been recommended that 90-120 kg N ha^{-1} fertilizer nitrogen is required for processing tomatoes for the soil conditions under study (OMAF, publication 363). The results clearly indicate that processing tomatoes under fertigation requires more nitrogen supply, 153-215% more in 2005, to develop the maximum production potential and to obtain the maximum profits. The result is consistent to those obtained in 2003 (80-140% more) and 2004 (140-224% more). One of the reasons for the increased demand for fertilizer nitrogen under fertigation can be due to the increase in marketable yield. For instance, marketable yield under fertigation was as high as 4 times (28.3 vs. 112.6 tonne ha^{-1}) of what under natural precipitation when the same amount of fertilizer nitrogen and phosphorus (240 kg N ha^{-1} plus 100 kg P_2O_5 ha^{-1}) were applied in this study.

Although the quadratic response of fruit yield to nitrogen rate, there appeared a linear relationship between stover yield and fertilizer nitrogen rate (Fig. 18). Addition of each kg of nitrogen increased dry mater accumulation of stover by 0.00547 tonne ha^{-1}. Clearly, excessive nitrogen application enhanced unnecessary vegetative growth, which may have produced some green fruit and/or other culled fruits, and consequently reduced the proportion of the marketable yield.

Similar to green peppers, the amount of fertilizer nitrogen required for each tonne of marketable yield production varied depending on the level of target yield (Fig. 19). Calculated values of fertilizer nitrogen required for each tonne of marketable yield production ranged from 0.12 to 2.7 kg N $tonne^{-1}$, which bracket those obtained from past two years, 0.1 to 2.1 kg N $tonne^{-1}$.in 2004 and 0.07 to 1.7 kg N $tonne^{-1}$ in 2003, implying the effects of varied weather conditions. The values of nitrogen required at the maximum yield ranged from 1.7 to 2.7 kg N $tonne^{-1}$.

There were no significant relationships found between fertilizer addition of either nitrogen or phosphorus on soluble solids, although nitrogen rate was related negatively to the contents of soluble solids in both 2002 and 2003, and a strong relationship between stover phosphorus content and soluble solids in 2003. It appeared that the relationships between nutrients nitrogen and phosphorus and soluble solids are extremely complicate. Further research is needed to determine the exact effects of nitrogen and phosphorus and the interaction on soluble solids of processing tomatoes, so that techniques can be developed to improve quality for processing.

Nutrient (N and P) removals and total uptake:

Fruit nitrogen removal ranged from 63 to 185 kg N ha^{-1}, and was interactively affected by fertilizer rates of nitrogen and phosphorus (Fig. 20). Fruit nitrogen removal was not affected by phosphorus rate when nitrogen was added at rate below 240 kg N ha^{-1}. When nitrogen was added at 360 kg N ha^{-1}, however, fruit nitrogen removal increased with increases in phosphorus application. Consequently, high rate of nitrogen in combination with high rate of phosphorus enhanced soil nitrogen removal with fruit harvesting. Increased phosphorus application can, again, pose potential for improving nitrogen use. As mentioned earlier, however, the significance of high nitrogen concentration of fruits need to be determined.

Fruit phosphorus removal ranged from 17.6 to 33 kg P ha^{-1} (40.3 to 75.6 kg P_2O_5 ha^{-1}), and responded quadratically to nitrogen rate, but not to the phosphorus rate (Fig. 21). The maximum phosphorus removal occurred with fertilizer nitrogen applied at 304 kg ha^{-1}, which is identical to the amount of nitrogen (302 kg ha^{-1}) required for production of the maximum marketable yield, indicating the importance of the coordinate supply of both nitrogen and phosphorus to meet crop needs.

In summary of stover and fruit uptake, both total nitrogen and phosphorus uptake reacted quadratically to added fertilizer nitrogen (Figs. 22 and 23). Total nitrogen uptake ranged from 97 to 251 kg N ha^{-1}, while total phosphorus uptake ranged from 24.8 to 44 kg P ha^{-1} (57 to 100.8 kg P_2O_5 ha^{-1}). The maximum nutrient uptake occurred with nitrogen applied at a calculated value of 470 kg N ha^{-1} for nitrogen and at 324 kg N ha^{-1} for phosphorus. These values are greater than amount of nitrogen required for either the maximum total fruit yield or the maximum marketable yield. Clearly, the additional nitrogen and phosphorus uptake which was enhanced by excessive nitrogen application contributed mainly to stover growth, and considered generally as luxury uptake.

Petiole (SAP) NO_3-N:

Similar to what was found in 2004, the petiole NO_3-N concentrations across various phosphorus treatments were relatively low in the early stage after first blooming, and reached the maximum at about full blooming stage, after which they declined gradually in the late season (Fig. 24). The changing pattern of petiole NO_3-N should have largely met the crop needs at various physiological stage, and thus formed a solid nutritional base for maximum marketable yield production. Levels of petiole NO_3-N increased with fertilizer nitrogen rate.

Apparently, marketable yield was related to petiole NO_3-N concentrations at various stages from first bloom to fruit set (data not shown). Changes of petiole NO_3-N concentrations accounted for a total of 83.4% of the variation in marketable yield. Having partitioned the contributions of petiole NO_3-N to marketable yield, however, levels of petiole NO_3-N at the early blooming stage (July 06) accounted for 82.1% , while levels of petiole NO_3-N at the later stages accounted for the rest of 1.3%. The result confirms what were obtained in 2004 that N fertilization should be performed right before full blooming.

The threshold vale of petiole NO_3-N at the early blooming stage was 2020 mg N kg^{-1} (Fig. 25), which is consistent with the value of 1934 mg N kg^{-1} in 2003.

Soil residual NO_3-N after harvest:

As expected, post-harvest soil profile (0-100 cm) NO_3-N contents increased with fertilizer nitrogen rate (Fig. 26). While majority of the soil residual NO_3-N remained in the depth of 0-20 cm, NO_3-N leaching was noticed with fertilizer nitrogen added at high rates, especially above 240 kg ha^{-1}. This value agrees with that the nitrogen required for maximum yield production, implying that any nitrogen applied would pose negative impacts on water quality, if not used by crop during the growing season.

The optimized fertilization techniques are essential to maximize crop marketable yield and to minimize adverse effects on environmental quality.

Table 1. Statistical significance of fertilizer nitrogen and phosphorus on green pepper yields, nutrients uptake and removals under drip fertigation in a sandy loam soil, Harrow, ON, 2005.

Factors	Nitrogen (N)	Phosphorus (P)	N*P
Yields and fruit size			
Total yield	**	NS	NS
Marketable yield	**	NS	NS
Fruit size	**	* *	†
Nutrient removals or uptake			
Fruit N removal	**	NS	NS
Fruit P removal	**	NS	NS
Stover N uptake	**	NS	NS
Stover P uptake	**	NS	NS

†, *, **; significant at *P*=<0.1, 0.05 and 0.01 levels, respectively. NS: Not significant at *P*=0.1 level.

Table 2. Statistical significance of fertilizer nitrogen (N) and phosphorus on processing tomato yields, fruits quality under drip fertigation in a sandy loam soil, Harrow, ON, 2005.

Factors	Nitrogen (N)	Phosphorus (P)	N*P
Yields			
Total yield	**	NS	NS
Marketable yield	**	NS	NS
Stover yield	**	NS	NS
Nutrient removals or uptake			
Fruit N removal	**	NS	**
Fruit P removal	**	NS	NS
Fruit K removal	**	NS	NS

†, *, **; significant at *P*=<0.1, 0.05 and 0.01 levels, respectively. NS: Not significant at *P*=0.1 level.

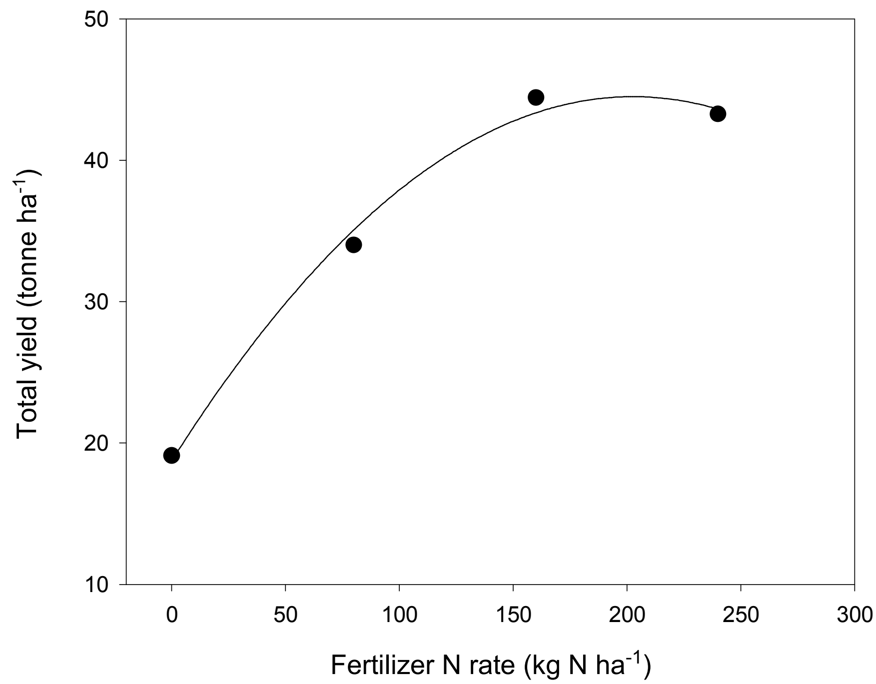

Fig. 1. Response of green pepper total yield to fertilizer nitrogen application with fertigation in a sandy loam soil, Harrow, ON, 2005.

