BIOLOGY AND CONTROL OF THE CARROT WEEVIL *LISTRONOTUS OREGONENSIS* (LeCONTE)

by

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TABLE OF CONTENTS

INTRODUCTION

The carrot weevil, Listronotus oregonensis (LeConte) has become, within recent years, a serious pest of carrot, celery, dill, and parsley in the Kansas River Valley and in northeast Kansas. This insect has been known to occur in Kansas for nearly 75 years, but has not, until recent years become an established pest. In the Wathena area, injury to early planted carrots in most gardens is nearly 100 percent. Carrots which are completely free from injury are seldom grown in most home gardens in northeastern Kansas.

Little information about the carrot weevil is found in the literature. Much of the published information concerns the taxonomy of the insect and not the biology or control. Information relating to the biology or control has been published by Boyce (1927), Chandler (1926), Chittenden (1924), Crosby and Chupp (1931), Harris (1926), and Pepper (1942).

The increasing importance of injury by the carrot weevil larvae to carrots in home gardens, in recent years, has suggested the necessity of formulating adequate control measures suitable for use under Kansas conditions. The lack of information in the literature has led to these research studies and the preparation of this thesis.

This thesis is based on observations of carrot weevil on carrots at the Northeast Kansas Experiment Fields insectary located at Wathena, Kansas, and observations on carrots, celery, dill, parsley, and other cultivated crops in gardens at Wathena. The observations extend over a period of three years, 1948, 1949, and 1950.

REVIEW OF LITERATURE

Taxonomic Position

The carrot weevil, Listronotus oregonensis (LeConte) was described in 1860 by LeConte (Henderson, 1940). Henderson gives the following note in summarizing the taxonomy and synonymy of the carrot weevil:

> The Listronotus latiusculus of American authors is L. oregonensis (LeConte). The type of Listroderes latiusculus Boheman has been examined and is a member of the genus Hypera. Under the name of Listronotus latiusculus (Boheman), LeConte, in 1876, says, "I refer this name to a species which occurs in the Middle and Southern States, and is by no means rare." This statement is followed by a description of the species which must be known as Listronotus latiusculus LeConte, nec Boheman, since it does not refer to Boheman's latiusculus. Listronotus latiusculus LeConte is a synonym of Listronotus oregonensis (LeConte), both names having been proposed for the same species. The latter name has priority by sixteen years.
>
> In 1876 LeConte described Listronotus impressifrons. The type of this species have been examined and L. impressifrons LeConte is found to be a synonym of L. oregonensis (LeConte).
>
> Blatchley described L. rudipennis in 1916. An examination of the type of L. oregonensis (LeConte) shows that it is the same species to which the name L. rudipennis was applied, and since L. oregonensis (LeConte) was the first name applied to the species, it has priority over all others.

The name "parsley stalk weevil" was given to Listronotus oregonensis (LeConte) when Chittenden (1903, p. 726) reported that the insect was found feeding on parsley and laying eggs in the stalks of the plants at Four Mile Run, Virginia. Some years later, it was found to be a serious pest on carrots and is now known as the "carrot weevil". This is the common name which has been approved by the American Association of Economic Entomologists (Muesebeck, 1946).

Biological and Economic Information

Popenoe (1877) first recorded information concerning the biology of the carrot weevil. He stated the species was common at Topeka, Kansas, and that it was found under stones and on Peucedanum faeniculaceum, a wild plant of the parsley family, in the spring.

This species was first reported causing economic injury by Chittenden (1903) when he reported it was discovered by F. C. Pratt causing serious injury to parsley grown at Four Mile Run, Virginia. The vegetable growers at Four Mile Run had noticed the damage at least two years earlier. Chittenden (1924) reported a serious infestation on parsley in 1916 in the experimental garden at Washington, D. C. In the same paper, the weevils were reported injuring carrots in a backyard garden at Washington, D. C., and in 1923, a serious pest of carrots in the vicinity of Valley Stream, Mineola, and Astoria, Long Island, New York.

The insect was reported as a serious pest on carrots in eastern Illinois by Chandler (1926). He reported only one generation in Illinois. He reported a severe infestation of carrots by carrot weevil in an area in southern Illinois, mostly within a 40-mile radius of East St. Louis.

Severe infestations of the carrot weevil in Iowa caused as much as 90 percent of the crop to be unfit for human consumption according to Harris (1926). Some growers had been troubled with the weevils injuring carrots for 20 years, or as long as they had been growing the crop. Harris stated there are probably three generations in Iowa.

Boyce (1927) gave a report of the weevil on Long Island and discussed the serious damage caused to carrots in market gardens. He reported that the early crop of carrots on Long Island was attacked and losses involving

as much as 75 percent of the crop were reported by growers. The later crop was practically free from injury.

Henderson (1940) reported carrot weevil specimens from Biloxi, Mississippi, which had been collected by M. M. High on turnip. The extent of injury to the turnips was not known.

The carrot weevil has become within recent years a pest on celery, carrots, and parsley in certain sections of New Jersey (Pepper and Hagmann, 1938 and Pepper, 1942). The damage to celery in the muck area of Bergen County has ranged up to 90 percent of the crop. In 1937, 1938, and 1939, according to Pepper, some of the celery growers in Bergen County harvested about one-half of a normal crop, a decrease due entirely to carrot weevil damage.

