PATHOGENIC BEHAVIOR AND LIFE HISTORIES OF THE ROOT-KNOT NEMATODES, *MELOIDOGYNE* SPP., ON SNAPDRAGON, *ANTIRRHINUM MAJUS*

By

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INTRODUCTION AND REVIEW OF LITERATURE[1]

For some time the degree of pathogenicity of the root-knot nematode to various crop plants has been the subject of extensive investigations. Numerous inconsistencies in results had indicated the possibility that populations or races of the nematode existed. Tufts and Day (22) reported that Bokhara, Shalil, and Yunnan peaches, when grown in soil uniformly infested with root-knot nematodes, were not attacked by these pathogens. In a later report (10), however, these investigators reported that each of the three peach varieties could show light infection by these nematodes. They referred to the fact that while growing hundreds of Shalil seedlings in a root-knot nematode infested nursery for 6 years, not one plant was attacked by nematodes, yet when the nursery site was changed to a location a mile away, 24 percent of the Shalil seedlings were attacked. These investigators concluded that different nematode strains existed at the two growing sites.

In experiments attempting to infect Shalil and Natural peach seedlings using root-knot nematode infested soil from 5 different locations, Clayton (9) found that in soil from 3 orchards Shalil roots remained free from root-knot while 50 to 70 percent of the Natural seedlings were affected. Both varieties, however, were equally susceptible to root-knot when grown in soil from orchards where Shalil seedlings were affected. On the basis of similar observations various investigators concluded that the root-knot nematode was comprised of races or strains (4, 6, 11, 17, 20, 24). Several of these races have

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[1]This project was carried out under a cooperative agreement with the Bureau of Plant Industry, Soils, and Agricultural Engineering, Beltsville, Md.

been tested against important fruit and vegetable crop plants. Christie and Havis (8) tested several races of the root-knot nematode against varieties of peach trees. Their results showed that individual varieties reacted differently in gall formation when infected with different races of the root-knot nematode. Reynolds (15) found that when 3 races of root-knot nematodes were tested on Egyptian and Upland cotton, differences in the mean number of nematode egg masses per plant resulting from the inoculations were all significant at odds of 99 to 1. Christie and Albin (6), who did some of the most thorough work investigating the possibility of the occurrence of races of the root-knot nematode, stated that plants may be susceptible to 1 race but resistant to another or that plants may be susceptible to each of 2 different races but may differ in the type of root galling produced by 1 race in comparison to that produced by the other. They found that peanut, cotton, and alfalfa were all susceptible to some races but resistant to others. In working with tomato which was equally susceptible to all races, they found that some races produced galls that were small, inconspicuous, and mostly confined to small roots with large roots near the base of the stem not being appreciably affected. Other populations produced similar galling of tomato plants except that most of the galls developed numerous radiating rootlets which in turn bore galls with radiating rootlets, resulting in a reticulate root system. One population, they found, caused swelling of all roots, many large galls, and a conspicuous absence of fine roots. They concluded that there were probably 5 or more distinct races of the root-knot nematode and claimed "the possibility that some races may possess distinguishing morphological characters cannot, as yet, be ruled out."

The occurrence of races or populations of the root-knot nematode was an accepted theory when Chitwood (3) separated the root-knot nematodes into 5 distinct species and revived the generic name Meloidogyne. The species of Meloidogyne, according to Chitwood, are separated by distinct morphological characters as well as differences in pathogenicity to various hosts in most cases. Meloidogyne exigua Goeldi 1887 was originally observed on coffee roots in Brazil. Adequate preserved material was available for study of the species but to date, abundant living material has been unavailable. Meloidogyne javanica (Treub 1885) Chitwood 1949 was originally described as infecting sugar cane in Java. In the United States, this species has been found infecting roots of root-knot susceptible and "resistant" peach varieties as well as several ornamental and vegetable crop plants. Meloidogyne hapla Chitwood 1949 was found originally on Green Mountain variety potato but has also been observed on strawberries, parsnips, peanuts, and tomatoes. Meloidogyne incognita (Kofoid and White 1919) Chitwood 1949 was originally found in fecal samples of soldiers in Texas and other southern states and was thought to have been present in vegetables eaten by the soldiers. Meloidogyne incognita is regarded as being the most common root-knot nematode in a large part of the United States (21). It has been reported infecting canaigre (Rumex hymenosepalus) in Arizona (16) and cinchona (Cinchona micrantha) in Guatemala (19). Chitwood (3) states that this nematode reproduces on Yellow Globe onions, cotton, celery, lima beans, peppers, and cactus. It does not reproduce on peanuts or Yunnan and Shalil peach roots. Taylor and Chitwood (21) claim that Lycopersicon peruvianum is not affected by M. incognita.

Meloidogyne incognita var. acrita Chitwood 1949 closely resembles the parent species in both morphology and pathogenicity. Slight differences in morphology are apparent in comparisons of the perineal regions and shapes of stylet knobs of nematodes between the variety and the parent species. Meloidogyne incognita var. acrita may be separated from M. incognita in that the former will infect Lycopersicon peruvianum while the latter will not (21). Meloidogyne arenaria (Neal 1889) Chitwood 1949 was first observed causing extensive damage on peanut. Although it is pathogenic to Lovell peach, it reproduces poorly if at all, on this host.

Snapdragon (Antirrhinum majus L.) was first listed as being susceptible to root-knot by Bessey (2). Watkins (23), strangely enough, regarded Antirrhinum as being resistant to root-knot nematode infection while Barrus, et. al. (1), Godfrey (12), and Parris (14) have all claimed that snapdragon was definitely susceptible to attack by the root-knot nematode. There are a number of instances on record in the files of the Division of Nematology, U. S. Department of Agriculture, Beltsville, Md., in which snapdragon roots have been found to bear well-established infections of root-knot nematodes.

The revision of the root-knot nematodes necessarily invalidated a great deal of the work which had been done previously on pathogenicity of this group to various plants. Now that several species of the root-knot nematode are recognized, the possibility exists that each may invoke a distinctly different pathological response from a specific host.

Research reported in this thesis involves the use of several root-knot nematode species in determining the effects of these parasites

on snapdragon as well as the effects of the host on the parasites. It was felt that such basic research into the problem might aid materially in determining additional similarities or differences between species.

MATERIALS AND METHODS

Nematode inoculum, used in the following experiments, consisted of egg masses of Meloidogyne arenaria, M. hapla, M. incognita, M. incognita var. acrita, and M. javanica. All species were maintained on the Rutgers variety of tomato, Lycopersicon esculentum Mill. on which production of egg masses readily occurs. In 2 of the 3 experiments to be discussed, the 3 levels of inoculum employed were 1, 10, and 100 egg masses. The 1 and 10 egg mass inoculums were obtained by the selection of small sections of root tissue in each of which was situated an ovipositing female nematode. This method was preferred in lieu of accumulating only the egg masses since it had been observed, in using the latter method, that many times a considerable number of eggs will adhere to the female in the process of separation. In obtaining the 100 egg mass inoculums, heavily infected roots bearing numerous egg masses were finely chopped and thoroughly mixed. Egg masses contained in a representative portion of this material were then counted under a dissecting microscope and the corresponding weight of roots containing approximately 100 egg masses was computed. It should be stressed that before any inoculum was selected from an infected plant, several representative egg masses were broken open, under a dissecting microscope, and the contents checked to insure the presence of either first stage or second stage larvae.

The 5 varieties of snapdragon used in these tests were Ball Red Hybrid #7, Christmas Cheer, Margaret, Maryland Pink, and Ball Yellow Hybrid #1. Plants were grown from seed germinated in vermiculite and transplanted, after growth for approximately a month, to five-inch pots half filled with a potting mixture of 1 part sand to 1 part soil.

After the proper inoculum was introduced into each pot and thoroughly mixed into the surface of the soil, potting mixture necessary to fill each pot was added and the pots watered thoroughly.

Due to the lack of adequate greenhouse space, plants were necessarily grown quite close to one another. This created the hazard of contamination of treatments from splashing between pots during watering. To eliminate this danger, a spray rig consisting of 8 dispersing nozzles was mounted on wires above the bench and was used to water the plants throughout these experiments (Fig. 1). This apparatus delivered a fine water spray to the plants and was effective in eliminating splashing between pots.

In harvesting, the root systems of the plants were washed gently in water so that all debris was eliminated. All weight measurements were expressed in grams. Indexing of infected roots was accomplished using the system proposed by Smith and Taylor (18). In this system of indexing, plants without any visible root infection received a rating of 0, those with root systems bearing 1 to 25 percent infection of the total amount of root surface received a rating of 1, those with root infections of 26 to 50 percent received a rating of 2, plants with 51 to 75 percent of their root systems infected received a rating of 3, and those with root systems bearing 76 to 100 percent infections received a rating of 4. One half of the root system of each infected plant was preserved in 5 percent formalin for future counts of females and egg masses at which time the roots were washed free of formalin, finely chopped, and thoroughly mixed. In selecting appropriate samples for counts of adult female nematodes and egg masses, 300 mg. of all plants which were originally inoculated with 1 egg mass, 200 mg. of

plants inoculated with 10 egg masses, and 100 mg. of plants inoculated with approximately 100 egg masses were weighed on a torsion balance with proper caution being exercised so that no 1 sample dried out more than others. Each weighed sample of roots was placed in a shallow layer of water in a Syracuse watch glass and carefully examined for the presence of adult female nematodes and egg masses.[1] Having obtained counts from each sample, values were then computed, on the basis of root weight of each plant, in order to represent the total number of females and egg masses per plant. Values for the rate of nematode reproduction for each plant were obtained by dividing the total number of egg masses per plant by the total number of females.

In the final experiment in which details of the development of each nematode species were studied, snapdragon seedlings of the Margaret variety growing in 3-inch pots were inoculated with egg masses collected from the roots of snapdragons grown in a previous experiment. A single egg mass was inserted into each of 5 small holes around the crown of each plant after which the holes were filled with soil and the plants watered.

The staining technique employed for demonstrating the presence of root-knot nematodes was suggested by H. W. Reynolds.[2] In preparation of the staining solution, 6 cc. of distilled water, 10 cc. of 1 percent chromic acid, 10 cc. of 10 percent acetic acid, and 2 cc. of 2 percent osmic acid were combined and heated to approximately 55° C. Roots were

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[1]As suggested by B. G. Chitwood, Department of Biology, Catholic University, Washington, D. C.

[2]Associate Nematologist, Division of Nematology, U. S. Field Station, Sacaton, Arizona.

stained in this solution for about 1½ hours after which they were washed in running water for 3 hours. They were then immersed in 15 percent ethyl alcohol for 15 min., 30 percent for 30 min., 50 percent for 1 hour, 70 percent for overnight, 80 percent for 2 hours, 95 percent for 2 hours, and absolute for 2 hours. The dehydrated roots were then cleared overnight in methyl salicylate (synthetic oil of wintergreen). Permanent mounts of root sections were made using Canada balsam as the mounting medium.

Photographs of plants were made with a 4 X 5 Pacemaker Speed Graphic using Ansco Isopan film. All charts were photographed with the same camera equipped with Kodak Contrast Process Panchromatic film. Photomicrographs of nematodes in root tissues were made with a Leitz "Makam" (Mikro-Aufsatzkamera) using Kodak Contrast Process Panchromatic film mounted on a Spencer microscope.

EXPERIMENTS AND RESULTS

1949 Tests

The first experiment was designed to investigate the effect of 5 species of root-knot nematodes at 3 levels of inoculum on 5 varieties of snapdragon. All possible combinations of these variables as well as 1 uninoculated control plant of each snapdragon variety were replicated in each of 5 blocks. Plants were placed in the greenhouse in a split plot design and grown at an average temperature of 22° C. After 2½ months data were obtained on top weight (weight of aerial parts), root weight, root-knot index, number of females, number of egg masses, and rate of nematode reproduction of each plant. An account of the procedures used in obtaining these data has previously been given. Tables I through XX present these data for nematode species, snapdragon varieties, and levels of inoculum as well as for the interactions of the above variables with each other.

In the interpretation of results throughout this paper, Meloidogyne incognita var. acrita will be regarded as a separate species and shall be referred to as M. incognita acrita. This is done for purposes of brevity in the presentation of these data. No attempt will be made to discuss all of the interactions shown in the various tables presented. In all cases, only those data which show significant differences between Meloidogyne species will be referred to except when otherwise stated.

Table I shows the mean top weight per plant of 5 snapdragon varieties at 3 levels of inoculum.

In inspecting the data for top weights of plants, differences between top weights of some varieties of snapdragons were evident.

These differences also occurred at each level of inoculum.

Table I. Mean top weight per plant of 5 snapdragon varieties at 3 levels of inoculum.

Snapdragon Varieties	Egg Masses in Inoculum 1	10	100	Variety Mean
Ball Red	16.4[a]	16.2	12.9	15.1
Christmas Cheer	20.9	18.2	14.2	17.8
Margaret	17.8	13.9	10.4	14.0
Maryland Pink	23.6	20.0	13.1	18.9
Ball Yellow	16.8	16.3	12.7	15.3
LSD .05[b]	.....	2.8	.....	1.6
LSD .01	.....	3.7	.....	2.2

[a]All weights are expressed in grams.

[b]LSD -- Least difference between means necessary for significance at the level indicated.

The effect in reduction of top weight due to increasing increments of inoculum is highly significant (Table II).

Table II. Mean top weights of plants inoculated with 5 species of Meloidogyne at 3 levels of inoculum.

Egg Masses in inoculum	Meloidogyne species arenaria	hapla	incognita	incognita acrita	javanica	Inoc. Mean
1	17.2	21.6	19.0	22.6	15.1	19.1
10	15.2	18.1	17.9	17.3	15.8	16.9
100	13.2	14.1	11.6	8.8	15.6	12.7
LSD .05	.....	2.8[a]	.....	6.6[b]	.....	1.3
LSD .01	.....	3.7	.....	8.9	.....	1.7

[a]Between inoculum levels, within a species.

[b]Between species within the same or different inoculum levels.

Further examination of these data shows considerable variation in the effect due to inoculum levels for different species. For instance, M. javanica produced no decrease in top weight as inoculum was increased, while there was a decrease in top weight of M. incognita

acrita infected plants when the level was increased from 1 to 10 egg masses and from 10 to 100 egg masses. Meloidogyne incognita infected plants showed a significant decrease in top weight only when the inoculum was increased to 100 egg masses. As with plants infected with M. incognita acrita, the mean top weight for plants infected with each inoculum level of M. hapla was different than that of plants at the other levels. Plants at the 1 egg mass inoculum level for M. arenaria had a higher top weight than those at the 100 egg mass level.

In comparisons between species at the same level of inoculum, plants infected with M. javanica had a lower mean top weight than M. incognita acrita infected plants at the 1 egg mass inoculum level, while the converse was true at the 100 egg mass level of inoculum.

There were no significant differences between mean top weights of varieties infected with Meloidogyne species as shown in Table III.

Table III. Mean top weight per plant of 5 snapdragon varieties inoculated with 5 species of Meloidogyne.

Meloidogyne species	Snapdragon Varieties					
	Ball Red	Christmas Cheer	Margaret	Maryland Pink	Ball Yellow	Species Mean
arenaria	13.2	17.1	12.9	17.2	16.1	15.3
hapla	18.0	18.1	17.7	21.3	14.7	17.9
incognita	18.4	16.2	12.9	19.4	14.0	16.2
incognita acrita	13.9	17.1	13.5	20.9	15.6	16.2
javanica	12.2	20.4	13.1	15.6	16.2	15.5
LSD .05	.....	3.7[a]	.....	7.0[b]	.....	n.s.[c]
LSD .01	.....	4.8	.....	9.3	.....	n.s.

