Relationship Between Population Densities of Meloidogyne hapla and Crop Losses in Summer-Maturing Vegetables in Ontario

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ABSTRACT

Five vegetable crops were grown in 20-cm-diam clay-tile microplots infested with 0, 666, 2,000, 6,000, or 18,000 northern root knot nematodes (*Meloidogyne hapla*) per kg of soil. At a nematode population density of 18,000, yields of cabbage and cauliflower were reduced by 9% and 24%, respectively, and cauliflower curd maturity was delayed by 3 days. The weight of marketable lettuce heads was inversely correlated with nematode populations, with a maximum decrease of 46% at the 18,000 density. The number and weight of marketable potatoes and onions decreased with increased nematode populations, whereas the number and weight of culls increased. Commercial losses for these crops were 46% and 64%, respectively, at the highest nematode density. Soil nematode populations under onions and potatoes at harvest were considerably larger than those under cabbage, cauliflower, or lettuce.

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Additional key words: population dynamics, economic loss threshold.

RESUMÉ

Cinq légumes furent cultivés dans des tuiles de drainage de 20 cm de diamètre infestés de 0, 666, 2,000, 6,000, ou 18,000 nématodes (*Meloidogyne hapla*) par kg de sol. A la densité de 18,000 nématodes, le rendement du chou et du chou-fleur fut réduit, respectivement, de 9% et 24%, et la maturité du chou-fleur fut retardée de 3 jours. Le poid de la laitue vendable sur le marché était inversement relié a la population de nématodes, avec une porte maximum de 45% a la densité de 18,000. Le nombre et le poid des pommes de terre et des oignons vendables diminua avec l'accroissement de la population des nématodes, tandis que le nombre et le poid non-vendable sur le marché était réduit. La perte commerciale de ces légumes fut, respectivement, de 46% et 64% a la plus grande population de nématodes. A la récolte des oignons et des pommes de terre, les populations de nématodes du sol étaient considerablement plus large que celles dans les cultures du chou, chou-fleur, ou laitue.

In 1970, more than 45,000 hectares of vegetables for fresh market and processing, worth 54 million dollars, were grown in Ontario (13). The northern root knot nematode, *Meloidogyne hapla* Chitwood, is present throughout the muck and light mineral soils where Ontario's vegetable industry is concentrated (8) and in New York (19). At present, less than 4,000 hectares, mainly muck soils, are fumigated each year in Ontario.

There are no data available on the relationship between numbers of root knot nematodes and crop losses in vegetables under field conditions in Ontario, and few data are known for other regions (1). Such data are essential to advisory services responsible for issuing economically sound control recommendations, and contribute to a better understanding of the population dynamics of nematodes in field situations. Moreover, the determination of economic thresholds for nematode populations has become of major importance in efforts to increase crop production efficiency without unduly disrupting the environment.

Because most nematodes reproduce slowly and are only slightly motile, the initial population density usually is positively correlated with subsequent crop damage (14). The extent of the damage is influenced to a large degree by the interactions of external conditions with the host-parasite relationship (21). Most information on the relationship between nematode population density and crop loss is based on yield comparisons between nematode-infested plots and those in which the nematode has been eliminated or greatly reduced in number by soil fumigation. The inherent disadvantages of this method are as follows: Usually only one population density is considered at a time; the size of the initial population varies from plot to plot; more than one plant-parasitic nematode species may be present; and the chemical soil treatment itself may cause yield increases regardless of nematode kill (17).

This paper reports the relationship between five preplant population densities of the northern root knot nematode and damage to five common vegetable crops, grown in clay-tile microplots under field conditions without the use of fumigants to avoid the disadvantages outlined above. A preliminary report has been published elsewhere (11).

MATERIALS AND METHODS.—The northern root knot nematode, *M. hapla*, used throughout this study was a local isolate reared for 6 years on celery (*Apium graveolens* L. var. *dulce* DC. 'Utah') in the greenhouse. Large soil populations of the larvae were reared on tomato (*Lycopersicon esculentum* Mill.

