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Title: BIOLOGY AND POPULATION REGULATION OF THE STRAWBERRY ROOT WEEVIL, *OTIORHYNCHUS OVATUS* (L.) (COLEOPTERA: CURCULIONIDAE)

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The life history of the strawberry root weevil, *Otiorhynchus ovatus* (L.), on peppermint was studied in the Willamette Valley of Oregon to provide the information necessary to develop effective control measures.

Adult weevils emerged from the soil from late May until mid-June and were active in the field until late July. Active feeding by adults occurred between one and seven hours after sunset. No significant migration for the purpose of feeding or oviposition was observed and no adults were found to overwinter. Oviposition occurred from mid-June until September in the laboratory but ceased by late July in the field. Egg incubation periods averaged 13 days in the laboratory with fertility rates of 70 to 80 percent. Fertility declined substantially in the laboratory after late July. Larvae occurred in the peppermint root systems from early June

until late May of the following year with pupation occurring from mid-April until the first of June. Carabid beetles, *Omaseus melanarius*, were found to be predaceous on adult strawberry root weevils but no other predators or parasites were discovered. Laboratory studies indicate that desiccation is a potential mortality factor acting on all immature stages.

Biology and Population Regulation of the Strawberry Root Weevil, *Otiorhynchus ovatus* (L.) (Coleoptera: Curculionidae)

by

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BIOLOGY AND POPULATION REGULATION OF THE STRAWBERRY ROOT WEEVIL, *OTIORHYNCHUS OVATUS* (L.) (COLEOPTERA: CURCULIONIDAE)

INTRODUCTION

The strawberry root weevil, *Otiorhynchus ovatus* (L.), has been a serious pest of strawberries in the United States for nearly a century. In addition to strawberries in the Pacific Northwest, this weevil has caused considerable damage to conifer nursery stock, other berry crops including raspberry and cranberry, and more recently to peppermint, *Mentha piperita* L.

Peppermint, a native of Europe, was introduced into the Northeastern United States about 1812 (Sievers and Stevenson, 1948). Success in establishing commercial mint cultures in the East and Middle West led to experimental plantings in other parts of the country with similar soils, including Oregon and Washington. Peppermint was introduced into Oregon about 1909 and has since become firmly established as a commercial crop (Figure 1 and Table 1).

The strawberry root weevil was reported as a peppermint pest as early as 1945 (Thompson, 1946). In the commercial peppermint plantings of Western Oregon, conditions are extremely favorable for the development of substantial populations of *Otiorhynchus ovatus*. The perennial nature of the mint plantings (two to five years), lack of cultivation in mature plantings, harvest dates (well after the adult

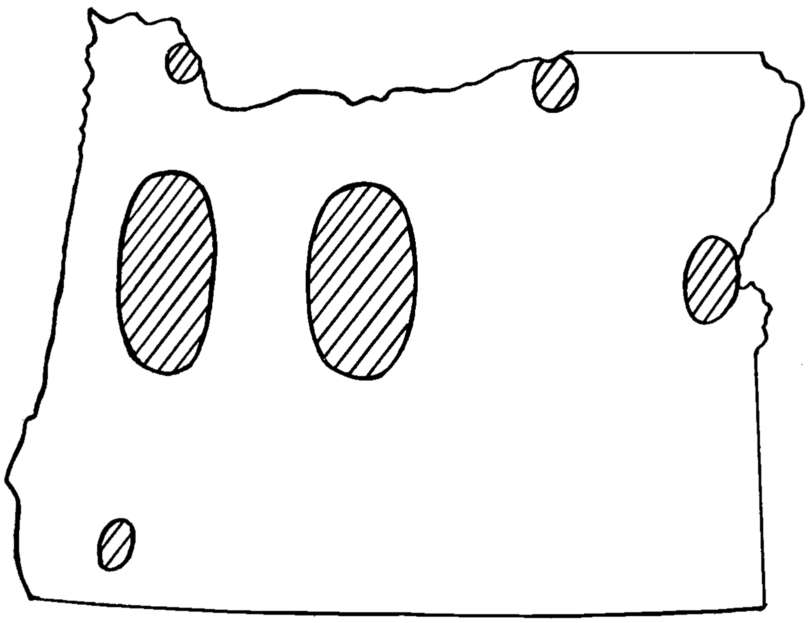

Figure 1. The principal peppermint producing areas of Oregon in 1974.

Table 1. Acres of peppermint harvested in Oregon in 1972, 1973, and 1974 by county.

County	Acres harvested		
	1972	1973	1974
Benton	1,900	2,000	2,200
Lane	3,900	4,300	4,200
Linn	4,500	4,700	4,500
Marion	3,800	3,900	3,800
Polk	1,550	1,550	1,450
Josephine	750	750	750
Umatilla	480	550	450
Malheur	1,300	1,400	1,550
Crook	1,400	1,420	1,600
Jefferson	13,500	15,000	13,750
Total other counties[1]	1,420	930	1,250
State total	34,500	36,500	35,500

[1] Includes Columbia, Wasco, Baker, Deschutes, and Lake counties.

weevils have oviposited and died), the habits of the immature stages (underground feeding and pupation) and the parthenogenetic nature of reproduction all allow populations to increase and remain at relatively high levels.

Both the larval and adult stages of the strawberry root weevil feed on the peppermint plant. Adult feeding is restricted to the foliage and aerial parts during the period when the plant is rapidly growing. Feeding damage by adults has little effect on plant growth and yield and is seldom visible in the field.

While adult damage is of little importance, larval feeding damage may seriously affect plant growth. By feeding on the small rootlets at first and the larger ones later, the plant's ability to produce new growth may be greatly reduced. Larval feeding can be especially damaging since it continues after harvest in late summer and fall and in the spring when there is little photosynthesis taking place.

The problem of finding a practical control for the strawberry root weevil has occupied the attention of entomologists, horticulturists and others for over a century in Europe and North America. Various measures have been investigated, including the influence of weather, parasites and predators, diseases, cultural practices and chemical means of control.

As with other pests of economic importance, ecologically sound control measures depend upon an understanding of the biology and population dynamics of the pest. Therefore, a study of the biology and population regulation of the strawberry root weevil was conducted in peppermint at two locations in the Willamette Valley of Oregon from April 1972 to July 1974.

LITERATURE REVIEW

Taxonomic Position

The strawberry root weevil, *Otiorhynchus*[1] *ovatus* (L.), is a member of the family Curculionidae, order Coleoptera. Linnaeus (1761) described the species *ovatus*, assigning it to the genus *Curculio*. Later, Latrielle (1802) erected the genus *Brachyrhinus* to include several of Linnaeus' *Curculio* species but according to Zimmerman (1968), this was originally a compound concept that included representatives of several genera. The genus *Otiorhynchus* was proposed by Germar (1824) and has been the accepted generic name by most workers world-wide.

Although the genus *Brachyrhinus* was validly proposed it has been largely ignored since it was erected except in the United States and Canada. Pierce (1913) and later the "Leng Catalogue" (Leng, 1920) refer to the genus *Brachyrhinus* as the valid genus, listing *Otiorhynchus* in synonomy. Since then many of the North American workers, including personnel of the United States Department of Agriculture and the United States National Museum, have used *Brachyrhinus* while their European counterparts have continued to use

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[1] Spelled *Otiorrhynchus* in some European literature.

Otiorhynchus. The Annual Review of Applied Entomology has, however, consistently used Otiorhynchus in its index.

In a plea for the suspension of the rules of the International Commission of Zoological Nomenclature in favor of the continuation of the use of Otiorhynchus, Zimmerman (1968, p. 33) summed up the situation as follows:

> It is thus evident that usage has been and is overwhelmingly in favour of Otiorhynchus and that Brachyrhinus has been suppressed by most workers since it was proposed in 1802. To avoid confusion and to establish stability and uniformity, we should conserve Otiorhynchus and suppress Brachyrhinus.

Acting on Zimmerman's request, the Commission in 1972 validated the genus Otiorhynchus and the subfamily Otiorhynchinae suppressing the genus Brachyrhinus and the subfamily Brachyrhininae (Opinion 982 . . .).

Additional confusion exists in the earlier literature of Otiorhynchus ovatus apparently stemming from an error by Leconte and Horn (1876). In their The Rhynchophora of America North of Mexico, Leconte and Horn list the species ligneous. Leng (1920) stated that this specific name was cited in error and was actually ovatus. Fortunately, ligneous was used in very little literature and has not been used for nearly a century in referring to O. ovatus.

In the North American literature of Otiorhynchus ovatus many common names have been used. Wilcox, Mote, and Childs (1934) list eight used at various times: Strawberry Weevil; Strawberry

Crown-Girdler; Ovate Snout-Beetle; Graveyard Bug; Pitchy-Legged Otiorhynchus; Strawberry Grub; Sleepy Weevil; and Strawberry Root Weevil. In addition, the name "Strawberry Root-Girlder" has occasionally been used in popular literature.

The name strawberry root weevil was approved as the accepted common name for this species by the committee on common names of the American Association of Economic Entomologists in 1933 (Common names . . .). Since this is the most widely used common name in recent literature, it will be the common name used in this study.

