A Survey of Plant Parasitic and Associated Species of Nematodes in the Carrot Producing Area of Cedar Valley, Iron County, Utah

Paul R. Fitzgerald

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A SURVEY OF PLANT PARASITIC AND ASSOCIATED SPECIES OF NEMATODES
IN THE CARROT PRODUCING AREA OF CEDAR VALLEY, IRON COUNTY, UTAH

by

Paul R. FitzGerald

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Zoology

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UTAH STATE AGRICULTURAL COLLEGE

Logan, Utah
APPROVED:

Thesis Director

Major Professor

Head of Department

Dean of the Graduate School
ACKNOWLEDGMENTS

Grateful acknowledgment and thanks are herein expressed to Mr. Gerald Thorne, Division of Nematology, Bureau of Plant Industry, United States Department of Agriculture. His patient guidance and assistance have been largely responsible for the information set forth in this thesis. Without his help the solution of the problem would have been exceedingly difficult. Mr. Max Fielding, also of the Division of Nematology, has been very generous with assistance.

Special supplies and equipment required for the successful completion of this problem were not available in the Zoology department. Dr. D. M. Hammond was instrumental in obtaining much of the needed equipment and supplies. His timely advice and friendly assistance has been greatly appreciated.

To all others who have contributed assistance or information contained in this paper the writer expresses his sincere thanks.

Paul R. Gerald
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INTRODUCTION

Importance

Plant parasitic nematodes have long been known to cause extensive crop losses through reduced yields, shortened productive life, or lowered value of produce. The root knot nematode, *Feterodera marioni*, is cosmopolitan. It destroys crops and causes economic losses equal to those of any other plant parasitic species. In 1948 this nematode caused an estimated loss to the carrot raising industry in Iron County, Utah of approximately $15,000. No estimates for the years prior to 1948 are available; however, reports of the county agent (14) for Iron County show that carrot production in the Cedar Valley is decreasing, and is possibly due to this nematode.

The importance of the root knot nematode to the carrot industry in the Cedar Valley was recognized by farmers at harvest time in 1948. Experimental applications of soil fumigants were tried on many farms with varying success in the spring of 1949. (See figure 1 page 2). One of these experimental plots showed spectacular results. When carrots were harvested in the fall those grown in fumigated soil were found to be of the highest quality and were growing in excellent stands; whereas, the carrots grown in unfumigated soil produced poorer stands of poor quality carrots. Before any conclusions as to the practical value of soil fumigants in carrot raising can be reached, additional tests must be conducted in the area.

The fact remains that the root knot nematode is present in the area and causes damage to carrots. If carrots, or any other susceptible crops, are to be grown an economical method of controlling this nematode must be found.
Purpose

The purpose of this study was to obtain information about plant parasitic and associated nematodes in the carrot producing area of Cedar Valley, Iron County, Utah; and to establish the identity, occurrence, and effect of these nematodes on various plants.

Scope

The study is primarily a taxonomic survey of nematode populations. Determining the presence of various nematode species and their relationships to plants will lay the groundwork for future control of plant parasitic nematodes through proper use of crop rotation. Such information also may be useful in reducing minor crop damage previously attributed to other causes.

Figure 1. Fumigating the soil with a homemade plow applicator to control nematode damage to carrots in the Cedar Valley, Iron County, Utah, April 1949. (Photo by Thorne)
Location and topography

Cedar Valley is a small valley in the eastern part of Iron County, Utah. It joins Parowan Valley on the north and is bordered on the west by mountains of 6,000 to 7,000 feet elevation. To the south and the east, mountains bordering the valley are from 9,000 to 11,000 feet high.

The altitude of the valley ranges from 5,275 to 5,800 feet at Cedar City. The farming area west of highway 91 is located on a smooth alluvial fan spreading northwestward from the mouth of Cedar Canyon. Other smaller alluvial fans formed by intermittent streams from the slopes of the western face of the High Plateau (28) merge with the larger fan from Coal Creek to form a long slope to the valley floor. The area is generally level in a north-south direction with an east to west slope.

Geology and soils

Cedar Valley is bounded on the east by the abrupt escarpment of the Hurricane Fault and the High Plateau. The mountains are mostly sedimentary in structure; but because of excessive faulting, tilting, and thrusting movements, many types of geologic formations are exposed. Coal Creek, as well as the smaller intermittent streams draining the High Plateau, has deposited many kinds of soil-forming materials.

Near the mountains the soil is shallow and contains deposits of medium to large boulders close to the surface. The soil of the valley floor is generally fine and deep; however, the texture may vary from gravel to clay on the same farm.

Climate

The climate of Cedar Valley approaches a semiarid state more closely than that of the more southern farming areas of the state. This is undoubtedly related to the fact that the valley is higher
than the more southern farming areas and is closer to the High Plateau.

The distribution of rainfall is irregular. Thomas and Taylor (28) report that the annual precipitation during 34 years prior to 1940 has averaged 12.99 inches. The precipitation averages 20 inches per year at the higher elevations of the Coal Creek drainage. The greatest monthly rainfall occurs in February, March, April, July, and August. The western drainage feeds water into the streams used to irrigate crops in the valley. Supplementary water is pumped from large deep wells.

The growing season is about 150 days, or approximately from the first week in May to the first week in October; however, killing frosts have been reported as late as July 3 and as early as September 5 (28). Year round temperatures in the valley average 52.1 degrees F. The January average for the 34 years prior to 1940 was 30.6 degrees F. July averages for the same 34 years was 73.6 degrees F. Extreme temperatures for the 34 year period were recorded as a high of 99 degrees and a low of -26 degrees F. (22).

Typical vegetation of the valley consists of sagebrush, rabbitbrush, willows, cottonwoods, and juniper; also june grass, quack grass, Russian thistle, sunflower, dandelion, ragweed, burdock, foxtail, cocklebur, and other plants commonly found in association with various farm crops.
Surveys in the United States

The first extensive survey of plant parasitic nematodes in the United States was completed in 1911 by Ernst A. Bessey. It dealt chiefly with the distribution and host plants of the root knot nematode, *Heterodera marioni* (Cornu) Goodey.

The root knot nematode is the most widespread of all the plant parasitic species (17). It is found throughout the United States, but the Southern states are the most heavily infested. Bessey (2) reported it as sporadic in Utah, Colorado, and Nebraska. He reported 480 plants parasitized by this nematode. The 1938 list compiled by Buhrer et al. (5) lists 1332 susceptible plants. Undoubtedly many additions to the list have been made since that date.

Surveys dealing with other nematode genera are mostly localized, and their specific value lies in their usefulness in combating local infestations.


The Division of Nematology, United States Department of Agriculture, conducts surveys where dangerous plant parasitic nematodes occur. Research projects are established in certain areas for the study of economically important species, and recommendations made for control by crop rotation or soil fumigation.
Research in Utah

Plant parasitic and soil inhabiting nematodes in Utah have been more intensively studied than those of any other state or country.* The more important studies have been made by members of the staff of the Division of Nematology Station, Salt Lake City, Utah. Their research in relation to the sugar beet nematode, *Heterodera schachtii*, has contributed greatly to the success of the beet sugar industry of the western states.