[a]Between varieties, within a species.

[b]Between species, within the same or different varieties.

[c]n.s. -- differences are not statistically significant.

In the analysis of these data for the effect of interactions between snapdragon varieties and Meloidogyne species, differences were evident between top weights for some nematode species infecting the various varieties of snapdragon. Plants of the Ball Red variety infected with M. hapla and M. incognita had greater weights than plants infected with the other species. Christmas Cheer variety snapdragons infected with M. incognita had a lower top weight than plants infected with M. javanica. Within Margaret variety, plants infected with M. hapla had a greater weight than plants infected by the other species of Meloidogyne. Whereas M. javanica infected plants of Maryland Pink variety had a lower top weight than plants infected by M. hapla, M. incognita, and M. incognita acrita, plants infected with M. arenaria had a lower weight than M. hapla and M. incognita acrita infected plants.

Top weights of plants grown as uninoculated controls are presented in Table IV. These values were not analysed statistically.

Table IV. Mean top weight per plant of uninoculated snapdragon controls.

Snapdragon varieties	Variety Mean in grams
Ball Red	27.2
Christmas Cheer	23.1
Margaret	19.7
Maryland Pink	28.6
Ball Yellow	11.7

When the average weight of each variety was computed, it was found that all varieties, with the exception of Ball Yellow, had a greater top weight than inoculated plants.

Block diagrams illustrating the results obtained in the analysis of top weight of plants are presented in Fig. 2.

Table V shows the mean root weight per plant of 5 snapdragon varieties at 3 levels of inoculum.

Table V. Mean root weight per plant of 5 snapdragon varieties at 3 levels of inoculum.

Snapdragon Varieties	Egg Masses in Inoculum 1	10	100	Variety Mean
Ball Red	18.2	18.7	12.7	16.5
Christmas Cheer	22.1	24.5	15.2	20.6
Margaret	24.0	18.9	14.4	19.1
Maryland Pink	30.5	21.5	13.0	18.7
Ball Yellow	21.3	16.5	13.1	17.0
LSD .05	.....	4.0	.....	2.3
LSD .01	.....	5.3	.....	3.1

Analysis of root weights of infected plants showed some differences between varieties of snapdragons. Some of these differences were significant for the 1 and 10 egg mass inoculum levels but not for the 100 egg mass level of inoculum.

A high degree of significance was apparent in the overall reduction of root weight due to the higher increment of inoculum (Table VI).

Table VI. Mean root weights of plants inoculated with 5 species of Meloidogyne at 3 levels of inoculum.

Egg Masses in inoculum	Meloidogyne species arenaria	hapla	incognita	incognita acrita	javanica	Inoc. Mean
1	17.7	21.3	23.2	28.0	17.6	21.6
10	15.8	20.9	22.4	23.5	17.5	20.0
100	13.4	17.3	12.0	10.8	14.3	13.5
LSD .05	.....	4.0[a]	.....	5.6[b]	.....	1.8
LSD .01	.....	5.3	.....	7.4	.....	2.4

[a]Between inoculum levels within a species.

[b]Between species, within the same or different inoculum levels.

These data show that root weights of the 100 egg mass inoculations were lower than for the 1 egg mass inoculations for plants infected with all nematode species except M. javanica. There were differences between M. incognita and M. incognita acrita infected plants in that for M. incognita there were no significant differences in root weight between the 1 and 10 egg mass levels while for M. incognita acrita the mean root weight for the 10 egg mass level was lower than for the 1 egg mass level. There were no apparent differences in root weight between plants infected with different levels of M. javanica.

Comparison of mean root weights of plants infected with the different species at the 1 egg mass level of inoculum disclosed that the weight of M. incognita acrita infected plants was higher than weights of M. arenaria, M. hapla, and M. javanica infected plants. Plants infected with M. incognita had a higher root weight than those infected with M. javanica. In the 10 egg mass inoculum level, both M. incognita and M. incognita acrita infected plants had a higher root weight than M. arenaria infected plants, while M. incognita acrita infected plants were higher in root weight than M. javanica infected plants. For the 100 egg mass inoculum group, plants infected with M. incognita acrita were lower in mean root weight than plants infected with M. hapla.

As shown in Table VII, M. hapla, M. incognita, and M. incognita acrita infected plants had higher root weights than those infected by M. arenaria and M. javanica.

The effect of interactions shown in Table VII indicate that only variety Ball Red had a comparable pattern of root weights when subjected to infection by species of Meloidogyne. For Christmas Cheer

variety, the mean root weight of M. javanica infected plants was higher than root weights of plants infected by M. arenaria, M. hapla, and M. incognita. In marked contrast, however, M. javanica infected plants of Margaret variety had a lower root weight than plants of the same variety infected by M. hapla, M. incognita, and M. incognita acrita. There were no significant differences in root weight of plants of Maryland Pink or Ball Yellow varieties infected by each of the 5 nematode species.

Table VII. Mean root weight per plant of 5 snapdragon varieties inoculated with 5 species of Meloidogyne.

Meloidogyne species	Snapdragon Varieties: Ball Red	Christmas Cheer	Margaret	Maryland Pink	Ball Yellow	Species Mean
arenaria	12.5	17.2	16.8	16.4	15.2	15.6
hapla	19.6	18.1	22.0	22.0	17.4	19.8
incognita	20.9	19.6	20.7	18.3	16.5	19.2
incognita acrita	19.4	21.9	21.5	20.8	20.1	20.8
javanica	10.1	26.2	14.4	16.0	15.6	16.5
LSD .05	.....	5.2[a]	.....	6.1[b]	.....	2.2
LSD .01	.....	6.8	.....	8.1	.....	2.9

[a]Between varieties, within a species.

[b]Between species, within the same or different varieties.

Root weights of plants grown as uninoculated controls are presented in Table VIII; these values were not analysed statistically.

Table VIII. Mean root weight per plant of uninoculated snapdragon controls.

Snapdragon Varieties	Variety Mean in grams
Ball Red	18.6
Christmas Cheer	17.8
Margaret	20.8
Maryland Pink	23.6
Ball Yellow	18.0

All varieties, with the exception of Christmas Cheer, had a greater root weight than plants which were inoculated.

Fig. 3 shows block diagrams of the results obtained in the analysis of root weight of plants.

As indicated in Table IX, analysis of root-knot indices of snapdragon varieties showed that no significant differences existed.

Table IX. Mean root-knot index per plant of 5 snapdragon varieties at 3 levels of inoculum.

Snapdragon Varieties	Egg Masses in Inoculum			Variety Mean
	1	10	100	
Ball Red	0.8	1.5	2.3	1.5
Christmas Cheer	0.6	1.4	2.2	1.4
Margaret	1.1	1.5	2.2	1.6
Maryland Pink	0.8	1.6	2.4	1.6
Ball Yellow	0.7	1.3	2.0	1.5
LSD .05	.....	0.3	.....	n.s.
LSD .01	.....	0.4	.....	n.s.

Further inspection of the above table reveals that differences existed between root-knot indices of snapdragon varieties when grown at different levels of inoculum.

Mean root-knot indices of plants subjected to different levels of inoculum increased significantly with the increase in inoculum (Table X).

Table X. Mean root-knot indices of plants inoculated with 5 species of Meloidogyne at 3 levels of inoculum.

Egg Masses in Inoculum	Meloidogyne Species					Inoc. Mean
	arenaria	hapla	incognita	incognita acrita	javanica	
1	0.9	0.4	0.8	1.0	0.8	0.8
10	1.4	1.0	1.8	2.2	0.9	1.5
100	2.0	1.5	3.4	3.4	1.2	2.3
LSD .05	.....	0.3[a]	.....	0.5[b]	.....	0.1
LSD .01	.....	0.4	.....	0.6	.....	0.2

[a]Between inoculum levels, within a species.

[b]Between species, within the same or different inoculum levels.

Differences are apparent in the behavior of each nematode species at each of the 3 rates of inoculum used. Mean root-knot indices of M. javanica infected plants, however, showed no differences in index rating between the 1 and 10 egg mass inoculations.

Meloidogyne hapla infections were manifested in a lower mean root-knot index at the 1 egg mass level than infections of M. arenaria and M. incognita acrita. At the 10 egg mass level M. javanica infected plants had a lower index than plants infected with M. arenaria, which, in turn, had a lower index than plants infected with M. incognita acrita. Both M. hapla and M. javanica infected plants had lower indices than plants infected with M. incognita and M. incognita acrita. Approximately the same relationships existed for the 100 egg mass level as for the 10 egg mass level.

A high degree of significance, in some cases, was evident between root-knot indices of plants infected with the 5 species of Meloidogyne (Table XI).

Table XI. Mean root-knot index per plant of 5 snapdragon varieties inoculated with 5 species of Meloidogyne.

Meloidogyne Species	Snapdragon Varieties: Ball Red	Christmas Cheer	Margaret	Maryland Pink	Ball Yellow	Species Mean
arenaria	1.5	1.5	1.1	1.7	1.5	1.4
hapla	1.1	0.9	1.3	0.9	0.7	1.0
incognita	1.9	1.7	2.1	2.1	2.2	2.0
incognita acrita	2.1	2.1	2.5	2.2	2.1	2.2
javanica	1.1	0.7	1.1	1.0	0.9	1.0
LSD .05	.....	0.4[a]	.....	0.7[b]	.....	0.3
LSD .01	.....	0.5	.....	0.9	.....	0.4

[a] Between varieties, within a species.

[b] Between species, within the same or different varieties.

As shown in Table XI, root-knot indices for M. incognita and M. incognita acrita infected plants were higher than for plants infected with the other species of Meloidogyne. Plants infected with M. arenaria had a higher mean index than did plants infected with M. hapla and M. javanica. These data also show that Ball Red plants infected with M. incognita and M. incognita acrita had higher indices than did plants infected with M. hapla and M. javanica. Within variety Christmas Cheer, plants infected with M. incognita and M. incognita acrita had a significantly higher mean root-knot index than did plants infected with M. hapla and M. javanica while the mean root-knot index for M. arenaria infected plants was higher than that for M. javanica infected plants. Within Margaret and Maryland Pink varieties, M. incognita and M. incognita acrita affected plants had indices which were higher than those for plants infected by the other 3 species. The mean root-knot index for plants of the Ball Yellow variety infected with M. incognita was significantly higher than that for plants infected with M. arenaria, M. hapla, and M. javanica. Meloidogyne incognita acrita infected plants had a higher index than plants infected with M. hapla and M. javanica. Plants infected with M. arenaria had a higher index than those infected with M. hapla.

Block diagrams of the results obtained in the analysis of root-knot indices are presented in Fig. 4.

Table XII presents the mean number of nematodes in 5 snapdragon varieties at each of the 3 inoculum levels.

As shown in the following table, there were no significant differences in mean number of females between snapdragon varieties or in the effect of interactions between snapdragon varieties with inoculum levels.

Table XII. Mean number of female nematodes per plant in 5 snapdragon varieties at 3 levels of inoculum.

Snapdragon Varieties	Egg Masses in Inoculum 1	10	100	Variety Mean
Ball Red	202	1063	1927	1064
Christmas Cheer	140	1128	2503	1257
Margaret	425	1071	1580	1025
Maryland Pink	287	981	1942	1190
Ball Yellow	120	602	1805	842
LSD .05	.....	n.s.	.....	n.s.
LSD .01	.....	n.s.	.....	n.s.

Counts of the mean number of females were found to differ significantly between levels of inoculum (Table XIII).

Table XIII. Mean numbers of female nematodes in plants inoculated with 5 species of Meloidogyne at 3 levels of inoculum.

Egg Masses in Inoculum	Meloidogyne Species arenaria	hapla	incognita	incognita acrita	javanica	Inoc. Mean
1	150	130	385	182	328	235
10	1147	551	1409	1759	340	1041
100	1323	1145	3041	2702	1546	1951
LSD .05	.....	577[a]	.....	788[b]	.....	258
LSD .01	.....	750	.....	1013	.....	336

[a]Between inoculum levels, within a species.

[b]Between species, within the same or different inoculum levels.

Examination of these data shows that the number of females in plants infected with M. arenaria at the 1 egg mass inoculum level was significantly lower than the number for the 10 and 100 egg mass levels. For M. hapla and M. javanica infected plants, there was no difference in counts between the 1 and 10 egg mass levels, but both of these were lower than for the 100 egg mass levels. Mean counts of females from M. incognita and M. incognita acrita infected plants indicated that an increase in inoculum level resulted in a corresponding increase in number of females.

Comparisons of the number of females for each species at the 10 egg mass level signify that M. javanica infected plants had fewer female nematodes than plants infected with M. arenaria. Both M. hapla and M. javanica formed fewer females than M. incognita and M. incognita acrita. For the 100 egg mass level, plants infected with M. incognita and M. incognita acrita had a greater number of females than plants infected with the other species.

Differences between some Meloidogyne species were apparent in Table XIV.

Table XIV. Mean number of female nematodes per plant in 5 snapdragon varieties inoculated with 5 species of Meloidogyne.

Meloidogyne Species	Snapdragon Varieties: Ball Red	Christmas Cheer	Margaret	Maryland Pink	Ball Yellow	Species Mean
arenaria	775	1032	650	1065	842	873
hapla	577	514	554	896	502	609
incognita	2154	1763	1231	1869	1043	1612
incognita acrita	1245	1725	1867	1589	1312	1548
javanica	569	1252	824	532	513	738
LSD .05	.....	.....	n.s.	.....	.....	417
LSD .01	.....	.....	n.s.	.....	.....	576

This table shows that M. incognita and M. incognita acrita formed a greater mean number of females than M. arenaria, M. hapla, or M. javanica. When the effect of interactions between snapdragon varieties and Meloidogyne species upon number of females was considered, it was found not to be significant.

Block diagrams of the results obtained in the analysis of mean root-knot indices are shown in Fig. 5.

Table XV presents the number of egg masses per plant in 5 snapdragon varieties at the 3 levels of inoculum.

Table XV. Mean number of egg masses per plant in 5 snapdragon varieties at 3 levels of inoculum.

Snapdragon Varieties	Egg Masses in Inoculum 1	10	100	Variety Mean
Ball Red	159	743	1478	793
Christmas Cheer	86	909	2067	1021
Margaret	315	697	1144	719
Maryland Pink	227	1071	1625	974
Ball Yellow	80	476	1455	670
LSD .05	.....	n.s.		n.s.
LSD .01	.....	n.s.		n.s.

Analysis of the mean numbers of egg masses per plant in the above table showed no significant differences between snapdragon varieties or between snapdragon variety -- inoculum level interactions.

The number of egg masses in each inoculum level, as shown in Table XVI, differed from those of other levels.

Table XVI. Mean numbers of egg masses in plants inoculated with 5 species of Meloidogyne at 3 levels of inoculum.

Egg Masses in Inoculum	Meloidogyne Species arenaria	hapla	incognita	incognita acrita	javanica	Inoc. Mean
1	121	98	296	97	255	174
10	964	301	1034	1289	308	779
100	1122	937	2306	2128	1276	1554
LSD .05	.....	654[a]	.....	927[b]	.....	292
LSD .10	.....	850	.....	1258	.....	380

[a]Between inoculum levels, within a species.