World Distribution

The genus *Otiorhynchus* is primarily European where it is represented by more than a thousand species (Hustache, 1923). *Otiorhynchus ovatus*, although an insect of wide distribution, has never been reported from outside the northern hemisphere and in injurious numbers it seems to be confined to the northern part of this hemisphere.

The present old world distribution of the strawberry root weevil, as compiled from the literature, includes Austria, Bulgaria, Czechoslovakia, England, Finland, France, Germany, Hungary, Italy, Norway, Poland, Spain, Sweden, Yugoslavia, Central Asia, Arctic and Western Siberia. In North America, the weevil has been reported from Canada and the United States.

History and Distribution in North America

Wickham (1894) reports the first record of *O. ovatus* in North America as a specimen from the Leconte collection collected in Massachusetts prior to 1852. Whether the weevil is indigenous or introduced is open to question. Hatch (1971) states, without elaborating, that all species of *Otiorhynchus* in North America have been introduced. Several other authors cite records of intercepting species of *Otiorhynchus* on nursery stock and other plants shipped to this country from Europe as being evidence of introduction (Sasscer, 1922; Weiss, 1915).

Evidence that the strawberry root weevil is a native insect is given by Downes (1922, p. 2). Following a careful research of *O. ovatus* and allied species in British Columbia, Downes says,

> There seems to be no doubt that the beetle is a native one. It is present in all the settled portions of the southern part of the province and has been found on rocky islands away from settlements where it could not possibly have been introduced artificially and at various altitudes up to 4,000 feet in the mountains.

Since the weevil cannot fly, its distribution into such remote areas seems only possible after long existence on this continent.

Additional evidence that species of *Otiorhynchus* are indigenous to North America is that at least four species belonging to this genus have been described as fossils from the early Tertiary Rocks in western Colorado and Wyoming (Wickham, 1920).

Whatever its origin, the strawberry root weevil has been reported from most of the northern states and as far south as New Mexico in the United States. In Canada, it has been a serious strawberry pest in British Columbia and has been reported from most of the southern provinces.

The first record of _O. ovatus_ as a pest in Oregon was in 1900 near Montavilla (Lovett, 1913). By 1913 it had been reported from several districts about Portland, in the Walla Walla Valley, and in small numbers at Hood River. A review of recent literature and museum material indicates that the weevil is now present throughout the state.

Host Plants

In addition to infesting strawberry and peppermint plantings, the strawberry root weevil has a wide range of other hosts. Wilcox, Mote, and Childs (1934) list 33 different host plants for adult weevils and 49 for larvae (see Appendix). Patch (1905) found that in confinement the weevils would feed on 40 additional plants. No doubt there are many other potential host plants. One adult weevil in this study, after its normal food supply of peppermint had been exhausted, was found to be eating the polyethylene cap of the vial in which it was confined, producing polyethylene fecal pellets.

Biology

Investigations for the control of the strawberry root weevil began as early as 1884 in North America when it was discovered as a strawberry pest in Michigan (Weed, 1884). Although there have been no biological studies of the weevil as it infests peppermint, several workers have reported life histories in relation to control measures on strawberries.

Treherne (1914) and Downes (1922) in British Columbia, Lovett (1913) and Wilcox, Mote, and Childs (1934) in Oregon, studied the various aspects of strawberry root weevil biology including the period of adult emergence, duration and habits of the life stages, preovipositional period, fecundity, oviposition, egg fertility and incubation period. Similar work in Europe was reported more recently by Stein ahd Küthe (1969) in Germany and Burov (1959) in Bulgaria. The larval habits and egg deposition have been studied by Cooley (1904) and Fidler (1936) and Spessivtseff (1923) reported on the seasonal history of the weevil in Sweden.

Natural enemies have been listed by Downes (1922), Feytaud (1918), Kalmbach and Gabrielson (1921), Lovett (1913), Treherne (1914), and Weed (1884). In Germany, Küthe and Stein (1969) reported some control of the strawberry root weevil by nematodes.

Parthenogenesis, rather uncommon in the Coleoptera, is quite general in *Otiorhynchus*. Parthenogenesis in this genus has been studied by many workers including Feytaud (1918). In *O. ovatus*, Downes (1922), Spessivtseff (1923) and Treherne (1920) have reported on parthenogenesis.

METHODS AND MATERIALS

Field Studies

Field Sites. The field site used during the 1972 season, hereafter called Site I, was located six and one-half statute miles east of Junction City, Lane County, Oregon, at an elevation of approximately 365 feet mean sea level (Figure 2). The site was limited to a roughly triangular peppermint planting about 12 acres in area and bordered on two sides by roads and associated borrow pit vegetation and on the third side by various grasses and deciduous trees and shrubs. Several larger peppermint plantings were present in the immediate area but random sampling showed them to be devoid of weevils.

Strawberry root weevils had been present in substantial numbers at Site I for at least three years prior to this study and probably much longer judging from the area of infestation. The eastern half of the site had been plowed and replanted with new peppermint in 1970 and was relatively free of weevils during the 1972 studies. The western half was sparsely populated with peppermint except for a thick growth along the western border. In this 15-foot wide swath and the adjacent sparsely planted area, weevils were numerous enough during the 1972 season to take preliminary samples and for collection of adults for laboratory studies.

Figure 2. Field Site I.

Figure 3. Field Site II.

During the summer, Site I was sprinkler irrigated about every eight days. The soil at the site was extremely hard and rocky which made sampling of immature stages difficult. On October 2, 1972, the western half of the site was stripped of all peppermint plants and disced, substantially reducing the weevil population. The following spring Site I was checked and found to have a relatively low population of mature larvae so the site was abandoned for study purposes.

Early in 1973 a new site was established, hereafter referred to as Site II, approximately four statute miles east of Jefferson, Linn County, Oregon, at a mean sea level elevation of about 250 feet (Figure 3). Site II consisted of a 20-acre peppermint planting bordered on the west by a large orchard grass planting and on the remaining three sides by various native trees, shrubs, and grasses.

The peppermint at the site had been present for the past four years prior to which the field had been planted with various vegetable crops. The grower reported that substantial numbers of weevils had been encountered at Site II for at least 12 years prior to this study. During the 1973 season the main weevil population appeared to be concentrated in the eastern half of the field so sections in that half were used for sampling and observations. Late in 1973 the western third of the site was plowed, confining the 1974 studies to the eastern section. Site II was sprinkler irrigated about every nine days during the summer and the soil was relatively soft and rockless which facilitated sampling.

Field Equipment and Techniques. Sampling of the immature stages (larvae, pupae, and teneral adults) in the field was accomplished by using the standardized soil sampler shown in Figure 4. This device consisted of a length of steel 27 by 2 by 5/16 inches bent into a three-sided square, one-half square foot in area. One edge of the sampler was tapered to allow it to be forced into the soil by foot pressure. When the plant to be sampled was selected, the sampler was forced into the soil around the plant and a garden spade used to remove all the soil and plant material within the sampler to a depth of 10 cm (preliminary sampling showed that the immature stages were seldom found below this depth). Each sample was then placed in a numbered plastic bag until it could be examined, usually the same day but never more than 24 hours after sampling.

After all samples were taken, the material in each was sequentially sifted through three screen-bottomed boxes, 23 in. by 23 in., with 4, 8, and 14 openings to the inch respectively (Figure 5). The final screen (14 openings to the inch) had sufficiently small openings to retain the immature weevils while allowing most of the soil to pass through. As the material was sifted, the immature weevils were removed with forceps, counted, and either collected into 70 percent

Figure 4. One-half square foot soil sampler used for sampling immature stages.