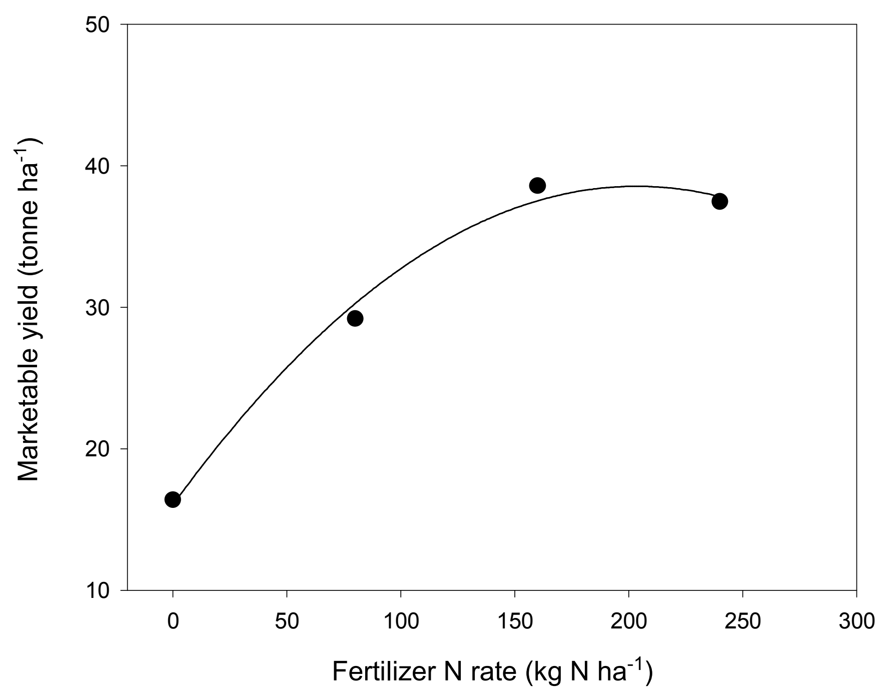

Fig. 2. Response of green pepper marketable yield to fertilizer nitrogen application with fertigation in a sandy loam soil, Harrow, ON, 2005.

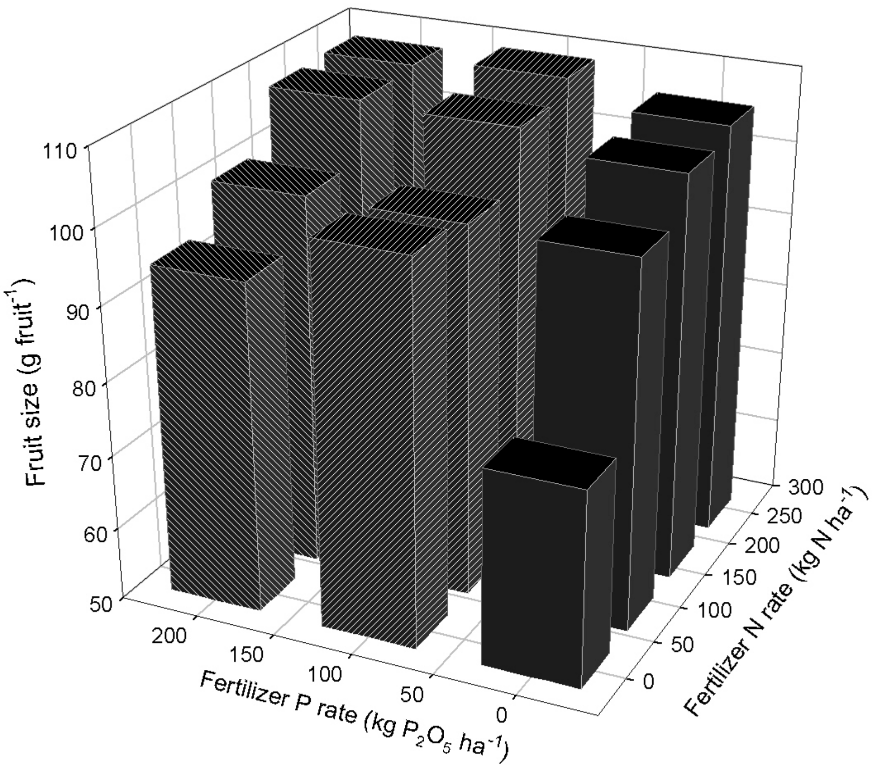

Fig. 3. Response of green pepper fruit size to fertilizer nitrogen and phosphorus rates in a sandy loam soil, Harrow, ON, 2005.

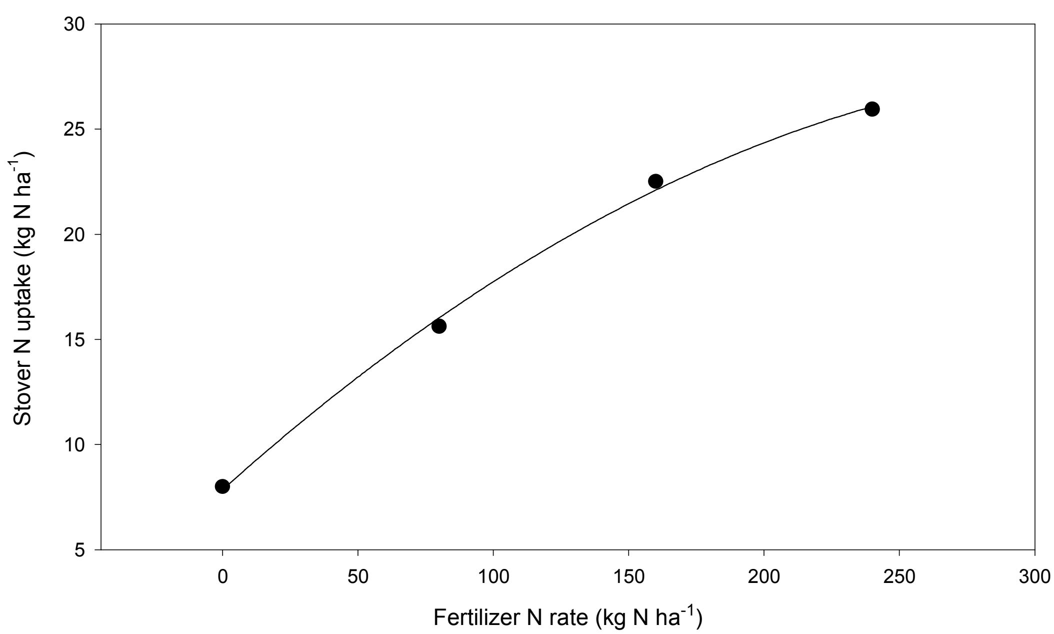

Fig. 4. Responses of green pepper stover nitrogen uptake to fertilizer nitrogen application in a sandy loam soil, Harrow, ON, 2005.

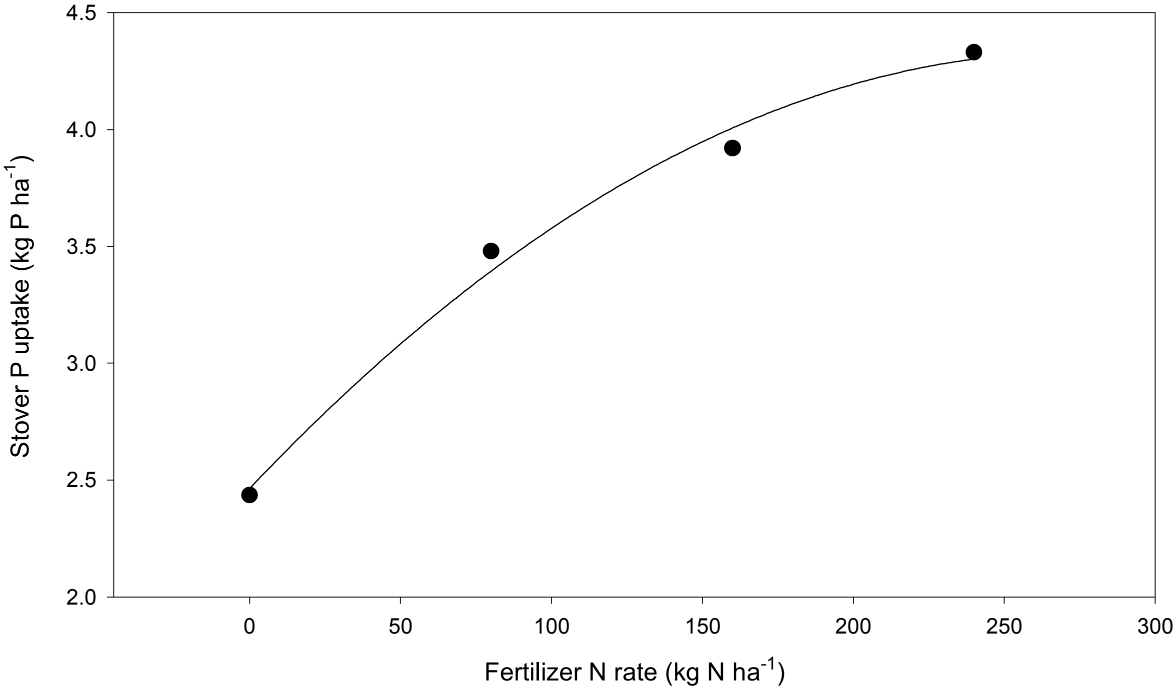

Fig. 5. Responses of green pepper stover phosphorus uptake to fertilizer nitrogen application in a sandy loam soil, Harrow, ON, 2005.