[b]Between species, within the same or different inoculum levels.

Counts of egg masses from plants originally inoculated with 1 egg mass of M. arenaria were lower than counts from plants inoculated at the 10 and 100 egg mass levels. Meloidogyne hapla, at 1 egg mass level of inoculum, formed a lower number of egg masses than at the 100 egg mass level of inoculum. Counts of egg masses at each level of inoculum

from M. incognita and M. incognita acrita infected plants were different from those of other levels. For M. javanica infected plants both the 1 and 10 egg mass levels of inoculum resulted in egg mass counts which were lower than that for the 100 egg mass level.

As shown in Table XVI, plants inoculated with M. hapla and M. javanica had fewer egg masses than plants inoculated with M. incognita acrita at the 10 egg mass inoculum level. Plants infected with M. arenaria and M. hapla at the next higher level formed fewer egg masses than M. incognita and M. incognita acrita infected plants while M. javanica infected plants formed fewer egg masses than plants infected with M. incognita.

Table XVII presented below is a comparison of the mean number of egg masses per plant in the 5 snapdragon varieties inoculated with the Meloidogyne species.

Table XVII. Mean number of egg masses per plant in 5 snapdragon varieties inoculated with 5 species of Meloidogyne.

Meloidogyne Species	Snapdragon Varieties: Ball Red	Christmas Cheer	Margaret	Maryland Pink	Ball Yellow	Species Mean
arenaria	632	865	537	898	746	736
hapla	385	432	272	678	460	446
incognita	1491	1396	847	1493	833	1212
incognita acrita	998	1309	1246	1371	933	1171
javanica	461	1102	691	432	380	613
LSD .05	.....	.....	n.s.	.....	.....	n.s.
LSD .01	.....	.....	n.s.	.....	.....	n.s.

As indicated in Table XVII, there were no significant differences between mean counts of egg masses between Meloidogyne species or between the effect of interactions of Meloidogyne species with snapdragon varieties.

Results of the analysis of mean number of egg masses are presented as block diagrams in Fig. 6.

The only significant results in the analysis of mean rates of nematode reproduction (mean number of egg masses per plant divided by the mean number of females per plant) were obtained between the low and higher levels of inoculum (Table XVIII).

Table XVIII. Mean rate of nematode reproduction per plant in 5 snapdragon varieties at 3 levels of inoculum.

Egg Masses in Inoculum	Meloidogyne Species					Inoc. Mean
	arenaria	hapla	incognita	incognita acrita	javanica	
1	0.48	0.36	0.50	0.30	0.43	0.42
10	0.82	0.68	0.74	0.74	0.75	0.71
100	0.85	0.70	0.77	0.77	0.76	0.77
LSD .05	.....		n.s.	.....		0.08
LSD .01	.....		n.s.	.....		0.10

It can be seen that when the increment of nematode inoculum was increased to 10 and 100 egg masses, the mean reproductive rate increased correspondingly. There were no significant differences between the interactions of Meloidogyne species with levels of inoculum.

Table XIX presents the mean rates of nematode reproduction in plants inoculated with Meloidogyne at 3 inoculum levels while Table XX presents mean rates of reproduction per plant of the 5 snapdragon varieties inoculated with the 5 Meloidogyne species.

As indicated in Tables XIX and XX, the effect of interaction between snapdragon varieties with inoculum levels and Meloidogyne species with snapdragon varieties does not significantly influence the reproductive rate of nematodes.

Fig. 7 illustrates the results obtained in the analysis of mean rates of nematode reproduction.

Table XIX. Mean rates of nematode reproduction in plants inoculated with 5 species of Meloidogyne at 3 levels of inoculum.

Snapdragon Varieties	Egg Masses in Inoculum			Variety Mean
	1	10	100	
Ball Red	0.48	0.63	0.77	0.63
Christmas Cheer	0.30	0.76	0.83	0.63
Margaret	0.44	0.68	0.71	0.61
Maryland Pink	0.46	0.79	0.75	0.66
Ball Yellow	0.40	0.69	0.81	0.63
LSD .05	.....	n.s.	.....	n.s.
LSD .01	.....	n.s.	.....	n.s.

Table XX. Mean rate of nematode reproduction per plant in 5 snapdragon varieties inoculated with 5 species of Meloidogyne.

Meloidogyne Species	Snapdragon Varieties					Species Mean
	Ball Red	Christmas Cheer	Margaret	Maryland Pink	Ball Yellow	
arenaria	0.74	0.70	0.63	0.65	0.89	0.72
hapla	0.48	0.62	0.45	0.60	0.42	0.51
incognita	0.67	0.59	0.72	0.71	0.66	0.67
incognita acrita	0.62	0.61	0.54	0.67	0.60	0.61
javanica	0.63	0.62	0.71	0.69	0.61	0.65
LSD .05	.....		n.s.	.....		n.s.
LSD .01	.....		n.s.	.....		n.s.

1950 Tests

A second experiment using the same techniques and materials as the previous experiment was performed in 1950. In place of 3 levels of inoculum, however, only 5 egg masses of each nematode species were used as the standard dosage level. Treatments were placed in the same type of split plot design used previously and grown at an average soil temperature of 24° C. for 2½ months. Harvested plants were subjected to the same measurements as in the previous experiment. Tables XXI thru XXXIV present data on top and root weight, root-knot index, number of females and egg masses per plant, and rate of reproduction per plant for nematode species, snapdragon varieties, and levels of inoculum as well as for the effect of interactions of these variables with each other.

The mean top weight per plant of 5 snapdragon varieties is shown in Table XXI. Plants of each variety were infected with each of the 5 species of Meloidogyne.

Table XXI. Mean top weight per plant of 5 snapdragon varieties.

Snapdragon Varieties	Variety Mean in grams
Ball Red	21.1
Christmas Cheer	26.3
Margaret	23.6
Maryland Pink	40.3
Ball Yellow	34.7
LSD .05	3.5
LSD .01	4.6

As indicated above, differences in top weight between some snapdragon varieties were highly significant.

In Table XXII it can be seen that plants infected with M. javanica had a lower mean top weight than plants infected with the other species

of root-knot nematodes.

Table XXII. Mean top weight per plant of 5 snapdragon varieties inoculated with 5 species of Meloidogyne.

Meloidogyne Species	Snapdragon Varieties: Ball Red	Christmas Cheer	Margaret	Maryland Pink	Ball Yellow	Species Mean
arenaria	19.7	28.8	24.9	38.9	39.0	30.3
hapla	20.8	30.0	24.6	48.3	44.3	33.6
incognita	20.6	24.9	19.8	44.8	38.4	29.7
incognita acrita	23.5	28.6	32.2	43.8	25.5	31.2
javanica	20.9	19.4	16.6	25.5	24.1	21.3
LSD .05	.....	7.7[a]	.....	8.4[b]	.....	4.6
LSD .01	.....	10.3	.....	11.2	.....	6.4

[a]Between varieties, within a species.

[b]Between species, within the same or different varieties.

As indicated in the preceding table, there were no significant differences in mean top weight for the effect of interactions of Meloidogyne species with Ball Red variety snapdragons. Top weights of Christmas Cheer variety snapdragons inoculated with M. javanica were lower than plants of the same variety inoculated with M. arenaria, M. hapla, and M. incognita acrita. Meloidogyne javanica and M. incognita infected plants of the Margaret variety had a lower top weight than plants infected with M. incognita acrita. Whereas M. javanica infected plants of the Maryland Pink variety had a lower top weight than plants infected with the other species, snapdragons infected with M. arenaria had a lower top weight than M. hapla infected plants. Ball Yellow variety snapdragons infected with M. incognita acrita and M. javanica had significantly lower root weights than plants infected with the other root-knot species.

Table XXIII presents the mean top weight per plant of uninoculated plants.

Table XXIII. Mean top weight per plant of uninoculated snapdragon controls.

Snapdragon Varieties	Variety Mean in grams
Ball Red	33.9
Christmas Cheer	37.7
Margaret	24.8
Maryland Pink	37.3
Ball Yellow	40.2

As can be seen in Table XXIII, uninoculated plants of each variety had greater top weights than infected plants with the exception of the Maryland Pink variety. These results were not analysed statistically.

Fig. 8 is a block diagram illustration of the results obtained in the analysis of top weight of plants.

Comparison of mean root weights per plant of each snapdragon variety is shown in Table XXIV.

Table XXIV. Mean root weight per plant of 5 snapdragon varieties.

Snapdragon Varieties	Variety Mean in grams
Ball Red	29.9
Christmas Cheer	29.3
Margaret	30.6
Maryland Pink	34.9
Ball Yellow	49.0
LSD .05	5.5
LSD .01	7.2

As indicated above, significant differences existed between the mean root weights of some of the snapdragon varieties.

Table XXV shows that there were some differences in root weight between plants infected by different species of Meloidogyne.

Table XXV. Mean root weight per plant of 5 snapdragon varieties inoculated with 5 species of Meloidogyne.

Meloidogyne Species	Snapdragon Varieties: Ball Red	Christmas Cheer	Margaret	Maryland Pink	Ball Yellow	Species Mean
arenaria	31.9	34.8	29.2	35.6	51.7	36.7
hapla	27.4	21.9	27.0	37.1	56.5	34.0
incognita	27.1	27.0	22.1	40.3	45.0	32.3
incognita acrita	33.4	36.1	50.0	34.0	64.9	43.7
javanica	29.8	26.6	24.9	27.5	26.9	27.2
LSD .05	.....	12.3[a]	.....	13.6[b]	.....	6.2
LSD .01	.....	16.2	.....	16.7	.....	8.5

[a]Between varieties, within a species.

[b]Between species, within the same or different varieties.

Plants infected with M. javanica had a lower mean root weight than plants infected with M. arenaria, M. hapla, and M. incognita acrita, while M. incognita acrita infected plants had a higher root weight than plants infected with the other species. A further examination of these data indicates that there were no differences in mean root weight between plants of snapdragon varieties Ball Red and Maryland Pink infected with various species of Meloidogyne. Plants of the Christmas Cheer variety infected with M. hapla were lower in root weight than plants infected with M. incognita acrita. The latter species also showed the same significance in greater mean root weight for infected plants of Margaret variety snapdragon than did plants of the same variety infected with other Meloidogyne species. When root weights of infected plants of the Ball Yellow variety were analyzed, it was found that plants infected with M. javanica had a lower root weight than plants infected with the other species. Plants infected with M. incognita were found to have a lower

root weight than those infected with M. incognita acrita.

Table XXVI presents the mean root weight per plant of uninoculated snapdragon control plants.

Table XXVI. Mean root weight per plant of uninoculated snapdragon controls.

Snapdragon Varieties	Variety Mean in grams
Ball Red	43.4
Christmas Cheer	33.7
Margaret	34.9
Maryland Pink	26.5
Ball Yellow	48.4

Uninoculated plants of Ball Red, Christmas Cheer, and Margaret varieties had greater mean root weights than infected plants while the converse was true for Maryland Pink and Ball Yellow varieties. These values were not analysed statistically.

Fig. 9 is a block diagram representation of the differences obtained in analysis of mean root weight of plants.

Comparison of the mean root-knot index of each snapdragon variety is shown in Table XXVII.

Table XXVII. Mean root-knot index per plant of 5 snapdragon varieties.

Snapdragon Varieties	Variety Mean
Ball Red	1.6
Christmas Cheer	1.7
Margaret	1.8
Maryland Pink	1.8
Ball Yellow	1.8
LSD .05	n.s.
LSD .01	n.s.

Analysis of the root-knot indices presented above showed that no significant differences existed between snapdragon varieties.

Significant differences between some of the mean root-knot indices of plants inoculated with Meloidogyne species are shown in Table XXVIII.

Table XXVIII. Mean root-knot index per plant of 5 snapdragon varieties inoculated with 5 species of Meloidogyne.

Meloidogyne Species	Snapdragon Varieties: Ball Red	Christmas Cheer	Margaret	Maryland Pink	Ball Yellow	Species Mean
arenaria	1.6	1.2	2.6	1.8	2.0	1.8
hapla	1.0	1.4	1.0	1.4	1.4	1.2
incognita	1.0	1.8	1.2	2.0	2.2	1.6
incognita acrita	1.8	1.6	1.8	1.2	1.2	1.5
javanica	2.6	2.6	2.6	2.6	2.2	2.5
LSD .05	.....		0.7	.....		0.4
LSD .01	.....		0.9	.....		0.5

Data presented in Table XXVIII show that the mean root-knot index of plants infected with M. hapla was lower than the indices of plants infected with M. incognita, M. arenaria, and M. javanica. Root-knot indices of plants infected with M. arenaria, M. incognita, and M. incognita acrita were lower than the mean index of plants infected with M. javanica. Analysis of the root-knot indices of the interactions between snapdragon varieties and Meloidogyne species indicated that significant differences were present between some species of Meloidogyne for each variety of snapdragon. Plants of the Ball Red variety infected with M. hapla and M. incognita had lower root-knot indices than plants infected with M. incognita acrita and M. javanica. Plants infected with M. arenaria and M. incognita acrita were lower, in regard to mean root-knot index, than M. javanica infected plants. Plants of the Christmas Cheer variety infected with M. javanica had a higher mean root-knot index than plants infected by the other species. Meloidogyne hapla infected plants of Margaret variety had

a lower mean index than plants infected by M. arenaria, M. incognita acrita, and M. javanica. Also in the same variety, M. incognita and M. incognita acrita infected plants had lower mean indices than plants infected with M. arenaria and M. javanica. Plants of Maryland Pink variety infected with M. incognita acrita had a lower mean root-knot index than plants infected by M. incognita and M. javanica. Within the same variety, M. arenaria and M. hapla infected plants had lower indices than M. javanica infected plants. Plants of Ball Yellow snapdragon infected with M. incognita acrita had a mean index significantly lower than those of plants infected with M. arenaria, M. incognita, and M. javanica. The mean index of M. hapla infected plants was lower than indices of plants infected with M. incognita and M. javanica.

Block diagrams of the data presented above appears in Fig. 10.

Comparison of mean number of female nematodes per plant in 5 snapdragon varieties is shown in Table XXIX.

Table XXIX. Mean number of female nematodes per plant in 5 snapdragon varieties.

Snapdragon Varieties	Variety Mean
Ball Red	411
Christmas Cheer	348
Margaret	418
Maryland Pink	400
Ball Yellow	495
LSD .05	n.s.
LSD .01	n.s.

There were no apparent significant differences between varieties of snapdragons in the analysis of mean number of females per plant.

Differences between Meloidogyne species are shown in Table XXX

which presents the mean number of females per plant in 5 snapdragon varieties inoculated with Meloidogyne species.

Table XXI. Mean number of female nematodes per plant in 5 snapdragon varieties inoculated with 5 species of Meloidogyne.

Meloidogyne Species	Snapdragon Varieties: Ball Red	Christmas Cheer	Margaret	Maryland Pink	Mall Yellow	Species Mean
arenaria	415	242	359	317	427	352
hapla	88	230	140	298	119	175
incognita	436	395	345	686	844	541
incognita acrita	674	501	897	290	727	618
javanica	443	372	347	411	359	386
LSD .05	.....	327[a]	.....	345[b]	.....	184
LSD .01	.....	431	.....	460	.....	254

[a]Between varieties, within a species.

[b]Between species, within the same or different varieties.