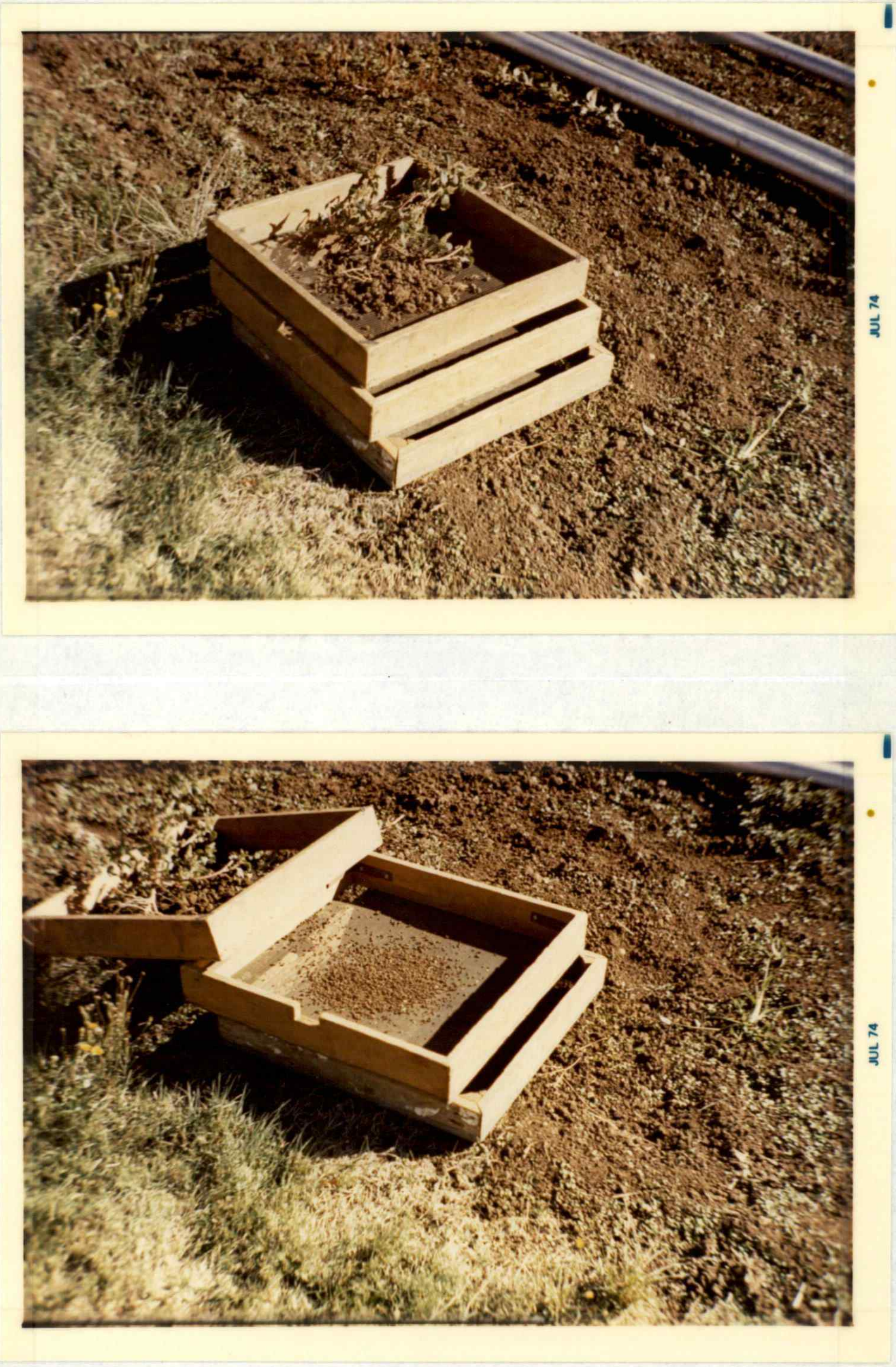

Figure 5. Sifting screens used to extract immature stages from plant material and soil.

alcohol or into one pint, paper, ice cream cartons partially filled with damp soil for transport to the laboratory.

During sampling, measurements of the depths at which the immature stages occurred were taken and their position on or near the plant roots noted. Soil temperatures and moisture content were monitored at three sites in the sampling area at a depth of 4 cm with a mercury thermometer and an electrical resistance type soil moisture tester.[2]

Sampling sites for immature stages were selected by taking random soil samples, in the above method, throughout the area of the field known to be infested with weevils. Once the area of highest concentration of immature stages was determined, ten quadrats, ten square feet in area each were selected at 50-foot intervals along a north-south transect and marked with numbered stakes. At seven-day intervals from April 13 until June 14 in 1973 and 1974 a one-half square foot sample was taken around a plant selected randomly in each quadrat to monitor development from the larval to the adult stage. During the latter part of the adult emergence period in 1974, samples were taken at two-day intervals to more accurately determine the final date of adult emergence.

In determining the date of first emergence of adult weevils from the soil, pit traps made from plastic cottage cheese containers

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[2] Delmhorst model KS soil moisture tester.

were placed in the soil with the tops flush with the soil surface. A metal funnel of the same diameter was placed in the mouth of each container to prevent escape of the trapped adults. Ten pit traps were placed adjacent to the quadrats sampled for immature weevils and checked at two-day intervals during the expected adult emergence period (determined by monitoring the subterraneously developing teneral adults). By checking this method against direct observation of plant bases for newly emerged adults, the pit trap technique provided a reliable determination of first emergence date.

The pit trap technique was intended to be used to monitor the relative numbers of adults during the season and the duration of their field activity. However, the presence of large numbers of carabid beetles which inadvertently fell into the traps and destroyed the trapped weevils at Site I made this method unreliable.

The daily and seasonal duration of adult field activity was determined by sweep sampling using a standard sweep net 15 inches in diameter with a 30-inch handle. Sampling consisted of counting the number of adult weevils collected in ten sweeps using a sweep arc of 180 degrees. Since disturbing the plants on which the weevils were feeding would cause them to drop to the ground, successive sweeps were made at a great enough distance from preceding sweeps to insure that the insects had not been dislodged. During all sampling an attempt was made to sweep at a uniform depth and arc in the foliage although variation in plant height modified this somewhat. When collection at night was necessary, all sweeping was done by what natural light was available and often in complete darkness to avoid disturbing the weevils with artificial light. After collection, the net contents were carried away from the sampling area and examined by flashlight.

It was known that adult strawberry root weevils are generally inactive at the plant bases during the day but actively feed on the upper foliage at night. To determine the daily period of adult feeding activity, 12 quadrats, 25 feet by 100 feet each, were established in the area of highest weevil concentration (Figure 6). This particular size was selected because it allowed the entire quadrat to be sampled with 100 sweeps while allowing sufficient distance between samples to prevent disturbing successive sweep areas. During this sampling regime, sundown was taken as the reference time and quadrats sequentially sampled, one every two hours, no quadrat being sampled more than once in any 24-hour period. At the start of each quadrat sampling, the air temperature and relative humidity at the level of the upper foliage were recorded. After sampling, all weevils collected in a particular quadrat were replaced randomly in that quadrat.

To determine the extent of adult weevil movement in the field, a capture-recapture method was employed. It was decided that a

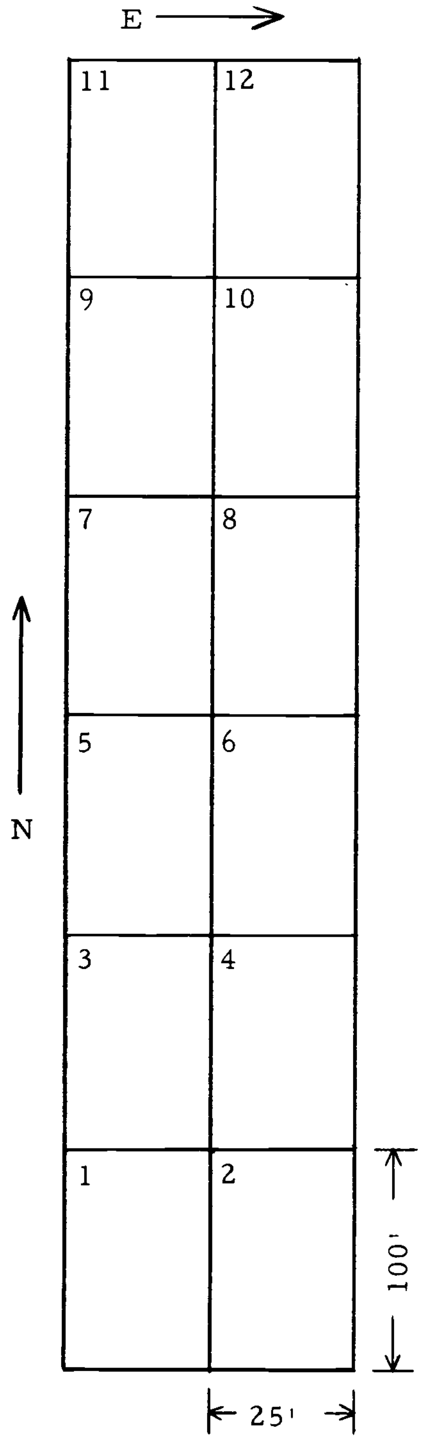

Figure 6. Diagram of field plots used to determine the adult daily activity period.

marking technique should be used that would allow weevil movement to be monitored for a relatively long period with a minimum of disturbance to the weevils during that period. Preliminary studies were conducted in the laboratory with a water based fluorescent poster paint and a fluorescent powder[3] as markers. Although the paint provided a clearer marker on the weevils, it was easily removed by moisture and its application was too time-consuming to use on large numbers of adults in the field. The fluorescent powder provided a less distinct marker but in addition to its ease of application, it was found to be retained on the weevils for a sufficiently long period of time to be useful. In the preliminary studies with caged adults, neither marker appeared to adversely affect weevil behavior or longevity.

After selection of the marker, adult weevils were sweep collected at night, placed in one-pint, paper, ice cream cartons with the fluorescent powder and allowed to become thoroughly coated with the pigment. On June 23, 1973, 600 marked adults were released at a marked site in the field and their movement away from the site monitored at three-day intervals with a portable ultraviolet lamp. Monitoring was accomplished by scanning the peppermint at varying radii around the release point two hours after sundown and recording

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[3] HELECON luminescent pigment 2210 obtained from the United States Radium Corporation.

the number of weevils and the distance moved. Constant radii were maintained by use of a marked wire attached to a pole at the release point.

In addition to soil and air temperatures recorded in the field, the average monthly temperatures for the period of this study were obtained from the National Oceanic and Atmospheric Administration's "Climatological Data, Oregon," and are presented in the Appendix.

Laboratory Studies

To provide a laboratory stock of adult weevils for dissections and behavioral observations, newly emerged adults were collected in the field and returned to the laboratory where they were maintained in one-pint, paper, ice cream cartons, approximately 50 weevils per carton. The carton tops were replaced with glass petri dishes to provide natural photoperiodic conditions and ventilation provided by small holes punched in the sides. The weevils were provided with peppermint cuttings inserted in vials of distilled water in the base of each carton, the cuttings were replaced as necessary to provide a constant source of fresh food. Under these conditions adult weevils were easily maintained for up to two months even through no attempt was made to regulate temperature or humidity.

