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Behavior Patterns of the Adult Alfalfa Weevil in Cache Valley, Utah

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BEHAVIOR PATTERNS OF THE ADULT ALFALFA WEEVIL IN CACHE VALLEY, UTAH

by

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INTRODUCTION

The alfalfa weevil, *Hypera postica* (Gyllenhal), was first found in the United States in Salt Lake City, Utah, during 1904 (Titus, 1910b). It spread from this point of original introduction and partially infested Cache Valley by 1912 (Titus, 1913).

The alfalfa weevil has become one of the more important insect problems currently affecting American agriculture. Recently, this problem has attracted national attention because of the development of resistance to insecticides by the alfalfa weevil, the outlawing of certain pesticides for use on forage crops and the rapid spread of the alfalfa weevil to new areas.

With this increased attention, many discrepancies have appeared in different reports of the alfalfa weevil's biology. The results of studies in the eastern United States often do not agree with those of studies which were made in Utah and vicinity during the early part of this century. In order to investigate the discrepancies or differences, and to determine the behavior patterns of the alfalfa weevil in Cache Valley, this study was undertaken. It was conducted from June, 1965, to August, 1966.

The main topics investigated were the adult alfalfa weevil's flight activities, reproduction, daily field activities, seasonal history including diapause, and respiration under controlled conditions.

REVIEW OF LITERATURE

Flight Activities

Spring Flight. Titus (1910b), Parks (1913), and Poinar and Gyrisco (1962) reported that as soon as the spring weather became warm enough, the overwintering alfalfa weevils became active, left their winter quarters, and many took to the air in flight. Titus, in Utah, apparently made only visual observations of the flights and noted that the weevils flew at heights ranging from a few feet off the ground to as high as the top of a high barn. Parks said weevils were observed in April falling indiscriminately in alfalfa and grain fields as well as along roadsides and right-of-ways. In New York, Poinar and Gyrisco (in addition to visual observations) used tanglefoot traps 6 feet by 3 feet in size to capture flying weevils.

Summer Flight. Overwintered adults gave rise to the new generation whose adults were also involved in a flight, according to several authors. Titus (1910b) and Parks (1913) said a summer flight began in June and continued for about three weeks, with weevils rarely seen flying after August 20-25. Poinar and Gyrisco (1962) and Prokopy and Gyrisco (1965) agree that in New York a summer flight began in mid June and continued until late July or early August. Prokopy and Gyrisco (1965) stated that 95 per cent of the adult weevil population participated in this migration and were 14 to 25 days old when they flew.

Fall Flight. A distinct fall (October and November) flight was reported in New York by Prokopy and Gyrisco (1963), which they suggested was coincident with the return of the alfalfa weevil adults to the alfalfa fields from the border areas. Pamanes and Pienkowski (1965) indicated this to be true also in Virginia, where the weevils left the alfalfa fields before the middle of July and started to return in October. In Maryland weevils were reported to return to the alfalfa fields in September (Manglitz, 1958). In North Carolina adult weevils (after being absent from the field all summer) returned to the fields in September through November with the peak in November (Campbell *et al.*, 1961).

Factors Affecting Flight. In California, where six cuttings of alfalfa were obtained, Michelbacher and Essig (1934) noted no general flight movement, although individuals were observed to fly. Prokopy and Gyrisco (1965) stated that under certain circumstances or conditions there might be little or no summer migration of the weevil from the fields. Alfalfa succulence and availability were given as factors influencing flights. They also stated that a decrease in light intensity stimulated flight activity, but the lowest temperature at which weevils flew was 18.3 C. The greatest flight activity was noted between 1830 and 2030 hours.

Reproduction

Copulation. Titus (1910a) found that copulation continued from spring to fall and that the males mated a number of times. Parks (1914) stated that copulation occurred repeatedly during the entire oviposition period. Both Titus (1910b) and Essig and Michelbacher (1933) reported dark-colored adults mating with light-colored adults, suggesting that some of the new generation would mate with the overwintered generation.

Egg Laying. According to Titus (1910b) egg laying began a few days after the spring appearance. Hamlin et al. (1949) stated that the first egg laying in the spring was restricted to the females which had reached sexual maturity the preceding fall. Parks (1914) reported that under Utah conditions eggs were laid from March to August, with most of the eggs laid in May, and that eggs deposited in the autumn were killed by winter temperatures. However, in Maryland, Manglitz and App (1957) maintained that eggs overwintered. In California, Michelbacher and Essig (1934) claimed that egg-laying probably continued throughout the winter to some extent as they found several batches of fresh eggs in January. In contrast, Campbell et al. (1961) found oviposition to commence in November in North Carolina, with the hatch commencing in December and peaking in April. In Tennessee, the peak of egg laying occurred in late fall and early winter (Bennett and Thomas, 1964).

Titus (1910b), Hamlin et al. (1949) and Manglitz and App (1957) found that eggs were at first laid in the litter on the ground and later in growing alfalfa stems. The female weevils laid their eggs in punctures made in the alfalfa stems. As many as 33 eggs clustered within a puncture were noted, but clusters of eight eggs were the most common, (Hamlin et al.,1949). Parks

(1914) found that higher temperatures were more conducive to egg laying. He said that a week of warm, dry weather during the beginning of oviposition resulted in a very large number of eggs being deposited in a short time.

Partial Intersterility. Cross matings between eastern and western United States alfalfa weevil populations were conducted by Blickenstaff (1965), whereby he demonstrated that the two were partially intersterile. An eastern female with western male cross produced infertile eggs. A western female with eastern male cross produced fertile eggs, but the progeny were preponderantly female. He concluded that the eastern and western populations should at least be considered subspecies.

Daily Field Activities

Titus (1910b) found the adult alfalfa weevils to feed mainly at night with some feeding at about daylight. He said most of the weevils went down to the ground and many stayed hidden until dark, though some fed during the day. Essig and Michelbacher (1933) also found adult weevils to be more active at night during the summer. Poinar and Gyrisco (1960) observed this behavior, and suggested that the behavior of the adults was related to light intensity rather than to temperature or relative humidity. Their experiments were conducted in late June when the adult population was at its peak.

In studying the feeding behavior of alfalfa weevil adults from the eastern and western United States, Koehler and Gyrisco

(1963) found that, when exposed to randomized alternate intervals of sunlight and darkness, weevils fed more frequently in darkness. Poinar and Gyrisco (1964) stated that adult behavior was controlled by light intensity and did not continue in either constant light or darkness. They concluded that the periodicity exhibited by the adults in the field was of the exogeneous type.

Diapause and Seasonal History

The summer diapause (aestivation) of the alfalfa weevil was studied in Maryland by Manglitz (1958) who observed that the newly emerged adults could survive several months without food and apparently did so through the summer. He found these adults in surface litter and in soil under trees, hedge rows, and fence rows bordering alfalfa fields. The weevils began to return to the field in September. The females had undergone no ovarian development during the summer.

Guerra and Bishop (1962) found that development of the female sex organs from weevils that emerged in May was considerably arrested during diapause and that sexual maturity was not reached until November. Adults observed emerging in September did not diapause and the females attained maturity in November. The diapausing weevils required six months to mature, whereas non-diapausing weevils reached maturity 81 days after emerging from the cocoons.

Huggans and Blickenstaff (1964) found they could alter the diapause pattern of the alfalfa weevil by rearing the larvae under an eight-hour day length. Weevils so reared became nondiapausing adults which began laying eggs an average of 45 days after emergence from the cocoons. Larvae reared under 12-hour day length conditions went into a prolonged adult diapause and their egg production began an average of 170 days after emerging from the cocoons.

Several other studies have been made on aestivating alfalfa weevils (Tombes, 1964; Bennett and Thomas, 1964; and Tombes, 1966), but none of these studies have been made in the western United States. Snow (1928) made a detailed study, in Utah, on the effect of ovulation on the seasonal history of the alfalfa weevil. Therein, he stated that beetles emerging in spring and summer remained immature for about four months after emergence, or until late September or October. He also stated that the small number of overwintering females still alive late in the season were enough to account for the small number of eggs and larvae found at that time of year.

Snow (1928) discounted the idea that there was more than one generation per year, as did Titus (1910a) and Campbell et al. (1961). Manglitz (1958) also attributed the late larval populations to the overwintered adults rather than to the new generation adults. Huggans and Blickenstaff (1964) suggested that a second generation might be possible in the South where larvae may overwinter and become nondiapausing adults.

Tombes (1964) presented the hypothesis that the alfalfa weevil in South Carolina aestivates during the summer but does not hibernate during the winter. Reeves (1927) said there was no definite period of hibernation for the alfalfa weevil. He described the adult weevils as quiet when they were cold and active when they were warm. Peterson (1960), when comparing the effects of low temperature on the survival of alfalfa weevils from Alberta and Utah, did not say the weevils hibernated, but he spoke of their cold resistance.