The mean number of female nematodes in plants infected with M. hapla was lower than in plants infected with M. incognita, M. incognita acrita, and M. javanica. Plants infected with M. arenaria had a lower mean count of females than those infected with M. incognita and M. incognita acrita. Meloidogyne javanica infected plants had a lower mean number of females than plants infected with M. incognita acrita. Further examination of these data showed that in Ball Red variety snapdragon M. hapla had a lower number of females than did M. incognita, M. incognita acrita, and M. javanica. There were no differences in the mean number of females of each species infecting Christmas Cheer variety. Within Margaret variety, M. incognita acrita formed more females than other Meloidogyne species. Maryland Pink variety snapdragon infected with M. incognita had a greater number of females than plants of the same

variety infected with M. arenaria, M. hapla, and M. incognita acrita. Within Ball Yellow variety snapdragon, M. hapla and M. javanica had a lower number of females than M. incognita and M. incognita acrita. Meloidogyne arenaria, in the same variety, formed a lower number of females than did M. incognita.

Fig. 11 presents block diagrams of the results obtained in the analysis of mean numbers of females.

Table XXXI gives the mean number of egg masses per plant in 5 varieties of snapdragon.

Table XXXI. Mean number of egg masses per plant in 5 snapdragon varieties.

Snapdragon Varieties	Variety Mean
Ball Red	284
Christmas Cheer	257
Margaret	282
Maryland Pink	294
Ball Yellow	341
LSD .05	n.s.
LSD .01	n.s.

As indicated in the preceding table, there were no significant differences between varieties in the analysis of mean number of egg masses.

Table XXXII presents the mean number of egg masses per plant in 5 snapdragon varieties inoculated with 5 species of Meloidogyne.

As indicated in the following table, females of M. hapla formed a lower number of egg masses than females of the other species. Females of M. incognita acrita formed a greater number of egg masses than did females of M. arenaria and M. javanica.

Table XXXII. Mean number of egg masses per plant in 5 snapdragon varieties inoculated with 5 species of Meloidogyne.

Meloidogyne Species	Snapdragon Varieties: Ball Red	Christmas Cheer	Margaret	Maryland Pink	Ball Yellow	Species Mean
arenaria	302	148	261	240	318	254
hapla	62	174	96	216	59	121
incognita	259	297	226	477	451	342
incognita acrita	463	381	558	225	544	434
javanica	336	286	271	314	331	307
LSD .05	.....		n.s.	.....		119
LSD .01	.....		n.s.	.....		164

Fig. 12 is a diagrammatic illustration of the results obtained in the analysis of number of egg masses per plant.

Mean rates of nematode reproduction in 5 snapdragon varieties are given in Table XXXIII.

Table XXXIII. Mean rate of nematode reproduction per plant in 5 snapdragon varieties.

Snapdragon Varieties	Variety Mean
Ball Red	0.68
Christmas Cheer	0.73
Margaret	0.63
Maryland Pink	0.74
Ball Yellow	0.65
LSD .05	n.s.
LSD .01	n.s.

As shown above, different varieties of snapdragon had no significant effect on the mean rate of nematode reproduction.

Table XXXIV presents the mean rate of nematode reproduction per plant of 5 snapdragon varieties inoculated with 5 species of Meloidogyne.

Table XXXIV. Mean rate of nematode reproduction per plant in 5 snapdragon varieties inoculated with 5 species of Meloidogyne.

Meloidogyne Species	Snapdragon Varieties: Ball Red	Christmas Cheer	Margaret	Maryland Pink	Ball Yellow	Species Mean
arenaria	0.74	0.58	0.74	0.76	0.79	0.72
hapla	0.58	0.78	0.55	0.66	0.41	0.60
incognita	0.65	0.78	0.48	0.68	0.52	0.62
incognita acrita	0.72	0.75	0.65	0.79	0.74	0.73
javanica	0.74	0.77	0.72	0.79	0.80	0.76
LSD .05	.....		n.s.	.....		0.09
LSD .01	.....		n.s.	.....		0.12

Meloidogyne hapla and M. incognita were found to have significantly lower mean rates of nematode reproduction than other species of Meloidogyne (Table XXXIV).

Block diagrams illustrating the results obtained in the analysis of mean rates of nematode reproduction are presented in Fig. 13.

Life Histories of the Root-Knot Nematodes

Literature on the life history of the root-knot nematode has been based on the assumption that root-knot nematodes belonged to a single species. Such work, although not invalidated by Chitwood's classification (3), now needs further clarification as to which species or mixture of species the investigators dealt with. An example of such a publication is the paper by Christie and Cobb (7) in which the authors described and presented drawings of various stages of development of the root-knot nematode.

In order to investigate the comparative development of the 5 species of Meloidogyne used in the previous experiments, seedlings of Margaret variety snapdragon were transplanted into 3 in. pots filled with a potting mixture of 2 parts sand to 1 part soil. After several days, during which time the plants had become established, 5 egg masses of 1 of the Meloidogyne species were placed in each pot. This was repeated for each of the other species so that plants were exposed to separate infections by each of the 5 Meloidogyne species. There were 30 replicate plants inoculated within each species. Two days after inoculation and at 2-day intervals thereafter, one half of the root system of a plant inoculated with each of the species of Meloidogyne was removed and stained. Since egg masses in the soil around the roots of each plant were discharging infectious larvae for a considerable period of time after the original inoculations, it was necessary to examine, in each case, the oldest established infections observed in the stained roots. During this experiment the average soil temperature in the greenhouse was 20.4° C.

Although each nematode species varied somewhat in the time required to reach a certain stage of development, no great differences were observed between species with respect to shape or behavior of the animals at the various stages of their life cycles. Data on the occurrence of molts and frequency of occurrence of males was not obtained since the staining technique used precluded the accurate observation of these details.

It was found, in the majority of cases, that the second stage infectious larvae penetrated the rootlet at the root tip or in the region of elongation behind the root tip. Once having penetrated the root, the larvae usually took a position parallel to the axis of the root. Roots examined 2 days after inoculation showed that larvae were not oriented consistantly within the roots. Most larvae were found with their heads nearest the root cap while their bodies extended back toward the older tissues; others were seen, however, heading in the opposite direction. Fig. 14 shows the anterior end of a larva of M. arenaria in the meristematic region of the root tip. Larvae were not always observed with their bodies parallel to the axis of the root and were, on several occasions, seen curled within the root tip (Fig. 15). Fig. 16 shows 2 larvae of M. javanica, one of which was in the process of penetrating the root tip when the tissue was fixed. As the root meristems grew beyond the sites of larval penetration, larvae oriented themselves by the 4th day to a position with their heads embedded in the outer tissues of the stele and their bodies in the tissues of the cortex extending downward toward the root tip. Early gall formation was noticed in several rootlets indicating that lateral growth of the infected areas must have started within the period

2 to 4 days after inoculation. Fig. 17 shows early gall formation in a root parasitized by a larva of M. incognita acrita. Not an uncommon sight were sections of roots which bore heavy infections of root-knot nematodes (Fig. 18). Root tips which were inhabited by large numbers of parasites were usually stunted with gall formation quite evident. This has also been observed by Godfrey and Oliveira (13) in their studies of root-knot nematode infections of pineapple roots. The nematodes increased slowly in width until between the 8th and 10th day after inoculation, when rapid increases in body width occurred. Widening of the body, in most cases, was uneven and irregular. Usually the region of the body directly posterior to the base of the esophagus increased in width first (Fig. 19). Immediately thereafter, the posterior third of the body widened with the middle of the body and the esophageal region increasing in width last. During this period of growth, the tail of the nematode remained unchanged, resulting in a "spiked" appearance of the posterior end of the animal (Fig. 21). In swelling, the esophageal area of the body went through a greater increase in width near the base of the esophagus and a lesser increase in width at the head, resulting in a tapered appearance of the body from the base of the esophagus to the head. Of decided interest was the appearance of heavily stained cells of the stele around the heads of the parasites about 8 to 10 days after inoculation (Figs. 19, 20, and 21). This indicated that formation of multinucleate giant cells (5) had been stimulated by the parasites, and had become filled with protoplasm which stained densely. In only one instance was an abnormality in the position of the nematode within the gall observed and that is illustrated in Fig. 20 in which

a larva of M. javanica is shown with the majority of its body in a gall while the posterior part of the body protrudes from the gall. At about 10 to 14 days after inoculations, nematodes of most species became "sausage-shaped" as illustrated in Fig. 21. Following the occurrence of the 3 molts described by Christie and Cobb (7), the parasites were observed as young females of the typical shape shown in Fig. 22. In one case, a young female of M. javanica was observed with a definite constriction offsetting the decidedly wider posterior portion of the body (Fig. 23). At this point in development there was a rapid increase in width as well as length of the females (Fig. 24). A female of M. incognita with a very unusual shape was observed in this stage of growth. As shown in Fig. 25, the posterior portion of this female was typically broadened but tapered decidedly to the terminus. Anterior to the widened posterior end the nematode body was slender and elongated where it was curled around the stele, while the anterior portion of the nematode body was somewhat thickened, although not as decidedly as the posterior portion (Fig. 25). A close inspection of a female of M. javanica killed 24 days after inoculation (Fig. 26) revealed the presence of the terminal anal and subterminal genital openings as drawn by Bessey (2). Nematodes of most species examined 26 days after inoculation were almost fully grown as shown in Fig. 27. In most cases, a gelatinous matrix was exuded by the females from 28 to 30 days after inoculation. Whereas normally this gelatinous mass would appear as shown in Fig. 28, the vigorous treatment to which some specimens were subjected during the staining technique presumably caused a separation of the gelatinous mass from the posterior end of the nematode (Fig. 29). The staining characteristics

of this gelatinous exudate are shown in Fig. 30. As a rule it was found that the formation of the gelatinous matrix preceded oviposition by as much as 2 days. Fig. 31 shows a female of M. incognita acrita with a number of newly formed eggs.

Whereas females of Meloidogyne arenaria, M. hapla, and M. incognita oviposited 30 days after inoculation of roots, oviposition by M. incognita acrita and M. javanica was not observed. Presumably the Margaret variety of snapdragons was not a suitable host to these 2 species under conditions of this experiment.

Periodic checks of plants revealed that eggs had hatched and that second generation larvae had re-entered root tips 66 days after inoculation in the case of M. arenaria and 68 days after inoculation in the case of M. hapla. Reinfection of root tips by second generation larvae of M. incognita was not observed.

Christie (4) grouped the root-knot nematodes into 5 categories on the basis of their shapes during development (Fig. 32). Larvae from the stage at which they had begun to grow to the stage at which they still possessed a more or less conical tail were put in Group A (Fig. 32, A). Group B included larvae from the stage at which they had acquired a more or less hemispherical posterior end terminated by a spike to a stage at which they were about to complete the final molts (Fig. 32, B). Group C included females from the stage at which they had completed the molts to the stage at which they were almost fully grown (Fig. 32, C). Group D included females that were fully grown or almost fully grown but had not yet laid eggs (Fig. 32, D). Group E included ovipositing females (Fig. 32, E).

The stages of development of the root-knot nematodes on snapdragon are compared, using Christie's groupings, in Table XXXV.

Table XXXV. Comparison of stages of development of the root-knot nematodes on snapdragons.

Stage of Development[a]	Meloidogyne Species				
	arenaria	hapla	incognita	incognita acrita	javanica
Group A	2-8[b]	2-10	2-8	2-8	2-8
Group B	10-12	12-16	10	10	10-12
Group C	14-22	18-26	12-22	12-26	14-26
Group D	24-28	28	24-28	28-30	28-36
Group E	30	30	30	---[c]	---

[a] Refer to Fig. 32.

[b] Days after inoculation.

[c] Ovipositing females were not observed.

During examination of the nematodes throughout this experiment, a record of the maximum nematode width in microns was kept for each species at each sampling date. Curves plotted for each species failed to reveal any outstanding differences between species, therefore a mean curve was plotted which was representative of all 5 species (Fig. 33). It shows that the greatest increase in width occurred during periods of 8 to 10 days after inoculation and 22 to 30 days after inoculation.

Having observed details of the life histories of some of the Meloidogyne species on snapdragon, it was thought advisable to investigate the more important details of the development of these nematode species on tomato, Lycopersicon esculentum Mill. var. Rutgers. Several month-old seedlings were transplanted into 4-inch pots containing soil well-infested with each of the 5 root-knot species and grown in the greenhouse at an average soil temperature of 21° C. Results of

examinations showed that females of M. javanica produced the gelatinous matrix preceding oviposition 35 days after inoculation of the plants. Females of the other 4 species were found to have produced this matrix by the 37th day after inoculation. Females of M. incognita acrita were found to have produced eggs in the gelatinous matrix 37 days after inoculation, while females of the other species had produced eggs by the 39th day after inoculation. Continued examinations showed that penetration of root tips by the second generation larvae of M. incognita occurred at 57 days after inoculation, while larvae of M. incognita acrita were found infecting root tips 59 days after inoculation. Second stage infectious larvae of the other 3 species were discovered in root tips 63 days after inoculation. A comparison of these results with those obtained in the studies on snapdragon are presented in Table XXXVI.

Table XXXVI. Comparison of stages of development of the root-knot nematodes in snapdragon and tomato.

Host	Meloidogyne Species	Gelatinous matrix Produced	Egg Production	Infection by second generation larvae
Tomato	arenaria	37[a]	39	63
	hapla	37	39	63
	incognita	37	39	57
	incognita acrita	37	37	59
	javanica	35	39	63
Snapdragon	arenaria	28	30	66
	hapla	28	30	68
	incognita	30	30	--[b]
	incognita acrita	30	--	--
	javanica	36	--	--

[a]Days after inoculation of plants.

[b]Not observed.

DISCUSSION OF RESULTS

The first and second experiments presented in this paper have shown that valid differences exist in the reaction of snapdragons to infection by each species of root-knot nematodes used and in the behavior of each of these species in the host plants. Results from both the 1949 and 1950 experiments showed that Meloidogyne hapla was separable from the other root-knot species in that infected plants showed a somewhat greater top weight. Root weights of M. hapla infected plants in both experiments, however, were not distinguishable from root weights of plants infected by the other species. This study indicated that M. hapla differed from other species by means of the root-knot index rating of plants infected by it. This rating was invariably quite low. A close inspection of M. hapla infected root systems showed that galls were spherical and quite small with prolific lateral rootlet formation. Only in one instance were the elongate, finger-like, continuous galls present that normally occur on plants infected by the other species. Meloidogyne hapla was also distinct in that it produced a lower number of females and egg masses and a lower rate of reproduction than other species infecting snapdragons.

Meloidogyne incognita and M. incognita acrita were somewhat similar in their overall effects on the host as well as in their development in the host. There were, however, several cases in the analysis of the effect of interactions of nematode species with inoculum levels and nematode species with snapdragon varieties in which there were significant differences shown between M. incognita and M. incognita acrita. Significant differences in top weight and root weight

between the interactions of M. incognita and its variety with Margaret and Ball Yellow varieties of snapdragon were shown in the 1950 tests (Tables XXII and XXV); these differences, however, were not apparent in the 1949 tests (Tables III and VII). Further differences exist between M. incognita and M. incognita acrita in the interactions between nematode species and snapdragon varieties for mean root-knot index (Table XXVIII) and mean number of females (Table XXX) in the 1950 tests. Also shown in the results of the 1950 experiment is an overall difference between M. incognita and its variety in their rates of nematode reproduction (Table XXXIV). Separation of M. incognita from M. incognita acrita on the basis of type and size of galls formed was not possible; both form numerous elongate, fleshy galls as well as an abundance of spherical galls.

