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ALFALFA WEEVIL, HYPERA POSTICA (GYLLENHAL), (COLEOPTERA: CURCULIONIDAE) RESPONSE TO ENVIRONMENTAL FACTORS IN ALFALFA FIELDS IN NORTHERN UTAH.

by

Larry Edward Jech

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

of

DOCTOR OF PHILOSOPHY

in

Biology
(Entomology)

Approved:

Major Professor	Committee Member
Committee Member	Committee Member
Committee Member	Dean of Graduate Studies

UTAH STATE UNIVERSITY

Logan, Utah

1988

ACKNOWLEDGEMENTS

I would like to thank Donald W. Davis, my major advisor, and the committee members, Raymond Sanders, Wilford Hanson, Ting Hsiao and Don Sisson for their valuable help and indulgence in preparation of this document.

There are two friends that did not see the final paper. Special thanks to George Knowlton and Joe Jech, my grandfather. Without their help and support this would not have been finished. Their gentle chiding and deep concern are appreciated.

Alan Roe helped collect the data and served as a sounding board for many ideas and helped solve many of the problems encountered. Lynn Forlow listened and suggested appropriate courses of action. Many other students helped but space will not allow a complete list.

William Brindley taught many valuable lessons and helped in many small ways. Dave Turner helped with statistical analysis and computer problems.

Larry Jech

September 1987

TABLE OF CONTENTS

LIST OF TABLES

Table Page

LIST OF FIGURES

ABSTRACT

Alfalfa weevil, Hypera postica (Gyllenhal),
(Coleoptera: Curculionidae) Response to Environmental
Factors in Alfalfa Fields in Northern Utah.

by

Larry Edward Jech, Doctor of Philosophy

Utah State University, 1988

Department of Biology
Major Professor: Dr. Donald W. Davis

Economic damage to forage alfalfa by the alfalfa weevil occurs frequently enough in northern Utah to warrant applications of an insecticide in some years but not all. Currently a five to ten day period is available to recognize injurious populations then make applications.

Sticky boards, pitfall traps, Berlese funnels sweep samples, stem bouquets, climatic variation and marking techniques were evaluated for alfalfa weevil population predictions. The prevailing climate was the most important factor controlling early adult activities. Early adult feeding and sexual development was the key to forecasting later larval populations. Regional surveys were not adequate for local control recommendations.

The effects of climate (especially temperature) on both weevils and alfalfa in six fields in areas with frequent alfalfa weevil damage were selected and studied in detail. The fields were selected for comparable age, alfalfa variety, type of irrigation and harvest practices. The development of both alfalfa and weevils were monitored using accumulated degree days at a developmental threshold of 9°C for the alfalfa weevil and 5°C for the alfalfa. When there was significant early season accumulated degree days (9°C), a weevil outbreak was likely. Adult weevils fed heavily and females developed eggs during this period. Cool spring conditions did not favor early weevil activity while alfalfa plants developed due to the lower development threshold.

When the climatic history of an alfalfa field was not known, growth about 5 May was an effective indicator of accumulated degree days. When the alfalfa was less than 25 cm tall and there were 3-4 total combined oviposition and feeding punctures per ten stems an injurious outbreak of weevil larvae invariably occurred about a month later. The method was not sensitive enough to detect marginal injurious population levels.

200 pages

INTRODUCTION

Integrated pest management programs propose reductions and maintenance of a pest below an economic threshold using predators, parasites, crop management and pesticides. Many of the programs forecast an outbreak or epidemic and allow alternative control strategies to restrict the pest numbers. One alternative is a pesticide application carefully timed to reduce the impact on beneficial insects. The Cache Valley region of northern Utah contains a diverse agricultural area that includes forage alfalfa as a major component. The area is ideally suited to study alfalfa weevil, Hypera postica (Gyllenhal), populations under a variety of environments and management practices.

The damage to alfalfa is done primarily by late instar larval feeding prior to first harvest and by newly emerged adults during the early second crop. Most damage could be prevented if the relationship between the overwintered adults and subsequent populations of larvae were understood relative to the weather regimes and alfalfa growth. Understanding the early season adult biology and population dynamics can lead to new opportunities for the prediction and suppression of outbreaks. Based on such information, decisions relating to early season pesticide application or modifications of cultural practices to reduce weevil numbers are facilitated.

Weevil adults become active in northern Utah in March or April. Adults feed and females oviposit as soon as temperatures and field conditions permit. By 5 May small larvae can usually be observed. Because of residues, most pesticides cannot be applied later than 20 May.

Currently, forecasting and controlling an outbreak by insecticides should be applied between 10 and 20 May. If an outbreak is discovered after this date, control strategies include early harvest or stubble sprays to control exposed larvae or newly emerged feeding adults in the second crop. Feeding by new adults reduces the crop vigor and shortens the stand life.

The following study focused on the weevil in an isolated valley (Cache Valley) in northern Utah to determine the causes of local outbreaks. The study incorporated local harvest and field management practices. The early season history of the weevil was studied for indicators of late first crop larval populations.

These studies were designed to increase our knowledge of adult alfalfa weevil bionomics during the early spring and its affect instar on larval populations just prior to the first alfalfa harvest in late May and early June.

The objectives were:

1. To measure adult alfalfa weevil population densities prior to oviposition in northern Utah alfalfa fields.
2. To correlate the preoviposition adult population densities in early spring with later egg numbers and larval populations.
3. To determine the overwintering survival of the adult weevils by comparing summer and spring populations in individual fields.
4. To study movement and activities of adult alfalfa weevils within fields during spring and early summer.

LITERATURE REVIEW

The estimated value of alfalfa forage and seed in the United States is 9.6 billion dollars, and 70 million in Utah (USDA, 1983). Since its introduction, the weevil has invaded most temperate areas of the North American continent. In the southern region of the USA, it prevents the planting of this valuable forage. The alfalfa weevil, Hypera postica (Gyllenhal) (Coleoptera: Curculionidae) damages both forage and seed crops every year in Utah.

Early history

Titus (1908) reported damage due to the alfalfa weevil larvae west of the Salt Lake County fairgrounds. Since the adult had small wings, Titus supposed active dispersal was by walking. Feeding larvae shredded the tips of the plant, which then appeared as frost damage when seen from the margin of the field. Eggs were reported as scattered around the terminals of the plants. The following year Titus (1909) documented the rapid expansion of infested territory, and noted weevil damage was more severe in old stands of alfalfa.

The host list (Titus 1910 a,b), defined by feeding and reproduction, included seven species of clovers and alfalfa. The infestation by 1910 had spread north to Roy, south to Provo and west to Lake View. The mountain valleys of Morgan, Summit and Wasatch Counties were also infested. Isolated populations of the alfalfa weevil were found at elevations of 1300 to 2300 meters. The weevil had a spring and summer flight followed by a third flight near the end of August.

Titus mentioned weevils might spread on rail cars and in hay hauled from infested fields. No parasites were recovered at this time. Control strategies included crop rotation, early spring tilling, removal of weeds from overwintering sites and burning the field.

Titus (1913), reported that the weevils were found on 2,800 meter mountain peaks east of Salt Lake City, these flights were not directed toward the alfalfa, but were dispersal flights. He also suggested grazing and brush drags as ways to improve yields.

By 1914, (Cooley, 1914) Montana had enacted a quarantine against the weevil by restricting movement of Utah fruits and vegetables during months of weevil activity. Gillette and List (1918), reported the weevil in Colorado. They observed flight activity in July and August, and considered eradication of the weevil as impractical.

Parks (1914) and Reeves et al. (1916) noted the early spring temperature regimes affected late season population densities of larvae. Warm springs led to more larvae feeding at once, cool springs were followed by larval feeding over longer periods. In some areas they found eggs continuously from 26 March to 10 August. The highest daily egg count from freshly collected weevils occurred on 18 May with 26 eggs per weevil. The mean total number of eggs deposited per weevil was 726. Some eggs were found in October but were killed by winter conditions.

Reeves (1917) observed that the heaviest larval populations near Salt Lake City occurred about 21 May. He reasoned that if heavy damage occurred the forage should be cut and fed immediately. Control could be obtained if the crowns and feeding weevils were covered with silt in the early spring by flood irrigation. Spraying with arsenicals had been tested and residues were not toxic when treated foraged was fed to cattle. The younger fields survived heavy weevil populations while old fields were destroyed (Hagan 1918). The brush drag was advocated for control of adults before they began to oviposit.

Wakeland (1920), studied the weevil in Colorado as it expanded its range. When sampled with a sweep net, the weevil population doubled within 24 hours. Wakeland suggested that at the earliest sign of damage the crop should be sprayed with arsenicals to prevent further damage. In 1924 (Wakeland) reported combinations of high elevation and cool temperature suppressed populations of weevils near Parma, Idaho. He emphasized good farm management and early harvest as a control technique to avoid damage.

Snow (1925) found weevils at Reno, Nevada near the race track. He suggested cutting the alfalfa when 38-46 cm tall, exposing the adults and larvae to hot weather and bright sun.

Chamberlin (1924) reported, after extensive search and importation, that the only parasite established was Bathyplectes curculionis (Thomson). The wasp then spread with the weevil as it expanded its range across the Great Basin. Cook (1925), studied the range and physical ecology of the weevil in Europe and Eurasia. He predicted the weevil would be confined to the West Coast and Great Basin areas of North America.

Snow (1928) developed a technique to describe ovarian development and stages of ovulation. Field studies suggested development of eggs halted in November and resumed in March when adult activity commenced.

Little or no damage should be expected from fall larvae. Reeves (1927), reported the mean number of eggs per oviposition was ten. He reported that use of the brush drag killed the crown of the alfalfa plants.

Life history summary. After 20 years of study the basic life history of the weevil became reasonably well understood. New control techniques were being sought as the agricultural system adapted to the new pest. The search for parasites in Europe continued. The area infested had expanded across the Intermountain West.

A summarized life history in the West is as follows: The overwintered adults resume activity in March or April as the weather warmed. Adult flight occurs by the middle of April and is not seen again until July and August. Mating occurs as soon as feeding commences and continues until the first crop alfalfa is cut. Oviposition is well along by the time the alfalfa reaches 9 to 12 cm during the spring. The weevils deposit about 6 to 12 eggs per puncture. Eggs hatch 7-16 days after oviposition. The first instar is completed in 5-8 days; the second, 12-20 days; the third, 6-15 days; the fourth, 6-15 days; the pupa, 6-14 days; and the adult lives 10 to 14 months. The average larval life span is about 29 days.

Most larvae began to pupate soon after cutting the first crop. Some continued to feed until they pupated or were killed by the heat. The newly emerged adults and larvae fed on the second crop. The newly emerged adults fed voraciously at night and avoided the bright sun. Some larvae were reported during the late fall just prior to the alfalfa entering dormancy.

Field ecology. Sweetman (1932) studied the field ecology of the alfalfa weevil to determine the effect of temperature on development and survival. He placed adults and larvae along with thermographs at various heights in the plant canopy (5 cm, the canopy and 1.1 m above the canopy). There were no differences between temperatures measured in the upper canopy and 1.1 m but those near the soil surface were cooler. Although cold weather reduced oviposition to near zero, oviposition rebounded rapidly when the weather warmed. Warmer conditions favored oviposition and larval development, while high temperatures finally reduced oviposition and larval development. Sweetman and Wedemeyer (1933) used controlled environment chambers to determine the effect of temperature and humidity on survival and development. Their technique followed Sanderson (1910) who presented the idea of accumulation of degrees and correlated this with rates of development. They found the upper threshold for oviposition was less than 28°C. Adults could not be maintained above 30°C. The adults were also killed by exposure to 27°C when relative humidities were below 40%. The minimum temperature for egg incubation was 10°C. The eggs hatched and larvae developed if the temperatures were between 20 and 30°C and relative humidities were between 55-95% for eggs and 30-95% for larvae. Larvae would not feed if the temperature was lower than 10°C. Varied temperatures rather than constant temperatures supported greater larval survival.

Essig and Michelbacher (1933) and Michelbacher and Essig (1934a) reported alfalfa weevils were found in the Central Valley of California. Although present for several years, the climate, presence of parasites and agricultural practices were credited with its slow spread. The early first harvest and thick stands of alfalfa minimized damage. In California, Michelbacher and Essig (1934b) reported new adults and larvae in the field during the entire season. This was much different than alfalfa weevil populations of the Great Basin which have distinct separation of generations. During this period the search for parasites of the weevil continued as well as research on weevil biology in the West (Sorenson 1934).

Insect field populations. Gray and Trelloar (1933) studied the sweep net in relation to the population sampled. They recognized that homogeneity of the habitat was not the same as homogeneity of the distribution of the insects. Williams (1937) compared large and small populations using logarithms. Logarithms were used to stabilize and manipulate the population means. Comparisons of populations on successive days and locations were possible. Beall (1939) modeled actual populations of potato beetle, Leptinotarsa decemlineata, to determine optimum strategies for sampling field populations. Findings suggested efficient sample paths do exist if the population has a known structure. There were no differences in numbers collected among the experienced samplers. Beall (1940) related the number of larvae per unit area to the survival of the larvae from the egg mass. The distribution of the egg masses was an important characteristic of the insects in a population. Poisson or random distribution was assumed but had not been checked by field observation. Davidson (1944) proposed the logistic curve as an empirical fit based on the rate of development of insects reared at constant temperatures. The model explained effects of prolonged exposure to extremes of high and low temperatures.

Lathrop and Dirks (1944) published a paper emphasizing the importance of plant phenology when observing insect population differences between seasons. Instead of a Julian calendar one based on plant phenology was suggested. This would allow summaries from phenological dates (later; biofixes), such as petal drop in apples.

Physical ecology. Michelbacher (1940) and Michelbacher and Leighly (1940) identified, based on their biological interpretation three climatic zones and four alfalfa weevil habitats in California. The climatic zones were cool, intermediate and hot. Three habitats were defined by reproductive interruption: winter only, summer only, and winter and summer. _B_. _curculionis_ also responded to these interactions and was most effective for alfalfa weevil population control under the cool moderate climate near San Francisco. Here the population of larvae built slowly until August. The heaviest damage occurred when April and May were warmer than usual or had more high temperature days.

Hamlin et al. (1949) reviewed previous work and conducted experiments with the western weevil. They found that warm early spring conditions promoted massive egg populations that were followed by an extensive hatch as the season warmed. The larvae fed and matured rapidly as the spring continued. The mean number of eggs per puncture varied but was near 10. Near Salt Lake City the peak egg production, two-thirds of the total, was centered on 14 May, plus or minus 21 days. The first larvae hatched during the first week in May. No correlation existed between large numbers of adults and damaging levels of larval populations. Warm early springs led to an outbreak while cool springs to prolonged feeding. Early harvest interrupted the population build-up by killing the first three instars.

Alfalfa weevil studies 1950 through 1960.

Alfalfa weevil studies changed during the 1950's in four important ways: 1) the use of pesticides was expanded; 2) the use of statistics became standard; 3) computers allowing data reduction became available for previously unapproachable problems of population dynamics; and 4) alfalfa weevils were found on the East coast of North America and spread rapidly, also the Egyptian alfalfa weevil expanded its range.

Models and population dynamics. Models of population distributions and dynamics began to describe the population means and standard deviations as characteristics of the species. Anscombe (1949) proposed a model for the population when the variance was greater than the mean. It converged to the Poisson when there was no clumping. Most populations exhibited contagious distributions, i.e., the means were smaller than the variances and populations are clumped. Evans (1953) tested both plant and insect populations for clumping against three theoretical distributions. The insect counts were best fitted by the negative binomial. The random distribution of colonies of insects was the same as the Neyman Type A distribution.

Pielou (1957) returned to the size of the quadrant in relation to the clump size of the population. Her studies assumed the plants were arranged in random clusters. She also assumed the number of individuals in a quadrant was random. The best population estimates were found when quadrants of different sizes were used in the analysis. Bliss (1958) pointed out that if the quadrants were too large the population would appear random as new clumps of insects were included. He listed sources variability that include both physical and biotic factors. Waters (1959) proposed clumping was both a statistical and fundamental biological function derived from activities of individuals. Statistics, means and variance functions, to describe the field populations began to be used. From this a framework for describing the population emerged.

Construction of life tables (Morris and Miller 1954) helped determine the sources of mortality for a population. The life table by itself did not lead to a population forecast. Watt (1960) proposed heavy competition for survival from conspecifics. Therefore, simply reducing the population of larvae did not lead to a lower number of eggs. Waters (1955) developed a sampling technique that allowed accurate estimates of a population by taking a series of subsamples and adjusting the quadrant size to reflect the population densities.

Heat units. The date of first flower opening, the culmination of complex phenology, was analyzed based on time-temperature records from central Illinois (Lindsey and Newman 1956). They pointed out that environmental conditions, in addition to temperature were important in controlling plant phenology. The combination of air temperature and 'bright sky', were important in the process. Arnold (1960) presented a simple formula for calculation of degree-days based on the upper and lower thresholds of development. More complex formulae were developed later but the increased precision did not lead to greater accuracy in forecasting a phenomenon.

Biology and control. Carlson et al. (1950) concluded the adult alfalfa weevil populations developed in response to the cropping and harvesting practices employed within the field. Insect control then became an individual field problem. Hastings and Pepper (1952) reported that applications of dieldrin before alfalfa growth resumed in the spring was sufficient to control the weevil larvae. Armbrust et al. (1966) used a pesticide to control the fall population of adults and prevented oviposition in the spring, a method determined to be superior to controlling the spring larval population for the eastern weevil biotype.

In the West, Knowlton (1954) found female weevils produced between 200-800 eggs per season. Manglitz and App (1957) reported the weevil in Maryland oviposited 8.8 eggs per cluster in the spring and 9.6 eggs in the fall. Eggs laid in the fall hatched in early winter or entered dormancy with the alfalfa and hatched in the spring. Evans (1959) studied the biology of the alfalfa weevil in Virginia and found the mean number of eggs per cluster was 9.9. The total number of eggs produced per female ranged from 113 to 1102 with a mean of 558 eggs per female.

The larvae did not leave the plant or migrate from the field even if all the food was consumed. In the east, fifty percent of the larval population in the spring was derived from the fall oviposition. Oviposition occurred at temperatures lower than required for egg development. Eggs then developed when the weather warmed above the developmental threshold.

Poinar and Gryrisco (1960) studied the relationship between adult activity and environmental conditions to discover flight triggers. During the late afternoon, rapidly changing light intensities were followed by increased adult activity. During July, night samples produced a nine-fold increase in adults collected over daylight samples. In the fall, Manglitz (1958) observed a reduction in adult weevils in the field and an increase in adults at the field margin or nearby areas.

Alfalfa weevil biology 1961 through 1970.

Behavioral and physiological adaptation allowed the weevil to invade a wide range of environments from north to the south. As the eastern weevil spread west, workers applied new techniques under a variety of conditions. The feeding, oviposition and flight biology came under close scrutiny. The use of different sweep nets, sweep styles and other techniques for population density evaluation were standardized. Models were refined as the field population were studied.

Field biology. Field studies helped to clarify the behavior of the weevil. Pesticides were timed to take advantage of the life history of the weevil and avoid damage to the beneficial insects. Peterson (1960) compared the overwintering behavior of weevils from Alberta, Canada with Logan, Utah. Utah weevils roused quickly from the overwintering state and began to feed and drink water, while the Alberta population remained inactive for a much longer period. This delay prevented the northern weevil from emerging into a short-lived favorable environment. The Alberta adults were not found in the field until the alfalfa was 28 cm high, compared to Utah where the adults could be found shortly after the snow melts.

Koehler and Gyrisco (1961) studied the temperature and relative humidity requirements for egg and larval survival in New York. The eggs developed at 9°C with 90% hatch at 12°C, although they did not hatch at 5% relative humidity. Larvae developed at 10°C.

Bass (1966) exposed adults in eastern USA to extreme temperatures to determine the lethal thresholds. The lower lethal threshold was -4°C; the lethal temperature for 50% of the adult population was -11.4°C. The upper lethal threshold was 46°C; the lethal temperature for 50% of the population was a 2 minute exposure was 48.8°C. These ranges were found to be consistent across the North American continent.

Overwintering survival of the different weevil stages was studied to determine the likely overwintering stage. Wide temperature tolerances were found. The eggs did not survive the winter in the field in the Intermountain West, but the eastern weevil in all except the extreme north survived as eggs.

Overwintering success of the eggs depended on the snow cover, severity of the winter and condition of the alfalfa plant. Woodside, Bishop, and Pienkowski (1968) studied fall oviposition behavior in Virginia. They found oviposition decreased with increasing altitude also the oviposition peak occurred earlier at lower elevations. In Pennsylvania, during winter and spring the lowest number of overwintered eggs were found in March. Larvae from these eggs did not hatch until April (Townsend and Yendol 1968).

Armbrust, White and Dewitt (1969) measured the supercooling point of the different stages and concluded the adult was the likely overwintering stage in cold areas. Pitre (1969) reported all stages passed the winter in Mississippi. Burbutis, Bray and Mason (1967) found overwintered eggs but felt spring crop damage was correlated with the number of pupae rather than the number of adults or larvae.

Mark-release-recapture. Pamanes and Pienkowski (1965) used marked-release-recapture of adults to study flight dispersal behavior of weevils. Wild weevils flew when the proper environmental conditions were met. Nineteen days after the release one weevil was recovered 0.8 km from the release site. During the following years, results were less dramatic and weevils were not recovered farther than 27 meters from the release site. The weevils did not appear to be strong fliers and if dispersal occurred, orientation was down wind.