Harris (1926) reported that although the adults possess well developed wings and are apparently able to fly, no specimen was ever observed to do so, but when disturbed would fall to the ground and remain motionless for several moments before walking away. Boyce (1927) stated the beetles have never been observed in flight although they have fully developed wings. According to Boyce, an examination of their wings furnishes some evidence that they do not fly except under the most favorable conditions, as the wings appear to be inadequate to support efficiently in flight a body of such size.

Pepper and Hagmann (1938) state:

> As reported by Boyce (1927), and others, the adults are sluggish and invariably feign death when disturbed. There is no record in the literature of beetles having been observed in flight; however, the senior author has observed them on wing. Four specimens which flew in the windows of a moving automobile were captured. Two adults were captured while in flight. From the above observations they seem to be poor fliers. Although the beetles fly, it is doubtful whether they migrate very far.

Specimens collected at a trap light at Lawrence, Kansas, in 1933 and 1934 were reported by Henderson (1940).

Distribution

According to Blatchley and Leng (1916, p. 161), the distribution of the carrot weevil is as follows: "The type is from Pennsylvania. Ranges from Quebec, New England, and Michigan, west and south to Colorado, Kansas, and Georgia." Buchanan (1932), Henderson (1940), and Pepper (1942) show the distribution to be rather general over the United States.

Buchanan (1932) studied specimens from Massachusetts, Rhode Island, New Jersey, New York, District of Columbia, Pennsylvania, Virginia, West Virginia, Florida, Louisiana, Michigan, Wisconsin, Illinois, Iowa, Missouri, and Kansas.

Specimens were examined by Henderson (1940) from 30 states and the District of Columbia. In addition to specimens reported by Buchanan (1932), Henderson studied specimens from New Hampshire, North Carolina, Georgia, Alabama, Mississippi, Kentucky, Indiana, Iowa, Oklahoma, North Dakota, South Dakota, Montana, and Oregon. Henderson did not examine specimens from the southwestern states but suggests the specimens may be present there.

The first record of the insect in Kansas was made by Popenoe (1877) who collected the insect in Shawnee County at Topeka in 1873. The late Professor J. W. McColloch reported injury to carrots in Wyandotte County in 1925. L. S. Henderson (1940) collected the beetles in Douglas County in 1933. Damage to carrots in Franklin County was reported in 1940 by C. C. Adamson at Ottawa.

In 1941 and 1942, a survey by the Department of Entomology, Kansas State

College, showed the carrot weevil caused damage to carrots in Doniphan, Leavenworth, Johnson, and Lyon Counties. Mrs. H. L. Gustafson in 1948 reported the insect was causing severe injury to carrots at Blue Rapids in Marshall County. Reports were received at the Department of Entomology during 1949 and 1950 of injury to carrots from Miami, Linn, Elk, Osage, Chase, Brown, Nemaha, Riley, Pottowattomie, Jefferson, and Atchison Counties.

Figure 1 is a map of Kansas showing the recorded distribution of the carrot weevil.

Host Plant Records

The following wild host plants are reported in the literature: wild carrot, Daucus carota L.; wild parsnip, Pastinaca sativa sylvestris L.; curly dock, Rumex crispus L.; patience dock, Rumex patienta L.; broad-leaved plantain, Plantego major L.; arrowhead, Sagittaria variabilis L., garden sorrel, Rumex scetosa L., and a wild plant of the parsley family, Pencedenum faeniculaceum.

Cultivated host plants reported in the literature are parsley, Apium petroselinum L.; dill, Anethum graveolens L.; celery, Apium graveolens L., carrot, Ducus carota sativa L.; and turnip, Brassica rapa L.

MATERIALS AND METHODS

To find possible new cultivated hosts of the carrot weevil as well as to confirm those reported in the literature, carrots, celery, dill, parsley, radishes, beets, parsnips, and turnips were grown in a garden next to the author's home in Wathena, Kansas, during 1949. Wild carrots near the garden

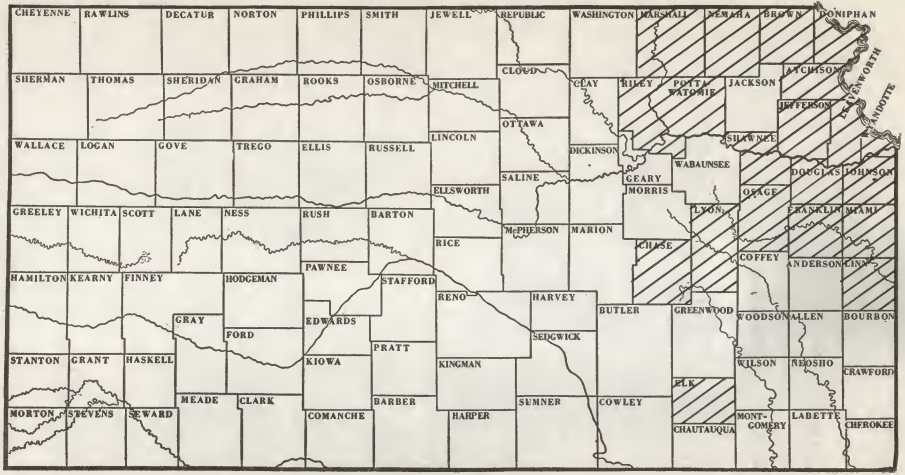

Fig. 1. Known distribution of the carrot weevil, Listronotus oregonensis (LeConte) in 20 eastern counties in Kansas, 1950. Cross hatching indicates counties in which investations have been reported.

site were also observed.

