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 2004)

Project Leader: **T.Q. Zhang (Soil Fertility & Water Quality)**

Collaborators: **C.S. Tan (Water Management), J. Warner (Field Vegetable), C.F. Drury (Soil Biochemistry), D. Reynolds (Soil Physics), A. Hamill (Weed Management)**

Technical Support: **B. Hohner, M. Reeb, K. Rinas, N. DiMenna, and T. Oloya**

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Greenhouse and Processing Crops Research Centre
Agriculture and Agri-Food Canada, Harrow, Ontario N0R 1G0
zhangt@agr.gc.ca

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

T.Q. Zhang, C.S. Tan, J. Warner, C.F. Drury, W. Reynolds, & A. Hamill
Agriculture & Agri-Food Canada, Harrow, ON, N0R 1G0

Interpretative Summary (2004)

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 ton 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 2004 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 44.8 ton ha^{-1} with added fertilizer nitrogen at 277 kg N ha^{-1}, which was about 4 times as much as the rate recommended by the OMAF publication 363. Green peppers require an increased nitrogen supply under drip fertigation.

Fruit nitrogen removal ranged from 17 to 71 kg N ha^{-1}. Total above-ground nitrogen uptake ranged from 24 to 103 kg N ha^{-1}. Both nitrogen removal and total uptake were linearly related to fertilizer nitrogen rate.

Amount of nitrogen required to produce each ton of marketable yield varied from 0.3 to 6.2 kg N ton^{-1}, depending on the level of target yield. The values are comparable with those (0.4 to 6.7 kg N ton^{-1})

obtained in 2003, but are higher than what obtained in 2002 (0.2 to 3.1 kg N ton^{-1}).

Total above-ground phosphorus uptake ranged from 6.4 to 20 kg P ha^{-1} (14.7 to 45.8 kg P_2O_5 ha^{-1}), with fruit phosphorus removal ranged from 4.1 to 13.6 kg P ha^{-1}. Phosphorus removal was linearly related to fertilizer nitrogen rate, while total phosphorus uptake was linearly related to fertilizer rates of nitrogen and phosphorus, respectively.

Total potassium uptake increased linearly with fertilizer nitrogen rate, and ranged from 50 to 160 kg K ha^{-1}.

Soil profile NO_3-N after harvest increased with increases in fertilizer nitrogen rate, with the majority of residual fertilizer nitrogen found in the top (0-20 cm) and non-root zone (40-100cm) soil layers. The results reflect significantly the effects of continuous fertigation and crop uptake.

Processing tomatoes: Both total and marketable yields responded quadratically to nitrogen application. A maximum marketable yield of 140 ton ha^{-1} was produced with 292 kg N ha^{-1} fertilizer nitrogen applied. Processing tomatoes under fertigation requires much more nitrogen supply (140-224% more in 2004) than the current recommendation to develop the maximum yield potential and to obtain the maximum profits.

Fruit nitrogen removal was related quadratically to fertilizer nitrogen rate, and ranged from 67 to 234 kg N ha^{-1}. The above-ground total nitrogen uptake reacted quadratically to added fertilizer nitrogen, and ranged from 82 to 293 kg N ha^{-1}.

The amount of fertilizer nitrogen required for each tonne of marketable yield production varied depending on the level of target yield. Calculated values of fertilizer nitrogen required for each tonne of marketable yield production ranged from 0.1 to 2.1 kg N ton^{-1}. The values are higher than those obtained in 2003 that ranged from 0.07 to 1.7 kg N ton^{-1}, presumably due to the variation in weather conditions.

Fruit phosphorus removal ranged from 19 to 36 kg P ha^{-1} (43.5 to 82.4 kg P_2O_5 ha^{-1}), and was affected interactively by the application of fertilizer nitrogen and phosphorus. Responses of fruit phosphorus removals to nitrogen were similar when phosphorus was added at rates below 100 kg P_2O_5 ha^{-1}. Increased phosphorus rate up to 200 kg P_2O_5 ha^{-1} increased phosphorous removals, especially when nitrogen was applied at rates above 100 kg N ha^{-1}.

Total phosphorus uptake ranged from 26 to 41 kg P ha^{-1} (60 to 94 kg P_2O_5 ha^{-1}), and responded quadratically to nitrogen rate. The maximum phosphorus uptake occurred with nitrogen applied at 245 kg N ha^{-1}. Increased phosphorus application enhanced total phosphorus uptake.

Total potassium uptake ranging from 218 to 459 kg K ha^{-1} (262 to 551 kg K_2O ha^{-1}) was also interactively related to nitrogen and phosphorus addition. Optimum combination of nitrogen and phosphorus maximized the total potassium uptake.

Relationships between petiole NO_3-N concentration and marketable yield were the highest at the full blooming stage, and declined substantially afterwards. Levels of petiole NO_3-N at the full blooming stage accounted for over 80% of the variation in yield. High levels of petiole NO_3-N at later stages reduced marketable yield. Nitrogen fertilization should be performed right before full blooming, and later application should be restricted. However, the threshold vale of petiole NO_3-N at the full blooming stage was not obtainable in 2004, because of the linear relationship between petiole NO_3-N content and the marketable yield. The threshold vale of petiole NO_3-N at the full blooming stage was 1934 mg N kg^{-1} in 2003.

Post-harvest soil profile NO_3-N contents increased with fertilizer nitrogen rate. While majority of the soil residual nitrogen remained in the depth of 0-20 cm, NO_3-N leaching was noticed with fertilizer nitrogen added at high rates. However, low contents of soil residual NO_3-N indicate that the potential impact on water quality during the non-growing season can be neglectable.

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 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. This may further increase the gap between the actual optimum fertilizer rate required to produce the maximum economic yield and the rate regulated in Ontario's NMAN nutrient management software.

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 2004 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 2004

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 were conducted in a Granby sandy loam soil at GPCRC, Harrow, ON. 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 and cull, and weights recorded. Total 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. 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. 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 ton 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:

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 neither total nor marketable yield.

Similar to 2003, total yield of green peppers across all rates of fertilizer phosphorus in 2004 increased quadratically with fertilizer nitrogen rate (Fig. 1). The maximum total yield of 49.8 ton ha^{-1} was obtained with fertilizer nitrogen applied at 300.8 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 44.8 ton ha^{-1} with added fertilizer N at 277 kg N ha^{-1}, which was about 4 times as much as the rate recommended by the OMAF publication 363. The results are similar to what was obtained in 2003 in which 200.7 kg N ha^{-1} fertilizer nitrogen was required to maximize the marketable yield of 30.2 ton ha^{-1}. Green peppers require an increased nitrogen supply under drip fertigation.

Nutrient (nitrogen and phosphorus) uptake and removal:
Stover nitrogen and phosphorus uptake: Stover uptake of nitrogen and phosphorus was related to both applications of fertilizer nitrogen and phosphorus (Table 1). Interactions between nitrogen and phosphorus were also found on stover uptake of both nitrogen and phosphorus.

Stover nitrogen uptake ranged from 6.4 to 37.7 kg N ha^{-1}, and increased quadratically with fertilizer nitrogen rate added (Fig. 3). The increases of nitrogen uptake with increased fertilizer nitrogen rate were further enhanced with increased phosphorus rate.

Stover phosphorous uptake ranged from 2.1 to 7.4 kg P ha^{-1}, and increased linearly with increases in fertilizer nitrogen when phosphorus was added at rates below 100 kg P_2O_5 ha^{-1}, but quadratically when phosphorus was added at 200 kg P_2O_5 ha^{-1} (Fig. 4). Clearly, high fertilizer nitrogen in combination with high phosphorus enhanced stover phosphorus uptake.

The increases of stover nitrogen and phosphorus uptake with increases in fertilizer nitrogen and phosphorus rates can be explained primarily by the increases in stover biomass production (Fig. 5). All the stover remains in the soil after harvest, which can contribute significant amount of available nitrogen and phosphorus to the next crop through mineralization.

Fruit nitrogen and phosphorus removal: Although a quadratic curveship was found between green pepper yield and fertilizer nitrogen rate, nitrogen removal by fruit harvest responded linearly to fertilizer nitrogen rate (Fig. 6), due to the linear increase of nitrogen concentration in fruits with increased fertilizer nitrogen rate (Fig. 7). The fruit nitrogen removal ranged from 17 to 71 kg N ha^{-1}.

Similar to nitrogen, fruit phosphorus removal was also linearly related to fertilizer rates of nitrogen and phosphorus, respectively (Figs. 8 &9). Fruit phosphorous removal ranged from 4.1 to 13.6 kg P ha^{-1}.

Total nitrogen and phosphorus uptake and amount of nitrogen required for each ton production of green peppers: In summary of stover and fruit nitrogen uptake, the total above-ground uptake reacted linearly to added fertilizer nitrogen (Fig. 10). Total nitrogen uptake ranged from 24 to 103 kg N ha^{-1}. Each kg addition of fertilizer nitrogen caused an increase of total uptake by 0.32 kg N ha^{-1}.

Amount of nitrogen required to produce each ton of marketable green pepper yield varied depending on the level of target yield (Fig. 11). Calculated values of fertilizer nitrogen required to produce each ton of marketable yield ranged from 0.3 to 6.2 kg N ton^{-1}. The values are comparable with those (0.4 to 6.7 kg N ton^{-1}) obtained in 2003, but are higher than what obtained in 2002 (0.2 to 3.1 kg N ton^{-1}).

Compared with year 2002, a largely increased precipitation during the growing season in 2003 and 2004 may have enhanced the leaching losses of fertilizer nitrogen in NO_3-N and thus resulted in a reduced fertilizer nitrogen use efficiency.

Total phosphorus uptake ranged from 6.4 to 20 kg P ha^{-1} and increased linearly with increases in fertilizer rates of nitrogen and phosphorus, respectively (Figs. 12 &13). Each kg addition of fertilizer nitrogen increased 0.054 kg P ha^{-1} total phosphorus uptake, while each kg (as P) addition of fertilizer phosphorus increased 0.022 kg P ha^{-1} total phosphorus uptake.

In addition, total potassium uptake increased linearly with fertilizer nitrogen rate, and ranged from 50 to 160 kg K ha^{-1} (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. The greatest fertilizer rate effect was observed in the soil depth below 60 cm, while the smallest fertilizer rate effect was found in the soil depth of 20 to 40 cm where cop roots were concentrated. The results indicate that significant leaching of soil NO_3-N occurred during the growing season, if not absorbed immediately by crops.

Processing tomatoes

Yields and quality:
Addition of fertilizer nitrogen affected significantly the yields of fruits (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.

Total yield of processing tomatoes across three fertilizer phosphorus rates was related quadratically to fertilizer nitrogen rate, with the maximum total yield of 157 ton ha^{-1} obtained with fertilizer nitrogen applied at 302 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 140 ton ha^{-1} was produced with 292 kg N ha^{-1} fertilizer nitrogen applied. Thus, an amount of 10 kg N ha^{-1} of excessive fertilizer nitrogen produced an additional of 17 ton 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 much more nitrogen supply, 140-224% more in 2004, to develop the maximum production potential and to obtain the maximum profits. 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 38% (122.8 vs. 88.8 ton ha^{-1}) higher than 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.

A quadratic curve-ship was also found between stover yield and fertilizer nitrogen rate (Fig. 18). An application of 295 kg N ha^{-1} fertilizer nitrogen resulted in the maximum stover biomass production. This was similar to what was required for maximum marketable yield (292 kg N ha^{-1}). It seems that the growth of vegetation and reproduction were highly coordinated with fertilizer nitrogen applied at this rate during the growing season.

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 0.1 to 2.1 kg N ton^{-1}. These values are higher than those obtained in 2003 that ranged from 0.07 to 1.7 kg N ton^{-1}, presumably due to the varied weather conditions.

Nutrient (N and P) removals and total uptake:

Fruit nitrogen removal was related quadratically to fertilizer nitrogen rate, and ranged from 67 to 234 kg N ha^{-1}(Fig. 20).

Fruit phosphorus removal ranged from 19 to 36 kg P ha^{-1} (43.5 to 82.4 kg P_2O_5 ha^{-1}), and was affected interactively by the application fertilizer nitrogen and phosphorus (Fig. 21). Fruit phosphorus removal responded quadratically to nitrogen rate at various phosphorus levels. Responses of fruit phosphorus removals to nitrogen were similar when phosphorus was added at rates below 100 kg P_2O_5 ha^{-1}. Increased phosphorus rate up to 200 kg P_2O_5 ha^{-1} increased phosphorous removals, especially when nitrogen was applied at rates above 100 kg N ha^{-1}.

It should be pointed out that the values of nutrient removals, especially phosphorus, by processing tomatoes are much higher even than field crops, such as grain corn.

In summary of stover and fruit uptake, the total nitrogen uptake reacted quadratically to added fertilizer nitrogen (Fig. 22). Total nitrogen uptake ranged from 82 to 293 kg N ha^{-1}. Total phosphorus uptake ranged from 26 to 41 kg P ha^{-1} (60 to 94 kg P_2O_5 ha^{-1}) and responded quadratically to nitrogen rate (Fig. 23). The maximum phosphorus uptake occurred with nitrogen applied at 245 kg N ha^{-1}. However, total phosphorus uptake was almost exponentially related to added fertilizer phosphorus (Fig. 24). Increased phosphorus application enhanced total phosphorus uptake.

In addition, total potassium uptake ranging from 218 to 459 kg K ha^{-1} (262 to 551 kg K_2O ha^{-1}) was also interactively related to nitrogen and phosphorus addition (Fig. 25). Optimum combination of nitrogen and phosphorus maximized the total potassium uptake by processing tomatoes.

Petiole (SAP) NO_3-N:

The petiole NO_3-N concentrations across various phosphorus treatments increased in the early season, with the maximum reached at about fruit set stage, after which they declined gradually in the late season (Fig. 26). 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.

Relationships between petiole NO_3-N concentration and marketable yield were the highest at the full blooming stage (middle July in 2004) and declined substantially afterwards (Fig. 27). Having partitioned the contributions of petiole NO_3-N to marketable yield, levels of petiole NO_3-N at the full blooming stage accounted for over 80% of the variation in marketable yield. High levels of petiole NO_3-N at later stages reduced marketable yield. The results clearly indicated that N fertilization should be performed right before full blooming, and later applications should be restricted. However, the threshold vale of petiole NO_3-N at the full blooming stage was not obtainable in 2004, because of the linear relationship between petiole NO_3-N content and the marketable yield (Fig. 28). The threshold vale of petiole NO_3-N at the full blooming stage in 2003 was 1934 mg N kg^{-1}.

On the other hand, the linear relationship between petiole NO_3-N content at the full blooming stage and the marketable yield in 2004 indicates the greater potential for yield increase with increases in nitrogen application.

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. 29). 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. However, the content of soil residual NO_3-N was generally low and thus the potential impact on water quality during the non-growing season can be neglectable.

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, 2004.

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

†, *, **; 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, 2004.