Respiration and the Effect of Controlled Environments

Tombes (1964) measured the respiration rate of the alfalfa weevil adults throughout the year. He found an 83 per cent reduction in oxygen consumption as the insects entered into aestivation. No attempt was made to vary conditions to observe changes in the respiration rate due to environment.

Sweetman and Wedemeyer (1933) observed the effects of various relative humidities and temperatures on all stages of the alfalfa weevil from egg to adult. No attempt was made to record respiration rate. They found temperatures of 30 to 37 C to be injurious to the adults especially when the relative humidity was high. Higher temperatures killed the adults in a few days. Relative humidity below 40 per cent, at least with temperatures of 27 C or higher, were very destructive to the adults. Koehler and Gyrisco (1961) made similar studies on the response of eggs, larvae, and pupae to temperature and humidity, but little dealt with adults.

METHODS AND PROCEDURE

Study Fields: Selection and Location

Four fields in Cache Valley, Cache County, Utah were selected for the studies. Other fields throughout Cache Valley were also observed in connection with weevil control programs. These four fields were selected at different elevations. They ranged from the valley floor up to the highest fields on the mountain side. They were designated as: the Christensen, Thurston 1, Thurston 2, and Gnehm fields. The Christensen field, consisting of 10 acres at approximately 4580 feet elevation, was located in North Logan at 2324 North 8 East. The Thurston field 1, consisting of 11 acres at approximately 4700 feet elevation, was located in Hyde Park at 480 East Center. The Thurston field 2, consisting of 3.1 acres at approximately 5300 feet elevation, was located 1.6 miles East of Hyde Park on a side hill below "Three Hill." The Gnehm field, consisting of 35 acres at approximately 5800 feet elevation, was located 2.5 miles East of Hyde Park on the bench above "Three Hill."

A recording hygrothermograph was installed in a weather station box at the Thurston 1 field on 10 June 1965. It was operated throughout the experiments.

Flight Activities

The flight activities of the alfalfa weevils were studied using two methods of capturing weevils in flight. They were sticky-board traps and a rotating net trap. The sticky-board traps were made of metal sheeting 3 X 18 inches and painted dull yellow. Dead Line sticky material was applied on one side to an area of 2 X 16 inches. Two such sticky boards were bolted to a wooden lath stake so that two sticky surfaces were exposed. The lath stakes were driven into the ground at the edge of the field so that one sticky surface faced toward the field and one faced away from the field. They were spaced at 200-foot intervals around the edges of each of the four fields.

The sticky-board traps were arranged as described to give information on the direction of the weevil flight and whether they were flying into or away from the field. These traps were placed around the Gnehm field on 2 July 1965, and around the other three fields on 6 July 1965.

The rotating net trap (Figure 1a) was powered by a small gasoline engine. The engine drove, by vee-belt, a 40:1 gear reduction box (Figure 1b), which through two bevel gears, turned the ten foot vertical mast. Two fifteen-inch nets made of tough nylon mesh were attached to the distal ends of the two six-foot horizontal booms. These were attached by a sliding "T" fitting to the vertical mast. The nets could be set at selected heights by rebolting the sliding "T" fitting at the desired height. The five-foot height was normally used, though other heights from three feet to ten feet were tried. In operation, the nets turned at 60 RPM.

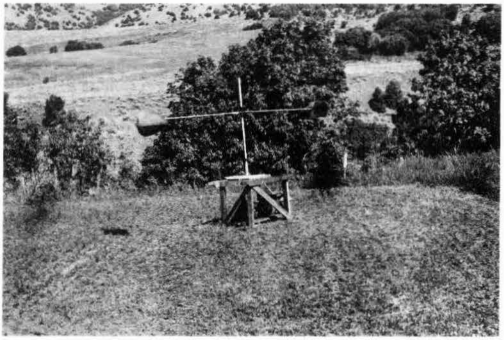

Figure la. Rotating net trap.

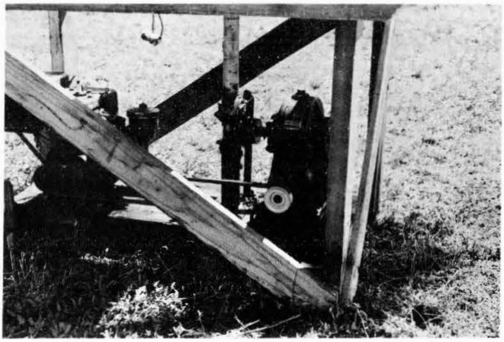

Figure lb. Close-up of the drive mechanism of the rotating net trap.

The rotating net trap was later altered by inverting the gear reduction box and eliminating the bevel gears. The vertical mast was then attached directly to the gear reduction box shaft. It was first operated at the Thurston field 1 on 5 August and was used in the fields as often as weather and other work would allow. After various mechanical problems were overcome, the rotating net trap could be left running for four hours or more without attention. Its purpose was to serve as a check on the effectiveness of the sticky-board traps and provide better data on the times of flight and the effects of wind velocity on flights.

An anemometer became available in the spring of 1966 and was used to measure wind velocities while running the rotating net trap.

Reproduction

Mating adult alfalfa weevils were observed in the alfalfa fields and in the laboratory. Adult weevils were collected from the field with sweep nets and placed in gallon glass jars covered with nylon netting. Stems of alfalfa were placed in vials of water. Cotton plugs held the stems in place and prevented weevils from falling into the water. These stems were then placed in the gallon jars as food for the weevils. It was in these gallon jars that many observations of mating habits were made.

More detailed observations were made on individual pairs of weevils taken while in copulation from the gallon jars and placed in test tubes. An alfalfa stem, placed in a procaine vial of water, was placed in each test tube. Water condensing on the test tube was a problem because it greatly increased weevil mortality. As a result, the first two mating tests (Series A and B) were unsuccessful. Several arrangements were tried to correct the condensation. The problem was solved by using a dry cotton ball situated in the bottom of the test tube to absorb moisture. A tuft of cotton was used to plug the open end to prevent the weevils from escaping, but yet allowing the interchange of gasses. In these tubes, the weevils were easy to observe, and any eggs laid could be easily seen, counted and removed.

Eggs laid by adult weevils under observation were checked for viability. An observation tube (Figure 2a), such as described above, was prepared and weevil eggs were placed inside the tube with a small camel's hair brush. The eggs would stick to the glass sides with their own natural adhesion. Ten eggs were placed in each tube and arranged together in a double row so they could easily be observed under a dissecting microscope. This system had the advantage that the developing embryo could be observed directly through the glass test tube (Figure 2b).

Daily Field Activities

Four field sampling times within a 24 hour period were selected. One time was selected at the coldest hour of the day (0500 hours). Another was selected 12 hours later for the warmest part of the day (1700 hours). The other two times selected

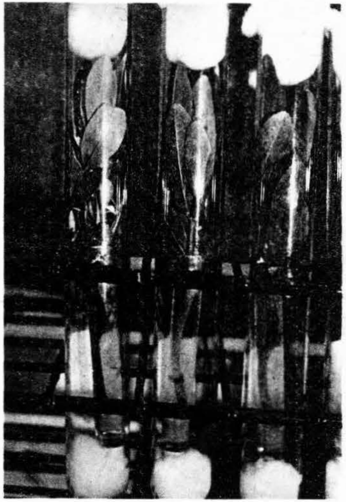

Figure 2a. Test tubes prepared for viability tests on weevil eggs.

Figure 2b. Developing larvae inside egg as viewed through test tube glass.

were at 1100 hours and 2300 hours with intermediate temperatures. Thus, every six hours through a 24 hour period, samples were taken.

All four fields were sampled at the hours mentioned above. A sample consisted of 25 sweeps of 180 degrees with a standard 15 inch diameter sweep net allowing the net to dip one half its diameter into the alfalfa. The samples were placed in labeled paper bags and stored at 4 C until they were counted.

Diapause and Seasonal History

General observations on seasonal history were made in the four study fields and in other areas of the Valley in connection with weevil control programs. Detailed observations were made on caged weevils in the field and on weevils subjected to artificial conditions in a growth chamber.

On 1 June 1966, the four study fields were sampled and 100 last instar larvae from each field were placed in the gallon jars used for observation cages and supplied with alfalfa stems for food. The four cages were placed in the weather box containing the hygrothermograph where they were reared to adults under approximate field conditions. The purpose of the experiment was to see if the weevils under field conditions avoided diapause and attained sexual maturity, and as a result, produced a second generation per year.