Feeding behavior. Laboratory and field experiments probed the feeding behavior of the larvae and adults in relation to field behavior. Poinar and Gyrisco (1960) found starved adults fed in the light. Well fed weevils fed in the dark, possibly to avoid parasites and predators. The threshold of response was as low as 4 foot-candles.

Koehler and Gyrisco (1963) compared feeding behavior of eastern and western weevil and found no differences. Second instar larvae fed on potted alfalfa were able to reduce the quality of the alfalfa but not as much as seen in a natural setting (Mathur and Pienkowski 1967). Interactions of light and temperature did not prevent starved adults from feeding at 34°C. Weevils in a free choice test responded to humidity gradients as small as 5% at 35°C. Starved and older weevils moved more quickly to the preferred humidity but ultimately there was no difference between conditions chosen by starved and fed weevils. When high light conditions were encountered, the adult weevil preferred high humidities (Springer and Pienkowski 1969). Interaction of hunger and temperature interactions might drive the summer/fall return to the field (Armbrust and Gyrisco 1968).

Flight behavior. Flight behavior of the weevil has been difficult to study because it occurs during very short periods, during the spring, summer and fall and varies with prevailing weather conditions in different areas of the country. A seasonal flight pattern of the eastern weevil shows three active periods.

Several authors have reported that the early spring flight in the eastern USA occurs as the weevil returns from hibernation sites outside the field. The summer flight follows maturation of new adults in June and early July. The adults aestivate in nearby areas and fly back to the field in late summer and early fall. Those not returning in the fall account for the early spring flight.

Poinar and Gyrisco (1962) found the weevils would remain in the alfalfa during the summer as long as it was uncut. Cutting resulted in flights of weevils at dusk. The flight depended on the maturity of the weevils, immature adults did not fly, even when exposed to the hot, dry conditions of summer. The summer flight in late June and early July was the heaviest (Prokopy and Gyrisco 1963).

Prokopy and Gyrisco (1965a) reported the largest migration of summer adults occurred when alfalfa was cut at 35 and 65 cm. They concluded that the majority of the weevils remained in the field. Weevils were observed flying between 5 and 11 pm when the wind was less than 5 kph. The weevils were able to avoid sticky traps (Prokopy and Gyrisco 1965b).

In the West, Southwick and Davis (1968), found the weevil flew in the spring and summer with no late summer or fall flight detected. Many weevils remained in the field. There was a slight shift in activity period compared with reports by Titus (1910 a and b) and Parks (1913). This may have been due to elevation and cooler conditions in Cache Valley compared to the Salt Lake area.

Question of orientation. How the weevil finds the alfalfa studied by Byrne and Steinhauer (1966). Adult weevils were placed in an olfactometer to determine the attractiveness of steam distillates and fresh cut alfalfa. Weevils were positively attracted to the alfalfa and were less responsive to steam distillates. Golik and Pienkowski (1969) found the weevils to be more active in the presence of food at both low and high temperatures. From these studies it seemed probable that the weevil could find alfalfa fields using odor and relative humidity.

Oviposition behavior. The oviposition behavior and biology of the weevils has been studied in relation to host plant resistance. Small stem diameters reduced the oviposition rate; however, a decumbent growth habit was the most important resistance factor found (Norwood et al. 1967). The mean number of eggs per stem in the field on 22 April was 3.8 which resulted in 2.15 larvae per stem on 27 May. Busbice et al. (1968) found they could reduce the stem diameter through plant breeding, but not enough to avoid weevil oviposition. They found an average of 6.2 to 9.0 eggs per stem with the average about 8 eggs per stem. Niemczyk and Flessel (1970) found mean eggs per cluster was 9.3-9.6. Drea (1969) found the oviposition period lasted 45 days (range 34 to 59 days). Oviposition ceased when females ran out of stored sperm. A few resumed oviposition when males were placed in the cage.

Control. In North Carolina, Campbell, Bowery and Jester (1961) found that weevils returned to fields in September and started ovipositing in mid November. Heptachlor controlled the adults before they began to oviposit overwintering eggs. Pfadt and Lavigne (1964) prevented larval and new adult feeding in the second crop by treating the stubble. In Ohio, Niemczyk and Flessel (1969) found the spring control of the weevil adults required two sprays in the in the southern portion of the state. In the fall they recommended one spray with a long-residual chemical to control the adults before ovipositing or overwintering. They found 87 eggs per 929 cm^2 in the treated plots and 344 eggs per 929 cm^2 in the controls.

In northern California, Koehler and Burton (1964) used a long residual spray to control Egyptian alfalfa weevils adults before the onset of oviposition. This was superior to controlling the larvae later (Tippins 1964). Bishop and Pienkowski (1967) found attempts to control larvae with either flame treatment or early season pesticides was not entirely successful.

Since early season feeding can retard development of the alfalfa, weevil larvae must be controlled before extensive feeding. Rating tip damage can be more useful than the sweep net for finding the economic threshold levels (Dickason and Every 1968, Kantack et al. 1973). Based on studies, if a tip feeding index of larval feeding were used, chemical control would be too late to prevent damage. The ratings, however, always lagged behind the larval population development (Carpenter 1970). Koehler and Rosenthal (1975) found that a larval population of 22 larvae per sweep at peak population was not enough to cause economic injury.

Field sampling techniques. Pass and VanMeter (1966) developed an efficient technique for separation of eggs from stems. The blender technique allowed the collection of large numbers of eggs for experiments and population estimates. Parker and Drangeid (1967) compared different numbers of sweeps and replications needed. They determined ten sweep samples from 5 locations in a field adequately sampled the alfalfa weevil population. Blickenstaff and Huggans (1969) compared four methods for sampling weevil larvae. The most time-intensive was a sequential technique using single stems. The 180 degree sweep sample gave good relative population measures but was not accurate when absolute densities were required. Beating 231 cm^2-samples into an enamel pan and a D-vac was also studied. The methods were all highly correlated (Hower and Ferguson 1972).

Growth and development.

Ricklefs (1967) suggested a simple approach to studying growth curves. The growth per temperature was converted to a logistic curve.

The equation was used to model and compare growths of related species. As in earlier studies, Baskerville and Emin (1969) measured the physical environment and found the ability to measure the temperature and calculate the growing degree-days did not improve the ability to predict the plant growth.

Improved sample techniques led to the use of more sophisticated models of the population based on seasonal changes. Watt (1960) compared subsequent weevil populations to determine if the population were expanding or contracting. Weevil egg density was an important factor in this analysis.

Harcourt (1969) reviewed information on the construction of life tables. The methods outlined above can be applied to sampling almost any insect population as long as the limits of the method are recognized. This outlines the kinds of samples and field arrangements that are useful and places limits on the kind of inferences that can be made.

Models. Models mimic nature and better models not only mimic, but provide some insight into how the system functions (Ruesink 1976). Simulation models are based on physiological time, growing degree-days or heat units above a baseline or developmental threshold. Models depend on life history studies (Miles et al. 1974). Problems are encountered when unknown aspects of insect biology are required to complete a model.

Stinner, Gutierrez and Butler (1974) presented an algorithm for the calculation of developmental rates. They pointed out that temperatures encountered are usually in the middle of an insect's temperature optimum and extremes were seldom encountered. Podler and Rogers (1975) presented a method to graphically represent the mortality between stages as the population matured. Welch, Croft, and Michels (1981) the best models had the ability to improve current practice, were easily understood were able to forecast population development under a variety of field conditions. Ruesink and Kogan (1982) suggested five factors to successfully estimate a poulation was the true population density; age class structure; level of activity of individuals; efficiency of sampling methods and response of a particular sex to traps. Ruesink (1982) pointed out that underlying cause and effect should be understood as well as how the various tactics applied to reduce insect population were going to interact. Shoemaker and Onstad (1983) applied stochastic dynamic modeling to the integration of weevil control. Based on literature, they concluded the weather and weevil densities were most important to decision formulation. The weevil population was not sensitive to *Bathyplectes sp*. The practice of early harvest was the most useful cultural control available.

Biofix and heat units. Heat units or physiological time had been developed to track plant phenology. As models became more sophisticated they required more detailed information on plant growth. Abrami (1972) developed a method for the calculation of heat units that removed some of the error. He attributed the remaining error to non-measured factors affecting the rate of plant development. Allen (1976) described a sine wave calculation that corrected for errors not accounted for in other methods. As mentioned above, increasing precision in the calculation of heat units did not lead to better predictions of growth. Bula et al. (1975) modeled the growth of alfalfa using a lower threshold of 5°C. They found stem growth, length and foliar mass were related and easy to measure. Alfalfa growth can be measured in centimeters recorded as a simple estimate of phenology and current degree-days(DD). The buds appear at 450 DD and first flowers at 600 DD.

Shade, Axtell and Wilson (1971) found the height of the alfalfa plant influenced the rate of alfalfa weevil larval development. There was no difference in the time of larval development among 131 alfalfa clones tested but the nutritional quality of taller plants was superior to shorter plants. Eklund and Simpson (1977) used a base temperature of 4.4°C to calculate DD. Degree-days were highly correlated with the height of the alfalfa. Larval weevil population peaked when the alfalfa reached 43.2 to 63.5 centimeters or 600-680 alfalfa plant DD. Cutting occurred at 800-900 alfalfa plant DD. Oviposition began when the alfalfa reached 22.9 cm or at 300 DD (the second week in May). It was easier to predict the onset of oviposition than the peak of oviposition. Peak weevil populations were forecast by measuring the alfalfa height. Adoption of such a method would simplify many problems associated with traditional degree-day calculations.

Riedl, Croft and Howitt (1976) followed the pheromone trap captures of codling moths to determine degree-day relationship to oviposition. Simple calculation of DD without reference to climatic conditions or later physiological events (molting or oviposition) led to inaccurate predictions. Sevacherian, Stern and Mueller (1977) started DD accumulation on 1 April. When the lygus population in cotton reached 3rd to 5th instar or after the proper DD interval, pesticides were applied. Outbreaks of forest tent caterpillars were related to trends of late winter, and early spring conditions (Ives 1973). Increasing populations experienced cool winters and warm early feeding conditions.

Yee and Harcourt (1981) published separate tables for each weevil instar and suitable calculations for DD based on three-hour intervals. Harcourt and Yee (1982) presented an algorithm, started on 1 April, for the calculation of the duration of each weevil instar. They found biotic factors were not as important as the weather. Later Harcourt (1981) found that oviposition was protracted and the appearance of other stages was an estimate of the rate of hatch. This model, based on 9°C, forecast the duration of each stage.

Alfalfa. Host plant resistance as a source of control for the alfalfa weevil has not progressed as rapidly as initially expected. One problem has been acceptability of the forage quality. Research on phylogenetically related plants has identified some feeding resistance factors (Keller et al. 1970, Campbell et al. 1975). Glandular hairs were identified as a factor (Shade, Thompson and Campbell, 1975). Johnson, Sorenson, and Horber (1980b) reported the hairs interfered with larval feeding. Plants without hairs were definitely preferred for oviposition (Johnson, Sorenson, and Horber 1980a). The presence of hairs was not related to the stem diameter. Alfalfa weevil larvae confined to some cultivars showed slower developmental rates and had convulsions (Johnson, Sorenson, and Horber 1980c). These larvae did not prepare a cocoon before pupation (Thompson, Shade and Axtell 1978). Busbice et al. (1978) reported a variety that outgrew the weevil by heavy budding and branching.

<u>Laboratory and field studies of weevil biology</u>.

Dively (1970) studied the overwintering success of eggs in alfalfa stubble, new growth and bud stage. There was no difference in the number of eggs in the three stand conditions and the number per stem was stable from 30 December to 15 March in New Jersey. The new-growth alfalfa stand had significantly more eggs by 15 April. After 15 April, oviposition became heavy in all fields.

Egg viability declined progressively during the winter and was dependent on snow cover and overwintering conditions. Viability from February to March ranged from 0-26%, but once spring arrived, 80-90% hatch of newly deposited eggs could be expected (Litsinger and Apple 1973). Roberts, Dewitt and Armbrust (1970) determined the lower threshold of development was near 7-10 degrees. As eggs matured they changed color. They hatched after 313 DD. Morrison and Pass (1974) found embryonated eggs to were resistant to cold. However, the head capsule stage was very susceptible to cold treatment. Crain and Armbrust (1978) found the effect of repeated cold treatment to be an additive mortality factor, independent of intervening time intervals. Cothran and Gyrisco (1966) and Day (1971) found that the adult survival through simulated winter was possible with no ill effects if the weevils were held at 1.7°C.

<u>Oviposition behavior</u>. Weevil oviposition response to the environment was studied to determine the reproductive capacity. LeCato

and Pienkowski (1970 and 1972a), and Hsieh and Armbrust (1974) found weevils in the laboratory responded rapidly to widely fluctuating temperatures by altering the number of eggs deposited. Introducing males reduced the number of eggs deposited because they spent up to 45% of the time mating. LeCato and Pienkowski (1972c) found isolated females oviposited for about 15 weeks or until they ran out of sperm. Interspersed matings produced the most eggs. Females confined with males and other females retained more eggs apparently due to interference and depletion of oviposition sites.

LeCato and Pienkowski (1972b) found a ten minute exposure to lower or upper lethal temperatures reduced oviposition. Coles and Day (1977) found some variability in egg production by local populations; ranging from 4190 in New Jersey, 3232 in Indiana, to 3102 in Kentucky. The females in these populations produced 50, 49, and 44 eggs per day, respectively.

Based on the literature, random egg cluster distribution was not expected in the field. Miller, Mukerji and Guppy (1972) used the methods outlined above and found all immature stages were highly aggregated, especially the eggs. Later, Harcourt, Mukerji and Guppy (1974) carefully designed an extensive experiment. The number of eggs recovered was regressed on the number of oviposition punctures and a linear relationship found (# of eggs = 0.01 + 10.99 (number of punctures)). They also found the number of eggs produced and the number of eggs per cluster was highly consistent between seasons and locations surveyed. They compared tip damage ratings with punctures per six-stem bouquet, taking into account the environmental variables:

temperature, rainfall, slope exposure and alfalfa variety (Harcourt and Guppy 1976). Tip damage methods did not allow prediction of an outbreak and was subject to abuse since damaging populations were not separated from noneconomic populations (Cothran and Summers 1974, Flessel and Niemczyk 1971). Using the oviposition puncture technique, an economic population was indicated if there were more than 12 oviposition punctures in ten bouquets (60 stems total). This employed a sequential sampling technique that varied with the density of the pest population. A significant mortality factor (26%) was associated with establishment of the hatched larvae in the terminal bud (Latheef, Parr and Pass 1979).

Larval population. The larval distribution reflected the adult oviposition, and changes in slope were interpreted as reflections of the mortality that occurred between stages. When the development threshold was followed to calculate the degree days accumulated it was considered possible to predict appearance of each stage through the season (Guppy and Mukerji 1974). Guppy, Harcourt and Mukerji (1975) assessed the larval population to determine the most efficient bouquet sample size. Hand-examined six-stem bouquets were one-third more efficient than using 12-stem bouquets. If the population was heavy, the field required 16-20 bouquets and two hours to count. If the field population was light, then 32-36 bouquets were required with four hours needed to count the larvae. Decisions based on counts of larvae required a large time commitment. Later weevil cocoons were assessed on the same plots (Harcourt and Guppy 1975). They were clumped and fit a negative binomial curve. A moderate population was about 75 insects per 929 cm^2 (Harcourt 1975). The number of samples required was inversely proportional to the population density and required about two hours to sample and count a field with moderate cocoon density.

Adult biology. Blickenstaff (1967) sampled adults during the winter and found them quite evenly distributed across the field (0.25-1.8 per 929 cm^2). The overwintered weevil densities were near 1 per 929 cm^2 and required about 160 samples per field to accurately sample the population (Guppy and Harcourt 1977). The density of newly-emerged summer adults ranged up to three adults per 929 cm^2. Autumn and spring populations fitted a negative binomial. Roberts et al. (1979 a, 1982) found the highest densities in the summer diapause generation in wooded areas near the field margins (2.08-2.58 per 929 cm^2) and the lowest during the summer in the middle of the field (0.17-0.34 per 929 cm^2). In the winter an intermediate population of 0.42-0.55 per 929 cm^2 was observed near the field centers. Adult overwintering mortality was high. Ninety three percent of the summer generation failed to return from overwintering sites. Latheef, Parr and Pass (1979) also found the population trend was determined by survival of larvae to the adult stage and could be measured by the change in slope of the logarithm of population changes between instars.

Orientation. Although the flying ability of the weevil cannot be doubted, the ability to locate alfalfa visually has been questioned by Meyer (1975). Behavioral studies of the visual acuity of the weevil adult indicated it can discriminate between alfalfa and non-host plants but not until the alfalfa covered 120 degrees of the field of vision. Based on calculations, to discover a 0.4 hectare field, 240 meters on a side, the weevil would have to be within 90 meters of the field. Weevils that dispersed farther probably used some other source of stimulus to rediscover the host.

Olfaction seemed to be a likely second choice. Tests had shown the weevil oriented in an air stream toward alfalfa odor or its steam distillates. These experiments were uncontrolled for relative humidity. The problem was dealt with by allowing the weevils a free choice in an arena surrounded by water (Meyer and Raffensperger 1974a and b). The difference between visual and olfactory response was measured by time spent in the presence of the host or a mimic. The alfalfa was three times as attractive as the model but the weevil had to be within 5 mm of the host to detect it. They concluded the weevil could not find the host by visual methods alone, possibly explaining why the weevils milled about at the margin of the field as they sought hibernation sites (Pamanes and Pienkowski 1965).

Movement and dispersal. Flights of the alfalfa weevil have been recorded from all areas where the weevil was studied. Most flights appeared to be related to dispersal. The micrometerology of the alfalfa field appeared to control many of the activities. Sherburne et al. (1970) observed nondirected downwind flights. The weevil did not fly toward the wooded edge, but 'circled' in the vicinity of the margin as it received different stimuli. No flights occurred if temperatures were above 23.8°C at 7 pm or when wind velocity was less than 0.8 kph but gusty. Christensen et al. (1974) found the Egyptian weevil returning from aestivation sites in response to the daily maximum-minimum temperature differences. The difference accounted for 50% of the variability out of thirteen independent variables chosen (78% + total variability explained). They noted that the cool temperatures per se did not influence flight activity.

Pinter, Hadley and Lindsay (1975) studied the temperature variability within the alfalfa plant canopy. The canopy moderated the environment (44°C versus 35°C ambient within the canopy). After cutting, the difference between the exposed soil surface (63°C) and that under the windrow (41°C) further influenced survival. Timely cutting and baling of the hay would be expected to lower the survival rate of the adults.

The fall migration of the weevils in the East was accomplished by short flights and ground movements (Barney et al. 1978a). Using a variety of methods they found the weevils concentrated along the edge of the fields. They detected the weevils as they moved to the center and then distributed themselves across the field. The weevils were able to avoid the sticky traps (Barney et al. 1978b, Sherburne et al. 1970).

Pausch et al. (1980) followed the alfalfa weevil return and found, as in California, the period of aestivation was terminated over a interval of ten days in early October. Flight did not occur until the weevils had been in the field twenty days. Davis (1970) reported no fall flights in Utah. The required environmental cues that control aestivation and the entire population as a unit are not known.

Harvest practices. It has been mentioned that harvest practices influenced the larval and subsequent adult populations. One of the simplest comparisons was the effects of harvest versus no harvest. The adult weevils did not leave the uncut field to aestivate (Manglitz 1976). In the spring adults were recovered first in the uncut field. The adults had returned to the unharvested field but became active later in the spring. In the eastern USA uncut fields have 55-fold the population of a cut field (Blickenstaff, Huggans and Schroeder 1972). By the following spring the population was about four-fold that of the cut field. Later, the larval population was 200-1000 times the adult population. The potential population buildup was tremendous if harvest practices favored the weevil (Miller and Guppy 1971).

Parasites and biological control. The preservation and enhancement of the beneficial insects in an alfalfa field was an early goal of many researchers. Parasitism has been studied extensively since the first Bathyplectes curculionis were discovered. The parasites were not intensively studied during the years immediately after initial introduction of organic pesticides. Hagan and Manglitz (1967) studied the relationship of B. curculionis and the alfalfa weevil in the west and credited the slow expansion of the weevil's range to this parasite. Life history studies indicated the parasite preferred the second and third instar larvae (Foster and Bishop 1970, Duodu and Davis 1974b, and Barney et al. 1978a). Synchrony of parasite and host appeared adequate across their range (Pike and Burkhardt 1974).

Alfalfa management practices can reduce the long term weevil populations. The proper alfalfa harvest (Casagrande and Stehr 1973), pesticide application (Wilson and Armbrust 1970, Walstrom 1974, and Hower and Luke 1979) and in combinations (Davis 1970, and Wedberg et al. 1977) was helpful in reducing the larval population and enhancing parasite survival. Winter grazing after the alfalfa became dormant reduced the overwintering weevil egg population and subsequent larval populations more than the B. curculionis (Senst and Berberet 1980). Herbicides applied to the fields resulted in 37% more oviposition in treated plots (Wolfson and Yeargan 1983).

Richardson et al. 1971 and Schroder and Metterhouse 1980, indicated the population decline which occurred in the eastern USA was a result of good management and parasites. New parasites were added to the B. curculionis population. One of these, B. stenostigma was not as effective as B. curculionis because it was out of synchrony with the preferred host stage (Yeargan 1979).