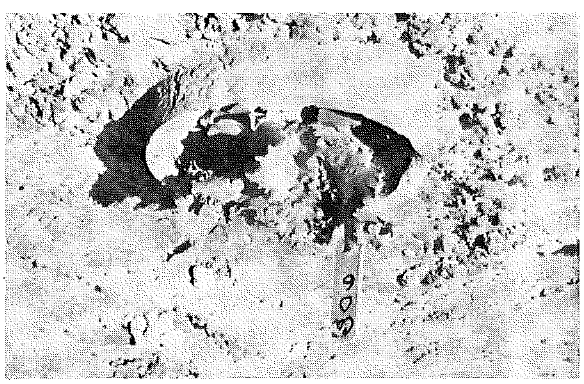


Fig. 1. A clay-tile microplot used in studies relating population densities of *Meloidogyne hapla* to crop losses in five field-grown, summer-maturing vegetables in Ontario.

'Glamour') and cabbage (*Brassica oleracea* L. var. *capitata* L. 'Jersey Queen') grown for 3 months in infested Vineland loam in a 3- X 6-m ground bed in the greenhouse. After removing all coarse roots and carefully mixing the infested soil, the population density was determined by processing ten 50-g samples by a modified Baermann funnel technique (20). Portions of the infested soil which contained an average of 80,000 larvae/kg were then thoroughly mixed with pasteurized Vineland loam for 5 min in a cement mixer to yield 666, 2,000, 6,000, or 18,000 nematodes/kg of soil. The soil for the control plots consisted of pasteurized Vineland loam. Nine kg of soil of each infestation level were placed in clay drainage tiles 20 cm in diam and 30 cm long (Fig. 1) which had previously been plunged in the field soil on 1.2-m centers. A randomized block design in a 12- X 12-m plot with 20 tiles (replicates) for each of the five nematode population densities (treatments) was used for each kind of vegetable. Within 4 days after filling the tiles with soil, one 5- to 6-week-old seedling of either Market Prize cabbage, cauliflower (*Brassica oleracea* L. var. *botrytis* L. 'Igloo'), or lettuce (*Lactuca sativa* L. 'Pennlake') was transplanted to each tile in the appropriate plot. Three 5- to 6-week-old seedlings of onion (*Allium cepa* L. 'Copper Gem') were transplanted per tile, and one seed potato eye (*Solanum tuberosum* L. 'Sebago') was planted per tile.

To determine nematode survival, soil samples were taken from all treatments immediately after transplanting. On the same day, moisture-temperature sensors were placed in one tile in each plot at depths of 15 and 30 cm. To ensure that all the tiles had the same microflora present, each received 50 ml of air-dried soil from the nematode-infested greenhouse ground bed.

Two days after transplanting, 8-32-16 fertilizer was added to each tile at the rate of 560 kg/hectare for lettuce, onions, and potatoes, as recommended by the Department of Soil Science, University of Guelph, Ontario; the potatoes also received ammonium nitrate at 168 kg/hectare. The other crops received the side dressing of ammonium nitrate 4 weeks later.

To control root maggots, cabbage and cauliflower received a 230-ml drench of Diazinon W50, 0.06 kg/100 liters, at transplanting and 2 and 4 weeks later. Onions were similarly drenched 4 weeks after a transplanting to control onion maggots. To control aphids and loopers, cabbage and cauliflower were sprayed at both 4 and 5 weeks after a transplanting with Diazinon W50, 0.2 kg/100 liters.

To determine the population densities of the nematode at midseason, soil samples were taken 44 days after transplanting to a depth of 15-20 cm from four microplots of each treatment for each crop, then processed by the method indicated above.

Marketable yields (15) and other growth data were obtained at crop maturity, which took 57, 66, 73, 100, and 114 days from transplanting, respectively, for lettuce, cabbage, cauliflower, potatoes, and onions. The final soil nematode population in each microplot was determined as described above (20), and the degree of galling on each root system was rated by the Daulton-Nusbaum Index (4).