Carrot weevil larvae in infested carrots were collected in May and June in 1948, reared to the adult stage and used in second generation life history studies. Adults collected during March and April in 1949 were used in first generation studies. Life history records were started when the adult females began to lay eggs. The eggs laid by the females were transferred to small carrot roots in salve boxes. The boxes were examined daily. Larvae hatched from the eggs were placed in holes made in carrots with a small, pointed probe. The carrots were placed in salve boxes containing sifted moist soil. No attempt to separate larvae hatched on the same date was made but the larvae were separated as they neared maturity, each larva being transferred to a small carrot and placed in a salve box containing sifted, moist soil.

To secure the number of eggs laid by each female, 15 females were confined during July and August, 1949, in screened, six-inch flower pots, one female to a flower pot. A single carrot with all but four inches of the tops removed was transplanted in each of the pots. The carrots were checked daily except Sunday to count the eggs on each of the potted plants.

Mortality tests to learn what insecticide materials would most readily kill adult carrot weevils under caged conditions were started in 1949. The tests were made in a series of salve boxes, in which five beetles were confined, one group of five beetles for each dosage of insecticide tested. Carrot foliage with treated insecticide was placed in each salve box. Untreated foliage was placed in the boxes which contained baits. One-half inch of moist, sifted soil was placed in each box. The salve boxes were examined daily for seven days. The insecticides tested in 1949 included

DDT, TDE, methoxychlor, parathion, chlordane, aldrin, benzenehexachloride, and a commercial sodium fluosilicate—apple pomace bait known as "Go West".

In an effort to make the conditions as near as possible to those in the field, mortality tests in 1950 were conducted in treated rows in carrot plots. Four glass panels, 12 inches in length and approximately 6 inches in width were placed as a fence around four plants in a single row in each treatment. Five beetles were placed in each enclosure after various spray or dust treatments were applied. The sprayed rows were allowed to dry before the beetles were released. The outside enclosures were examined daily for seven days. The insecticides tested in 1950 included chlordane, parathion, aldrin, methoxychlor, lindane, benzenehexachloride, cryolite—apple pomace bait, and "Go West" bait.

Insecticide baits, sprays, and dusts were used in field tests in 1948 and 1950. Each insecticide was applied to three replicates, each replicated treatment consisting of three adjacent carrot rows 20 feet in length. A check plot receiving no insecticide was included in each replicate. The dusts were applied at the rate of approximately 25 pounds per acre with a hand duster, and the sprays were applied with a knapsack sprayer at the rate of approximately 100 gallons per acre. The baits were broadcast at the rate of about 50 pounds per acre. Four applications at 7-day intervals were applied in both 1948 and 1950.

The insecticides applied in 1948 and 1950 included benzenehexachloride, parathion, DDT, aldrin, methoxychlor, lindane, sodium fluosilicate—apple pomace bait, cryolite—apple pomace bait, and a commercial bait consisting of sodium fluosilicate and apple pomace known as "Go West".

RESULTS

Descriptions of Life Stages

The carrot weevil has complete metamorphosis. The life stages of this insect are the egg, larva, pupa, and adult.

The eggs when first laid are light yellow in color, but after one or two days begin to turn light brown and may become almost black just before hatching. The eggs are ovoid in shape and measure about 0.75 mm in length and about 0.50 mm in width.

The larvae are small, active, legless grubs measuring 1 to 1.3 mm in length when first hatched from the eggs. The larvae may vary considerably in size when full grown, ranging from 6 to 9 mm in length. The larvae are creamy-white to yellowish in color and have reddish-brown heads. Each segment of the body bears a series of setae and there are a few setae on the head. The spiracles are rather prominent.

The pupae are creamy white in color and measure 6 to 7.5 mm in length. They are of the exarate type, the developing legs and wings not being tight to the body. Strong spines occur on the head, thorax, and femora of the legs and in a transverse row on each abdominal segment.

The adults are from 3.5 to 7 mm in length, the males being much smaller than the females. The ground color of the body is dark brown to nearly black. The thorax and elytra are covered with dark gray and copper tinged scales. Each stria of the elytra bears a row of short grayish setae. The head, and femora and tibia of the legs have numerous setae scattered on their surfaces.

Figure 2 shows the life stages of the carrot weevil.

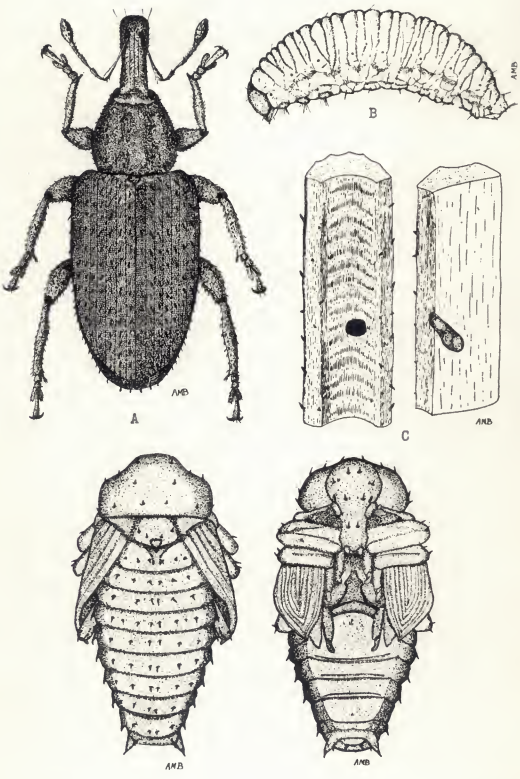

Fig. 2. Life stages of the carrot weevil. A - adult, B - full grown larva, C - egg cavity in carrot leafstalk, D - pupa, dorsal view, E - pupa, ventral view. (After A. M. Boyce)

Host Preference

Carrot weevil adults were reared in 1949 from larvae taken from roots of wild carrot, carrot, curly-leaved parsley, celery, and dill. The cultivated plants were located in a garden in Wathena, Kansas, known to be infested with carrot weevil in 1947 and 1948. The carrots, celery, parsley, and dill were planted in 1949 to establish host preferences. The infested wild carrot plants were found a short distance from the garden plot. Radishes, beets, parsnips, and turnips planted in the same garden were uninjured. No new hosts were found.