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

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

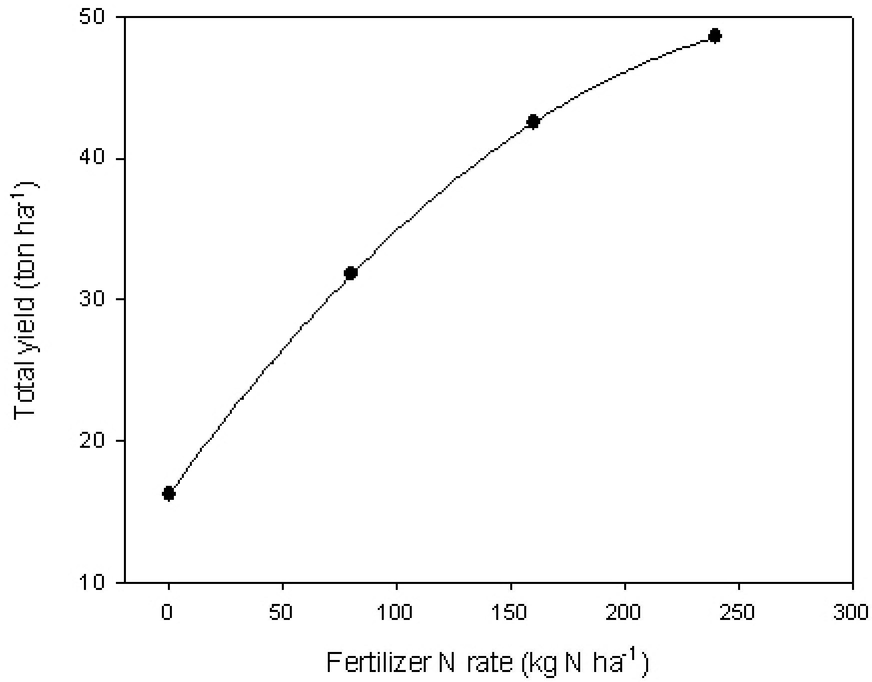

Fig. 1. Response of green pepper total yield to fertilizer nitrogen application with fertigation in a sandy loam soil, Harrow, ON, 2004.

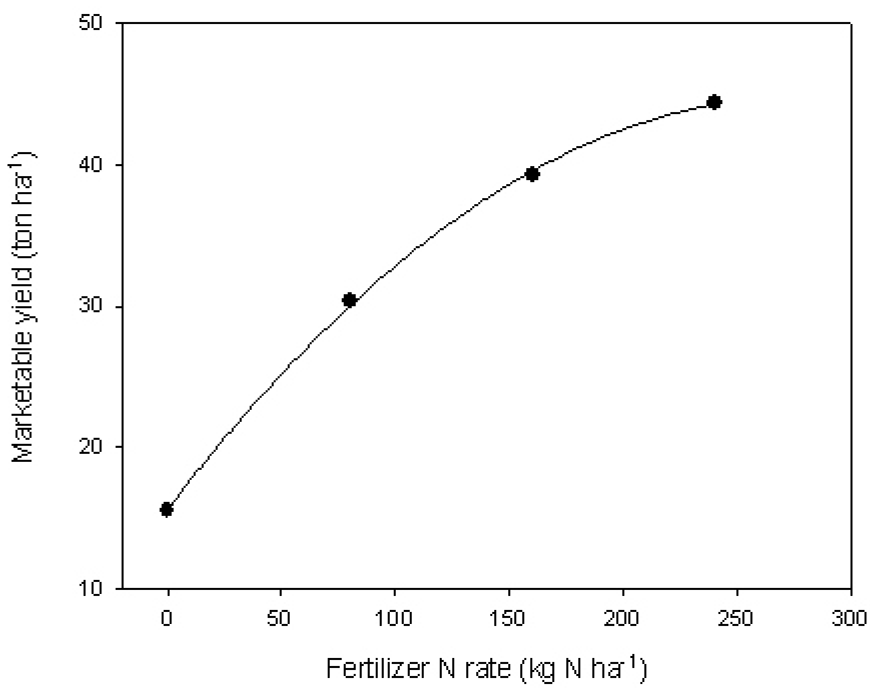

Fig. 2. Response of green pepper marketable yield to fertilizer nitrogen application with fertigation in a sandy loam soil, Harrow, ON, 2004.

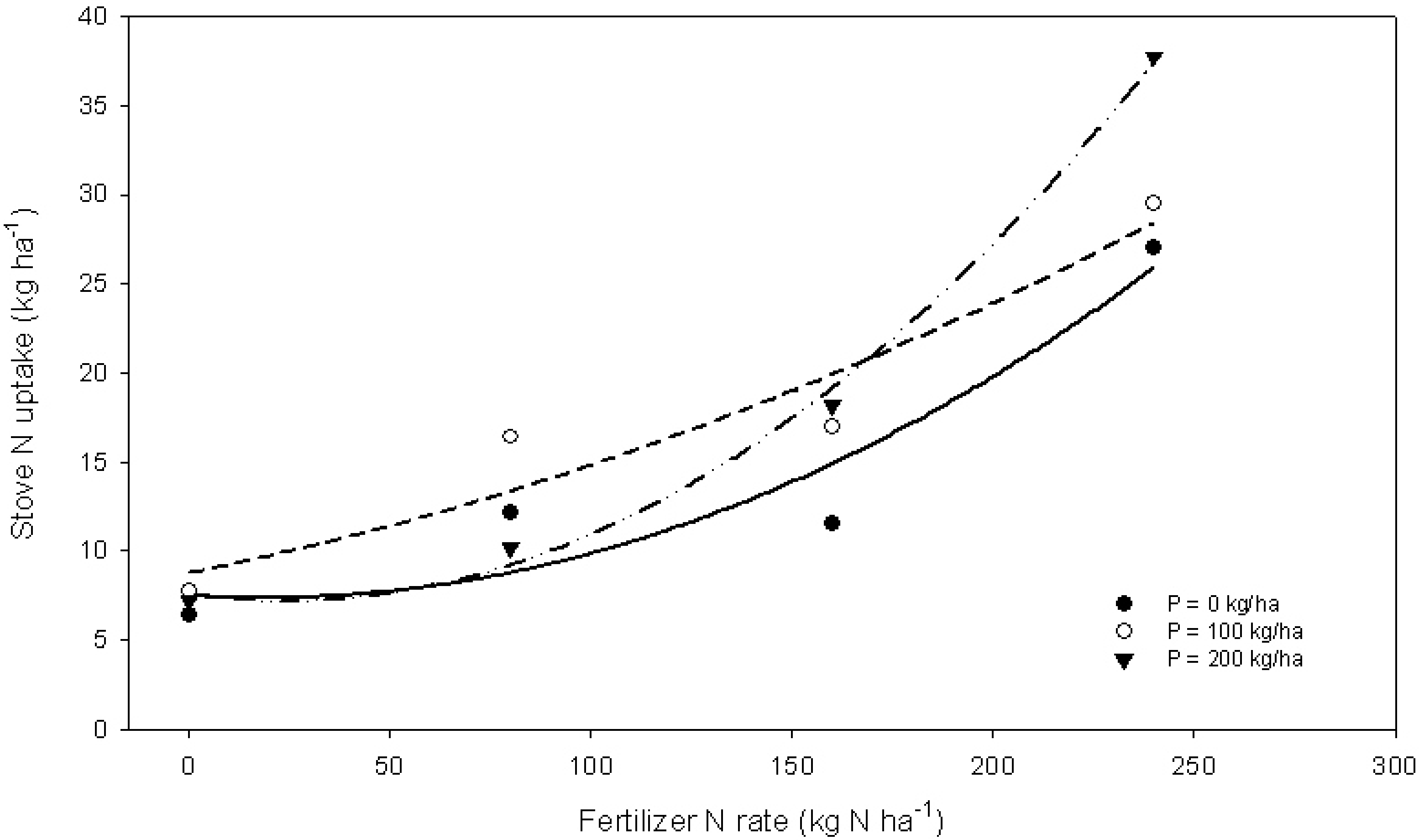

Fig. 3. Response of green pepper stover N uptake to fertilizer nitrogen at various phosphorus rates in a sandy loam soil, Harrow, ON, 2004.

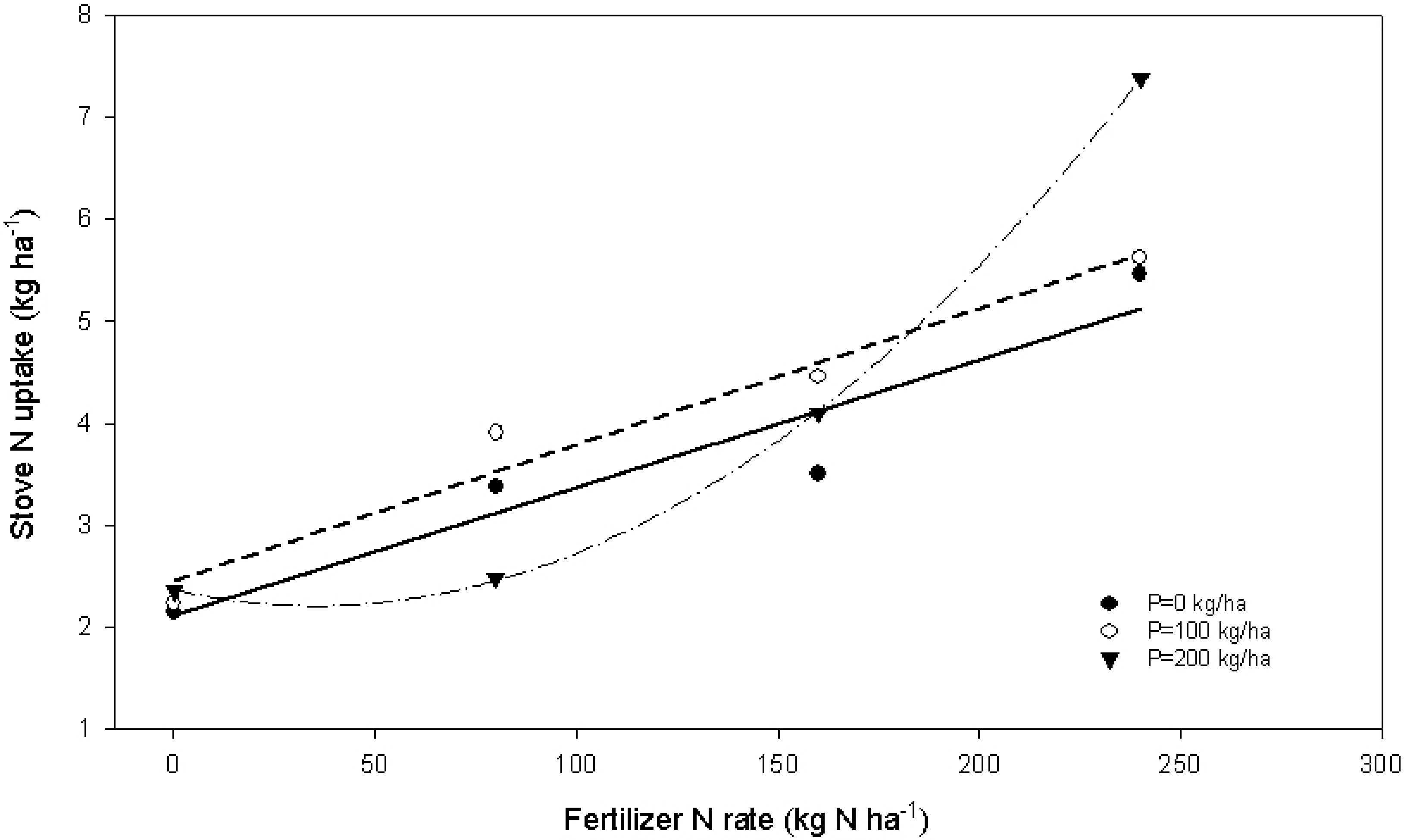

Fig. 4. Response of green pepper stover P uptake to fertilizer nitrogen at various phosphorus rates in a sandy loam soil, Harrow, ON, 2004.

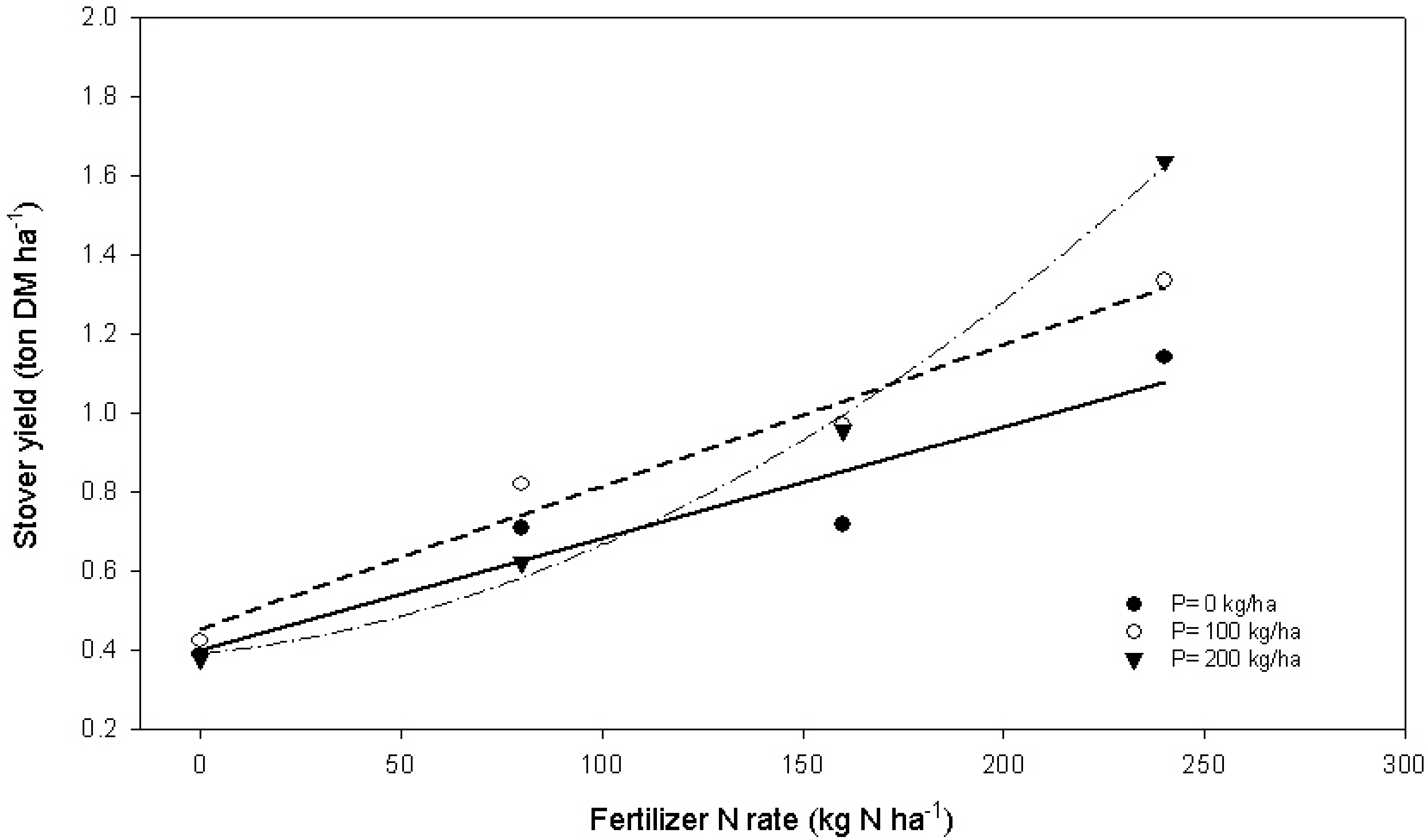

Fig. 5. Response of green pepper stover yield to fertilizer nitrogen at various phosphorus rates in a sandy loam soil, Harrow, ON, 2004.