Ovipositional and Fecundity Studies. An attempt to rear pupae through to adults to obtain ovipositional data was termined due to relatively high pupal mortality. To overcome this difficulty, pre-emergence teneral adults were collected in the field and maintained individually in four-dram, glass vials with cotton stoppers. Each vial contained loose soil to a depth of 1 cm and was supplied with a fresh peppermint leaf, with petiole, daily. The vials were maintained in growth chambers with a 16-hour light, 8-hour dark photophase with temperatures of 24 $^{\circ}$C and 15 $^{\circ}$C respectively for the light and dark cycles.

At the same time each day the adult weevils and leaves were removed and the eggs and soil flushed from the vials into petri dishes with a gentle stream of distilled water maintained at the same temperature as the ovipositional vials. The number of eggs deposited by each individual was then recorded. The vials were then cleaned with distilled water and the adults replaced with fresh leaves and soil. At various times during the season, adult weevils were collected in the field and maintained in the laboratory to monitor oviposition of the field population. This method was used to determine the length of the pre-ovipositional, ovipositional, and post-ovipositional periods and adult longevity and overcame the difficulties of maintaining confined individuals and detecting the small eggs in the field.

After removal of the eggs from the ovipositional vials, an eye-dropper with a sufficiently large opening to prevent egg damage was used to transfer the eggs to clean, four-dram vials. Following transfer, the distilled water was drained off, the eggs blotted dry with paper toweling, and the vials stoppered to maintain sufficient humidity to prevent desiccation. These incubation vials were then maintained in the laboratory under regulated temperature and photoperiodic conditions and monitored daily until hatch. During the 1973 ovipositional period, eggs were maintained at 20°C under a 24-hour dark photophase. During the 1974 period, a photophase of 16 hours light and 8 hours dark with temperatures of 24°C and 15°C respectively for the light and dark cycles was used during incubation.

Egg observations were made at the same time each day using a binocular dissecting microscope. During observation, the vials were opened to allow gas exchange and a drop of distilled water added if no visible moisture was present. Observations were conducted for as short a period as possible to minimize temperature variations. Mold was a problem in less than two percent of the egg vials so no additional precautions were taken. Infected vials were omitted from the final calculations for hatch.

Duration of the Pupal Stage. To determine the duration of the pupal stage under regulated conditions, mature strawberry root weevil larvae were collected in the field and returned to the laboratory for rearing. To preclude the possibility of larvae being "starved into pupation" in the laboratory, only larvae that had formed cells in the soil in preparation for pupation, and thus had completed feeding, were collected. After collection, the larvae were individually maintained in one-dram shell vials with cotton stoppers at 15^{o}C under a 24-hour dark photophase. The temperature of 15^{o}C was selected to approximate the mean daily soil temperature at pupal depth (4 cm) during May, 1974.

During the 1974 pupal period, 50 mature larvae were maintained under the above conditions and monitored daily for pupation and adult emergence. During each observation, a drop or two of distilled water was added to the vials, as necessary, to prevent desiccation. Although as many precautions as practicable were taken in handling and rearing, a very high pupal mortality occurred.

RESULTS AND DISCUSSION

Life History and Habits

The seasonal life history of the strawberry root weevil on strawberries was given by Wilcox, Mote, and Childs (1934). Data from the present study on peppermint are summarized in Figure 7 which represents the periods when the particular life stages were found in significant numbers. The open-ended boxes representing eggs and adults indicate that under "ideal conditions," as evidenced by laboratory studies, some adults might have been present and ovipositing in the field even though sampling produced none this late in the season.

Adult. Newly emerged adult weevils are oblong-oval in shape and average about 5 mm in length. Color varies from light to dark brown approaching black, the legs and antennae being a reddish-brown. The thorax is truncate at the base and apex and covered with numerous elongate tubercles or ridges while the elytra are oval and punctate-striate, the striae being more distinct on the sides. Numerous short, yellowish, semi-prostrate hairs cover the body but are most numerous on the legs and snout (Figure 8).

The spring emergence of adult weevils from the soil is dependent on the weather, especially temperature, soil moisture and texture. Previous work in the Willamette Valley on strawberries

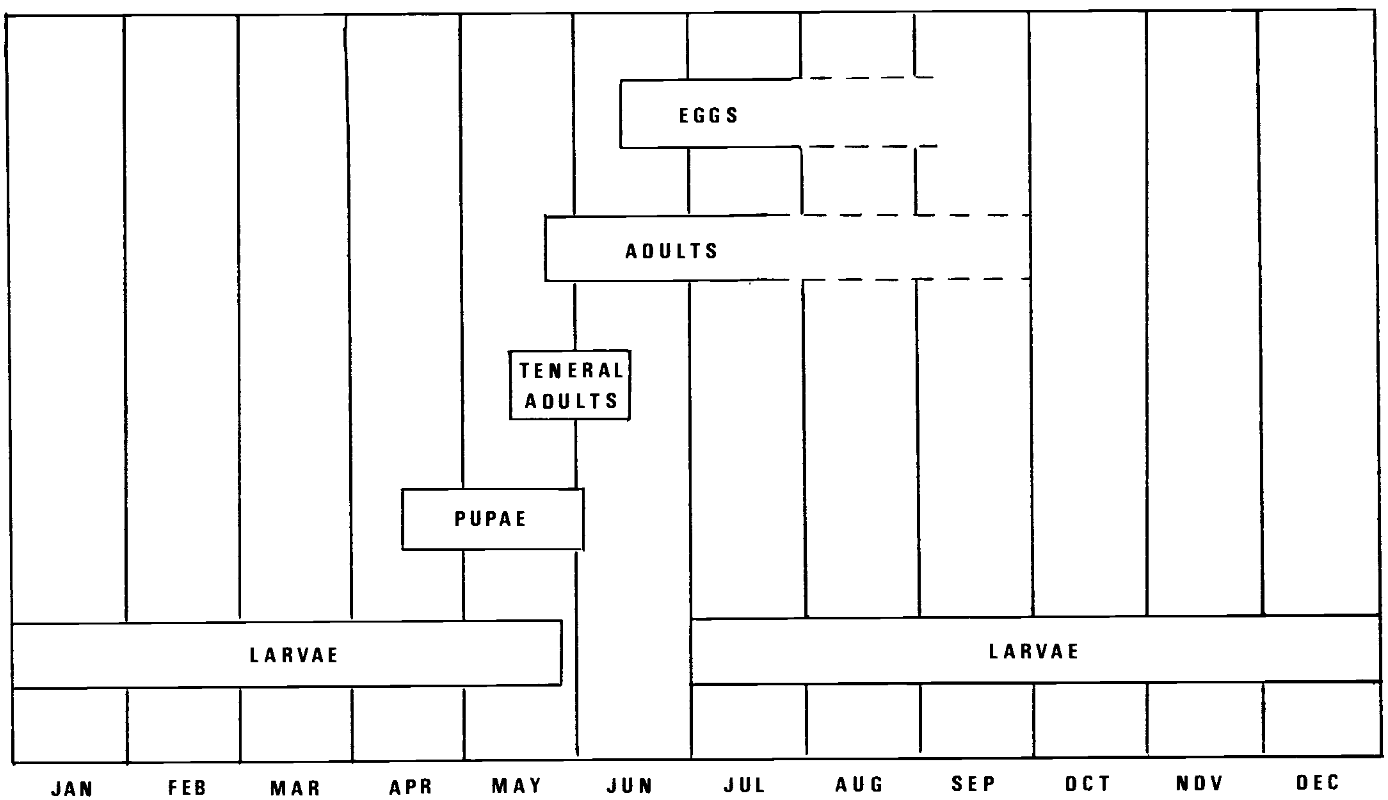

Figure 7. Summary of the seasonal life history of Otiorhynchus ovatus on peppermint from Sites I and II.

Figure 8. Otiorhynchus ovatus adult.

(Wilcox, Mote, and Childs, 1934) showed that the first adult emergence occurred as early as April 28, and as late as May 23 in successive years. In British Columbia, Downes (1922) reported that the first emergence in 1920 occurred on June 10. During this study, the first adult emergence from the soil began in the latter half of May and continued until the middle of June. Based upon the dates of discovery of the first adults above ground and the last teneral adults below ground the mean emergence period for the three years was 21 days (Table 2). This agrees with previous work in the Willamette Valley (Wilcox, Mote, and Childs, 1934) in which the majority of weevils were found to emerge in less than 30 days.

Table 2. Emergence period of *Otiorhynchus ovatus* adults.