RESULTS.–Marketable yields of cabbage were reduced 9% at the highest nematode population density as compared with the yield of the control treatment (Fig. 2). Cauliflower yields were reduced 11% at the 6,000 density and 24% at the 18,000 density; at the latter, curd maturity was delayed an average of 3 days. Yields of marketable lettuce heads were reduced at all nematode densities. At the 2,000 density, Canada No. 1 onion bulbs (5.0 cm and larger) were reduced 31%; and at the 6,000 and 18,000 densities, by 72% and 64%, respectively. Correlated with these reductions was a progressive decrease in the number of marketable bulbs and a concomitant increase in numbers of unmarketable culls. Marketable yields of potatoes as well as total weight of tubers (marketable tubers plus culls) were severely reduced at all nematode densities. Initial populations as low as 666 nematodes/kg of soil caused a decrease in the number of Canada No. 1 potato tubers (4.5 cm and larger) and an increase in the number of undersized cull tubers. Many tubers harvested from the 6,000 and 18,000 density plots were blemished by large masses of parenchymatous tissue 1-15 mm in diam (Fig. 3).

Total top weight of cabbage and cauliflower increased with increasing nematode densities, but dropped below the control at the 18,000 density (Fig. 4, left). In contrast, top weight of lettuce and onions consistently decreased with increasing densities. Top weight of potatoes at the 666 density dropped significantly below the control, but this effect was reduced with each increase in nematode density.

Root weight of cabbage increased slightly with increasing nematode densities; in contrast, that of cauliflower increased greatly with rising densities except at the 18,000 density (Fig. 4, right). Root weights of lettuce and onions were below those of the control at the lowest density; however, they increased progressively with higher initial populations. Root weight of potatoes was higher than the control at the 666 and 18,000 density, but lower at the intermediate densities.

Average midseason nematode population densities on all vegetables are presented in Table 1. The gall rating of the roots of all crops increased with increasing preplant population densities (Fig. 5, left). The majority of the galls on cabbage and cauliflower occurred on the fibrous, lateral roots rather than on the primary roots. The galls were only slightly coalesced, with typical adventitious root proliferation. Most galls on lettuce roots were single; coalescence resulting in round knots (up to 15-mm in diam) occurred only at the 18,000 density. The fibrous onion roots had fusiform-shaped, coalescent galls rather than discrete galls. Hooked tips or sharp bends in the roots indicated points of larval attack. The numerous, discrete, golden-brown galls on potato roots were usually small and rounded, without much adventitious root formation or coalescence.

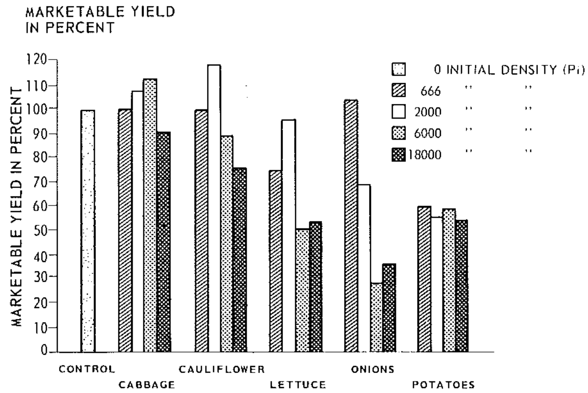


Fig. 2. The effect of population densities of *Meloidogyne hapla* on marketable yield of five field-grown vegetables in Ontario. Marketable yields are expressed as per cent of control.

