THERMAL AND CHEMOTHERAPEUTIC MEASURES AGAINST NEMATODE PESTS OF ECONOMIC PLANTS

by

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THERMAL AND CHEMOTHERAPEUTIC MEASURES AGAINST NEMATODE PESTS OF ECONOMIC PLANTS

INTRODUCTION

The first published reports of nematodes as pests of economic plants in the United States appeared in 1889 (1, pp. 177-226), 37, p. 10) and 42, pp. 1-43). Subsequently the spread of plant parasitic nematodes has been found to be due largely to the movement of infected plants, plant parts (seed, cuttings, tubers, bulbs and roots) and infested soil surrounding plant roots.

Oregon's agricultural industries export and import large quantities of plants and plant parts which may contain various nematode pests. As Oregon's agriculture becomes older and more specialised the need of therapeutic or curative measures for freeing infected plants of nematodes becomes more necessary. The exchange of plant materials will continue and new areas may become infested with plant parasitic nematodes. In recent years discoveries of nematode infections on various crops (29, pp. 522-523) and 47, 230-231) in widely scattered areas of the state have revealed the extent of the nematode distribution.

For example, a root-lesion nematode, Pratylenchus penetrans (Cobb, 1917) Sher and Allen, 1953, has been reported as a pest of the following crops in Oregon: (a) Easter lily in Brookings, (b) Narcissus in Sandy and Warrenton, (c) seedling cherry and other nursery crops in Multnomah and Washington counties, and (d) Chrysanthemum in various greenhouses.

The overall nematode (foliar, root-knot, root-lesion) disease situation offers the following serious repercussions for growers and consumer alike: (a) dissemination of various nematodes in plant tissue and soils to new areas, (b) reduction or loss of the sales value of affected plants, (c) a weakening of various crops by secondary organisms, (d) loses due to improper utilization of fertilizer, land, and water by affected plants, and (e) increased production cost incurred by measures taken to control nematodes.

The desired goal of this investigation is the elimination of all or most of the nematode pests in various plant tissues.

LITERATURE REVIEW

Treatment of infected plant material by various therapeutic methods has long been a popular means designed to control nematode pests. Hot water soaks was one of the earliest therapeutic measures employed and is in wide use at the present time. Ramsbottom (40, pp. 65-78) in 1918 found he could effectively control Ditylenchus dipsaci (Kuhn, 1857) Filipjev, 1936 on narcissus by soaking the bulbs in a 110°F. water bath 2 to 4 hours. More recently, 1954, Bruinsma and Seinhorst (5, pp. 437-446) recommended hot water at 115°F. for 1 hour against D. dipsaci infecting shallots. Table 1 gives a summary of the investigations on this method of control. (The pertinent data are presented in tabular form for clarity rather than confound the text with the numerous items.)

There is little or no agreement on a standard treatment for any specific nematode. One reason for this variation was discovered by Christie and Croseman (9, pp. 98-103), who found that 4 strains of Aphelenchoides fragariae (Ritzema Bos, 1891) Christie, 1932 from different host plants each have a different time-temperature relationship.

A chemical soak for control of nematodes in plants may appear to be an easy and economical method of control but it has had a very discouraging history (Table 2). The chemicals tested were either ineffective or injurious to plants treated.

Ordinary fumigation or vacuum fumigation has been unsatisfactory at dosages tolerated by plants, although, effective fumigation for nematodes on machinery and in grains has been obtained (Table 3).

Desiccation as a means of controlling endoparasitic nematodes in plant root tissue could be considered feasible from the investigations of previous workers. Godfrey and Hoshino (20, pp. 41-62) tested survival of root-knot nematodes at different degrees of dryness and found that less than 100 percent humidity is fatal at certain periods of exposure. Hastings (25, pp. 39-44) found the root-lesion nematode very susceptible to desiccation. No living nematodes were recovered from invaded oat root tissue that had been air dried.

The several therapeutic measures have been employed against plant parasitic nematodes with varying degrees of success. Hot-water treatment with its various modifications has had the widest utilization. Chamber fumigation has been restricted to machinery and seed.

Only in relatively recent years has the seriousness of the root-lesion nematode become recognized. Regardless of the success achieved by these therapeutic measures against other plant parasitic nematodes they were investigated as possible control methods for root-lesion nematodes. Previous therapeutic work with root-lesion nematode infected plants is negligible (Table 2). The tolerances of the root-lesion nematode, Croft lilies and Mazzard seedlings to the various treatments and to standard and experimental nematocides were unknown. Hence, this investigation was undertaken without benefit of recourse to previous work.

Table 1. A summary of hot-water treatments reported in the literature for the control of plant parasitic nematodes.

Nematode	Host	Temperature in degrees F.	Time	Worker	Date	Literature citation
Anguina agrostis (Steinbuch, 1799) Filipjev, 1936	bentgrass seed	126	2 hrs	Courtney Howell	1952	14, p. 81
A. tritici (Steinbuch, 1799) Filipjev, 1936	wheat	122-133	5-30 min	Byars	1920	6, pp. 1-40
Aphelenchoides besseyi Christie, 1942	rice	122-127	15 min	Cralley	1952	15, p. 5
A. fragariae (Ritzema Bos, 1891) Christie, 1932	strawberry	118	20 min	Brooks	1931	4, pp. 1-27
" "	strawberry	110	20 min	Hodson	1934	27, pp. 1158-1160
" "	Bellingham hybrid lily	111	1 hr	Jensen Caveness	1954	30, pp. 181-184
" "	Croft lily	111	1 hr	McWhorter Millsap	1946	35, pp. 1-4
" "	begonia	110	20 min	Christie Crossman	1935	9, pp. 98-103
" "	a northern strawberry	110	35 min	"	"	"

Table 1. Continued

Nematode	Host	Temperature in degrees F.	Time	Worker	Date	Literature citation
A. fragariae	a southern strawberry	110	7 hrs	Christie Crossman	1935	9, pp. 98-103
" "	chrysanthemum	110	2.5 hrs	"	"	"
A. ritzema-bosi (Schwartz, 1911) Steiner, 1932	chrysanthemum	115	5 min	Staniland	1950	44, pp. 11-18
Ditylenchus dipsaci (Kuhn, 1857) Filipjev, 1936	narcissus	110	2-4 hrs	Ramsbottom	1918	40, pp. 65-78
" "	"	110	3 hrs	Scott	1924	41, pp. 497-502
" "	"	110 & 114	1-3 hrs	Doucette	1927	16, pp. 236-237
" "	"	110-113	1-4 hrs	Griffiths	1930	23, pp. 8-12
" "	bulbous iris	110-112	1 hr	Hastings Bosher Newton	1939	26, pp. 144-146
" "	" "	110	4 hrs	Courtney Gould	1951	13, p. 41
" "	teasel seed	122	1 hr	Courtney	1952	12, p. 308

Table 1. Continued

Nematode	Host	Temperature in degrees F.	Time	Worker	Date	Literature citation
Ditylenchus dipsaci	shallots	115	1 hr	Bruinsma Seinhorst	1954	5, pp. 437-446
Heterodera schachtii Schmidt, 1871	potatoes	118	30 min	Triffit Hurst	1935	46, pp. 219-222
Meloidogyne sp.	in test tubes					
	larvae	104-127	2 hrs - 1 sec	Hoshino Godfrey	1933	28, pp. 260-270
	eggs	104-136	4.5 days 1 sec			
Meloidogyne spp.	Prunus Mahaleb Lovell peach	120	20 min	Nyland	1955	39, pp. 573-575
" "	peony	120	30 min	Tilford	1939	45, p. 133
Pratylenchus sp.	strawberry	121-130	7-1 min	Goheen McGrew	1954	21, pp. 818-826

Table 2. A summary of chemical soak treatments reported in the literature for the control of plant parasitic nematodes.

Nematode	Host	No. chemicals tested	Chemicals recommended	Time	Worker	Literature citation
A. tritici	wheat		None	-	Leukel	32, pp. 951-952
D. dipsaci	narcissus	21	None	-	Ramsbottom	40, pp. 65-78
" "	sweet potato	8	None	-	Kreis	31, pp. 678-683
H. rostochiensis Wollenweber, 1923	potato	252	Aaventa 1%	1 hr	Feldmesser Shafer	17, p. 13
H. schachtii	potato		Formaldehyde 20 - 40%	1 hr	Franklin	19, pp. 113-126
			Phenol 5%	1 hr		
" "	potato	1	Phenyl isothiocyanate 0.001%	3 days	Smedly	43, pp. 31-38
P. penetrans	potato	1	None	-	Cobb	10, p. 31

Table 3. A summary of fumigation trials reported in the literature for the control of plant parasitic nematodes.