Year	First emergence	Last emergence		Emergence period (days)
1972	May 17	June 10		24
1973	May 22	June 14		23
1974	May 28	June 14		17
			Mean =	21

After emergence from the soil, adult strawberry root weevils are primarily nocturnal, but may occasionally be found in small numbers on the upper peppermint foliage during daylight. By day, the majority of the adult weevils are inactive and remain hidden around the bases of the plants, under clods and dead leaves and in shallow crevices in the soil. In June, 1974, the adult weevils became active about one hour before sunset, climbing to the upper foliage and feeding. Figure 9 illustrates the daily activity cycle of adults as measured by the number of weevils sweep collected from the upper peppermint foliage at two-hour intervals for three 24-hour periods. Each sampling period began two hours before sunset on the days of June 18-19, 24-25, and 27-28, 1974. Temperature and relative humidity readings were taken at the level of the upper foliage during each sampling. The number of weevils collected on the upper foliage remained relatively high until shortly after sunrise but had declined to near zero by late morning (Figure 9). This can be roughly translated into a 12-hour active, 12-hour inactive daily cycle during the latter half of June.

Although relatively large numbers of adults were present on the foliage throughout the hours of darkness, the individual weevils exhibited their most active movement and feeding within the hour prior to and the two hours following sunset. The high humidity in the form of dew and the lower temperatures occurring after this period tended to reduce individual activity. Weevils were noticeably sluggish and were occasionally found stuck in the moisture that had formed on the leaves, their activity so reduced by the lower temperatures that they were unable to free themselves.

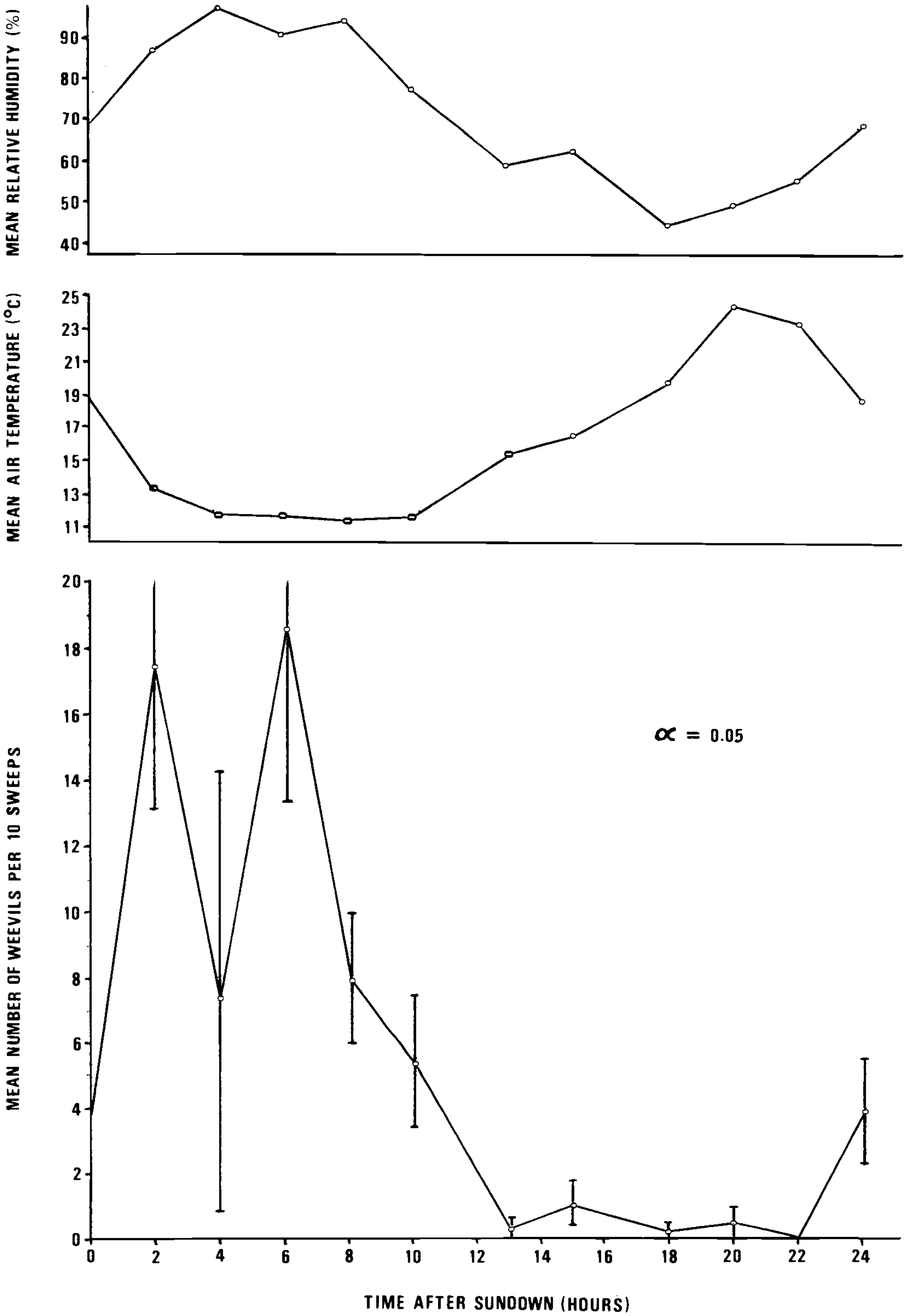

Figure 9. Adult Otiorhynchus ovatus daily activity cycle on peppermint foliage at Site II in June, 1974.

These data suggest that a program of sweep sampling to monitor adult strawberry root weevil infestations on peppermint would more accurately reflect population trends if conducted between one and seven hours after sunset. During this study, however, it was found that separation of the weevils from the plant material that was invariably collected while sweeping was much easier when samples were taken one or two hours after sundown, before much dew had formed on the foliage and lower temperatures had reduced individual activity. By placing the sweep samples on a sheet of light colored cardboard the weevils could easily be removed with forceps and counted as they crawled from the plant debris. Separation of weevils from the damp leaves collected later proved time consuming as they often remained stuck in the moisture film on the leaves and had to be removed individually by hand.

Adult strawberry root weevils begin feeding on the peppermint foliage upon emergence from the soil. Even incompletely hardened individuals were found to begin feeding within 24 hours of emergence.

In captivity, when feeding was limited to one leaf per day, peppermint foliage exhibited two types of feeding damage. In the first type, the weevils straddled the leaf margins and cut into the edges of the leaves giving them a notched or ragged appearance. This type of damage was not confined to any particular area but would occur at any point along the leaf margin. The second type of damage always occurred on the underside of the leaf on one of the leaf veins. This feeding began as a "rasping away" of the vein until a hole was eaten through the leaf. As the hole was enlarged, the weevils began feeding along the margins of the opening enlarging it further.

In addition to these two types of feeding damage, weevils were also found to eat peppermint stems when no leaves were available. This feeding, as with the leaf feeding, always began on a narrow, projecting part of the plant, in this case along the corners of the square stems.

Although adult feeding damage was quite evident in the laboratory, in the field it was almost impossible to detect since the weevils only feed for a short time on any particular leaf before moving to another. The rapid growth of healthy peppermint during the period of adult weevil activity insures that damage will be insignificant. On strawberries, adult weevil feeding damage was also found to be minimal (Wilcox, Mote, and Childs, 1934).

Adult strawberry root weevils are difficult to locate in the field. As mentioned before, the weevils are primarily nocturnal, hiding by day under various plant debris or in cracks in the soil. During field observations, adult weevils were often found inside dried, curled leaves or clinging to the underside of dried stolons. Their dark brown color blends in well with surface debris and with their antennae and legs drawn in, they often resemble small clods or stones and are easily overlooked.

As with many other foliage feeding beetles, adult strawberry root weevils feign death when disturbed by drawing in their legs and antennae, falling from the plants and remaining motionless. During evening and early morning hours when some natural light was present, the casting of a sudden shadow on the feeding weevils would elicit this response. During hours of darkness, a sudden flash of white light from a flashlight would also cause the weevils to drop from the foliage. It is interesting to note, however, that the ultraviolet light used in the movement studies appeared to have no affect on the weevils.

Adult weevils are normally present and actively feeding in the field from late May until late July (Figure 7). Sweep sampling at night and visual searches on the plant bases during the day showed that the peak adult population occurred about the middle of June and by early July had begun a noticeable decline. Previous work in the Willamette Valley on strawberries in 1926 (Wilcox, Mote, and Childs, 1934) showed that 40 percent of the adult weevils were alive on September first, indicating a duration of about four months for adults in the field. The adult duration of approximately two months shown in the present study was probably not due to migration from the field as no adults were found in the surrounding areas. Instead, the decline seemed to be due to direct adult mortality as the proportion of dead adults observed in the field showed a marked increase corresponding to the decline of the living populations.

Adult weevils confined in the laboratory generally showed a longer life span than those in the field. During both the 1972 and 1973 seasons, only about 50 percent of the laboratory population had died by the end of July while the field populations had virtually disappeared. The last surviving laboratory adults died on October 3, and August 23, during the 1972 and 1973 seasons respectively, suggesting a possible adult duration of three to four months under laboratory conditions.

Overwintering by adult weevils is a common occurrence in the more northerly latitudes. In Sweden, adults transform in the fall but remain in the ground until the following spring with oviposition occurring in July and August (Spessivtseff, 1923). In British Columbia, Downes (1922) reported on the migration of adults to and from overwintering sites. Adults also overwinter at higher elevations in Oregon. Wilcox, Mote, and Childs (1934) found numerous overwintering adults in strawberry plantings at an elevation of about 1,800 feet in Hood River County but practically none in the Willamette Valley. In the present study, no adult weevils were found in the fields or surrounding areas after July and none survived in the laboratory after August.