The host preference based on frequent observations during the summer months was, in order of preference, carrot, dill, celery, and parsley. All carrots were heavily infested by June 24. The dill was killed before the seeds could mature, and 60 percent of the celery was unfit for food at the time of harvest. The leaves on some of the parsley plants turned yellow and some of the plants died from larval feeding on the roots.

Table 1 shows the dates of emergence of adult carrot weevils collected June 24, 1949, on celery, dill, parsley, carrot, and wild carrot growing in and near a garden at Wathena, Kansas.

Table 1. Dates of emergence of adult carrot weevils collected on June 24, 1949, at Wathena, Kansas.

Plant	Number of larvae collected	Dates of adult emergence
Celery	9	July 6 to July 12
Dill	8	July 6 to July 13
Parsley	6	July 11 to July 18
Carrot	10	July 6 to July 11
Wild carrot	3	July 9 to July 15

Life History and Habit Studies

Observations on the life history and habits of the carrot weevil at Wathena, Kansas, have been made over a period of three years. Three full broods of the insect occur in northeast Kansas. There is a considerable overlapping of broods since all life stages can be found in carrot fields from early June to late October.

The Egg. The female deposits her eggs in small cavities which she eats in the depression of the leafstalk anywhere from the leaflets to the base of the plant. During the oviposition of the first generation females, an occasional egg cavity was observed on the exposed upper portion of the carrot root. After the eggs are laid, the female covers the opening of the cavity with a black sticky substance which soon dries and seals the opening of the egg pocket. The number of eggs in a single cavity vary from 1 to 16 although 4 or 5 eggs were most often observed. Twenty cavities were observed June 29, 1948, in the leaf stems of a single carrot plant with a total of 97 eggs. Some of the cavities, although covered with a black exudate, contained no eggs.

Oviposition by the first broad females in 1948 began in the insectary at Wathena on June 9 while egg laying by the overwintering females collected in 1949 began in the insectary May 4.

Table 2 gives the life history records of 171 second generation specimens reared under insectary conditions at Wathena in 1948.

Table 2. Life history records of 171 second generation carrot weevils completing development at the field insectary, Wathena, Kansas, June and July, 1948.

Stage of development	Time in days required to complete development		
	Minimum	Maximum	Average
Egg	5	7	5.69
Larva	14	27	18.09
Prepupa[1]	1	5	3.68
Pupa	6	11	8.66
All stages	27	46	31.12

[1]Included in larvae stage of development.

The average incubation period for second generation eggs laid in 1948 was 5.69 days; the incubation period varied from 5 to 7 days.

Table 3 gives the life history records of 225 first generation specimens reared under insectary conditions in 1949.

Table 3. Life history records of 225 first generation carrot weevils completing development at the field insectary, Wathena, Kansas, May and June, 1949.

Stage of development	Time in days required to complete development		
	Minimum	Maximum	Average
Egg	6	12	10.1
Larva	12	20	16.2
Prepupa[1]	1	5	3.3
Pupa	6	13	8.3
All stages	29	43	33.2

[1]Included in the larvae stage of development.

In 1949, the incubation period of the eggs varied from 6 to 12 days for the first generation with an average of 10.1 days.

A summary of the various life stages is made following the record of each life stage.

Fifteen female carrot weevils were confined during July and August in 1949 in screened, six-inch flower pots, one female to a pot, and observed to secure the number of eggs laid by a single female and the average number of eggs laid during the season. The adults used in the observations were reared from larvae collected during the first generation. The first eggs were laid on July 6 and by July 13 all females had begun to lay eggs. One beetle laid eggs until August 27 making the total egg laying period extend for 53 days. Table 4 is a summary of the oviposition records of fifteen second generation female carrot weevils reared under insectary conditions at Wathena, Kansas, during July and August, 1949.

As shown in Table 4, the average length of the egg laying period for the 15 females was 44.8 days. The females averaged 388 eggs each for the period observed or 8.66 eggs per day.

The Larva. The larvae begin feeding a few minutes after hatching. They may tunnel to the carrot root inside the leaf stem in which they hatch from the eggs or they may crawl or drop to the ground and re-enter the carrot at or below the surface of the soil. The new entrance holes often have tiny spots of rust color surrounding them. The rust color is especially noticeble on many of the larger carrot roots.