In much of southern USA the alfalfa weevil has destroyed the alfalfa forage industry. Morrill (1979) replanted alfalfa in an area that had been abandoned for alfalfa production. Weevils and parasites were recovered from the field during the first season. Both had survived in the area without the benefit of extensive alfalfa culture.

Studies of parasitized larvae indicated they consumed less and took longer to develop than unparasitized larvae (Duodu and Davis 1974a). Duodu and Davis (1974c) found no significant difference in the amounts of food consumed by parasitized and unparasitized weevil larvae related to different temperatures. Barney et al. (1979a) found no differences in developmental times between parasites reared at either constant or fluctuating temperatures.

The lower threshold for parasite development was about 6-8°C. The upper lethal limit was near 60°C for a 2-4 hour exposure. The lower lethal threshold was near $-25^{\circ}C$. From this, Cherry, Armbrust and Ruesink (1976) concluded that the B. curculionis was more susceptible to summer heat than to the cold conditions of winter. Parrish and Davis (1978) concluded the diapause was prevented by cool nights and short days of spring.

Predators and pathogens. Predators were the greatest source of adult weevil mortality. In most cases the predators have chosen other offered prey (Yadava and Shaw 1968, Hussain 1975 and Ouayogode and Davis 1981). The alfalfa weevil larvae have been included in many feeding choice tests as prey items. Collops sp. beetles, however have been outstanding predators of alfalfa weevil larvae in laboratory trials. Philonthus cognatus, a carabid beetle, has been identified as a predator in the field. Barney et al. (1979b) identified another carabid, Harpalus pennsylvanicus, and a cricket, Gryllus pennsylvanicus, as predators of adult weevils overwintering in the field. Barney and Armbrust (1980) tethered adult weevils within an exclosure and recovered 100%. Predation accounted for 70-100% mortality of the weevils outside the exclosure. B. curculionis cocoons were also destroyed, 95-100%, by the predator complex (Cherry and Armbrust 1975). The weevil eggs were parasitized by a mymarid wasp, Patasson luna. They were also eaten by flower thrips (Barney et al. 1979c).

The phycomycete fungus, Entomopthora phytonomi, attacked weevils in central USA and southern Canada. It responds to rainfall, temperature and host density (Harcourt et al. 1974). Puttler et al. (1979) found the fungus widespread over Missouri. Later it was found in central Illinois where Barney et al. (1980) found 10-90% mortality in a survey throughout Illinois.

Harcourt, Guppy and Binns (1977 and 1984) in Canada hypothesized the long term decline of the weevil was due to both parasites and diseases. They felt the disease was important in the control. Richardson et al. (1971) in New York supposed the parasites were more important. There seemed to be no conflict in the analyses, just perspectives on biological control in different areas.

Comparative samples. The sweep net has some major drawbacks when used alfalfa weevil populations as a census tool. It did not capture many first instar larvae and therefore failed as a predictive tool (Cothran and Summers 1972). The sweep net was not comparable to square foot (929 cm^2) samples taken in the same area (Stevens and Steinhauer 1973). However, Surgeoner and Ellis (1976) compared square foot samples with sweep net and found them correlated. The 180-degree sweep captured about 1.8 times as many weevil larvae as the pendulum sweep (Cothran, Summers and Franti 1975). Statistical differences have been detected among samplers without reference to the field populations sampled.

One problem often encountered in sweeping was the large number of individuals returned in a sample. Parker (1970) recommended using a volumetric measure with a counted sample as a calibration for population estimates. Another recommendation was to use a sequential sampling procedure based on the number of captures of the target species. However, problems with the sweep net are outweighed by its utility in determining relative population densities and ease of sampling.

Other tools and techniques have been used to determine the field populations. The D-vac has been used extensively in the field. Stevens and Steinhauer (1973) released marked weevils in confined areas and then sampled the plot three times with the D-vac (30 seconds each). They recovered 75% of the weevils released and concluded the natural population was much more difficult to sample. Manglitz et al. (1978), studied soil removal and sifting, following pyrethroid soil drenches to estimate the number of adults in the field. The drench produced twice the number found by sifting soil without a drench. They also labeled adults by feeding them alfalfa enriched with radioactive phosphorus then recovered the adults during the following six weeks in the field. Harcourt, Binns and Guppy (1983) compared the D-vac with the soil drench technique. The sample site was chosen by tossing a sample frame. The variation between sample units was the greatest source of error. The D-vac was more efficient than the soil drench. The soil drench required between 100 and 165 samples and seven hours to evaluate depending on whether 929 or 464.5 cm^2 were used. In another study of sampling efficiency, an area was swept three times to determine the proportion of insects captured. Pruess, Saxena and Koinzan (1973) found that weevil larvae fell off the plants and were unavailable for later capture. Care should be exercised when choosing and comparing sample methods.

Once a sample was returned to the laboratory, the insects must be sorted from the 'sample trash'. Stem samples have been commonly placed in Berlese funnels for a specified period of time to separate insects from the debris. Berlese funnels require a large commitment of space, time and heat to drive the insects from the sample. Roberts, Bartell and Armbrust (1979) evaluated hand-sorting of stems and Berlese extraction of insects. They found the Berlese funnels as good as hand-sorting but with less labor and the results were suitable for absolute density estimates. Summers and Newton (1983) found a 30-minute treatment with 4-methylpentanone-z in an ice cream carton gave reproducible results.

Ruppell (1974) compared diurnal sweep sampling for capture of weevils. They found larval samples did not vary with time of day, but more adults were captured in the early morning and evening. Southwick and Davis (1968) using a rotating net did not capture adults flying in the morning or evening during early spring, suggesting the flights occurred during the day when weevils returned to the fields.

Traps. Emergence, pitfall and sticky traps have been used to study alfalfa weevil populations. Miller, White and Smith (1972) studied overwintering parasitism by capturing weevils as they emerged from overwintering sites. Smaller emergence traps were used by Roberts et al. (1978 and 1979 b) to correlate the return of weevils from aestivation sites and movement within the field.

Pitfall traps techniques and uses were reviewed by Adis (1979). His suggestions were followed in the current studies in placement of the traps. Gist and Crossley (1973) offered some good suggestions, including how to drain the water from traps. Morrill (1975) published plans for a pitfall trap that was constructed of readily available materials. Pausch et al. 1979 published plans for a linear pitfall trap that was able to capture large numbers of arthropods because of its unique structure. Wise (1981) pointed out that there may be behavioral differences in the sexes that did not allow for an accurate estimate of the population based on captures alone.

Feeding and control. Hintz, Wilson and Armbrust (1976) stated that early larval feeding reduced the yield of the first harvest at densities as low as 1 larva for 4 stems. Liu and Fick (1975) stated that weevils not controlled as larvae would reduce second crop yield due to feeding on the regrowth. Wilson, Stewart and Vail (1979) studied the effects of uncontrolled weevil feeding and found they could defoliate a stand completely. They felt the benefit of control did not come with the first harvest but was justified because of increased yield of subsequent crops.

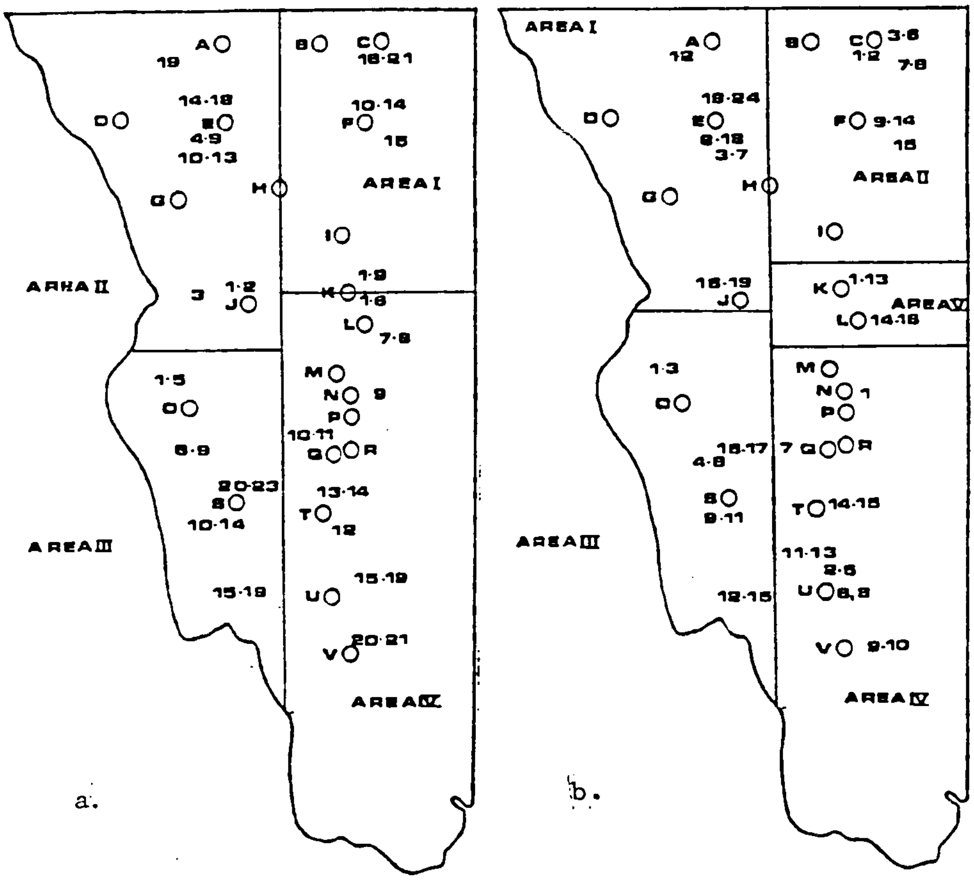
Recommendations are often made to control the weevil with malathion stubble-treatments then credit rapid regrowth to reduction of late instar larval feeding. Feeding studies of newly emerged adults (summer adults) indicated they ate 4.5 times as much as feeding larvae or 35.3 mg per individual on the average from egg to adult ready to oviposit the following spring (Bjork and Davis 1984). This was enough to stop the regrowth of the second crop and was an additional reason to control the larval population before it matured and damaged the alfalfa.

METHODS

Population trends of insects associated with forage alfalfa in Cache Valley, Cache County, Utah were assessed in approximately 100 fields during 1977-1979. The fields were chosen by consulting the Cache County Cooperative Extension Agent and obtaining a list of progressive producers. From this list, growers from each of four representative areas (Fig. 1) were chosen and their permission obtained to include their fields in the study. All fields had been in alfalfa for a minimum of two years. Younger stands were added to replace fields removed from production during the study. The new fields were commonly not adjacent to fields initially evaluated but were in the same area. These studies served as the foundation for the later, more detailed studies in six selected fields studies conducted during 1980-81. A list of growers, field locations and soil types is included in the Appendices (A1).

General field description.

The same methods were used to sample all fields regardless of location and size. When full sets of samples could not be collected from a given field on a sample date, no samples were taken. Problems related to incomplete data sets were minimal, but occasionally irrigation or weather prevented the completion of sampling. Alfalfa fields were selected from the Idaho border near Cornish and Cove on the north end of Cache Valley to the south end near Avon, Utah; selection crossed the width of the valley, an area approximately 40 X 16 km.



A. CORNISH
B. LEWISTON
C. COVE
D. CLARKSTON
E. TRENTON
F. RICHMOND
G. NEWTON
H. AMALGA
I. SMITHFIELD
J. BENSON
K. HYDE PARK
L. NORTH LOGAN
M. LOGAN
N. RIVER HEIGHTS
O. MENDON
P. PROVIDENCE
Q. NIBLEY
R. MILLVILLE
S. WELLSVILLE
T. HYRUM
U. PARADISE
V. AVON

Fig. 1. Map of alfalfa insect survey areas and approximate field locations in Cache Valley, Utah for: a) 1977-1978 and b) 1979.

Each field was to be sampled once a week during the growing season. A sampler was assigned to each of the areas. Samples were returned and processed in the laboratory rather than in the field to ensure that the counts were as accurate as possible. The samples were taken early in the week, frozen and counted the same week. Most samples were taken between 10 a.m. and 6 p.m., but night samples were taken after 10 p.m. during late July, prior to the second cutting of alfalfa for evaluation of adult weevil populations. Usually 20 to 30 minutes were required to sample a field. Some larger fields required more time due to the distance between sample sites. The number of fields sampled per day, per sampler, ranged from 3 to 7 depending on the distance travelled between fields and the height of the alfalfa.

Alfalfa sampling was adjusted around the harvest schedules. The first cutting normally occurred between 1 and 14 June (Julian day 152 to 165). The second crop was harvested near the end of July or during early August. The third crop was cut after the middle, or during late, September. The alfalfa was sampled with a short-handled (61 cm) sweep net (38 cm diameter). Stem samples were also taken as described in the sampling section. As the alfalfa developed, insect populations increased and sample processing became more difficult. Insect populations were highest prior to the first two cuttings and were low in the third crop during August and September.

The study included all areas and agricultural practices common in Cache Valley. Soil types were determined using the Cache Valley soil survey, and broad categories only are listed in Appendix A (Erickson and Mortensen, 1974). Three types of water management were common:

sprinkle, flood irrigation, and non-irrigated. Dryland fields were surveyed only during the spring since there was little or no regrowth after the spring soil moisture was depleted. Fields ranged in size from 1.2 to 62.5 ha. In 1979 we increased the number of areas and fields in order to obtain replicates within selected areas. The valley was divided into five areas instead of four and the number of fields was increased from 84 to 98. The overall arrangement was kept the same but replicates for the Hyde Park area were added (Fig. 1 b, Area V).

Extra help was hired during the 1979 season. The sample schedule was maintained and the samples quickly processed. Forty-two fields were in the study for the entire three year period. Thirty fields were included for two years and 50 for one year.

Field sampling outline. Each field was an experimental unit and was sampled as a stratified random subsample as follows. Field samples were drawn from five areas designated within the field as northeast (NE), northwest (NW), southeast (SE), southwest (SW) and center (C). Each general area was predetermined, but the sample site was chosen at random within each area (Fig. 2). Similar schemes have been used successfully in many integrated pest management (IPM) studies.

Each set of field samples included both stems and sweeps. Each field was assessed for alfalfa weevil populations, including adults, larvae and eggs, plus other insects including parasites and predators. The sweep samples were used to estimate the number of weevil adults and late instar larvae present. The stem samples was used to estimate the number of first and second instar larvae. Hand examination of ten stems taken from the stem sample was used to estimate the number of

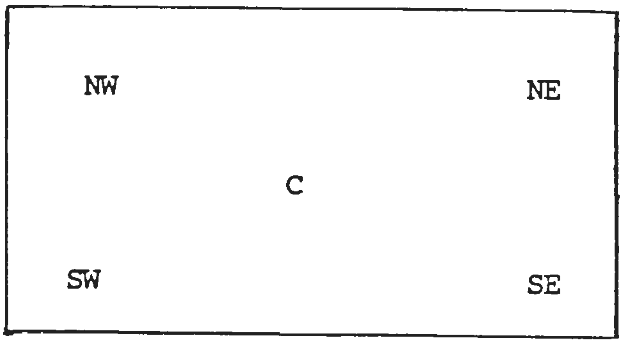


Fig. 2. Randomized subsample scheme used to guide sampling a field

oviposition and feeding punctures and total eggs. This allowed a comparison of the sweep net technique with two absolute population estimates obtained from the same vicinity.

The sweep samples were gathered with a standard sweeping net. The handle was 61 cm long, the hoop was 38.1 cm in diameter and the bag was made from muslin. The 180 degree sweep had a radius of about 1.8 m, the hoop covered an area of 12.2 m^2 and enclosed a volume of 3.6 m^3. The sweep sample was randomized by throwing the sweep net into the alfalfa and taking the sweeps in the direction the handle pointed. When sweeping, the net was swung in a 180 degree arc starting at the side and drawn in front of the body, finishing on the opposite side. Twenty sweeps were taken while walking, covering about 18 meters from the initiation point. If the path intersected the outer field margin before completion, the sampler proceeded in a 'J' pattern. Sweep sample paths did not cross on the same day but no attempt was made to avoid sampling adjacent to another subsample area. The sweep sample was emptied into a cardboard pint container, returned to the laboratory and frozen for later counting. A stem bouquet was collected before sweeps were taken. It consisted of an entire crown (about 25-35 stems). The sample was clipped as close to the ground as possible, or within three centimeters of the soil surface. It was then placed in a paper bag, protected from heat and returned to the laboratory for evaluation.

Field records included the field identification, date, time of day, height of the alfalfa and the name of the sampler. Current weather conditions were recorded. Including information on cloud cover, crop condition and an estimate of the wind and temperature. These data were collected in all fields on each sample date.

Laboratory procedure. The stem bouquets were divided into two groups with ten stems processed in a Berlese funnel for 24 hours and ten stems examined by hand.

Stems for hand examination were stored in a refrigerator at about 5^{o}C if they could not be processed immediately. Stems in the Berlese funnels were removed after 24 hours to reduce egg hatch. The larvae were counted using a dissecting microscope. Larval instars were determined by a head capsule caliper (Bartell and Roberts 1974) whenever doubt existed as about the instar.

Ten stems from each sample were examined by hand. The length of each stem was determined to the nearest inch and recorded. The total number of punctures was recorded for each bouquet. Total punctures included feeding holes and those with eggs present which were considered as oviposition punctures. The stems were then split and the number and color of eggs per oviposition site were recorded. The eggs were divided into three color classes: 1) yellow, indicating freshly oviposited eggs; 2) light brown, the middle and longest stage and, 3) head capsule visible, indicating imminent hatch.

Sweep samples. The number of each instar from the sweep samples was recorded during the early experiments. However, low incidence of first and second instar larvae in sweep counts compared to Berlese funnel samples caused doubts about the validity of early instar sweep data. Total larvae in sweep samples were counted and pooled for later work.

The sweep samples were removed from the freezer and placed in an 36 x 41 cm white photographic developing tray. The time to enumerate each 20-sweep sample required from 5 minutes to 2 hours depending on the number of insects. Adult weevils, weevil larvae, *Bathyplectes curculionis*, adults of each species of predatory insect and miscellaneous insect pest were counted. When pea aphid numbers were high, the sample was spread evenly over a grid and aphid numbers estimated. Each area of a field was evaluated and recorded separately then data were combined to calculate a population mean.

Logan area samples

The early studies were centered on alfalfa weevil population trends and comparisons between areas. The studies did not yield the detailed information needed for long range forecast of outbreaks. During this phase of the work, I served as a technician in the alfalfa ecosystem studies. For the more specific PhD work starting in 1980, six fields were chosen near Logan, Utah. Detailed analyses of both biotic and abiotic factors centered on these fields. The fields were located along an east-west transect from the eastern foothills, the bench, area to the valley floor near the Logan airport.

Fields were sampled daily or as weather permitted during the early spring. The data were collected for regression analyses and included factors to explain the insect population growth, population relationships and finally, prediction of weevil outbreaks. Pitfall traps and sticky board traps were placed in each field starting in 1980. Maximum-minimum recording thermometers were placed in three of the fields. All fields were planted with the alfalfa cultivar 'Ranger' and were sprinkle-irrigated.

Each field had a linear array of pitfall traps to sample ground movement of adult weevils, and sticky boards to sample insects in flight. During 1981, three grid array sample areas were added to study insect movement in mark-release-recapture experiments.

Stem density of each field was determined after the first cutting by tossing a metal ring into the field and counting number of alfalfa crowns and stems. The ring enclosed 929 cm^2. Stem density was determined in many areas of each field. The number of adults in each pitfall trap was recorded, then captured adults were marked and returned immediately to the field. Insects on sticky boards were counted and removed. Insects collected in sweep nets were not returned to the fields.

Field procedure. The biota in the alfalfa field were first sampled as weevils began their activity in the spring. Attempts to sample the entire insect population simultaneously led to several different approaches. When the alfalfa was short the pitfall traps and sticky boards were important. As the crop developed the sweep net became useful. After harvest the crop was not normally sampled until growth resumed.

Pitfall trap. The pitfall trap was used to monitor ground movement of adult alfalfa weevils especially as they returned from overwintering sites to the field. Pitfall traps were also used in mark-release-recapture studies. Adults crawling on the surface would fall into the trap where they were unable to escape. The traps were functional for 24 h a day in contrast to the few minutes for most other sampling methods, including the sweep samples. A trap consisted of three Solo^{R}. cups that fitted one inside the other (Fig. 3).

The 946.3 ml cup was buried to the rim in the soil and the two smaller cups were placed inside it. The 118 ml cup was placed in the bottom of the large cup and held the insects. The tightly fitting cone-shaped cup, with the point of the cone cut away, snapped into the large cup and acted as a funnel for insects which fell into the cup. Small holes were punched in the bottoms of the 946.3 ml and 118 ml cups to allow water to drain out. After placement in the field, traps were covered by 10.2 x 10.2 x 0.64 cm plywood boards to prevent ground nesting bees from becoming trapped. The covers were held above the trap by three long nails with large heads. The traps were checked daily unless inclement weather prevailed. Following inclement weather, the traps were cleared of any debris or captured insects.