Nematode	Host	No. of chemicals tested	Chemical recommended lbs/1000 cuft.	Time	Worker	Literature citation
			Fumigation			
A. besseyi	rice	1	methyl bromide 1.25	12 hrs	Cralley	15, p. 5
D. dipsaci	bulbous iris	3	none	-	Newton Hastings	38, pp. 175-181
" "	sweet potato	3	none	-	Kreis	31, pp. 678-683
Heterodera sp.	potato	1	sulfur dioxide saturated atmosphere	24 hrs	Fenwick	18, pp. 41-50
H. rostochiensis	potato	3	none	-	Chitwood	8, p. 44
" "	on machinery	1	methyl bromide 23	16 hrs	Mai Lear	33, pp. 22-23
Meloidogyne sp.	beets carrots	3	none	-	Harrington Pratt	24, p. 6
			Vacuum Fumigation			
Meloidogyne sp.	potato	1	none	-	Boock Lordello	3, pp. 363-364

MATERIALS AND METHODS

Infected Croft Easter lilies and Mazzard cherry seedlings were obtained from plantings with symptoms of root-lesion nematode parasitism (Figures 1, 2 & 3). The importance of lilies and nursery crops in the economy of the state, their availability, and the prospect of good grower cooperation made them suitable plants for investigative purposes. These crops may also be considered as representative of the root-lesion problem in Oregon.

Collection of materials

Mazzard cherry seedlings were dug after the plants had become dormant in late November. The roots were shaken free of soil and tied into bundles of 50 plants. The seedlings were healed-in in straw or sawdust until needed for experimental trials.

Croft Easter lily bulbs (number 9 and 7 commercials and yearling) were obtained from fields having a history of root-lesion infestation. The bulbs were packed in moist peat or sawdust as for shipment and held in cold storage at 35°F. for a minimum period of 60 days before treatment.

Examination of individual plants or bulbs revealed the presence of root-lesion nematodes in 92 percent of the lilies and 100 percent of the cherry seedlings.

Methods of examining for nematodes

Teasing (shredding the root tissue with dissecting needles beneath the low power of a stero-microscope) was a useful method of finding root-lesion nematodes when they were numerous. However, sparse infections were overlooked or found only after much time had been

expended in root examination. Determining the viability of nematodes teased from root tissue was a perplexing problem. The root-lesion nematodes would often remain motionless for long periods of time and appear to be dead. The eggs deposited by nematodes in root tissue were almost impossible to detect unless special staining methods were used.

A survey was conducted of various plants generally found as weeds on or near agricultural lands for use as an indicator plant (a highly favorable host plant used for the detection of plant parasitic nematodes). Of the 22 kinds of plants examined only 2 were not invaded by the root-lesion nematode (Table 4). Hairy vetch (Vicia villosa Roth.) was selected to be used as the indicator plant. The employment of indicator plants in all trials eliminated the less accurate and time consuming teasing of root tissue to locate root-lesion nematodes. Indicator plants were used when the Mazzard seedlings had ceased growth or the Croft lilies had bloomed.

The indicator plant method for determining the surviving root-lesion nematode population has several advantages: (a) these migratory nematodes are attracted from the soil, (b) only viable nematodes are collected for counting, (c) surviving eggs are stimulated to hatching, and (d) small root-lesion nematode populations are increased where they might have otherwise passed undetected.

After growing for approximately 60 days the indicator plants were freed of soil by washing, comminuted for 5 seconds in a Waring blendor, and placed in a Baermann type funnel (2, p. 41) to recover

any root-lesion nematodes present. The portion of the water containing the nematodes was drained from the funnels and the nematodes were counted directly or if they were numerous the sample was diluted then counted. To ascertain the root-lesion nematode population of soil, the gravity-screening method was employed (11, pp. 13-16).

The centrifugal-flotation technique (7, pp. 87-89) was the best method available to obtain viable root-lesion nematodes and eggs from plant tissues. The isolated root-lesion nematodes and eggs were used in trials to evaluate the effects of hot-water treatments.

General greenhouse culture methods

After treatment the Mazzard seedlings or the Croft lily bulbs were planted in steam sterilized sandy loam in number 10 (3/4 gallon) cans. Peat or other similar soil supplementing materials were not used because of difficulty of separating the roots from such material. Adequate moisture was supplied for growth. The greenhouse temperature was maintained at approximately 66°F. throughout the growing period.

Specific variation in methods will be mentioned with the individual experiment.

Figure 1. Field of yearling Mazzard cherry understock. Note the areas of stunted plants caused by root-lesion nematode parasitism. (Photo by H. J. Jensen)

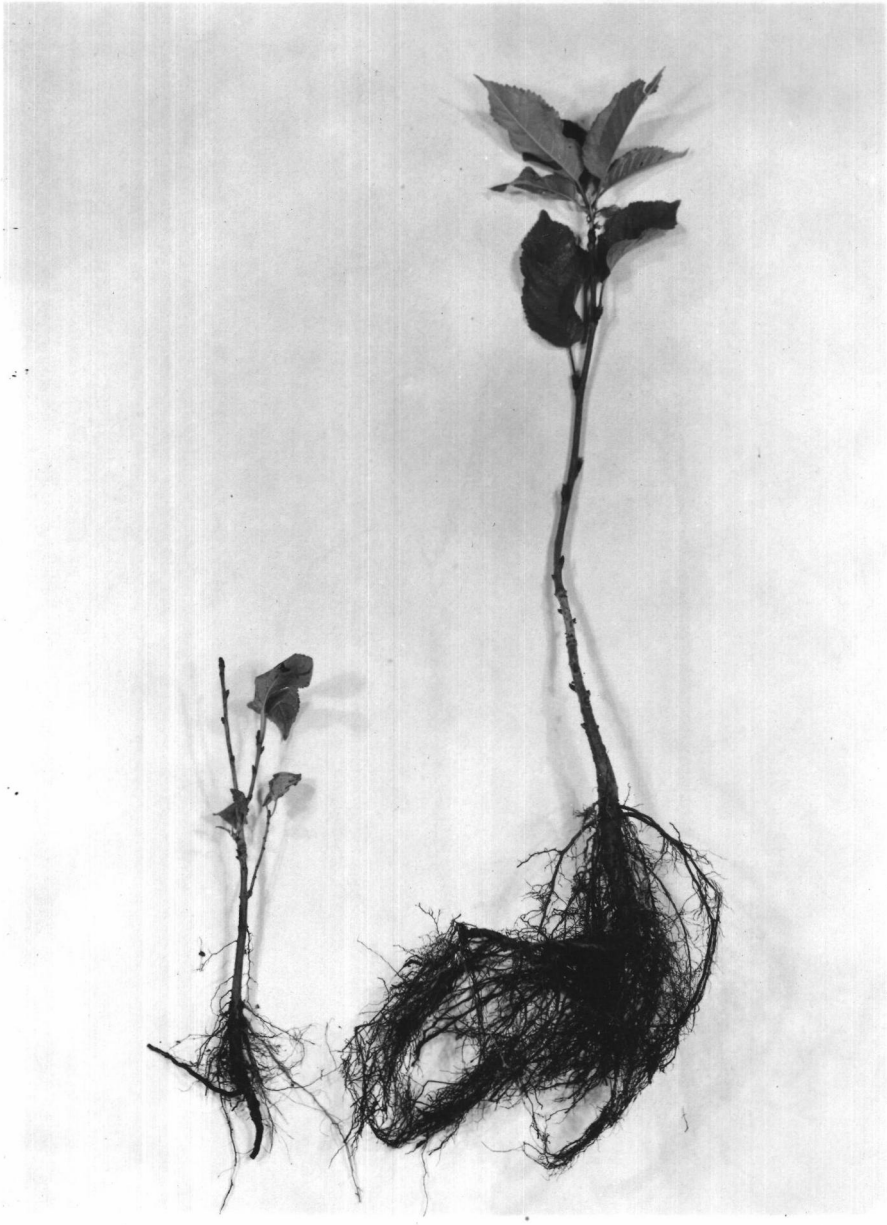

Figure 2. Mazzard cherry seedlings of similar age from the field shown in figure 1. Right, plant from lightly infested area of the field. Note the more abundant root system and average height. Left, a stunted plant with a greatly reduced root system from a heavily infested area. (Photo by H. H. Millsap)