In the laboratory a growth chamber (Gro-Lab CEL-25-HL from Sherer Gillett Company) was maintained at 26.7 C and 20-40 per cent relative humidity until 7 January 1966, when a humidification system was attached and the relative humidity raised to 70 per cent. It was programmed for an eight hour day, using both incandescent and flourescent lighting. Weevil cultures were kept in this environment, and reared from eggs to adults in an attempt to shorten the period needed to attain sexual maturity as accomplished in the East (Huggans and Blickenstaff, 1964).

Respiration Experiments

Two respiration experiments were conducted, using a Gilson Differential Respirometer. A basic solution (NaOH or KOH) was placed in the center well of the Warburg flasks to absorb carbon dioxide as it was liberated by the respiring insects. In this manner, the amount of oxygen consumed could be detected and was considered to be a measure of metabolism and physical activity. Wire screen caps covered the center wells to prevent the four weevils placed in each flask from dropping into the basic solution. Each experiment was set up as a completely randomized design.

The first experiment, on 23 March 1966, was designed to see if there was any difference in the respiration rate between one group of weevils that had been given a cold treatment and another that had not. The weevils were taken from two cultures of adults that had been reared in darkness as a part of a parasitism study, but were not parasitized. The weevils in cage "D" were taken as newly emerged adults on 23 July 1965, and the weevils from cage "G" were taken also as newly emerged adults on 19 July 1965. As of 11 March 1965, neither group had shown any sign of sexual maturity, and on that day cage "D" was placed in the refrigerator at 4 C in darkness where they stayed until the day of the experiment. Cage "G" was left in the growth chamber.

Four weevils, two males and two females, were used as the experimental unit, and placed together in a Warburg flask. There were four replications of each of the two treatments. To absorb carbon dioxide, 0.1 ml of 15 per cent NaOH was placed in the center well of each Warburg flask. The water bath was set at 27 C. The lights and the shaker were not used. Readings were made every ten minutes for 90 minutes.

The second experiment, on 3 and 7 June 1966, was designed to test the effect of temperature, humidity, and light intensity on male and female alfalfa weevils. It was set up as a factorial experiment. The weevils were taken from the field on 1 June 1966, which was before any new generation adults had been observed in the field. Thus, they were all assumed to be overwintered adults.

Four weevils of a single sex were used as the experimental unit, and were placed together in a Warburg flask. To absorb the carbon dioxide, KOH solutions were used (Umbreit et al. 1964). Three different concentrations of KOH were used so that they could also regulate the humidity (Peterson, 1959). These solutions were prepared by using KOH in distilled water at the concentrations listed in Table 1. These are hereafter referred to as 20, 40, and 70 per cent humidities. The proper KOH solution was added to the center well of each flask in 0.3 ml units.

The experiment was run in four segments. For the first two, which were conducted on 3 June, the water bath was maintained at 27 C.

Table 1. Carbon dioxide absorbing and relative humidity controlling solutions (from Peterson, 1959)

Grams KOH per 100 ml.	Humidity Rating
110.0	21%
75.0	39%
37.5	69%

The first segment was in high light intensity with a 30-watt reflector light bulb burning under each flask. The second segment was in darkness. Darkness was obtained by placing two layers of black, rubber-impregnated cloth over and around the part of the respirometer containing the Warburg flasks. The instrument's lights were turned off.

The third and fourth segments were run on 7 June, at a temperature of 10 C. The third segment was in high light intensity, and the fourth segment was in darkness.

Each of the four segments was run for 90 minutes, with readings taken every ten minutes. Each half of the experiment was conducted at a single temperature with the 90-minute period of high light intensity followed ten minutes later by the 90-minute period of darkness. A new randomization and a new group of weevils were used for the 10 C half of the experiment. Both groups of weevils were from the same source and had been treated alike.

RESULTS

Flight Activities

Sticky-Board Traps. The sticky-board traps were checked beginning 6 July 1965, but no alfalfa weevils were found until 20 August when two lightly colored weevils were taken from traps 12 and 13 in the Gnehm field, and another one was found on a trap in the Christensen field. A week later (27 August) another alfalfa weevil was taken from Gnehm trap 13. Traps checked on 3 September showed no alfalfa weevils, but weevils of the genus *Sitona* were often found. Occasionally as many as five *Sitona* were found on one trap. On 11 October, one alfalfa weevil was taken from Gnehm trap 12.

Many problems were associated with the sticky-board traps. The greatest problem was the cluttering of the traps with flying insects, particularly Lepidoptera. Their large wings covered up the sticky material, making it unavailable for trapping other insects. Hunters also seemed to enjoy using the traps for target practice. Because of these problems and the general lack of success, the sticky-board traps were not used the following spring.

Gnehm traps 12 and 13 were located close to a triangle of alfalfa that was never cut. Because three of the four weevils taken from traps 12 and 13 were found on the side facing away from the main alfalfa field but facing the uncut alfalfa, it was assumed that these weevils probably came from that uncut alfalfa.

Rotating Net Trap. Sampling with the rotating net trap began 5 August 1965. On 20 August, the first alfalfa weevils were caught. The last weevil caught in 1965 was on 2 September. In the spring, the first weevil was caught 28 March 1966, and the last on 1 April. New generation adults were caught beginning 27 July 1966.

As indicated in Table 2, there were 16 weevils caught in the summer of 1965, eleven of which were females. One male and one female of that group were darkly colored and were captured on 1 and 2 September, respectively. Only one weevil was observed in flight. It alighted on the motor of the rotating net trap as it was being started at 1330 hours on 1 September.

As soon as the spring weather warmed up, the rotating net trap was set up and on 28 March, one weevil was caught. Also on that day one adult female alfalfa weevil was observed to have alighted on a white sheet hung on a clothes line. It was several blocks from the nearest alfalfa field, although some volunteer alfalfa was found growing within the block. The only other weevil captured in flight during the spring was taken on 1 April. All three of these weevils were females.

Sampling with the rotating net trap continued into the summer. On 24 July 1966, the second crop alfalfa hay was cut on Thurston field 1. It was raked early in the morning on 27 July. Three weevils were caught that day, two females and one male. The following day two weevils were caught, a male and a female. No more samples were taken after 28 July 1966.

Table 2. Alfalfa weevils caught with the rotating net trap at Hyde Park, Utah

Date	Field	Time of catch		Temperature	% Relative	Number caught	
		After	Before	C	humidity	Male	Female
1965							
20 Aug.	Gnehm	1430	1530	25.6	40	0	2
24 Aug.	Gnehm	1330	1430	25.6	36	0	1
24 Aug.	Gnehm	1430	1630	24.4	38	0	2
24 Aug.	Gnehm	1630	1700	23.3	42	1	0
25 Aug.	Gnehm	1300	1400	24.4	35	0	1
26 Aug.	Gnehm	1230	1400	23.3	36	2	1
26 Aug.	Gnehm	1400	1600	22.2	45	1	2
1 Sept.	Gnehm[a]		1330	23.3	36	(1)	
1 Sept.	Gnehm	1500	1600	23.3	40	1	1
2 Sept.	Gnehm	1230	1600?	24.4	40	0	1
1966							
28 March	[b]		1500	21.1	20	0	1
28 March	Thurston 1	1530	1630	20.0	20	0	1
1 April	Thurston 1	1500	1630	21.1	24	0	1
27 July	Thurston 1	1630	1830	33.3	26	1	1
27 July	Thurston 1	1830	2030	26.7	34	0	1
28 July	Thurston 1	1400	1700	36.1	12	1	1

[a]Saw it alight, but did not catch it.

[b]Saw it alight on a sheet.

Wind Velocity. No accurate measurements of wind velocity were possible during the 1965 flight study. Weevils were not observed to fly when winds reached an estimated 15-20 miles per hour. During the spring of 1966, an anemometer was used. On 28 March, when the first weevil was caught in flight, the wind velocity ranged from zero to ten miles per hour, with an average of about 4 miles per hour. On 1 April, when another weevil was caught, the wind velocity seldom got higher than 7 to 8 miles per hour. No weevils were caught on 4 April when the wind was blowing briskly, sometimes at more than 15 miles per hour, with an average of 9-10 miles per hour. On 8 April the wind velocity stayed at 0-5 miles per hour, but no weevils were caught flying; nor, were any caught thereafter regardless of climatic conditions until 27 July when the wind velocity stayed below 5 miles per hour.

Temperature. During the summer of 1965, the weevils were caught in the rotating net trap at temperatures ranging from 22.2 to 25.6 C (Table 2), with an average of 24.0 C. In the spring of 1966, weevils were caught at 20.0 and 21.1 C. In July of 1966, the temperature range was between 26.7 and 36.1 C with most of the weevils being caught when the temperature was above 33 C. In all cases, these temperatures were the peak temperatures for the day, or at least closely following the peak for that day.