Meloidogyne arenaria, in comparison with the other species, was found to be intermediate both in behavior and in its pathogenicity on snapdragon. In regard to mean rate of reproduction, this species was somewhat higher than the others in the 1949 tests (Table XX) but reverted to the more normal pattern of behavior in the 1950 tests (Table XXXIV). As for size of root-knot gall formed, M. arenaria galls were more or less an intermediate between the size of galls formed by M. incognita and those formed by M. hapla. Both spherical and elongate, somewhat fleshy galls were formed by this species.

Meloidogyne javanica was more pathogenic on snapdragons in the 1950 tests than in the 1949 tests. It likewise appeared to form more females and egg masses and to have a higher rate of reproduction than other species in the 1950 tests but not in the 1949 tests. Appearance of galls formed by this species were somewhat similar to M. arenaria

galls being both of the spherical type and elongate, multiple-infection type with the former being more numerous in occurrence.

Differences existing between the results of the 1949 and 1950 tests may be explainable in that the 1949 and 1950 tests cannot be regarded as comparable experiments, in a strict sense, since soil temperatures and levels of inoculum differed for each experiment.

All of the Meloidogyne species used were capable of infecting each of the 5 varieties of snapdragons. It was possible to differentiate between species on the basis of measurements of the pathological response of snapdragons to infection and also, to some extent, by the difference in developmental behavior of species.

Studies on the life histories of the root-knot nematodes indicated that there were no basic, outstanding differences between them in regard to their development on snapdragon. Ovipositing females of M. incognita acrita and M. javanica were not observed (Table XXXIII). Failure of females of these two species to form eggs was extremely enigmatic in view of the fact that all species readily attained maturity and reproduced in the 1949 and 1950 tests. Christie (4), in a paper on the effects of the host on root-knot nematodes, presented several facts which aided in explaining the abnormal behavior of M. incognita acrita and M. javanica in these studies. Christie tried to maintain root-knot nematodes on tomato by repeated inoculations and found that subsequent infections became less severe. Attempts to maintain populations from single egg masses resulted in some of the populations forming a correspondingly fewer number of egg masses. In his conclusions Christie stated:

> Retarded development of the parasites is a manifestation of unsuitability or (if we define resistance in a plant as its condition of being an unsuitable host) of resistance. There appears to be no correlation between the suitability of the host and the freedom with which larvae enter its roots. Many plants that are highly unsuitable are invaded as freely as more suitable ones . . . . There appears to be a direct correlation between suitability of the host and rate of parasite development and a direct correlation between rate of parasite development and egg production. When parasite development is only slightly retarded the effect may be little more than to reduce the number of generations that occur in a given period. When development is more strongly retarded many of the females may never reach maturity and there may be a reduction in the egg output of those that do. In extreme cases, development is almost completely suppressed and, of course, eggs are not produced. Unsuitability of the host with its various consequences is not necessarily accompanied by a corresponding reduction in severity of galling.

In the 1949 and 1950 experiments, in which all species readily infected snapdragons, the original inoculum was obtained from tomato, thus the employment of an alternate host provided for maximal infection of that host by the parasites. Inoculum used for the life cycle studies of the nemas on snapdragon, however, was obtained from snapdragon and correspondingly both M. incognita acrita and M. javanica apparently failed to reproduce on snapdragon which had become an undesirable host. Subsequent attempts to infect snapdragons with larvae from egg masses of these two species from snapdragon likewise suggested the unsuitability of the plant as a desirable host for subsequent generations of these two species. Although usually no difficulty was encountered in obtaining larval penetration of root tips when snapdragons were used repeatedly as host plants, these plants failed to grow properly and their root systems soon became predominantly necrotic. Inspection of such roots in several cases showed the presence of galls which had also been destroyed. A further indication that unsuitability of the snapdragons used in the life cycle studies was responsible for the

lack of fecundity in *M. incognita acrita* and *M. javanica* was suggested when tomato plants became heavily infected when placed in infested soil in which snapdragons either failed to grow or grew poorly. Each of the *Meloidogyne* species infecting the tomato plants formed numerous egg masses (Table XXXIV). It is also shown in the same table that species of *Meloidogyne* have a shorter life cycle and have more generations when infecting snapdragon than when infecting tomato.

SUMMARY

A recent revision of the classification of root-knot nematodes into 5 species has necessitated the study of these animals and their effects on a suitable host.

In the first experiment conducted in 1949, Meloidogyne arenaria, M. hapla, M. incognita, M. incognita var. acrita, and M. javanica were used in infecting varieties Ball Red Hybrid #7, Christmas Cheer, Margaret, Maryland Pink, and Ball Yellow Hybrid #1 of the common snapdragon, Antirrhinum majus, at inoculum levels of 1, 10, and 100 egg masses. Measurements of the reaction of plants to infection by each nematode species after 2½ months of growth were obtained by recording weight of the above-ground parts (top weight), root weight, and root-knot indices of each plant. Measurements of the effect of the host on the parasite were obtained by recording number of females, number of egg masses, and rate of reproduction (number of egg masses divided by the number of females) per plant. It was found, in the majority of cases, that significant differences existed between the Meloidogyne species themselves and between plants infected by these species. Significant differences between M. incognita and M. incognita var. acrita were not indicated in examination of the data.

The second experiment, which was conducted in 1950, was set up similar to the first experiment except that only 5 egg masses of each species were used as a standard inoculum. The same measurements used in the first experiment were applied to the plants in this experiment. It was found that significant differences existed between species of Meloidogyne and between plants infected by these species. The results

of this experiment were somewhat similar, although not identical, to the results from the previous experiment. It was explained that differences in results between these experiments might have been a result of the differences in soil temperature under which each experiment was grown, or to the differences in inoculum levels used for each test. Significant differences between M. incognita and M. incognita var. acrita were found in some of the interactions between nematode species and varieties of snapdragons and also in their rates of reproduction.

A study of the life history of each Meloidogyne species on Margaret variety of snapdragon failed to reveal any outstanding differences between species. A failure of M. incognita var. acrita and M. javanica to reproduce was attributed to the fact that inoculum for this experiment had been obtained from snapdragon. Use of the same host plant for the subsequent generations was believed to have caused a failure in reproduction of these species due to the unsuitability of the host. It was shown that females of M. arenaria, M. hapla, and M. incognita oviposited 30 days after the plants were originally inoculated. Reinfection of root tips by the second generation larvae was detected 66 days after inoculation for M. arenaria and 68 days after inoculation for M. hapla. When tomato seedlings were placed in soil infested by each of the 5 nematode species, M. incognita var. acrita formed eggs in 37 days while the rest of the Meloidogyne species required 39 days for oviposition. Reinfection of roots by the second stage larvae occurred 57 days after inoculation for M. incognita, 59 days after inoculation for M. incognita var. acrita, and 63 days after inoculation for M. arenaria, M. hapla, and M. javanica.

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Figure 1

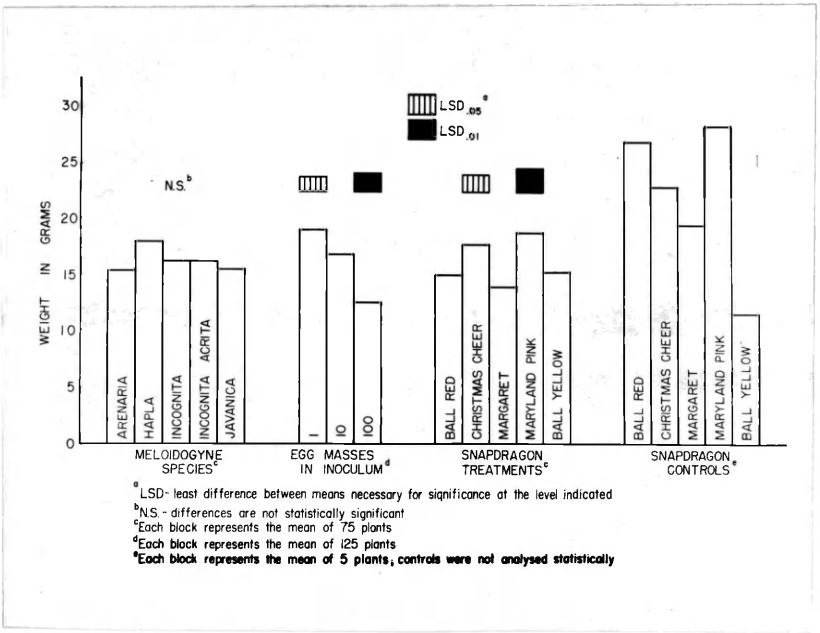
A view of some of the plants grown in the first experiment. The hazard of contamination from splashing between pots was eliminated by use of the spray rig situated directly above the plants. Note the fine mist-like spray being delivered to the plants.

Figure 2

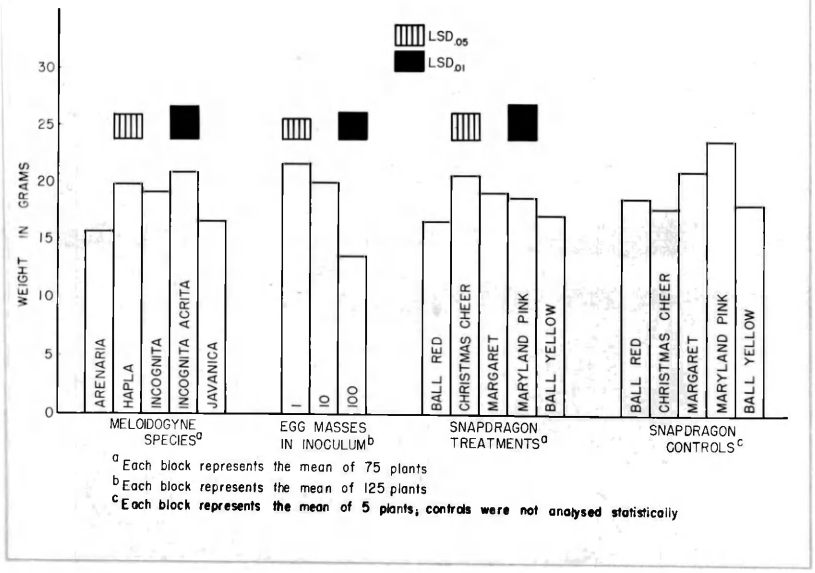
Composite effect of Meloidogyne species, levels of inoculum, and snapdragon varieties on mean top weight of plants.

Figure 3

Composite effect of Meloidogyne species, levels of inoculum, and snapdragon varieties on mean root weight of plants.



[a] LSD- least difference between means necessary for significance at the level indicated
[b] N.S. - differences are not statistically significant
[c] Each block represents the mean of 75 plants
[d] Each block represents the mean of 125 plants
[e] Each block represents the mean of 5 plants; controls were not analysed statistically



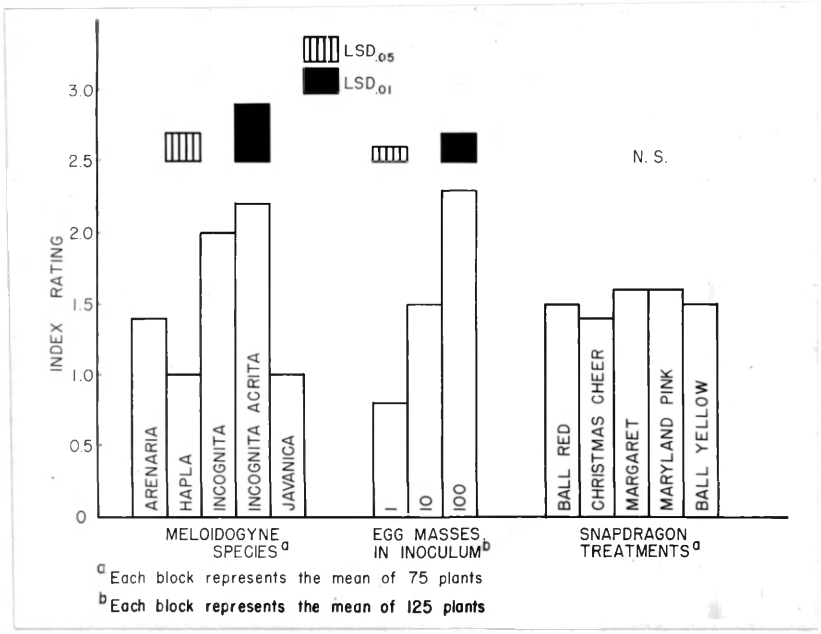
[a] Each block represents the mean of 75 plants
[b] Each block represents the mean of 125 plants
[c] Each block represents the mean of 5 plants; controls were not analysed statistically

Figure 4

Composite effect of Meloidogyne species, levels of inoculum, and snapdragon varieties on mean root-knot index of plants.

Figure 5

Composite effect of Meloidogyne species, levels of inoculum, and snapdragon varieties on mean number of females in plants.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LSD.01
N. S.
INDEX RATING
3.0
2.5
2.0
1.5
1.0
0.5
0
ARENARIA
HAPLA
INCOGNITA
INCOGNITA ACRITA
JAVANICA
1
10
100
BALL RED
CHRISTMAS CHEER
MARGARET
MARYLAND PINK
BALL YELLOW
MELOIDOGYNE SPECIES a
EGG MASSES IN INOCULUM b
SNAPDRAGON TREATMENTS a
a Each block represents the mean of 75 plants
b Each block represents the mean of 125 plants

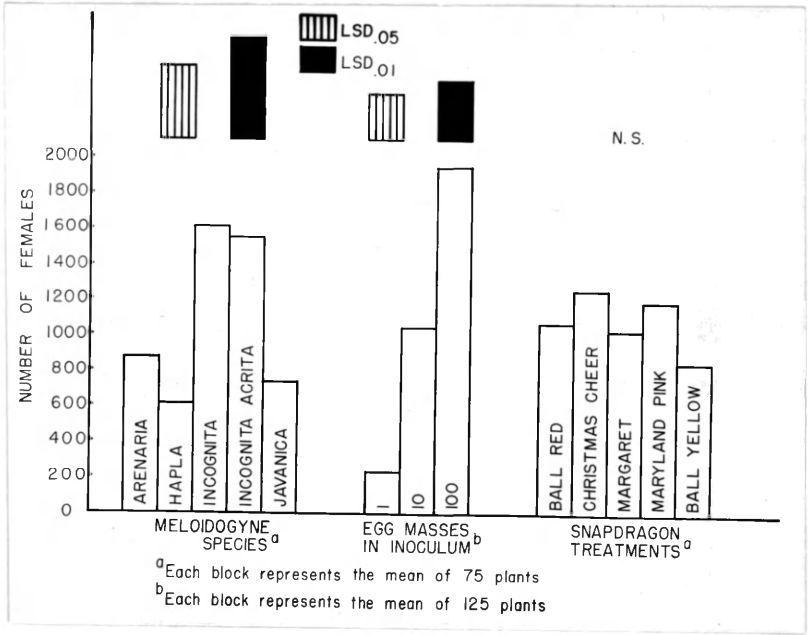
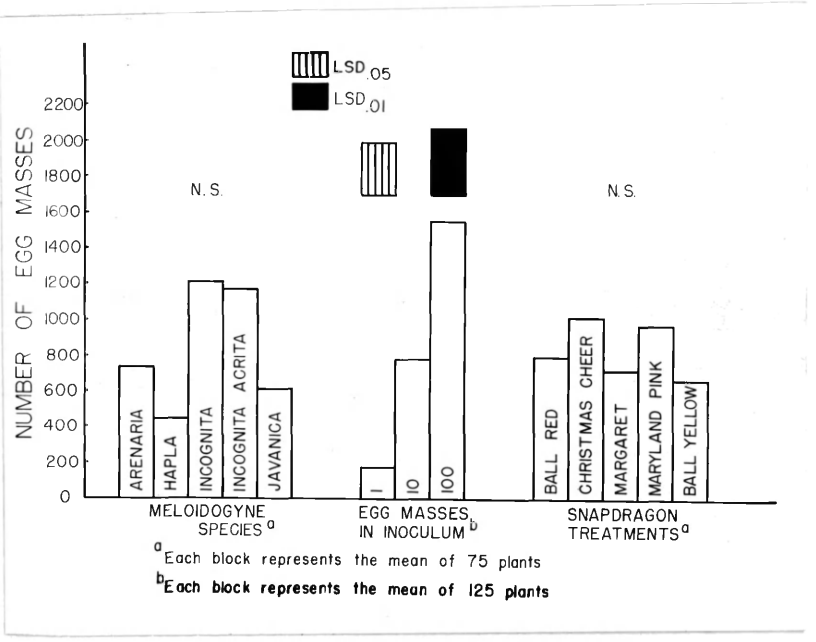

LSD.05
LSD.01
N. S.
NUMBER OF FEMALES
2000
1800
1600
1400
1200
1000
800
600
400
200
0
ARENARIA
HAPLA
INCOGNITA
INCOGNITA ACRITA
JAVANICA
1
10
100
BALL RED
CHRISTMAS CHEER
MARGARET
MARYLAND PINK
BALL YELLOW
MELOIDOGYNE SPECIES a
EGG MASSES IN INOCULUM b
SNAPDRAGON TREATMENTS a
a Each block represents the mean of 75 plants
b Each block represents the mean of 125 plants

Figure 6

Composite effect of Meloidogyne species, levels of inoculum, and snapdragon varieties on mean number of egg masses in plants.