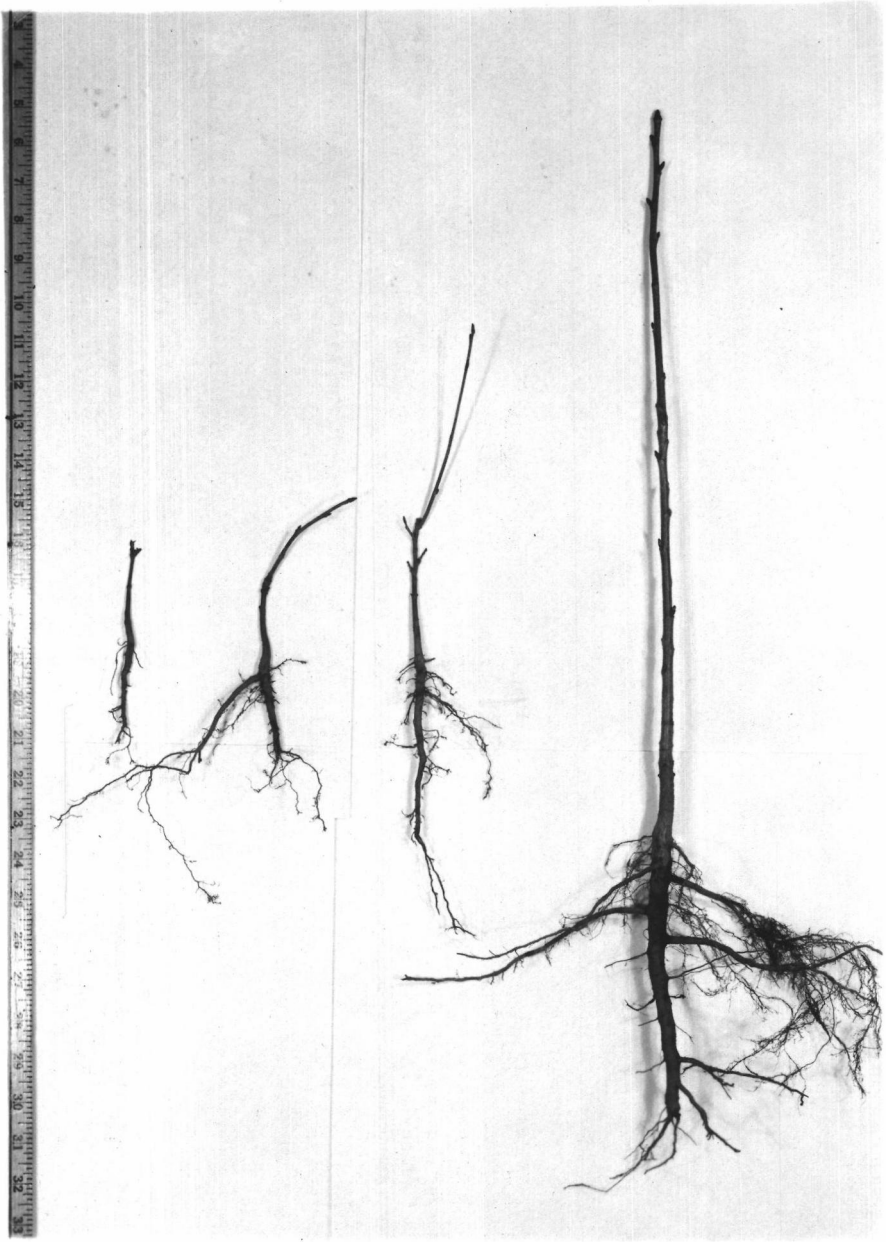

Figure 3. Mazzard cherry seedlings of similar age from the field shown in figure 1. Right, a plant from an area lightly infested with the root-lesion nematode. Left, three plants from areas of heavy investation of root-lesion nematodes. Note the differences in heights and root systems. (Photo by H. H. Millsap)

FUMIGATION TRIALS

A 250 cubic foot fumigation chamber was maintained at a temperature of 70°F. by thermostatically controlled electric lights. Air within the chamber was circulated by a 6 inch electric fan.

The fumigant, methyl bromide[1], was introduced into the chamber via copper tubing and collected in a splash pan from which it vaporized. The plant material to be treated was arranged on boxes about 3 feet above the floor so air could circulate freely.

Trial I. Mazzard seedlings infected with the root-lesion nematode were treated for 1, 2 and 3 hours at the concentrations equivalent to 2 and 3 pounds of methyl bromide per 1000 cubic feet. Following treatment the Mazzard seedlings along with untreated control plants were placed in storage at 35°F. and examined for viable nematodes 48 hours later.

When the roots of the treated Mazzard seedlings were teased apart only motionless and apparently dead nematodes were found. Examination of the control plants also revealed nematodes in the same condition. Thus the viability of the nematodes could not be determined by ordinary visual observation. Root-lesion nematode eggs were not observed and if they had been their viability could not have been determined without the use of an indicator plant. This difficulty led to growing the seedlings of subsequent trials before attempting to recover the viable root-lesion nematodes.

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1. A list of the chemicals used in some of the trials is given in Table 5.

Trial II. To eliminate whatever effects dry roots had on the root-lesion nematodes in Trial I, Mazzard seedlings with moist roots were fumigated for 1 - 3 hours at concentrations of 1 - 4 pounds of methyl bromide per 1000 cubic feet (Table 6).

After growing the plants in the greenhouse the viable root-lesion nematodes were isolated by the Baermann funnel technique. Only a slight reduction from the mean of the root-lesion nematode population in the control plants was achieved.

Trial III. Soil infested with 350 root-lesion nematodes per quart of soil was placed in gauze bags approximately 1 by 6 by 6 inches. Then the bags were exposed to methyl bromide fumigation for 1 - 3 hours at concentrations of 1 - 4 pounds per 1000 cubic feet (Table 7). Prior to treatment the soil was brought to the same temperature as the fumigation chamber. The soil moisture equivalent was 34.05 percent. The treated soil was planted to hairy vetch in 5 inch clay pots.

Methyl bromide appeared to have less effect on root-lesion nematodes in soil than in root tissue of Mazzard seedlings. No reduction in the root-lesion nematode population was obtained.

VACUUM FUMIGATION TRIALS

Nine materials were tested in these trials using Croft lilies and Mazzard seedlings. A vacuum chamber of 0.29 cubic feet was evacuated with a water aspirator. The fumigation was carried out at room temperature although the flask containing the fumigant was immersed in boiling water to facilitate introduction of the gas into the chamber.

Trial I. Mazzard seedlings were fumigated for 5 hours with CBP and formaldehyde at 50 and 34 pounds per 1000 cubic feet respectively (Table 8).

A large reduction in the root-lesion nematode population was obtained by fumigation of Mazzard seedlings with CBP and formaldehyde under vacuum. However, total elimination of root-lesion nematodes from root stocks was not realized.

Trial II. Croft lilies were treated with 7 materials at concentrations varying from 34 - 55 pounds per 1000 cubic feet for 2, 7 and 15 hours (Table 9).

The vapors of the materials introduced into the vacuum chamber proved to be phytotoxic in most instances. However, 3 materials, (CBP, formaldehyde and PN-1414) were generally non-injurious and greatly reduced the populations of root-lesion nematodes.

Trial III. Half of the Croft lilies treated had roots removed to within 1/8th inch of the basal plate to determine the combined effect of vacuum fumigation and root pruning. Seven materials were used as fumigants varying in concentration from 10 to 200 pounds per

1000 cubic feet. The period of exposure was for 5 hours (Table 10).

Increased concentrations of fumigants resulted in a reduction of the root-lesion nematode population. As in earlier trials eradication was not obtained and some fumigants caused stunting of the plants treated. Formaldehyde at all concentrations and EDB at 100 pounds per 1000 cubic feet approached a complete kill of root-lesion nematodes without injury to the plants.

CHEMICAL SOAKS

Dipping or soaking of plants or plant parts is a feasible and economical means of therapeutic treatment against plant diseases. In the chemical soak trials 16 materials were tested for their efficacy to penetrate root tissue and function as nematocides without causing injury.

Trial I. Croft lilies were soaked in 11 experimental materials for periods of 5 and 30 minutes at concentrations from 1 - 100 percent (Table 11). Dilutions were made with water then mixed to form a suspension.

At the concentrations used the materials included in the trial proved to be phytotoxic or ineffective in eradicating root-lesion nematodes. The chemicals were water soluble or soluble in organic solvents. To simulate these properties of solubility, oil and water soluble red dyes were selected to determine the degree of penetration into root tissue. Prolonged soaking of bulbs in oil or water soluble dyes in open vessels or under vacuum indicated that the roots were not penetrated except in small localized areas near wounds or broken endr of roots.

Trial II. The effects of root pruning and 9 chemical soaks were tested by removing the roots to within 1/8th inch of the basal plate of one half of the Croft lily bulbs (Table 12). Indicator plants were not used and the root-lesion nematode counts were obtained directly from the Croft lily roots.

Vapam at concentration of 0.5 and 1.0 percent reduced the root-lesion nematode population to a low level. All other chemicals tested were injurious or ineffective against root-lesion nematodes.

HOT WATER TRIALS

Hot-water treatment of plants and plant parts has long been an effective means of controlling some nematode diseases. Methods to adapt hot-water control for root-lesion nematodes and their host plants were investigated.

Trial I. Root-lesion nematode eggs, larvae and adults were separated from vetch root tissue by the centrifugal-flotation technique, suspended in water in test tubes, and subjected to hot-water treatments. The temperatures ranged from 101°F. to 120°F. For the temperatures below 115°F. the periods of exposure were 1 to 12 hours and for those above 5 to 60 minutes (Table 13).

In all instances except two adults, larvae and eggs failed to survive removal from root tissue or the hot-water treatment. The very low survival of the control isolates indicated the sensitivity of root-lesion nematodes when removed from their parasitic environment.

Trial II. The effect of hot water on the survival of root-lesion nematodes infecting Mazzard seedlings was investigated. The Mazzard seedlings were immersed in a precision hot-water treating unit (23, pp. 8-12). Temperatures ranged from 104°F. to 128°F. The periods of exposure were from 10 to 30 minutes (Table 14).

Populations of root-lesion nematodes were reduced to low levels by hot-water treatments of Mazzard seedling roots. However, death or severe plant injury resulted at temperatures 116°F. and above before root-lesion nematodes were eradicated.

Trial III. The effect of hot water and formaldehyde, at the rate

of one pint for each 25 gallons of water, on Mazzard seedlings was also investigated. The seedlings were treated for 1 hour at 110°F. and 114°F. (Table 15).

The efficacy of hot water against root-lesion nematodes in Mazzard seedlings was increased by the addition of formaldehyde. However, Mazzard seedlings were killed at two degrees lower (114°F.) than by hot water alone. After treatment at 110°F. the growth of Mazzard seedlings was reduced where hot water alone had no such effect.