Humidity. Alfalfa weevils caught in the rotating net trap during the summer of 1965 were taken when the relative humidity was between 35 and 45 per cent. In the spring, the weevils were caught at 20 and 24 per cent relative humidity. In July of 1966, the relative humidity at the time of capture ranged from 12 to 34 per cent (Table 2).

Time of Day for Flight. Because the rotating net trap was allowed to run for an hour or more at a time before checking for alfalfa weevils, it was impossible to pinpoint the exact time a weevil was caught. The beginning and end of a run was recorded (Table 2), which gave the period of time in which the weevil was captured, rather than the specific time. During the summer of 1965, most weevils were caught between 1400 and 1530 hours. In the spring of 1966, the weevils were taken between 1500 and 1630 hours. During July of 1966, the average time of capture was 1620 to 1820 hours. The two direct observations on flying weevils occurred at 1330 hours in the summer and 1500 hours in the spring. All of these times were near the peak temperature for the day. It seemed that the time of flight was at least partially dependent on the temperature.

Advantages and Disadvantages of Equipment. The advantages of the sticky-board traps over the rotating net trap proved to be the little maintenance required and their constant presence in the fields. Their disadvantages were the way they could be cluttered with flying insects other than alfalfa weevils and the small sizes of the sticky area. A sticky surface over a greater area would probably have been better as a sampling tool.

The advantages of the rotating net trap were its efficient methods of capturing weevils in flight and its ease in correlation with the time of day that weevils were caught. The disadvantages were that it could not be replicated or put in more than one field at the same time, and that it had occasional mechanical failures. Two or more of the machines would have been necessary to make flight comparisons between the different fields.

Reproduction

Gross Observations. Adult alfalfa weevils emerging from their overwintering sites in the spring were observed to be capable of egg laying. No attempt to find eggs laid in duff or litter was made, but eggs were easily found in punctures made in the stems of growing alfalfa. The greatest number of eggs was found in first crop alfalfa. Pairs of alfalfa weevils were observed to copulate on alfalfa stems in the field.

In the laboratory, overwintering alfalfa weevil adults which had been collected from the field on 17 May 1966, were observed in a gallon jar. As soon as they were placed together in the jar, several pairs began to copulate. Of the 125 weevils in the jar, 14 pairs were observed in copulation at one time. Several minutes after copulation commenced, some females began to lay eggs on the sides of the glass. The bulk of the eggs was laid on the first day of captivity. These adults fed readily upon alfalfa offered to them. After 6 days about 25 per cent were dead.

On 22 July 1965, 33 adults which had been held in the refrigerator at 4 C were placed in a flask without alfalfa. Immediately, some began to copulate. A few hours later 46 eggs were found in the bottom of the flask. In this way fresh eggs were obtained for rearing.

On 28 July, a group of adult weevils was placed in a jar, but they were less active in finding mates for copulation than in previous trials. Some of the females began laying eggs, but they were laid less frequently than before. When alfalfa was placed in the jar with them, they began to feed and almost immediately copulation and egg laying increased. Eggs were laid on the jar floor and on the alfalfa stems. No egg laying in punctures inside the stems was noted. The addition of alfalfa was noted to increase copulation in several trials.

Weevil adults collected in connection with past control studies were often observed mating. The question arose as to whether or not our treatment of the weevils during the counting process influenced their mating habits. It was our practice to refrigerate the weevils to slow down their activities and to anesthetize them with carbon dioxide. An experiment was carried out in which five groups of weevils were observed: (1) left out-of-doors, (2) brought indoors, (3) given a cold treatment, (4) given a carbon dioxide treatment, and (5) given both a cold and a carbon dioxide treatment. The responses of these non-replicated groups are recorded in Table 3. Carbon dioxide treatments seemed to stimulate egg laying.

Mating Tests. Individual weevils were observed to determine whether or not the female alfalfa weevil mated more than once. Of twenty pairs (Series C and D), eleven of the females were

Table 3. Eggs laid by weevils subjected to different treatments

Treatment	No. of weevils	No. of eggs	No. of eggs per weevil
Out-of-doors	151	149	.987
Indoors	146	122	.836
Cold[a]	158	124	.785
CO_2	87	139	1.598
CO_2 + Cold	63	78	1.238

[a]4 C for one hour

observed to mate a second time, six mated a third time and three mated a fourth time (Table 4). Some of these repeated matings took place on the same day while others were as much as nine days apart. Series C differed from series D in that the weevils were confined in the tubes for the first seven days of observation without a cotton wad at the tube bottom to absorb humidity. Females lived from 5 days to about three months under observation. Only one of the twenty females failed to lay any eggs after the initial copulation. Eggs were laid on the glass of the test tubes and water vials and on the alfalfa stems, but no eggs were noted inside the stems. Egg production from ten of the females (Series D) was recorded. While under observation, from 1 to 28 eggs were laid with a mean of 11.5 eggs per female.

In another group of twenty pairs of weevils (Series E and F), the males were allowed to remain with the females for five days,

Table 4. Copulation frequency, egg production, and life span of weevil pairs while under observation

Series C	No. of times copulation occurred	No. of eggs produced	Life span, days Female	Male
1	1	a	47	13
2	1	a	6	31
3	1	a	11	21
4	1	a	14	14
5	4	a	24	74
6	1	a	21	96
7	1	a	10	6
8	1	a	5	14
9	1		49	6
10	3	a	21	46
Mean	1.5		20.8	32.1
Series D				
1	2	4	13	13
2	3	1	33	22
3	4	8	16	13
4	2	28	27	29
5	2	18	19	16
6	4	23	91	57
7	3	1	15	13
8	2	12	16	16
9	1	11	9	91+
10	2	9	19	22
Mean	2.5	11.5	25.8	29.2

[a]Produced eggs, but number not recorded

Table 5. Alfalfa weevil egg production comparing yields with males absent and present

Series E[a]	Number of eggs laid: First 5 days	Number of eggs laid: Remaining 22 days	Total	Percent of total eggs laid after 1st 5 days
1	6	5	11	45.5
2	0	0	0	--
3	0	0	0	--
4	2	2	4	50.0
5	5	0	5	00.0
6	9	0	9	100.0
7	7	2	9	22.2
8	9	6	15	40.0
9	0	1	1	100.0
10	23	1	24	4.2
Total	61	17	78	21.8
Series F[b]				
1	2	2	4	50.0
2	13	3	16	18.8
3	0	0	0	--
4	0	1	1	100.0
5	0	0	0	--
6	0	0	0	--
7	0	0	0	--
8	0	0	0	--
9	0	1	1	100.0
10	3	0	3	00.0
Total	18	7	25	28.0

[a]Males removed after first five days

[b]Males present for entire period

after which the males were removed from Series E. In the following 22 days, the ten pairs which were allowed to remain together (Series F) produced 28.0 per cent of their total eggs. The ten females (Series E) that had been separated from their mates produced 21.8 per cent of their total eggs after the separation (Table 5), indicating no increased egg production due to the continued presence of males.

Egg Viability Tests. A check was made on the viability of eggs laid by adults which had received the five different treatments of temperature and carbon dioxide. The results after 14 days of incubation are recorded in Table 6.

Table 6. Tests on the viability of alfalfa weevil eggs laid by weevils subjected to various treatments

Treatment to adults	Number hatching				Total	Per cent hatch
	Rep.1	Rep.2	Rep.3	Rep.4		
Out-of-doors	3	1	0	2	6	15.0
Indoors	2	5	6	4	17	42.5
Cold[a]	6	3	3	6	18	45.0
CO_2	3	1	1	4	9	22.5
CO_2 + Cold	2	3	1	3	9	22.5

[a]4 C for 1 hour

A viability check was made of eggs laid by two groups of weevils that had undergone diapause. One had received a 12 day cold treatment at 4 C (Cage D) and the other (Cage J+F) had received no such treatment. The test showed no significant difference in the per cent of hatch between the two groups (Table 7).

Table 7. Alfalfa weevil eggs hatching following a 12 day cold treatment of 4 C

Treatment	Number hatching				Total	Per cent hatch
	Rep. 1	Rep. 2	Rep. 3	Rep. 4		
Cold (D)	5	6	9	6	26	65.0
Check (J+F)	5	4	7	9	25	62.5

Daily Field Activities

Variations were noted in the number of adult alfalfa weevils collected in 25-sweep samples taken at different times of the day. On 9 August 1965, samples were taken every six hours. Adults were segregated into light-colored and dark-colored groups (Figure 3). Pubescence of the darker ones was not considered. At 1100 hours, the light-colored adults accounted for only 3.7 per cent of the adult population on the stems; at 2300 hours, when it was dark, they accounted for 61.2 per cent (Figure 4). There were 75 times more light-colored adults on the alfalfa stems at 2300 hours than there were at 1100 hours, while the increase in the dark-colored adult population on the stems for the same times was only 1.8 times.