Thorne states** that the first observations on plant parasitic nematodes in Utah were made by Parley Austin about 1895 when he observed sugar beet nematodes in a field near Lehi. Bessey (2) confirmed Austin's observations and identified the sugar beet nematode in his report, which was the first written record of the pest in Utah. In 1918 Thorne was assigned to make a survey of the state. He made biological studies of life history, depth of habitat, dormancy, methods of distribution, natural enemies, and host plants.

The first record of *H. marioni* was noted by Thorne and H. J. Pack*** in 1919 from a field near Layton in Davis County. Between 1919 and 1921 Thorne and Pack found approximately fifty fields infested with this nematode in Utah, Salt Lake, Davis, Box Elder, and Cache counties. In the course of studying *H. marioni* and *H. schachtii*, other nematodes were collected, including numerous undescribed plant parasitic, predacious, free living, and saprophagous species; as well as many of uncertain position and habits.

* Unpublished address by Gerald Thorne given at the fall meeting of the Utah Academy of Sciences, Arts, and Letters, Logan, Utah. 1949.
** Ibid.
*** Unpublished records of the Division of Nematology, Salt Lake City, Utah.
Damage by the root knot nematode is not new in southern Utah. In 1935 it was found to be a pest in the St. George area, attacking both gardens and field crops. Farmers in that area stated that they had observed damage to crops for many years, but did not know the causal agent.*

Prior to 1948 no study of nematodes had been made in the Cedar Valley, but in that year Thorne received carrots infested with *H. marioni*. On November 3, he visited the infested fields and made collections of soil and plant roots. In the spring of 1949 soil fumigation experiments were started on the basis of Thorne's diagnosis. The writer, fortunately, was able to assist in setting up and observing the operation of fumigating equipment.

Possible Sources of Inoculum

There is a possibility that the root knot nematode is indigenous to Cedar Valley because certain carrot growers reported that their crops were infested when planted on fields just broken from virgin soil on which sage, and other native plants were growing. The annual reports of the county agent give the following information on the production of carrots, peas, and other crops.

In 1940 commercial production of broccoli was halted** because sets produced for transplanting were of very poor quality. No information was available as to where these sets were grown or why they were of poor quality. Sixty acres of carrots were produced in the county. No further reference was made to carrots. Sixty carloads of peas were shipped. Early peas were almost a complete failure; moreover, a

---

* Conversation with Mr. Thorne.
** Records previous to 1940 were not available.
decrease in the size of the late crop was attributed to extremely dry, hot weather, lack of water, and attacks of pea aphids and thrips.

In 1941, 136 carloads of excellent quality carrots were shipped. Four hundred crates per acre was the average production rate. A shipment of 10 carloads of peas, in 1941, compared with 60 carloads the previous year, indicates a poor crop.

In 1942 there was a general abandonment of attempts to grow commercial peas. Uncertainty of weather, water, and frost were given as the primary reasons. Buhrer (5, 6) reports peas as a host of H. marioni. Four hundred acres of commercial carrots were to be grown; however, there was no report of the outcome.

Eighty acres of carrots grown in the county in 1943 produced 56 carloads of first quality carrots. Three Parowan farmers produced 27 acres of carrot seed from 1942 rootstocks. The yield of 200 pounds of seed per acre was considered poor.

Records for 1944 were unavailable.

In 1945, 4 carloads of certified potato seed were shipped into the county from Idaho. Certified seed from local growers also was planted. One acre of celery was grown successfully in Cedar Valley; whereas, seven acres grown in Parowan Valley in 1944 were a complete failure. No reason was given.

In 1946, 200 acres of carrots were planted in Iron County. Approximately 50 of these were lost because of poor germination of seed and extremely unfavorable weather. Ninety carloads were shipped.

In 1947 no reference was made to carrot production; however, a specific reference was made to growers of the county who planted good
quality potato seed that was not certified. Potatoes have been reported as a host of the root knot nematode (3, 4, and 8).

In 1948, 220 acres of carrots were planted with less than half being harvested for shipment.* Continuous high cold winds, dry weather, and shortage of irrigation water were given as causes for abandoning 150 acres in the county in June. No mention was made of nematode damage.

During 1949, 36 carloads of carrots were grown in Cedar Valley. Eighty-five acres were abandoned because heavy rains and hail at the beginning of the planting season caused crusting of the soil. A few farmers were forced to replant their carrots, resulting in late development and reduced yields and quality. No reference was made to results of fumigation.

Throughout these reports no reference is made to damage caused by nematodes; but the reported crop failures imply that factors in addition to poor germination, dry weather, rains, hail, and winds may have had direct bearing upon crop failures.

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* First year of reported heavy loss due to nematodes.
METHODS OF PROCEDURE

In the field

Collection. Samples of roots from various plants and soil from around the roots of these plants were collected at regular intervals during the summer of 1949. Sampling sites shown in figure 2 were selected from farms known to have had carrots damaged by nematodes. These farms represent the varied farming conditions in Cedar Valley.

Each plant was dug carefully to preserve a maximum number of root hairs. The excess soil was broken away, placed in a quart ice cream carton, and moistened with water. The addition of water was necessary to keep the nematodes from dying before they could be separated from the soil in the laboratory. The root system was washed and freed of all remaining soil particles, then folded, wrapped in cheese cloth, and labeled. Information recorded on each label was as follows: the number of the sample, date, location, the name of the plant, and a short description of the sampling site. Each plant sample was placed in a jar of 6 percent formalin to kill and preserve it for later examination.

Apparatus. Field apparatus consisted of a shovel, one dozen two quart jars, 85 round, one quart ice cream cartons with slip on tops, fine mesh cheese cloth, 1 1/2" X 4" paper labels, and strong cord for tying root bundles and tagging specimens. The preserving solution was made by diluting formaldehyde to the desired strength.

Treatment of samples in the laboratory

Plants. Plant tissues had been preserved in formalin for periods of 3 to 8 months, therefore, it was necessary to perfect a satisfactory staining technique that would stain the nematodes in the tissues. The following technique gave best results on preserved specimens:
Figure 2. Location of sampling sites Cedar Valley, Iron County, Utah, June 6 to September 17, 1949. a, west Bryant farm; b, Bryant farm; c, corn patch east of Bryant farm; d, Palmer farm; e and f, Davis farm; g, northwest Luke farm; h, northeast Luke farm; i, Jones farm; j, Luke home farm.
1. Roots were taken from the preservative and rinsed in cool clean water to clear excess formalin from the tissues. 2. They were then placed in 35 percent alcohol for 15 minutes to make the replacement of formalin by water more gradual. 3. The roots were taken from the alcohol and immersed in tap water for a minimum of 10 minutes, then taken from the water and placed in the staining solution.

The method of staining nematodes in plant tissues found to be most successful was a modified version of the lacto-phenol-glycerine-acid fuchsin stain described by Goodey (20). Seventy-five cc. of lactic acid, phenol, and glycerine in a 100 cc. beaker was heated to 70 degrees C. and enough one percent acid fuchsin added to give the solution a deep cherry red color.* Roots were immersed in this solution for 10 to 15 minutes depending upon the size of the roots.