Each field had a linear pitfall array starting in a corner. The corner was chosen at random. The angle between the field margin and

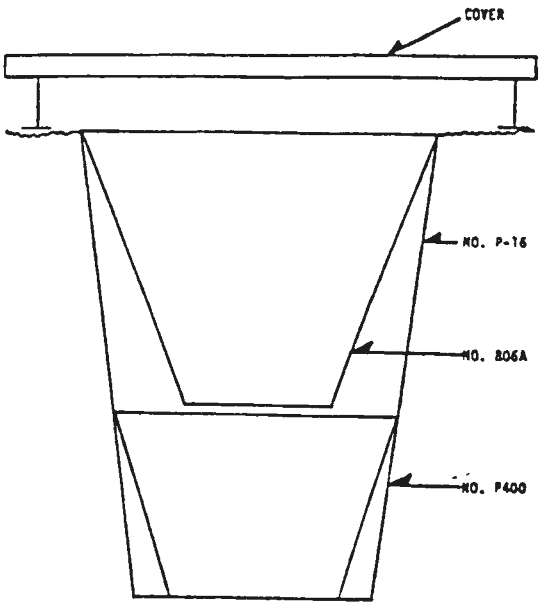


Fig 3. Diagram of a pitfall trap in place in the field (numbers refer to Solo^R numbers).

the array was 45 degrees and extended 40 m into the field. The array consisted of 20 traps, 2 m apart (Fig. 4 A).

<u>Sticky boards</u>. Flight has been shown to be involved in both re-invasion and dispersal of alfalfa weevils. Totally satisfactory aerial trapping techniques were not available; however, stationary sticky board traps supplied some data. They allowed continuous sampling with minimum maintenance.

One set of sticky boards was placed in each field. Each sticky board was a 10 x 20 cm of aluminum sheeting painted yellow. They were attached to a wooden cross constructed of two 5 x 5 cm boards, 1.2 m long. The arms of the cross were oriented to the cardinal points of the compass. The cross was attached to a steel fence post and placed at the end of each linear pitfall array (Fig. 4 A). Five sticky boards were attached to each arm of the cross. This resulted in 20 units, 5 facing each direction. The bottom of each unit was 90 cm above the

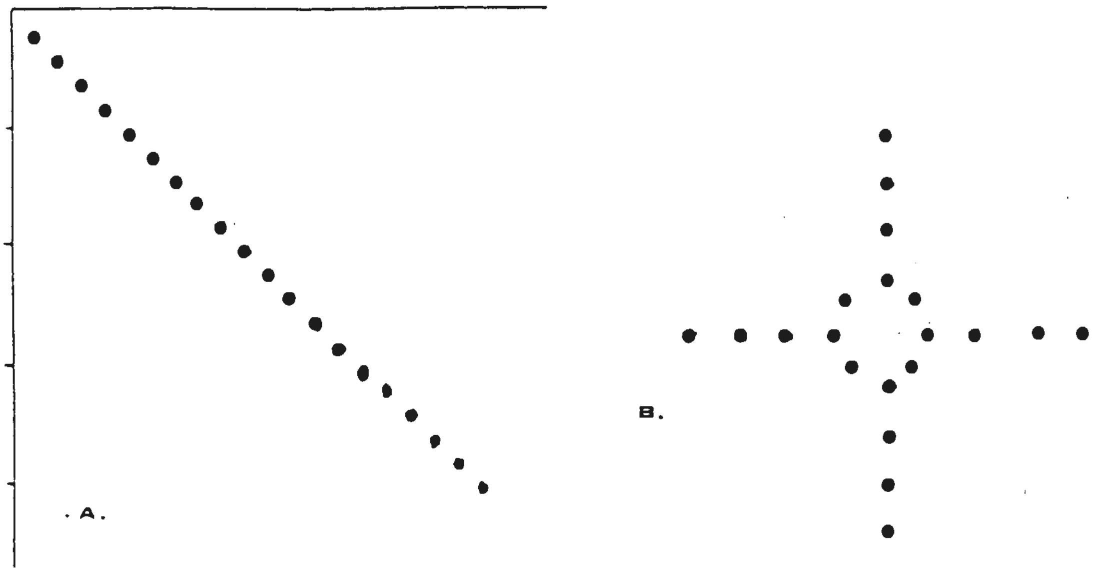


Fig. 4. Diagram of the two pitfall arrays used to sample alfalfa weevil on the ground. (a) two meters between traps (b) six meters between traps.

soil surface. As the alfalfa grew, the distance between the plant canopy and the bottom of the trap narrowed. The panels were coated with polyisobutylene (Tacktrap^R). When no longer tacky, they were removed, cleaned and one side recoated with Tacktrap. Recording thermometers were placed in three fields at the base of the sticky board traps. High, low and current field temperatures were recorded when insects on the panels were counted. Numbers of alfalfa weevils, lygus bugs, coccinellids, nabids and lacewings were recorded. These insects were removed from the boards during each examination

<u>Mark-release-recapture</u>. Weevil adults were collected with a sweep net and taken to the laboratory. Then the insects were marked with one of several colored enamels to indicate the date of release. The weevils were returned to the field and released in the same area where they were captured. The paints were tested in the laboratory for toxicity, with no effects detected. The enamel was applied to the

elytra in 1980. During 1981 fluorescent spray paints were used to mark larger numbers of insects. After a sample was counted, the insects were checked under ultraviolet light. Marked insects were easily detected.

Grid arrangement of pitfall traps. In 1981, a grid arrangement of pitfall traps centered on release sites was used (Fig. 4 B). Efforts were concentrated in three fields (Fields 1,4, and 5). Adult weevils were collected in fields not being studied, marked and then released in the center of one of the grids. The grid array of pitfall traps was checked daily. No sweep samples were taken in the grid area until just prior to harvest, then the grid area was swept intensively.

The grid array yielded information on the distribution and movement of insects. The array was oriented along the cardinal points of the compass. There were four traps in each cardinal direction and four extra traps near the release point for a total of twenty traps at each site. Traps were spaced 6.1 meters apart. Marked adults were released at the central point of the grid array. Five sweeps with an insect net were taken to the right and to the left of each pitfall trap just before harvest. The area between traps was swept in a final attempt to recover as many marked adults as possible. The central area was also swept thoroughly. Information was obtained on distribution of both weevil adults and larvae.

Field descriptions.

The fields were chosen along an elevation gradient representative of Cache Valley. They were all within 8 km of the Utah State University Research Greenhouse. The Wallace Beutler fields (Field 1 and Field 2) were located near North Logan. The Clair Allen fields (Field 3 and Field 4) were located near Hyde Park. The Claude Wennergren fields (Field 5 and Field 6) were located near the center of the valley to the south and east of the Logan-Cache County Airport. Fields 1, 2 and 3 sloped 3-6% from east to west. Field 4, Fields 5 and 6 sloped between 0-2% and had high water tables. Alfalfa yields were estimated at 5 metric tons per ha, per year, except for Field 3 which had an estimated yield of 4 metric tons per ha, (Erickson and Mortensen, 1974). All fields were sprinkle-irrigated, although irrigation was seldom required during the spring. Field 3 was a relatively new field which had been in production only three years. Field 2 had been in production for more than six years. These two fields had stony soil, and the thinnest alfalfa stands.

Field 1 was about 4.9 ha in size. There was a thin stand of alfalfa in the northeast area of the field. The soil was Parley silt loam, a well drained soil on the high Lake Bonneville terraces, benches. This field had pasture on both the north and east borders. To the south was alfalfa, and small grains were growing in the fields to the west

Field 2 field was about one-half mile west of Field 1. This 1.2 ha field was the smallest in the experiment. The soil was a Parley silt loam series with a high productive potential. To the east was a pasture. The field to the north was an alfalfa field. The west was bordered by a grain field. The southern border was a road and across the road was a pasture.

Field 3 was located within Hyde Park. It was about 3.2 ha in size. The soil was Ricks gravelly loam. It was located next to a residential area. The eastern border was a road. Across the road, was a field used for vegetable production. The northern border was a combination of homes and an alfalfa field. The western border was a canal. Across the canal was another residential area with a few livestock corrals. To the south was a mink farm and a residence. Litter and droppings from the mink farm were used as a soil amendment in this field.

Field 4 was located at the southeast border of Hyde Park. The soil was Collett silt loam. The northern half of this field had been drilled with alfalfa seed after the original stand had been established, and it had a higher stem density than the older half. This field was about 4.0 ha in size. It was bordered on the south, east and north by alfalfa fields. To the west was a road and across the road was a pasture.

Fields 5 and 6 had Millville silt loam soils of high potential alfalfa production. Field 5 was about 2.8 ha size and Field 6 was about 2.0 ha. This area had a high water table and was seldom irrigated. Both fields had strips of alfalfa on the northern margins that were cut about ten to fourteen days after the first cutting in the experimental fields.

Field 5 was bordered on the north by a pasture. To the west was an alfalfa field and to the south a field of small grain. To the east was a road, across the road was a pasture.

It was difficult to gain access to Field 6. Access to the sample area required a 0.4 km walk. To the east was an alfalfa field. To the north and west were pastures, while the south was bordered by a small grain field.

Statistical methods.

The data were analyzed using analysis of variance, regression multiple regression and Chi-square analyses. The areas (I through IV, 1977-1978; V, 1979) and the fields (1 through 6) were considered the experimental units in early analyses.

The analysis of variance is an arithmetic process for partitioning a total sum of squares into components associated with sources of error (Steele and Torrie 1960). The temperature regimes and populations of alfalfa weevil adults and larvae and Bathyplectes curculionis adults were compared in this manner. The areas were the experimental units with individual fields as replicates.

When the F-test was significant the means were separated using the Least Significant Difference (LSD). The LSD was calculated (Steele and Torrie 1960) and means compared at the level of significance implied by the F-test. Unequal means were handled with the unequal means formula.

Linear regression analysis is considered to be most useful when the independent variable contains unique information about the dependent variable. The equation describes the functional relationship between the variables observed (Ostle and Mensing 1975). The independent variable usually has the dimensions of Julian day, accumulated day degree, alfalfa height or some other factor likely to correlate with a change in the independent variable.

The calculated regression line is a simple summary of the relationship (Nie et al. 1983). The general formula is:

Y(estimated)=intercept(Inter) + (slope coefficient) X (variable).

The slope is a measure of the strength of the relationship between the Y variable and the X variable and is often designated the regression coefficient. The proportion of the variability explained in Y by X is designated correlation coefficient (R^2).

In some regression analyses, homogeneity of regression coefficients have been calculated (Steele and Torrie, 1960). The hypothesis was that no difference existed in the regression coefficients. If the test was significant the regression coefficients were compared with a t-test. The test slope was the combined slope of all fields analyzed as if taken from the same field (Combined). If a difference was detected (significant F-test) and the test completed, the fields that responded differently were marked accordingly.

Multiple linear regression was used in later experiments to determine the effects of multiple variables to estimate the Y variable. The strength of the of the correlation is reflected by R^2, the proportion of the variability explained (Nie et al. 1983).

Two factor analysis of variance allows the analysis of data that can be grouped according to two separate classifications and tests for significance applied to both categories. If interaction among factors exists the data can be plotted and the degree of interaction studied to determine how much one factor depends on the level of the other factor (Ostle and Mensing 1975, Ryan, Joiner and Ryan 1976). Nonsignificant interaction indicates the main factors were free of interference from other effects.

Covariance is used as a technique for controlling error and adjusting treatment means. In this case the covariates measured the environment, i.e. stem density, accumulated degree days, alfalfa height and lodging and had no direct relation to the insect population levels.

Chi-square analysis was used to analyze the count data associated with the pitfall traps. The test is not an exact test and cannot be used to separate means. The two way classification is based on distance from the margin of the field and in which field the adults were captured.

RESULTS

The results will be presented in two sections. The first will deal with the data collected from 1977-1979. The principle focus will be on environmental effects on the alfalfa and the weevil adults, larvae and the larval parasite, Bathyplectes curculionis during the first crop. This study centered on the relationship between the local temperature regimes and the rate of plant development and insect population dynamics measured with a sweep net.

The second section will present data from the six fields in the high population area and estimates of the number of eggs, larvae, and pupae.

Daily degree accumulation.

Daily degree-day accumulations were used to compare the seasonal development of both plants and insects.

Alfalfa plant. The physical environment of the alfalfa plant and associated insect fauna was compared with the temperature records of weather stations in Cache Valley (US Dept of Commerce, 1977-1981). Complex models of heat unit accumulation required more detailed data than available and provided no increase in reliability.

Initially, calculations were carried out for the January to June period. Only a few short periods above the lower threshold of 9°C were encountered before the first of March, so all later calculations were begun on 1 March. The dates are presented as Julian days.

The season was divided into early spring (1 March-19 April; day 60 to day 109) and late spring (20 April until harvest; days 110 to 155). Because the alfalfa growth was short few sweep samples were taken during early spring. Late spring started when growth was adequate for the sweep net to be used and ended when the fields were cut. Mid-April was also about the time of the first detectable signs of alfalfa weevil feeding and oviposition in the fields.

Degree-days were used as indicators of daily physiological development. Warm years had a greater accumulation of DD. A two factor analysis of variance was calculated using DD for alfalfa during early spring (Table 1). This tested the effects of the weather regimes from the valley locations on both weevils and alfalfa.

The factor analysis of early-season degree-days (Table 1), indicates there were significant differences between years with no significant differences among the sites and no interaction between years and sites. The early-season's temperature regimes from year to year were different. The means (Table 1) represent the degree-day means for each year and weather station mean for the three years.

The coolest early spring season was 1979 and the warmest was 1978. By late April, a substantial number of degree-days was accumulated during warm years. One weather station in Cache Valley can be used to represent the entire area during early spring with minimal error.

Late-spring mean separation of the alfalfa degree-days is presented in Table 1. The temperatures recorded during each of the three years and at each of the five sites were significantly different (P>0.01%). The yearly means separate into high, average and low

Table 1. Mean separation of degree days for the three years (1977-1979) and five weather stations in Cache Valley.

	Julian day 60-109		Julian day 110-155	
YEAR	PLANT 5°C	WEEVIL 9°C	PLANT 5°C	WEEVIL 9°C
1977	0.68 a **	0.13 a **	8.42 c **	4.75 b **
1978	2.29 c	0.42 c	6.24 a	2.90 a
1979	1.29 b	0.29 b	7.61 b	4.16 b
WEATHER STATIONS				
KVNU	1.51 NS	0.29 NS	6.99 a *	3.66 a *
USU	1.75	0.38	8.46 b,c	4.79 b
SW5	1.51	0.32	6.86 a	3.43 a
RICH	1.73	0.32	7.19 a,b	3.73 a
TREN	1.48	0.23	6.60 a	3.25 a
SOIL	1.41	0.15	8.60 c	4.77 b

Note: means followed by the same letter are not significantly different; NS=nonsignificant; *=P>0.05%; **=P>0.01%.

seasons. The soil temperature was lower than the ambient air temperatures during early spring but warmer during the late-season. By late spring, it was possible to distinguish both warmer or cooler areas and years based on mean degree-days. Because there was no interaction between the years and the sites, interpretation of the means was as above. Degree-day accumulations were different between sites in the valley. The Green Canyon bench area was the warmest and the Southwest Experiment Station was the coolest. The harvest pattern was similar, warm areas were cut first and cooler areas were cut last. The same pattern extended from 1977-1979 through 1980-1981.

The soil temperature taken at SW5 was a rough comparison between the ambient air and soil temperatures. The soil and air temperatures were not significantly different during the early spring. Later, the mean soil temperatures were significantly warmer than the air temperature.

Alfalfa weevil. The alfalfa weevil developmental threshold used was 9°C. Two factor analysis of variance was carried out on the alfalfa weevil daily degree-days. These were similar to the analysis of the alfalfa plant development. Mean separation (Table 1) was carried out when the F-test (Appendices B1) was significant. Typically, the weevil development threshold was reached on only a few days during early spring. The annual temperature patterns were significantly different during the study period. The warmest was 1977 and the coolest, 1979. The annual first degree-days were accumulated as early as 18 March (1978) and as late as 6 April (1979). A steady but faltering increase in the daily mean temperatures followed the first accumulations. The weather station mean temperatures were not significantly different during the early-season, were different during the late-season.

The two factor analysis of variance of late-season weevil degree-day patterns is presented in Appendices B1. There were significant differences in accumulated degree-days between years but nonsignificant interactions. Regardless of development threshold temperatures, the accumulation patterns were the same for both weevils and alfalfa plants.

Accumulated degree-days during early spring were significantly different between years for both plants and insects. No significant differences were detected among the various valley weather stations for early spring during the three years. Trenton had the lowest mean degree-day accumulation for alfalfa weevils during the early spring (0.226 DD/Day) and the USU station at North Logan had the highest

(0.377 DD/Day). No interaction occurred between year and site. This allowed a comparison of local environments that were warm or cool.

During the late spring there was no interaction between year and location for accumulated degree days at weather stations. Years with warm temperatures in early spring were not necessarily those with warm temperatures in late spring. SW5 was warmer during early spring, but cooler in the late spring; otherwise weather stations held their relative positions. Late spring temperatures at the weather stations were stable between years, indicating warm and cool locations exist in the valley. For analyses involving low and high temperatures, the USU site was chosen as the high-temperature station and SW 5 the low-temperature station.

<u>Accumulated degree-days</u>. Mean alfalfa and alfalfa weevil accumulated degree-days were calculated from the combined data set. This combined regression was used as the best estimate of temperatures condition for an 'average' spring. Results for each year were compared to the test regression using a t-test for significance of the intercept and slope. The intercept was interpreted as degree-days accumulated during the early spring, and the slope was equivalent to the average growing degree-days accumulated per day above the threshold. The results of the regression analysis are shown in Table 2.

It was inferred from Table 2 that the accumulate degree-days per day during the spring were similar among years. Over the entire late spring period for the 3 years the plants accumulated degree-days at 1.8 times the average rate of the insect (alfalfa plants mean 7.75 DD/day and weevils 4.36 DD/day).

Table 2. The relationship of alfalfa plant and alfalfa weevil accumulated degree days (5°C and 9°C) on Julian days (20 April to 4 June; Julian days 110 to 155) during late spring for three years in Cache Valley.

YEAR = EARLY DD. + J DAY	(R^2)	T-Value	
		Intercept	Slope
Threshold temperature			
5°C			
1977 = −827 + 8.13 J Day	92.0 %	**	**
1978 = −663 + 6.79 " "	89.2 %	**	**
1979 = −907 + 8.37 " "	93.0 %	**	**
9°C			
1977 = −492 + 4.63 " "	85.7 %	**	**
1978 = −368 + 3.46 " "	82.1 %	NS	**
1979 = −458 + 4.53 " "	87.0 %	**	**
Years			
(1977 + 1978 + 1979)			
(5°C) = −804 + 7.75 " "	87.6 %		
" (9°C) = −466 + 4.36 " "	76.5 %		

J Day = Julian day; degrees of freedom = 300; NS = Not significant; **=P>0.01%.

Colder early springs were indicated by slopes lower than the three year average and warm late spring slopes were higher than the mean slope. The alfalfa weevil developmental threshold was higher than that of alfalfa but few differences in the early spring patterns were detected (Fig. 5). A lower alfalfa developmental threshold resulted in large differences during the start of early spring alfalfa growth (1977 versus 1978). Early-season differences disappeared by the end of the May. The early differences were important to both alfalfa development and to weevil egg development. During very early spring the alfalfa accumulated roughly 5- to 6-fold the degree-days as the weevil. Compare number of degree-days accumulated in the early spring of 1978 for the alfalfa plant and weevil. The crop developed well ahead of the weevils.

An aspect not seen in Table 2 was the occurrence of cool periods during the late spring. The mean regression line along with the three-year high (1979) and three-year low (1978) is presented in Fig. 5. The upper line represents the highest degree-days accumulated (USU, 376 DD total), while the lower line was the lowest (SW 5, 278 DD total) during 1978. As seen in Table 2 the fit around the line was good (R^2=87.6%). The plotted average daily accumulated degree-days had some curvature and underestimated both early-season and late season degree-days. Log transformation straightened the line but there was only sight improvement in the fit (92.6%).