A similar test was repeated on 24 August 1965, (Figure 5) with the same apparent trend. The light-colored adults accounted for only 9.5 per cent of the population on the stems at 1100

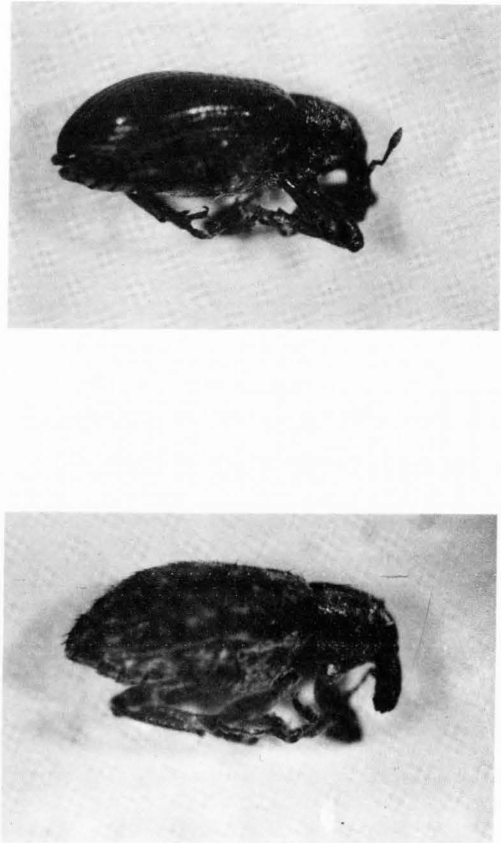

Figure 3. Alfalfa weevil adults, top: dark-colored (overwintered), bottom: light-colored (new generation).

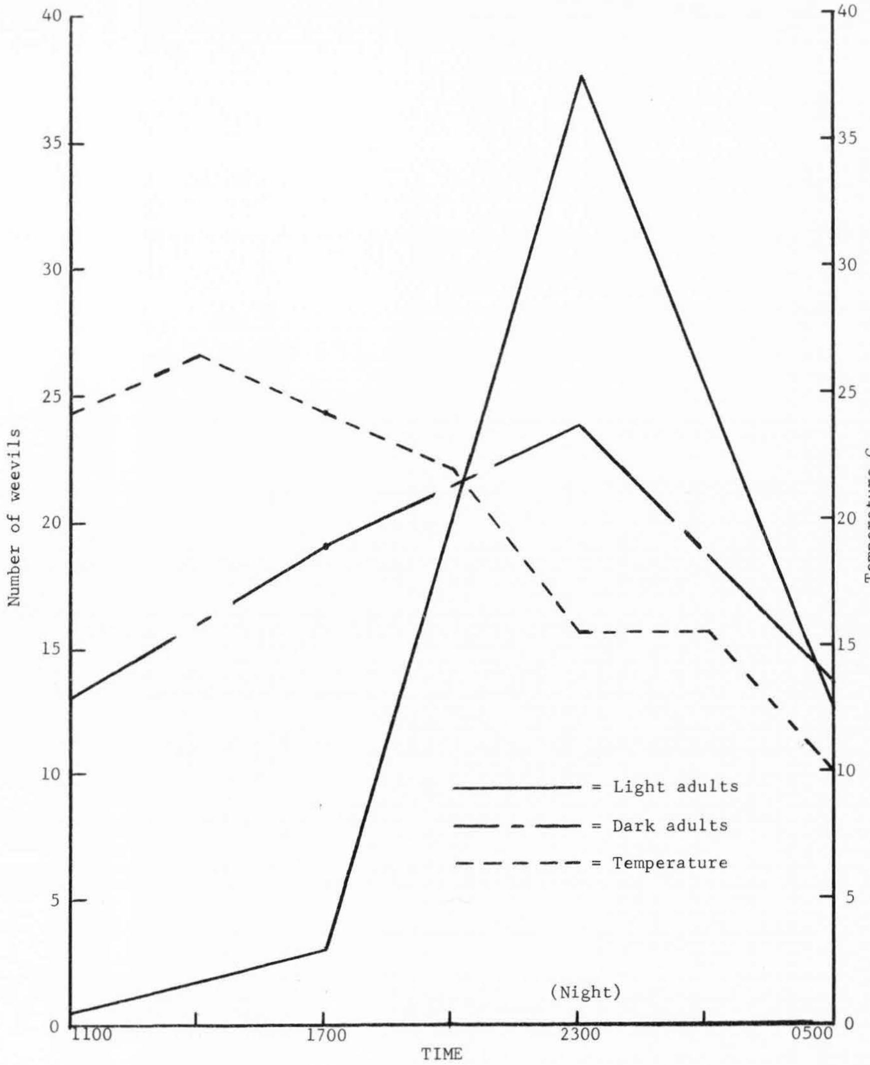

Figure 4. Comparative adult alfalfa weevil populations on alfalfa stems associated with time of day, 9 August 1965 (Means of four 25-sweep samples)

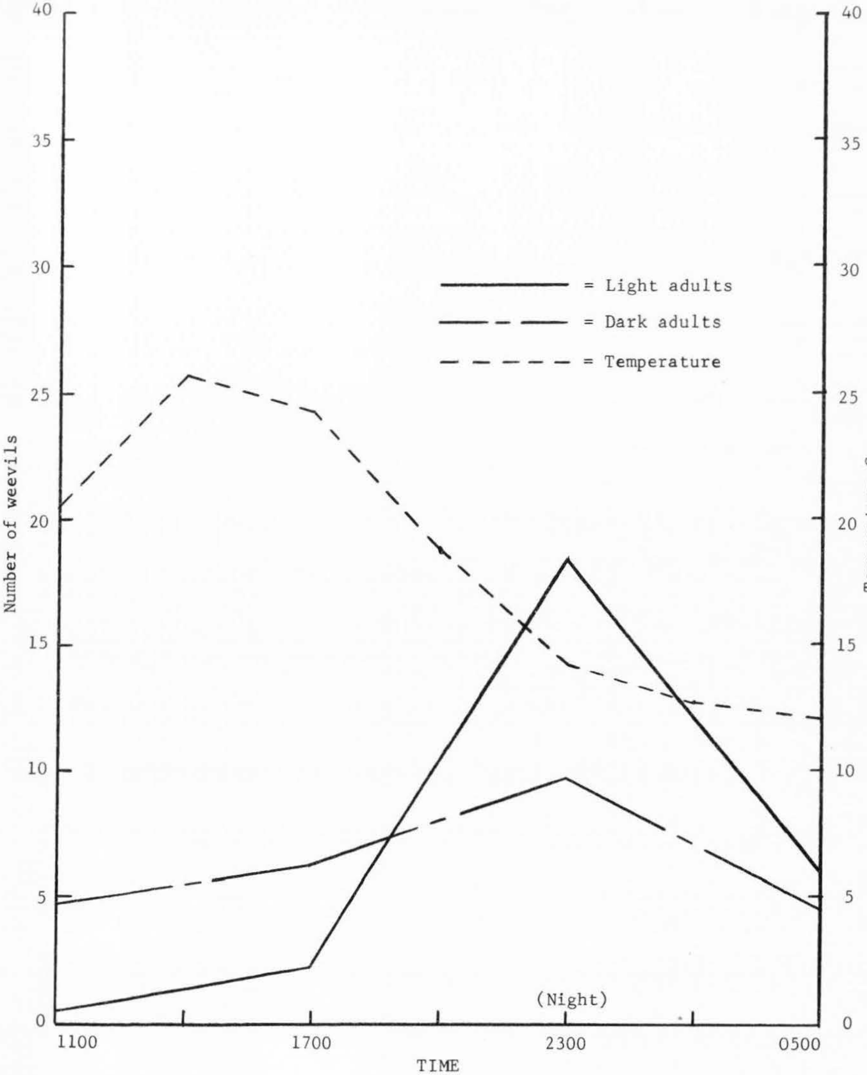

Figure 5. Comparative adult alfalfa weevil population fluctuation on alfalfa stems associated with time of day, 24 August 1965 (Means of four 25-sweep samples)

hours while at 2300 hours, when it was dark, they accounted for 72.5 per cent of the population. There were 37 times more light-colored adults on the alfalfa stems at 2300 hours than there were at 1100 hours, while the dark-colored adult population increased only 2.1 times.

Temperatures were recorded for the periods of sampling but no relationship between temperature and population fluctuation was apparent. The main factor affecting the population seemed to be light intensity, and the light-colored adults were much more affected than were the dark-colored adults. Light-colored adults were considered to be new generation adults and dark-colored adults to be overwintered adults.