In the presence of adequate food, there does not appear to be any significant adult migration or movement throughout the field for the purpose of feeding or egg distribution. Results of the capture-recapture experiment with marked adults showed that the vast majority of weevils remain within two meters of the release point until death. Of the 600 marked adults released on June 23, 1973, only 10 were recaptured or observed beyond two meters. After 17 days, only three weevils had traveled as far as six meters from the release point.

An attempt was made during this study to determine the mortality factors acting upon each life stage of the strawberry root weevil. In the 1973 and 1974 adult emergence periods, many teneral adults, identified by their light yellow color, were observed above ground. Approximately twice as many of these teneral adults were found dead at the plant bases as were the fully hardened adults. Examination of the dead individuals showed no visible predator or parasite damage. The most probable cause of this mortality was desiccation.

During the 1972 season, carabid beetles, Omaseus melanarius, were inadvertently captured in the pit fall traps with adult weevils, completely destroying the weevils. Large numbers of these carabids were apparently present in the field as four or five were found in each pit trap each time they were checked. When confined in the laboratory with only adult strawberry root weevils to feed upon, six O. melanarius consumed an average of three weevils per day for five days. No O. melanarius were found at Site II in 1973 or 1974.

With the exception of spiders, no other predators were observed in this study even though there are a number reported in the literature. Treherne (1914) found the carabid Amara farcta feeding on adults and larvae of the strawberry root weevil and Downes (1922) reported the larvae of Therevidae as predators on larvae of Otiorhynchus ovatus. Spiders have been reported attacking adult weevils by Lovett (1913) and Treherne (1914) and a Gamasid mite was found feeding on O. ovatus eggs by Lovett (1913). Weed (1884) reported finding O. ovatus in the stomachs of blackbirds and robins and Kalmbach and Gabrielson (1921) found O. ovatus in the stomachs of starlings. Treherne (1914) considered moles important predators of O. ovatus and Weed (1884) found the remains of over 200 weevils in the fecal mass of one skunk. No parasites were found during this study nor are any reported in the literature.

Egg. Newly laid eggs of Otiorhynchus ovatus are oblong-oval, averaging 0.47 mm in length and 0.37 mm in diameter and covered with a clear liquid which hardens shortly after oviposition to secure the eggs to the ovipositional site. When deposited, the eggs are an opaque, pearly white but change to an amber color within 24 to 48 hours if viable (Figure 10). The failure of eggs to change color

Figure 10. Otiorhynchus ovatus eggs.

within 48 hours is a reliable indicator of inviability. Although a few eggs observed in this study failed to develop after the color change, in no case did eggs which remained white after 48 hours develop. The color change takes place within the chorion itself rather than in the internal contents of the egg since the shell retains the amber color after the larva has emerged. During development, the chorion is transparent and the embryo can be seen within. After about six or seven days of incubation, head capsules and mandibles become visible and the developing embryos respond to increased temperatures or vibrations by moving within the egg.

Egg incubation periods were determined for the 1973 and 1974 laboratory populations in regulated temperature chambers. During the 1973 ovipositional period, eggs were maintained at a constant temperature of 20°C (the mean daily field soil temperature at egg depth during early June, 1973) under a 24-hour dark photophase. During June and July of 1974, eggs were maintained under a photophase of 16 hours light and 8 hours dark with temperatures of 24°C and 15°C respectively for the light and dark cycles. Figures 11 and 12 illustrate the incubation periods for the two seasons, showing the percent of total seasonal egg population and the number of eggs hatched on any given day of incubation.

The mean (and standard deviation) incubation period for eggs collected in 1973 (13.9 $\pm$ 1.54 days) was significantly different

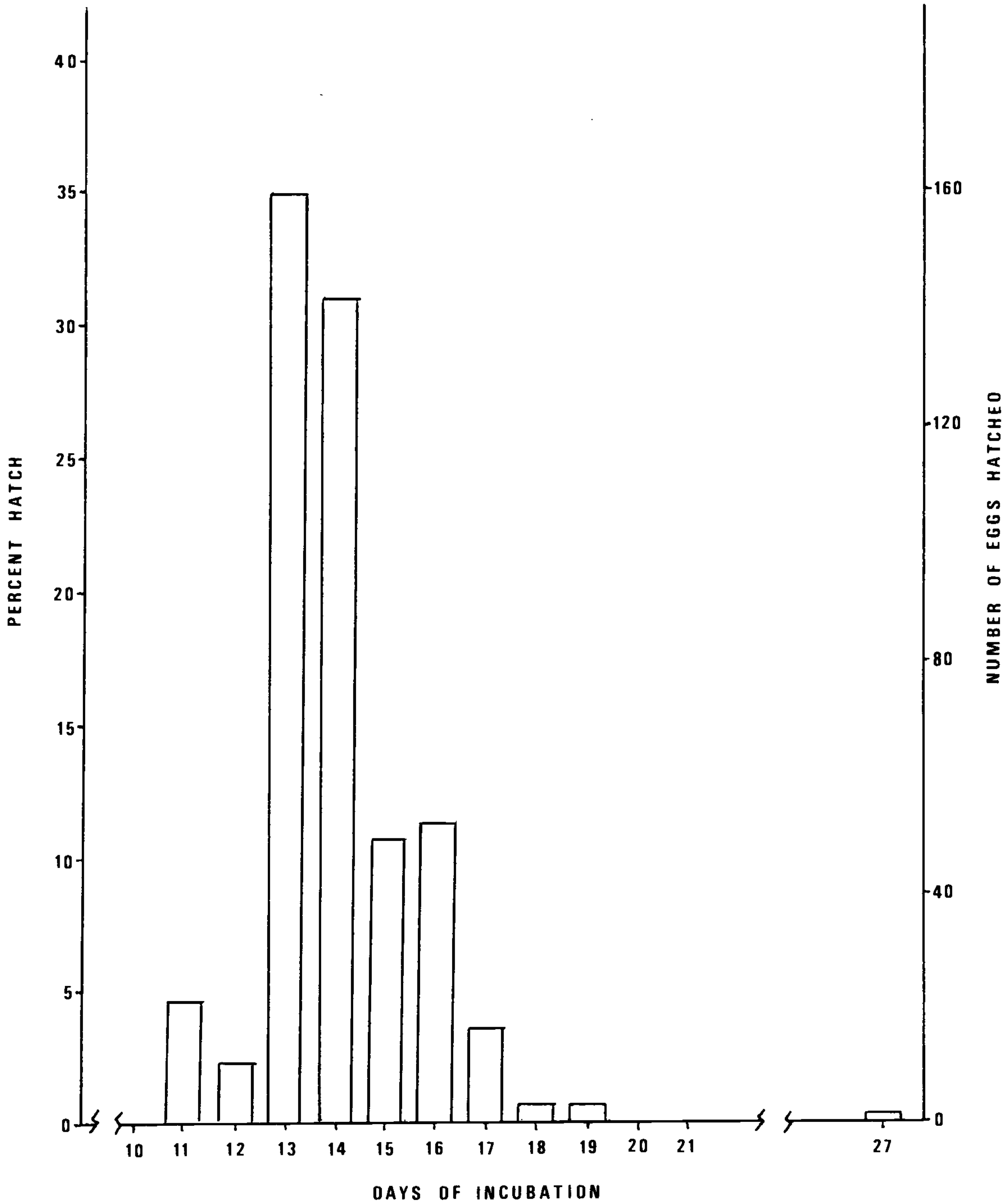

Figure 11. Incubation periods of Otiorhynchus ovatus eggs from the 1973 laboratory population.