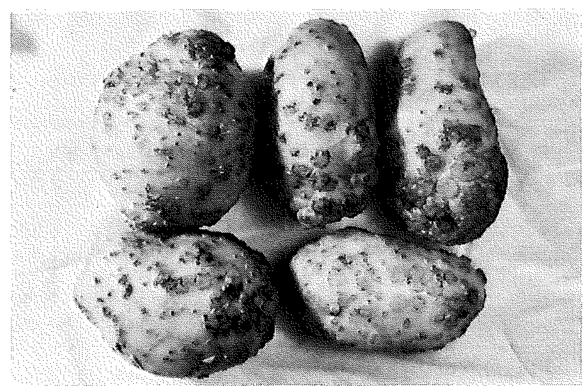
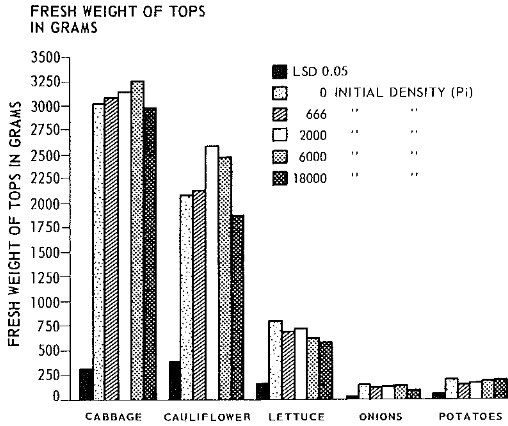


Fig. 3. Potato tubers blemished by parenchymatous tissue growth caused by high densities of *Meloidogyne hapla.*

The changes in nematode population densities, based on the difference between initial and final densities, are shown in Fig. 5, right. Soil in microplots planted to potatoes and onions contained higher nematode populations at harvest than at planting, except for onions at the 18,000 density. Final soil populations for the other crops were lower than the initial population densities.

Soil moisture and temperature were favorable for growth of the vegetables during the experiment (7) (Fig. 6). Natural rainfall, supplemented with irrigation when necessary, maintained moisture near field capacity in the root zone.

DISCUSSION.–Because the main purpose of this investigation was to provide the Ontario Nematode Diagnostic and Advisory Service with reliable data on which to base control recommendations, the concept of the economic loss threshold was adopted. This threshold, which is dependent on the value of a crop, represents a percentage of the total value of the crop equivalent to the cost of nematode control. An economic loss threshold of 5% of the marketable



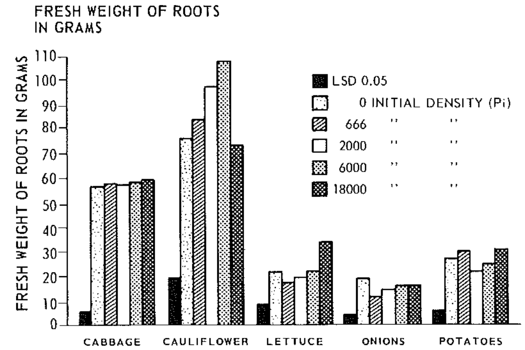


Fig. 4. The relationship between five population densities of *Meloidogyne hapla* and growth of five field-grown vegetables in Ontario. (Left) Effect on fresh weight of tops. (Right) Effect on fresh weight of roots.

TABLE 1. Midseason[a] soil population densities of *Meloidogyne hapla* under five vegetables in Ontario

Crop	Initial *M. hapla* densities/kg of soil 666	2,000	6,000	18,000
Cabbage	20	960	2,360	8,300
Cauliflower	240	1,200	2,560	11,400
Lettuce	40	1,160	5,320	4,320
Onions	120	2,000	5,200	6,700
Potatoes	200	2,600	4,400	10,800

[a] Forty-four days after transplanting.

yield was derived from knowledge of the market values of the five vegetables (13) and the cost of nematode control by fumigation (12). Consequently, any nematode-induced loss which exceeds 5% of the marketable yield is considered sufficient to warrant soil fumigation.