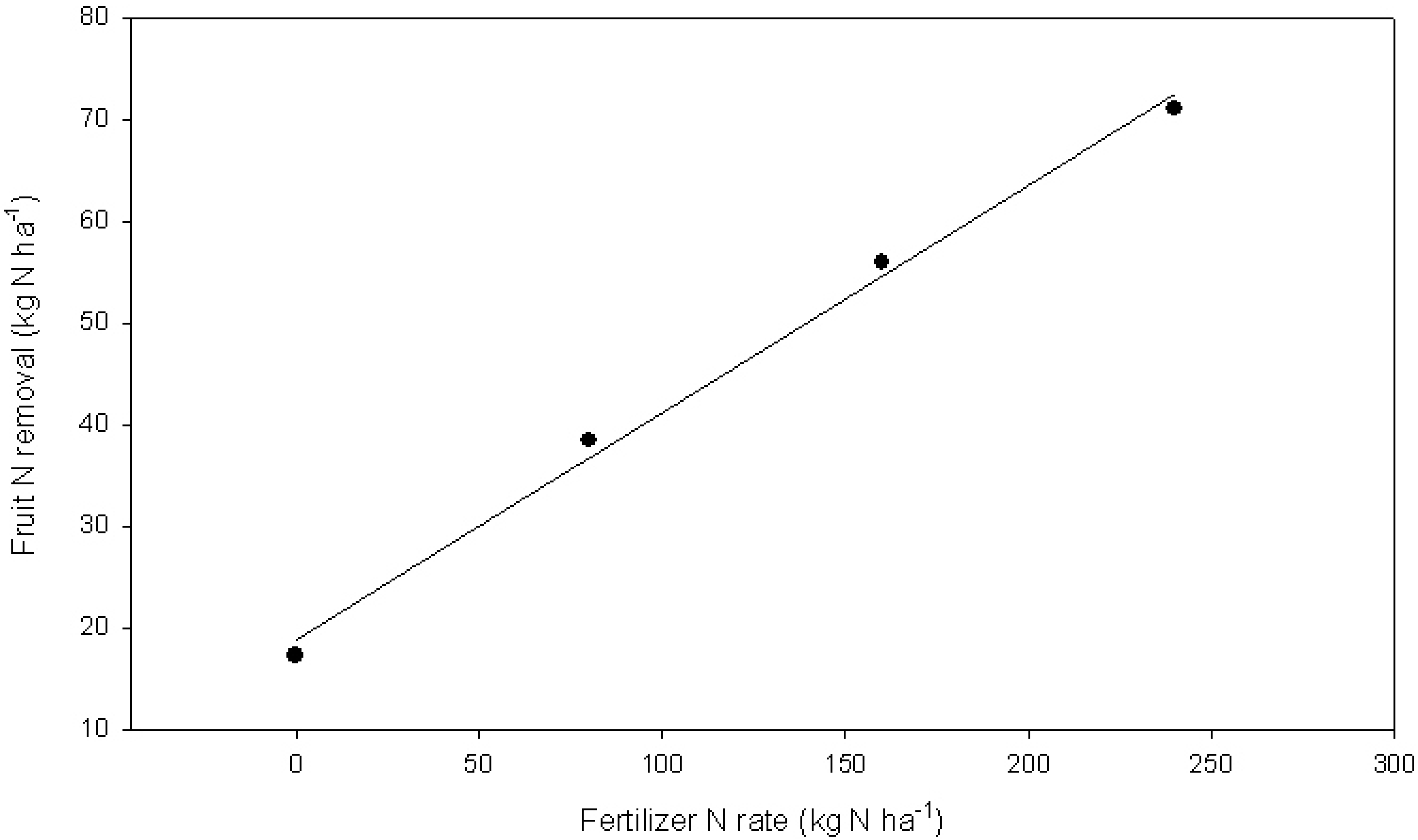

Fig. 6. Responses of green pepper fruit nitrogen removal to fertilizer nitrogen application in a sandy loam soil, Harrow, ON, 2004.

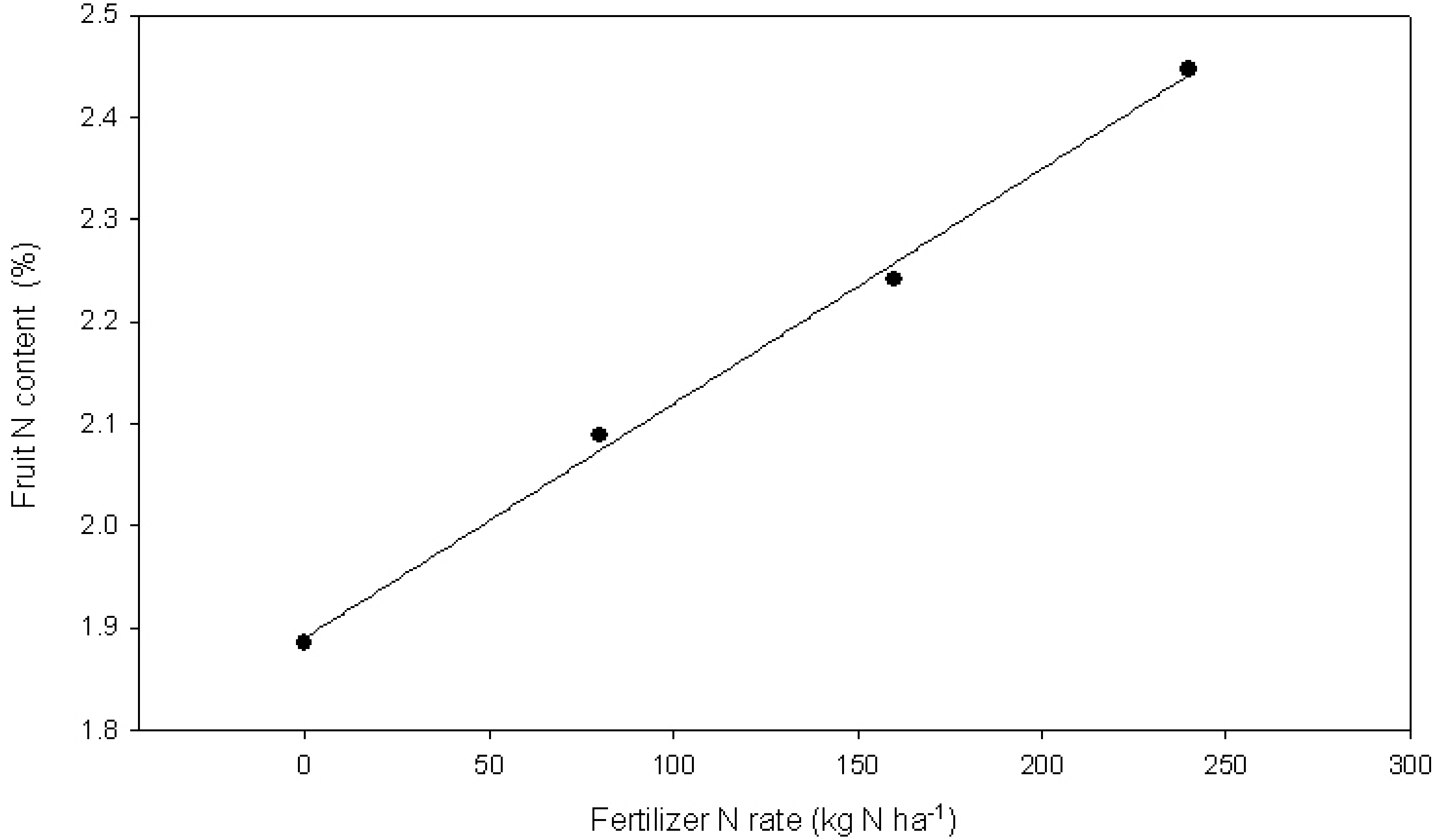

Fig. 7. Responses of green pepper fruit nitrogen content to fertilizer nitrogen application in a sandy loam soil, Harrow, ON, 2004.

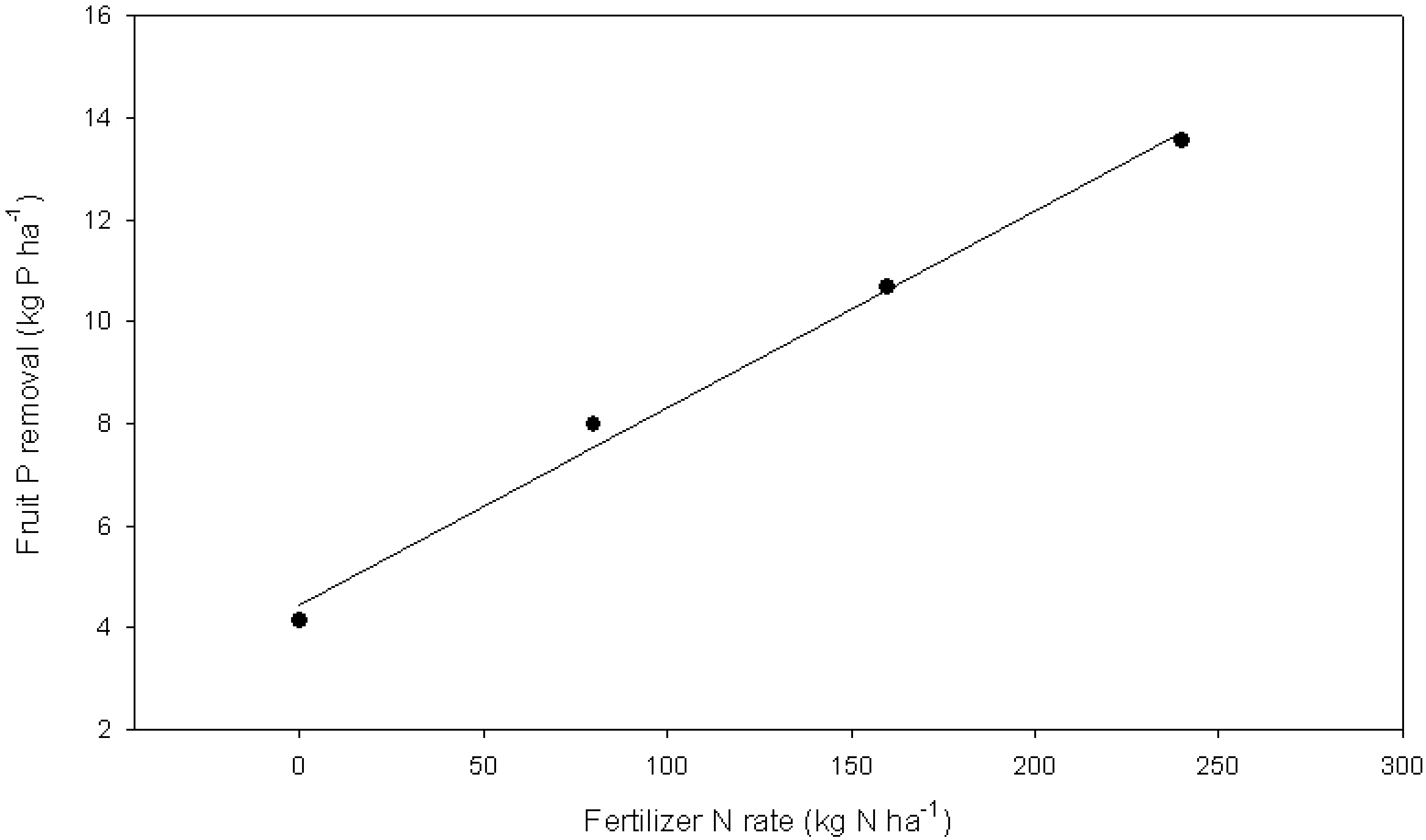

Fig. 8. Responses of green pepper fruit phosphorus removal to fertilizer nitrogen application in a sandy loam soil, Harrow, ON, 2004.

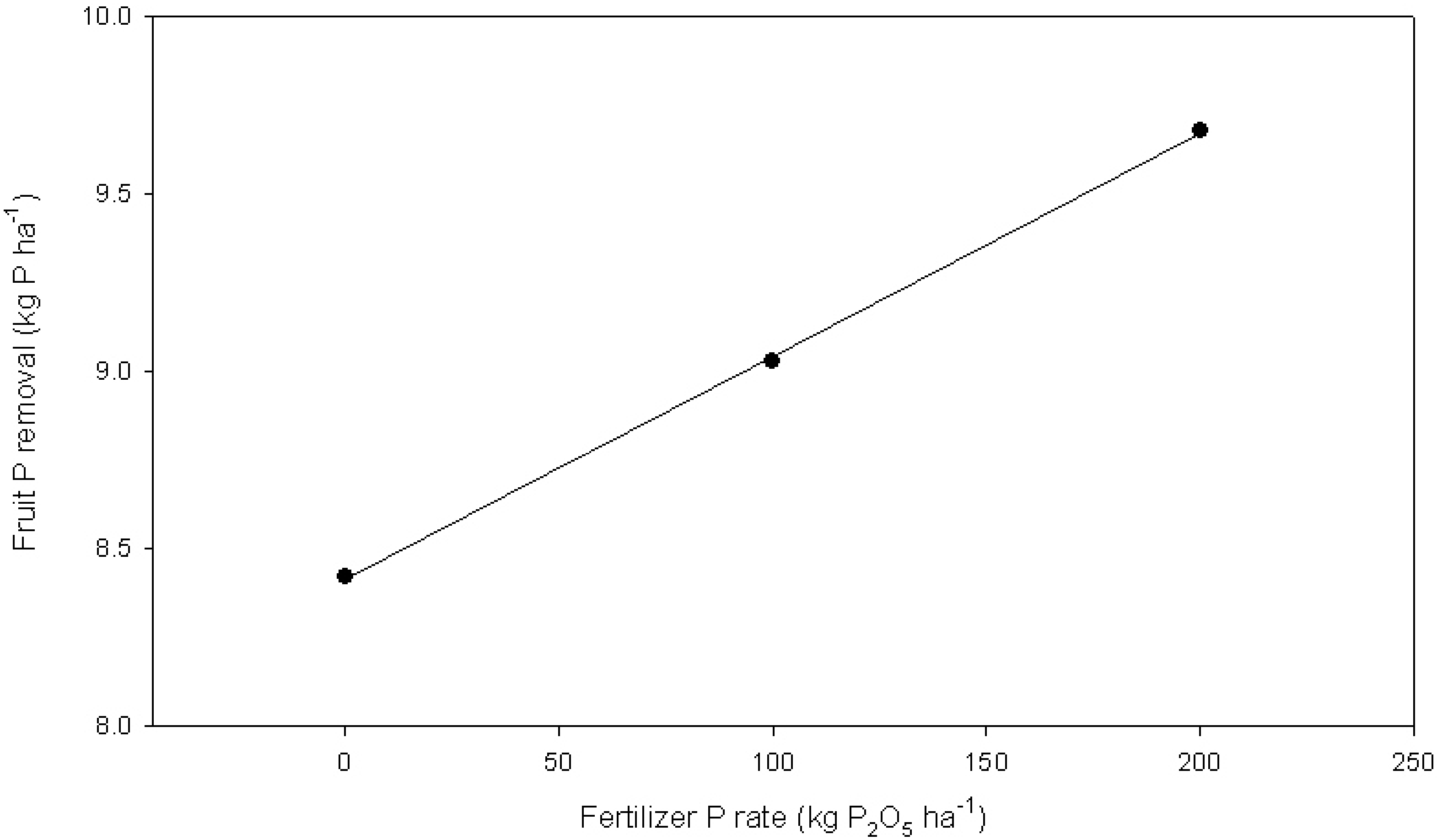

Fig. 9. Responses of green pepper fruit phosphorus removal to fertilizer phosphorus application in a sandy loam soil, Harrow, ON, 2004.