Upon removal, the stained tissues were cut in \( \frac{1}{3} \) to 1 inch lengths, placed in a watch glass, and covered with lacto-phenol-glycerine stock solution. Small amounts of 35 percent acid alcohol were added to destain the tissues; the total amount depending upon root size. If too much acid alcohol was added, destaining was too rapid and could not be stopped at the proper time. Destaining was most successful when the temperature of the stock solution was 70 degrees C. To save time, stoppered bottles of lacto-phenol-glycerine stock solution and staining solution were kept heated to 70 degrees C. in a thermostatic oven. If the bottles were not stoppered, water evaporated leaving a thickened solution that had poor staining and penetrating qualities. Destaining was stopped when the nematodes were clearly visible in the plant tissues. Plant tissues destained more rapidly than nematodes.

* Correspondence with Harold Reynolds, Nematologist, Sacaton, Arizona.
When nematodes were found in the tissues they were removed in a section of the root, placed in a 25 mm. miniature watch glass of the Plant Industry type, and covered with the lacto-phenol-glycerine stock solution. Each watch glass was labeled with the proper field number and placed in a stender dish with a small vial of anhydrous calcium carbonate. The stender dish was sealed with petroleum jelly to keep moisture out and allow the calcium carbonate to absorb the water slowly from the stock solution. This requires approximately 3 weeks, after which the plant tissues were mounted in acidified glycerine on 25 mm. square coverslips. The tissues were covered with 18 mm. round cover slips and sealed with Zut* ringing compound. The slide was completed when the 25 mm. cover slip was placed in an aluminum holder.

Soil samples. Preservation of soil samples was impractical, so nematodes in each sample were separated from the soil and preserved in six percent formalin. Final mounting and identification were made during the fall and winter.

The Cobb sifting and gravity methods (12) were used to separate nematodes from the soil. These consist of a series of graduated screens through which progressively smaller particles are separated from a soil solution. In this study, brass wire cloth screens of 20, 50, 100, 150, and 300 meshes per inch were used. (Figure 3). Although the 300 mesh screen is more expensive than bolting silk, it repays its extra cost in time saved. Screen residues containing the nematodes were preserved in six percent formalin after being separated from the soil.

* Manufactured by Bennett Paint and Glass Co. Salt Lake City, Utah.
Preserved nematodes from the soil sample were concentrated by pouring the solution in which they were preserved through the 300 mesh screen. The residue, left in the bottom of the screen, was washed from the inverted screen with a small stream of water into an enameled pan. The water, containing nematodes and organic material, was poured from the pan into a 100 cc. beaker and allowed to settle. Three-fourths of the water was decanted and a small amount of the remainder poured into a watch glass, placed under a dissecting binocular microscope, and examined for nematodes.
Individual nematodes were lifted from the watch glass with the aid of a slender spine from the Prickly Pear cactus inserted in the split, sharpened end of a wooden needle holder.* Specimens picked out of the water were placed in a miniature watch glass containing formalin-acetic acid-alcohol fixative and allowed to remain overnight. The following morning the fixative was drawn off with a fine-pointed eye dropper, and the miniature watch glass, containing the nematodes, was filled with 30 percent alcohol containing 2 1/2 percent glycerine. The miniature watch glass and a vial of anhydrous calcium carbonate were sealed in a slender dish and the solution allowed to evaporate to pure glycerine. Unstained nematodes were mounted in pure glycerine on 25 mm. cover slips. The 18 mm. top cover slip must be supported with fine glass rods slightly smaller in diameter than the nematode. The two cover slips are sealed with Zut and mounted in aluminum holders as explained above for plant tissues.

Identification. Identification of nematodes in plant tissues, as well as nematodes from the soil samples, was confirmed by Mr. Thorne and Mr. Fielding in the Salt Lake City office of the United States Division of Nematology.

*The wooden needle holder was preferable to the bacteriological type needle holder because it is smaller, lighter, and more easily manipulated.
RESULTS

Nematodes were found in the root tissues of twenty out of twenty-eight species of plants collected in the summer of 1949. (Table 1). Eight of the twenty-eight were common cultivated field plants. Twelve others were weeds common to farms in the area. Eight plants harbored no nematodes. Carrots, wild parsnip, and sagebrush were found to be hosts of *Heterodera marioni*.

Reference is made to plants acting as hosts of *H. marioni* in the following pages. In addition, attention is called to the potential nematode invaders found in the soil around the roots of other plants. The relationship of many of these nematodes to plants is still unknown.

A classified list of all nematodes discussed appears in a separate section of this paper and the reader is referred to this for feeding habits, as far as they are known, of specific nematodes found in the soil around plant roots.

**Nematodes found in root tissues and in soil around the roots of cultivated field plants**

*Heterodera marioni* in carrots. The value of the carrot as marketable produce is lost when the carrot fails to meet accepted standards. A hairy, deformed, stunted carrot is typical of the damage resulting from attacks of *H. marioni*.

Nematode induced damage of two types are manifest in the carrot. One type of damage probably results from a continuous invasion of the hair and lateral roots by the nematodes. Figure 4 shows a carrot which reacted to such an invasion by sending out additional roots in an attempt to offset the damage caused by the nematode. Under such attacks
Table 1. Nematodes found in the roots of various plants of Cedar valley, Iron County, Utah, June 7 to September 17, 1949. (X) Nematodes found in plants of this study. (*) Known host plants of Heterodera marioni but not found infested in this study. (†) Some species of the plant are known hosts of H. marioni.

<table>
<thead>
<tr>
<th>Plants collected</th>
<th>Nematodes found in plant root tissues</th>
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<tbody>
<tr>
<td></td>
<td>Aphelenchus avenae</td>
</tr>
<tr>
<td>Alopecurus aequalis</td>
<td></td>
</tr>
<tr>
<td>Amaranthus retroflexus</td>
<td>X</td>
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<tr>
<td>Agropyron repens</td>
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<tr>
<td>Ambrosia sp.</td>
<td>#</td>
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<td>Arctium minus</td>
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<td>Artemesia tridentata</td>
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<tr>
<td>Atriplex sp.</td>
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<tr>
<td>Avena sativa</td>
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<tr>
<td>Brassica alba</td>
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<tr>
<td>Bromus tectorum</td>
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<tr>
<td>Cerastium vulgatum</td>
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<tr>
<td>Chrysanthemum sp.</td>
<td></td>
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<tr>
<td>Daucus carota</td>
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<tr>
<td>Helianthus sp.</td>
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<tr>
<td>Hordeum vulgare</td>
<td>X</td>
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<tr>
<td>Lycium sp.</td>
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<tr>
<td>Malva rotundifolia</td>
<td>X</td>
</tr>
<tr>
<td>Medicago sativa</td>
<td>X</td>
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<tr>
<td>Melilotus alba</td>
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<tr>
<td>Pastinaca sativa</td>
<td>X</td>
</tr>
<tr>
<td>Physalis subglabrata</td>
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<tr>
<td>Rumex sp.</td>
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<td>Salvia kali</td>
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<tr>
<td>Solanum tuberosum</td>
<td>*</td>
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<tr>
<td>Taraxacum officinale</td>
<td>*</td>
</tr>
<tr>
<td>Triticum aestivum</td>
<td>*</td>
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<tr>
<td>Xanthium sp.</td>
<td>#</td>
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<tr>
<td>Zea mays</td>
<td>X</td>
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</table>
The carrot must continually send out new rootlets to gather enough food to keep alive. Growth occurs in the lateral roots instead of the tap root of the plant. Such growths probably result from continuous serious infestation. The tap root of the carrot is not extensively damaged and could be eaten without any harmful effects (24); however, it has little market value.