Trial IV. Croft lily bulbs infected with root-lesion nematodes were immersed in the precision hot-water treating unit for treatment at temperatures ranging from 104°F. to 118°F. Water was heated in a pan for temperatures exceeding 118°F (Table 16). Each series (variations of time and temperature) consisted of 8 bulbs. Three bulbs were planted in the greenhouse for forcing. The other 5 bulbs were planted in a field near Brookings, Oregon for field observations.

The hot-water soak at 128°F. for a 10 minute period proved to be the most effective for eliminating the root-lesion nematode. The treatment with hot water except the most extreme (above 128°F.) appeared to have very little effect upon the forcing qualities of the lilies. The results were very different for the bulbs grown in the field where many of the time-temperature varients appeared to result in injury to the bulbs. This indicates that treatment of field planting stocks by hot-water soaks would have to be carefully controlled as many of the treated bulbs planted in the field grew poorly and/or split.

Unfortunately, most of the bulbs receiving soaks of 170°F. and 212°F. were destroyed by gophers in the field planting.

Trial V. The combined effect of root-pruned Croft lily bulbs and treatment with hot water on the viability of root-lesion nematodes was the objective of this trial. Temperatures ranged from 125°F. to 170°F. with periods of immersion from 3 - 60 minutes (Table 17). The roots were removed to within 1/8th inch of the basal plate of one half of the bulbs. Indicator plants were not used in this trial or in trial VI. The root-lesion nematodes were recovered directly from the Croft lily roots.

Root-lesion nematodes were recovered from bulbs which had been treated in hot water at temperatures up to 160°F. for 3 minutes. Differences in numbers of nematodes recovered from root-pruned bulbs and those bulbs with roots were inconsistant. The 128°F. hot-water soak, as in trial IV, was most effective for bulb treatment. The numbers of nematodes were reduced considerably but eradication was not obtained.

Trial VI. Formaldehyde was added to hot water at the rate of 1 pint for each 25 gallons of water for treating Croft lily bulbs, of which one half were root pruned as above. The range in temperatures was from 125°F. to 170°F. The periods of exposure were from 3 to 60 minutes (Table 18).

The combination of formaldehyde and root pruning did not add to the efficacy of the hot-water treatment. A higher number of root-lesion nematodes was recovered from the bulbs soaked at 128°F. for

10 minutes than the equivalent treatment without formaldehyde. The numbers of root-lesion nematodes recovered from bulbs with or without roots were erratic. Root-lesion nematodes were also obtained from bulbs which had been treated for as long as 3 minutes at 150°F.

HOT CARBON TETRACHLORIDE TRIAL

Miller (36, p. 87) reported carbon tetrachloride to be a good material for heat treatment of seed-borne diseases of peas and beans. He listed the advantages of carbon tetrachloride to be as follows: (a) non-phytotoxic, (b) readily evaporated, (c) leaves no residue, (d) does not wrinkle seed coat, (e) long periods of immersion have little effect on viability, and (f) seeds could be heated to higher temperatures in hot carbon tetrachloride without harmful effects than in hot water.

Trial I. This trial was designed to determine if the effects as listed by Miller could be reproduced with Croft lily bulbs. One-hundred-seventy Croft lily bulbs were immersed in hot carbon tetrachloride at temperatures ranging from 121°F. to 170°F. (boiling point for carbon tetrachloride). The periods of treatment were from 5 to 60 minutes. One half of the bulbs had been root pruned before treatment.

The treatment with hot carbon tetrachloride proved to be lethal to all Croft lily bulbs at all periods and temperatures. A preliminary trial with 10 Mazzard seedlings indicates carbon tetrachloride may be used more successfully with plants other than Easter lilies. The Mazzard seedlings were immersed in carbon tetrachloride for 10 minutes at 128°F. Three of the plants leafed and one lived, whereas no Mazzard seedlings survived hot water beyond 116°F. The surviving Mazzard seedling was still infected with root-lesion nematodes.

STORAGE-DESICCATION TRIALS

Hasting (25, pp. 39-44) reported a high susceptibility of root-lesion nematode to drying. Earlier observations (see fumigation trial I) also suggested lethal results from drying of roots. To evaluate the effect of time and desiccation on the survival of root-lesion nematodes in root-tissue, infected Mazzard seedlings were placed in temperature-controlled storage chambers. The average humidity, estimated by wet and dry bulb thermometers, was 78 percent.

Trial I. The seedlings to be exposed to desiccation were placed in open paper bags. For control plants seedlings were sealed in vapor proof plastic bags. A bag of dried seedlings and one of controls were removed from storage each day for 7 days, then each third or sixth day thereafter for a total of 31 days.

Time and drying had little or no effect on decreasing root-lesion nematode populations before the Mazzard seedlings were injured (Table 19). Death of the terminal and lateral buds was common, especially at the higher temperatures (Figures 4 & 5).

Trial II. Seedlings were handled as in trial I. An open paper bag and a sealed plastic bag were removed at 14 day intervals beginning with the 38th day of storage. The last pair was removed on the 108th day.

The extended time of desiccation was not sufficient to eliminate all root-lesion nematodes. Most of the seedlings were severely injured or killed (Table 20).

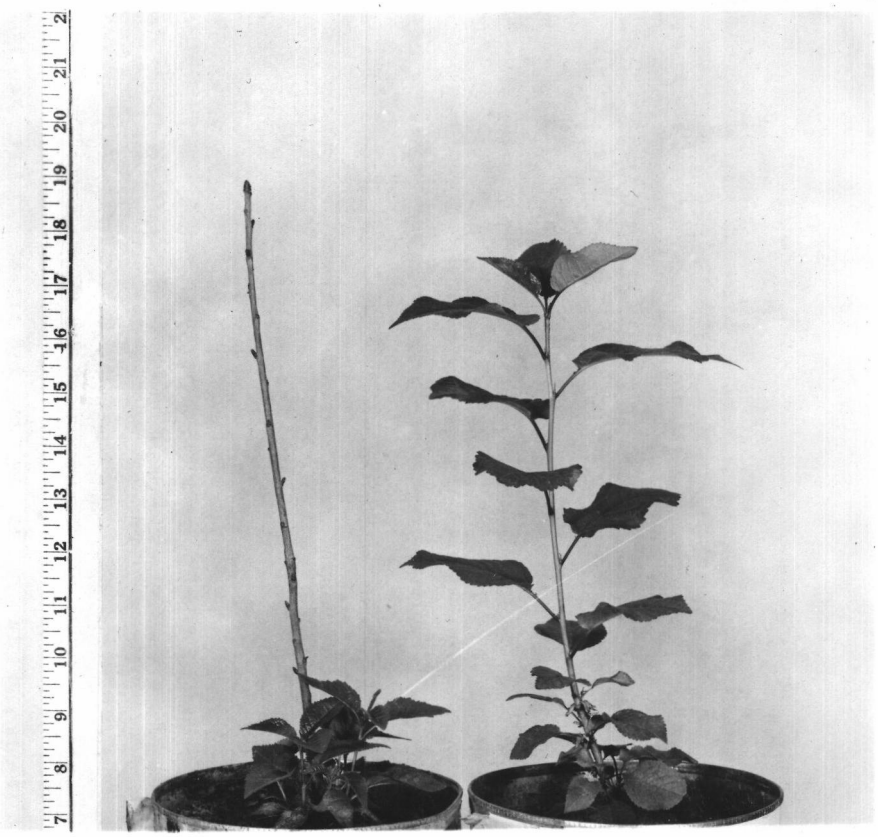

Figure 4. Growth of Mazzard cherry seedlings after 31 days of storage-desiccation treatment at 35°F. Right, control plant from sealed bag. Left, plant from open bag. The drying effect was lethal to the terminal and lateral buds. New adventitious buds have developed near the soil line. (Photo by H. H. Millsap)