There are usually several larvae in a single carrot which feed inside the carrot root. If the carrot is small they may eat the entire inside, moving on to other carrots. As many as eighteen larvae have been removed

Table 4. The number of eggs laid, the length of the egg laying period in days, and the average number of eggs laid per day by 15 second generation female carrot weevils from July 6 to August 27, Wathena, Kansas, 1949.[1]

Weevil number	Number of eggs laid during egg laying period	Length of egg laying period in days	Average number of eggs per day
1	386	46	8.39
2	353	49	7.20
3	191	39	4.90
4	391	44	8.89
5	79	26	3.04
6	279	43	6.49
7	311	46	6.76
8	377	45	8.38
9	426	46	9.26
10	483	47	10.28
11	376	37	10.16
12	397	41	9.68
13	229	47	4.66
14	417	53	7.17
15	375	48	7.81
Av. for season	388	44.8	8.66

[1]The females from which the eggs were counted were confined under insectary conditions.

from a single carrot. The larvae sometimes feed inside the carrot plant at the base of the leaf stalks causing the leaves to die and turn brown. Most of the feeding is confined to the upper portion of the root although in small carrots larvae may sometimes be found in the small tip of the root. Injury to carrots is shown in Fig. 3 and 4.

The area of feeding may cover a considerable portion of the carrot under the epidermis and into the core. The epidermis usually turns brown and breaks exposing the tunneling beneath. Carrots that have been injured by carrot weevil larvae are often severely stunted, tasteless, and woody. Injured carrots often are invaded by a soft rot and decay in the field.

The larvae grow rapidly, reaching full growth in 1948 within 14 to 27 days and in 1949 within 12 to 20 days. After full growth, the larvae leave the carrot root and enter the soil to a depth of two to three inches. Earthen cells are constructed in one to three inches of the carrot root from which the larvae migrated. A quiescent period of 1 to 5 days is spent in the earthen cell before pupation. The larvae interval, including the quiescent or prepupae period, varied from 14 to 27 days or an average of 18.09 days for the second generation in 1948 and from 12 to 20 days or an average of 17.2 days for the first generation in 1949 (see Tables 2 and 3).

The Pupa. Earthen pupal cells are constructed in one to three inches of the carrot root from which the larvae migrated. The cells usually are found in the soil at a depth from two to three inches. If the pupal cell is destroyed, the pupa is capable of reconstructing a new cell provided the soil is moist enough to stick together as it wriggles its abdomen back and forth, firming the soil around its body. The pupa will remain inactive if not disturbed. The thickness of the cell wall depends on the amount of moisture in the soil and the ability of the larvae or pupae to firm the soil.

Fig. 3. Injury to small carrots showing internal injury.

Fig. 4. Injury to half grown carrots showing external injury and injury to crown area of the carrot.

In damp soils the cells are larger and the walls thicker than in dry soils.

The inside measurements of the pupal cells depend on the size of the pupae and vary in length from 7 to 9.5 mm. Some of the cells are nearly spherical being slightly longer than wide.

The pupal period extended from 6 to 11 days or an average of 8.66 days for the second generation in 1948 and 6 to 13 days or an average of 8.3 days for the first generation in 1949 as shown in Tables 2 and 3.

Over 300 adult weevils were reared in the insectary at Wathena in 1948 and 1949 without constructing pupal cells. Soil of good tilth was placed in salve boxes and firmed in the bottoms to a depth of one-half inch. The eraser end of a pencil was used to press holes about three-eights of an inch deep in the packed soil. Larvae that had reached the quiescent period were placed in the boxes, one larva to a hole. The prepupal and pupal stages were passed in the depressions without the natural forming of pupal cells. Daily observations were easily made by removing the tops of the salve boxes.

The Adult. The beetles remain in the pupal cells for 1 to 5 days after transforming to the adult stage and then migrate to the surface of the soil.

The adults in 1948 fed for 5 to 10 days before the females began to lay eggs. The adults feed by chewing into the epidermis or by making cavities into the tissue of the leaf stalks. Leafstalks sometimes break and fall over when several feeding or egg laying cavities are close together. A carrot one-half inch in diameter and nearly four inches long placed with 40 to 50 caged specimens for food was almost entirely eaten in 5 days in 1949.

Because of their habit of feigning death, the adults are difficult to locate in the field, although they may be plentiful. When disturbed, they drop to the ground and remain motionless for several minutes. The adults are

more active at night, on cloudy days, and during the cool part of the day. At various periods during the warm part of the day in 1948, 1949, and 1950, as many as ten adults were found in groups under small clods in or near carrot rows. Few beetles were found under clods in the early morning.

Specimens have been found with a heavy coating of dried soil clinging to their backs making their identification difficult. The presence of a crust of soil on the backs of some specimens would indicate the beetles seldom fly but travel by walking from their hibernation quarters to host plants. The spreading of the weevils within a field is slow with the area nearest the hibernating quarters being attacked early in the season.

The author removed a carrot weevil specimen from a window screen at his home in Wathena, Kansas, on July 10, 1948, about 9:30 p.m. and one specimen from the same window screen shortly after noon on August 6, 1950. The specimen found on July 10 had apparently responded to light within the house. The beetles may have migrated from a near-by garden in which dill, celery, parsley, and carrots were grown for the purpose of observing and rearing carrot weevil.

The adults used in the life history studies were reared from larvae collected in hibernation quarters. After several weeks of thorough searching, in March, 1949, the adults in hibernation quarters were readily found under straw mulch in two strawberry fields adjacent to the insectary. One field was located immediately north of the area used for carrot plantings and the other field was on the west side of the area. The beetles were usually found between dead strawberry leaves or under other debris near the strawberry plants beneath the mulch. The straw mulch in both fields was about two inches in depth.

The adults apparently start to leave hibernation quarters during the last week of April. Two adults were seen in emergence cages on April 22 and April 23 in 1950 when the temperature reached nearly 90° F.