In summary, the ambient air temperature regimes from five weather stations were used to calculate the mean daily degree-days for Cache Valley. The greatest differences among stations occurred early in the

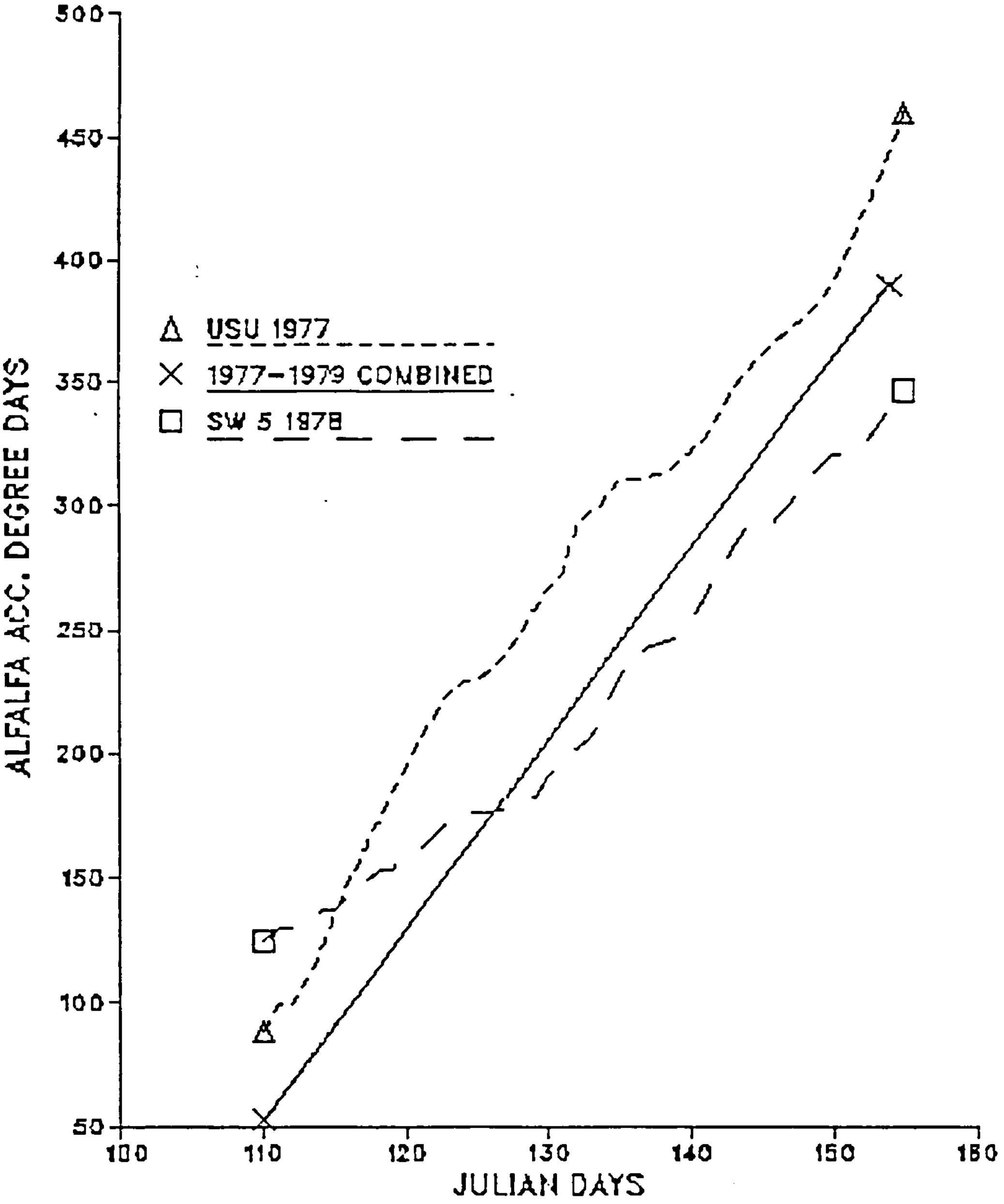


Fig. 5. Alfalfa plant accumulated degree days (5°C) for the location and year in Cache Valley with the highest degree day accumulation (Green Canyon, 1977), the lowest accumulation (Southwest Experiment Farm, 1978) and the three year mean (all stations for 1977–1979).

season. During the latter part of the season, degree-days were accumulated rapidly. The daily mean degree-day accumulations for alfalfa were plotted for the three years in Fig. 6.

Cool periods appear as flatter portions of the graph in Fig. 6. During 1979 the early spring was cool and only 34 degree-days, at 5°C, were accumulated. The late spring was warm averaging 8.37 DD/day. The season progressed rapidly to the first cutting. 1977 was also a cool (37 DD) early spring and finished with the greatest degree accumulation (340 accumulated degree-days). The latter two years accumulated 295 and 292 DD respectively.

The pattern for the alfalfa weevil degree-day accumulations (Fig. 7) was similar to that of the alfalfa (Fig. 5) except that the threshold was 9°C. The overall correlation for the three years of data was 76.5% (Table 2). The upper line presents the station with the highest temperature (USU 1977) 219 DD total, and the lower line represents the 1978 low, Trenton (194 DD). Only a few degree-days were accumulated during early May at Trenton during 1978. Cool periods lasted no more than a few days, but combined to slow the weevil population development.

Mean annual degree day accumulation above 9°C is shown in Fig. 8. The warmest year 1977 began with a warm spell followed by a cool period and a final warm period. The coolest late spring year was 1978. However, alfalfa and weevil degree-day accumulations started early in 1978. The weevils accumulated fewer degree-days compared to the plants. The threshold for the plant (5°C) was low enough for continued development while weevil threshold (9°C) was rarely reached during the

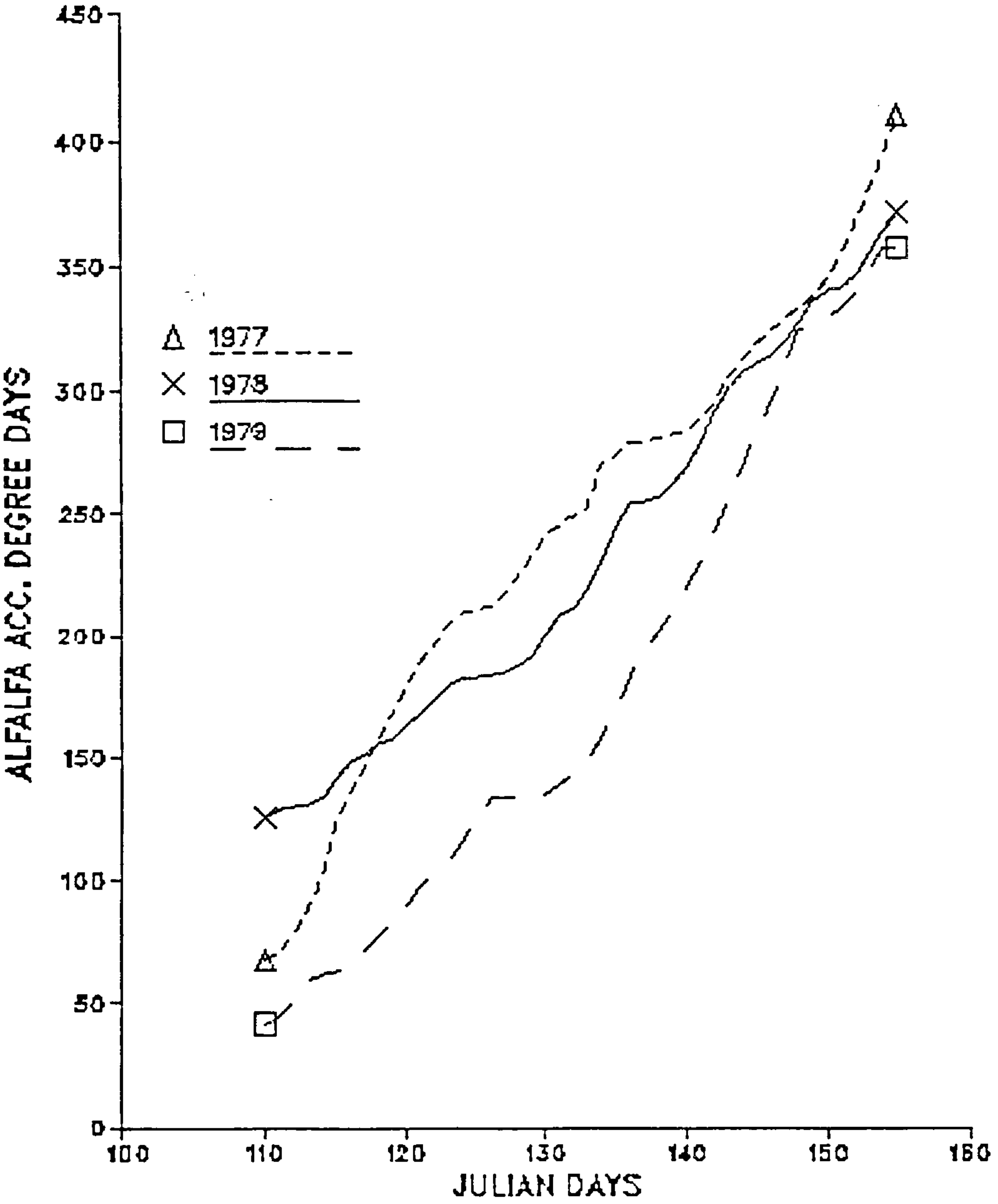


Fig. 6. Alfalfa plant annual mean accumulated degree days above 5°C for Cache Valley for 1977 through 1979.

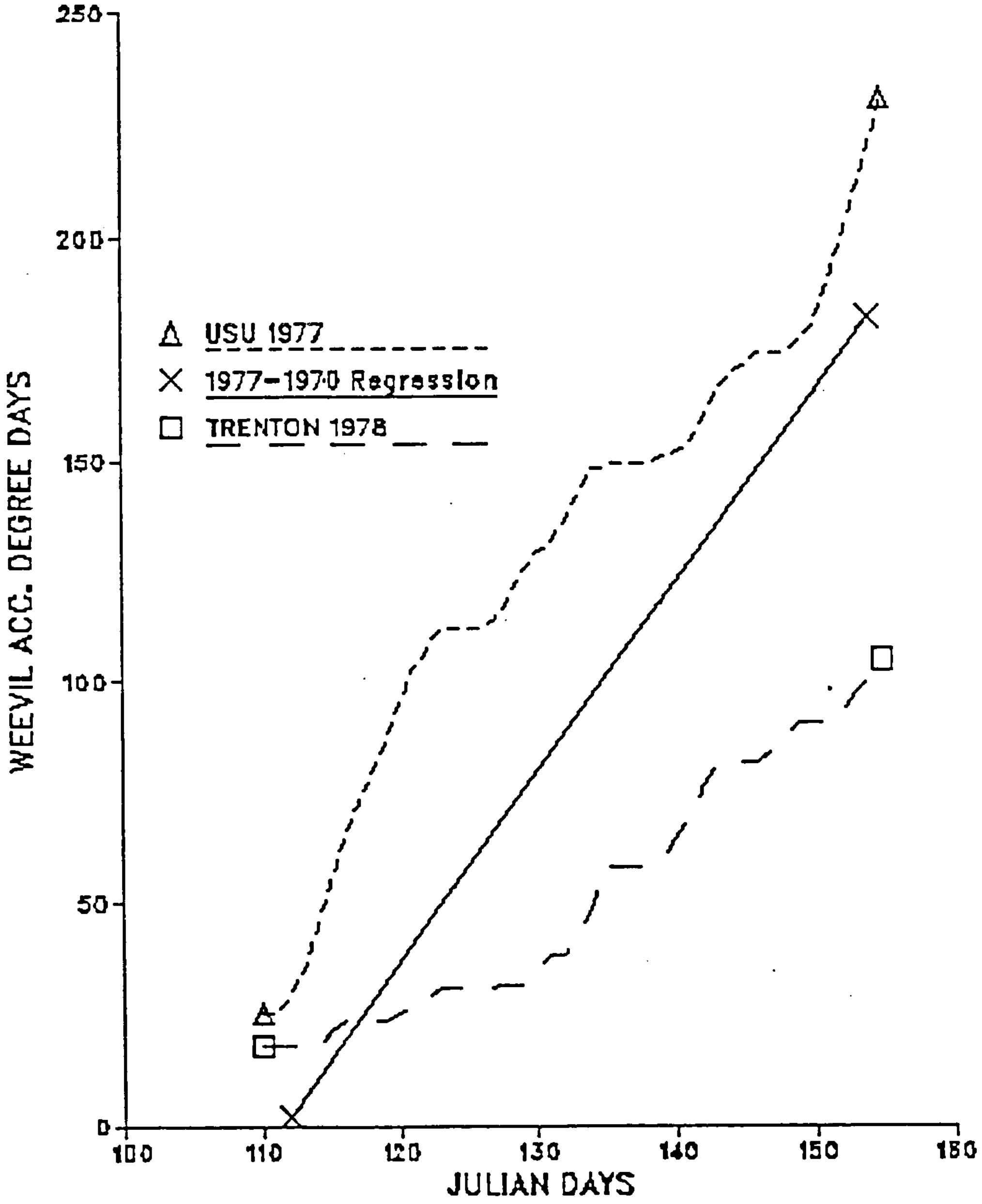


Fig. 7. Alfalfa weevil accumulated degree days (9°C) for the greatest spring accumulation, Green Canyon, 1977, lowest accumulation, Trenton, 1978 and the overall stations mean for 1977-1979.

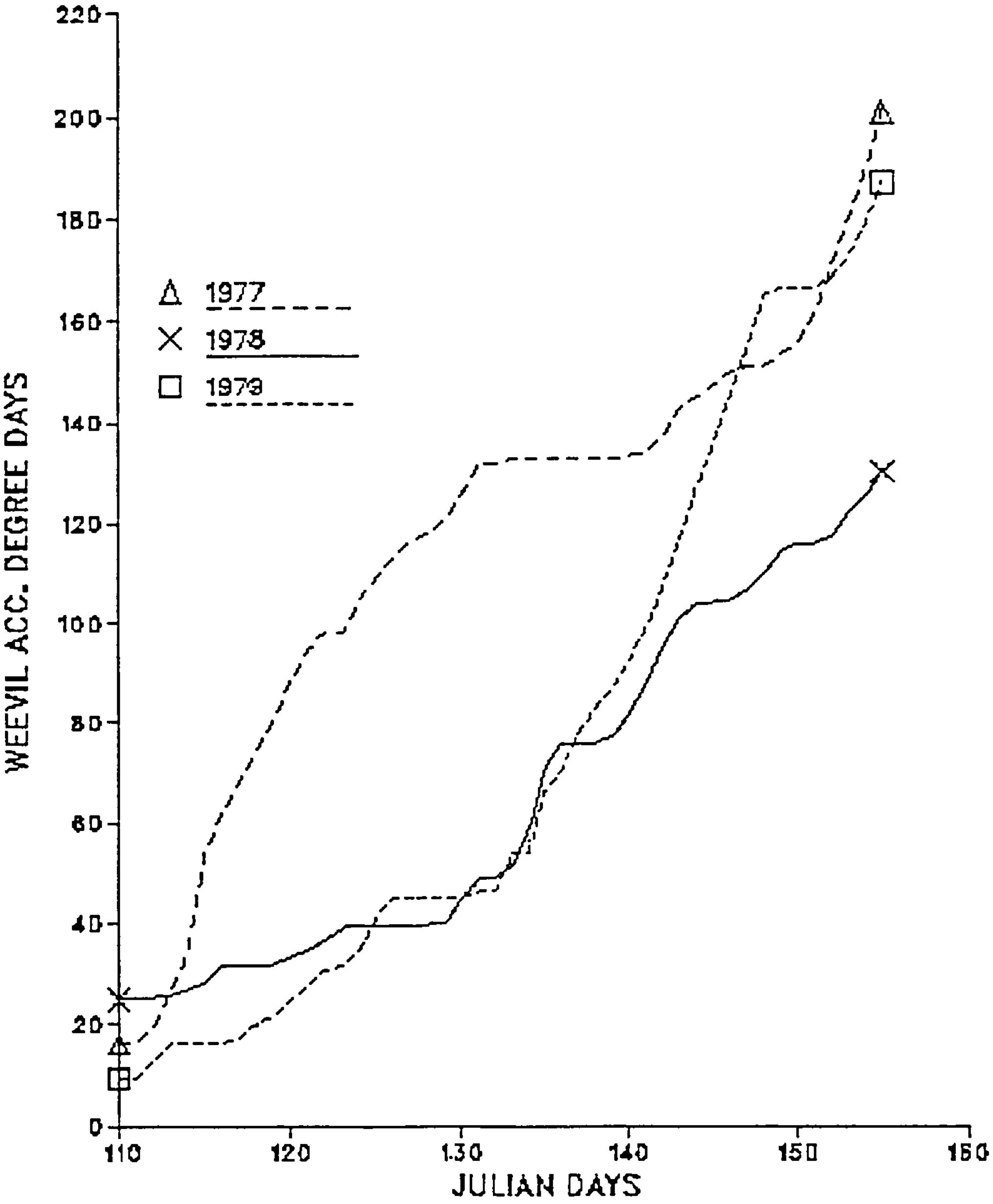


Fig. 8. Mean annual accumulated degree days above 9^{O}C for Cache Valley for 1977 through 1979.

same period (Figs. 6 and 8). The differences between the three years was more obvious in the alfalfa weevil degree-day accumulations (Julian days 60 to 109) than in the alfalfa plant degree-days over the same period. Since the adults fed and developed eggs during the early spring (Julian days 60 to 109), early season degree-days appeared to be more important to later larval population development, because of early environmental influence on adults. After the first of May, degree-days for both plants and weevils were accumulated at a more constant and predictable rate.

Environmental effects on alfalfa growth dynamics.

The physical environment governs the growth and development of both plants and insects. The alfalfa harvest date, based on projected alfalfa height, could be forecast and compared to the alfalfa height at any given date. That difference represents the expected degree-days required to complete plant development. Weevil populations can also be predicted based on life stages and numbers present at a given date. Weevil growth and development parallel alfalfa development.

Alfalfa height. Alfalfa height is an index of degree-days accumulated above the alfalfa developmental threshold (5^oC) and becomes an estimate of the seasonal progression. Two measurements of the seasonal progression were made in the current studies, one was field height and the other was stem lengths. Field height was recorded when sweeps were taken and reported as a field average. Stem lengths were recorded and averaged by field area for Berlese experiments.
More than half of the observations were recorded after Day 140 (20 May), and before Day 159 (9 June) during the period of greatest weevil

damage. The first ten days of the season had little growth and were not well represented.

The harvest was predicted to occur at or near 50 cm measured stem length, after Day 150. By Day 159 the limits around the mean stem length began to increase and the mean dropped to near zero (Day 165, 16 June). This indicated that the first crop had been harvested. The mean daily height means are presented in Fig. 9. The means were pooled stem lengths from 1977-1979. The confidence intervals around the mean would have been wider if the alfalfa growth varied greatly between years. Cutting was initiated around Day 156 (7 June) in those fields receiving the greatest number of growing degree-days; fields sampled later were those remaining after other fields had been cut.

When the measured stem length approached 45 cm, secondary growth tended to inhibit primary stem growth. The reported field heights were depressed because of plant lodging. Lodging was common with stem lengths greater than 50 cm. Mean field heights were therefore greater than indicated. The stem lengths were longer during warm years and in warm areas. Stem growth from each year was selected and the relationship with daily degrees was calculated (Table 3).

The 1978 season was chosen for analysis. The mean heights for both 1978 and 1979 had much tighter fits than the 1977 season. Their slopes were similar, ranging from 0.0099 to 0.012 cm growth per degree-day. Based on all weather station data from Cache Valley, the plants would be expected to grow about 50-55 cm in 555 degree-days during 1978 and only about 45 cm for 1979 based on analyses (Table 3).

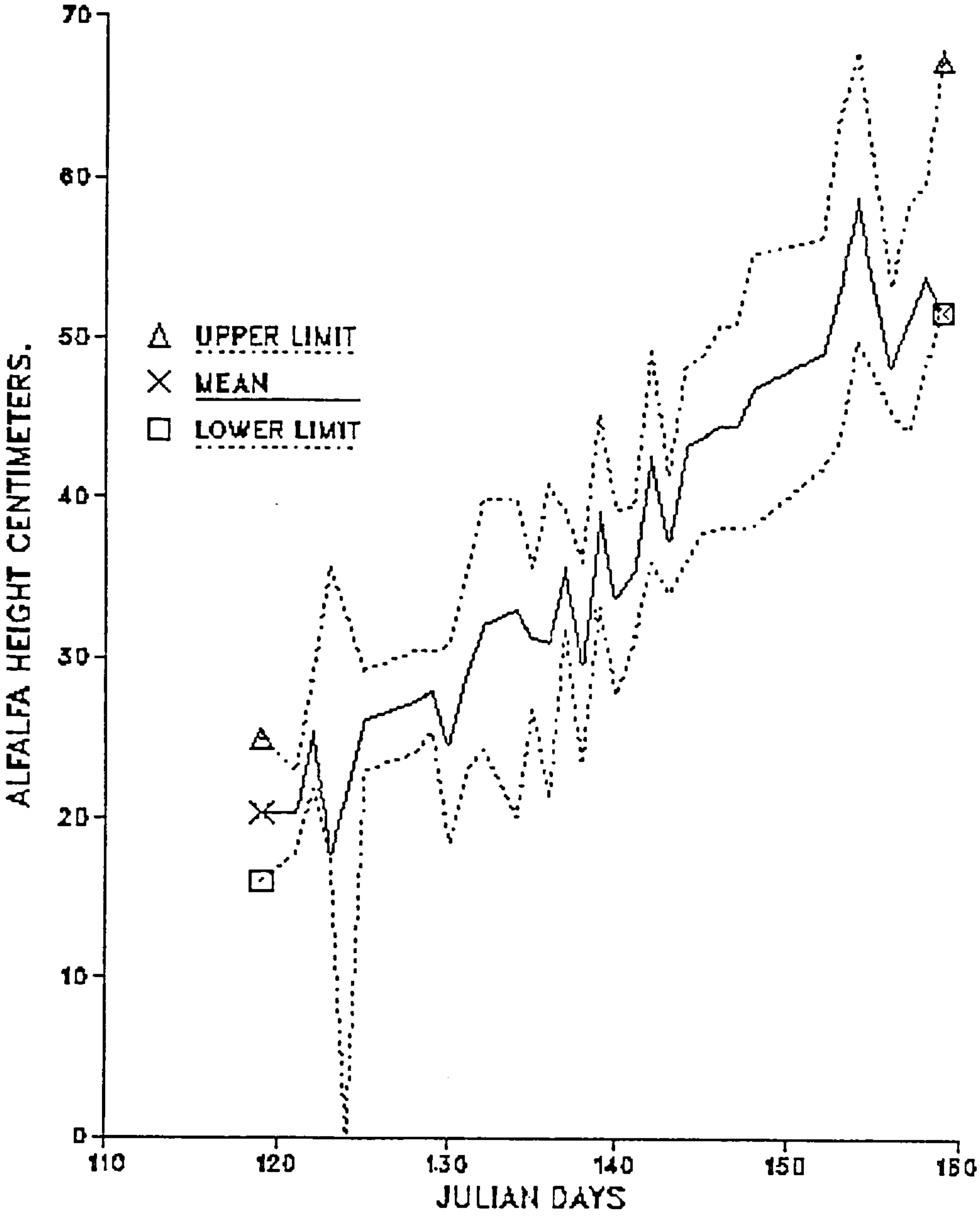


Fig. 9. The average alfalfa height for all three years; upper line is the mean plus one standard deviation, and the lower line is the mean minus one standard deviation.