Figure 4. Damage to carrots as a result of root knot nematode attacks in the Cedar Valley, Iron County, Utah, 1948. (Photo by Thorne)
The second type of damage, shown in figure 5, is probably the results of a damaged tap root when the plant was young. It is easily confused with damage caused by improper soil, irrigation, or tillage methods. As a result of this early damage, the tap root split into several branches and grew gnarled and twisted. An unknown factor caused the disappearance of many of the nematodes in the plant. A few galls are present but they are far less numerous than those on the plant shown in figure 4.

Nematodes from the soil around the roots of the carrot were: Acrobeles complexus, Ditylenchus sp., Dorylaimus penetrans, and Placodira sp.

Figure 5. Damage to carrots resulting from root knot nematode attacks in the Cedar Valley, Iron County, Utah, 1948. (Photo by Thorne)
Alfalfa. A sample of *Medicago sativa* growing on the Luke home farm was collected on June 8, 1949. The plant was growing in a field on high ground adjacent to wheat.

Microscopic examination of a root section 5-6 mm. long revealed 4 specimens of *Aphelenchus avenae* lying midway in the cortex. (Figure 6). No outstanding damage to the root was noted. The foliage of the plant appeared to be as healthy as that of any of its neighbors. However, it was separated from other alfalfa plants by a ring of bare soil.

Unfortunately all of the nematodes prepared for identification from the soil around the roots were too immature to be identified and were discarded.

Figure 6. *Pratylenchus* sp. in the cortex tissue of alfalfa root.
Barley. Two root samples of Hordeum vulgare collected on the Bryant farm June 7, 1949, were found to have the cortex tissue infested with nematodes. Aphelenchus avenae was present in large numbers in one sample. The same soil was heavily infested with H. marioni in 1948. The second sample was a volunteer plant associated with young alfalfa. The cortex tissue of this plant harbored specimens of Panagrolaimus subelongatus, Paraphelenchus sp., and Tylenchus sp., along with several eggs. The inner root parts were not infested.

The soil around the roots of the first sample contained specimens of Acrobeles maximus, Aporcelaimus vorax, Carceralaimus teres, Dorylaimus monhystera, Dorylaimus sp., and Nygolaimus sp.

Aphelenchoides parietinus, Boleodorus thylactus, Chiloplacus symmetricus, Deladenus durus, Dorylaimus miser, D. monhystera, Panagrolaimus subelongatus, Paraphelenchus sp., and Rhabditis sp. were found in the soil around the roots of the second sample.

Corn. A very young specimen of Zea mays was collected from a field east of the Bryant farm June 7, 1949. The plant was about 4 inches high when dug; the root was small and seed coat intact. The roots and inner part of the seed were uninfested, but the seed coat was highly infested. Figure 7 shows the nematode population in an area less than two millimeters square.

Two species of nematodes, Aphelenchus avenae and Chiloplacus symmetricus, were identified as the invaders. The presence of partially embryonated eggs was an indication that the nematodes had invaded the seed coat shortly after it was planted. When the field was observed at a later date, conspicuously stunted corn plants were present in the area where this sample of corn was taken.
Associated species of nematodes found in the soil around the roots were *Acrobeles complexus*, *Chiloplacus contractus*, *Diplogaster sp.*, and *Discolaimium conure*. 

Figure 7. *Aphelenchus avenae* and *Chiloplacus symmetricus* in the seed coat of corn.
A sample of *Avena sativa* was collected from a ditch bank on the Luke home farm August 11, 1949, where it was a volunteer plant associated with willows and wheat. The outer cortex of the root at the crown was dead. Several invaders appeared to be feeding on the tissues. A small unidentified oligochaete worm was imbedded in the outer tissues with several eggs and adults of *Chiloplacus symmetricus* and *Panagrolaimus subelongatus*. Fungi hyphae were growing all through the cortex of the plant.

The soil from around the roots yielded a large number of specimens tentatively identified as *Ecphyodophora tenuissima*. In addition, specimens of *Aphelenchus avenae*, *Carcharolaimus teres*, *Diptherophora perplexans*, *Discolaimus major*, *Dorylaimus* sp., *Pratylenchus* sp., and *Tylenchus* sp., were found.

**Potato.** Some excellent samples of *Solanum tuberosum*, growing in fine, sandy, loam soil were collected June 7, 1949, on the Davis farm. No infestation of the roots was noted. The inner part of the tuber contained no nematodes; however, several specimens of *Chiloplacus symmetricus* were found in the cortex. Several eggs were located in the same layer.

The land was plowed out of alfalfa in 1948 and planted with potatoes in the spring of 1949. *Heterodera marioni* has caused damage to potatoes in nearly every section of the country where potatoes are grown (3, 4, and 8).

Unfortunately most of the nematodes from the soil sample were lost when the jar containing them broke. However, large numbers of *Rhabditis* sp., and *Chiloplacus symmetricus* were salvaged from the preservative that was recovered.
Wheat. A sample of *triticum aestivum* collected on the Palmer farm June 7, 1949, was a volunteer plant in an idle field. The field had been planted to wheat in 1948. High quality carrots were grown in the sandy, loam soil in 1946 and 1947.

A heavy infestation of *Chiloplacus symmetricus* was noted in the outer cortex near the crown. Eggs were abundant in the same tissue. The nematodes and a species of fungus had entered the root and appeared to be feeding on the dead and dying plant cells. The inner parts of the root were not attacked.

In addition to *Chiloplacus symmetricus*, *Chiloplacus contractus*, and *Panagrolaimus subelongatus* were found in the soil surrounding the roots.

**White Sweetclover.** A single large specimen of *Melilotus alba* collected from a ditch bank July 8, 1949, on the Luke home farm, was found to be host of a species of *Pratylenchus*. The nematodes, with several eggs, were found in the cortex tissue. Microscopic examination of the plant tissues did not show specific damage to the healthy inner cells of the root. The plant was growing in soil immediately adjacent to soil severely infested with *H. marioni* in 1948.

*Acrobeles complexus*, *Acrobelaoides butschlii*, *Boleodorus thylactus*, *Discolaimium conura*, and *Tylenchorhynchus* sp. were associated nematodes found in the soil around the roots.

**Nematodes found in root tissues and soil around the roots of weed plants**

**Burdock.** A single sample of *Arctium minus* collected on the Luke home farm September 20, 1949, was host to a few specimens of *Chiloplacus symmetricus*, loosely attached, and just within the cortex tissue. The plant was growing in association with barley. No specific damage to
the living root tissues was observed. The clay, loam soil had been planted to carrots in 1948; however, most of the carrots were not dug because of the serious damage caused by H. marioni.

Specimens of Boleodorus thylactus, Cylindrolaimus sp., Discolaimus major, Ecphyodophore tenuissima, Pratylenchus sp., Prismatolaimus stenurus, and Tylencholaimus teres were identified from the soil around the roots.

Cheese weed. A specimen of Malva rotundifolia collected near a roadway on the Palmer farm June 7, 1949, was more intensely infested by nematodes than any other plant examined. Cortical tissue of the main root harbored 75 to 100 nematodes in a piece of root less than one-fourth of an inch square. Two species, Panagrolaimus subelongatus, and Aphelenchus avenae were identified in the mass.