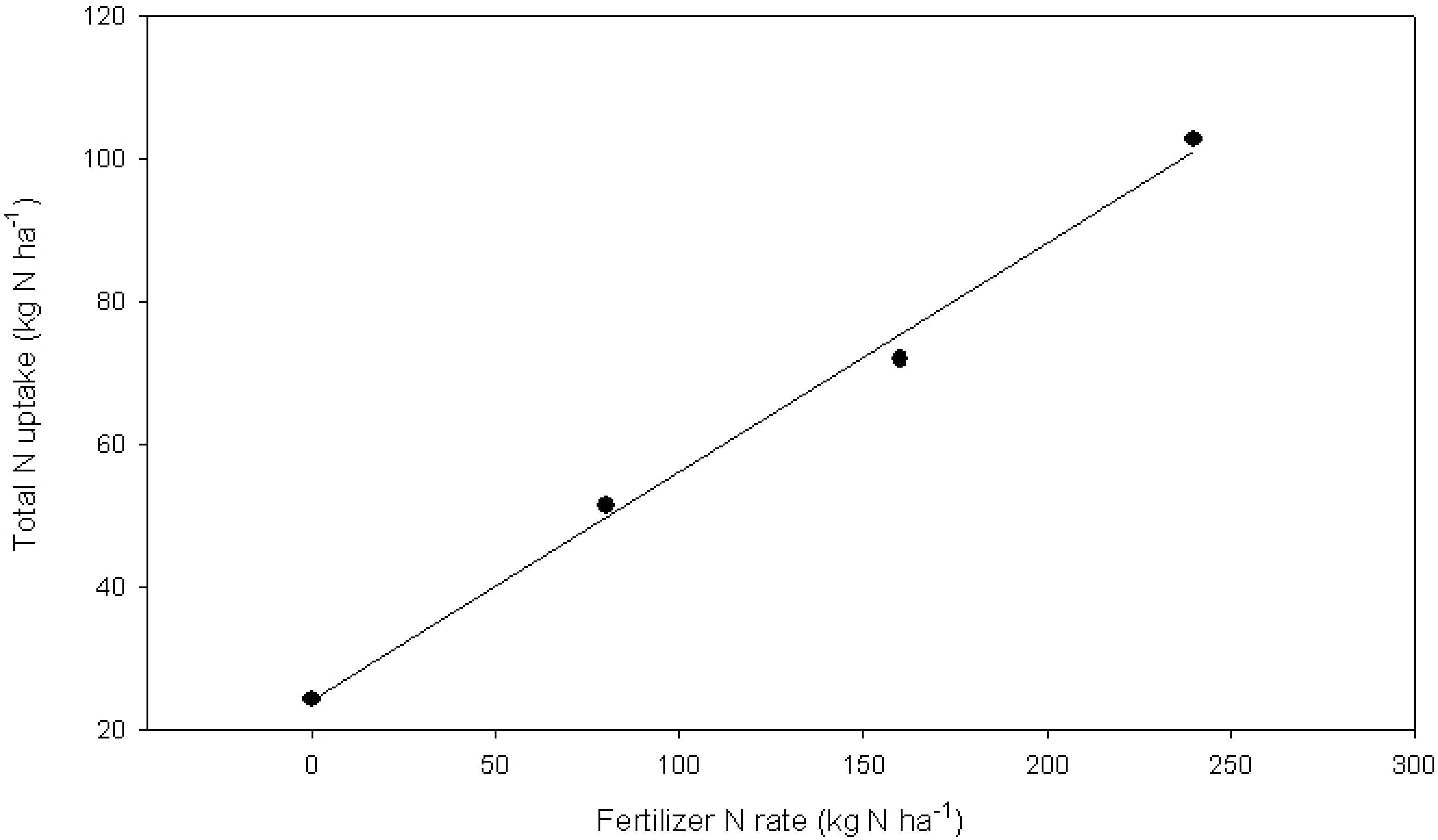

Fig. 10. Responses of green pepper total nitrogen uptake to fertilizer nitrogen application in a sandy loam soil, Harrow, ON, 2004.

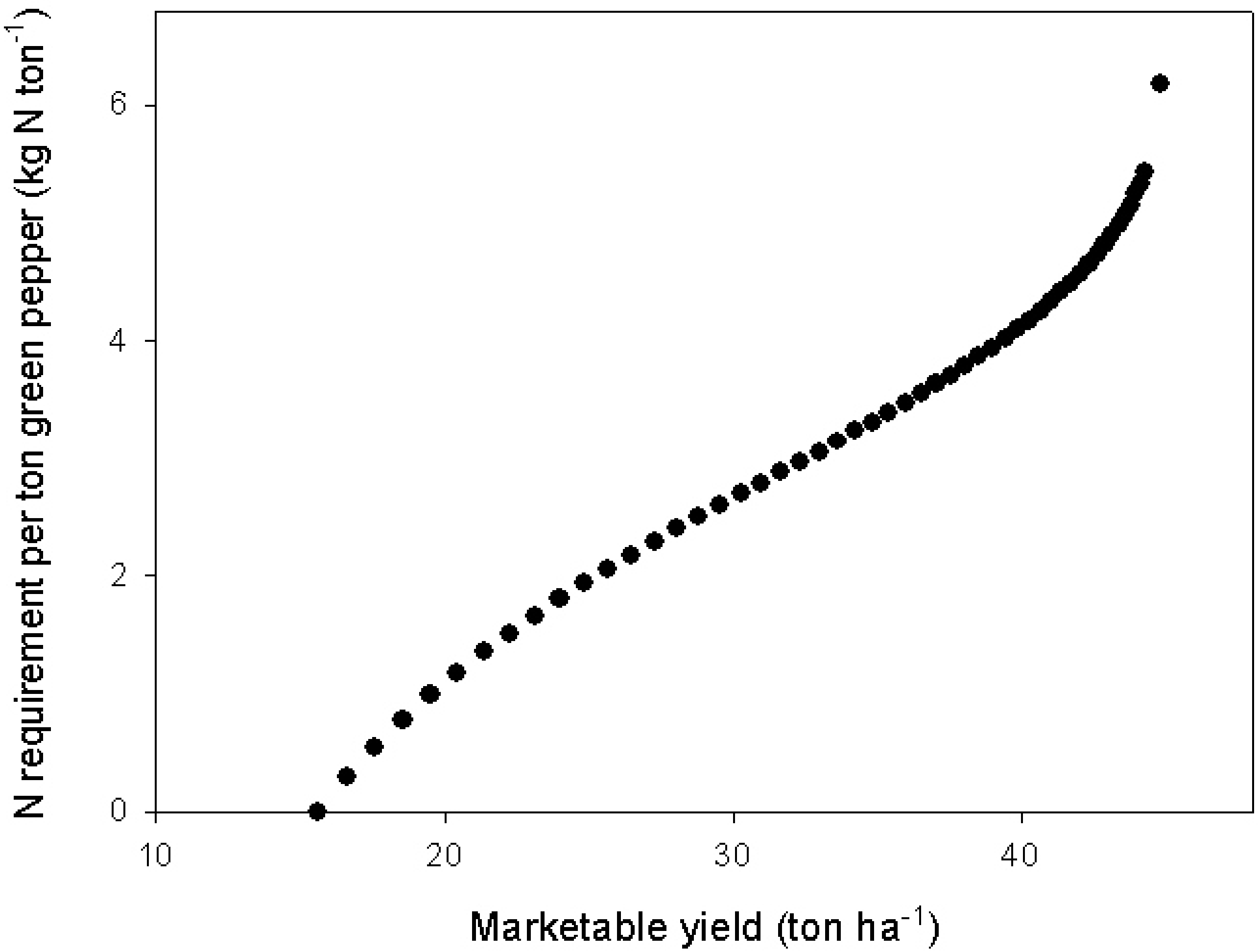

Fig. 11. Amount of nitrogen required to produce each ton of green peppers, a sandy loam soil, Harrow, ON, 2004.

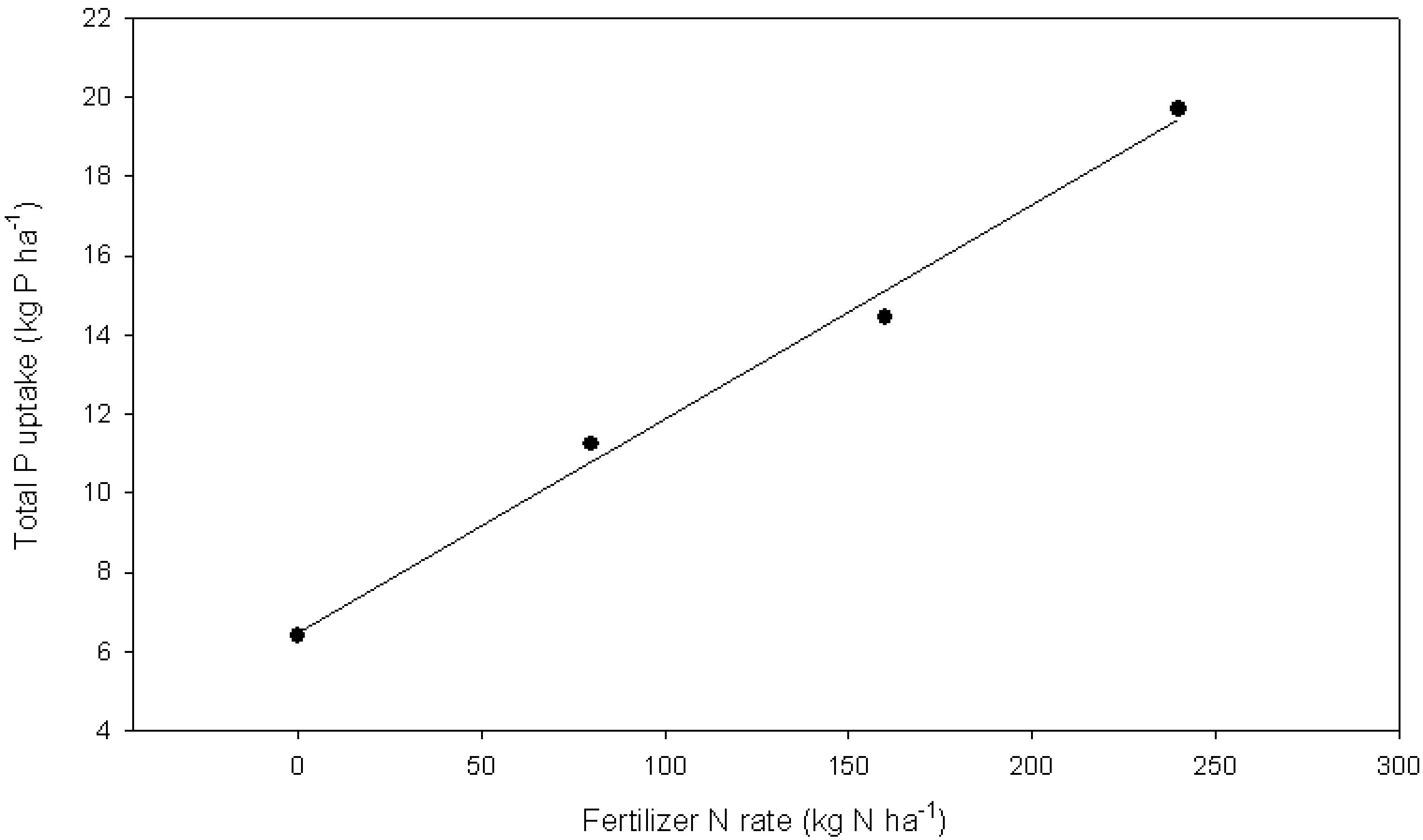

Fig. 12. Responses of green pepper total phosphorus uptake to fertilizer nitrogen application in a sandy loam soil, Harrow, ON, 2004.

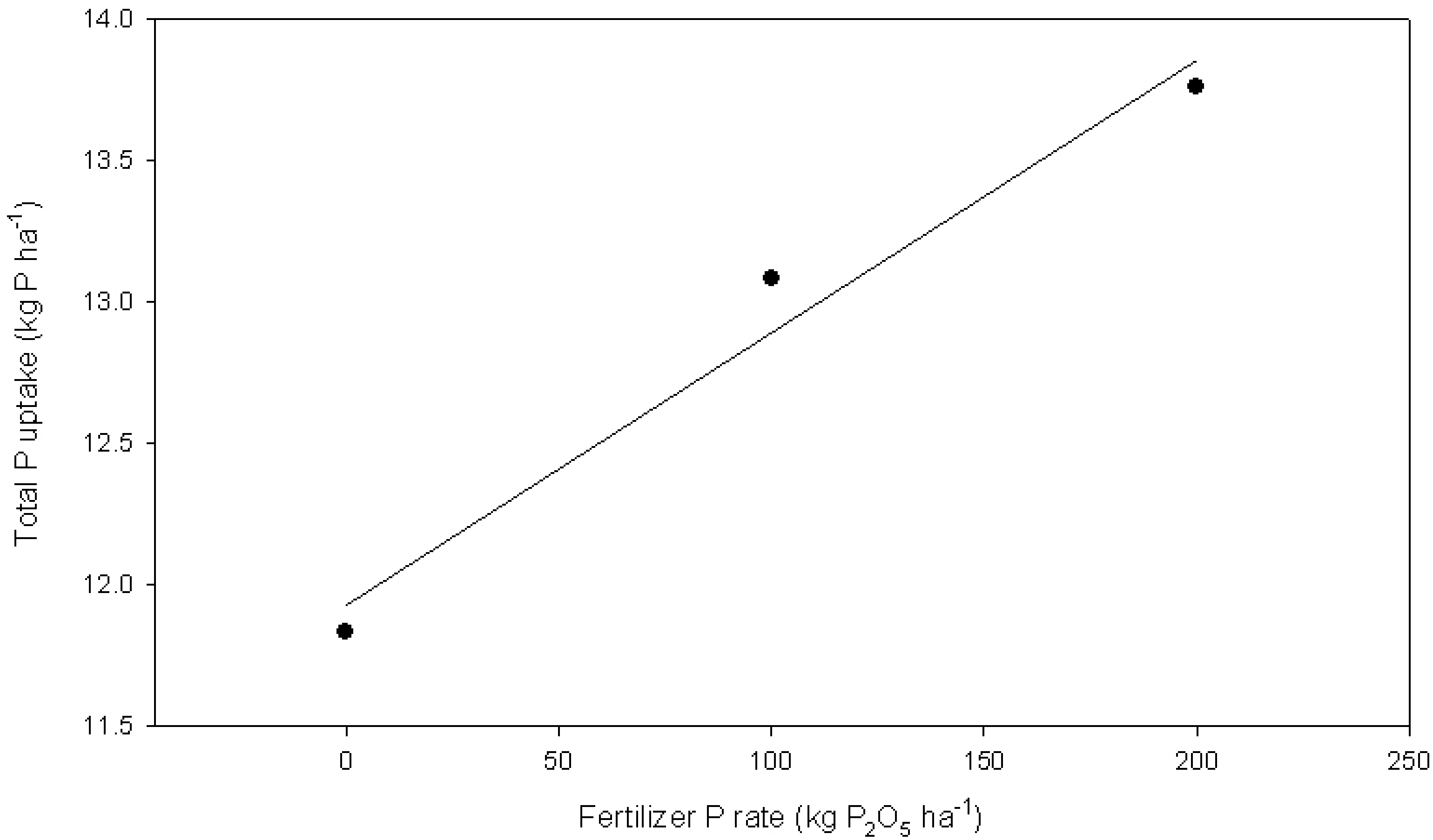

Fig. 13. Responses of green pepper total phosphorus uptake to fertilizer phosphorus application in a sandy loam soil, Harrow, ON, 2004.