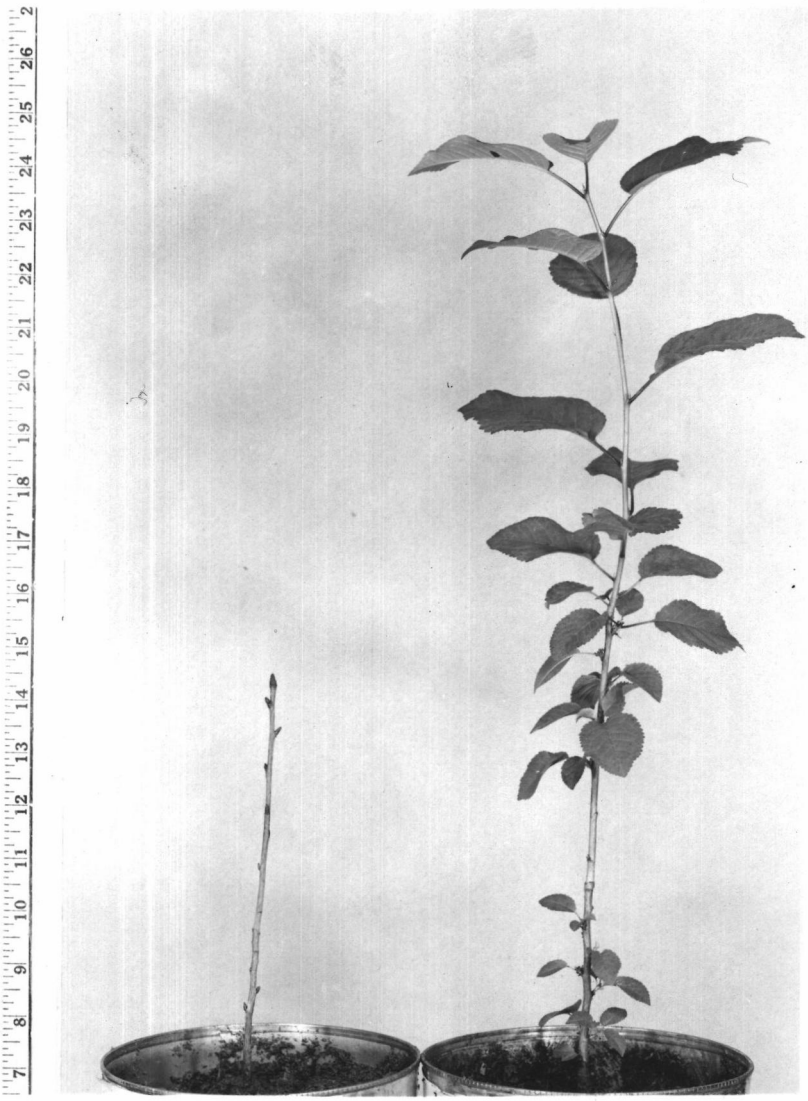

Figure 5. Growth of Mazzard cherry seedlings after 25 days of storage-desiccation treatment at 50°F. Right, control plant from sealed bag. Left, plant from open bag. The drying treatment caused the death of the entire plant. (Photo by H. H. Millsap)

DRY HEAT TRIAL

A dry-heat treatment would subject plants to extremely unnatural conditions. Croft lilies when dormant are highly tolerant to unfavorable conditions and were used for this trial.

Trial I. Croft lily bulbs were exposed to dry heat in temperature controlled ovens at temperatures from 100°F. to 190°F. for 1, 5 and 10 hours (Table 21). Each treatment consisted of 5 bulbs with roots and 5 bulbs with the roots removed to within 1/8th inch of the basal plate.

Root-lesion nematodes were recovered at all temperatures and periods of treatment where bulbs survived. As in other trials the differences in numbers of root-lesion nematodes recovered were not consistant with root-pruned bulbs or those bulbs with roots.

ROOT-PRUNING TRIALS

Reduction or elimination of a root-lesion nematode infection by removing diseased plant parts is possible since there are some plants that tolerate such pruning. Croft lilies are in this group and were used in the study of root-lesion nematode survival in bulbs from which roots had been removed.

Trial I. Root remnants were removed to within 1/8th inch of the basal plate of 25 Croft lily bulbs (number 9 commercials) to determine the proportion of root-lesion nematode carry-over. The removal of the root remnants from 25 Croft lily bulbs, known to be infected prior to treatment, eliminated the nematodes from 84 percent of the bulbs. There were no apparent adverse effects on the forcing performance of root-pruned bulbs that had been held in cold storage. (On the basis of 100 percent infection the root-pruned bulbs had a 17.4 percent carry-over). The control plants proved to have a 92 percent carry-over.

Trial II. Root remnants were removed to within 1/8th inch of the basal plate of 50 Croft lily bulbs (number 7 commercials) and the basal plates were scraped free of all root remnants of another 50 bulbs (Figure 6).

A 4 percent carry-over occurred in the 50 Croft lily bulbs which had the roots trimmed. (On the basis of 100 percent infection the root-pruned bulbs had a 16.7 percent carry-over). Of the Croft lily bulbs which had the basal plates scraped, a 2 percent carry-over was found. (On the basis of 100 percent infection the treated bulbs had

an 8.3 percent carry-over). The control plants had a 24 percent carry-over of root-lesion infection.

Trial III. Twenty-five Croft lily bulbs (yearlings) were root pruned to within 1/8th inch of the basal plate for a basis of comparison with Croft lily bulbs used in trials combining root pruning with a therapeutic treatment.

Root removal had no effect in reducing root-lesion nematode infection in yearling bulbs as both the root-pruned bulbs and the controls had a 96 percent carry-over. These results were different from trials I and II where root-lesion nematode carry-over in number 9 bulbs was 17.4 percent and 16.7 percent in number 7 bulbs. Possible explanations of differences in amount of carry-over in the three trials may be that: (a) root-lesion nematodes invade the scales or basal plates of yearling bulbs to a greater extent than older bulbs; (b) the nematodes migrate from the older scales as food reserves are translocated to other areas; (c) competition from other organisms limit or exclude root-lesion nematodes.

Figure 6. Examples of various degrees of root pruning of Croft Easter lily bulbs. Right, control non-pruned bulb. Center, bulb with roots pruned to within 1/8th inch of the basal plate. Left, bulb with all roots removed and the basal plate scraped. (Photo by H. H. Millsap)

ANTIBIOTIC TRIAL

The feasibility of using antibiotics as a therapeutant against plant parasitic nematodes was initiated with a preliminary screening trial. Using Panagrellus silusiae (de Man, 1913) Goodey, 1945 as a test organism, 13 antibiotics were tested for lethal activity against nematodes. The nematodes, approximately 1700, were placed in petri dishes on agar containing various concentrations of an antibiotic. The various antibiotics were tested at concentrations of 1 to 10,000 ppm and examined at 2 and 14 day intervals.

Six of the antibiotics tested affected the nematodes adversely only at high concentrations (2,000 and/or 10,000 ppm). The other antibiotics were ineffective even at a 1 percent concentration (Table 22). These results did not warrant further investigation of antibiotics as therapeutic agents.

DISCUSSION

Methyl bromide frumigation of plant roots reduced the numbers of root-lesion nematodes. This reduction indicates that an additional reduction or perhaps eradication may be achieved with an increase in methyl bromide concentration, or time, or both.

A high moisture equivalent may account for the lack of effect by methyl bromide on the soil population of root-lesion nematodes. These results point out one of the difficulties that may be encountered if fumigation of balled nursery stock is attempted where a high organic soil content may also be found.

Complete elimination of root-lesion nematodes from root tissue was not achieved using the principle of vacuum fumigation. However, Vapam, EDB and formaldehyde reduced the root-lesion nematode populations to very low levels. These surviving root-lesion nematodes may be inconsequential in the culture of some crops. In all instances, however, the transmission of root-lesion nematode infestations to new areas is not desirable.

The phytotoxicity of nematocides tested made them useless as therapeutants in chemical soak treatments. To be effective the killing agent must penetrate the roots and be non-phytotoxic. None of the materials used in these trials possessed all of the desired characteristics.

Hot-water treatment is an effective tool in the control of foliar and other kinds of nematodes. Elimination of the root-lesion nematodes from roots of infected plants was not realized without injury

to the plants. However, in almost all treatments a reduction in the numbers of root-lesion nematodes surviving was obtained. In some cases they averaged less than one root-lesion nematode per plant.

Since the adults and larvae of the root-lesion nematode are readily killed in dried root tissue one may assume that the egg is the surviving stage. However, even the egg is highly susceptible to changes of environment if it is removed from the protective root tissue in which it was layed (see section on hot-water trials).

That some stage of the root-lesion nematode survives drying is clearly demonstrated in the dry heat trial. Root-lesion nematodes were recovered from bulbs which had been heated to 190°F. for 1 hour and 128°F. for 5 hours. Such data definitely suggest some resistant life stage.

With Easter lilies and similar ornamentals the practice of reducing root-lesion nematode populations by removal of plant parts is at best only a temporary measure. The root pruning trial where all root remnants were removed and the basal plate scraped had an 8.3 percent carryover of root-lesion nematodes. Hence, even with extreme measures all the root-lesion nematodes were not eliminated. Root pruning of Easter lily bulbs, therefore, can be employed as a means of partial control.

The showing of such low nematocidal activity indicates that antibiotics will probably not be useful as nematode-control agents. Antibiotics, however, may be used for external and possibly for internal sterilization of nematodes for aseptic studies.

SUMMARY

Eight therapeutic methods were investigated as means of eradicating root-lesion nematodes from Croft Easter lily bulbs and Mazzard cherry seedlings.

Fumigation was effective in reducing total numbers of root-lesion nematodes. Methyl bromide fumigation brought about slight reductions in root-lesion nematode populations. Elimination of root-lesion nematodes from root tissue was not achieved by vacuum fumigation although Vapam, EDB and formaldehyde reduced the nematode populations to low levels.

The materials tested in chemical soaks were phytotoxic or ineffective in controlling root-lesion nematodes in root tissue. However, reduction of root-lesion nematode populations to less than one per plant was obtained by hot-water treatments although some plant injury was usually sustained. Trials employing hot carbon tetrachloride as the heating medium were lethal to all the Croft Easter lily bulbs treated although one Mazzard cherry seedling and the infesting root-lesion nematode population survived 128°F. for 10 minutes.

Mazzard cherry seedlings were severely injured or killed by drying in storage to eradicate the root-lesion nematode by desiccation. The seedlings died before the root-lesion nematode could be controlled. Dry heat was also ineffective as a root-lesion nematode control measure. Bulbs which had been heated to 190°F. for 1 hour and 128°F. for 5 hours still retained viable root-lesion nematodes.