The effect of these nematodes on the plant was not definitely determined; however, the cortex was folded and swollen so that the root appeared to have galls on the side. Numerous eggs were present in the root tissues. The foliage of the plant was not detectably different from that of any other plant of the same species.

Specimens of Acrobeloides maximus, Aphelenchus avenae, Chiloplacus symmetricus, Discolaimium sp., Ditylenchus intermedius, Dorylaimus obscurus, Dorylaimus sublabiatus, Panagrolaimus subelongatus, Rhabditis sp., and Tylenchorhynchus sp. were identified from the soil taken from around the roots of the plant.

Dandelion. A specimen of Taraxacum officinale collected from a ditch bank September 20, 1949, on the Bryant farm harbored several specimens of Pratylenchus sp. Most of these nematodes were in the inner cortex, but a few were in the vascular system of the plant. The foliage was not
unusual and the root system appeared healthy. Microscopic examination of the tissues showed some damaged cells where the nematode had entered the root.

Specimens of Alaimus primitivus, Ecphyodophora tenuissima, Mononchus sigmaturus, Prismatoleimus stenurus, and Tylenchus filiformis were identified from the soil around the roots.

Ground cherry. Specimens of Physalis subglabra collected on the Bryant farm August 11, 1949, were associated with alfalfa and new carrots. In 1948 carrots grown in the sandy, loam soil suffered from attacks of H. marioni.

A few specimens of Aphelenchoides parietinus were located in the cortex tissue. Some damage to the plant tissues around the nematodes was observed.

Nematodes identified as Acrobeles butschlii, Diphtherophora perplexans, Dorylaimus miser, Mononchus sigmaturus, Prismatoleimus stenurus, Tylenchorhynchus sp., and Tylenchus sp. were found in the soil sample from around the roots.

June grass. Two specimens of Bromus tectorum, one collected in June and the other in July from the Palmer farm, harbored specimens of Pratylenchus sp. In the specimen taken in June the nematodes were found in the cortex of the root, while in the July specimen they were nearer the vascular tissues. Both plants were taken from a field of alfalfa; however, there was no alfalfa growing close to the grass. The July specimen was very heavily infested, while the June specimen was only slightly infested.

Associated species of nematodes found in the soil around the roots of the plant collected in June were: Acrobeles complexus, Aphelenchus
avenae, Chiloplacus symmetricus, Panagrolaimus subelongatus, Paratylenchus sp., Prisematolaimus stenurus, Tylenchorhynchus sp., Tylenchus costatus, T. filiformis, Ditylenchus intermedius, Tylencholaimus teres, and Xiphinema americanum.

Specimens of Axonchium solitare, Boeleodorus thylactus, Carcharolaimus teres, Chiloplacus contractus, Chiloplacus symmetricus, Cylindrolaimus obtusus, Dorylaimus sp., and Placodira sp. were the nematodes from the soil around the roots of the plants collected in July.

Quack grass. A specimen of Agropyron repens, collected on the Bryant farm July 7, 1949, harbored a few specimens of Pratylenchus sp. The nematodes were in the inner cortex and vascular layer of the root.

The outer layer of the cortex was being sloughed off. Microscopic examination of the root indicated no extreme damage, although some cells in the path of the nematodes were destroyed. The plant was growing in association with June grass and orchard grass on a ditch bank.

Associated nematodes found in the soil around the roots were: Acrobeloides butschlii, Chiloplacus sp., Diphtherophora perplexans, Discolaimium conure, Dorylaimus miser, Dorylaimus sp., Nygolaimus sp., Pratylenchus sp., Psilenchus hilarulus, and Tylenchorhynchus sp.

Ragweed. A specimen of Ambrosia sp. collected August 11, 1949, from the Luke home farm harbored a few immature specimens of Pratylenchus sp. in the cortex of the root. Some cells had died, or had been killed, and had broken away from the surface of the root. The outward appearance of the plant was not unusual and no particular symptoms of distress were noted. The plant was a volunteer in a field of wheat. In 1948 the same soil, growing carrots, was heavily infested with H. marioni.
Specimens of Cylindrolaimus obtusus, Dorylaimus obscurus, a new Dorylaimus species related to D. penetrans, Leptonchus granulosus, Nygolaemus sp., Panagrolaimus subelongatus, Psilenchus hilarulus, and Tylenchus filiformis were the associated nematodes found in the soil around the roots.

Red Root. A specimen of Amaranthus retroflexus collected from sandy, loam soil from a ditch bank on the Bryant farm July 7, 1949, was harboring three different nematodes. One specimen of Aphelenchus avenae, in the peripheral layer of the root, had its spear extended and thrust through the cell wall. Evidently it was feeding upon the contents of the cell directly in front of the head. The body of the worm lay parallel to the longitudinal axis of the root in several destroyed cells within the cortex. Specimens of Acrobeles complexus and Carcharolaimus teres were identified in the same position in the cortex.

Associated nematodes found in the soil around the roots were: Acrobeloides butschlii, Boleodorus thylactus, Chiloplacus sp., Discolaimus major, Dorylaimus penetrans, Nygolaemus sp., Prisuratolaimus stenurus, Psilenchus hilarulus, and Tylenchus filiformis.

Russian Thistle. Salsola kali collected on the Bryant farm June 7, 1949, was host to a few immature specimens of Chiloplacus symmetricus. A few damaged plant cells in the cortex surrounded the nematode. No symptoms of distress in the plant were noted.

Specimens of Acrobeloides butschlii, Aphelenchus avenae, Panagrolaimus subelongatus, and Ditylenchus intermedius were found in the soil around the roots.
Sagebrush. A specimen of Artemesia tridentata collected on the northwest Luke farm from land being plowed out of native sagebrush for the first time, furnished a section of root containing an immature female and 3 larvae Heterodera marioni. The land was not known to have been irrigated previously. Infestation could have occurred from surrounding farm lands, on tillage equipment, or on the feet of animals or birds (2).

The root was not producing galls, although the cells in which the immature female was lying were destroyed. The root cells at the head of the immature female did not appear to be forming giant cells (9). Either the female had not been there long enough to cause the root to form a gall or the plant was not obviously affected by the nematode feeding on the cell contents.

This species of Artemesia is not listed by Buhrer (5, 6) and is evidently a new host plant record. The sample was collected June 7, 1949, from sandy, loam soil, and was associated with unidentified weeds and sweetclover.

Several specimens of Acrobeles complexus, Axonchium solitare, Dorylaimus obscurus, D. sublabiatus, Placodira sp., and Xiphinema americanum were identified from the soil around the roots of the sagebrush

Sunflower. The sample of Helianthus sp. collected on the Palmer farm August 11, 1949, was host to a few isolated nematodes loosely attached to the plant tissues. Unfortunately these were lost in preparation. The sunflower was associated with a field of scrubby corn. Heterodera marioni caused heavy damage to carrots grown in the same soil in 1948.
Acrobeloides butschlii was the only associated nematode found in the soil sample from around the roots.

Wild parsnip. A specimen of Pastinaca sativa L. collected September 20, 1949, from the northwest Luke farm proved to be a host plant of H. marioni. The outward appearance of the plant was normal. The roots appeared healthy and there was no excessive number of hair roots such as appears in carrots. Small galls were noted throughout the small roots. The plant was a volunteer growing in clay, loam soil on a ditch bank. Plenty of water was supplied by seepage from the ditch.