Early in the growing season, 1 June 1966, the same procedure was followed. Only overwintered adult alfalfa weevils were present in the fields at that time. The results were quite different, as shown in Figure 6. The adult population on the alfalfa stems was 3.3 times as great at 1700 hours as it was at 0500 hours. The stem population fluctuation seemed to bear a close relationship to temperature, while the period of darkness seemed to have no effect.

Diapause and Seasonal History

General Observations. As soon as the weather became warm enough in the spring, the overwintering adult alfalfa weevils became active. On 28 March 1966, adults were observed on alfalfa stubble, walking up and down dead stems. The temperature that day

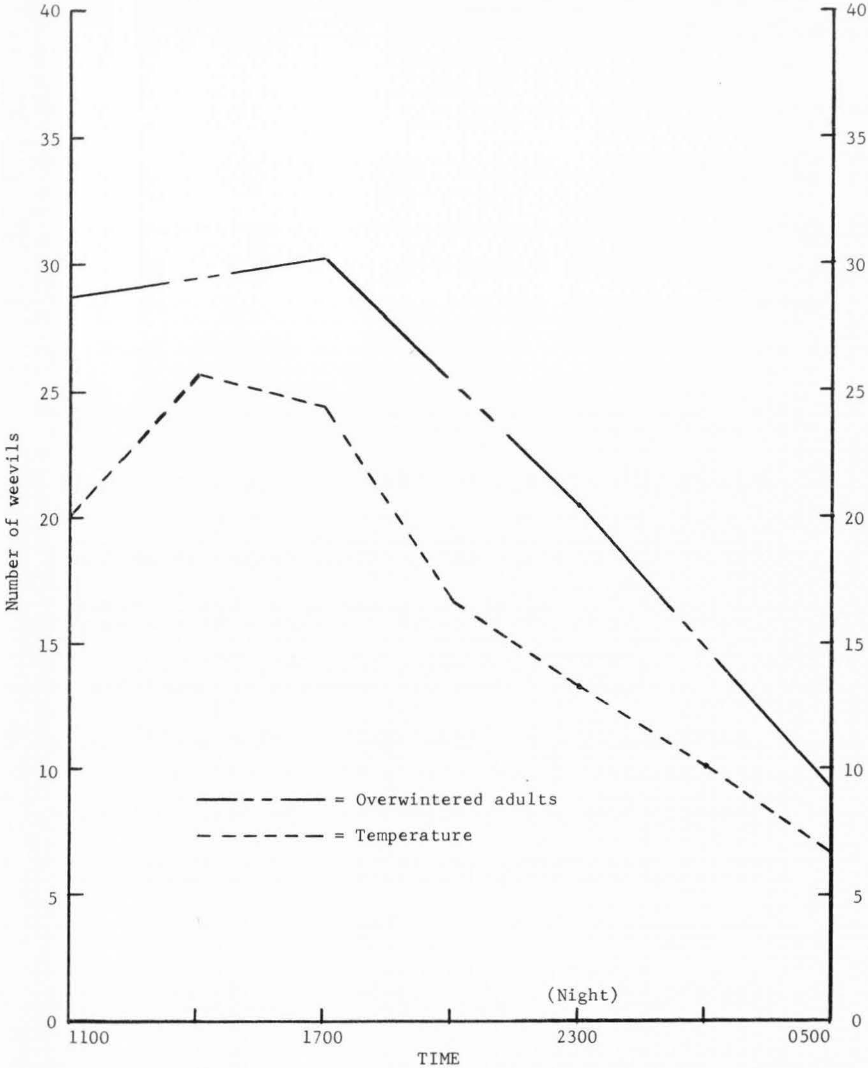

Figure 6. Adult alfalfa weevil population fluctuation on alfalfa stems associated with time of day, 1 June 1966 (Means of four 25-sweep samples)

reached 21 C and dropped to 0 C that night. There had been a consistent rise in daytime temperature peaks from 4 C for seven days.

The overwintered weevils were still quite light in color early in the spring, but gradually darkened as the season progressed. They were easily collected after the alfalfa was high enough to sweep with a net. Alfalfa weevil larvae began to appear early in May, but no new generation adults were observed until after most first-crop hay was cut.

The stage of development for the new generation at the time of first-crop hay cutting was indicated when a farmer in Richmond, Utah, used a swather to cut his hay. The alfalfa along with the weevils was thrown into a narrow windrow. The hay dried for about three days in these windrows, then was baled and removed. After the alfalfa began to grow back, it was very evident where the windrow had been. The alfalfa in the windrow strip had not begun to leaf out, while the alfalfa where the cut hay had not fallen had grown as high as 6 and 10 inches. The striking difference suggested that more was involved than three days shading from the sun. An examination of the dry hay leaf litter left in the windrow strip was made, and the findings from about two pounds of litter are recorded in Table 8. Emerged adults, empty cocoons and adults in cocoons were considered to indicate the number that survived the cutting. Those that did not survive far outnumbered those that survived. Although the windrow stip had a slower start, no difference in height of the alfalfa was

Table 8. Alfalfa weevils found in two pounds of dry hay leaves from windrow sites

Weevil evidence	Number
Emerged adults	3
Empty cocoons	40
Adults in cocoons	14
Pupae (most dead)	68
Dead larvae in cocoons	44
Bathyplectes curculionis cocoons	19

observed at the time of second crop cutting. The windrow strip could still be discerned because its alfalfa was in the prebud stage, while that where cut hay had not fallen had reached the full-bloom stage.

New generation adults were more numerous than were the over-wintered adults at the time the second crop was cut. The new adults began to leave the field toward the end of the second crop, but were found in third-crop hay in low numbers. For example, on 22 September 1965, sixteen light-colored adults, no dark-colored adults, and four larvae were found in 200 sweeps.

On 9 September 1965, two samples of the litter and soil from alfalfa stem bases were placed in Berlese funnels but no alfalfa weevils were found. On 22 September, two litter samples were taken -- one from the uncut alfalfa triangle and one from under a grove of maple trees bordering the Gnehm field. One female was taken from the alfalfa litter and one male and one female were taken from the maple leaf litter.

On 17 March 1966, about two feet of snow covered the Gnehm field and the surrounding country side. On that day, two bags of litter were collected from under the snow within the same maple grove sampled the previous fall. One male and one female adult were obtained from the samples. They became active soon after being brought into the warm laboratory.

Dr. G. F. Knowlton obtained eight alfalfa weevils on 25 March 1966, from juniper duff collected along the east windbreak edge of the Utah State University campus in Logan. Six of these were examined, three were males and three females. Later, on 8 April, this same juniper windbreak was sampled again but no alfalfa weevils were found, suggesting that they may have moved out during the preceding warm weather.

Field Cages. Most of the weevils from each field cage that successfully reached the adult stage did so about the end of June. A count was made on 5 July, and the results are shown in Table 9.

Table 9. Adult alfalfa weevils and parasites obtained from rearing larvae in the field

Field	Adult weevils	Parasites (Bathyplectes)
Christensen	16	17
Thurston 1	35	31
Thurston 2	16	24
Gnehm	24	26

The disparity between the numbers shown in the table and the starting number was attributed to larval death. After the count, the weevil adults were replaced in the field. No evidence of sexual maturity was observed by 5 August 1966, when these weevils were placed in the growth chamber.

Growth Chamber Colonies. Alfalfa weevil adults that were reared from larvae to adults in darkness as a part of a separate parasitism study were placed in the growth chamber for observation in July 1965. These were weevils which had escaped parasitism, not parasitized weevils. Additional weevil adults placed in the growth chamber were from larvae reared under natural light conditions and from field collections (Table 10). They all fed on alfalfa placed with them for food. By 6 November 1965, the weevils were observed to be inactive, feeding very little, and spending most of their time hiding under and within a crumpled piece of tissue paper placed in each cage. This continued until 7 January 1966, when a humidifying system was attached and the relative humidity was raised to 70 per cent. The weevils then became much more active than they had been for months. Many more individuals were observed to be active on the alfalfa stems during the period of dark than during the period of light.