Stem lengths from Area III, representing a relatively homogeneous area near the mountains in the southwest portion of Cache Valley, were regressed on degree-days from USU bench and SW5 valley floor locations (Table 3 b). There was a high level of correlation (high R^2) as more homogeneous portions of the valley were examined.

The mean alfalfa growing season to pre-bloom was 555 DD based on $5^{o}C$ (from Bula, et. al, 1975). By knowing either accumulated degree-days or the alfalfa height, an estimate of the heat units remaining to complete the season can be calculated. From Table 3, growth rates were site specific due to local cold or warm spots.

For instance, the estimated time to cutting based on a current eight of 38 cm and the cutting height of 53 cm would be calculated as follows:

53 cm cutting height/555 estimated degree-days to maturity;

=10.47 DD/cm (or cm/DD) = 1.0 cm/10.5 DD.

The average degree-days accumulated at this time of year (Table 3) were: = 7.67 DD/Day.

Substituting and subtracting within the equation:

53 cm (cutting hgt.)-38 cm (current hgt.)=

15 cm, (the amount of growth before harvest occurs)

converted DD to Julian days:

Height remaining X Number of DD to grow 1 cm=

estimated time to harvest/by the average daily degree =

time in Julian days to harvest, or

15 cm X 10.4 DD/cm=156 DD/7.67 DD/day = 20.3 days

or roughly 20 days to cutting.

Table 3. Relationship of the measured alfalfa stem lengths (Julian day 110 to 155) and accumulated degree days ($5^{o}C$) for weather stations in Cache Valley.

(YEAR Site)	= Height	+ SLOPE X (Acc DD)	DF	R
a. Valley (Areas I through IV) pooled stem length (cm):				
(1978 USU)	= 0.84	+ 0.0116 (Acc DD)	157	0.887
(1979 ")	= 2.30	+ 0.0099 (Acc DD)	157	0.865
b. Southwest Bench (Area III) stem length (cm):				
(1978 SW5)	= 0.861	+ 0.0157 (Acc DD)	71	0.958
(" USU)	= -.036	+ 0.0099 (Acc DD)	73	0.950

These calculations allow an estimate of the time remaining before harvest, based on expected accumulations of degree days. This information would allow for the adjustment of watering dates to facilitate early harvest which would increase insect mortality due to heat exposure. Pesticide applications could be used if needed.

Early season alfalfa and weevil degree-days. Not only was the alfalfa plant development predictable using degree-days, it was also possible to predict weevil development based on plant degree-days. The lower threshold temperature for plant development differed from those of alfalfa weevil, but the rates of degree day accumulation are parallel. The alfalfa and weevil degree-days for 1977, based on the USU recording station were plotted on Julian days (Fig 10).

During 1977, an early warm period lasted until 14 May, then the weather became unsettled and cool until late May. After Julian day 149 the weather became fair for the remainder of the season. The alfalfa gained about 3.1 degree-days per day during late April even when the weevil's threshold had not been reached. The slopes for alfalfa and

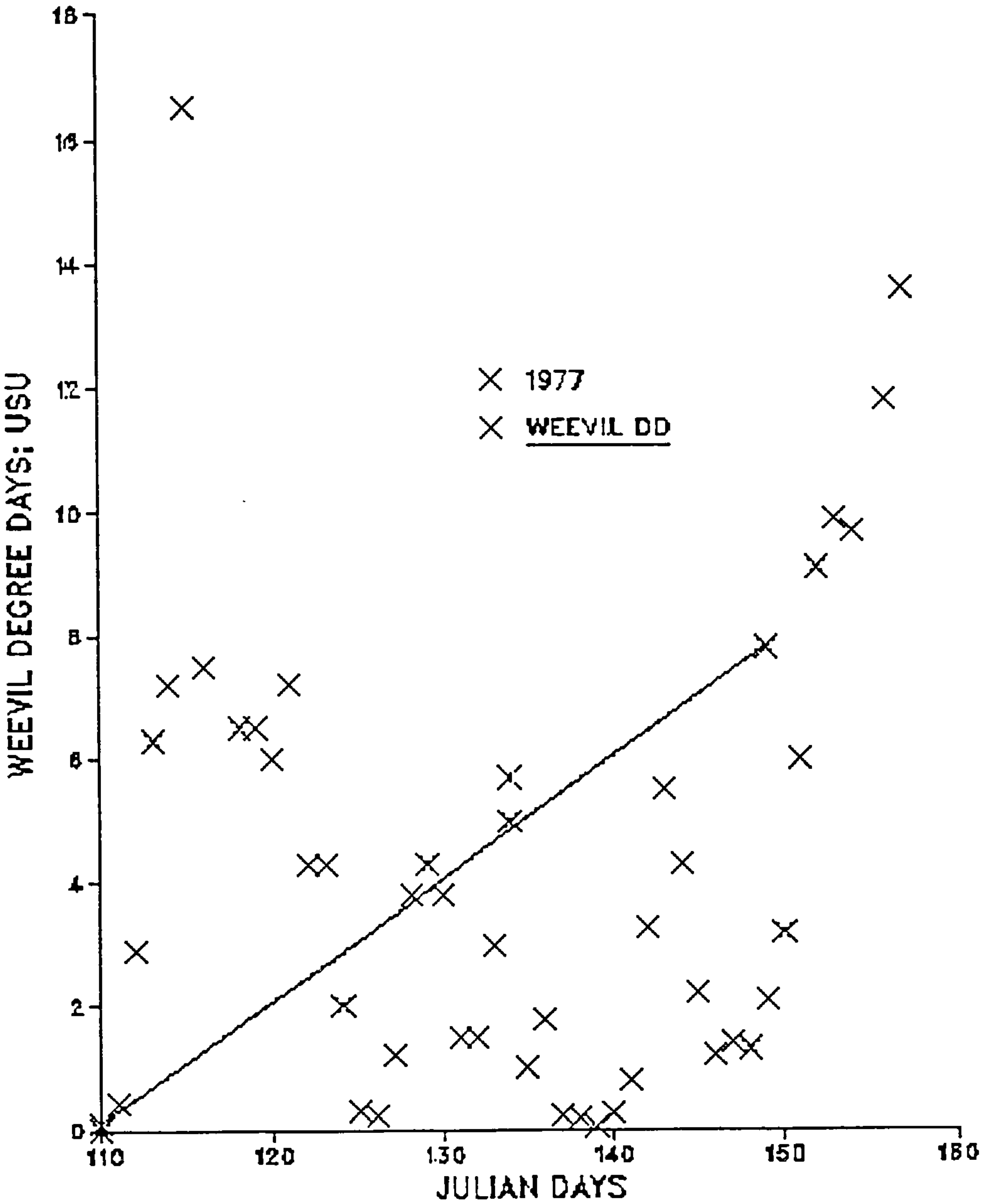


Fig. 10. The daily degrees days at USU for 1977 plotted on the Julian day. The plotted line is the regression line for the same season.

Table 4. Relationship between early spring alfalfa plant and weevil ($5^{o}C$ and $9^{o}C$) accumulated degree (Acc. DD) days regressed on Julian days (J day)(60 to 109) during 1977.

THRESHOLD	INTERCEPT DD		Acc. DD	X (J day)	R
9 deg C	-13.1	+	0.269	X (J DAY)	0.727
5 deg C	-16.3	+	0.261	X (J Day)	0.531

Note: INTERCEPT DD = degree days accumulated when measurement started; R = correlation coefficient.

weevil were parallel (accumulated degree day per Julian day, Table 4.). Late April and early May warm spells did not result in any daily degree day accumulations greater than 12.5 DD for weevils.

Sweep sample results.

Sweep net samples were taken from all valley areas under as many conditions as possible. The net could not be used when the alfalfa was wet or too short. The net was not effective on all stages of the weevil or under all conditions. The adult weevil movement on the plant is not totally understood and varies with time of day, related to both light and temperature, and the physical condition of the weevil. The first and second instars were never well represented in sweep samples and were also lost in the debris. There was a correlation between high populations of weevil adults and late instar larvae. The relationship between the weevil and its parasite, *Bathyplectes curculionis* was not easily measured with a sweep net. Large populations of aphids and weevil larvae made accurate counts of all insects difficult.

Daily means for adult and larval alfalfa weevils and *B. curculionis* are presented in Figs. 11 to 13 for populations samples taken during during 1979. These are similar to other years. The fields were designated according to the five valley areas and analyses followed.

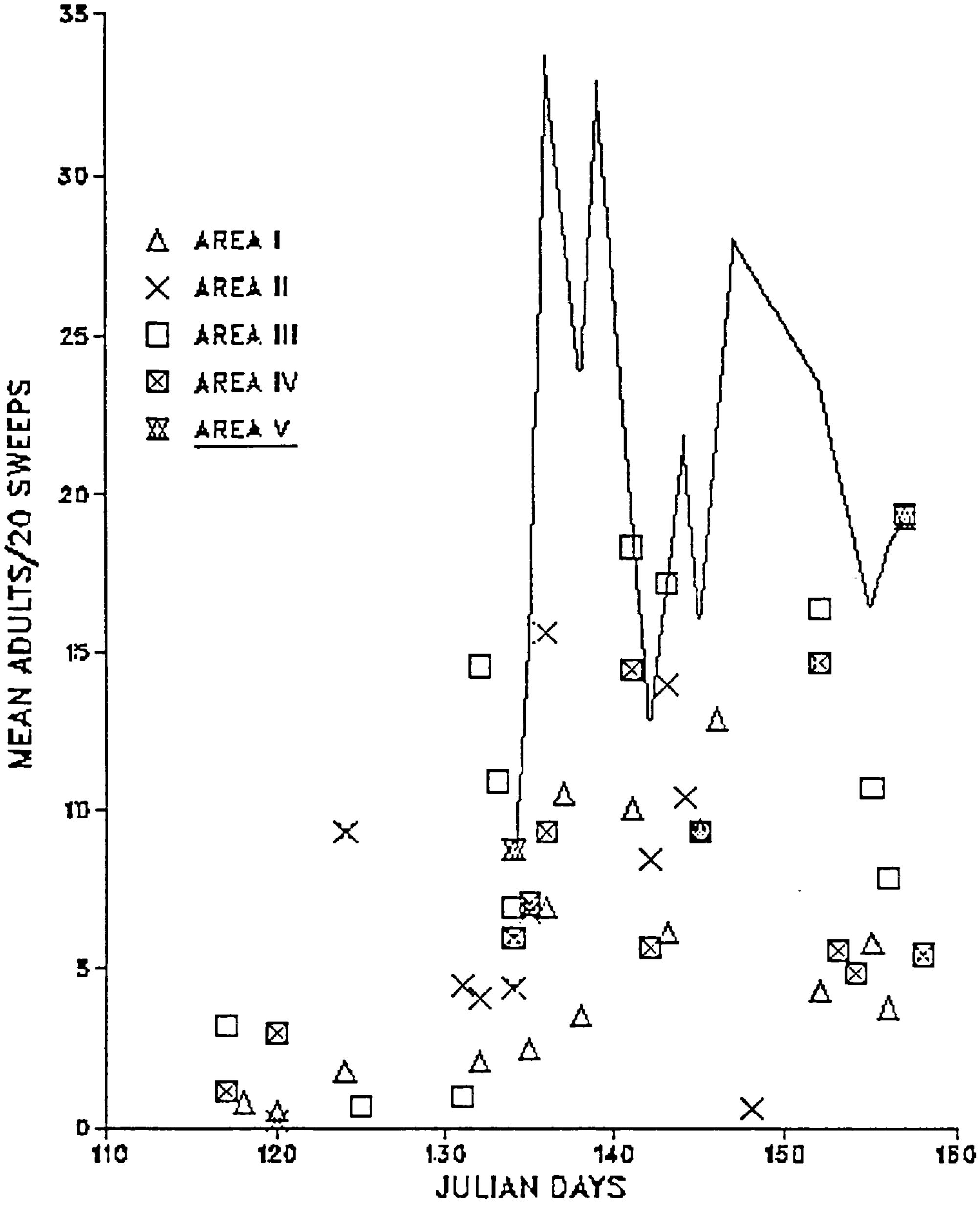


Fig. 11. The daily mean number of alfalfa weevil adults from the 5 Areas within Cache Valley during the 1979 season. The values from the Hyde Park area (Area V) located in the foothill areas on the east side of the valley are plotted.

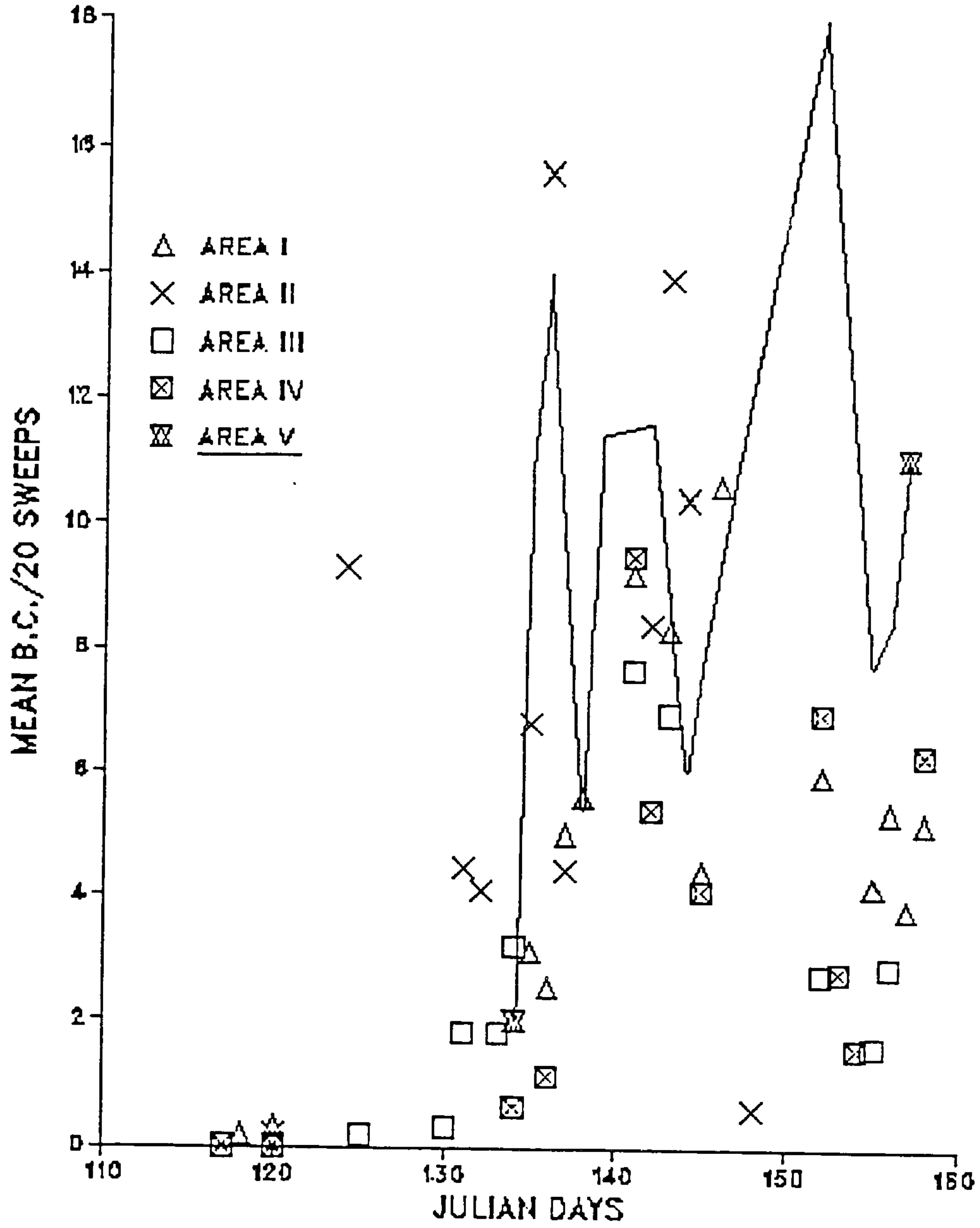


Fig. 12. Mean number of Bathyplectes curculionis adults collected in five areas in Cache Valley during the 1979 season. The means for Hyde Park (Area V) are connected.

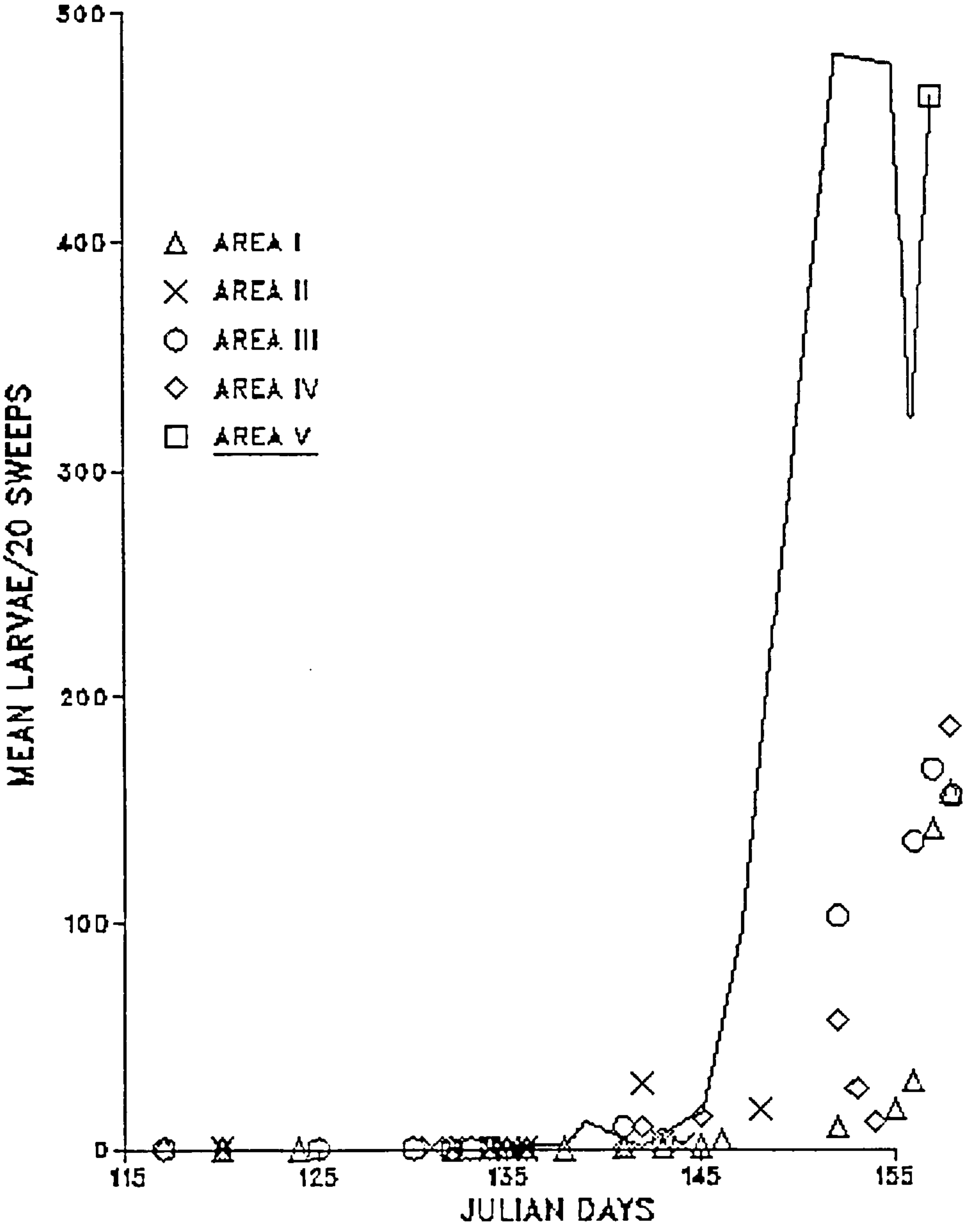


Fig. 13. Mean number of alfalfa weevil larvae collected in five areas in Cache Valley during the 1979 season. The means for Hyde Park (Area V) are connected.

Adult alfalfa weevil sampling. The mean number of adults per 20 sweeps during the 1979 season is presented in Fig. 11. The adult capture pattern was similar in all regions of the valley. The population, from Area V, had the highest mean seasonal capture rate (21.26/20 sweeps). Areas II, III and IV were intermediate (6.73, 8.83 and 12.63/20 sweeps respectively). Area I which was cooler developed later and had lower weevil populations (5.12/20 sweeps)(see Fig. 1 and Table 4). The population in Area I followed the same basic population curve, but at one-half the level of the higher population areas. Low population regions were detected but the cause was not determined.

Alfalfa weevil adults were captured in sweep samples starting when the alfalfa was about 18 cm tall, Fig. 9. The mean captures rose until the alfalfa lodged then they declined. Later, in June and early July, the number of adults rose as the new generation emerged and began to feed. No sampling method has been devised which can compensate completely for adult behavior and environmental effects.