Heterodera marioni was easily seen in the gall after staining. Many young females were exposed when the gall was broken open (figure 8) and examined under the microscope. Several stages of development were observed; however, the infestation was apparently one that had begun during the same year. One adult gravid female was observed on the outside of the gall after it had been opened. Apparently she had been pushed to the outside when the gall was opened.

In the gall large numbers of embryonated and unembryonated eggs were located. Figure 9 shows the eggs in the tissues and figure 10 shows one of the embryonated eggs about ready to hatch.

In addition to Heterodera marioni, a young specimen of Aphelenchus avenae was identified in the same gall; however, it was impossible to determine whether it caused any damage to the plant.

The soil around the roots of the wild parsnip was infested with specimens of eight genera in addition to the two already mentioned: Alaimus primitivus, Aporcelaimus vorax, Diphtherophora sp., Dorylaimus filicaudatus, D. obscurus, Rhabditis sp., Tylencholaimus teres, Tylenchorhynchus sp., and Tylenchus sp.
Figure 8. Immature Heterodera marioni females in gall tissue formed in wild parsnip.

Plants uninfested by nematodes

Eight of the 28 plants were uninfested by nematodes; although some of them are known to act as hosts of Heterodera marioni (5, 6). The eight uninfested plants are listed as follows:


2. Shadscale, Atriplex sp., growing in trash and dirt piled along a roadway on the Bryant farm.

3. Mustard, Brassica alba, from a farm roadway on the Bryant farm, is listed by Buhrer (5) along with sixteen other species of Brassica as host plants of H. marioni.
Figure 9. *Heterodera marioni* eggs in a root gall on wild parsnip, *Pastinaca sativa*, collected in the Cedar Valley, Iron County, Utah, 1949.

Figure 10. Embryonated egg of *Heterodera marioni* found in the galled root tissue of wild parsnip, *Pastinaca sativa*. 
4. Mouse-ear, *Cerastium vulgatum*, collected from a ditch bank on the Bryant farm.

5. Rabbitbrush, *Chrysothamnus* sp., collected from native brush land on the Luke northwest farm. Its lack of infestation may be due to the extremely hairy condition of the roots. The large number of hair roots possibly acts as a mechanical barrier to nematodes.

6. Tea plant, *Lycium* sp., collected from a ditch bank on the Luke home farm contained a large number of mites in the crown. Tyler (39) reports mites as being predacious upon nematodes.

7. Dock, *Rumex* sp., was collected from a ditch bank on the Luke northeast farm. Six species of the genus are known hosts of *Heterodera marioni*.

8. Cocklebur, *Xanthium* sp., was collected from a barley patch on the Bryant farm. In 1948 the same land was planted to carrots that were badly infested with *H. marioni*. *Xanthium canadense* has been recorded as a host plant of *H. marioni*.

**Classification and feeding habits**

Order: *Tylenchida* (37).

Superfamily: *Tylenchoidea*

Family: *Heteroderidae*

*Heterodera marioni* (Cornu) Goodey (17, 19, 36)

Feeding habits: Plant parasitic. Enters healthy plant roots and feeds on cell contents.

Family: *Tylenchidae*

*Pratylenchus* sp. Filipjev (26, 36)

Feeding habits: Plant parasitic.
Tylenchus costatus DeMan (17)

Feeding habits: Probably plant parasitic.

Tylenchus filiformis (Buchhlii) DeMan (17)

Feeding habits: Generally found free in the soil. It has been observed on healthy and diseased plants, although a relation with plant disease has not been proven.

Ditylenchus intermedius DeMan (17)

Feeding habits: Common in wet and dry soils. Probably ectoparasitic on higher plants. May possibly feed on fungal hyphae.

Psilenchus hilarulus DeMan (37)

Feeding habits: From virgin and cultivated soils. Probably ectoparasitic on higher plants or fungi.

Tylenchorhynchus sp. Cobb (37)

Feeding habits: Plant parasitic.

Ecphyodophora tenuissima DeMan (16)

First record: DeMan described the genus and species from a single male specimen he collected in a vegetable earth covered with grass in the forest of Ulvenhout near Breda, Netherlands, July 24, 1920. No other specimens have been reported since that time.

Record in Utah: Several specimens tentatively identified as females of this genus were collected from soil around the roots of the plants previously mentioned. Some differences in the head region indicates a possible new genus or species. Detailed morphological examination, with
proper equipment, is necessary before it can be definitely placed in any category.

DeMan reports the male specimen he collected to be 0.9 mm. in length. Female specimens collected in the Cedar Valley average 0.7 to 0.8 mm. in length and 0.01 mm. in width at the widest point.

Feeding habits: Nothing is known about the feeding habits. However, the spear is similar to those of the plant parasitic species, although much smaller and probably less effective.

Family: Neotylenchidae

Deladenus durus Cobb (35)

Feeding habits: Cobb described the nematodes from galls of Chestnut oak. Often found in decaying fungus and under dead bark of cottonwood. Probably saprophagous or it may feed on fungus hyphae.

Boleodorus thylactus Thorne (35)

Feeding habits: Commonly appears in cultivated soil, especially about alfalfa crowns. Probably saprophagous or ectoparasitic on plants of fungi.

Family: Criconematidae

Paratylenchus sp. Micoletzky (17)

Feeding habits: Ectoparasitic on higher plants.

Superfamily: Aphelenchoidea

Family: Aphelenchidae

Aphelenchus avenae Bastian (11, 17, 23)
Feeding habits: Plant parasitic or saprophagous. From its position in plant tissues in this study, it appears to be plant parasitic.

*Aphelenchoidea pteretinus* Bastian (11)

Feeding habits: Not completely worked out, but probably plant parasitic.

*Paraphelenchus sp.* Micoletzky (17)

Feeding habits: From its appearance in the tissue of plants in this study it is probably plant parasitic.

Order: Enoplida (7)

Superfamily: Dorylaimoidea

Family: Dorylaimidae

*Dorylaimus filicaudatus* Daday (38)

Feeding habits: Probably ectoparasitic on higher plants.

*Dorylaimus miser* Thorne (38)

Feeding habits: Probably ectoparasitic on higher plants.

*Dorylaimus monhystera* DeMan (38)

Feeding habits: Probably ectoparasitic on higher plants.

*Dorylaimus obscurus* Thorne (38)

Feeding habits: Has been found in *Heterodera schachtii* cysts (38), possibly feeding predaciously upon this nematode. Probably is more commonly ectoparasitic on plants.

*Dorylaimus penetrans* Thorne (38)

Feeding habits: The long spear indicates possible ectoparasitic relations with plants having a thick cortex. Species of this type are probably desert living species.
Aporcelaimus vorax Thorne (38)
Feeding habits: Chiefly predacious on oligochaetes.

Disnothlaims major Thorne (34)
Feeding habits: Predacious, principally on oligochaetes.

Disnothlamium conura Thorne (34)
Feeding habits: Probably predacious on oligochaetes.

Tylencholaimus teres Thorne (34)
Feeding habits: Probably predacious on oligochaetes.

Carcharolaimus teres Thorne (34)
Feeding habits: Probably most commonly predacious on oligochaete worms.