Ten adults were collected on April 10, 1950, and confined in a quart fruit jar contining moist soil. Insect screen was placed in the screw cap to provide ventilation and to prevent escape. The beetles were well supplied with food in the form of pieces of carrots and carrot tops. The length of life of the ten adults is shown in Table 5.

The length of life of the ten weevils confined in the quart jar varied from 66 to 162 days. Since the adults used in the test were removed from hibernation quarters on April 10, 1950, the actual length of the life of each adult cannot be stated.

Control Studies

The greatest damage to plants by the carrot weevil is done by larvae feeding on or within the roots. Since there is no effective way to kill the larvae within the plant tissues, the most logical means of controlling this insect is to protect the crop from attack through the use of insecticides.

Mortality Tests. A series of mortality tests under caged conditions were conducted in 1949 at the field insectary at Wathena to give some indication of the effectiveness of various insecticides to control carrot weevil adults. The results of the 1949 mortality tests are shown in Table 6.

DDT, methoxychlor, chlordane, and TDE were less effective than other insecticides used in tests under cage conditions as shown in Table 6.

Table 5. Length of life in days of 10 adult carrot weevils collected on April 10, 1950, Wathena, Kansas.

Adult number : April 10, 1950 :	Date of death	: Length of life in days
1	June 15	66
2	June 26	77
3	July 12	93
4	July 14	95
5	August 3	105
6	August 9	121
7	August 17	129
8	September 5	148
9	September 7	150
10	Alive on Sept. 18	162

Parathion dust killed all five beetles in the test in an average of 1.6 days. "Go West" bait killed all beetles in an average of 1.8 days. Parathion spray, benzenehexachloride dust, and aldrin dust killed all adults in an average of two to three days. All the beetles were alive in the check and TDE dust treatments at the end of seven days.

In an effort to make the conditions of the 1950 mortality tests as near those in the field as possible, the beetles were confined in square foot glass enclosures following the insecticide applications. Four glass panels twenty-four inches in length and approximately six inches in width were placed (similar to a fence) around several plants in two rows in the check plot and in each insecticide treatment. The area enclosed by the panels

Table 6. Mortality tests for the control of carrot weevils under caged conditions, August 1 to 8, 1949, at Wathena, Kansas.

Insecticidal sprays, dusts, and poison baits and dosages at standard horticultural rates	No. days to kill ea. of 5 adults in ea. treatment					Av. number of days to kill adults
DDT, 50%, 2 lbs. to 100 gals.	3	4	6	7	7	5.4
Methoxychlor, 50%, 2 lbs. to 100 gals.	4	4	4	7	7	5.2
Methoxychlor, 5% dust	2	4	4	6	7	4.6
Parathion, 25%, 1 lb. to 100 gals.	1	2	2	2	3	2.0
Parathion, 1% dust	1	1	1	2	3	1.6
Chlordane, 50%, 2 lbs. to 100 gals.	3	4	5	5	7	4.8
Aldrin, 1% dust	2	2	3	4	4	3.0
Benzenehexachloride, 5% dust	1	2	2	3	4	2.4
TDE, 5% dust	None died during test					--
"Go West", a commercial apple-pomace bait	1	1	2	2	3	1.8
Check, no insecticide treatment	None died during test					--

was not covered. Considerable difficulty was experienced with this method for the area in which to search in an effort to recover the beetles was too large. The panels were reduced to 12 inches in length and placed around four plants in the center row of each treatment. Recovery of the beetles was made quite easy in the reduced area.

DDT and TDE were omitted from the field tests in 1950. Benzenehexachloride and lindane, the pure gamma isomer of benzenehexachloride, were

added as sprays to the 1950 tests. A cryolite apple pomace bait prepared at the insectary and used in the 1948 field tests was included in the tests.

The results of the 1950 mortality tests under field conditions are shown in Table 7.

Table 7. Mortality tests for the control of carrot weevils under caged conditions, July 7 to July 13, 1950, at Wathena, Kansas.

Insecticidal sprays, dusts, and poison baits and dosages at standard horticultural rates	No. days to kill ea. of 5 adults in ea. treatment					Av. number of days to kill adults
Methoxychlor, 50%, 2 lbs. to 100 gals.	1	1	3	3	4	2.4
Parathion, 25%, 2 lbs. to 100 gals.	1	1	1	1	2	1.2
Parathion, 1% dust	1	1	1	2	2	1.4
Chlordane, 40%, 2 1/2 lbs. to 100 gals.	1	1	1	2	3	1.6
Aldrin, 25%, 1/2 lb. to 100 gal.	1	1	2	2	2	1.6
Benzenehexachloride, 50%, 2 lbs. to 100 gals.	2	2	3	3	6	3.2
Benzenehexachloride, 5% dust	1	2	3	3	4	2.6
Lindane, 1 lb. to 100 gals.	1	3	3	3	4	2.8
"Go West", a commercial apple-pomace bait	1	2	3	3	3	2.4
Cryolite, 3/4 lb. apple-pomace, 15 lbs.	1	2	2	3	3	2.2
Check, no insecticide treatment	None died during test					—

All insecticides used in the field mortality test in 1950 killed the five beetles released in each treatment in one to six days. Parathion, chlordane, and aldrin killed all beetles in an average of 1.2 to 1.6 days. The apple pomace baits were slightly less effective than parathion, chlordane, and aldrin but killed all beetles in an average of 2.2 to 2.6 days. Benzenehexachloride, lindane, and methoxychlor were about equal in effectiveness, killing all beetles in 2.4 to 3.2 days.