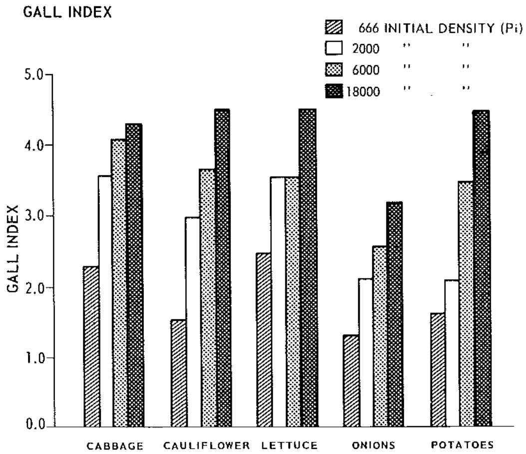
Table 2 presents the lowest initial nematode densities for the five vegetables at which the economic loss threshold was reached or exceeded in this study. Therefore, based on this investigation, fumigation would become economically feasible if preplant nematode densities in the field were to exceed those presented in Table 2. Further research is needed to narrow down the critical initial density required for economic loss. However, the data constitute a quantitative assessment of crop damage to be expected at comparable densities and under conditions resembling those in this experiment. Such damage was previously suggested qualitatively for lettuce by Wong et al. (23); for potatoes by Griffin & Jorgenson (5); and for lettuce and onions by Sherf (19). The Advisory Manual, used by the Bedrijfslaboratorium voor Grond- en Gewasonderzoek at Oosterbeek, The Netherlands, states the likelihood of damage to potatoes and greenhouse lettuce at population densities of *M. hapla* of 200 or less/kg of soil, which supports our observations. The initial population densities in our investigation were similar to those encountered in growers' samples from muck and sandy soils in Ontario (8). In view of the main purpose of this study, no attempt has yet been made to relate the data to mathematical models characterizing relationships between nematode populations and crop damage as has been done in The Netherlands (14, 18); rather we have adopted the economic loss approach similar to that of Wallace (22).

Total top weights of cabbage and cauliflower were increased at all population densities except the highest. In response to nematode attack, these crops may have formed new roots which, up to a point, overcompensated for those destroyed; adventitious root formation was particularly noticeable with these crops. This hypothesis is supported by the increases in root weights of these crops with rising nematode population densities; the one exception, cauliflower at the 18,000 density, is probably the result of greater sensitivity of this crop (Table 2) and consequent lack of new root formation. The large, numerous, coalesced galls on lettuce at the 18,000 density may explain the increase in total root weight of that crop (9). Root weights of onions and potatoes

TABLE 2. Preplant soil population densities of *Meloidogyne hapla* causing economic crop loss[a] in five vegetables in Ontario

Crop	No. *M. hapla* larvae per kg of soil	lb. of soil
Cabbage (Market Prize)	18,000	8,100
Cauliflower (Igloo)	6,000	2,700
Lettuce (Pennlake)	666	300
Onions (Copper Gem)	2,000	900
Potatoes (Sebago)	666	300

[a] Economic loss threshold = 5% of marketable yield which approximates cost of fumigation per acre.



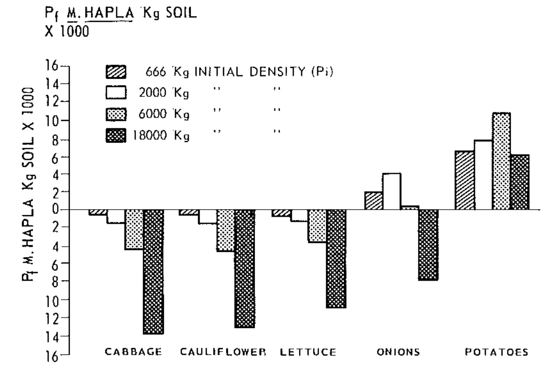


Fig. 5. Gall indices of root systems and changes in nematode populations of *Meloidogyne hapla* on five field-grown vegetables in Ontario. (Left) Gall indices of root systems. (Right) Changes in nematode populations, based on the difference between initial (P_i) and final (P_f) densities. Columns below the base line signify fewer nematodes, and above the base line, more nematodes in the soil at harvest than at planting.

were not noticeably affected, as the galls were small, with little or no adventitious root formation.