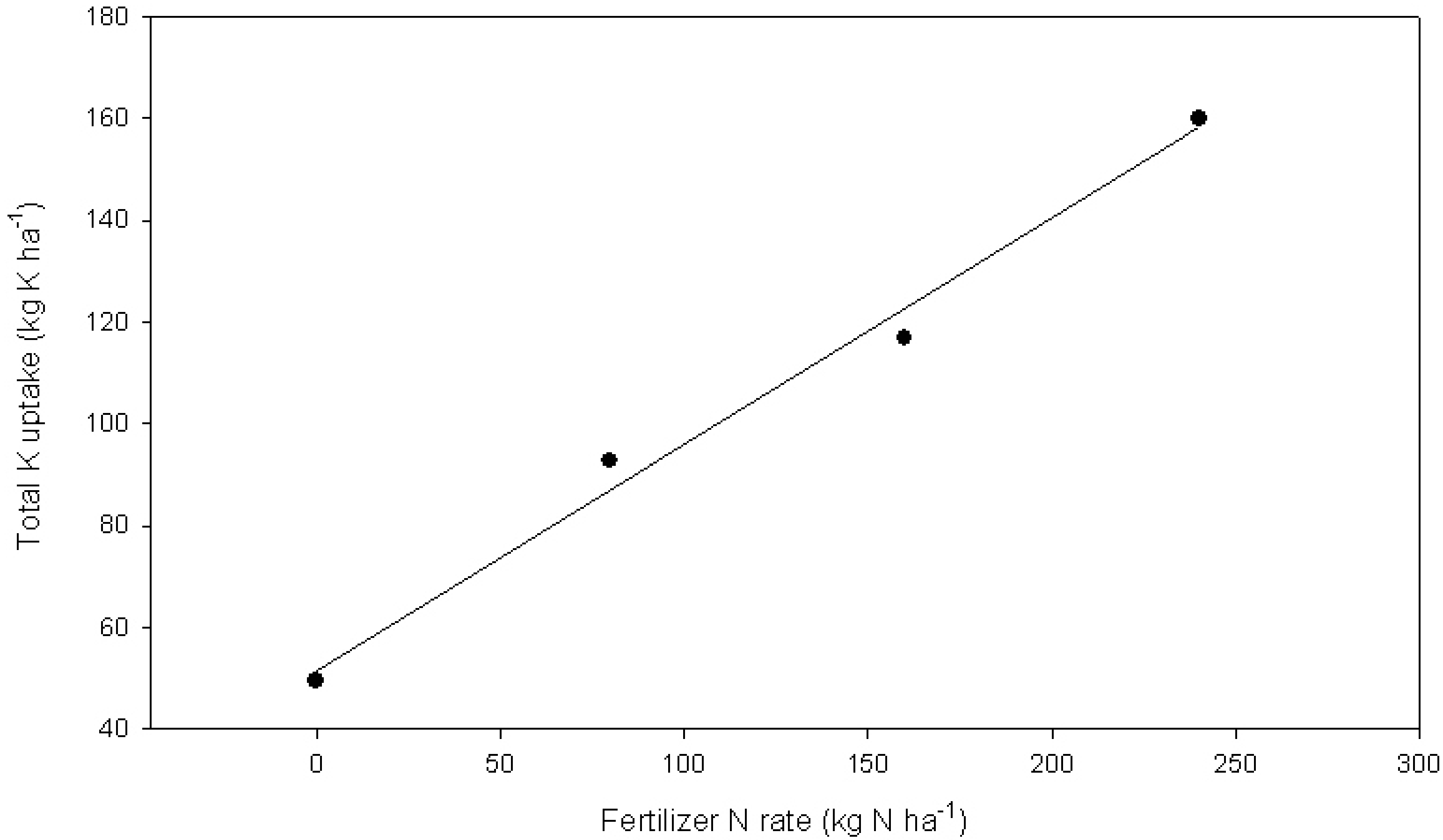

Fig. 14. Responses of green pepper total potassium uptake to fertilizer nitrogen application in a sandy loam soil, Harrow, ON, 2004.

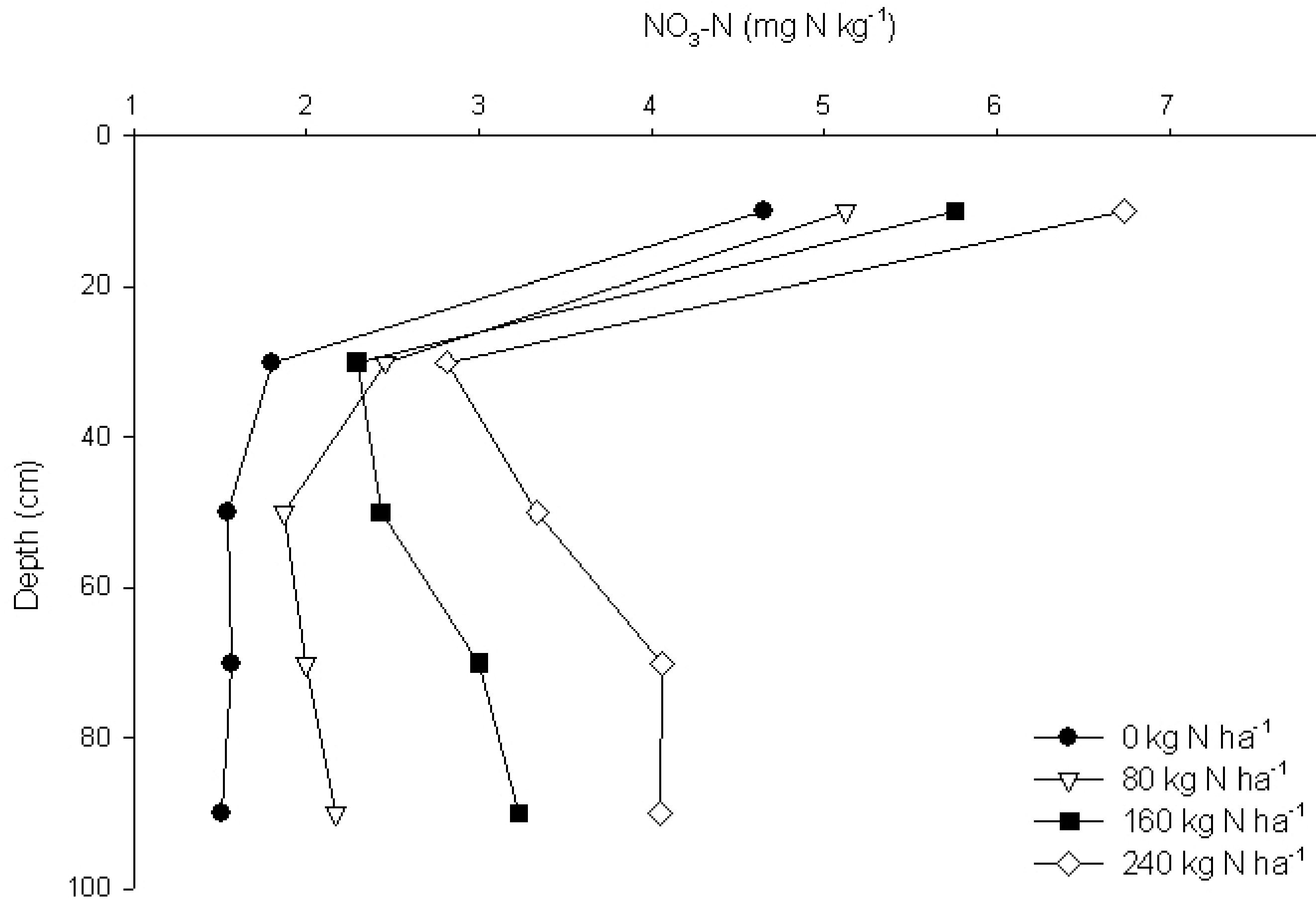

Fig. 15. Post-harvest soil profile (0-100 cm) NO_3-N as influenced by fertilizer N rate under green peppers with drip fertigation in a sandy loam soil, Harrow, ON, 2004

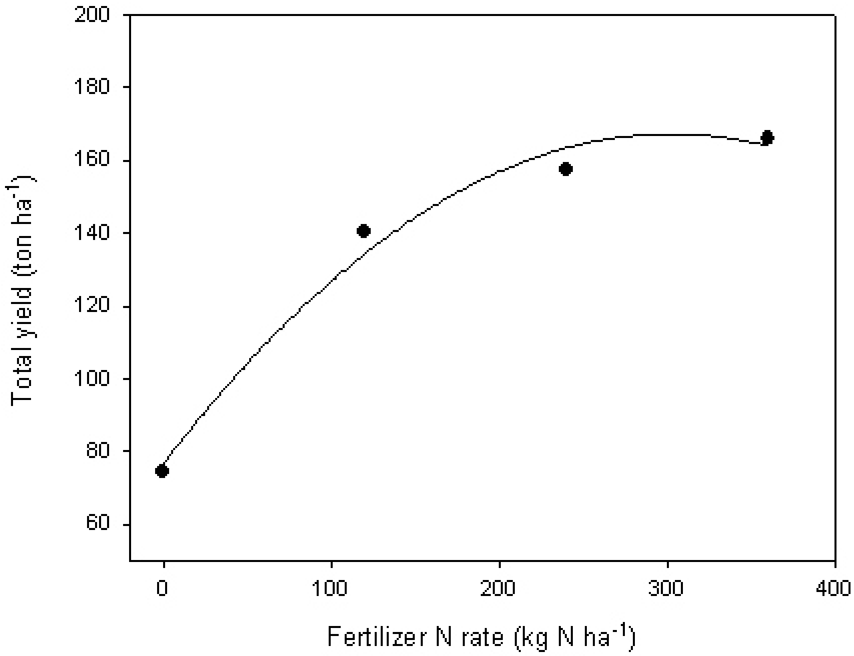

Fig. 16. Response of processing tomato total yield to fertilizer nitrogen application with fertigation in a sandy loam soil, Harrow, ON, 2004.

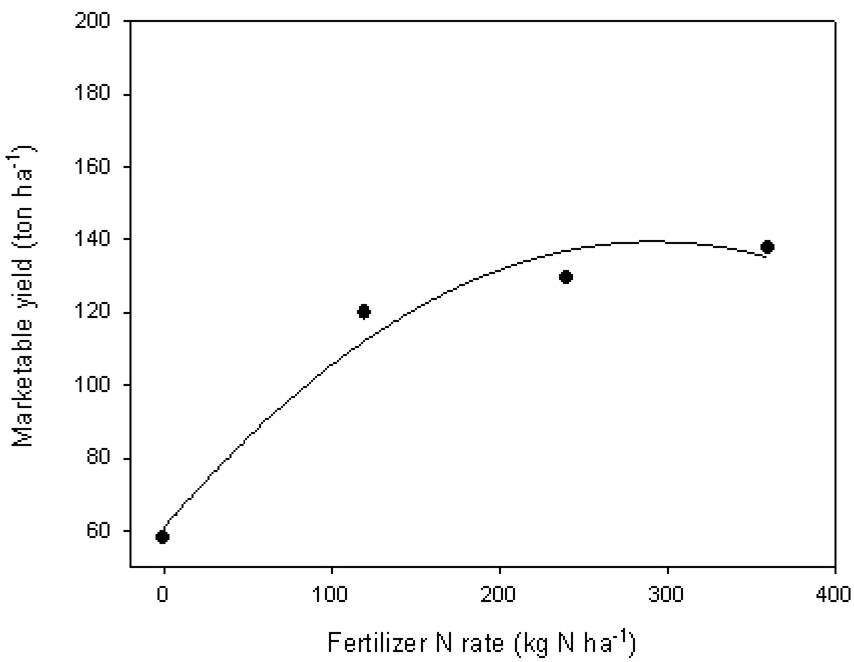

Fig. 17. Response of processing tomato marketable yield to fertilizer nitrogen application with fertigation in a sandy loam soil, Harrow, ON, 2004.