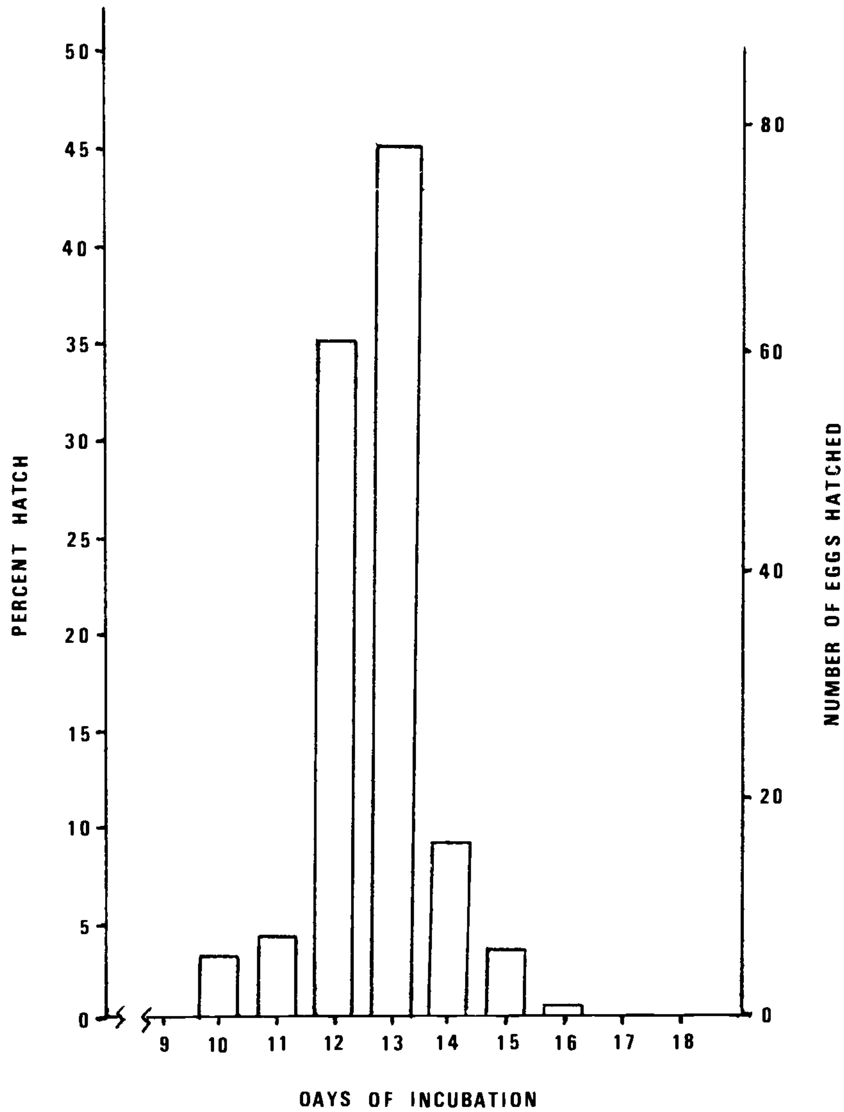

Figure 12. Incubation periods of Otiorhynchus ovatus eggs from the 1974 laboratory population.

(P < 0.05) from the incubation period in 1974 (12.6 $\pm$ 0.97 days) according to the Student-Newman-Keuls test. This difference was likely due to the higher maximum temperature used to incubate the eggs in the 1974 studies. The mode, however, remained the same for the two seasons, with more eggs hatching at 13 days of incubation than at any other period.

Reports in the literature indicate that the incubation period for Otiorhynchus ovatus eggs is quite variable. Lovett (1913) reported that the eggs hatched in 9 to 24 days, with an average of 14 days; Cooley (1904) indicated that they hatched in about 20 days; Downes (1922) reported incubation periods of from 15 to 22 days and Treherne (1914) found a minimum incubation period of 12 days and a maximum of 25 days. The maximum incubation period reported in the literature is 33 days and the minimum, one day (Wilcox, Mote, and Childs, 1934). Melander and Spuler (1926) reported that the weevils lay living young; however, this seems doubtful as it has not been reported in other literature nor was it observed during the present study. In the 1973 season, the maximum incubation period was 27 days for one egg, and although the egg hatched the larva was extremely weak and died within a few hours. Several eggs remained viable beyond 27 days but failed to hatch. One embryo could be seen moving within its egg after 43 days of incubation.

Although the strawberry root weevil is a parthenogenetic insect, egg fertility was substantially less than the expected 100 percent. Table 3 gives the egg fertility data for the laboratory populations during the 1973 and 1974 seasons. The percent fertile eggs includes those eggs that hatched and those that failed to hatch but contained fully developed embryos. Eggs listed as infertile were those that failed to develop to the point of visible head capsules and mandibles.

Table 3. Fertility of Otiorhynchus ovatus eggs from 1973 and 1974 laboratory populations.

	1973[a]	1974[b]
Number of eggs	760	239
Percent fertile	68.3	82.0
Percent hatched	60.7	72.8
Percent infertile	31.7	18.0

[a]Data for eggs laid from June 19 to August 11, 1973.
[b]Data for eggs laid from June 11 to July 5, 1974.

The percent egg fertility for 1974 was somewhat higher than for 1973; however, the relatively low fertility rates observed in late July and August of 1973 do not appear in the 1974 data as incubation experiments were terminated earlier in 1974. Egg fertility rates of 68.3 percent and 82.0 percent respectively for 1973 and 1974 can be compared with previous work by Downes (1920) and Treherne (1914) in which 80 percent of the eggs laid by summer weevils were reported to be fertile.

The incubation periods for eggs laid later in the season (i.e., after mid-July) were not noticeably different than those of eggs laid in early June; however, there was a difference in fertility and hatch. Table 4 shows the decrease in percent hatch beginning in mid-July and reaching zero by August. Although the percent fertility remained relatively high until late July, it too declined rapidly after July 29.

Table 4. Weekly fertility and hatching rates of _O. ovatus_ eggs from the 1973 laboratory population.

Week beginning	Number of eggs	Percent fertile	Percent hatch
June 17	154	79.9	79.9
June 24	100	88.0	88.0
July 1	49	95.9	95.9
July 8	136	75.6	66.9
July 15	64	60.9	59.4
July 22	93	73.1	44.1
July 29	104	44.2	31.7
August 5	60	8.3	0

Many of the eggs laid after July had thin shells and a clear, watery fluid inside. These inviable eggs began to shrivel shortly after deposition and dried up within three days unless maintained in a high moisture environment.

Wilcox, Mote, and Childs (1934) suggested that the lack of egg fertility was caused, at least in part, by the fact that the eggs that are laid first are undersized and therefore undernourished. In the present study, no such size differential was observed between the eggs laid first and those deposited later. In addition, eggs laid first exhibited about the same fertility as those laid later (excluding those eggs deposited in late July and August). Although there was a large decrease in egg fertility of the laboratory population in late July and August, some infertile eggs were laid by each weevil throughout the season. In fact, nearly every daily batch of eggs deposited by each adult contained some infertile eggs.

It is possible that egg damage after oviposition may have been responsible for some of the observed infertility, but it seems unlikely since all eggs were examined under a microscope and any obviously damaged eggs were removed before incubation. Since all eggs were handled identically and some daily batches exhibited 100 percent hatch, the cause of the "random" infertility appears to be physiological.

In addition to the possible physiological causes of egg infertility, only desiccation was found to contribute to egg mortality in this study. In laboratory tests, eggs exposed to open air at room temperature lost enough moisture after two days to become noticeably shriveled. After four to five days of such exposure, the eggs were completely desiccated and would not recapture moisture even when submerged in water. No egg parasites are reported in the literature, and none were found in this study.

Larva. Newly hatched *Otiorhynchus ovatus* larvae are white with conspicuous orange-brown head capsules and are about 0.48 mm in length. As the larvae grow they become more grub-like in appearance and assume the typical "C" shape when extracted from the soil. Ocellar pigment is absent and all segments show relatively long setae. Mature larvae (Figure 13) are 6 to 7 mm in length and possess six prominent epicranial setae on the head and four setae in the anterior row on the pronotum arising from small tubercles. These setal patterns may be used to separate larvae of *O. ovatus* from larvae of *Dyslobus* and other *Otiorhynchus* species found in the Willamette Valley.

After hatching, the young larva immediately begins to make its way down to the fine rootlets in the soil. Upon locating a small crack in the soil or a space between small clods, the larva burrows down using rhythmic body contractions to force the head capsule into the opening. In this process, the body setae are used to brace the posterior of the larva against the soil. Various lateral and dorso-ventral movements of the head during burrowing tend to enlarge the tunnel and aid in penetration of the soil. Young larvae are fairly active and are even able to climb vertical glass if a film of moisture is present.

Strawberry root weevil larvae were present in substantial numbers in the field from about the first of July until late May of the

Figure 13. Otiorhynchus ovatus larva.

following year (Figure 7). A few individual larvae were collected in June but they were generally small and weak and died before pupation when maintained in the laboratory. The larval stage lasts about 10.5 months during which time the larvae are always found among the roots of the peppermint plants, often within 1 cm of the surface. During this study, no larvae were found deeper than 10 to 15 cm, the lower limit of the peppermint roots.

In the larval stage, strawberry root weevils are somewhat solitary as compared with the often gregarious adults. Larvae under observation in the laboratory exhibited violent thrashing movements of the anterior body when prodded or when inadvertently bumped by another larva. These movements always caused the approaching larva to move away. During field sampling, even though many larvae were found among the roots of one plant, they were never found in close proximity to one another but rather evenly spaced through the root system.

Feeding begins on the fine rootlets and as the larvae grow, larger roots are attacked. Generally, the larvae remain active and feed throughout the winter; however, there may be periods of relatively little activity during colder temperatures. Larvae pass through at least five instars in the Willamette Valley, usually completing four by mid-winter and passing through the fifth in the spring (Wilcox, Mote, and Childs, 1934). Molting takes place in small cells formed in the soil near the site of last feeding. The final molt to the pupal stage also occurs in an earthen cell, usually among the roots of the plant but never more than a few centimeters from the root system.

Lovett (1913) reported that newly hatched larvae are quite hardy and could live in dry soil for 36 hours without food. Downes (1922), however, suspected that large numbers of the young larvae are starved before they can reach suitable food and that this natural factor was responsible for the destruction of the majority of the newly emerged larvae. In the present study, larvae hatched from laboratory incubated eggs were successfully maintained in a high humidity environment at 22°C for up to six days after eclosion without food. However, when newly hatched larvae were exposed to open air at room temperature they normally died of desiccation within two days.

Soil moisture content was monitored in the field throughout the study but there was no correlation between it and larval development. Rainfall and irrigation kept soil moisture relatively high and even during periods of lowest soil moisture, larvae showed no adverse effects.