Other workers have reported that lack of water (10), age of seedlings (2), host nutritional deficiency (3), and other stress factors may aggravate the damage caused by root knot nematodes and affect nematode populations. Cultural practices and environmental conditions were favorable to growth of the vegetables in this investigation (7) and crop damage by *M. hapla* may be greater when growing conditions are more adverse.

Soil populations of *M. hapla* had decreased under all crops by midseason (Table 1), except for potatoes at the 2,000 density. Soil populations under cabbage and cauliflower continued to decline from midseason to harvest (Table 2, Fig. 5), whereas those under onions and potatoes increased. Lettuce soil populations showed increases at the 666 and 18,000 densities and declines at the other two densities during the same period. Whether or not a grower might expect large preplant soil populations for his next crop would depend on whether the population had declined or increased in the previous growing season. This, in turn, would be dependent upon whether length of the crop season allowed ample time for nematode reproduction, and whether or not the gall-bearing roots were dug out during harvest, and upon the inherent suitability of the previous crop as a host. The above emphasizes the likelihood of the presence of large root knot nematode populations after onions or potatoes, while also strongly indicating the need for prompt removal of galled roots of cabbage, cauliflower, and lettuce by cultivation.

The microplots used in this investigation combine the advantages of ease of handling, close approximation of field conditions, and minimal expense. They also permit the incorporation of

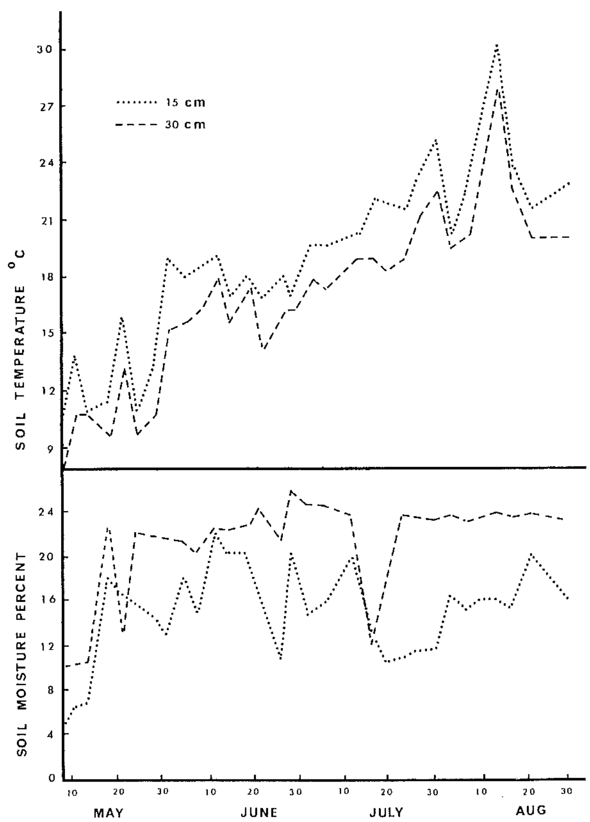


Fig. 6. Soil moisture and temperature in microplots cropped to onions at Vineland Station, Ontario, monitored twice weekly.

several population densities within an experimental design and the establishment of fairly uniform densities within a treatment. They differ from those of Jones (6) and Ross (16) in being considerably smaller, serving only one cropping season, and containing monospecific nematode populations without the use of fumigants. In summary, we found the microplot technique to be a valuable method for assessing economic loss thresholds of vegetable crops exposed to several preplant densities of nematodes.