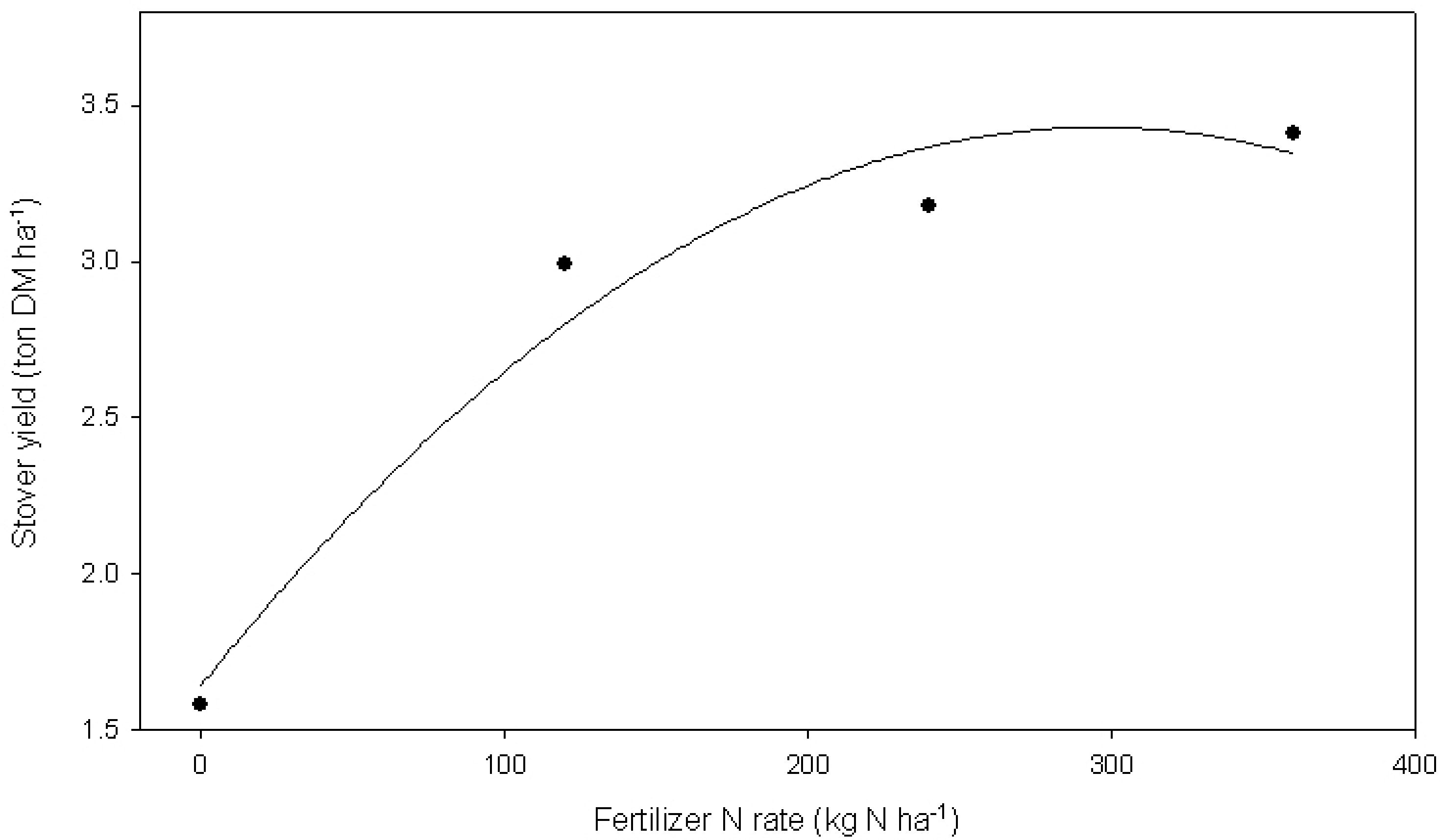

Fig. 18. Response of processing tomato stover yield (dry matter) to fertilizer nitrogen application with fertigation in a sandy loam soil, Harrow, ON, 2004.

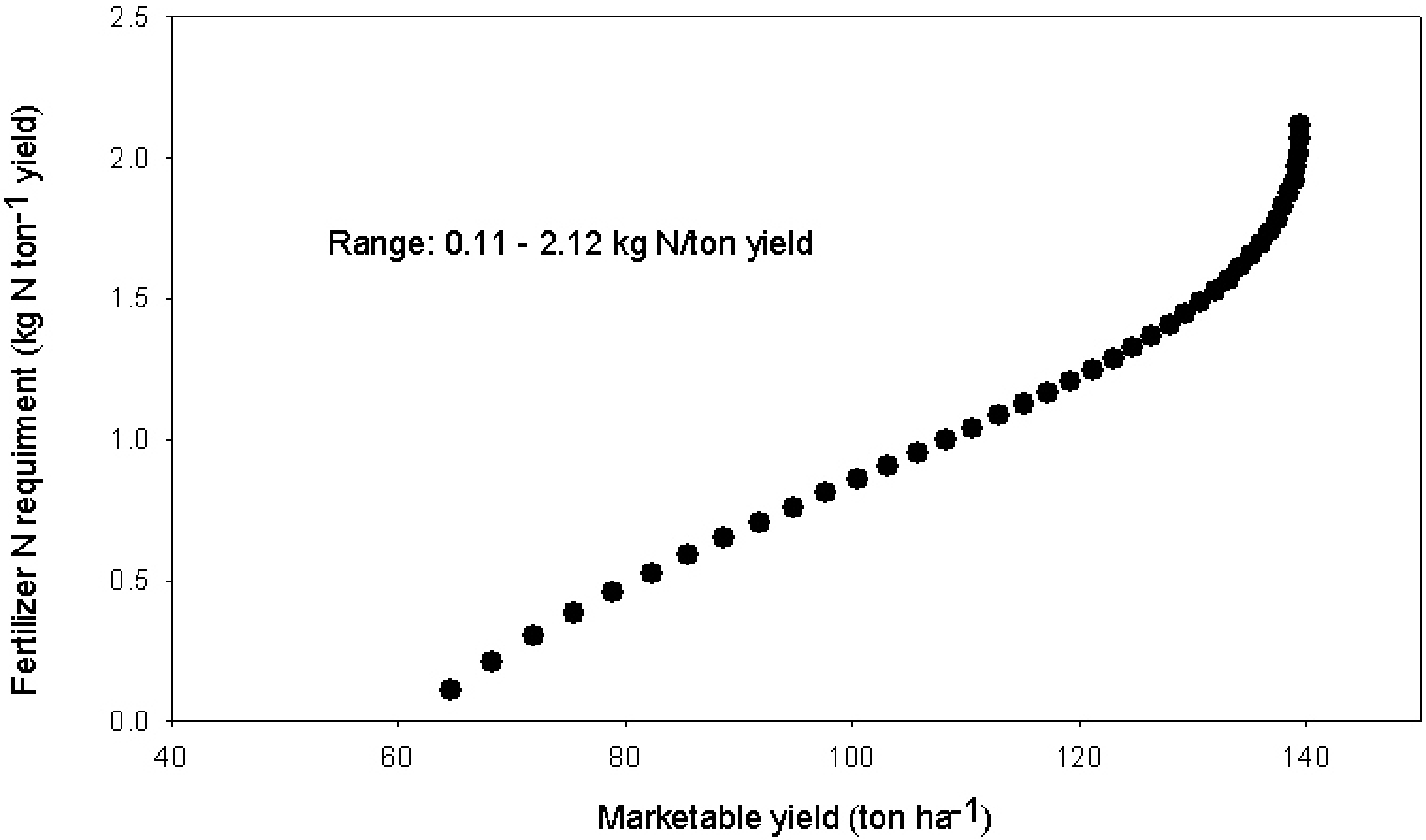

Fig. 19. Fertilizer N requirement per ton marketable yield production in a sandy loam soil, Harrow, ON, 2004

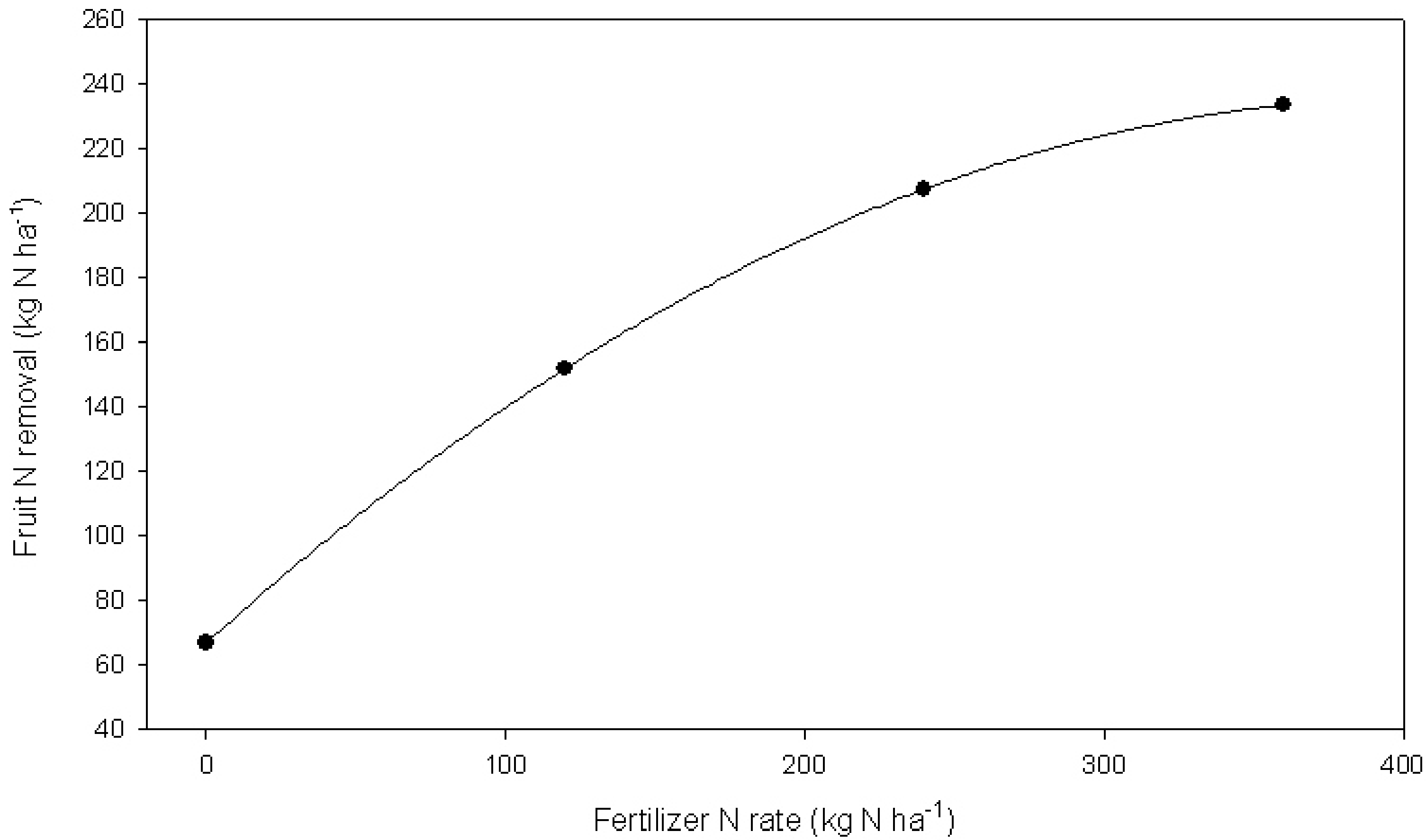

Fig. 20. Response of processing tomato fruit nitrogen removal to fertilizer nitrogen application in a sandy loam soil under fertigation, Harrow, ON, 2004.

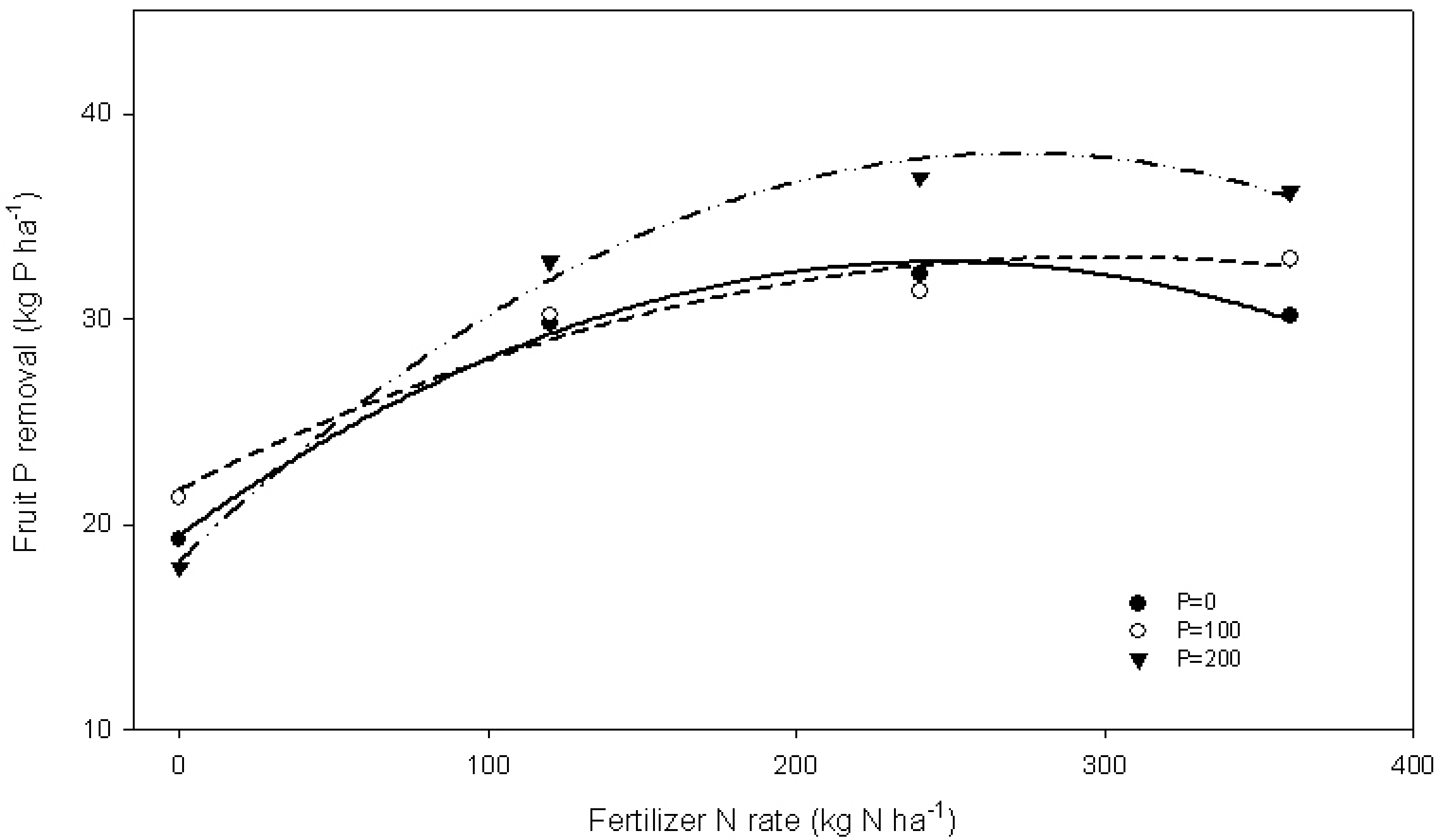

Fig. 21. Response of fruit phosphorus removal of processing tomatoes to fertilizer nitrogen at various phosphorus rates in a sandy loam soil, Harrow, ON, 2004.