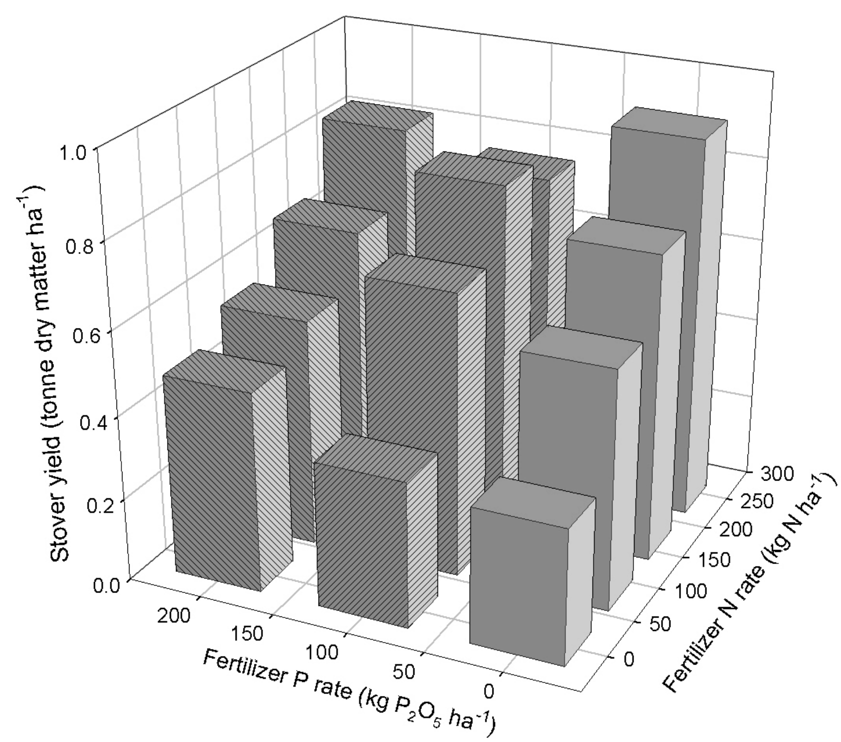

Fig. 6. Response of green pepper stover yield (dry matter) to fertilizer nitrogen and phosphorus rates in a sandy loam soil, Harrow, ON, 2005.

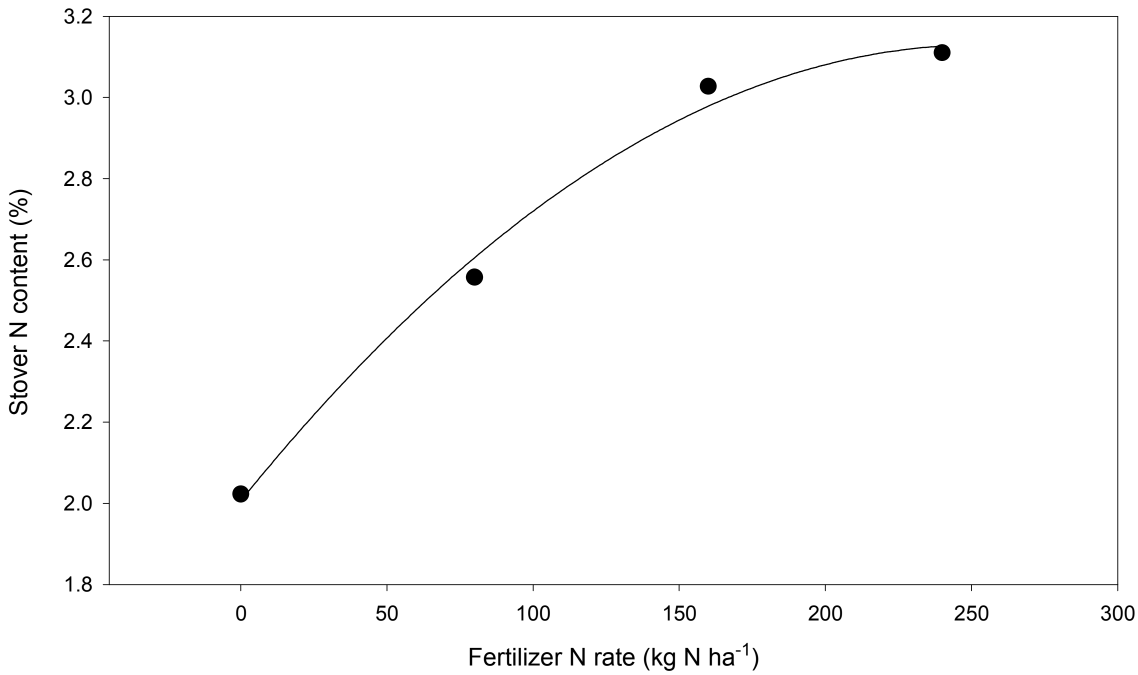

Fig. 7. Responses of green pepper stover nitrogen concentration to fertilizer nitrogen application in a sandy loam soil, Harrow, ON, 2005.

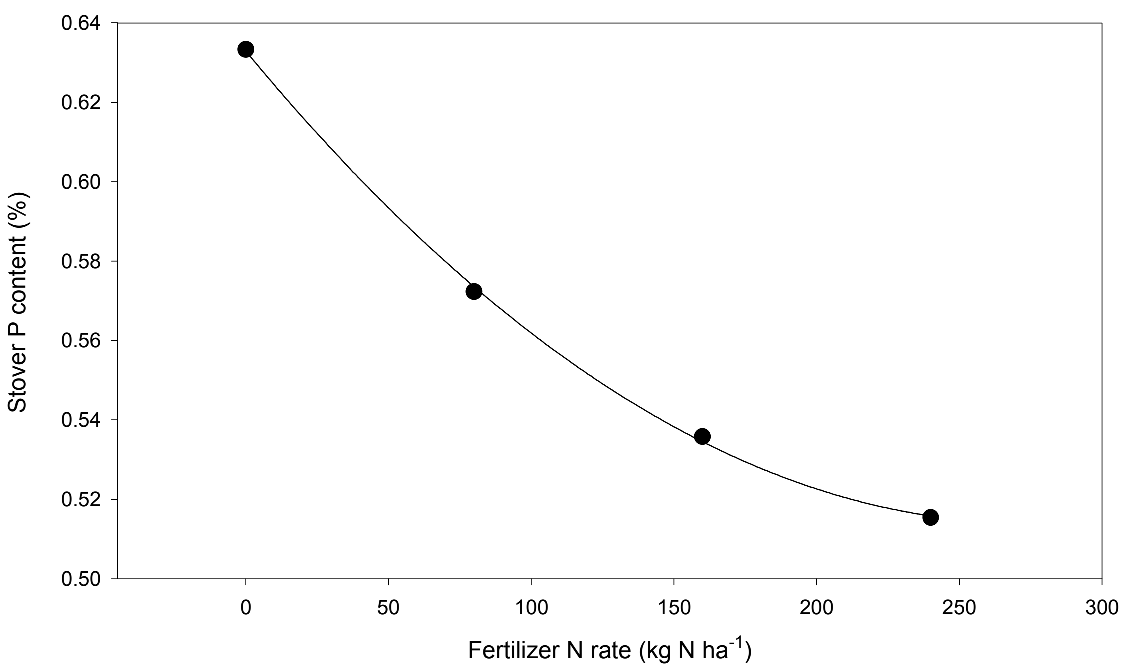

Fig. 8. Responses of green pepper stover phosphorous concentration to fertilizer nitrogen application in a sandy loam soil, Harrow, ON, 2005.

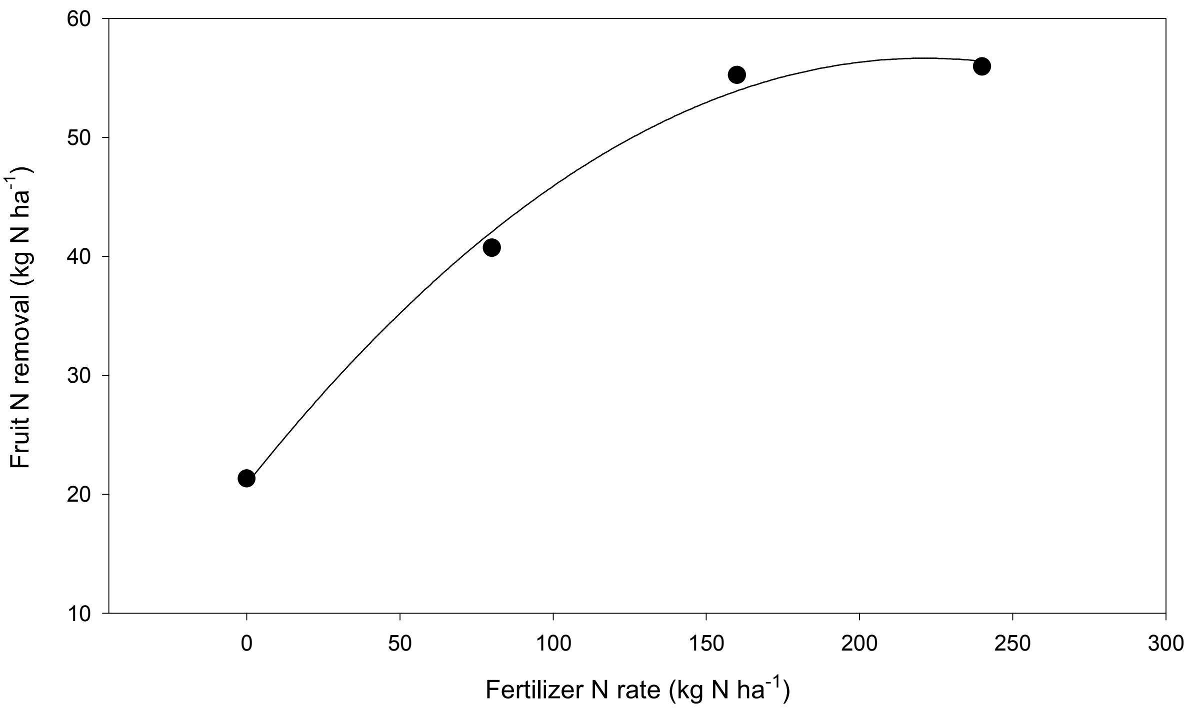

Fig. 9. Responses of green pepper fruit nitrogen removal to fertilizer nitrogen application in a sandy loam soil, Harrow, ON, 2005.