LITERATURE CITED

1. BARKER, K. R., & C. J. NUSBAUM. 1971. Diagnostic and advisory programs, p. 281-300. *In* B. M. Zuckerman et al. [ed.]. Plant parasitic nematodes, Vol. I. Academic Press, New York.
2. BERGESON, G. B. 1968. Evaluation of factors contributing to the pathogenicity of Meloidogyne incognita. Phytopathology 58:49-53.
3. BIRD, A. F. 1970. The effect of nitrogen deficiency on the growth of Meloidogyne javanica at different population levels. Nematologica 16:13-21.
4. DAULTON, R. A. C., & C. J. NUSBAUM. 1961. The effect of soil temperature on the survival of the root-knot nematodes Meloidogyne javanica and Meloidogyne hapla. Nematologica 6:280-294.
5. GRIFFIN, G. D., & E. C. JORGENSON. 1969. Life cycle and reproduction of Meloidogyne hapla on potato. Plant Dis. Reptr. 53:259-261.
6. JONES, F. G. W. 1956. Soil populations of beet eelworm (Heterodera schachtii Schm.) in relation to cropping. II. Microplot and field plot results. Ann. Appl. Biol. 44:25-56.
7. KERR, S. E. 1970. The weather at Vineland Station and Simcoe, Ontario in 1970, p. 151-156. Hort. Res. Inst. Ontario, Rep. for 1970.
8. MARKS, F., J. L. TOWNSHEND, J. W. POTTER, T. H. A. OLTHOF, & A. CORNELISSE. 1971. Plant-parasitic nematode genera associated with crops in Ontario in 1970. Can. Plant Dis. Surv. 51:127-128.
9. MAYOL, P. S. 1969. The role of secondary invaders in premature breakdown of plant roots infected with Meloidogyne incognita. Ph.D. Thesis, Purdue Univ. 101 p.
10. O'BANNON, J. H., & H. W. REYNOLDS. 1965. Water consumption and growth of root knot nematode-infected and uninfected cotton plants. Soil Sci. 99:251-255.
11. OLTHOF, T. H. A., & J. W. POTTER. 1971. The relation between preplant populations of Meloidogyne hapla and crop losses in field-grown vegetables in Ontario. J. Nematol. 3:322 (Abstr.).
12. OLTHOF, T. H. A., J. L. TOWNSHEND, J. W. POTTER, & C. F. MARKS. 1969. Plant-parasitic nematodes of economic importance in Ontario. Entomol. Soc. Ontario Proc. 100:8-9.
13. ONTARIO DEPARTMENT OF AGRICULTURE AND FOOD. 1970. Agricultural statistics for Ontario. Publ. 20, Farm Econ., Coop. Statist. Branch, Toronto, Ontario. 107 p.
14. OOSTENBRINK, M. 1966. Major characteristics of the relation between nematodes and plants. Meded. Landbouwhogeschool Wageningen 66:3-46.
15. QUEEN'S PRINTER AND PUBLISHER. 1970. The farm products grades and sales act and regulations respecting fruit and vegetables. Farm Products Inspection Branch, Ont. Dep. Agr. Food, Toronto, Ontario. 144 p.
16. ROSS, J. P. 1964. Interaction of Heterodera glycines and Meloidogyne incognita on soybeans. Phytopathology 54:304-307.
17. SEINHORST, J. W. 1963. Enkele aspecten van het onderzoek over plantenparasitaire aaltjes. Meded. Dir. Tuinb. 26:349-358.
18. SEINHORST, J. W. 1966. The relationships between population increase and population density in plant parasitic nematodes. I. Introduction and migratory nematodes. Nematologica 12:157-169.
19. SHERF, A. 1970. Root-knot nematodes on New York vegetables. Vegetable Dis. Leaflet No. 6, Dep. Plant Pathol., Cornell Univ., Ithaca, N.Y. 4 p.
20. TOWNSHEND, J. L. 1963. A modification and evaluation of the apparatus for the Oostenbrink direct cottonwool filter extraction method. Nematologica 9:106-110.
21. WALLACE, H. R. 1970. Some factors influencing nematode reproduction and the growth of tomatoes infected with Meloidogyne javanica. Nematologica 16:387-397.
22. WALLACE, H. R. 1971. The influence of the density of nematode populations on plants. Nematologica 17:154-166.
23. WONG, T. K., F. C. HARPER, & W. F. MAI. 1970. Soil fumigation for controlling root knot of lettuce on organic soil. Plant Dis. Reptr. 54:368-370.