Root-lesion nematode carry-over was reduced to 8.3 percent of Croft Easter lily bulbs by scraping the basal plate free of root remnants. Pruning of the roots to within 1/8th inch of the basal plate of commercial size bulbs reduced the root-lesion nematode carry-over to an average of 17.1 percent. Yearling bulbs had a 96 percent carry-over.

Thirteen antibiotics were screened for nematocidal activity. Six were toxic to the nematodes at 2,000 and/or 10,000 ppm. The others had no effect on the nematodes even at the highest concentrations used.

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APPENDIX

Table 4. A list of plants selected for a host range study on the root-lesion nematode, *Pratylenchus penetrans*.

Scientific Name	Common Name
Host Plants of *Pratylenchus penetrans*	
Avena sativa L.	Oat
Brassica campestris L.	Wild Turnip
Bryophyllum sp.	
Cerastium viscosum L.	Annual Mouse-eared Chickweed
Chenopodium album L.	Lamb's Quarter
Chrysanthemum leucanthemum L.	Ox-eye Daisy
Dactylis glomerata L.	Orchard Grass
Festuca myuros L.	Rat-tail Fescue
Galium sp.	
Geranium dissectum L.	Cut-leaved Geranium
Linaria vulgaris Hill	Toad-flax
Poa annua L.	Annual Bluegrass
Polygonum hydropiper L.	Common Smartweed
Senecio vulgaris L.	Groundsel
Sisymbrium officinale (L.) Scop.	Hedge Mustard
Sonchus asper (L.) Hill	Spiny-leaved Sonchus
Spergula arvensis L.	Corn Spurry
Stellaria media (L.) Cyr.	Common Chickweed
Trifolium dubium Sibth.	Smallhop Clover
Verbascum Blattaria L.	Moth Mullein
Plants Not Hosts of *Pratylenchus penetrans*	
Anthemis cotula L.	Dog-fennel
Rumex acetosella L.	Sheep Sorrel

Table 5. A list of the chemical compounds referred to in the text and tables.

Code no. or abbreviation of chemical	Trade name of chemical	Technical name of chemical
Systox	Systox	Ethyl mercaptoethyl diethyl thiophosphate
AC-14	None	Methyl acrylate
Gentian violet	Gentian violet	Triamino-triphenyl methane group mixture
Phenol	Carbolic acid	Phenol
1197	None	Not disclosed
NP-1093 &	None	1,4-dichloro 2-butyne
NP-1353	None	Propargyl chloride
N-339	None	Dimethyl disulfide
EDB	Dowfume W-85	Ethylene-dibromide
CBP	CBP-55	Chlorobromopropene
DD	Shell DD mixture	Dichloropropene-dichloropropane
PN-1414	None	Ethylisothiocyanate
Lysol	Lysol	Soap, orthothydroxydiphenyl, alcohol, cresylic acid
Vapam	Vapam	N-methyl dithiocarbamate
Nemagon	Nemagon	1,2-dibromo-3-chloropropane
Allyl bromide	Allyl bromide	3-bromo-propene-1
Formaldehyde	Formaldehyde	Formaldehyde
Methyl bromide	Methyl bromide	Bromomethane

Table 6. The average number of root-lesion nematodes (Pratylenchus penetrans) recovered from Mazzard cherry seedling roots after treatment by methyl bromide fumigation.

Methyl bromide lbs/1000 cu.ft.	Period of exposure in hours	No. of nematodes recovered per plant*	Plant response
1	1	996	Normal**
	2	483	Normal
	3	358	Normal
2	1	621	Normal
	2	279	Normal
	3	42	Normal
3	1	112	Normal
	2	271	Normal
	3	167	Normal
4	1	137	Normal
	2	162	Normal
	3	187	Normal
Control		514***	Normal

* Average of 12 plants.
** Normal in respect to the control plants, i. e. approximately 15-60 cm. new growth.
*** Average of 48 plants.

Table 7. The average number of root-lesion nematodes (Pratylenchus penetrans) recovered from infested soil after treatment by methyl bromide fumigation.

Methyl bromide lbs/1000 cu.ft.	Period of exposure in hours	No. of nematodes recovered per pot*
1	1	80
	2	80
	3	70
2	1	530
	2	670
	3	570
3	1	860
	2	220
	3	100
4	1	63[illegible]
	2	610
	3	240
Control		595**

* Average of 5 replications.
** Average of 40 replications.

Table 8. The average number of root-lesion nematodes (Pratylenchus penetrans) recovered from Mazzard cherry seedling roots after treatment by vacuum fumigation.

Fumigant	Concentration of active ingredients lbs/1000 cubic feet	No. of nematodes per plant* 5 hours exposure	Plant response
CBP	50	2.5	Normal**
Formaldehyde	34	20.5	Normal
Control		142.0	Normal

* Average of 20 plants.
** Normal in respect to the control plants, i. e. approximately 15-60 cm. new growth.

Table 9. The average number of root-lesion nematodes (Pratylenchus penetrans) recovered from Croft Easter lily roots after various treatments by vacuum fumigation.

Fumigant	Concentration of active ingredients lbs/1000 cu. ft.	Nematodes recovered from each period of exposure per plant* 2 hrs	7 hrs	15 hrs	Plant Response
EDB	50	17	42	0	Normal**
EDC	47	150	0	17	Slight dwarfing
CBP	50	33	0	0	Normal
Allyl bromide	55	0	0	0	All dead
DD	50	0	0	0	Dead or slight dwarfing
Formaldehyde	34	80	17	0	Normal
PN-1414	38	0	8	0	Slight dwarfing above 2 hours exposure
Control		400***			Normal

* Average of three plants.
** Normal in respect to the control plants, i. e. approximately 35 cm. in height and producing 1-3 blossoms.
*** Average of 7 plants.

Table 10. The average number of root-lesion nematodes (Pratylenchus penetrans) recovered from Croft Easter lily roots after various periods of vacuum fumigation.

Fumigant	Concentration of active ingredients lbs/1000 cubic feet	No. of nematodes recovered per plant* 5 hours exposure		Plant response	
		Root pruned	With roots	Root pruned	With roots
EDB	75	10.0	19.2	Normal	Normal
	100	1.0	3.6	Normal	Normal
	150	-	-	All dead	All dead
CBP	50	-	-	All dead	All dead
	75	-	-	All dead	All dead
	100	-	-	All dead	All dead
Allyl bromide	10	-	-	All dead	All dead
	20	-	-	All dead	All dead
	40	-	-	All dead	All dead
DD	10	0.0	0.2	Normal	Normal
	20	0.0	0.8	Normal	Normal
	40	17.8	7.8	Normal	Normal
Formaldehyde	50	0.0	0.0	Dwarfed	Dwarfed
	100	0.0	0.2	Normal	Normal
	200	0.2	0.0	Normal	Normal
Vapam	10	0.0	2.0	Dwarfed	Dwarfed
	40	0.0	0.0	Dwarfed	Dwarfed
	80	1.2	0.8	Dwarfed	Dwarfed

Table 10. Continued.

Fumigant	Concentration of active ingredients lbs/1000 cubic feet	No. of nematodes recovered per plant 5 hours exposure		Plant response	
		Root pruned	With roots	Root pruned	With roots
Nemagon	10	0.0	0.2	Dwarfed	Dwarfed
	40	0.5	1.2	Dwarfed	Dwarfed
	80	13.4	26.8	Normal	Normal
Control**		34.0	46.2	Normal	Normal

* Average of 5 plants.
** Average of 25 plants.

Table 11. The average number of root-lesion nematodes (Pratylenchus penetrans) recovered from Croft Easter lily roots after treatment by chemical soaks.

Chemical	Percent Concentration	Period of treatment and number of nematodes recovered per plant* 5 minutes	30 minutes	Plant Response
Systox 42%	20	0	0	All dead
AC-14	1	0	0	All dead
Gentian violet	1	0	0	All dead
Phenol	1	0	0	All dead
1197	100	0	0	All dead
339	5	100	160	Normal**
EDB	100	0	0	All dead
CBP	100	0	0	All dead
DD	100	0	0	All dead
PN-1414	1	0	0	All dead
NP-1093 & NP-1353	1	25	60	Slight dwarfing
Control		150	475	Normal

* Average of three plants.
** Normal in respect to the control plants, i. e. approximately 35 cm. in height and producing 1-3 blossoms.

Table 12. The average number of root-lesion nematodes (Pratylenchus penetrans) recovered from Croft Easter lily bulbs after treatment by chemical soaks.

Chemical	Percent concentration	Period of exposure in minutes	No. of nematodes per plant*		Plant response	
			Root pruned	With roots	Root pruned	With roots
Systox-lysol mixture	0.005 & 0.005	30	42.0	87.2	Normal	Normal
	0.01 & 0.01	30	28.4	18.2	Normal	Normal
	0.1 & 0.1	30	8.5	16.2	Normal	Normal
Systox	0.005	30	6.2	60.4	Normal	Normal
	0.01	30	3.4	44.0	Normal	Normal
	0.1	30	4.0	32.0	Normal	Normal
Lysol	0.005	30	17.2	132.6	Normal	Normal
	0.01	30	35.4	203.8	Normal	Normal
	0.1	30	5.4	52.4	Normal	Normal
EDB	0.5	60	0.3	0.2	Dwarfed	Dwarfed
	1.0	60	17.6	43.3	2 dead	2 dead
	5.0	60	-	-	All dead	All dead
CBP	0.5	60	0.0	7.3	1 dead	2 dead
	1.0	60	0.0	10.0	Dwarfed	Dwarfed
	5.0	60	-	-	All dead	All dead
Vapam	0.5	60	1.6	15.0	Normal	Normal
	1.0	60	1.3	2.2	Normal	Normal
	5.0	60	-	-	All dead	All dead
Nemagon	0.5	60	0.0	0.0	4 dead	3 dead
	1.0	60	-	-	All dead	All dead
	5.0	60	-	-	All dead	All dead

Table 12. Continued.