No larval parasites or predators were found during this study. In the literature, Treherne (1914) found the carabid Amara farcta feeding on larvae of O. ovatus and Downes (1922) reported the larvae of Therevidae as predators on the larvae of O. ovatus. The potential mortality factors of starvation and desiccation of newly hatched larvae appear to be minor in Willamette Valley peppermint plantings.

Pupa. Newly formed Otiorhynchus ovatus pupae are milky white, about 6 mm in length and 3 to 4 mm in width from knee to knee (Figure 14). These pupae may be separated from related species by the presence of four setae in the anterior row on the pronotum arising from small tubercles.

Pupation occurs in oval cells formed in the soil by the mature larva in or near the root system of the peppermint plant. Pupae were normally found between 1 and 10 cm below the soil surface and never more than 5 or 6 cm from roots.

In the field, pupation began in mid-April and most larvae had pupated by mid-May during this study. The first teneral adults appeared in late May and by the first week in June the majority of the population had completed pupation (Figure 7). Individuals collected in the field as mature larvae and maintained in the laboratory at 15°C under a 24-hour dark photophase averaged 22.6 days in the pupal stage with a range of from 17 to 26 days. Previous workers have reported pupal periods of from 10 to 26 days (Downes, 1922) and 21 days (Treherne, 1914).

After emerging to the adult stage, the weevils typically remain in the pupal cell for some time before burrowing to the surface. At first, the teneral adult is milky white like the pupa but soon turns

Figure 14. Otiorhynchus ovatus pupa.

brown as the exoskeleton hardens. Within two to three days the adult weevils are able to move about actively.

The pupal stage is the most fragile stage in the development of the strawberry root weevil, even careful handling often damaged individuals during this study. Because of this, any soil movement, such as tillage operations, could result in relatively high pupal mortality and subsequent population reduction.

SUMMARY AND CONCLUSIONS

The life history of the strawberry root weevil, *Otiorhynchus ovatus*, on peppermint was studied in the Willamette Valley of Oregon to provide background data for future control measures.

Adult weevils began emerging from the soil during late May and had completed emergence by mid-June. Any population control measures aimed at the adult stage, such as insecticides, should commence at the beginning of the emergence period and continue until all adults have emerged. Adult control measures should begin before the start of oviposition (i.e., mid-June) for effective population suppression. A program to monitor the onset of adult emergence should be used to time adult control measures, but such a program should be studied under different climatic conditions which may cause emergence dates to vary.

Adult weevils were actively feeding in the field from late May until late July with the peak population occurring in mid-June. Active feeding occurs between one and seven hours after sunset and a program of sweep sampling to monitor adult infestations should be conducted one or two hours after sunset before dew forms or lower temperatures reduce weevil activity.

The majority of adult weevils migrated less than two meters in this study suggesting that population spread is very slow. No adults were found to overwinter.

Oviposition occurred from mid-June until early September in the laboratory but probably ceased by the end of July in the field. Egg incubation periods averaged 13 days in the laboratory with 70 to 80 percent of the eggs fertile. Fertility declined substantially during late July and early August.

Larvae were present in the field from the first of July until late May of the following year. Pupation began in mid-April and lasted until the first of June.

In irrigated mature peppermint plantings, the chances for survival of eggs and young larvae are quite good. At this time, the peppermint is rapidly adding foliage which tends to reduce soil moisture loss through evaporation. This and the periodic addition of irrigation water reduce the potentially important mortality factor of desiccation to one of minor importance. In hotter, dried areas, desiccation of eggs and young larvae may be quite important in reducing populations.

Tillage operations may be beneficial in reducing populations in areas where verticillium wilt is not a problem. Plowing or tilling the soil around peppermint for weevil reduction would be most effective during the pupal period as this stage is the most susceptible to mechanical damage. Tillage would also increase the possibility of desiccation to all of the immature stages. Wilt in most Willamette Valley areas precludes this method of weevil control.

Removing all peppermint plants and fallowing the land in late summer could be an effective method of population control.

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APPENDIX

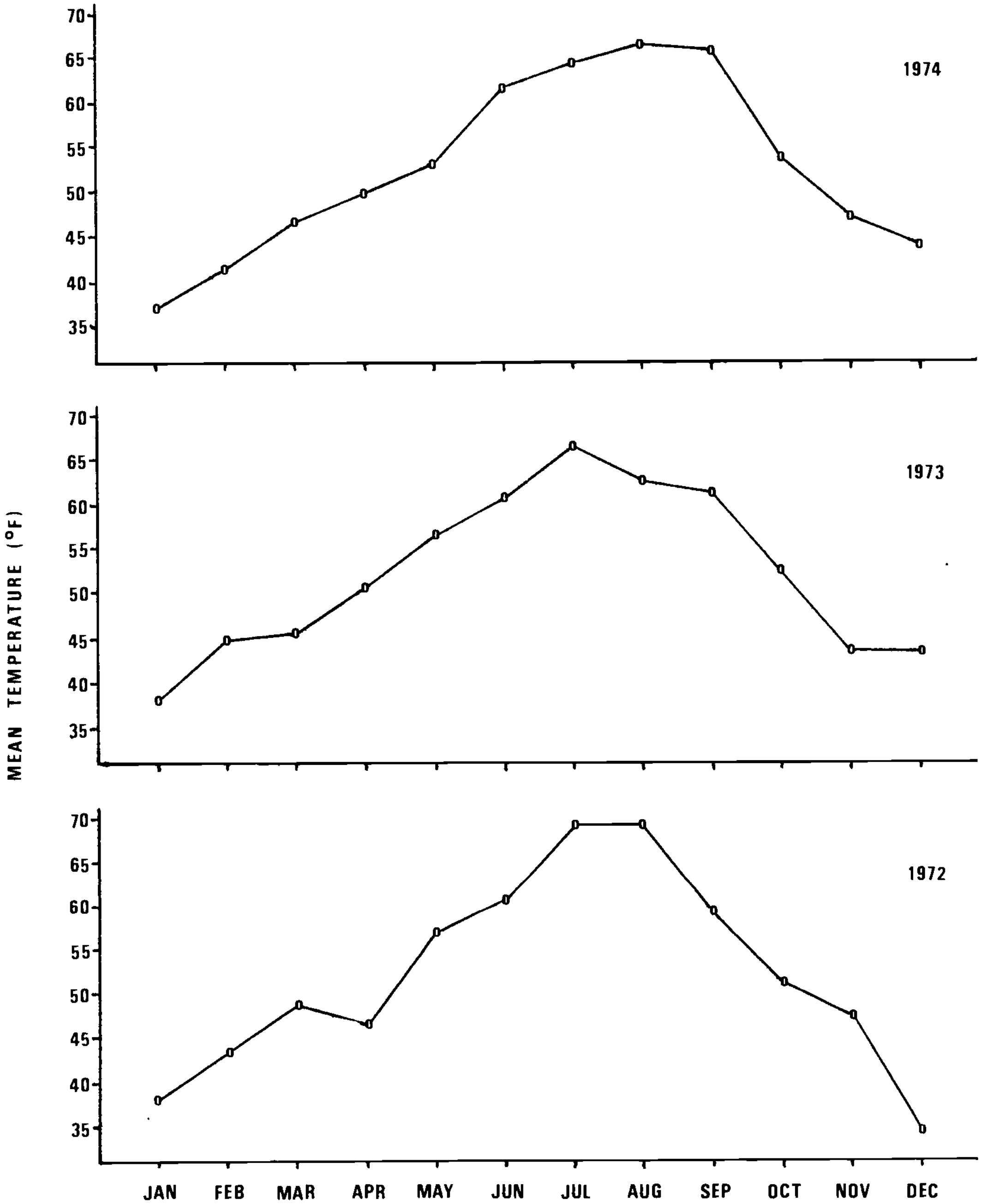
STRAWBERRY ROOT WEEVIL HOST PLANTS

Adults

Apple fruit
Apple leaves
Beet
Blackberry
Bluegrass
Borage leaves
Cabbage
Cauliflower
Cherry
Corn
Corn stalk
Currant
Dahlias blooms
Hemlock
Loganberry
Muskmelon foliage
Neottia (*Ophius*) *nidus-avis*
Orchid fruit
Peach foliage
Peach fruit
Pear fruit
Peppermint
Potato
Pumpkin
Raspberry foliage
Raspberry fruit
Red clover
Roses
Sorrel
Strawberry
Sweet briar
Wheat
Wild buckwheat
Wild rose

Larvae

Alfalfa
Apple (young)
Arbor vitae
Balsam
Beet
Blackberry
Bluegrass
Blue spruce (young)
Cabbage
Clover
Cranberry
Conifer seedlings
Currant (young)
Douglas-fir (young)
Hemlock (young)
June grass
Juniperus virginiana (young)
Loganberry
Norfolk spruce (young)
Oak
Peach
Pear (young)
Periwinkle
Peppermint
Pitch fir (young)
Pine
Poa flava
Poa pratensis
Poa serotina
Polyanthus
Potato
Potentilla glandulosa
Quackgrass
Raspberry
Red clover
Red pine (young)
Rhubarb
Scotch pine (young)
Snowberry
Sorrel
Spruce (three-year)
Strawberry
Sugar maple (seedlings)
Timothy
Trefoil
White clover
White pine (young)
Wild strawberry



Average monthly temperatures at field sites.