Field Control Tests. In 1948 and 1950 the distribution of injury to carrots in various replicates was relatively uniform. The chlordane spray, parathion dust, and benzenehexachloride dust treatments in one replicate in 1950 were adjacent to a strawberry field in which many adults hibernated.

A poor and uneven stand of carrots in test plots in 1949 made field tests during that year useless. The carrots were left growing in the field to help establish a concentration of beetles for the 1950 tests.

Field tests to control the carrot weevil were begun in 1948 with insecticidal sprays, dusts, and baits. The insecticides were applied in 1948 and 1950 to control the adults. In order to prevent the larvae from infesting the carrots, it is necessary to destroy the adult females before eggs are deposited in the leafstalks; for once the eggs are present, there is no way to poison the larvae.

In determining the infestation in each plot, one hundred consecutive plants in the center row of each replicate were carefully examined for injury to the carrot crown or root.

The summary of the 1948 field tests is shown in Table 8.

Test 8. Summary of three replicated plots, three replicated counts of 100 carrots each, in comparative insecticidal treated field tests for the control of carrot weevil in 1948 at Wathena, Kansas.[1]

Insecticidal sprays, dusts, and poison baits and dosages at standard horticultural rates	No. of infested plants	Percent of plants infested
DDT, 50%, 2 lbs. to 100 gals.	85	28.33
DDT, 3% dust	76	25.33
Benzenehexachloride, 50%, 2 lbs. to 100 gals.	20	6.67
Benzenehexachloride, 5% dust	14	4.67
Parathion, 25%, 1 lb. to 100 gals.	20	6.67
Parathion, 1% dust	13	4.33
"Go West", a commercial apple-pomace bait	27	9.00
Sodium fluosilicate, 3/4 lb. apple-pomace, 15 lbs.	42	14.00
Cryolite, 3/4 lb. apple-pomace, 15 lbs.	18	6.00
Check, no insecticide treatment	174	58.00

[1]Insecticidal materials were applied June 29, July 6, July 13, and July 20. The carrots were examined September 10.

The infestation in the series of tests in 1948 ranged from 58 percent in the untreated checks to 4.33 percent in the three replicates dusted with parathion and 4.68 percent in the replicates dusted with benzenehexachloride. Six percent of the carrots in the replicates baited with cryolite --apple pomace bait were inferior to the cryolite--apple pomace bait. In replicates sprayed with parathion and benzenehexachloride, 6.67 percent of

the carrots were injured. DDT spray and dust were inferior to all other insecticides tested with 25.33 to 28.33 percent of the plants being injured.

The 1948 field tests and the 1949 mortality tests indicated parathion might be used as an insecticide to control carrot weevil adults. The dosage used in 1948 was one pound of the 25 percent wettable powder in 100 gallons of spray. This dosage was doubled in the 1950 tests and two pounds were used in 100 gallons. Lindane, the pure gamma isomer of benzenehexachloride, chlordane, aldrin, and methoxychlor were added to the 1950 tests. Sodium fluosilicate--apple pomace bait was not included in the 1950 field tests. This insecticide was less effective than other baits tested in 1948.

Table 9 is a summary of the 1950 field control tests. The carrot weevil infestation in the series of field tests in 1950 ranged from 86 percent in the untreated checks to 1 percent in replicates sprayed with two pounds of 25 percent parathion.

Benzenehexachloride spray was the least effective of all the insecticides tested; 10.33 percent of the carrots were infested with carrot weevil larvae. Nine percent of the carrots sprayed with lindane were injured. Methoxychlor spray, benzenehexachloride dust, and cryolite-apple pomace bait resulted in 7 percent infestation. In replicates sprayed with aldrin, 5.33 percent of the carrots were injured. Parathion dust was slightly less effective in reducing the number of infested carrots than was "Go West" bait; 4.33 percent were infested in the parathion dust replicates and 3 percent were injured in the "Go West" bait replicates. Chlordane spray ranked next to parathion spray in reducing the number of infested carrots; only 2.33 percent were injured.

Table 9. Summary of three replicated plots, three replicated counts of 100 carrots each, in comparative insecticidal treated field tests for the control of carrot weevil in 1950 at Wathena, Kansas.[1]

Insecticidal sprays, dusts, and poison baits and dosages at standard horticultural rates	No. of infested plants	Percent of plants infested
Benzenehexachloride, 50%, 2 lbs. to 100 gals.	31	10.33
Benzenehexachloride, 5% dust	21	7.00
Lindane, 1 lb. to 100 gals.	27	9.00
Parathion, 25%, 2 lbs. to 100 gals.	3	1.00
Parathion, 1% dust	13	4.33
Chlordane, 40%, 2 1/2 lbs. to 100 gals.	7	2.33
Aldrin, 25%, 1/2 lb. to 100 gals.	16	5.33
Methoxychlor, 50%, 2 lbs. to 100 gals.	21	7.00
"Go West", a commercial apple-pomace bait	15	3.00
Cryolite, 3/4 lb. apple-pomace, 15 lbs.	21	7.00
Check, no insecticide treatment	258	86.00

[1]Insecticidal materials were applied May 29, June 5, June 12, and June 19. The carrots were examined September 10.

DISCUSSION

Observations on the life history and habits of the carrot weevil showed all stages of the insect can be found in carrot plantings in gardens in northeast Kansas from early June to late October. The overlapping of the broods can be accounted for by the long period of movement from hibernation; thus, delaying egg laying by some females, by the long period of egg laying once the activity gets under way, by the short period of development, and by the long life of the adults.