Nygolaimus obtusus Thorne (13, 34)
Feeding habits: Predacious, feeding mostly on Oligochaetes.

Sectonema ventralis Thorne (34)
Feeding habits: Mostly predacious on oligochaetes. The specimen of this nematode was misplaced and therefore, could not be assigned to any particular sample.

Yipherinema americanum Cobb (34)
Feeding habits: Chiefly ectoparasitic on plants. Probably another desert inhabiting type.

Family: Belondiridae

Axonchium solitare Thorne (34)
Feeding habits: Probably ectoparasitic on roots or hyphae of fungi.

Family: Leptonchidae

Leptonchus granulosus Cobb (34)
Feeding habits: Probably ectoparasitic on plants.

Family: Diphtherophoridae

Diphtherophora perplexans Cobb (34)

Feeding habits: Probably saprophagous.

Family: Alaimidae

Alaimus primitivus DeMan (34)

Feeding habits: ???

Superfamily: Enoploloidea

Family: Mononchidae

Mononchus sigmaturus Cobb (13, 29)

Feeding habits: Predacious on nematodes and other microorganisms.

Order: Rhabditida (7)

Family: Rhabditidae

Rhabditis sp. Dujardin (17)

Feeding habits: A saprophagous free living form. Some are parasitic on worms and larval snails.

Family: Cephalobidae

Acrobeles complexus Thorne (30)

Feeding habits: Commonly found in soil and in decaying roots. From observations of plants in this study, the nematode may be either saprophagous or plant parasitic. Some evidence indicates a possible predacious relationship.

Acrobeloides butschlii DeMan (30)

Feeding habits: Free living in the soil. Chiefly saprophagous. Thorne has reported it in the cysts of Heterodera schachtii.
**Acrobeloides maximus** Thorne (30, 32)

Feeding habits: Found in decaying pea shoots, and in sugar beet fields. Probably saprophagous, although some species of the genus appear to be plant parasitic.

**Chiloplacus contractus** Thorne (30)

Feeding habits: Generally considered saprophagous. From the common occurrence in plant tissues in this study it may be plant parasitic.

**Chiloplacus symmetricus** Thorne (30)

Feeding habits: The common occurrence in plant tissues observed in this study indicates a possible plant parasitic relationship.

**Panagrolaimus subelongatus** Cobb (33)

Feeding habits: Generally thought to be saprophagous. Indications in this study are that it is possibly plant parasitic.

**Placodira sp.** Thorne (33)

Feeding habits: Probably plant parasitic, but not definitely known.

**Family: Diplogasteridae**

**Diplogaster** sp. M. Schulze (17)

Feeding habits: Filipjev reports *D. labiata* as a true parasite of insects. Plant relationships are unknown.

**Order: Chromadorida** (7)

**Family: Bastianiiidae**

**Cylindrolaimus obtusus** ( )

Feeding habits: Probably predacious.
Prismatolaimus stenurus Cobb (40)

Feeding habits: Probably predacious.
DISCUSSION

Christie (10) suggests that plants vary in their suitability for given races of the root knot nematode. The carrot shown in figure 5 evidently was seriously attacked by nematodes. After the initial attack most of the nematodes disappeared, leaving only a few specimens to form galls on the roots. It is entirely possible that two or more races of *Heterodera marioni* occur in the Cedar Valley.

*Heterodera marioni* is generally thought to enter the root by forcing apart the cells and working into the root intercellularly (9). Occasionally the nematodes may destroy the cells by passing through them. Once inside the root tissues they feed upon the individual cells, destroying the cell walls in the process. Christie (9) reports that the penetration of the tissues by the nematode probably takes place close to the root tip. The first noticeable change to take place upon entrance is hypertrophy of the cortical cells. This hypertrophy is not confined to the direct path taken by the nematode, but adjacent cells may also be affected. The hypertrophied cells and other abnormalities may begin to appear after about 24 hours and depends upon the severity of the infestation. Christie (9) and Steiner (26) state that the presence of the nematode parasite suppresses the mitotic activity in the apical meristem and thus retards or terminates growth. When growth is terminated in such a manner new roots are sent out from the main root to take the place of the root whose growth has stopped. The carrot shown in figure 4 is undoubtedly an extreme example of this abnormal development.
Filipjev (17) has listed five morphological features resulting from root knot nematode attack on plants. (1) Growth retardation is almost always present, resulting in a dwarfed plant. This is most likely attributed to galls (figure 11) impeding the water circulation in the plant so that above ground structures do not get enough water. Also, the withdrawal, by the nematodes, of food which would ordinarily go to the plant retards plant growth. (2) Plants may wither during periods of extreme drought and heat. (3) There is a decrease in their viability and in their resistance to infection by bacteria and fungi.

Figure 11. Gall on a carrot root caused by Heterodera marioni.
This is probably attributed to the tenderness of the gall tissue and its failure to offer resistance to secondary infection. (4) A chlorotic condition is noticeable when compared with other plants. (5) Finally, if the infection is severe the plant may be killed; if not killed outright, the yield is so reduced that the plant is of no economical value. In carrots growth retardation does not seem to be particularly evident. Foliage of plants infested with nematodes is not greatly different from that of the uninfested plant.

Steiner (24, 25) reports that nematodes of the genus *Pratylenchus* are some of the most important primary factors in root destruction of cultivated and uncultivated plants. The overall damage is possibly greater than that which is attributed to the root knot nematode. Five plants in this study were found to be infested with *Pratylenchus* sp.; whereas, only three plants were infested with *H. marioni*. Crossman and Christie (15) have determined a wide variety of plants in which *Pratylenchus* sp. has caused considerable damage. Steiner (24) states that *Pratylenchus* sp. must be regarded as an important widespread plant parasitic nematode of a pronouncedly destructive nature. Occurrence in the cortex and vascular tissues of the infested plants of this study indicates that it causes much undetected damage.

One of the most numerous nematodes found in plant tissues was *Aphelenchus avenae*. This nematode occurred in healthy root tissues of six species of plants. Its appearance in these tissues seems to indicate that it is probably more frequently a plant parasite than it is generally given credit to be. Goodey (18) states that the occurrence of the nematode in decaying plant tissues indicates saprophagous habits.
Christie and Arndt (11) report that they found both *Aphelenchus avenae* and *Aphelenchoïdes parietinus* associated with lesions on underground parts of plants. In experimentation they found both of these nematodes could be grown on agar, but that the nematodes did not reproduce unless fungi was present on the agar. Steiner (26) has reported *Aphelenchoïdes parietinus* as parasitic on rice plants. The presence of these nematodes in the root tissues of numerous plants in this study indicates that they are probably more commonly plant parasitic in their habits.

*Paraphelenchus* sp. was found in the tissues of just one plant. Filipjev (17) reports that species of the genus have been found on diseased peanut, healthy and diseased strawberry, potatoes, *Narcissus* sp., and cocklebur. No doubt it has been found on many other plants. Its relationship to barley, in which it was found in this study, is not definite. Association with three other species of nematodes, all found in the outer cortex, indicates probable saprophagous habits.

*Tylenchus* sp. was found in only one plant. The nematodes relationship to the barley in which it was found is indefinite. Associated with it were nematodes representing three other species. From its position in the cortex it could have been either saprophagous or parasitic. Many species of the genus are true plant parasites (15), while others are free living forms (17).