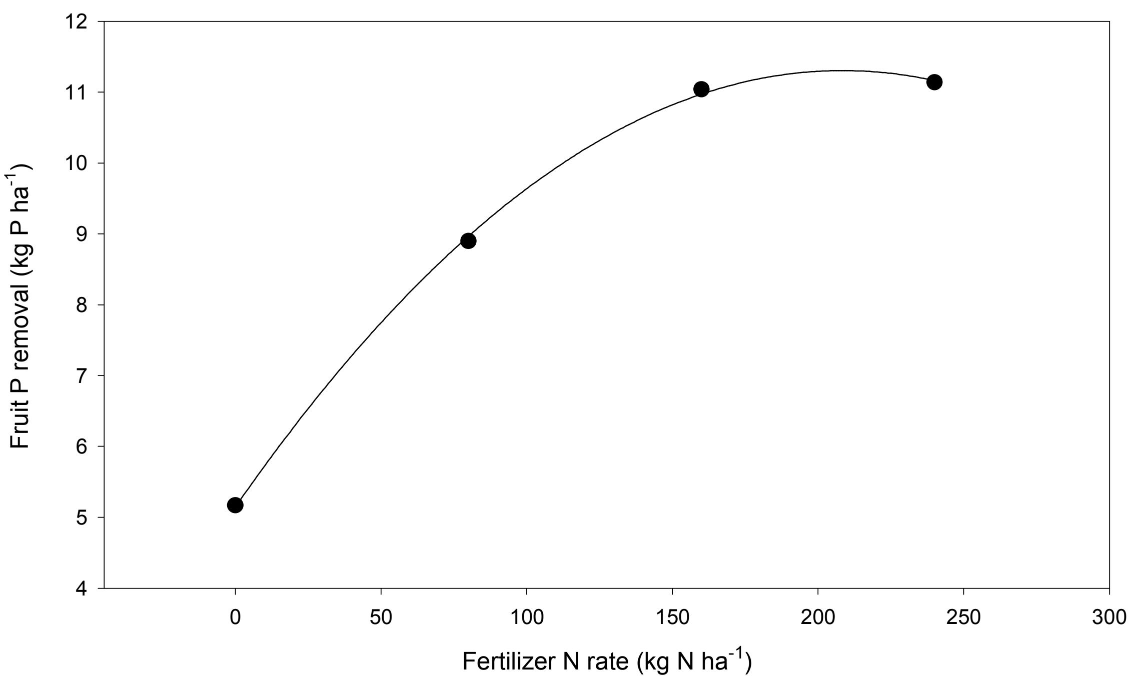

Fig. 10. Responses of green pepper fruit phosphorus removal to fertilizer nitrogen application in a sandy loam soil, Harrow, ON, 2005.

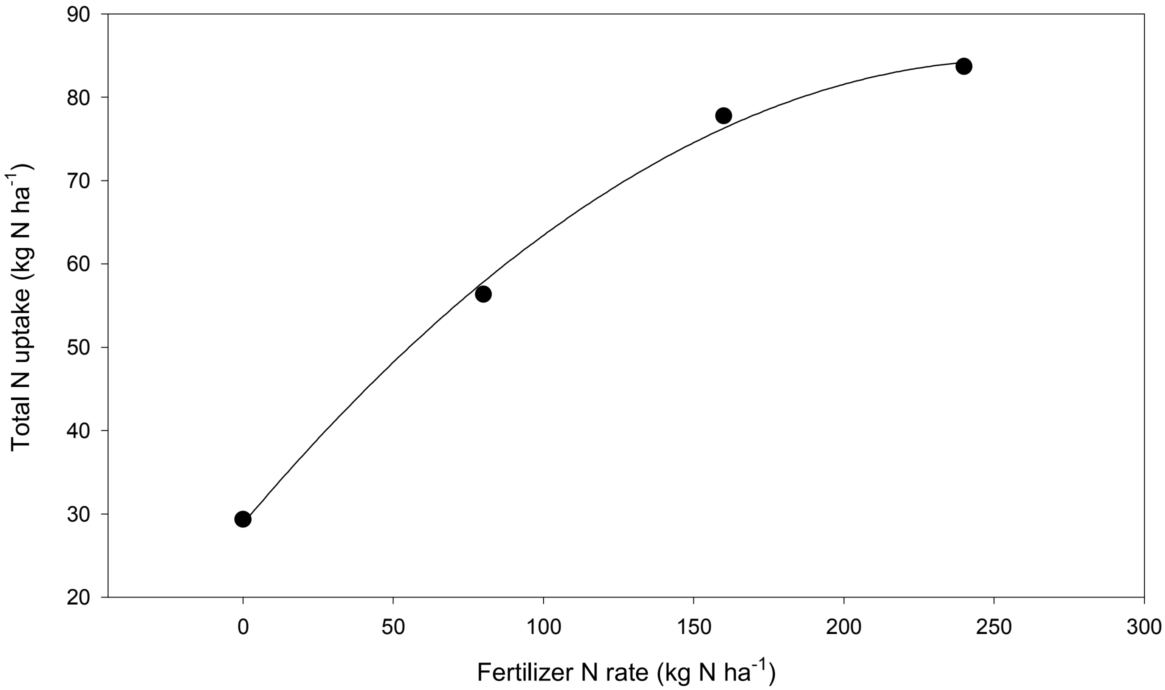

Fig. 11. Responses of green pepper total nitrogen uptake to fertilizer nitrogen application in a sandy loam soil, Harrow, ON, 2005.

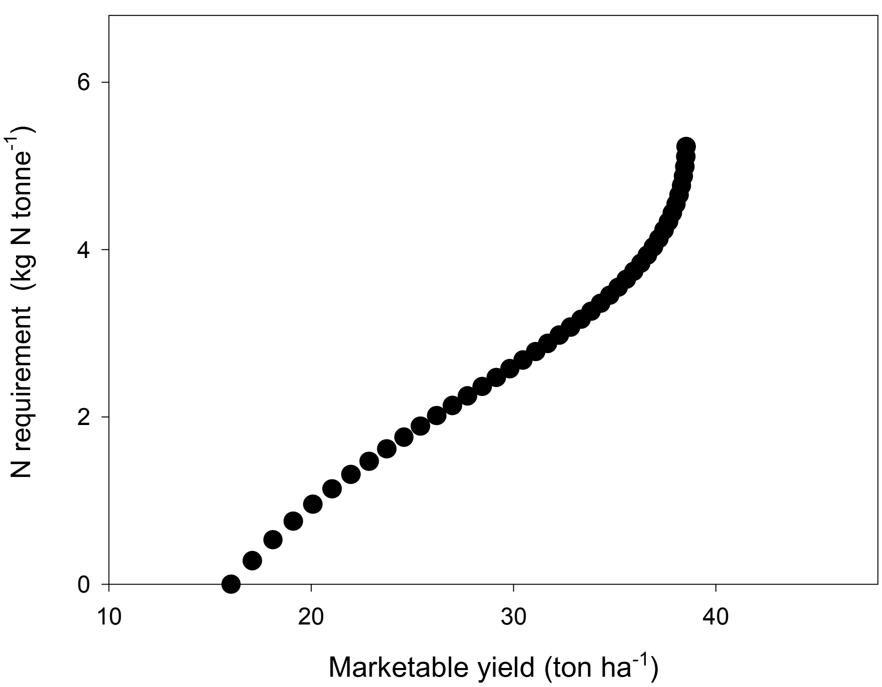

Fig. 12. Amount of nitrogen required to produce each tonne of green peppers, a sandy loam soil, Harrow, ON, 2005.