Figure 7

Composite effect of Meloidogyne species, levels of inoculum, and snapdragon varieties on mean rate of nematode reproduction in plants.


LSD.05
LSD.01
NUMBER OF EGG MASSES
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
N. S.
N. S.
ARENARIA
HAPLA
INCOGNITA
INCOGNITA ACRITA
JAVANICA
1
10
100
BALL RED
CHRISTMAS CHEER
MARGARET
MARYLAND PINK
BALL YELLOW
MELOIDOGYNE SPECIES a
EGG MASSES IN INOCULUM b
SNAPDRAGON TREATMENTS a
a Each block represents the mean of 75 plants
b Each block represents the mean of 125 plants

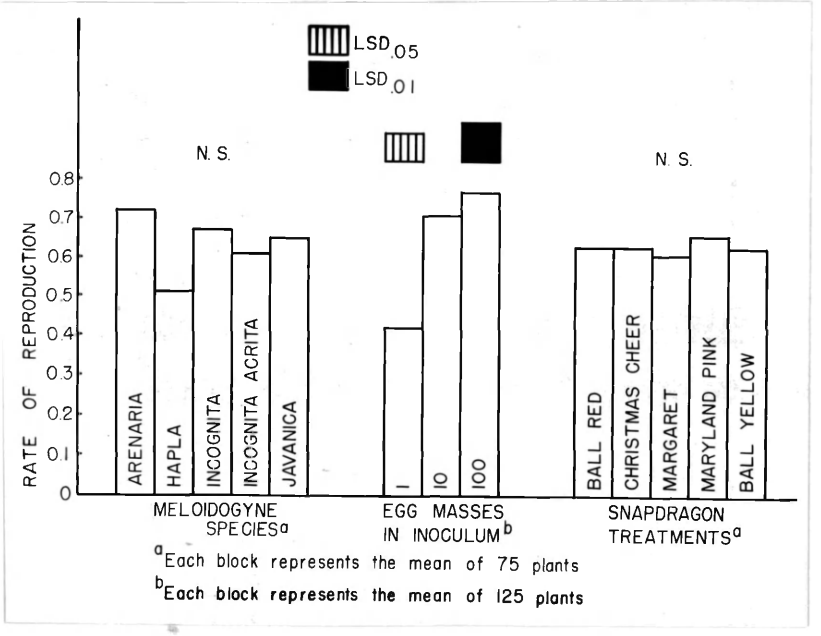
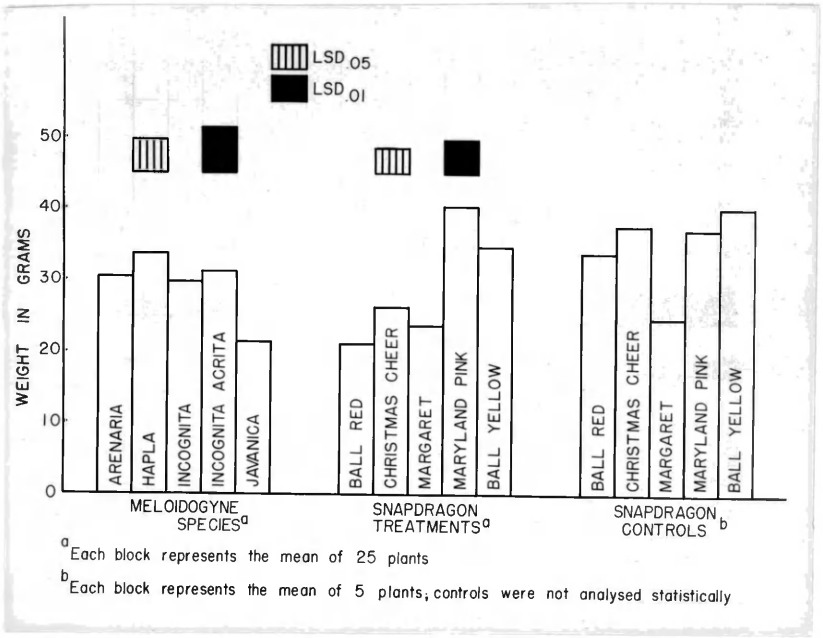

LSD.05
LSD.01
RATE OF REPRODUCTION
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
N. S.
N. S.
ARENARIA
HAPLA
INCOGNITA
INCOGNITA ACRITA
JAVANICA
1
10
100
BALL RED
CHRISTMAS CHEER
MARGARET
MARYLAND PINK
BALL YELLOW
MELOIDOGYNE SPECIES a
EGG MASSES IN INOCULUM b
SNAPDRAGON TREATMENTS a
a Each block represents the mean of 75 plants
b Each block represents the mean of 125 plants

Figure 8

Composite effect of Meloidogyne species and snapdragon varieties on mean top weight of plants.

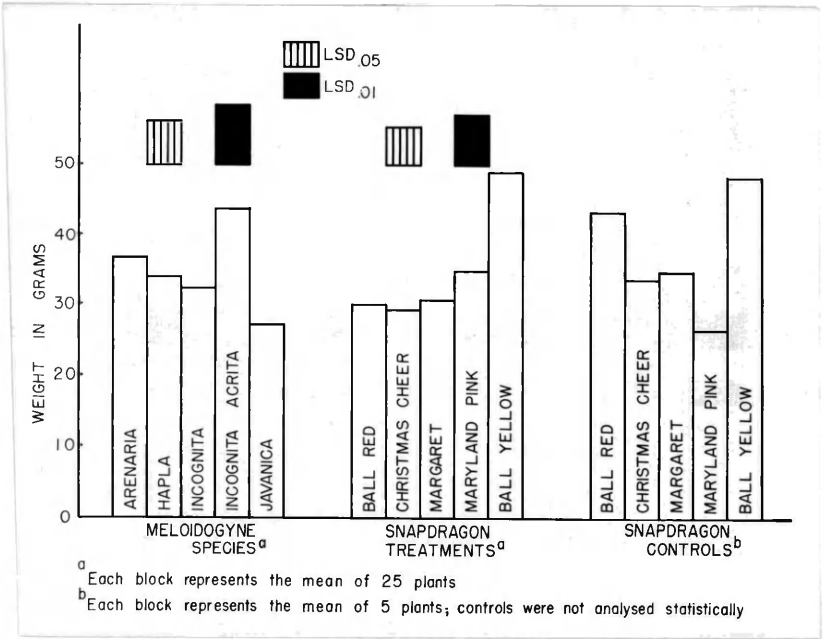
Figure 9

Composite effect of Meloidogyne species and snapdragon varieties on mean root weight of plants.



[a] Each block represents the mean of 25 plants

[b] Each block represents the mean of 5 plants; controls were not analysed statistically



[a] Each block represents the mean of 25 plants

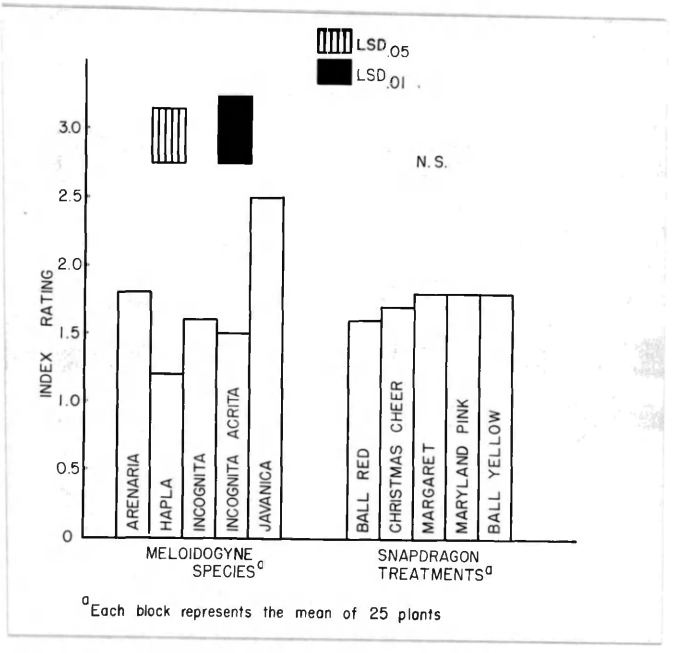
[b] Each block represents the mean of 5 plants; controls were not analysed statistically

Figure 10

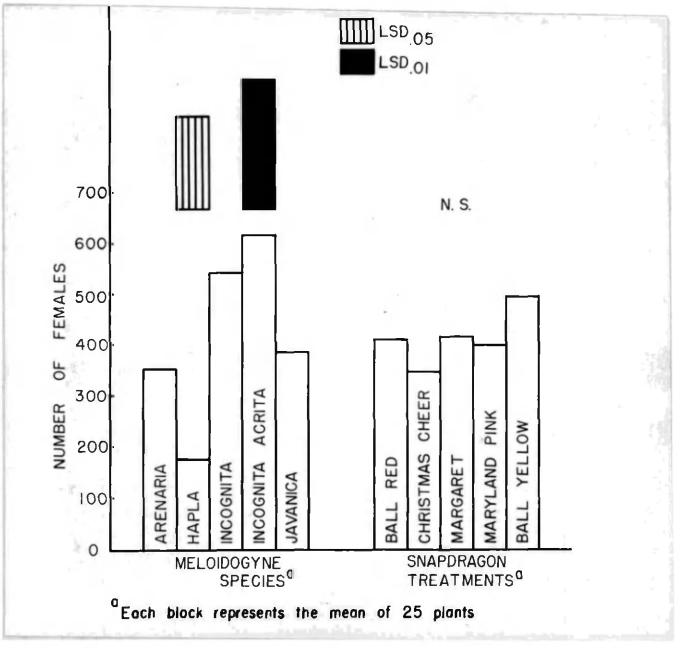
Composite effect of Meloidogyne species and snapdragon varieties on mean root-knot index of plants.

Figure 11

Composite effect of Meloidogyne species and snapdragon varieties on mean number of females in plants.



[a]Each block represents the mean of 25 plants



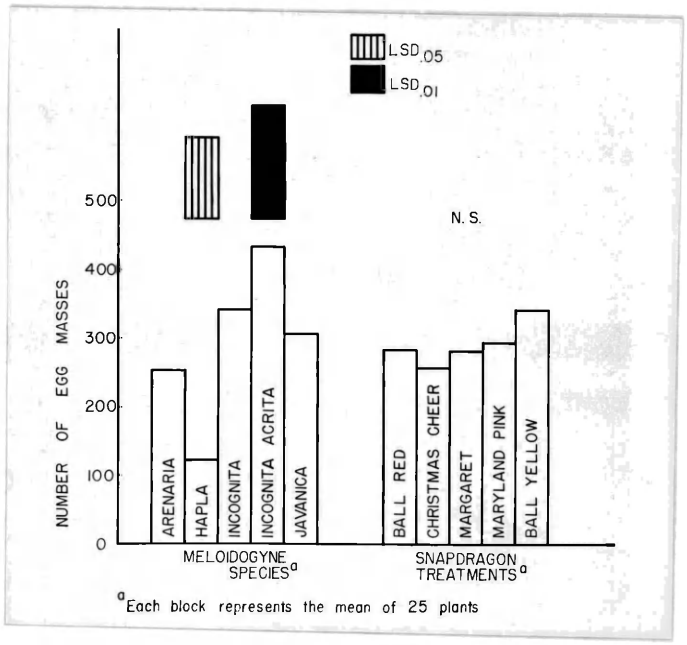
[a]Each block represents the mean of 25 plants

Figure 12

Composite effect of *Meloidogyne* species and snapdragon varieties on mean number of egg masses in plants.

Figure 13

Composite effect of *Meloidogyne* species and snapdragon varieties on mean rate of nematode reproduction in plants.