Bathyplectes curculionis sampling. Bathyplectes curculionis were not captured in large numbers before the 10th of May (Day 130) during any year of the studies (Fig. 12). The mean number captured reached a maximum near Day 145, and then decreased before the alfalfa was harvested. Area III (mean = 3.26/20 sweeps) appeared to have the lowest B. curculionis populations, while Area V (mean = 9.96/20 sweeps) had the highest populations. Areas I, II and IV had similar means (4.78, 4.86 and 6.62/20 sweeps respectively). The B. curculionis numbers correlated weakly with both adult and larval weevil populations.

Alfalfa weevil larval sampling. The mean capture of larval alfalfa weevils per 20 sweeps during late spring (Julian day 110 to 155) for 1979 is shown in Fig. 13. Comparing Figs. 11 and 13, not that there was a delay between the capture of the first adults and the first larvae. Just before harvest, there was a rapid increase in the mean number of larvae captured due to the more effective capture of later instars coupled with the rapid increase in population size.

Area II had the lowest larval alfalfa weevil populations, (mean = 4.8/20 sweeps) while Area V had the highest larval weevil population for the season (mean = 202.3/20 sweeps). The mean populations in Areas I, III and IV were 16.6, 42.3 and 76/20 sweeps respectively. Differences in larval populations were not well correlated with numbers of adults in the same fields. If strong correlations between adults and larvae existed, Area V should have had the largest larval populations. While Area I did not have the lowest capture rate of larvae, it had the lowest number of adults. Area II had the lowest larval capture rate and an intermediate adult population.

The different larval stages in the sweep samples were verified using a head size caliper. First and second instar larvae were in low numbers and difficult to separate from debris in the bottom of containers. They were not easily dislodged during the sweep procedure. Sweep samples favored third and fourth instars. At normal cutting dates, the third instars still outnumbered fourth instars. The third and fourth instar larvae were seldom present in the fields until late May in cool areas or seasons. The sweep net did not allow accurate estimates of larvae prior to mid-May.

Such a poor relationship between early season adult numbers and subsequent larval populations were not expected. This was due apparently to adult behavior that resulted in inadequate sampling of adults, followed by difficulties in assessing larval instars I and II. Sweep samples of third and fourth instar larvae were quite consistent. Apparently adult population sampling was the primary source of error.

Seasonal trends

The abundance of the adult and larval populations relative to each other and related to the height of the alfalfa was important in determining the thresholds for larval control strategies.

Adult population trends. Overwintered adults were first found in fields before the alfalfa could be swept in the early spring. This occurred when the alfalfa had grown to 5-8 cm. The first sweep samples were taken when the alfalfa was about 10-13 cm tall, usually about the third week in April. As the alfalfa developed the sweep net engulfed more alfalfa. The number of adults captured with sweep nets declined when the alfalfa lodged. The alfalfa harvest in the valley began about 1 June during warm years and was delayed until 10 June or later in cool years.

In the second crop growth relatively few old adult weevils were captured but many new generation adults were captured. The overwintered females either died or became non-reproductive as the summer progressed. Few overwintered adults were collected in daytime sweeps during summer, but a few persisted through the season. When the alfalfa regrowth resumed during June, the new generation of adult weevils emerged and were captured in sweep samples. There was a difference in the collection patterns between the old and new generation weevils, with new adults being more strongly nocturnal. The total number of adults recovered appeared to be related to the alfalfa height. The mean numbers in daytime samples during the second crop were never as high as in the first crop.

After the alfalfa was cut the second time in late July or August adults were not seen in high numbers until the following spring. The weevils in eastern USA have been recorded flying from the field during the summer, then returning to overwinter in alfalfa fields. In Utah no late summer or fall return flight activity has been recorded. In these northern Utah studies weevils were captured in early spring on sticky boards, indicating spring flight activity.

Larval population trends. During early spring a very few larger larvae were captured in sweep nets when the alfalfa was short, indicating the probability of occasional development from fall eggs. When the alfalfa reached about 38 cm, about 20 May, the population of large larvae increased exponentially until the alfalfa was cut two or three weeks later. The highest populations sampled consisted of 1,800-2,000 third and fourth instar larvae per 20 sweeps in occasional fields. Ten to 40 per sweep were more common numbers encountered just prior to first harvest (Fig. 13).

After the first harvest the larval populations were much lower, due to reduced oviposition and non replacement of the larvae. Weevil larvae in the second crop rarely reached high enough population levels to cause damage. The larvae present were accounted for by continued egg production, or eggs in the stems hatching after the bales had been removed. A few larvae survived through the cutting process. If fields were watered soon after hay removal there was increased larval survival and adult oviposition. The larval population declined rapidly through June and July and by the end of the second crop very few were present.

Occasionally larvae were recovered during August and September. The late populations never exceeded one per sweep. These larvae were otherwise undetectable and caused no visible damage. They disappeared as the season drew to a close.

Bathyplectes curculionis population trends through the season. B. curculionis adults were found in the spring, and the population peak occurred shortly before high populations of late instar weevil larvae were collected. The population peaked at about the 38-40 cm alfalfa growth stage. The highest populations were usually in the range of 40 adults in 20 sweeps during mid-May. The distribution was rather uniform across a field but varied with location in the valley or between fields. Some resurgence of B. curculionis adults occurred toward the end of June.

B. curculionis numbers were synchronized with first and second instar weevil larvae which were sampled with the sweep net used to sample the adult parasites. After the first cutting, the later populations of B. curculionis were probably due to the emergence of second generation that had not entered diapause.

Detailed studies of six fields, 1980-1981.

These six fields were located in a warm area of the valley with a high population of alfalfa weevils. On initial inspection the fields were homogeneous. The studies conducted were similar to the earlier large area studies. The samples were taken as often as possible within acceptable weather and sampling conditions.

Field stem density. Stem density per 929 cm^2 was measured during sampling for larvae after the first cutting. The stem counts were taken from all areas of the field. The means are separated in Table 5. Low stem densities caused an increase in early-season heating of the ground and a consequent increase in plant and insect growth. Two Fields, 3 and 4, were also different in other ways, such as soil type and slope aspect. The stem density and alfalfa stem lengths were later used in covariate analyses.

Accumulated degree-days, max-min thermometers. Accumulated degree-days (DD) were compiled using max-min recording thermometers in the plant canopy. The thermometers were placed directly on the soil surface in 3 fields (1, 3 and 6). As plants grew the alfalfa shaded the thermometers. The data were compared with records from three local weather stations USU, KVNU, and SW5 from May through the alfalfa harvest period. Correlation analysis among the daily accumulated DD from each site was performed (Table 6).

Accumulated degree-days and alfalfa growth. Correlation between field height and measured stem length was fairly high (R^2=0.759). The alfalfa growth could be determined using either method.

The correlation coefficients were slightly better if USU weather station accumulated DD were used rather than field thermometers (Table 7). One source of variability in field thermometers was their nonuniform exposure to the same conditions from day to day. Some thermometers were shielded by the vegetation more than others. Another

Table 5. Analysis of variance of the alfalfa stem density (929^2cm) for the six alfalfa fields near Hyde Park and North Logan.

Field	1	2	3	4	5	6
Reps	48	41	23	50	26	28
Mean	34.8	25.4	23.2	43.8	33.0	33.1
**	b	a	a	c	b	b

Note: **=P>0.01%. Means followed by the same letter are not significantly different. See Appendices B2 for ANOVA.

Table 6. Correlation between weather stations and max-min recording thermometers in three fields (accumulated degree day 9°C) during the late spring (Julian days 121 to 155) for 1980 and 1981.

	LOGAN	KVNU	SW5	FIELD 1	FIELD 2
KVNU	0.999				
SW5	0.999	1.00			
FIELD 1	0.956	0.950	0.952		
FIELD 3	0.979	0.977	0.977	0.992	
FIELD 6	0.974	0.971	0.972	0.995	0.999

Table 7. Relationship of alfalfa height (cm) and accumulated degree day (9°C) with either USU Station (1 April to 10 June; Julian day 91 to 161) or Field 1 recording thermometer (1 May to 10 June; Julian day 121 to 161).

SOURCE		WEATHER SHELTER			MAX-MIN THERMOMETER		
FIELD	DF	INTER	SLOPE	%VAR.	INTER	SLOPE	%VAR.
2 a,c	57	-1.98	0.168	89.1	15.2	0.094	84.3
Comb.	350	2.42	0.178	88.4	18.8	0.097	85.4
4 b,d	49	1.97	0.201	94.0	20.7	0.107	94.0

Note: a=low intercept Julian days; b=high slope Julian days; c=low intercept accumulated degree days; d=high slope accumulated degree days; Comb=mean for all fields through the time period; DF=degrees of freedom; INTER=intercept; SLOPE=coefficient X accumulated degree day; %VAR=percent variability explained by the linear relationship. See Appendices B3 for ANOVA.

major difference among the fields was the alfalfa height at the start of the sampling regime.

The correlations were 10 to 15% lower if stem lengths were used instead of measured field heights, the difference was related to the manner of data collection. The field height was recorded once for each field on each date. Measured stem length was recorded 50 times from single stems and reported as five means. The variability around the measured stem lengths was higher but both measured the same phenomenon. Large area field heights were difficult to compare with the smaller area replicated samples (Table 8).

Weather stations and field thermometers gave similar accumulated DDs with no detectable differences among the data. 1980 and 1981 data from the USU weather station were used in the analyses.

Regression analysis of accumulated degree-days on Julian days. Regression analysis of accumulated degree-days, based on $9^{\circ}C$, on Julian days was an estimate of the developmental increments accumulated for the plants and alfalfa weevil larvae. Since these are parallel (compare Tables 7 and 8). From the last week of April through the first week in June (Julian day 110 to day 155), the regression equation was:

$$\text{accumulated DD} = 63 + 5.34 \text{ X (Julian Day)}.$$

$$\% \text{ VAR.} = 98.2\%, \text{ DF} = 439$$

About 63 DD were accumulated from the first of March to 20 April when the first field samples were taken. This represents about 11% of total heat units needed for plant development to the pre-bloom stage (Bula,

Table 8. Relationship of measured alfalfa stem length (cm) and accumulated degree day (9°C) using USU Station (1 April to 10 June; Julian day 91 to 161) and Field 1 recording thermometer (1 May to 10 June; Julian day 121 to 161).

SOURCE		WEATHER SHELTER			MAX-MIN THERMOMETER		
FIELD	DF	INTER	SLOPE	%VAR.	INTER	SLOPE	%VAR.
2 a	72	-8.03	0.198	83.0	9.8	0.109	74.3
3 b	73	4.95	0.216	75.7	18.5	0.086	75.2
Comb.	439	-1.74	0.198	73.9	14.8	0.102	68.8
5 c,d	70	-6.93	0.213	72.7	12.2	0.117	67.0

Note: a=low intercept Julian days; b=high slope Julian days; c=low intercept accumulated degree days; d=high slope accumulated degree days; Comb=mean for all fields through the time period.
See note Table 7.

et. al 1975 and Eklund and Simpson 1977). The slope (5.34) was the daily mean number of degree days above the 9°C threshold.

Regression analysis of the observed alfalfa growth, from field height measurements, on accumulated DD Logan USU was (COMB, Table 7):

Field Height (cm) = 2.42 + 0.178 (accumulated DD 9°C).

% Corr = 88.4, df = 350.

When the average length of the ten stems for each area was used as the dependent variable and regressed against the accumulated DD Logan USU, the equation was (COMB Table 8):

Measured stem length (cm) = -1.75 cm + 0.185(accumulated DD 9°C)

% VAR. = 73.9%, df= 439.

The relationship between field height and accumulated degree days resulted in a good fit (VAR. = 73.9 %) around the regression equation. The alfalfa growth in all fields was similar (Tables 8 and 9).

Substituting the seasonal start of sampling (20 April; Julian day 110) in the equation above it is noted that all fields were about the same height. When the field height was regressed on the accumulated DD

Table 9. Relationship between field alfalfa height (cm) and late spring days (Julian days 110 to 155) and accumulated degree days ($9^{o}C$, 0 to 400) from USU, during 1980.

		JULIAN DAYS			ACCUMULATED DD		
FIELD	DF	INTER	SLOPE	%VAR.	INTER	SLOPE	%VAR.
4 a,b,d	59	-135	1.381*	84.7	1.946	0.198	94.6
Comb.	348	-102	1.091	77.4	2.416	0.175	88.4
2 c	59	-88	0.952	84.8	-0.198	0.168	89.1

a=low intercept Julian days; b=high slope Julian days; c=low intercept accumulated degree days; d=high slope accumulated degree days; Comb = combined slope for all fields through time period. *=P>0.05. See note Table 7. See Appendices B5 for ANOVA.

USU and extrapolated back to Julian day 60, (1 March), there was good agreement among the fields in their growth pattern, Table 9. Either accumulated DD or Julian days were good estimators of the growth and had high correlations. The accumulated DD measured physiological aspect of time and would give a better estimate of current growth if nothing else were known about the weather history of an area. The estimate would be obtained by calculating the current accumulated DD or Julian day of the season and comparing it with mean field height or the measured stem length. As in earlier studies, local weather station information appeared to be adequate.

There were no significant differences between the accumulated DD from the field records and temperature data recorded from the local weather stations. There were small differences among the 6 fields in the study area in the valley after the end of April, contrasted with the large differences observed in previous studies of the entire valley.

Stem puncture analysis.

The relationship between Julian days and total punctures, oviposition punctures and total number of eggs per oviposition puncture per bouquet were analyzed. All fields were combined within a single season for 1980 and 1981 and used as test slopes. An analysis of the slopes and covariances was carried out to detect differences among the six fields. Homogeneity of regression coefficients (a covariance test) was used to determine if the slopes were different. If differences existed, a t-test was used to determine which fields were different.

Daily punctures. The relationship between total punctures and eggs per puncture, per ten alfalfa stems, was compared with larval numbers in sweep samples taken from the same area. The feeding punctures and egg punctures per bouquet were counted repeatedly through the growing seasons and tested in regression analyses. The comparisons of adult feeding punctures and oviposition punctures were made during the 1980 and 1981 seasons. Both total punctures and oviposition punctures were evaluated for usefulness as predictors of late-season larval populations.

The largest number of samples was taken in 1980. Due to reductions in personnel in 1981, fewer samples were taken. The 1980 regression analysis of the total punctures from ten alfalfa stems is shown in Table 10.

The covariance test for homogeneity showed significant differences existed between the fields for number of total punctures per Julian day. The t-test showed Field 6 had a slope that was significantly higher when compared against the combined slope. During the 1981

Table 10. Relationship of total punctures per alfalfa stem bouquet (5 reps of 10 stems/field) with Julian days (110 to 155) for 1980 and 1981.

	1980				1981			
FIELD	DF	INTER	SLOPE	%VAR.	DF	INTER	SLOPE	%VAR.
Comb.	527	-6.32	0.065	16.0	286	-1.42	0.028	2.4
6 a,b c,d	88	-13.07	0.115*	32.6	43	-7.61	0.077	20.3

a=low intercept 1980; b=high slope 1980; c=low intercept 1981; d=high slope 1981; Comb = combined slope for all fields through time period. *=P>0.05. See note Table 7. See Appendices B6 for ANOVA.

season the rate of both the feeding and oviposition lagged behind the 1980 season. The intercepts were higher in 1981 than during the 1980 season. This indicated that the 1981 season started sooner than the 1981 season. The peak rates of feeding and oviposition were reached sooner and then declined faster, possibly due to a warmer early season or to a greater number of active adults in the field during 1981.

Number of oviposition punctures. There were fewer total oviposition punctures per alfalfa bouquet. When these were regressed on Julian days (110 to 155), the results were similar and parallel to the number of total punctures per alfalfa bouquet, Table 11. Fields low in total punctures were low in oviposition punctures and vice versa. The slope for the number of oviposition punctures was parallel to the combined punctures (SLOPE Tables 11 and 10). Field 6 (Table 11) had a steeper slope than the combined fields slope.

Fewer oviposition punctures per bouquet occurred during 1981 than in 1980. During 1981, Field 2 had a lower than expected slope when compared with the combined slope otherwise the feeding and oviposition rate measured per alfalfa bouquets was similar for both 1980 and 1981

Table 11. Relationship between the number of oviposition punctures per day per stem bouquet (5 reps of ten stems per field) and the Julian days (110 to 155) for fields during 1980 and 1981.

	1980					1981				
FIELD	DF	INTER	SLOPE	%VAR.	F	DF	INTER	SLOPE	%VAR.	F
4 a,c,d	78	-5.08	0.045	24.5		44	-53.62	0.049	21.1	
6 b,	88	-0.38	0.058**	32.6		44	-3.48	0.039	10.2	
Comb	527	-3.86	0.035	16.3	4.63	268	-2.58	0.025	8.4	3.96
2 e	88	-2.15	0.021	7.9		44	1.59	-0.008*	0.0	

a=low intercept 1980; b=high slope 1980; c=low intercept 1981; d=high slope 1981; e=low slope for 1981; Comb = combined slope for all fields through time period. *=P>0.05. See note Table 7. See Appendices B7 for ANOVA.

indicating a uniform response between years despite changes in adult population levels.

<u>Number of eggs per puncture</u>. The number of total eggs per ten stems per day was regressed on Julian days (110 to 155). The intercept represents the initiation of oviposition and the slope the total number of eggs expected on a daily basis. The average daily egg accumulation (SLOPE Table 12) paralleled the combined punctures (SLOPE Table 11) per day.

The problem with the egg data was the total daily number of eggs recovered from a field was low. For 1980 the intercepts were negative indicating that oviposition had not started when the sampling commenced. Field 2 did not have as many eggs deposited (0.157 per stem) as the mean field slope (Comb. = 0.322 per stem) on a daily basis.

A similar analysis of the 1981 daily number of eggs per ten stems was carried out and the results are presented in Table 12. Two fields, Fields 2 and 3, had slopes (-.171 and 0.136 eggs per ten stems per Julian day) that were significantly lower than the test slope (0.263

Table 12. Relationship of the total number of eggs per ten stem alfalfa bouquet (5 reps per field) with Julian days (110 to 155) for 1980 and 1981.

	1980					1981				
FIELD	DF	INTER	SLOPE	%VAR.	F	DF	INTER	SLOPE	%VAR.	F
6 a,c	93	-54.2	0.478	23.9		43	-41.9	0.407	9.0	
4 b,d	83	-54.7	0.480	24.5		43	-61.7	0.542	25.4	
Comb.	558	-35.8	0.322	12.3	3.13	258	-27.2	0.263	7.3	4.60
2 e,f	93	-15.5	0.157*	4.1		43	27.1	-.171**	5.6	
3 f	93	-34.8	0.315	10.0		43	-12.0	0.136*	10.0	

a=low intercept 1980; b=high slope 1980; c=low intercept 1981; d=high slope 1981; e,f=low slope for 1980; Comb = combined slope for all fields through time period. *=P>0.05; **=P>0.01%. See note Table 7. See Appendices B8 for ANOVA.

eggs per ten stems). The intercept of Field 2 (27.1 eggs per ten stems) was higher for the 1981 season and indicated that significant oviposition had begun by Julian day 110 and was followed by an early decline. This was probably due to the thin alfalfa stand. Fields with negative intercepts had higher correlations and steeper slopes, indicating a delayed onset of oviposition.

Dividing the total number of eggs collected by the total number of oviposition punctures and regressing on the current Julian day (110 to 155) gave an estimate of the mean number of eggs per oviposition site per day. These slopes were essentially flat, with no correlation with days. The intercept was near the overall mean number of eggs per puncture per ten stem alfalfa bouquet. The overall mean was about ten eggs per puncture during the period (Table 13). The slopes were slightly positive or negative but close to zero. The 1981 season had lower slopes and reflected a slight reduction in the number of eggs per oviposition site.

Table 13. Relationship between the total number of eggs per stem bouquet divided by the total oviposition punctures on Julian days (110 to 155) during 1980 and 1981.

	1980					1981				
FIELD	DF	INTER	SLOPE	% VAR.	F	DF	INTER	SLOPE	%VAR	F
Comb.	210	16.9	0.052	1.5	3.45	214	16.6	0.124	1.5	2.77
1 c	30	7.9	0.018	0.0		13	-9.5	0.162	0.0	
2 d	31	19.5	0.075	4.8		17	24.7	0.129*	15.2	
4 a	38	1.7	0.059	0.0		22	-4.1	0.103	1.5	
6 b	41	27.6	0.126	11.3		25	2.9	0.053	0.0	

a=low intercept 1980; b=high slope 1980; c=low intercept 1981; d=high slope 1981; Comb = all fields through time period. *=P>0.05; **=P>0.01%. See note Table 7. See Appendices B9 for ANOVA.

Field 2 had a significantly lower rate of total and oviposition punctures for both seasons, with Fields 3 and 5 low compared to the combined 1980 + 1981 mean rates of feeding and oviposition. The intercepts were stable for both seasons and no differences were detected. This seems to be a reflection of the weevil biology and harvest practice.

Combined 1980 and 1981 seasons. The effects across the years were checked by combining the data. Slopes in Table 14 indicated Field 6 had a higher than expected number of eggs both years based on the t-test of either slopes or intercepts (Table 14 and Fig. 14). The significant F-test was interpreted as difference expected among coefficients.

A similar analysis of the number of oviposition punctures, revealed both lower (Field 2) and higher slopes (Fields 4 and 6) across the years as shown in Table 14 (also lower set of curves Fig. 14)

Fields 1 and 2 had positive intercepts, which indicated oviposition starting earlier on the higher foothills. It had been noted that low stem density or cover led to early oviposition. Field 2

Table 14. Relationship of total and oviposition punctures and total eggs divided by total oviposition punctures per ten stem bouquet with Julian days (110 to 155).