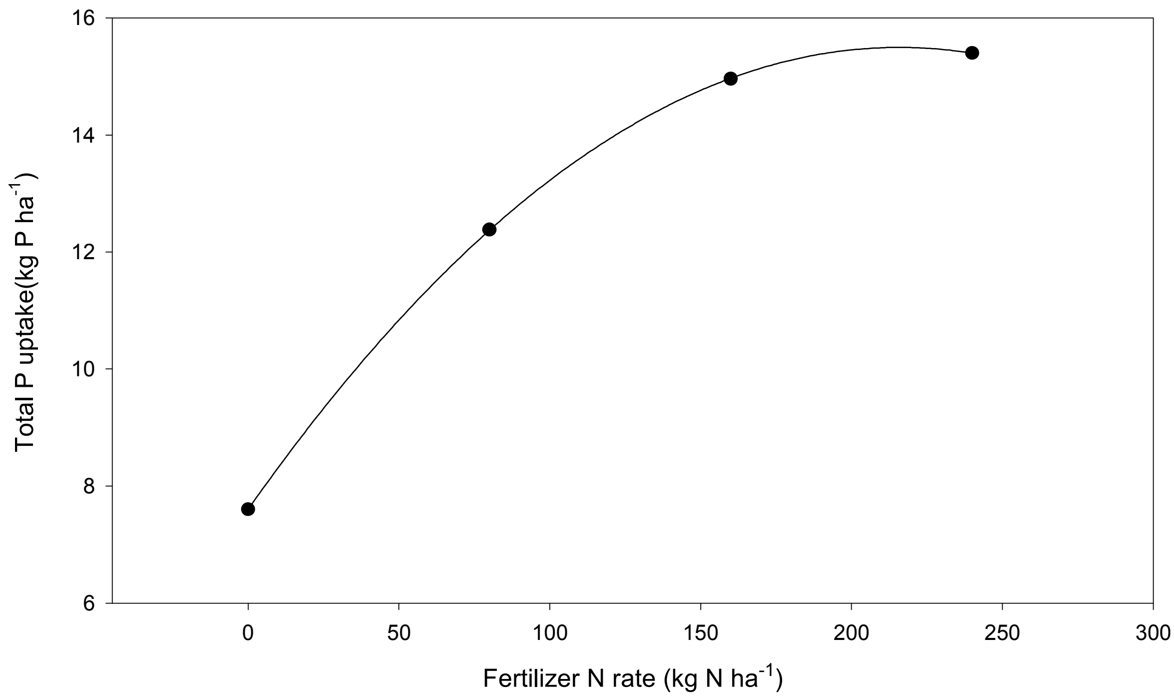

Fig. 13. Responses of green pepper total phosphorus uptake to fertilizer nitrogen application in a sandy loam soil, Harrow, ON, 2005.

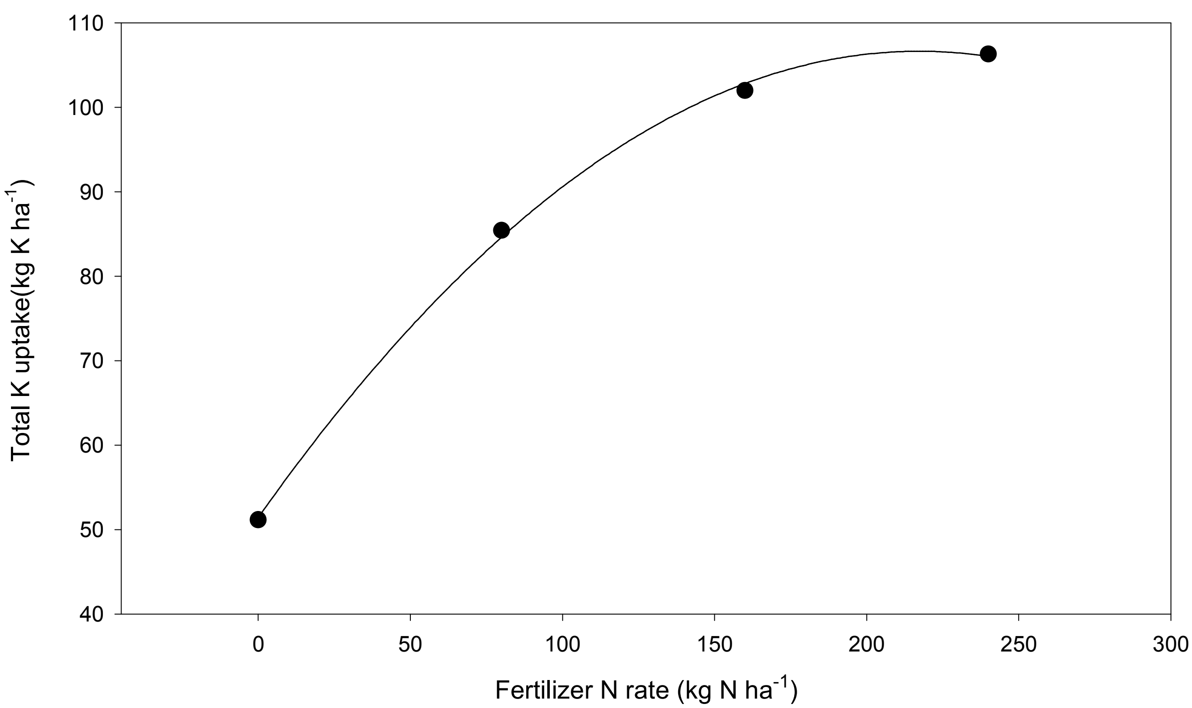

Fig. 14. Responses of green pepper total poptassium uptake to fertilizer nitrogen application in a sandy loam soil, Harrow, ON, 2005.

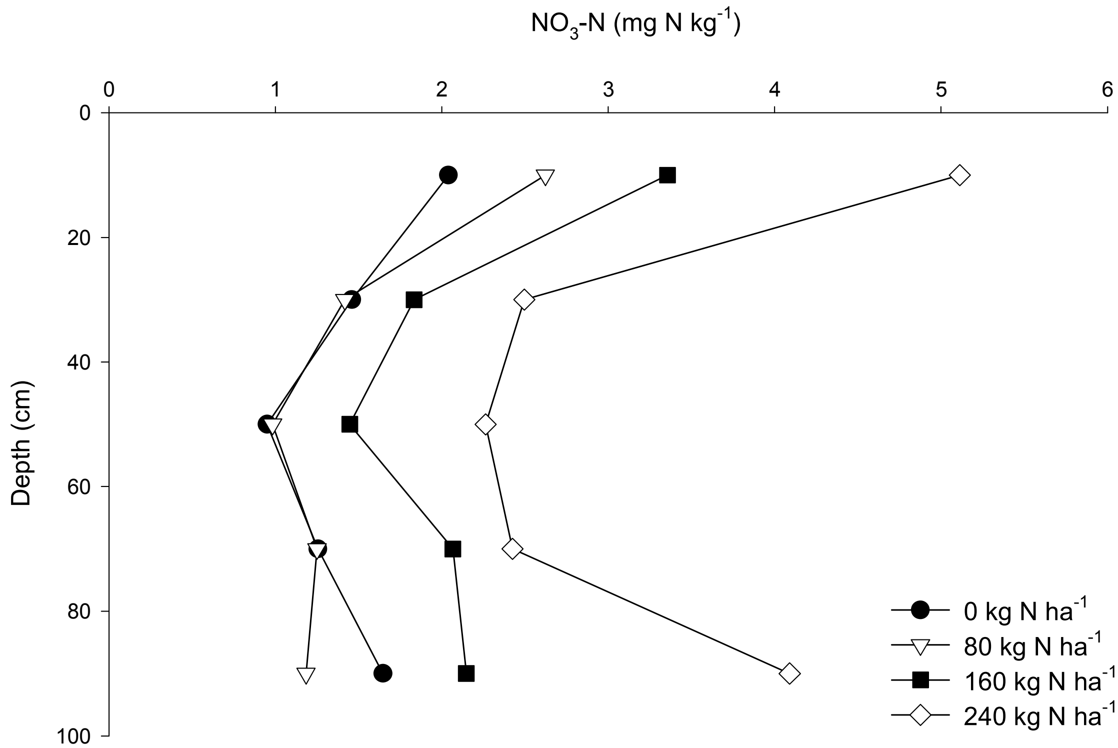

Fig. 15. Post-harvest soil profile (0-100 cm) NO_3-N as influenced by fertilizer N rate under green peppers with drip fertigation in a sandy loam soil, Harrow, ON, 2005

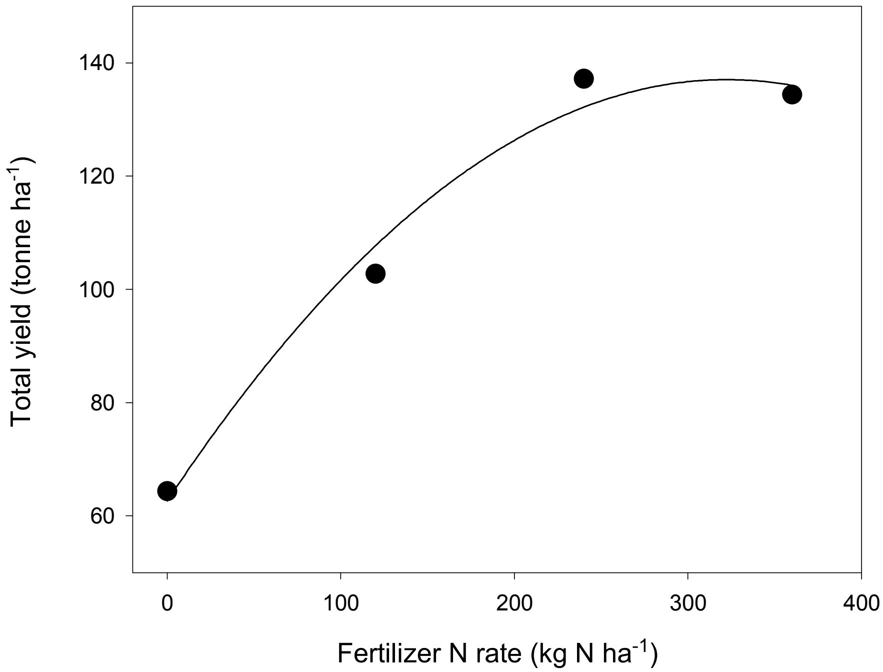

Fig. 16. Response of processing tomato total yield to fertilizer nitrogen application with fertigation in a sandy loam soil, Harrow, ON, 2005.