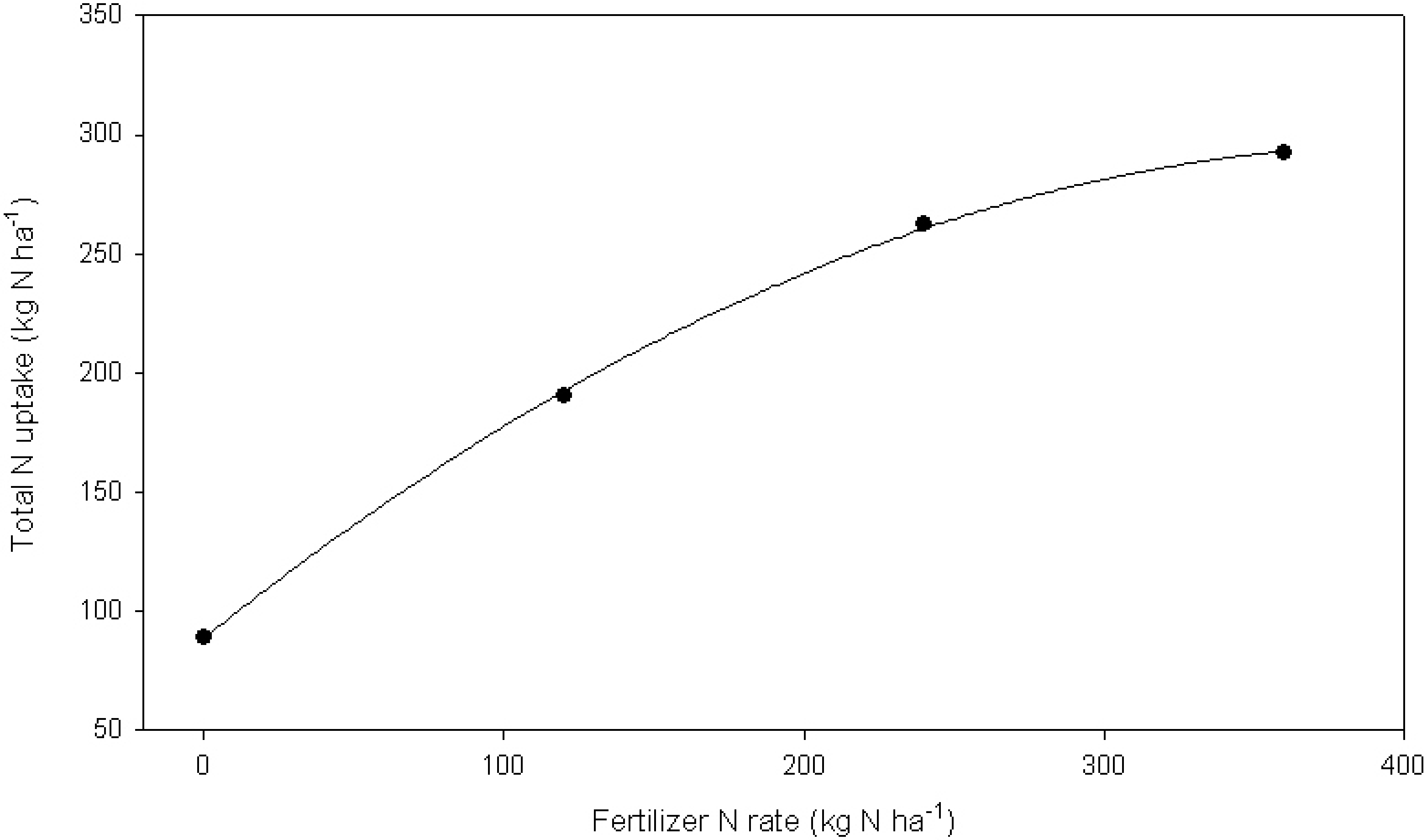

Fig. 22. Response of processing tomato total nitrogen uptake to fertilizer nitrogen application in a sandy loam soil under fertigation, Harrow, ON, 2004.

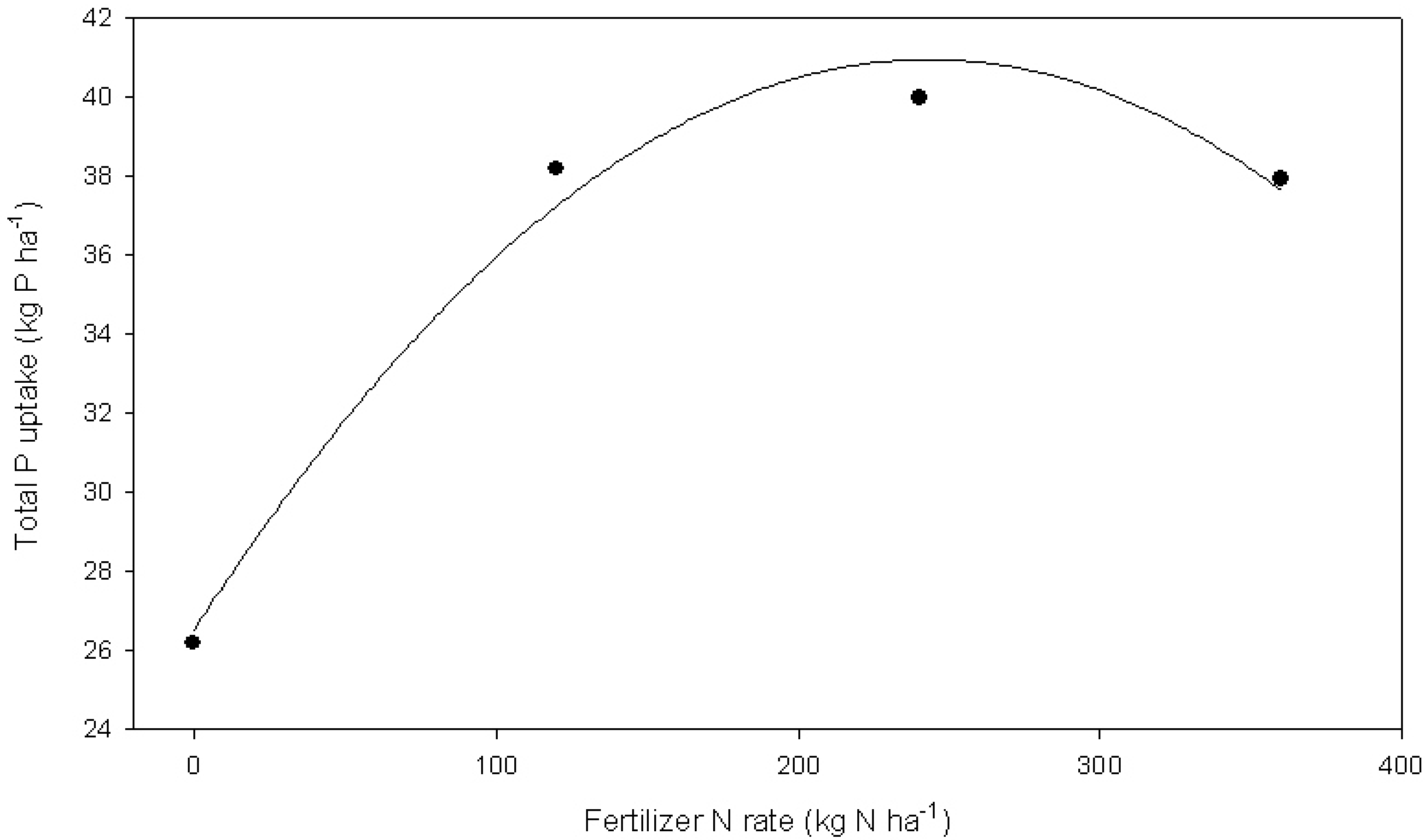

Fig. 23. Response of processing tomato total phosphorus uptake to fertilizer nitrogen application in a sandy loam soil under fertigation, Harrow, ON, 2004.

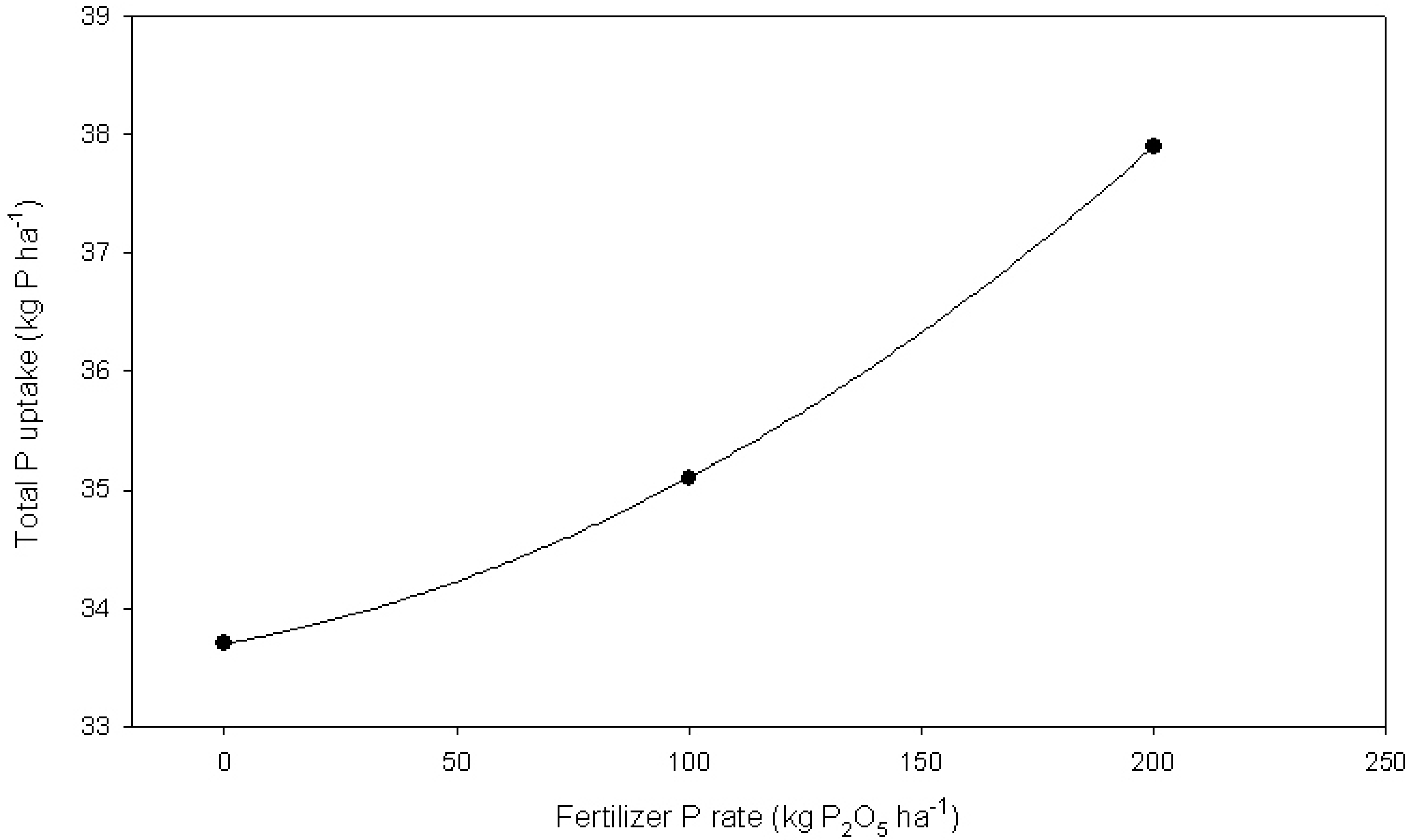

Fig. 24. Response of processing tomato total phosphorus uptake to fertilizer phosphorus application in a sandy loam soil under fertigation, Harrow, ON, 2004.

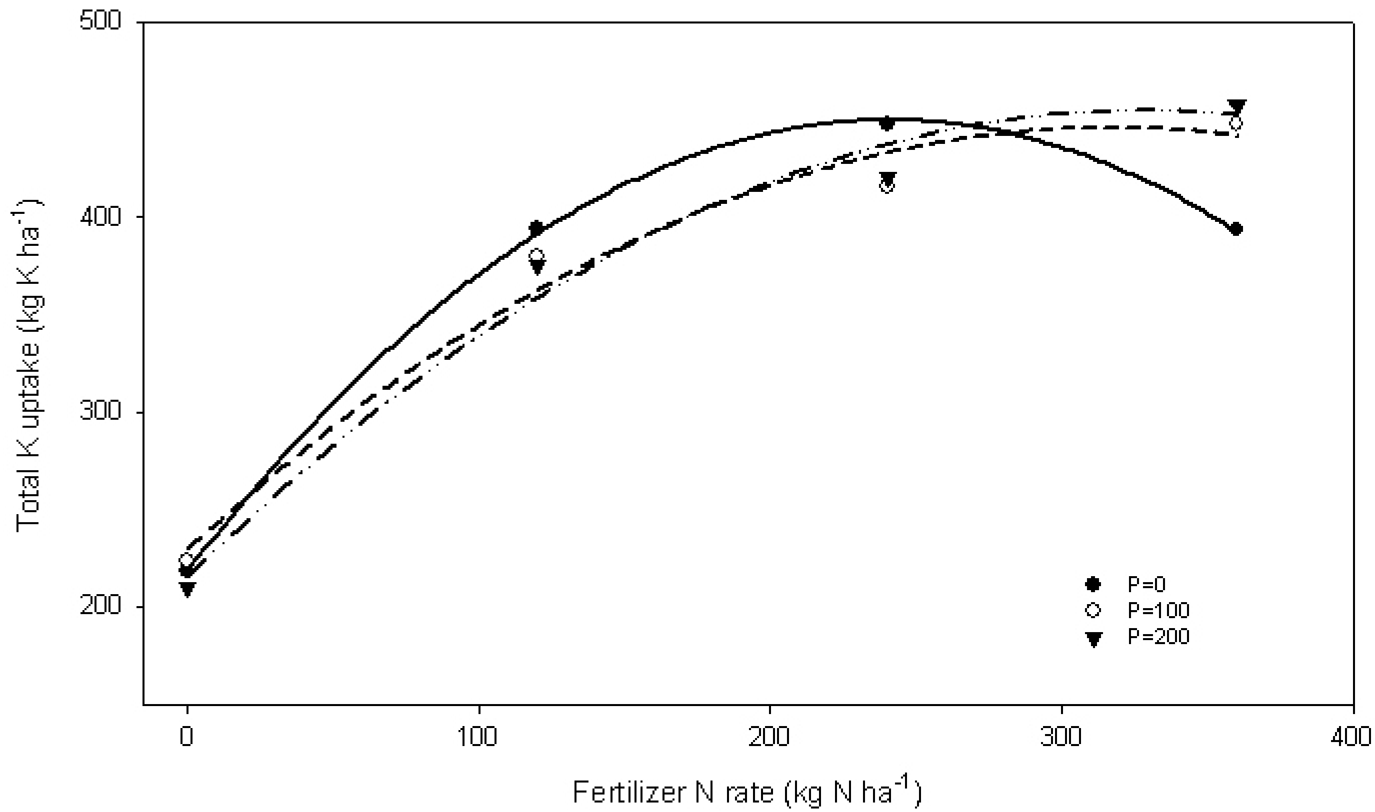

Fig. 25. Response of total potassium uptake of processing tomatoes to fertilizer nitrogen at various phosphorus rates in a sandy loam soil, Harrow, ON, 2004.