This activity continued, but by 11 March 1966 no copulation or egg laying had been observed. On that date, one cage of weevils (Cage D) was placed in the refrigerator at 4 C and left there until 23 March, when they were returned to the growth chamber. On 26 March, one pair that had received the cold treatment was

Table 10. Record of eggs produced at the end of diapause for growth chamber colonies by alfalfa weevils from different sources

Cage	Source of adult weevils	Date adults were obtained	#[a]	Date and number of eggs produced: 30 Mar	4 Apr	9 Apr	12 Apr	20 Apr	25 Apr	29 Apr	4 May	27 May	Total eggs produced	Months of adulthood before egg laying
A	Reared from eggs in lab.	27 Aug 65	11	0	0	0	0	0	0	0	0	0	0	----
B	Reared from eggs in lab.	30 Sept 65	7	0	0	0	0	0	0	0	0	0	0	----
C	Field Collected	14 Sept 65	33	9	0	0	0[b]	0	0	8	0	0	17	6.5
D	Reared in Darkness[c]	23 July 65	36	0	0	0	0	0	0	0	0	0	0	----
D'	Reared in Darkness[c]	23 July 65	2	44	24	31	6	7	0	Dead	---	---	112	8.2
E	Reared in Darkness[c]	12 July 65	31	0	0	0	0[b]	0	0	0	0	0[b]	0	----
G	Reared in Darkness[c]	19 July 65	32	0	0	0	0	0	0	0	0	8	8	10.2

Table 10. Continued

Cage	Source of adult weevils	Date adults were obtained	#[a]	Date and number of eggs produced: 30 Mar	4 Apr	9 Apr	12 Apr	20 Apr	25 Apr	29 Apr	4 May	27 May	Total eggs produced	Months of adulthood before egg laying
J+F	Field Collected	19+26 July 65	55	50	70	17	0	0	0	0	0	0	137	8.2
I+H	Field Collected	24+30 June 65	32	1	0	0	0	0	0	0	0	0	1	9.2
W	Captured in Flight	28 March 66	4	0	4	22	69[b]	30	45	1	0	0	171	?

[a]Number of adults as of 8 January 1966 except for Cage W

[b]Pair found in copulation

[c]Reared in darkness as part of a parasitism study

observed to copulate and was placed in a separate cage (D'). The stimulus to induce copulation might have been the cold treatment. On 30 March, eggs were obtained from that pair. The other cages were also checked and three other cages contained eggs (Table 10). These eggs were, for the most part, laid inside punctures in the alfalfa stems. Any effect that the cold treatment may have had was confounded by the start of egg laying by the other groups of caged weevils. Those that laid eggs did so after they had been adults at least 6.5 to 10.2 months with a mean of 8.5 months.

Of the adults obtained from eggs reared under an eight hour day length, two groups (Cages A and B) never copulated or laid eggs. Three other groups, started from eggs in the spring of 1966, were observed until early in August of 1966, or three to four months. No evidence of sexual maturity had been observed by that time. The eight hour daylight schedule was maintained throughout the entire larval development of each of these groups.

Respiration Experiments

Results of the first respiration experiment are given in Table 11. The amount of oxygen consumed by the four weevils in each replication is expressed in microliters per 90 minutes.

The weevils receiving the cold treatment consumed 1.57 times as much oxygen in 90 minutes as did the weevils receiving no cold treatment. An analysis of variance (Table 12) showed significance at the five per cent level. The increased oxygen

Table 11. Results of first respiration experiment comparing adult alfalfa weevils with and without a cold treatment

Treatment	Microliters of oxygen consumed per 90 minutes			
	Rep 1	Rep 2	Rep 3	Rep 4
Cold Treatment (D)	48.7	59.8	50.6	41.4
Check (G)	25.3	29.3	24.2	49.1

Table 12. Analysis of variance of first respiration experiment with adult alfalfa weevils

Source of variation	Degrees of freedom	Sum of squares	Mean square	F
Treatments	1	658.85	658.85	6.85*
Error	6	577.41	96.24	
Total	7	1,236.26		

* Significant at 5 per cent level

consumption may have been due to increased physical development or perhaps just due to increased activity.

The results of the second respiration experiment are expressed in Table 13. The amount of oxygen consumed by the weevils in each replication is expressed in microliters per 90 minutes.

The mean amounts of oxygen consumed in 90 minutes for each factor observed are recorded in Table 14.

Statistical significance was attained from temperature and sex at the one per cent level (Table 15). The weevils at 27 C consumed 3.4 times as much oxygen in 90 minutes as did the weevils at 10 C. Female weevils consumed 1.3 times as much oxygen as did the male weevils in the same amount of time. Differences between light intensities and between relative humidities showed no statistical evidence of having occurred by any reason other than chance.

Table 13. Results of second respiration experiment using varied temperatures and relative humidities with adult alfalfa weevils

Treatment				Microliters of oxygen consumed/90 minutes		
Temp.	Light	Relative humidity (%)	Sex	Rep 1	Rep 2	Rep 3
27 C	HLI[a]	20	Female	159.5	57.1	74.9
		20	Male	93.7	62.4	54.8
		40	Female	73.6	99.9	68.9
		40	Male	51.4	63.7	61.7
		70	Female	97.5	73.9	78.1
		70	Male	62.5	64.2	77.7
27 C	Dark	20	Female	80.9	49.4	27.8
		20	Male	58.9	70.8	59.1
		40	Female	67.7	46.8	78.4
		40	Male	47.7	62.7	58.3
		70	Female	108.2	99.6	81.8
		70	Male	63.5	68.2	88.8
10 C	HLI[a]	20	Female	28.1	18.9	25.9
		20	Male	20.9	17.1	18.2
		40	Female	34.8	10.9	37.5
		40	Male	14.0	19.3	20.2
		70	Female	29.3	42.2	18.5
		70	Male	25.3	18.2	12.1
10 C	Dark	20	Female	19.2	12.5	10.7
		20	Male	12.2	13.4	10.0
		40	Female	20.8	22.1	10.2
		40	Male	33.7	12.6	9.0
		70	Female	19.3	24.4	82.7
		70	Male	17.0	15.0	6.6

[a]High light intensity

Table 14. Means for each factor observed in second respiration experiment

Factor observed	Mean
27 C	72.23
10 C	21.19
High Light Intensity	49.63
Dark	43.79
20% Relative Humidity	44.02
40% Relative Humidity	43.00
70% Relative Humidity	53.11
Female	52.73
Male	40.69

Table 15. Analysis of variance of second respiration experiment with adult alfalfa weevils

Source of variation	Degrees of freedom	Sum of squares	Mean square	F
Temperature (A)	1	4,689.53	4,689.53	154.99**
Light (B)	1	615.42	615.42	2.03
Humidity (C)	2	1,486.22	743.11	2.46
Sex (D)	1	2,607.62	2,607.62	8.62**
AB	1	113.75	113.75	.38
AC	2	314.14	157.07	.52
AD	1	104.88	104.88	.35
BC	2	1,664.55	832.27	2.75
BD	1	170.20	170.20	.56
CD	2	580.91	290.45	.96
ABC	2	418.66	209.33	.69
ABD	1	249.02	249.02	.82
ACD	2	122.33	61.17	.20
BCD	2	877.96	438.98	1.45
ABCD	2	215.81	107.91	.36
Error	48	14,522.91	302.56	
Total	71	70,958.92		

** Significant at 1 per cent level

DISCUSSION

Flight Activities

Evidence of a spring flight of the alfalfa weevil was found in Cache Valley during 1966. This flight was assumed to be the return of the alfalfa weevils from their places of overwintering to the fields. This flight is assumed to correspond to the spring flight recorded by Titus (1910b) and Parks (1913) for Utah and by Poinar and Gyrisco (1962) for New York.

A late summer flight was found to occur at, or shortly after, the time the second-crop alfalfa hay was being cut. In August of 1965, alfalfa weevils were captured in flight just prior to, during, and after the Gnehm field was cut for second-crop hay. In July of 1966, weevils were captured in flight just after the cutting of second-crop hay on the Thurston field 1. The Gnehm field, being a dry-land alfalfa field and 1100 feet in elevation higher than the irrigated Thurston field 1, was always harvested later than the Thurston field. This also could account for the later flight of the weevils.

This flight seems to correspond to the summer flights described by Titus (1910b) and Parks (1913) even though it was observed to take place later than the flights they observed, which began in June. Their observations were made in the Salt Lake Valley which has earlier growing seasons and hotter summers than does Cache Valley. Also, they described the adult weevil populations as much heavier than those observed in Cache Valley. Perhaps the earlier growing season, an overcrowding effect of large populations, and hot dry alfalfa fields could account for the recorded flights which began earlier than those observed in Cache Valley.

In the eastern United States, however, the summer flight, as reported by Prokopy and Gyrisco (1965), takes place prior to and during the cutting of first crop hay. The flight follows the maturation of the weevils very closely. This could be an advantage for the weevils, as most of the population would be able to attain adulthood and leave the field before the alfalfa was cut. Cutting of alfalfa hay greatly reduces the weevil population in the fields according to several authors.

The summer flight was considered to be the flight of the weevils from the alfalfa fields to the places where they would overwinter, such as the litter under a maple grove bordering the field. It did not appear to be a pre-aestivation flight as noted in eastern United States. No fall flight of weevils returning to the fields was observed and it is believed that none exists under Cache Valley conditions.