Chemical	Percent concentration	Period of exposure in minutes	No. of nematodes per plant		Plant response	
			Root pruned	With roots	Root pruned	With roots
Allyl bromide	0.5	60	-	-	All dead	All dead
	1.0	60	-	-	All dead	All dead
	5.0	60	-	-	All dead	All dead
Formaldehyde	18.5	60	-	-	All dead	All dead
	37.0	60	-	-	All dead	All dead
Control***			34.0	46.2	Normal	Normal

* Average of 5 plants.
** Normal in respect to the control plants, i. e. approximately 35 cm in height and producing 1-3 blossoms.
*** Average of 25 plants.

Table 13. The average number of root-lesion nematodes (*Pratylenchus penetrans*) recovered by indicator plants after treatment of eggs, larvae and adults with hot water.

Temperature in degrees Fahrenheit	Period of exposure	No. of larvae & adults per test tube	No. of eggs per test tube	No. of nematodes recovered by indicator plants* larvae & adults	eggs
101	1 hour	950	300	0	0
	2 hours			0	0
	3 hours			8	0
	6 hours			0	0
	9 hours			0	0
	12 hours			0	0
	Control			100	33
104	1 hour	1500	800	0	17
	2 hours			0	0
	3 hours			0	0
	6 hours			0	0
	9 hours			0	0
	12 hours			0	0
	Control			50	50
107	1 hour	1200	800	0	0
	2 hours			0	0
	3 hours			0	0
	6 hours			0	0
	9 hours			0	0
	12 hours			0	0
	Control			50	108
110	1 hour	1500	1000	0	0
	2 hours			0	0
	3 hours			0	0

Table 13. Continued.

Temperature in degrees Fahrenheit	Period of exposure	No. of larvae & adults per test tube	No. of eggs per test tube	No. of nematodes recovered by indicator plants larvae & adults	eggs
110	6 hours			0	0
	9 hours			0	0
	12 hours			0	0
	Control			42	25
115	5 minutes	700	400	0	0
	10 minutes			0	0
	20 minutes			0	0
	30 minutes			0	0
	40 minutes			0	0
	50 minutes			0	0
	60 minutes			0	0
	Control			25	70
120	5 minutes	1200	1500	0	0
	10 minutes			0	0
	20 minutes			0	0
	30 minutes			0	0
	Control			50	50

* Average of 3 replications.

Table 14. The average number of root-lesion nematodes (*Pratylenchus penetrans*) recovered from Mazzard cherry seedling roots after treatment with hot water.

Temperature in degrees Fahrenheit	Period of exposure in minutes	No. of nematodes recovered per plant*	Plant response
104	10	2080	Normal**
	15	1210	Normal
	20	990	Normal
	25	1110	Normal
	30	1250	Normal
108	10	1490	Normal
	15	590	Normal
	20	880	Normal
	25	1020	Normal
	30	930	Normal
110	10	490	Normal
	15	490	Normal
	20	520	Normal
	25	200	Normal
	30	490	Normal
112	10	710	Normal
	15	330	Normal
	20	860	Normal
	25	560	Normal
	30	240	Normal
116	10	140	Normal
	15	110	Normal
	20	60	Normal
	25	100	2 dead
	30	0	4 dead
122	10	0	1 dead
	15	0	4 dead
	20	0	5 dead
	25	0	5 dead
	30	0	4 dead

Table 14. Continued.

Temperature in degrees Fahrenheit	Period of exposure in minutes	No. of nematodes recovered per plant	Plant response
128	10	0	5 dead
	15	0	5 dead
	20	0	5 dead
	25	0	5 dead
	30	0	5 dead
Control		1265***	Normal

* Average of 5 plants.
** Normal in respect to the control plants, i. e. approximately 15-60 cm. new growth.
*** Average of 10 plants.

Table 15. The average number of root-lesion nematodes (*Pratylenchus penetrans*) recovered from Mazzard cherry seedling roots after treatment with hot water and formaldehyde.

Temperature in degrees Fahrenheit	Period of exposure in hours	No. of nematodes recovered per plant*	Plant response
110	1	0.066	Slight dwarfing
	Control	43.000	Normal**
114	1	-------	All dead
	Control	142.000	Normal

* Average of 15 plants.
** Normal in respect to the control plants, i. e. approximately 15-60 cm. new growth.

Table 16. The average number of root-lesion nematodes (*Pratylenchus penetrans*) recovered from Croft Easter lily roots after treatment by hot water.

Temperature	Period of Exposure	No. of Nematodes Recovered per Plant*	Greenhouse Observation	Field Observation
104°F.	1 hr	900	Normal**	Normal
	2 hrs	650	Normal	Normal
	3 hrs	775	Normal	Normal
	4 hrs	900	Normal	Slight dwarfing
	5 hrs	700	Normal	Slight dwarfing
	6 hrs	625	Normal	Slight dwarfing
	10 hrs	425	Normal	Slight dwarfing
108°F.	1 hr	850	Normal	Normal
	2 hrs	125	Normal	Normal
	3 hrs	275	Normal	Normal
	4 hrs	650	Normal	Slight dwarfing
	5 hrs	125	Normal	Slight dwarfing
	6 hrs	33	Slight dwarfing	Slight dwarfing
	10 hrs	375	Slight dwarfing	Slight dwarfing
110°F.	5 min	325	Normal	Normal
	10 min	300	Normal	Normal
	20 min	300	Normal	Slight dwarfing
	40 min	550	Normal	Slight dwarfing
	1 hr	1100	Normal	Slight dwarfing
	1.5 hrs	150	Normal	Slight dwarfing
	2 hrs	825	Normal	Slight dwarfing
	3 hrs	525	Normal	Slight dwarfing

Table 16. Continued.

Temperature	Period of Exposure	No. of Nematodes Recovered per Plant	Greenhouse Observation	Field Observation
112°F.	5 min	425	Normal	Normal
	10 min	350	Normal	Normal
	20 min	425	Normal	Normal
	40 min	200	Normal	Normal
	1 hr	225	Normal	Normal
	1.5 hrs	125	Normal	Slight dwarfing
	2 hrs	350	Normal	Slight dwarfing
	3 hrs	100	Normal	Slight dwarfing
114°F.	5 min	250	Normal	Normal
	10 min	225	Normal	Normal
	20 min	325	Normal	Normal
	40 min	200	Normal	Normal
	1 hr	150	Normal	Normal
	1.5 hrs	125	Normal	Slight dwarfing
118°F.	5 min	200	Normal	Normal
	10 min	275	Normal	Slight dwarfing
	20 min	275	Normal	Slight dwarfing
	40 min	17	Normal	Slight dwarfing
128°F.	5 min	25	Normal	Slight dwarfing
	10 min	0	Normal	Slight dwarfing
	20 min	0	Normal	Slight dwarfing

Table 16. Continued.

Temperature	Period of Exposure	No. of Nematodes Recovered per Plant	Greenhouse Observation	Field Observation
170°F.	5 min	0	Slight dwarfing	Destroyed by gophers
	10 min	0	All dead	
	20 min	0	All dead	
212°F.	5 sec	42	Slight dwarfing	Destroyed by gophers
	10 sec	0	Slight dwarfing	
	15 sec	0	Slight dwarfing	
	20 sec	25	Slight dwarfing	
	30 sec	0	Slight dwarfing	
	40 sec	17	Slight dwarfing	
	50 sec	0	Slight dwarfing	
	60 sec	8	Slight dwarfing	
	120 sec	0	All dead	
	180 sec	0	All dead	
	240 sec	0	All dead	
	300 sec	0	All dead	
Control		600***	Normal	Normal

* Average of three plants.
** Normal in respect to the control plants, i. e., approximately 35 cm in height and producing 1-3 blossoms.
*** Average of ten plants.

Table 17. The average number of root-lesion nematodes (*Pratylenchus penetrans*) recovered from Croft Easter lily bulbs after treatment with hot water.

Temperature in degrees Fahrenheit	Period of exposure in minutes	No. of nematodes recovered per plant*		Plant response	
		Root pruned	With roots	Root pruned	With roots
125	10	0.2	0.5	Dwarfed	Dwarfed
	30	-	-	All dead	All dead
	60	-	-	All dead	All dead
128	6	1.3	0.0	Dwarfed	Dwarfed
	7	1.4	0.2	Dwarfed	Normal**
	8	2.0	1.0	Dwarfed	Normal
	9	7.5	6.2	Dwarfed	Normal
130	3	18.0	17.2	4 dead	Normal
140	3	5.0	3.5	Dwarfed	Dwarfed
150	3	0.0	0.0	Normal	Normal
160	3	0.7	0.0	Dwarfed	Dwarfed
170	3	-	0.0	All dead	Dwarfed
Control***		34.0	46.2	Normal	Normal

* Average of 5 plants.
** Normal in respect to the control plants, i. e. approximately 35 cm in height and producing 1-3 blossoms.
*** Average of 25 plants.