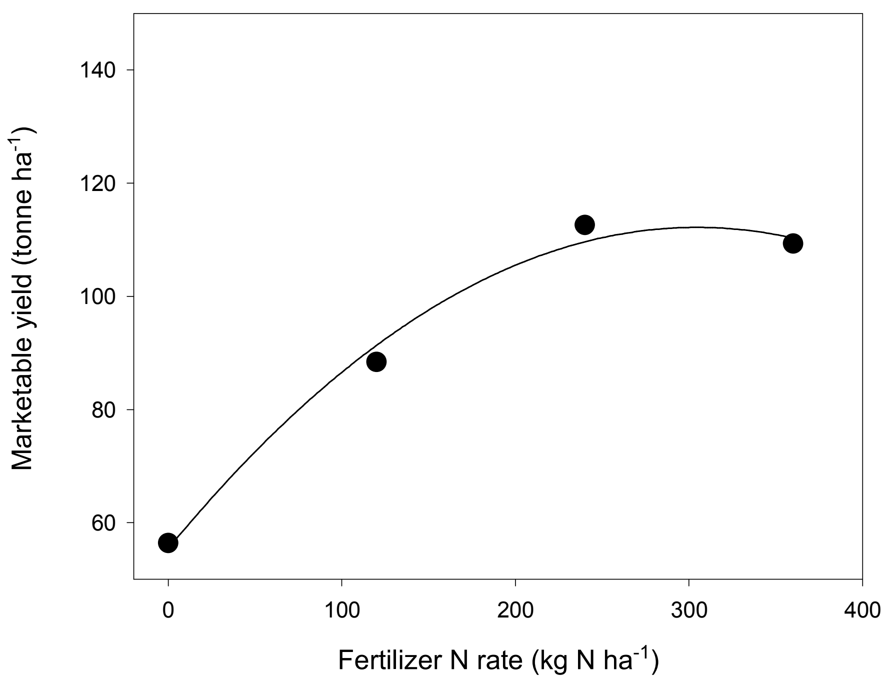

Fig. 17. Response of processing tomato marketable yield to fertilizer nitrogen application with fertigation in a sandy loam soil, Harrow, ON, 2005.

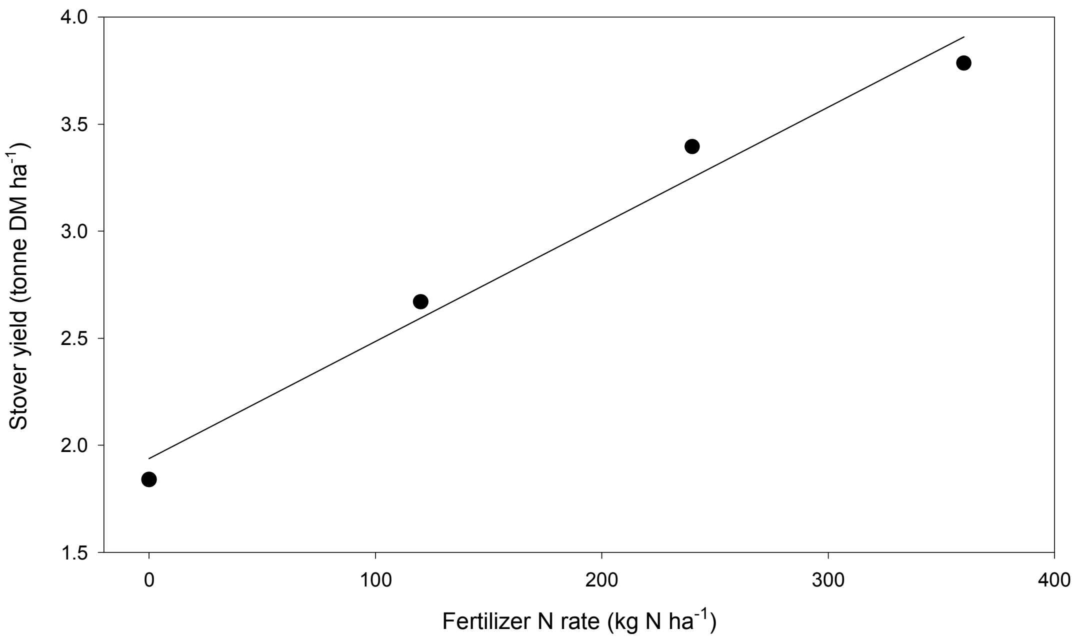

Fig. 18. Response of processing tomato stover yield (dry matter) to fertilizer nitrogen application with fertigation in a sandy loam soil, Harrow, ON, 2005.

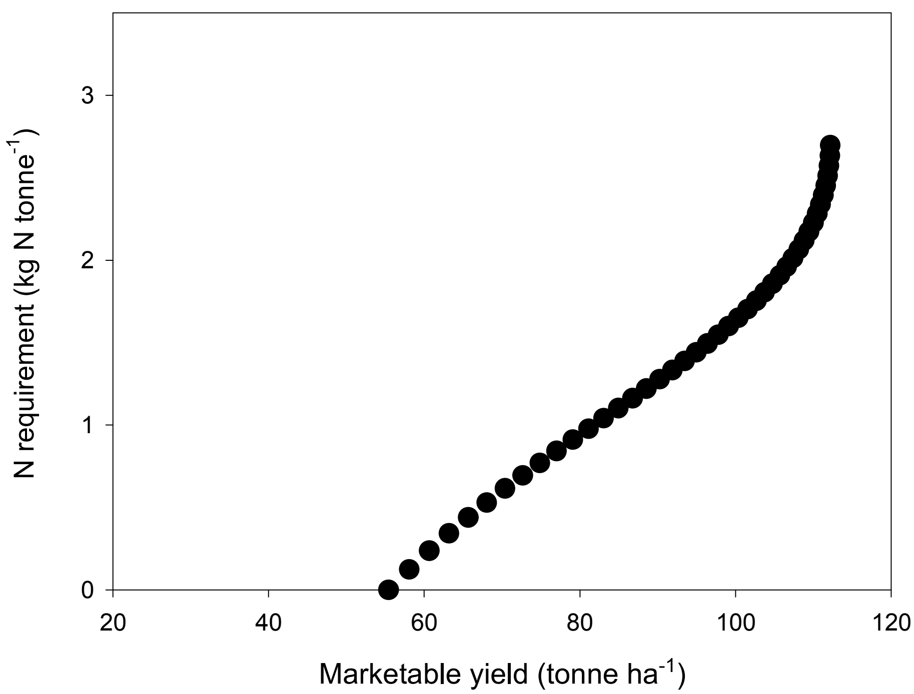

Fig. 19. Amount of nitrogen required to produce each tonne of marketable processing tomatoes, a sandy loam soil, Harrow, ON, 2005.

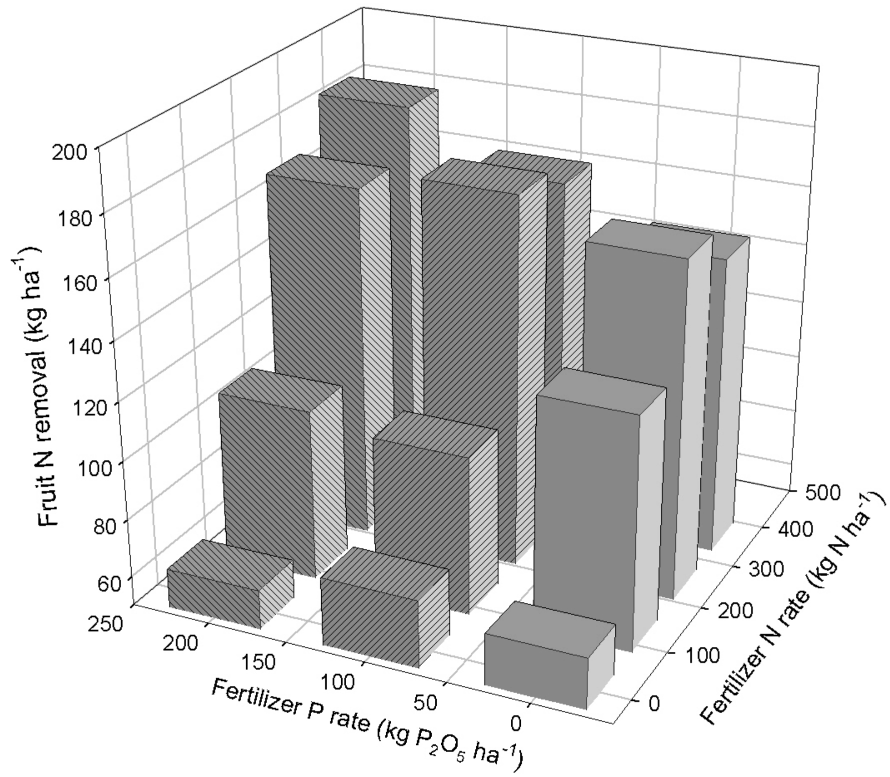

Fig. 20. Response of fruit nitrogen removal to fertilizer nitrogen and phosphorus rates in a sandy loam soil, Harrow, ON, 2005.