In order to prevent weevil infestation in carrots, it is necessary to destroy the adult females before they can deposit eggs in the leafstalks of the carrot plants. The adult stage of the insect is the most vulnerable in the life cycle for all other stages of the insect are found inside the leafstalk, within the carrot root, or in the soil.

Protection of the crop from attack by carrot weevil through the use of insecticides is the most logical means of controlling this insect. To be most effective, control measures should be applied to early planted carrots about the time they reach two inches in height. A choice of the control measures applied will depend on the availability of the insecticide, the ease of application, the possible plant residues involved, and the hazard to the operator.

Experiments in 1948 and 1950 indicate poison apple pomace baits, parathion, and chlordane, when used at seven-day intervals while the plants are small, were effective insecticides to control carrot weevil adults. Aldrin, methoxychlor, benzenehexachloride showed promise of effective control of this insect and deserve further study.

Many problems connected with this study have remained untouched and should be studied in the near future. The study of native parasites and preditors, the search for other wild hosts, the effect of host plant removal, the ecology as it relates to temperature and moistre, and the effects of insecticides applied to the soil are important problems to be considered.

CONCLUSIONS

The study of the biology and control of the carrot weevil during 1948, 1949, and 1950 resulted in the confirmation of some of the findings reported in the literature and the adding of new information.

During the studies, carrot weevils were reared from carrot, parsley, dill, celery and wild carrot grown in and near a garden in Wathena. Radishes, beets, parsnips, and turnips were grown in the same garden but were not attacked. The host range of the carrot weevil among the cultivated crops is narrow since few garden plants are attacked.

The study of the biology and habits of the carrot weevil indicated there are three full broods in northeast Kansas with a considerable overlapping of broods since the insect was found in all life stages in the field from early June to late October. This study indicated the overlapping of the broods was caused by the long life of the adults, the long period of egg laying, the uneven migration from hibernation, and the relatively short period for development of the various life stages. The entire life cycle from egg to adult averaged 33.2 days for the first brood and 31.12 days for the second brood. No study was made of the length of life stages of the third brood.

The appearance of adults in emergence cages indicates the adults apparently start to leave hibernation quarters on warm days by the last week in April. Observations indicated the adults are more active at night and during the cool part of the day. At various periods during the warm part of the day, small groups of adults were found under clods in or near carrot rows. Few beetles were found under clods in the early morning.

Carrot weevil specimens have been found with a heavy coating of dried soil cling to their backs making their identification difficult. The presence of the dried soil on the wing covers indicate the adults seldom fly but travel from hibernation quarters to host plants by walking. Two specimens were collected from a window screen in Wathena, one at night and the other near noon, indicating the beetles are capable of flight.

The adults that enter hibernation choose suitable hibernation quarters close to the carrot plantings. Adults were readily found under the straw mulch in two strawberry fields adjacent to the carrot plantings.

Observations during these investigations indicated several larvae are usually found in a single carrot which feed inside the root. If the carrot is small they eat the entire inside and move to other carrots.

Observations indicate the greatest damage by the carrot weevil is done by the larvae feeding on or within the roots.

To prevent weevil infestation in carrots, it is necessary to destroy the adult females before they deposit eggs in the leafstems of other parts of the plant. Protection of the crop through the use of insecticides is the most logical means of controlling the insect since there is no effective way to kill the larvae within the plant tissues.

Tests using various insecticides developed since 1945 to control carrot weevil have not been reported in the literature. Some of the newer insecticides were tested in plots in 1948 and 1950.

Mortality tests to give an indication of the effectiveness of various insecticides to kill carrot weevil adults were conducted in 1949 and 1950. These tests indicated parathion, aldrin, chlordane, methoxychlor, benzenehexachloride, lindane, and apple pomace baits were promissing as controls for carrot weevil.

Experiments in field tests indicated two pounds of 25 percent parathion in 100 gallons of water, two and one-half pounds of 40 percent chlordane in 100 gallons of water, 1 percent parathion dust, "Go West" bait, or a bait consisting of three-fourths pound of cryolite and 15 pounds of apple pomace were effective to control carrot weevils when used at seven-day intervals starting when the carrot plants are two inches in height. In tests, the sprays were applied at the rate of about 100 gallons per acre, the dusts were applied at the rate of about 25 pounds per acre, and the baits were applied at the rate of about 50 pounds per acre.

SUMMARY

The biology and control of the carrot weevil, Listonotus oregonensis (LeConte), which has become within recent years a serious pest of carrots, celery, dill, and parsley in 20 counties in the eastern third of Kansas are reported.

The wild and cultivated host plants reported in the literature are: wild carrot, wild parsnip, curly dock, patience dock, broad leaved plantain, arrowhead, garden sorrel, curly leaved parsley, dill, celery, carrot, and

turnip. No new host plants were found.

Three full broods of the insect occur in northeast Kansas. There was a considerable overlapping of broods since all stages could be found in carrot plantings from early June to late October.

To prevent weevil infestation in carrots, it was necessary to destroy the adult females before they could deposit eggs. Protection of the crop through the use of insecticides was the most logical means of controlling the insect.

Experiments in 1948 and 1950 indicate poison apple pomace baits, parathion, and chlordane gave effective control of carrot weevil when used at seven-day intervals starting when the plants are quite small.

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BIOLOGY AND CONTROL OF THE CARROT WEEVIL, *LISTRONOTUS OREGONENSIS* (LeCONTE)

by

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