Table 18. The average number of root-lesion nematodes (Pratylenchus penetrans) recovered from Croft Easter lily bulbs after treatment by hot water with formaldehyde.

Temperature in degrees Fahrenheit	Period of exposure in minutes	No. of nematodes recovered per plant*		Plant response	
		Root pruned	With roots	Root pruned	With roots
125	10	0.2	0.8	Dwarfed	Dwarfed
	30	-	-	All dead	All dead
	60	-	-	All dead	All dead
128	5	0.8	4.6	Normal**	Normal
	6	0.0	0.4	Dwarfed	Dwarfed
	7	0.4	5.2	Dwarfed	Normal
	8	0.4	2.0	Dwarfed	Dwarfed
	9	0.4	0.8	Dwarfed	Normal
	10	18.4	0.4	Normal	Normal
130	3	3.8	1.2	Normal	Dwarfed
140	3	0.4	0.5	Dwarfed	Dwarfed
150	3	3.0	0.0	Dwarfed	Dwarfed
160	3	0.0	0.0	Dwarfed	Dwarfed
170	3	0.0	0.0	Dwarfed	Dwarfed
Control***		34.0	46.2	Normal	Normal

* Average of 5 plants.

** Normal in respect to the control plants, i. e. approximately 35 cm in height and producing 1-3 blossoms.

*** Average of 25 plants.

Table 19. The average number of root-lesion nematodes (Pratylenchus penetrans) recovered from Mazzard cherry seedling roots after treatment by storage-desiccation.

No. of days storage	Temperature in degrees Fahrenheit	No. of nematodes recovered per plant* open bag	control	Plant response open bag	control
1	35	2100	2220	Normal **	Normal
	40	1720	4320	Normal	Normal
	45	1760	980	Normal	Normal
	50	1710	1680	Normal	Normal
2	35	1600	1720	Normal	Normal
	40	1500	2160	Normal	Normal
	45	1540	1630	Normal	Normal
	50	1220	1300	Normal	Normal
3	35	2480	2450	Normal	Normal
	40	2900	2200	Normal	Normal
	45	3530	3740	Normal	Normal
	50	2300	2770	Normal	Normal
4	35	1680	3520	Normal	Normal
	40	2980	5000	Normal	Normal
	45	3810	3160	Normal	Normal
	50	2530	2730	Normal	Normal
5	35	3370	1870	Normal	Normal
	40	3170	2880	Normal	Normal
	45	1890	1660	Normal	Normal
	50	3500	2600	Normal	Normal
6	35	2000	2470	Normal	Normal
	40	2510	2680	Normal	Normal
	45	1970	2060	Normal	Normal
	50	900	2440	Bud kill***	Normal
7	35	2390	2000	Normal	Normal
	40	1910	1120	Normal	Normal
	45	1720	1730	Normal	Normal
	50	130	1670	1 dead & bud kill	Normal
10	35	1150	2470	Normal	Normal
	40	2560	2470	Normal	Normal
	45	1220	2010	Normal	Normal
	50	633	1280	2 dead & bud kill	Normal

Table 19. Continued.

No. of days storage	Temperature in degrees Fahrenheit	No. of nematodes recovered per plant open bag	control	Plant response open bag	control
13	35	1620	2400	Normal	Normal
	40	1470	1970	Normal	Normal
	45	890	1940	Normal	Normal
	50	100	2280	3 dead & bud kill	Normal
19	35	100	2150	1 dead & bud kill	Normal
	40	510	700	bud kill	Normal
	45	590	1210	bud kill	Normal
	50	0	1030	all dead	Normal
25	35	200	1640	4 dead & bud kill	Normal
	40	600	1670	1 dead & bud kill	Normal
	45	330	560	bud kill	Normal
	50	0	1090	all dead	Normal
31	35	225	980	3 dead & bud kill	Normal
	40	550	550	2 dead & bud kill	Normal
	45	0	1180	all dead	Normal
	50	0	1240	all dead	Normal

* Average of 5 plants.
** Normal in respect to the control plants, i. e. approximately 15-60 cm. new growth.
*** Terminal bud usually with some lateral buds dead.

Table 20. The average number of root-lesion nematodes (Pratylenchus penetrans) recovered from Mazzard cherry seedling roots after treatment by storage-desiccation.

No. of days storage	Temperature in degrees Fahrenheit	No. of nematodes recovered per plant* open bag	control	Plant response open bag	control
38	35	0	0	Normal**	Normal
	40	133	66	Normal	Normal
52	35	0	117	All dead	Normal
	40	0	75	New top & root growth***	Normal
66	35	0	133	All dead	Normal
	40	17	100	New top & root growth	Normal
80	35	0	50	All dead	Normal
	40	0	66	All dead	Normal
108	35	0	38	All dead	Normal
	40	0	25	All dead	Normal

* Average of 3 plants.
** Normal in respect to the control plants, i. e. approximately 15-60 cm. new growth.
*** New roots and stems developed near ground line.

Table 21. The average number of root-lesion nematodes (*Pratylenchus penetrans*) recovered from Croft Easter lily bulbs after treatment with dry heat.

Temperature in degrees Fahrenheit	Period of exposure in hours	No. of nematodes recovered per plant*		Plant response	
		Root pruned	With roots	Root pruned	With roots
100	1	1.8	55.2	Normal**	Normal
	5	3.0	3.4	Normal	Normal
	10	-	0.0	All dead	Dwarfed
110	1	4.8	6.2	Normal	Normal
	5	0.0	0.2	Dwarfed	Dwarfed
	10	-	-	All dead	All dead
120	1	7.4	24.4	Normal	Normal
	5	2.5	-	3 dead	All dead
	10	-	-	All dead	All dead
128	1	16.0	7.4	Normal	Normal
	5	0.4	5.0	Normal	Normal
	10	-	-	All dead	All dead
135	1	-	7.0	All dead	Dwarfed
	5	-	-	All dead	All dead
	10	-	-	All dead	All dead

Table 21. Continued.

Temperature in degrees Fahrenheit	Period of exposure in hours	No. of nematodes recovered per plant		Plant response	
		Root pruned	With roots	Root pruned	With roots
190	1	0.0	133.0	3 dead	3 dead
	5	-	-	All dead	All dead
	10	-	-	All dead	All dead
Control***		34.0	46.2	Normal	Normal

* Average of 5 plants.
** Normal in respect to the control plants, i. e. approximately 35 cm in height and producing 1-3 blossoms.
*** Average of 25 plants.

Table 22. Percent of surviving Panagrellus silusiae on agar containing an antibiotic.

Antibiotic	Manufacturer	Concentration in ppm	Percent of nematodes alive* 2 days	14 days
Streptomycin sulfate 600 mig/mg	Pfizer & Co.	1	100	100
		10	100	100
		100	100	100
		1,000	100	100
		10,000	100	100
Terramycin 390 mig/mg	Pfizer & Co.	1	100	100
		10	100	100
		100	100	100
		1,000	100	50
		10,000	0	0
Tetracycline 135 mig/mg	Pfizer & Co.	1	100	100
		10	100	100
		100	100	100
		1,000	100	100
		10,000	100	0
Agrimycin**	Pfizer & Co.	1	100	100
		10	100	100
		100	100	100
		1,000	100	100
		10,000	100	100
Terramycin hydrochloride 910 mig/mg	Pfizer & Co.	1	100	100
		10	100	100
		100	100	100
		1,000	100	100
		10,000	100	100

Table 22. Continued.

Antibiotic	Manufacturer	Concentration in ppm	Percent of nematodes alive 2 days	Percent of nematodes alive 14 days
Neomycin***	Merck & Co.	1	100	100
		10	100	100
		100	100	100
		1,000	100	100
		10,000	100	100
Candicidin***	Merck & Co.	1	100	100
		10	100	100
		100	100	100
		1,000	100	100
		10,000	100	100
Pleocidin***	Merck & Co.	1	100	100
		10	100	100
		100	100	100
		1,000	100	100
		10,000	100	0
Streptothricin hydrochloride***	Merck & Co.	1	100	100
		10	100	100
		100	100	100
		1,000	100	100
		10,000	100	0

Table 22. Continued.

Antibiotic	Manufacturer	Concentration in ppm	Percent of nematodes alive 2 days	14 days
Actidione 10 mg/tablet	Upjohn & Co.	1	100	100
		10	100	100
		100	100	100
		1,000	100	100
		10,000	100	100
Penicillin G. potassium***	Upjohn & Co.	1	100	100
		10	100	100
		100	100	100
		1,000	100	100
		10,000	100	100
Neomycin sulfate 650 mig/mg	Upjohn & Co.	1	100	100
		10	100	100
		100	100	100
		1,000	100	100
		10,000	100	3
Antibiotic Q-19 6000 units/mg	Upjohn & Co.	0.2	100	100
		2	100	100
		20	100	100
		200	100	100
		2,000	25	0
Control**			100	100

* Average of 3 replications.
** Average of 14 replications.
*** Concentration not given.