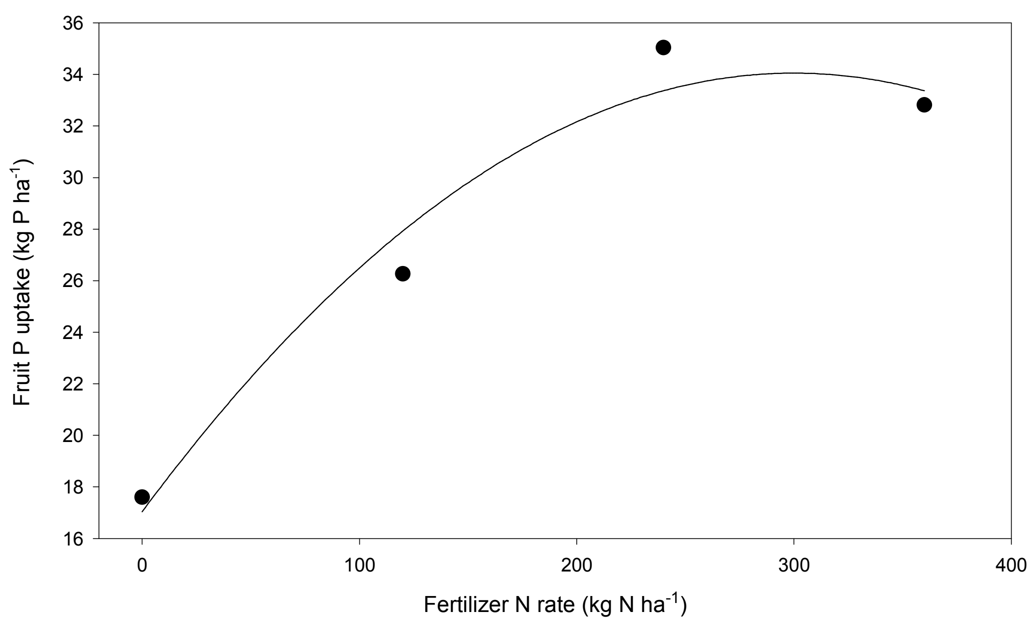

Fig. 21. Response of processing tomato phosphorus removal to fertilizer nitrogen application in a sandy loam soil under fertigation, Harrow, ON, 2005.

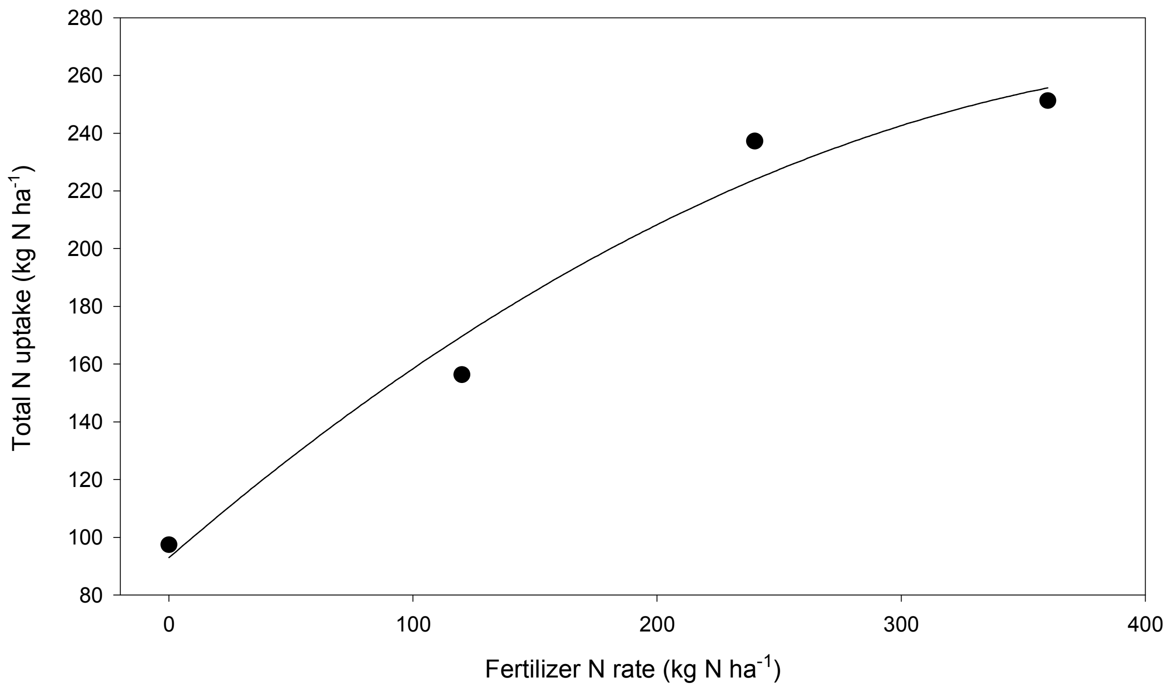

Fig. 22. Response of processing tomato total nitrogen uptake to fertilizer nitrogen application in a sandy loam soil under fertigation, Harrow, ON, 2005.

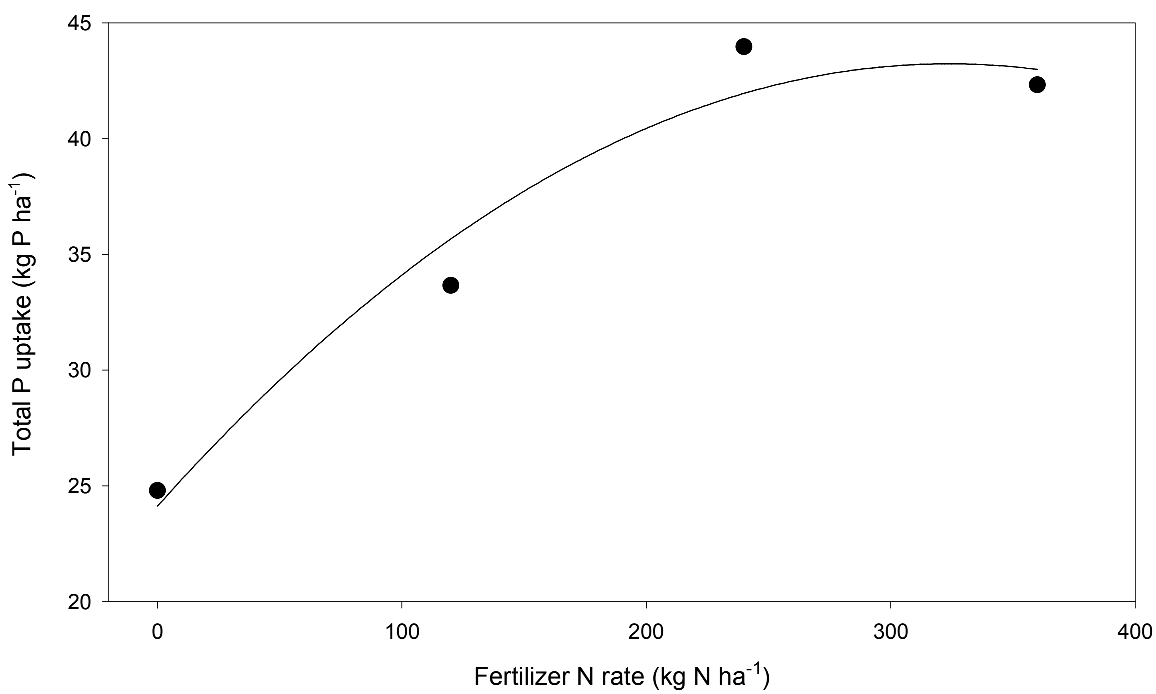

Fig. 23. Response of processing tomato total phosphorus uptake to fertilizer nitrogen application in a sandy loam soil under fertigation, Harrow, ON, 2005.