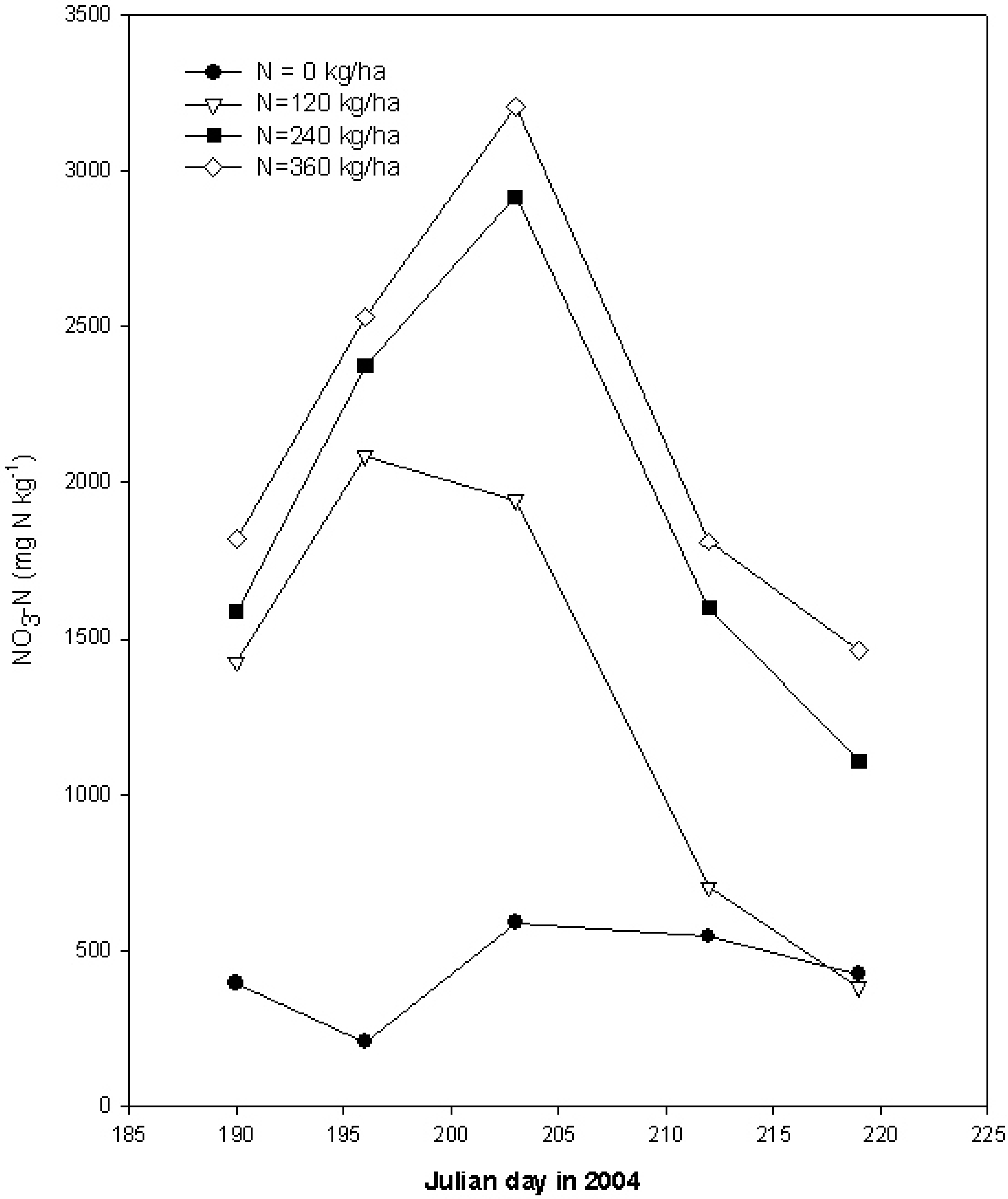

Fig. 26. Leaf petiole sap NO_3-N concentration across various fertilizer phosphorus treatments as influenced by fertilizer nitrogen rate in a sandy loam soil, Harrow, ON, 2004

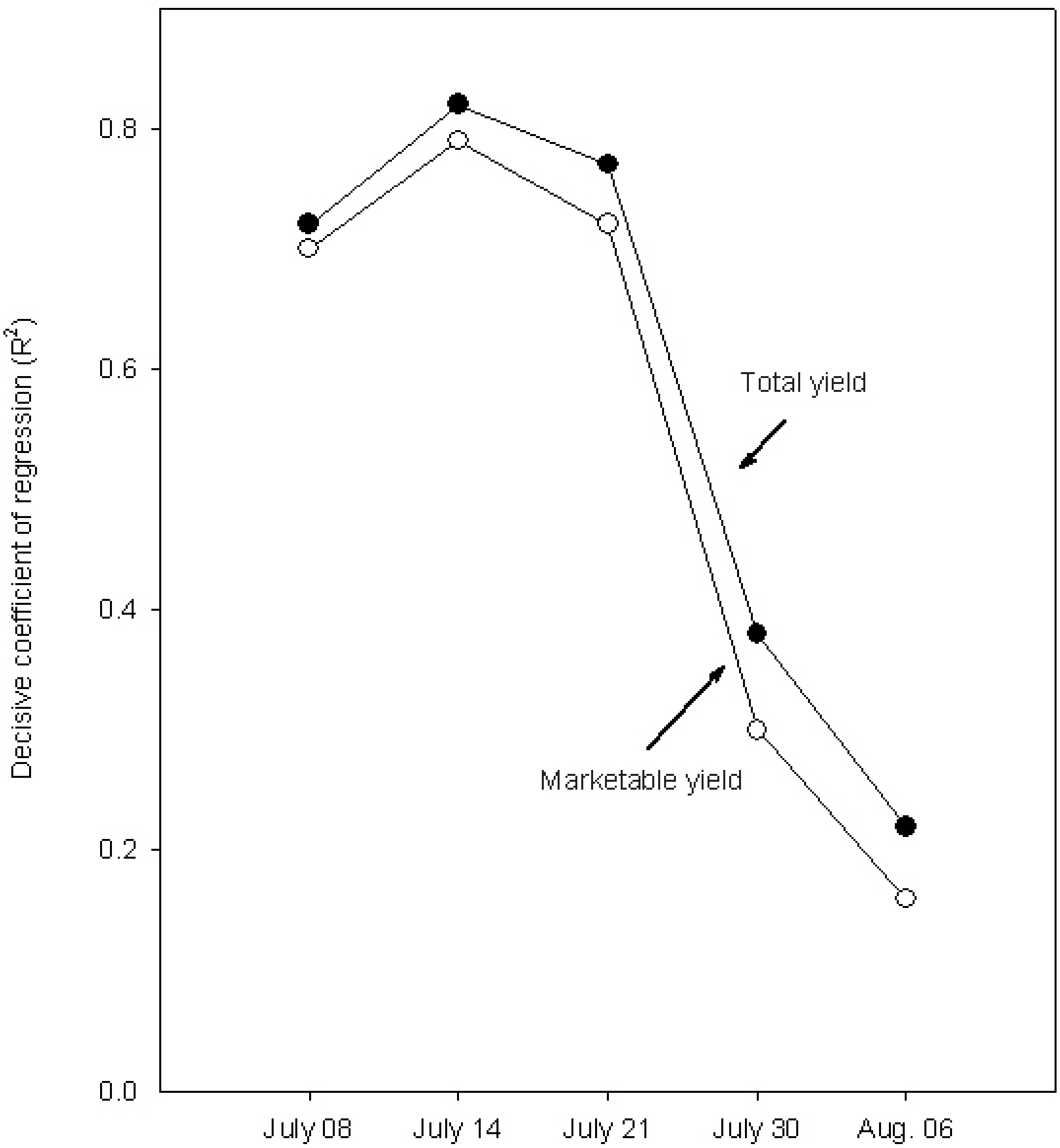

Fig. 27. Relationships between yields of processing tomatoes and petiole NO_3-N concentration at various stages, Harrow, ON, 2004

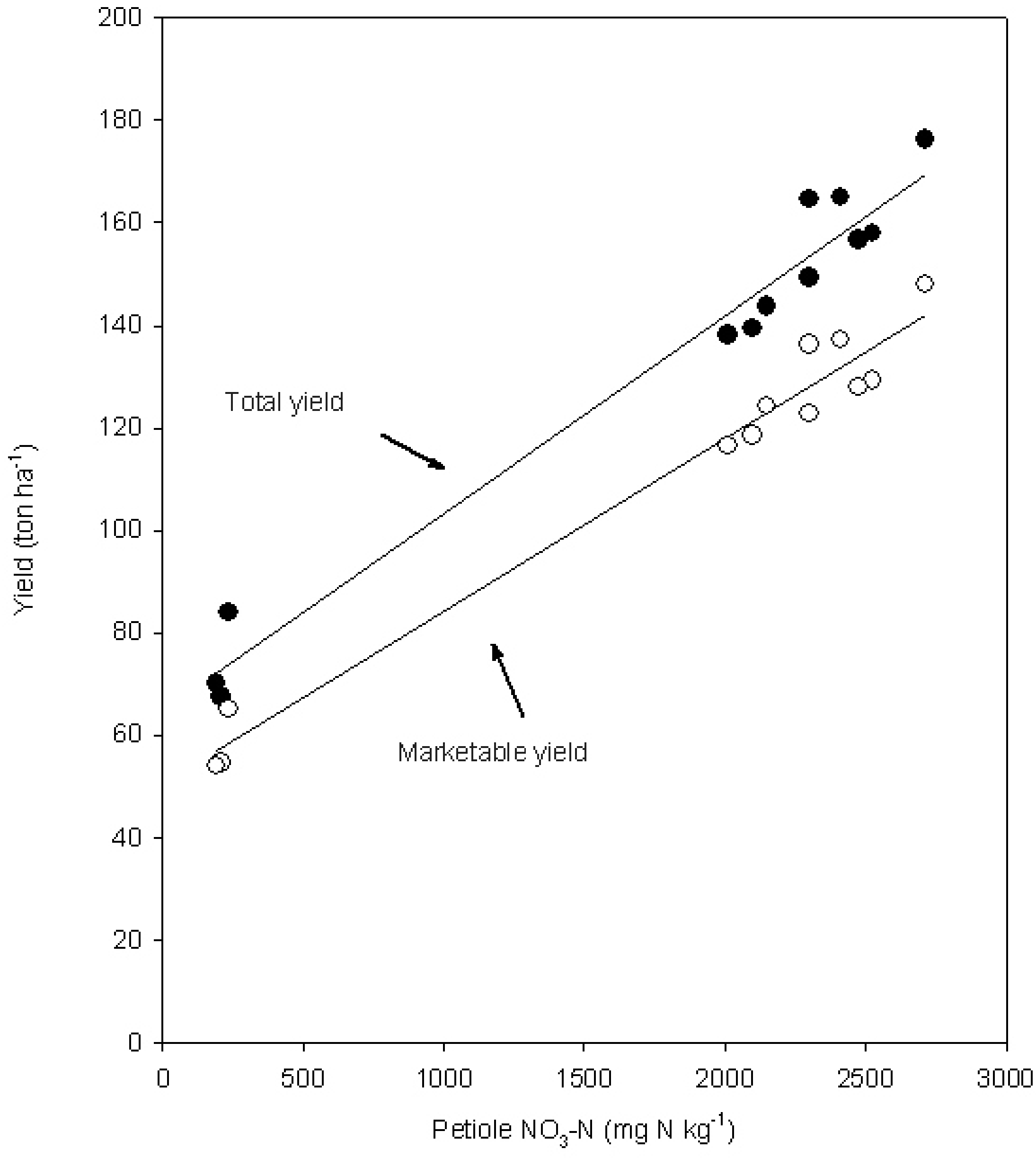

Fig. 28. Relationships between yields of processing tomatoes and petiole NO_3-N concentration, Harrow, ON, July 14, 2004

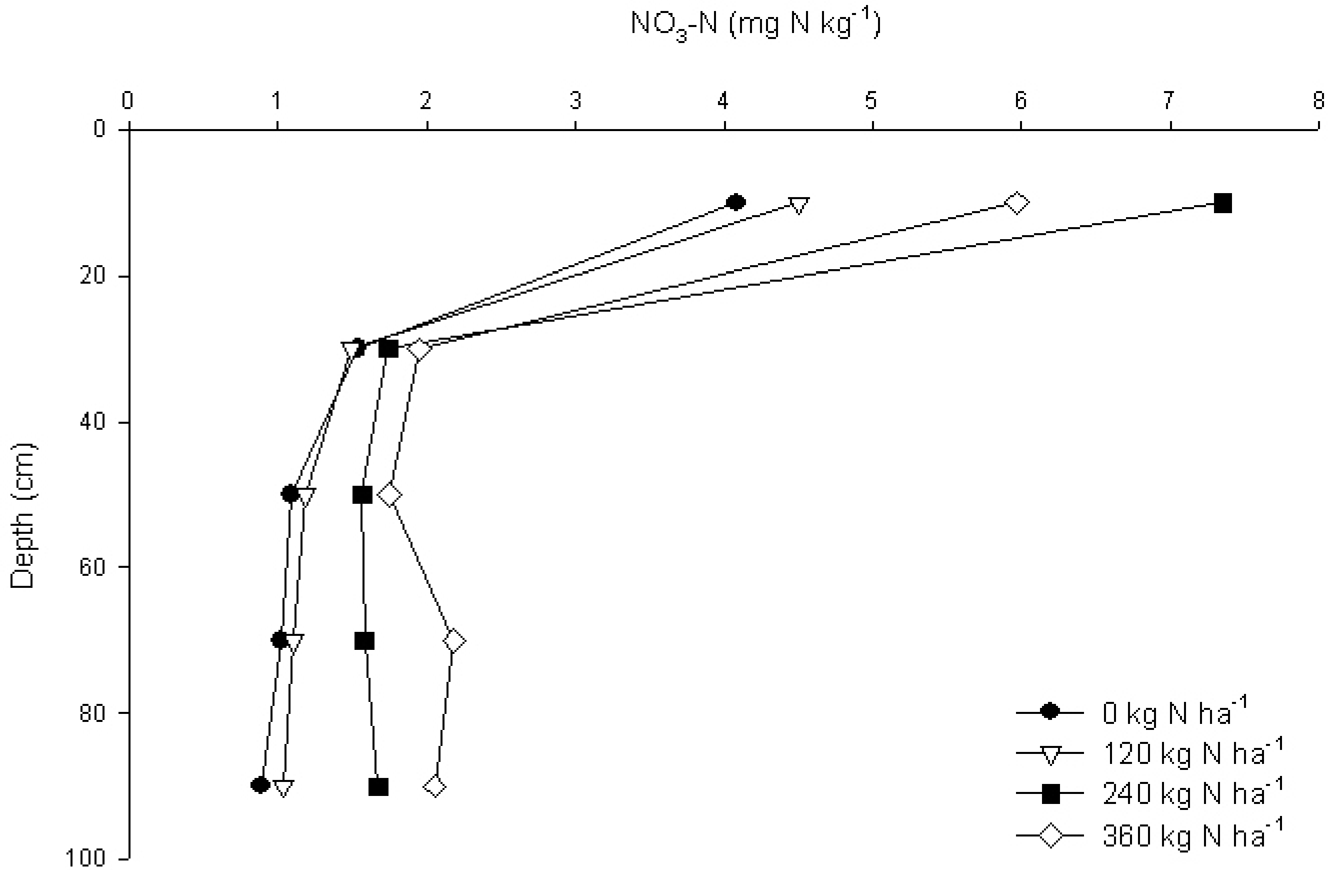

Fig. 29. Post-harvest soil profile (0-100 cm) NO_3-N as influenced by fertilizer N rate under processing tomatoes with drip fertigation in a sandy loam soil, Harrow, ON, 2004