Christie and Arndt (11) report that *Panagrolaimus* sp. is capable of considerable damage to the roots of plants. In this study, *Panagrolaimus subelongatus* was found in the root tissues of three plants. Its occurrence in the cortex tissues of oats and barley may indicate parasitism, although the nature of its association with three other species of nematodes in the barley is unknown. In the tissues of mallow
Panagrolaimus subelengatus was extremely numerous, but here again it was associated with equal numbers of Aphelenchus avenae. The nematode may be a plant parasite or it may be a secondary invader feeding upon tissues after they have been previously attacked by another organism. Cairns* has been doing some research on the idea that P. subelengatus may live directly on bacteria or indirectly upon the slimy by-products of the bacterial action. Whether the nematode carries the bacteria with it, or is an invader of plant tissues after bacteria has begun to act, is not yet known. Allen (1) reports that negative results were obtained in experiments on nematode transmission of the virus responsible for the big vein disease of lettuce when Aphelenchus avenae, Aphelenchoides parietinus, Acrobeloides butschlii, Chiloplacus sp., Criconemoides mutabile, Dorylaimus monhystera, D. obscurus, D. simplex, Panagrolaimus subelengatus, Paratylenchus macrophallus, Rhabditis monhystera, and Tylenchus filiformis were used as possible vectors.

The appearance of Carcharolaimus teres in the tissues of Amaranthus retroflexus is probably accidental. Its relationship with the plant may have been either parasitic or saprophagous, although such relationships do not seem likely. It is thought that the nematode followed oligochaete worms into the plant tissues to prey upon them.

Another important group found in the root tissues seems to be closely related to parasitism. Chiloplacus symmetricus was found in the roots of six different plants. Its occurrence in the seed coat of corn is particularly interesting. When nematodes are present in the tissues of a plant in numbers such as they were in this case,

* Unpublished minutes of a staff meeting, Division of Nematology, September 10, 1948.
they undoubtedly influence the growth of the plant. Thorne (30) states that many of the species of this genus are saprophagous. He also states that C. symmetricus has been found in the brown cyst form of the sugar been nematode in what was apparently a parasitic relationship.

_Acrobeles complexus_ was found in the roots of just one plant. Its association with two other species of nematodes in the same plant points to saprophagous habits.

The carrot raising industry of Cedar Valley is seriously threatened and unless steps are taken to control the root knot nematode the industry may be ruined. Farmers that expect to continue to grow carrots in Cedar Valley must learn to control this nematode.

_Crop rotation_ is the most economical method of control. Any rotation adopted should consider the fact that the root knot nematode is perpetuated in carrots, parsnip, and sagebrush. Reference to table 1 page 17 will indicate other plants commonly found in the farming area that may be expected to be hosts of this nematode. A rotation consisting of small grains, sweetclover, potatoes, a grass forage crop, and carrots, may be satisfactory; however, the extremely wide host plant range of the root knot nematode makes any rotation system set up as a control measure liable to failure.

At the present time it appears that the most successful method of combating nematode damage is through the use of chemical soil fumigants. The greatest objection to this control measure is its cost. As a control for the root knot nematode soil fumigants should be applied to the soil each year, especially if the carrots have been seriously damaged in previous years. Soil fumigants kill most of the nematodes in the soil when they are applied correctly. Periodical elimination of
nematodes through soil fumigation may be highly beneficial to crops such as alfalfa, corn, small grains, clover, and potatoes. Observations made in this study indicate that by controlling nematodes through fumigation crop yields may be increased. The increased yields may not be entirely due to the direct destruction of the nematodes. The failure of other organisms, such as bacteria, spores, and insects, to gain entrance to the plant through root lesions would prevent destructive secondary infection.

The information compiled in this paper gives support to the view that many of the lesser known nematodes attack plants in numerous ways. Although Heterodera marioni is usually considered to be the most destructive nematode, there are many others that seriously affect plants. Whatever the damage caused by the root knot nematode, the damage caused by other nematodes is probably greater. Alfalfa, small grains, and scrubby corn patches are a few crops that are apparently influenced by nematodes in the Cedar Valley. Undoubtedly there are other crops that are influenced by nematode attacks. The extent of the damage caused by the less well publicized nematodes can only be determined by more extensive research.
1. The root knot nematode causes severe damage to carrots grown in the high, semiarid Cedar Valley of Iron County, Utah. Soil fumigation has been introduced as a means of controlling the root knot nematode; but additional studies, designed to determine the host plants of this nematode and other associated nematodes, are necessary before a basis for economical control can be found.

2. Eight-five samples of plant roots and an equal number of soil samples from around the roots of these plants were taken in the summer of 1949. The roots, as well as the nematodes that were separated from the soil by the Cobb sifting and gravity methods, were preserved in 6 percent formalin. These roots and nematodes were stained in lacto-phenol-glycerine-acid fuchsine stain and mounted on cover slips in aluminum holders.

3. Nematodes were found in the root tissues of twenty out of twenty-eight species of plants collected in the summer of 1949. Eight of these were common field plants and twelve others were weed plants common to farms in the area. Carrots, wild parsnip, and sagebrush were found to be hosts of *Heterodera marioni*. Sagebrush is apparently a new host record.

4. Forty-three species, assigned to 15 families, represented four orders of nematodes. One new species of the genus *Dorylaimus* and one new species of the genus *Tylenchus* were found. Several female specimens, tentatively identified as *Ephydorophora tenuissima* DeMan, were found in assorted soil samples.
5. The root knot nematode has been studied in detail while many other nematodes, apparently just as important, have been only slightly studied. Species of *Pratylenchus*, *Aphelenchus*, *Chiloplacus*, and *Panagrolaimus*, apparently are parasitic in the roots of both cultivated field plants and weeds.

6. The carrot raising industry of the Cedar Valley, Iron County, Utah is seriously threatened by the root knot nematode, *Heterodera marioni*. At present, the most successful control measure is through the correct use of soil fumigants. Crop rotation is more economical, but is very difficult to work out because of the wide range of plants that are hosts of *Heterodera marioni*. 
LITERATURE CITED


(39) Tyler, Jocelyn. The root knot nematode. University of California Agricultural Experiment Station Circular 330. 1933.

Figure 13. A rough preliminary sketch of the nematode tentatively identified as a female specimen of *Ecphydophora tenuissima* DeMan.
Figure 14. *Ecphyodophora tenuissima* as originally drawn by DeMan.
Figure 15. Head of *Carcharolaimus teres* showing development of the peculiar basket-like development of the oral cavity. This species is probably parasitic on oligochaetes. (From Thorne)
Figure 16. Head region of *Discolaimus major*. Probably a predacious species. (From Thorne)
Figure 17. Head region of Acrobeles complexus showing development of probalae. This form is probably saprophagous.
(From Thorne)
Figure 18. Head region of *Diphtherophora perplexans*. This type is probably saprophagous. (From Thorne)
Figure 19. Head region of *Xiphinema* sp. Nematodes having such long spears are probably plant parasitic on plants having thick cortex layers. (From Thorne)
Figure 20. Head region of Deladenus obesus showing typical bulbar enlargements at base of spear. Such a spear is typical of true plant parasitic specimens. (After Thorne)