LSD.05
LSD.01
N. S.
NUMBER OF EGG MASSES
0
100
200
300
400
500
ARENARIA
HAPLA
INCOGNITA
INCOGNITA ACRITA
JAVANICA
BALL RED
CHRISTMAS CHEER
MARGARET
MARYLAND PINK
BALL YELLOW
MELOIDOGYNE SPECIES[a]
SNAPDRAGON TREATMENTS[a]
[a]Each block represents the mean of 25 plants

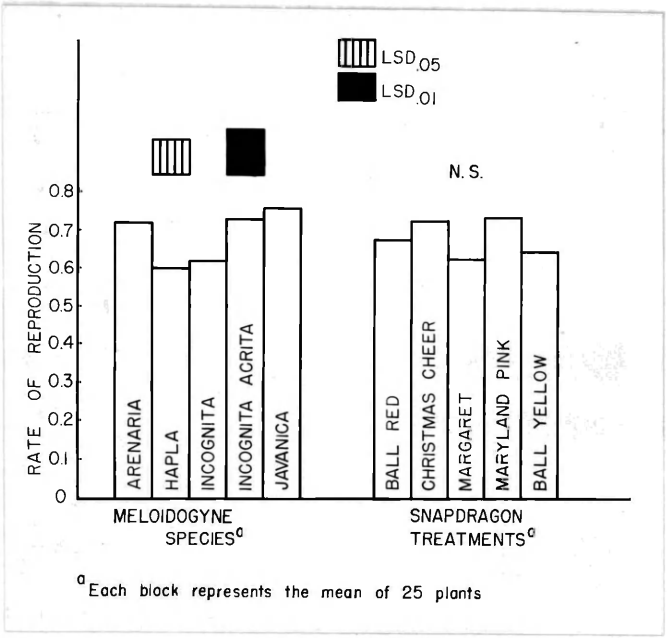
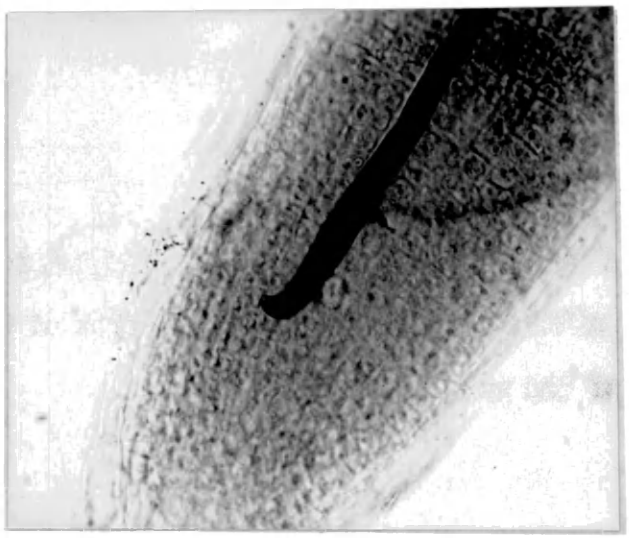

LSD.05
LSD.01
N. S.
RATE OF REPRODUCTION
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
ARENARIA
HAPLA
INCOGNITA
INCOGNITA ACRITA
JAVANICA
BALL RED
CHRISTMAS CHEER
MARGARET
MARYLAND PINK
BALL YELLOW
MELOIDOGYNE SPECIES[a]
SNAPDRAGON TREATMENTS[a]
[a]Each block represents the mean of 25 plants

Figure 14

The anterior end of a larva of Meloidogyne arenaria in a root tip of snapdragon 2 days after inoculation. Note position of the head within the meristem of the root tip X440.

Figure 15

A larva of Meloidogyne javanica 2 days after inoculation. Note the curled position of the nematode within the root tip X100.



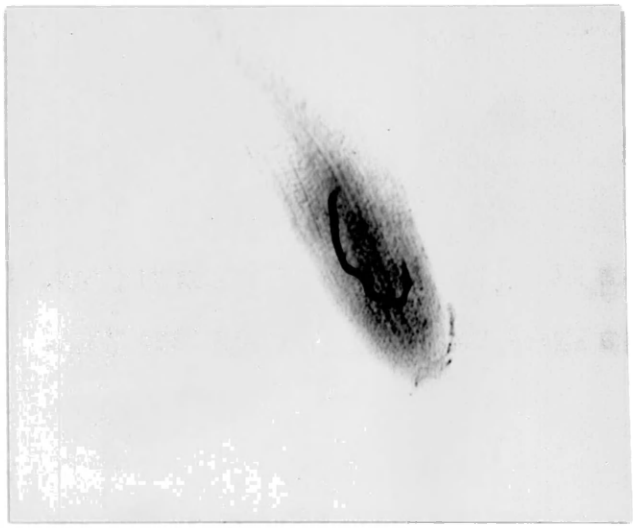
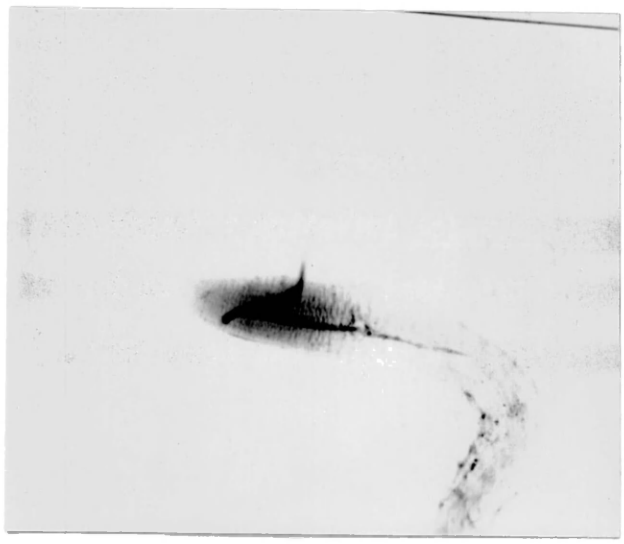


Figure 16

Two larvae of Meloidogyne javanica infecting a snapdragon root tip 2 days after inoculation. Note that 1 larva was in the act of penetrating the root tip when the tissue was fixed X100.

Figure 17

A larva of Meloidogyne incognita var. acrita 4 days after inoculation. Note the inception of gall formation X100.



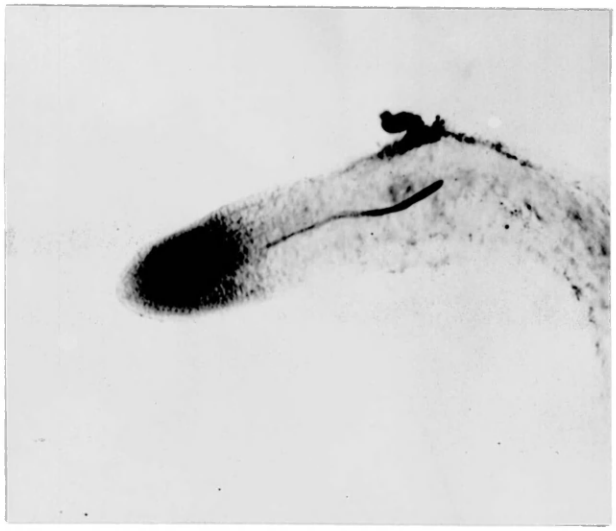
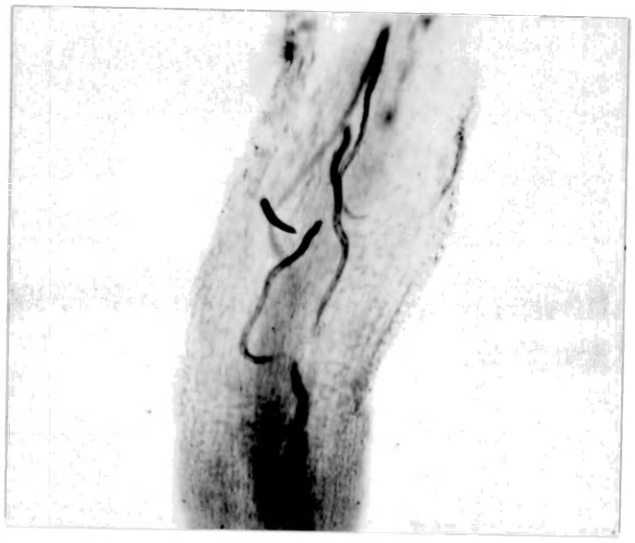


Figure 18

Several larvae of Meloidogyne arenaria infecting a snapdragon root 6 days after inoculation X100.

Figure 19

A second-stage larva of Meloidogyne hapla 10 days after inoculation showing partial thickening of the body immediately posterior to the esophageal region X100.



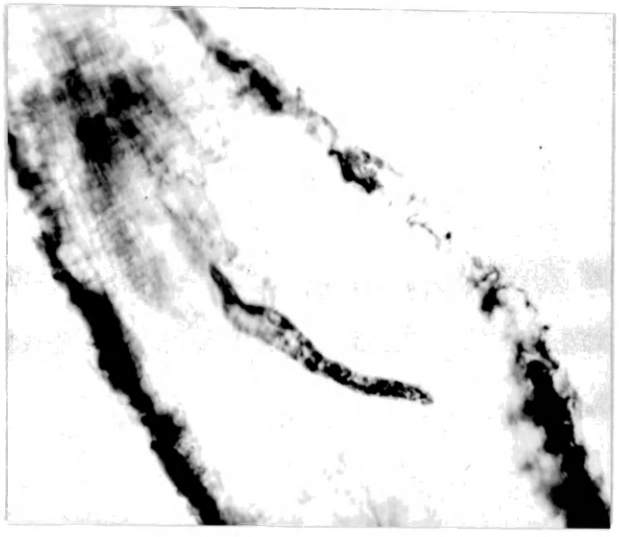
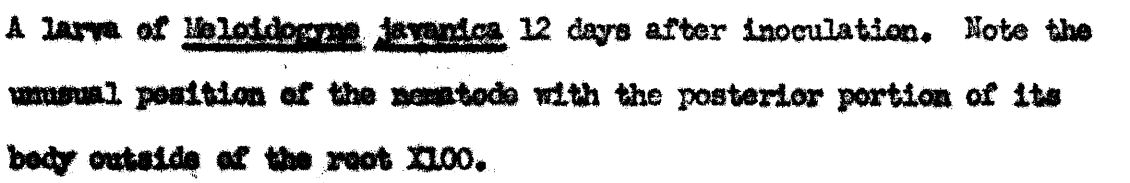
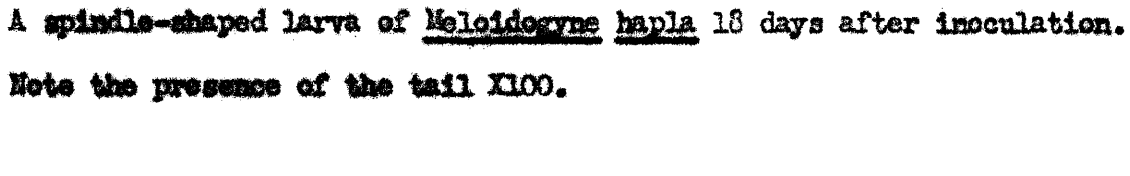


Figure 20



A larva of Meloidogyne javanica 12 days after inoculation. Note the unusual position of the nematode with the posterior portion of its body outside of the root X100.

Figure 21



A spindle-shaped larva of Meloidogyne hapla 18 days after inoculation. Note the presence of the tail X100.

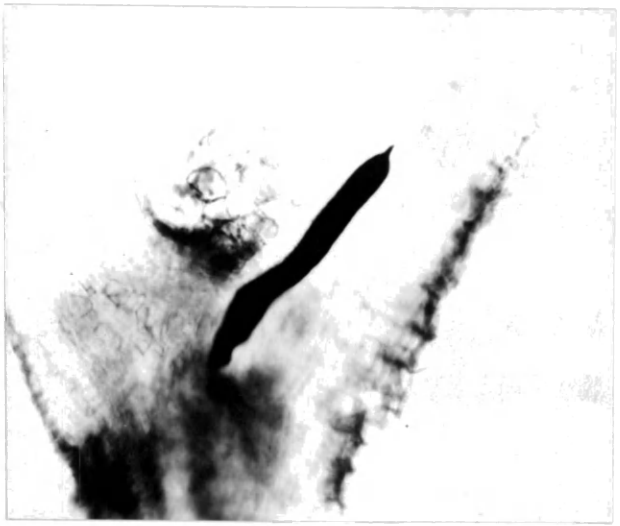
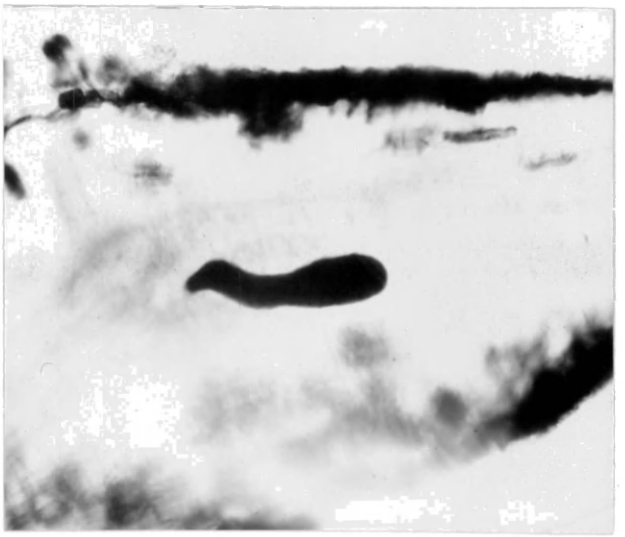


Figure 22

A developing larva of Meloidogyne javanica 20 days after inoculation. Note the absence of a tail X100.

Figure 23

A somewhat abnormally developed larva of Meloidogyne javanica 20 days after inoculation. Note the constriction of the body X100.



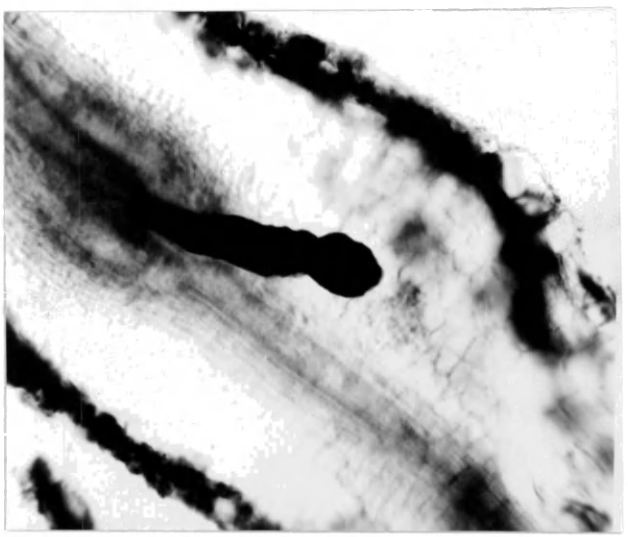


Figure 24

A developing larva of Meloidogyne javanica 24 days after inoculation. Note the increase in body width X100.

Figure 25

An abnormally developed larva of Meloidogyne incognita 24 days after inoculation. Note the curvature of the body around the stele of the root X100.

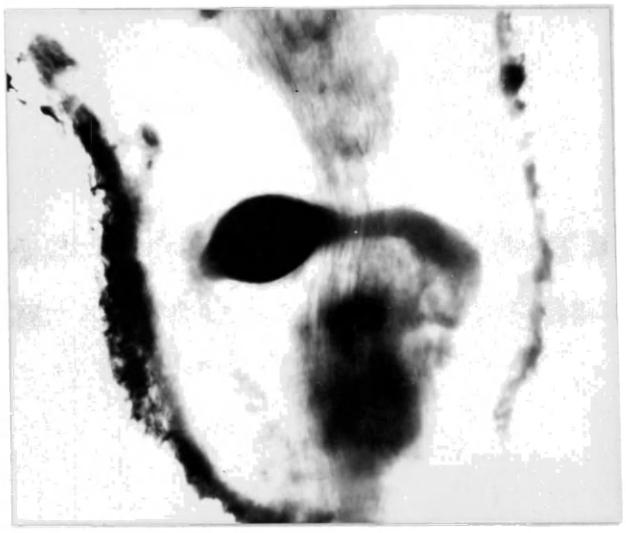
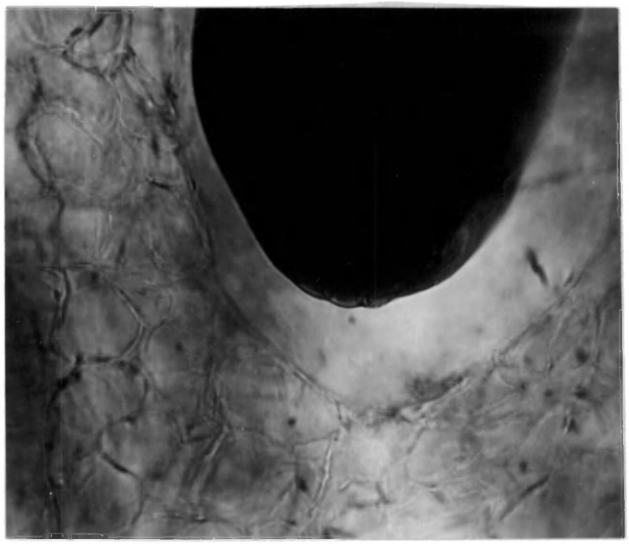


Figure 26

The posterior end of a young female of Meloidogyne javanica 24 days after inoculation. Note the terminal indentation which is the anal opening and the subterminal indentation which is the genital opening X440.