Prokopy and Gyrisco (1963) suggested that the fall flight in New York was coincident with the return of the alfalfa weevil adults to the alfalfa fields. The spring flight in New York completes the migration of the new generation adults to the alfalfa fields (Poinar and Gyrisco, 1962). In Virginia, (Pamanes and Pienkowski, 1965); Maryland (Manglitz, 1958); and North

Carolina (Campbell et al., 1961) the main migration of the alfalfa weevils to the alfalfa fields is in the fall. In Cache Valley, this return appears to be only in the spring. These variations in the alfalfa weevil flight habits are not considered to be contradictions, but simply the response of the alfalfa weevils to the climatic conditions of the area in which they live.

For the climatic conditions of Cache Valley, the alfalfa weevil is considered to have two flight periods. One is in the spring when the overwintered alfalfa weevils return to the alfalfa fields. The other is in the summer, mostly in August, when new generation alfalfa weevils leave the fields for the cover of overwintering sites.

Reproduction

Overwintered alfalfa weevils are apparently capable of egg-laying as soon as or shortly after they emerge from their overwintering sites. Copulation probably continues throughout spring and summer. Under Cache Valley conditions, the bulk of the eggs are laid in the spring and early summer during first crop, while under conditions in Tennessee, (Bennett and Thomas, 1964) and North Carolina (Campbell et al., 1961) the peak egg laying occurs in the late fall and early winter.

This apparent discrepancy in time of egg laying is probably due to the fact that the alfalfa weevil does not have a true hibernation. It becomes active at any time during the winter when temperatures are mild enough. During these warmer periods they mate, feed and lay eggs. These warmer periods which result in weevil activity are common in southeastern United States, but rare in Cache Valley, Utah.

Laboratory observations indicated that copulation stimulated egg laying. Feeding increased copulation and egg laying. Crowded conditions in cages and high humidity may have caused the egg laying on the glass sides of cages rather than within the alfalfa stems as is normal in the fields.

One experiment suggested that a carbon dioxide gas treatment of adults increased egg laying while a cold treatment may have slowed egg laying. The experiment was not replicated so no estimate of the variance was possible. Only half as many eggs hatched from the carbon dioxide treatment as compared with the cold treatment.

Mating tests showed that female alfalfa weevils mate more than once, but there was no evidence that repeated matings were necessary to produce a full complement of eggs. There was no assurance that the field collected females used in the mating tests were mating for the first time when the test was started. This must have introduced much variation among pairs. Eggs produced by these pairs cannot be considered as the total production.

Daily Field Activities

Findings in Cache Valley agreed with those reported from Utah by Titus (1910a), from California by Essig and Michelbacher (1933) and from New York by Poinar and Gyrisco (1960) that during the summer the alfalfa weevil is more active at night than during the day. Results of experiments conducted during the summer were in harmony with Poinar and Gyrisco (1960) suggesting that this daily behavior was related to light intensity rather than to temperature.

Both overwintered (dark-colored) and new generation (light-colored) adult alfalfa weevils were found to be most active at night during the summer, but the new generation adults seemed to be much more affected by light intensity than were the overwintered adults. Although Poinar and Gyrisco (1960) reported no attempt to distinguish between overwintered and new generation adults, their results must have been strongly influenced by the new generation adults because they state that their experiments were conducted in late June when the adult population was at its peak.

Early in the growing season, when only overwintered adults were present in the fields the above mentioned daily behavior associated with light intensity was not found. In the spring, temperature seemed to be the major influencing factor. Perhaps this temperature dependence early in the season was related to the effects of temperature in reactivating the weevil during the spring thaw.

Diapause and Seasonal History

In the eastern United States, the aestivation (summer diapause) of the alfalfa weevil has been observed and described, (Manglitz, 1958; Guerra and Bishop, 1962; Tombes, 1964; Bennett and Thomas, 1964; and Tombes, 1966). The weevils apparently leave the field in the summer to aestivate and then return in the fall after aestivation. No such phenomenon was observed in Cache Valley. The new generation adults remained in the alfalfa fields until late in the season, well after they reached maturity. Their departure from the fields by flight, and possibly crawling, appeared to be as an aid in seeking winter shelter. Their presence on the alfalfa foliage along with some plant injury throughout the season indicated they were feeding. These adults also fed under laboratory conditions. Observations made in Cache Valley did not indicate aestivation of the alfalfa weevils.

The high percentage of dead immature weevils in the dry alfalfa litter left in the field by first-crop hay cutting indicated that the majority of the new generation alfalfa weevils had not developed sufficiently at that time to attain maturity without further feeding. A big reduction in the alfalfa weevil population resulted from first crop cutting. Larvae with sufficient development to attain adulthood and larvae that found additional forage in time to complete development after the first-crop hay was cut, accounted for most of the new generation adult population. Damage to the second crop occurred from larval and adult feeding on the new alfalfa growth.

Although aestivation was not found in the field, a diapause-like condition was observed in the growth chamber colonies. Even though these colonies were maintained at 27 C during the fall and winter, compared to weevils in the field which were subjected to subfreezing temperatures, the onset of egg laying occurred on almost the same date. This indicated that there could be some intrinsic control within the weevils.

The length of time required by adult alfalfa weevils in Cache Valley to attain sexual maturity seemed to be longer than that recorded in the eastern United States. Rearing larvae under conditions of an eight hour day showed no evidence of hastening sexual maturity or of breaking adult diapause. No success was obtained in rearing multiple generation weevils as reported by several workers with eastern weevils.

Respiration Experiments

The increased oxygen consumption of alfalfa weevils following a cold treatment indicated an increased metabolism and perhaps rapid sexual maturation. This was not substantiated as egg laying seemed to commence at the same time in many of the colonies regardless of cold treatment. However, when one compares the 8.2 months of adulthood required by the cold treatment group (D) before the beginning of egg laying, with the 10.2 months required by the check (G), the inference is that the cold treatment hastened sexual maturity. But only one female from each group laid eggs at these intervals so the biological significance remains questionable.

It is not known whether the increased respiration was due to an increased rate of physical development or simply to a temporary increase in activity after the weevils had been kept in the cold.

The respiration rate of weevils at 27 C was expected to be significantly higher than at 10 C because the alfalfa weevil, like all insects, is a poikilothermal animal. The amount of oxygen consumed by females might be expected to be greater than that consumed by males because the females are generally larger than the males and would require more oxygen.

While light intensity and relative humidity did not have significant effects in this experiment, it should be remembered that these weevils were overwintered adults and different results might have been obtained had new generation or diapausing adults been used.

SUMMARY

This study was undertaken to determine the behavior patterns of the adult alfalfa weevil in Cache Valley and to compare the findings with those reported in the literature.

In the spring, as the temperature began to rise above 20 C, the alfalfa weevil adults became active. They emerged from their places of overwintering and some of them took to the air in flight. Adult weevils were active in the alfalfa fields before the alfalfa had begun to leaf out. Weevil eggs were found within punctures in growing alfalfa stems after the alfalfa was several inches high. Early in the season the daily field activities of the overwintered adults was closely related to temperature with the field activity being greatest when the temperature was highest.

The bulk of the eggs was laid and the weevil larval population heaviest during the first crop. Very few new generation adults developed until after the first-crop hay was cut. The cutting of the first-crop hay greatly reduced the weevil population. New generation adults were found in increasing numbers until the time the second crop was ready for cutting, when the new generation adults greatly outnumbered the old, overwintered adults. Some of the new generation adults then took part in a summer flight. This summer flight corresponded to the time of the second crop cutting on either dryland or irrigated alfalfa although the harvest dates were about a month apart.

Daily field activity of the adults during the second crop growth was closely related to light intensity with temperature having little effect. The new generation adults were much more affected by light intensity than were the overwintered adults. New generation adults that left the field during the summer apparently did not return until the following spring. No fall flight was found.

Overwintered adult populations declined steadily after first-crop cutting. A few overwintered adults were still present in the field late in the season, and the few larvae found in the fall were attributed to them rather than to the new generation adults. Sexual maturity was not observed in the new generation until the following spring.

In laboratory observations, the female alfalfa weevil mated more than once.

When adults were maintained at 27 C through the winter, it took an average of 8.5 months of adulthood before egg laying commenced. The beginning of egg laying by the weevils maintained in the laboratory coincided almost exactly with the beginning of egg laying by the weevils that had overwintered in the field.

Adults reared from eggs under an eight-hour day length did not become sexually mature more rapidly than weevils reared in the field.

Respiration of weevil adults given a 12-day cold treatment was 1.57 times that of the control weevils without a cold treatment. Weevils at 27 C consumed 3.4 times as much oxygen as did weevils at 10 C. Female weevils consumed 1.3 times as much oxygen as male weevils.

Differences in the alfalfa weevil biology reported from the eastern and western United States can be explained largely on the basis of differences in climatic conditions. However, the opinion expressed by Blickenstaff (1965), that the eastern and western populations should be at least considered subspecies, is not altered by any such explanation.

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