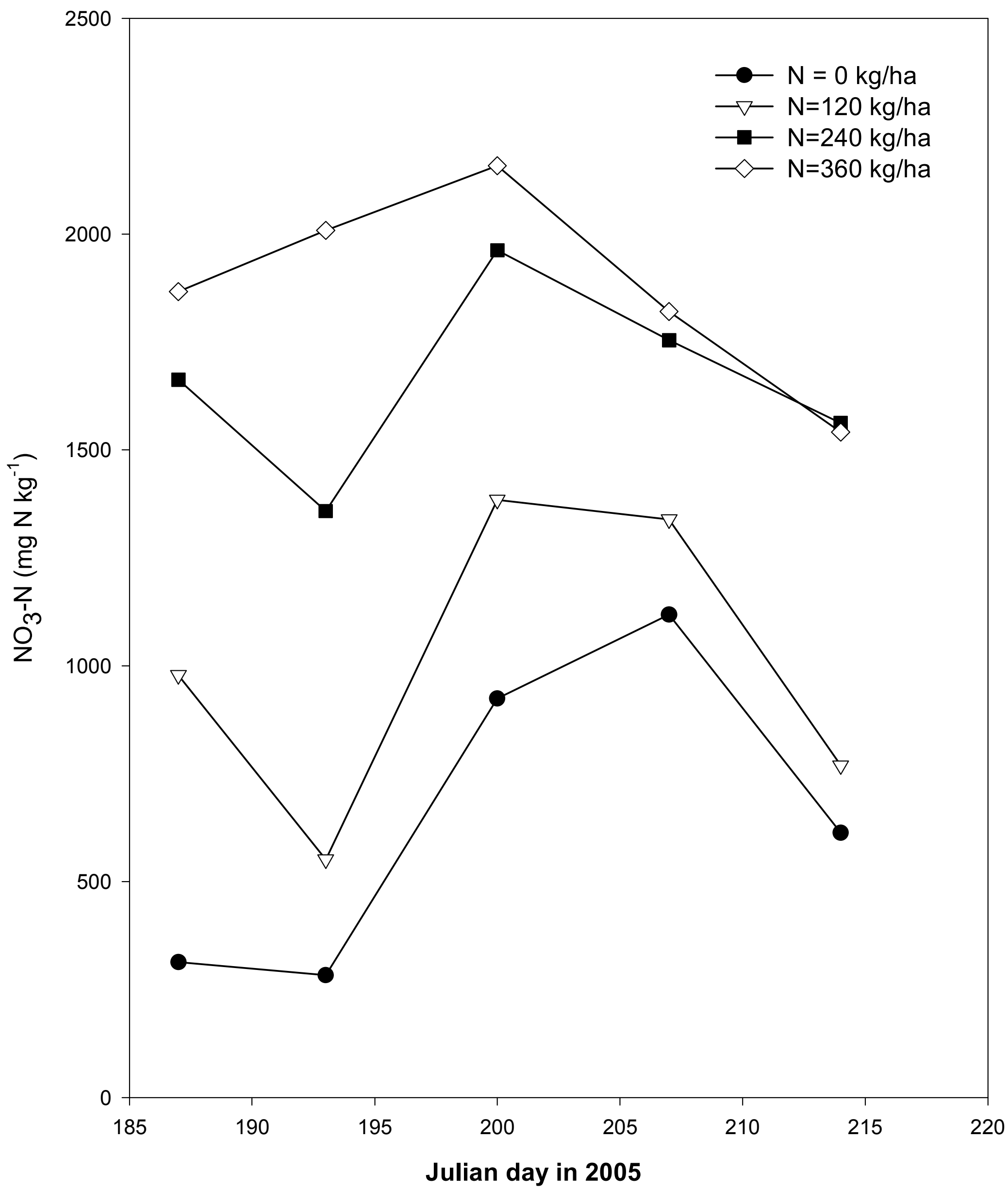

Fig. 24. Leaf petiole sap NO_3-N concentration across various fertilizer phosphorus treatments as influenced by fertilizer nitrogen rate in a sandy loam soil, Harrow, ON, 2005

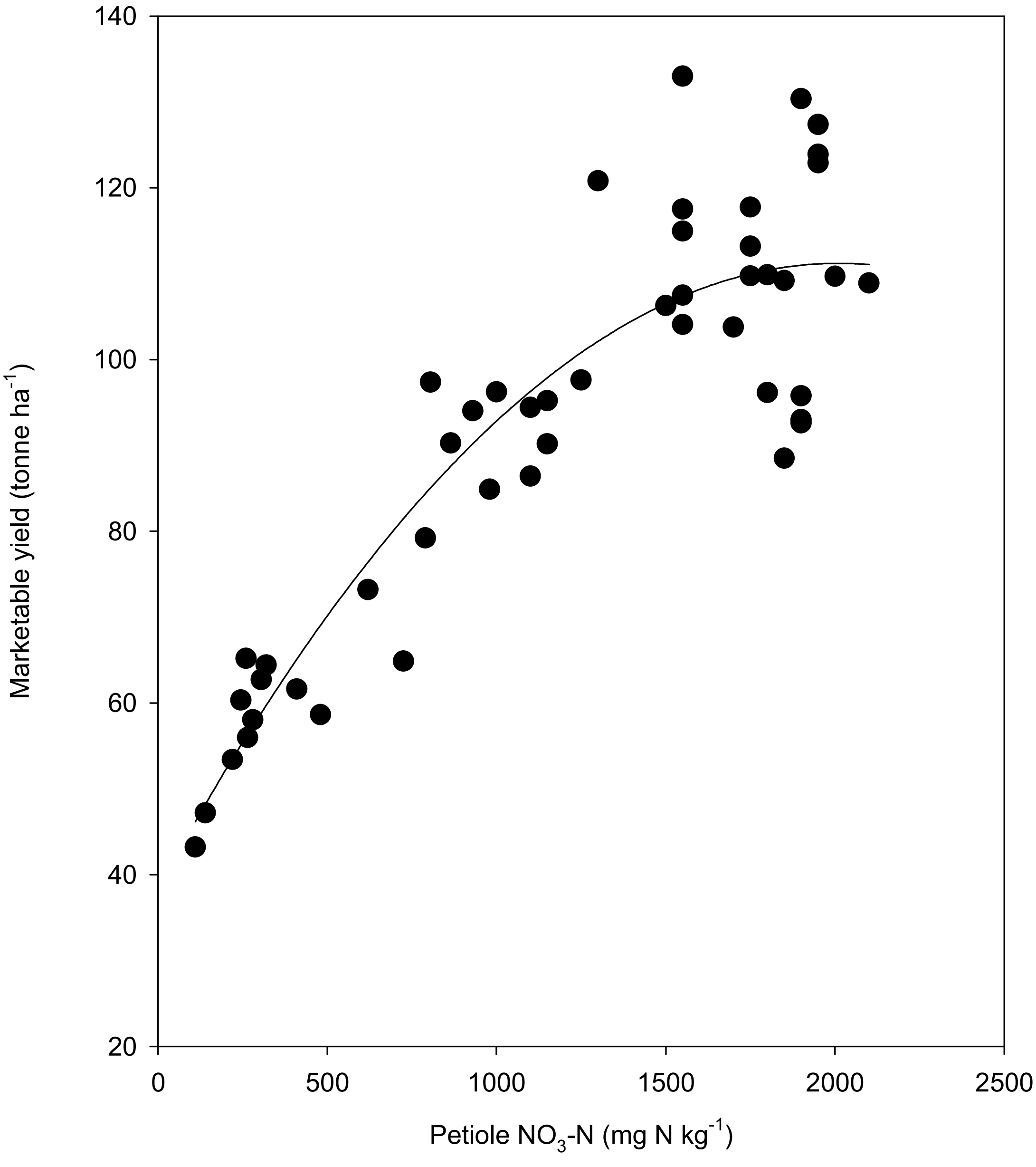

Fig. 25. Relationships between marketable yield of processing tomato and petiole NO_3-N concentration sampled on July 06, Harrow, ON, 2005

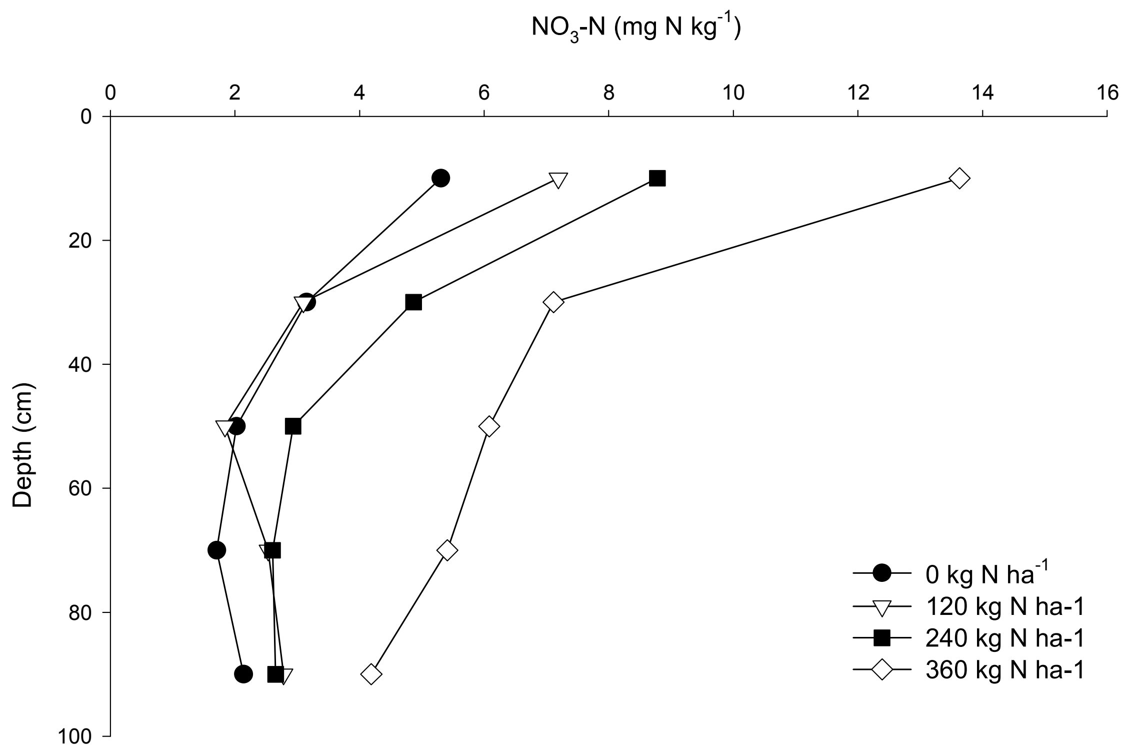

Fig. 26. Post-harvest soil profile (0-100 cm) NO_3-N as influenced by fertilizer N rate under processing tomatoes with drip fertigation in a sandy loam soil, Harrow, ON, 2005