Figure 27

A young female of Meloidogyne incognita 26 days after inoculation X100.



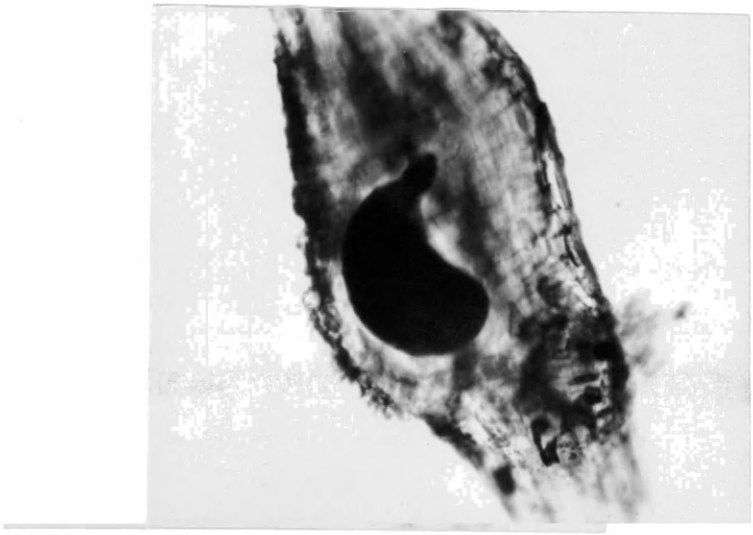
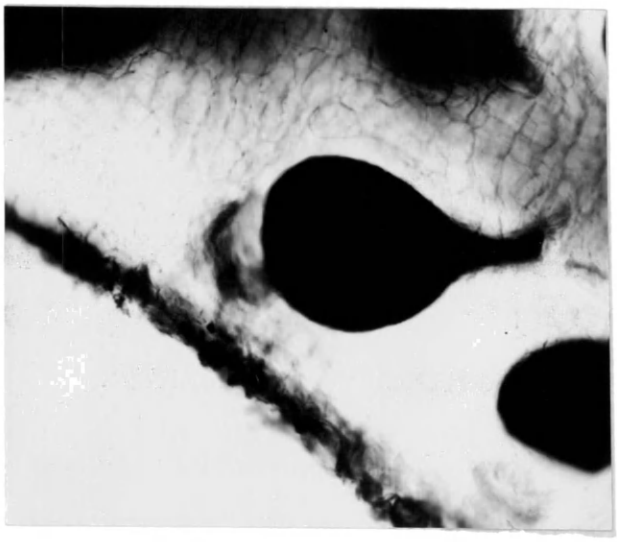


Figure 28

A gravid female of Meloidogyne incognita 30 days after inoculation. Note the gelatinous matrix, the formation of which always precedes oviposition, at the posterior end of the animal X100.

Figure 29

A gravid female of Meloidogyne arenaria 30 days after inoculation showing the gelatinous matrix formed below the posterior end of the nematode X100.



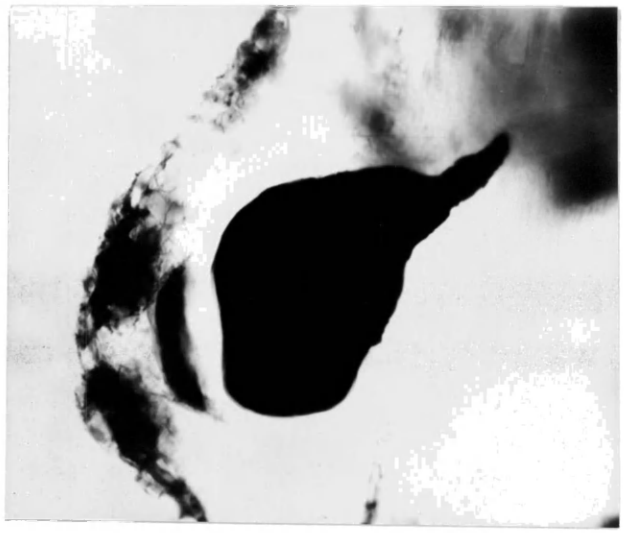
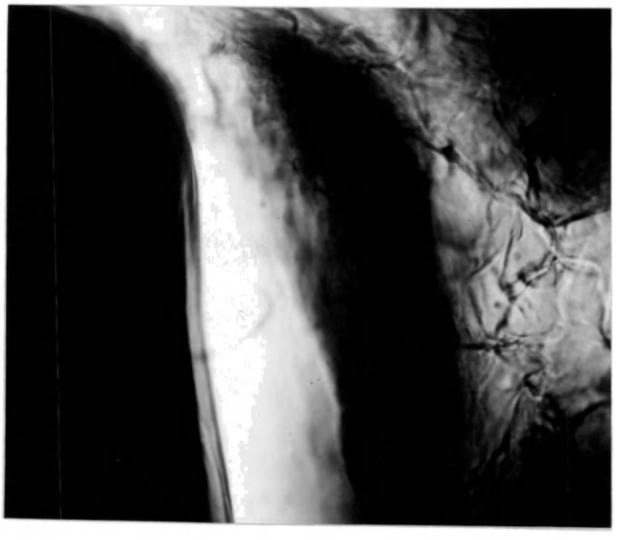


Figure 30

A higher magnification of the gelatinous matrix formed by a gravid female of Meloidogyne arenaria 30 days after inoculation. The dark structure at the left is the posterior end of the female. The darkened elongate structure in the middle of the photograph is the gelatinous matrix. At the right are parenchymatous cells of the cortex within the snapdragon root X440.

Figure 31

An ovipositing female of Meloidogyne incognita var. acrita X100.



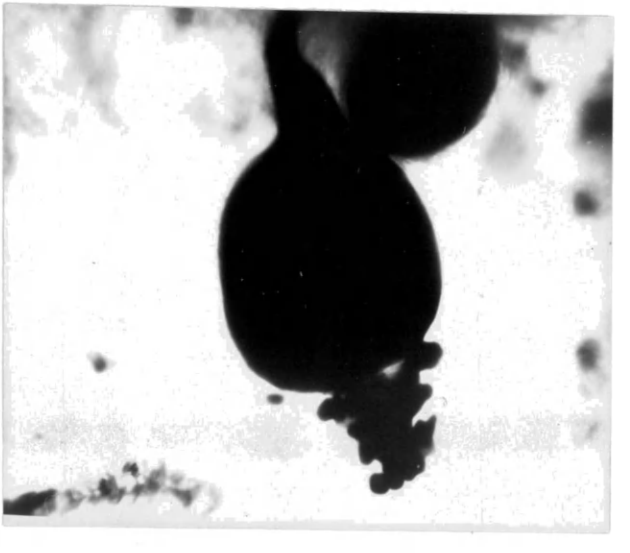
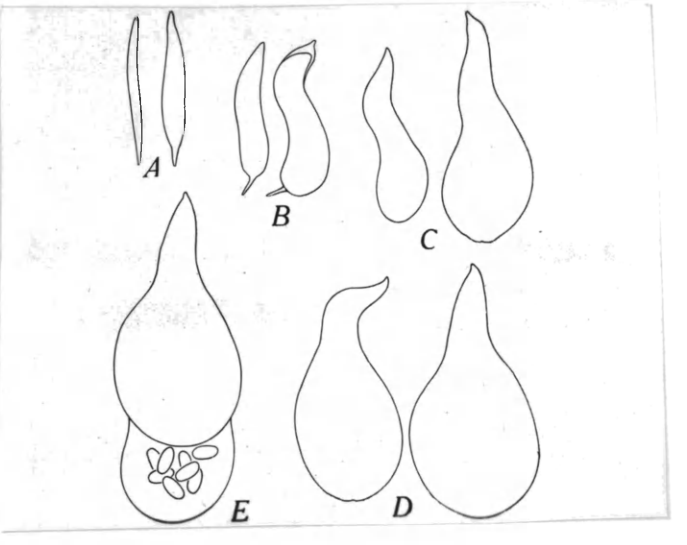


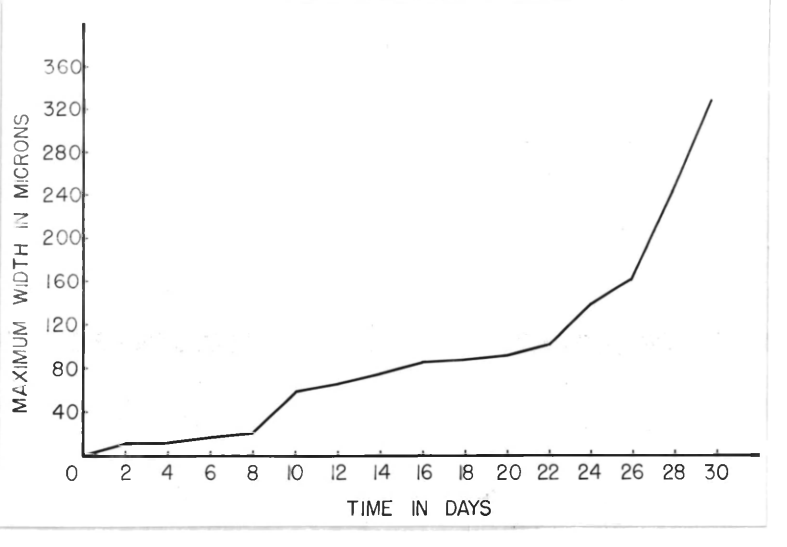
Figure 32

Groups A through E into which the parasites were classified according to the amount of development undergone (after Christie).

Figure 33

Mean growth curve of the root-knot nematodes as determined by maximum increase in size.


A
B
C
D
E


MAXIMUM WIDTH IN MICRONS
360
320
280
240
200
160
120
80
40
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
TIME IN DAYS

VITA

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Greenbelt, Maryland

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Place of birth: Cambridge, Massachusetts

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Collegiate institutions attended:	Dates	Degrees	Date of Degree
Rutgers University	1940-43 1946-47	B. S.	June, 1947
University of Maryland	1947-49	M. S.	June, 1949

Publications:

(see following page)

Positions held:

1. July, 1947 to June, 1950, graduate assistant, Botany Department, University of Maryland.

2. July, 1950 to present, assistant nematologist, Division of Nematology, Bureau of Plant Industry, Soils, and Agricultural Engineering, United States Department of Agriculture, Beltsville, Maryland.

PUBLICATIONS

1. The meadow nematode disease of boxwood. (abstr.) Phytopath. 38: 577. 1948.

2. Two new nematode diseases of the African violet. With C. E. Cox. U. S. Dept. Agr., Pl. Dis. Reptr. 32: 256. 1948.

3. Inefficacy of ethylene chlorobromide as a therapeutic agent in the treatment of gardenias infected with the root-knot nematode. (abstr.) Phytopath. 38: 577. 1948. Phytopath. 38: 845-847. 1948.

4. Utilization of the Baermann method as a means of assay of root infection by meadow nematodes, Pratylenchus spp. (abstr.) Phytopath. 39: 26. 1949.

5. A new disease of pin oak, possibly caused by the nematode, Hoplolaimus coronatus. With R. M. Viggars. U. S. Dept. Agr., Pl. Dis. Reptr. 33: 132-133. 1949.

6. Studies on selenium therapy of meadow nematode-infected boxwoods. (abstr.) Phytopath. 39: 505. 1949.

7. Preliminary tests with seed treatments in prohibiting root-knot nematode infection of cucumber seedlings. With J. E. Moore. U. S. Dept. Agr., Pl. Dis. Reptr. 33: 447-450. 1949.

8. Parathion therapy of meadow nematode-infected boxwoods. (abstr.) Phytopath. 40: 27. 1950.

9. A consideration of mineral nutrition of boxwood in relation to infection by meadow nematodes, Pratylenchus spp. Jour. Wash. Acad. Sci. 40: 157-161. 1950.

10. Investigations of meadow nematodes attacking boxwoods, and the therapeutic value of sodium selenate as a control. Phytopath. 40: 1111-1124. 1950.

11. Parathion...its action against the meadow nematode. Agr. Chem. 5: 32-34, 95, 97. 1950.

12. An explanation of the revision of the root-knot nematodes, Meloidogyne spp. U. S. Dept. Agr., Pl. Dis. Reptr. 35: 216. 1951.

13. Observations on nematodes associated with decline of ornamental plantings. U. S. Dept. Agr., Pl. Dis. Reptr. 35: 217-218. 1951.

14. Association of certain nematodes with yellow tuft of bentgrass. With M. E. Ferguson. (abstr.) Phytopath. (in press).

15. Pathological behavior of the root-knot nematodes on snapdragon. (abstr.) Phytopath. (in press).

ABSTRACT

Armen Charles Tarjan, Ph. D. 1951 (M. S. University of Maryland, B. S. Rutgers University)
Title of thesis: Pathogenic behavior and life histories of the root-knot nematodes, Meloidogyne spp., on snapdragon, Antirrhinum majus
Thesis directed by Professor W. F. Jeffers and Dr. Gotthold Steiner
Major: Plant Pathology, Department of Botany
Minors: Botany and Horticulture
Pages in thesis, 82. Words in abstract, 292

Five species of root-knot nematodes, Meloidogyne arenaria, M. hapla, M. incognita, M. incognita var. acrita, and M. javanica were investigated as to their pathological effects on the following varieties of the common snapdragon, Antirrhinum majus: Ball Red Hybrid #7, Christmas Cheer, Margaret, Maryland Pink, and Ball Yellow Hybrid #1. In the first experiment each nematode species was employed at inoculum levels of 1, 10, and 100 egg masses while in the second experiment only a standard inoculum of 5 egg masses was used. Two and one half months after inoculations measurements of the reaction of plants to infection by each species were obtained by recording the weight of above-ground parts, root weight, and root-knot index of each plant. Expressions of the effect of the host on the parasite were obtained by recording the number of females, number of egg masses, and rate of reproduction (number of egg masses divided by the number of females) per plant. Significant differences were found to exist, in many cases, between the Meloidogyne species themselves and between plants infected by these species. A study of the life history of each of the 5 Meloidogyne species infecting Margaret variety of snapdragon failed to reveal any outstanding differences between species. It was shown that Meloidogyne arenaria, M. hapla, and M. incognita oviposited 30 days

after plants were inoculated. Reinfection of root tips by second generation larvae was detected 66 days after inoculation for M. arenaria and 68 days after inoculation for M. hapla. When tomato seedlings, Lycopersicon esculentum var. Rutgers, were inoculated with each of the 5 Meloidogyne species, M. incognita var. acrita formed eggs in 37 days while the other species required 39 days for oviposition. Reinfection of root tips by second stage larvae occurred 57 days after inoculation for M. incognita, 59 days after inoculation for M. incognita var. acrita, and 68 days after inoculation for M. arenaria, M. hapla, and M. javanica.