FIELD	DF	INTER	SLOPE	% VAR.	F
TOTAL PUNCTURES					
Comb	777	-3.60	0.045	5.5	0.87
1	132	-1.90	0.029	2.6	
2	133	-1.14	0.026	0.9	
3	133	-3.94	0.049	6.5	
4	123	-4.15	0.051	7.9	
5	133	-2.35	0.032	3.3	
6	133	-8.54	0.086*	12.6	
OVIPOSITION PUNCTURES					
Comb	777	-3.80	0.032	13.9	2.32
1	132	-2.24	0.022	6.5	
2	133	-1.14	0.013*	3.0	
3	133	-3.55	0.032	15.2	
4	123	-5.23	0.047*	23.9	
5	133	-3.55	0.031	14.2	
6	133	-5.81	0.052*	25.7	
TOTAL EGGS/BOUQUET					
Comb	336	13.2	-0.025	0.2	5.58
1	45	5.6	0.030	0.0	
2	50	18.8	-0.075	6.2	
3	56	21.9	-0.092	3.9	
4	62	-0.2	0.074	1.8	
5	45	10.9	-0.003	0.0	
6	68	19.2	-0.067	2.6	

Differences are significant at: *=P>0.05%, **=P>0.01%

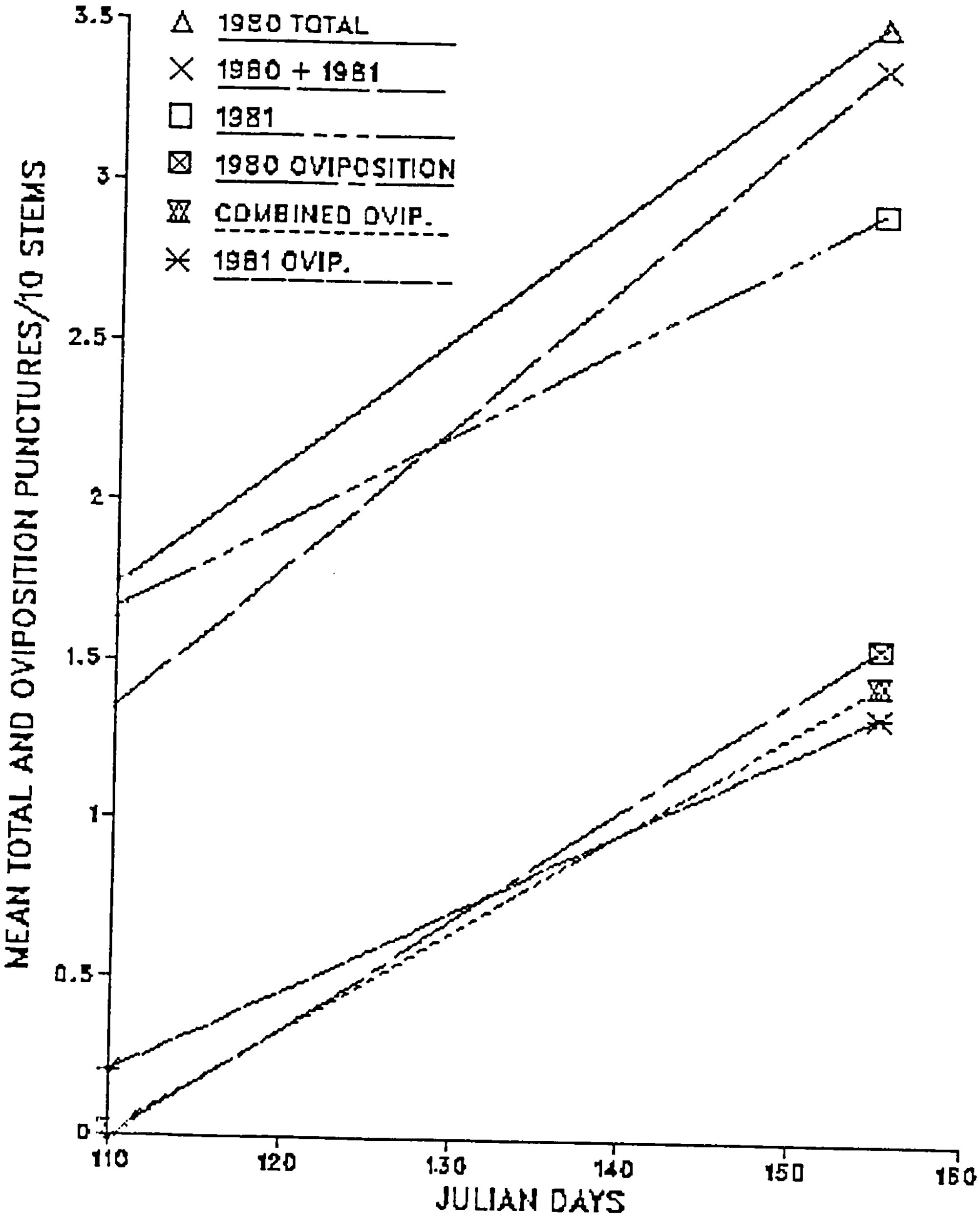


Fig. 14. The mean number of feeding and oviposition punctures (upper three lines) per alfalfa stem bouquet (10 stems) for the 1980, 1981 and the combined years. The lower group of lines represents the mean number of oviposition punctures per alfalfa stem bouquet (10 stems) for the 1980, 1981 and combined years.

had a low slope and poor correlation with days over both years. The lower intercepts occurred in cooler areas, especially the valley floor, indicating a later oviposition initiation date. As the fields in the valley warmed, the alfalfa growth at lower elevations was as great as in fields where oviposition had started early.

Some fields had steeper slopes aspects and more punctures (Fields 4 and 6; 0.047 and 0.052 oviposition punctures per ten stems; Table 14) and one field with a high slope aspect had low oviposition (Field 2; 0.013 oviposition punctures per ten stems) for both years. These had been identified in earlier oviposition puncture analyses. Field 4, although without enough oviposition punctures to be labelled as the high population field either year, was detected when the years were combined for the analysis. Field 4 had a dense stand of alfalfa and heavy adult population, while Field 2 had a sparse stand of alfalfa, which may account for the differences.

The total number of eggs divided by the total daily oviposition regressed on Julian days indicated there no detectable difference, based on a t-test, among fields. The F-test indicated that differences exist (Table 14 also Figs. 15 and 16).

Based on these and earlier data, trends within a field may be continued from year to year. Otherwise there would not be the continued low and high population levels seen between seasons. This stability was comparable to area wide studies seen earlier, and this may result from populations adapting to environments within an area and a field.

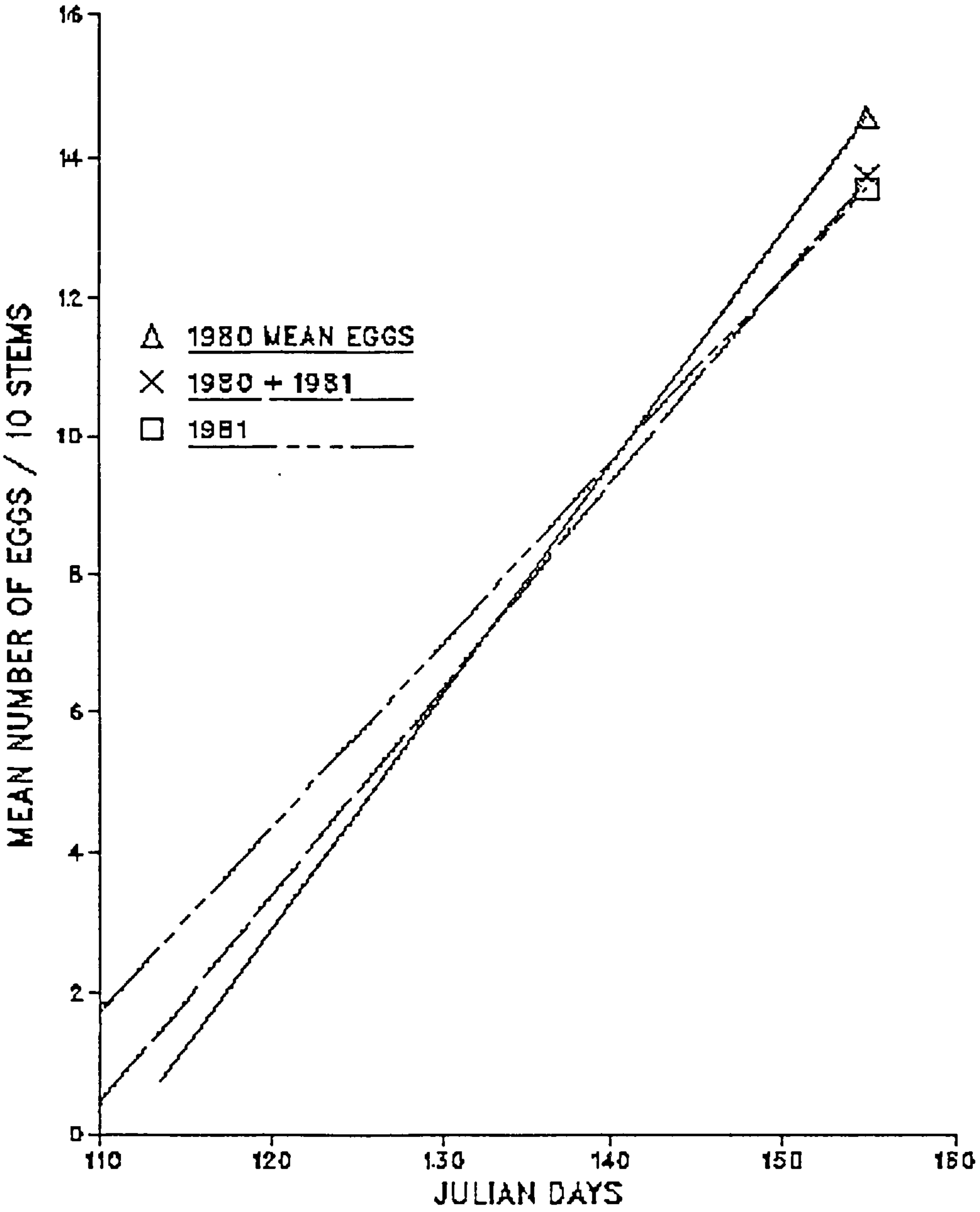


Fig. 15. Mean number of eggs (total number of eggs/ total number of oviposition punctures) per alfalfa bouquet (10 alfalfa stems: 5reps/field) plotted on Julian day for 6 fields near Hyde Park and North Logan.

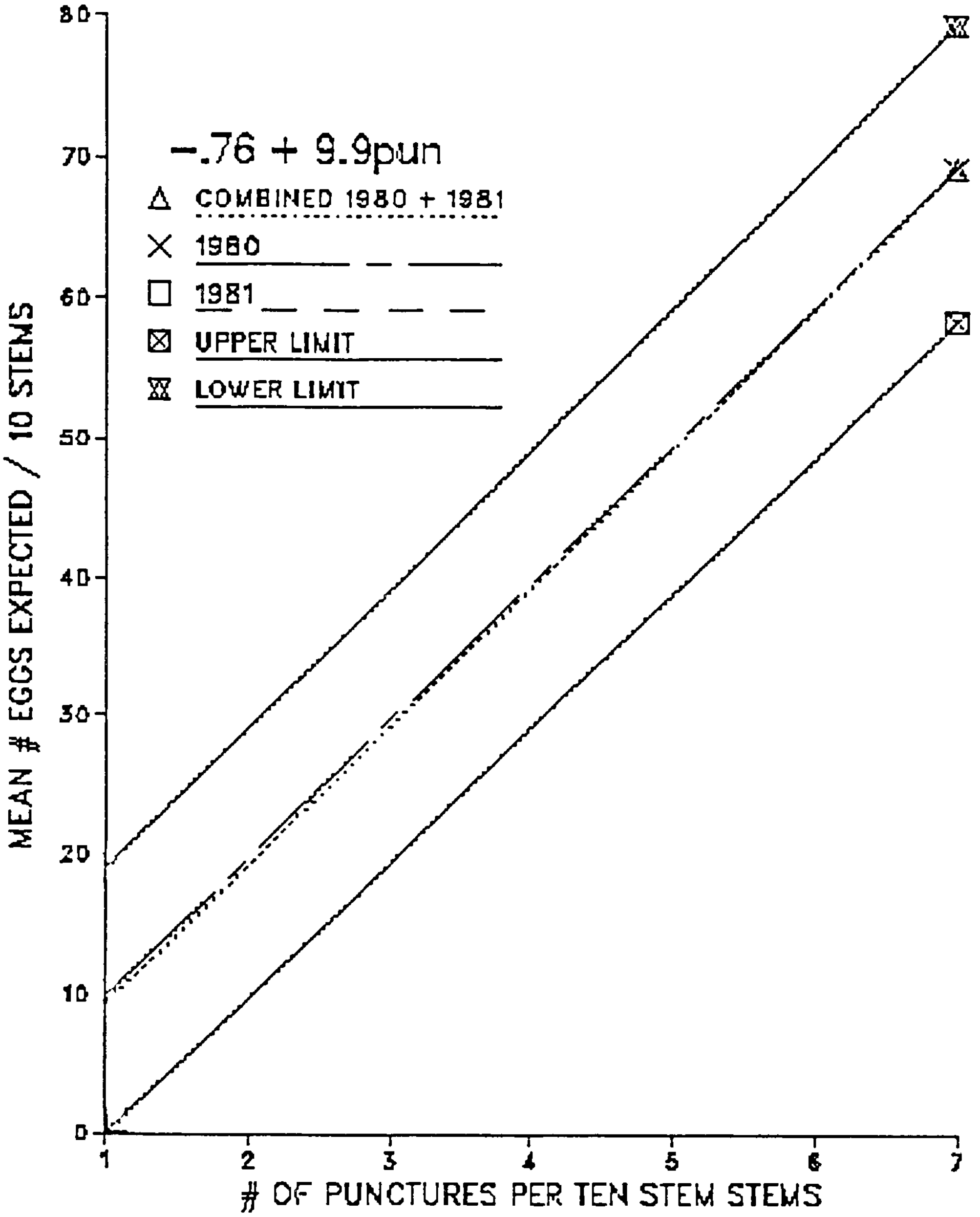


Fig. 16. The mean number of eggs that could be expected for up to 6 punctures per alfalfa bouquet (10 stems/ 5 reps per field) for the 6 fields near Hyde Park and North Logan during both 1980 and 1981. Note that both seasons are very similar.

Protected LSD for weevil populations during the 1980 season.

F-tests were performed on sweeps, stem and Berlese samples for representative days during the 1980 field season. This allowed direct comparison to determine whether any early season sampling regime would reflect late May larval populations.

The five sets of samples from a single field were considered replicates of the field and compared with other fields for the same day. Using a 'protected' LSD, the means were inspected to determine if fields that had high populations of adults early in the season had comparable populations of larvae late in the season.

Protected LSD for adults. On each day that an F-test was performed it was possible to separate adult populations into at least two categories, low and high. Low adult population fields did not become high adult population fields but it was not possible to predict which field would have the daily high (Table 15). Adults were captured in the earliest seasonal sweep samples. Early means were low and no pattern was discerned that linked adult captures with later larval populations.

Protected LSD for larvae. No pattern from any early larval sampling method was able to predict levels of alfalfa weevil larvae later on. Mean populations of larvae in 20 sweeps (Table 16) indicate Fields 4, 5 and 6 had high mean populations. Significant differences were obtained from sweep data starting on Julian day 126. The alfalfa was already 38 cm tall and had accumulated 200 DD. There was a consistent pattern among early mean captures, but this was not precise enough to predict the late season larval populations. Early larval

Table 15. Mean separation by days for the adults and larvae per 20 sweeps along with total punctures and total eggs per ten stem bouquet.

DAY	114	119	125	126	127	131	142	152
FIELD				ADULTS				
1	2.4 ab**	4.4 a**	16.8 ab**	13.6 a**	12.4 bcd**	18.4 a**	19.6 b**	14.6 ab**
2	2.0 ab	6.6 a	7.2 a	11.6 a	2.8 a	13.2 a	23.7 bc	16.4 b
3	5.0 bc	17.4 c	16.0 ab	26.8 ab	7.4 ab	21.6 ab	24.0 bc	15.6 b
4	6.0 c	15.0 b	47.2 d	46.8 d	17.2 cd	49.6 c	29.4 c	8.6 a
5	0.6 a	3.4 a	19.6 bc	21.4 a	11.0 bc	17.8 a	9.6 a	24.0 c
6	2.6 abc	8.6 ab	29.6 bc	25.4 a	18.4 d	27.8 b	31.8 c	12.4 ab
				LARVAE				
1	0.4 a	1.2 a	1.6 a**	3.8 a**	2.0 a**	6.2 a**	167 ab**	183 ab**
2	0.2 a	0.8 a	1.6 a	3.2 a	4.0 a	6.2 a	164 a	290 ab
3	0.2 a	1.8 a	3.8 ab	5.6 a	5.4 a	12.6 ab	130 a	407 b
4	0.2 a	3.8 a	4.8 ab	11.0 b	5.4 a	15.6 b	230 b	141 a
5	1.0 a	1.4 a	5.4 b	11.6 b	6.6 a	12.6 ab	140 ab	706 c
6	0.8 a	3.6 a	11.4 c	11.0 b	14.0 b	33.6 c	432 c	1427 d
				TOTAL PUNCTURES				
1	3.6 a	0.6 a	0.8 a	1.6 a	1.2 a	1.8 a	--	6.0 b*
2	3.6 a	0.6 a	0.8 a	1.0 a	0.8 a	1.2 a	--	2.0 a
3	2.0 a	1.0 a	1.0 a	1.2 a	2.2 a	2.4 a	--	1.6 a
4	2.0 a	3.2 a	1.0 a	1.4 a	1.2 a	0.8 a	--	3.4 ab
5	1.4 a	0.2 a	0.6 a	0.6 a	2.0 a	1.4 a	--	5.8 b
6	2.8 a	0.8 a	0.4 a	1.2 a	0.6 a	2.2 a	--	6.5 b

Table 15. cont.

				TOTAL EGGS/TEN STEMS				
1	6.0 a	4.0 a	0.0 a	8.8 a	3.2 a	1.4 a*	14.8	5.0 c*
2	1.8 a	1.4 a	0.0 a	6.4 a	1.4 a	0.0 a	22.2	0.8 a
3	0.0 a	1.6 a	0.0 a	2.2 a	2.6 a	21.8 b	12.4	0.8 a
4	0.0 a	2.2 a	1.2 a	5.4 a	0.0 a	0.0 a	9.6	1.6 ab
5	1.6 a	0.0 a	0.0 a	3.4 a	0.0 a	11.2 ab	14.4	3.4 bc
6	2.8 a	1.4 a	0.0 a	4.8 a	0.0 a	3.8 a	17.6	2.6 ab
6	2.8 a	1.4 a	0.0 a	4.8 a	0.0 a	3.8 a	17.6	2.6 ab

Note: Means followed by the same letter are not significantly different from each other; *=P>0.05%, **=P>0.01%.

population means in Fields 5 and 6 indicate the highest populations were likely to occur in these fields, but trends were not clear enough to recommend controls at this early date.

<u>Protected LSD for total stem punctures</u>. When the total daily punctures were analyzed, no separation of means was observed until near the end of the season, Julian day 152 (3 June) Table 15. There was no apparent relationship between the punctures and the final population of larvae in the field. This was somewhat surprising, considering that oviposition started later in the fields near the valley center. The number of both total punctures and total eggs per puncture for Field 6 was high.

<u>Protected LSD for the total number of eggs per ten stems per field</u>. The total numbers of eggs recovered on a given day were analyzed as previous sets of data. There was no early separation of fields into high and low populations that would indicate that the outbreak would occur in a particular field. By Julian day 131 the populations of eggs could be separated, well enough to determine which fields were high and which ones were low (Table 15).

There was a significant difference among the fields for punctures during the 1980 season. From Table 15, Field 6 had the highest larval population. During early spring Fields 1 and 2 had the highest number of total punctures. The analysis of variance of total punctures indicated no significant difference between either the number of oviposition punctures nor total number of eggs. Although, the order among the fields was consistent it could not be used to predict later economic larval populations.

Fields 4, 5 and 6 were fields with early high adult populations and feeding along with oviposition punctures (Table 15). Field 4 was managed, by early cutting, to avoid damage from weevil larvae. Field 1 appeared to have a large population of eggs but this did not result in a high population of larvae. The fields on the valley floor later developed heavy populations of alfalfa weevil larvae even though the mean number of eggs per stem was never high. The important factors appeared to be the interaction of management practices and environment.

Analysis of variance of alfalfa stem punctures. The daily counts of punctures were not predictive of late-season events but did appear to be stable within fields. The areas (NE, NW, SE, SW and C) within a field were considered replicates of that field through the season and the analysis of variance was carried out as a split plot in time (Field 1 through 6). When the F-test was significant the LSD test was applied at the levels implied by the analysis. There were usually two or three groups of means, these were interpreted as low (medium) and high populations. Means were also presented without separation indicating a nonsignificant F-test.

The means of oviposition punctures and total number of eggs per ten stems were not significantly different in fields and are shown only for comparison. The relative order of the fields and means of punctures were consistent with other sampling techniques.

During 1980, Field 6 had the highest weevil populations shown by all methods and eventually became the field with the highest overall larval mean. Initially Field 5 populations were low but eventually developed the second highest mean population. Field 4 did not produce a heavy larval population but early adult sampling indicated that one was expected. There were no differences between mean populations of punctures in the fields in 1981. There was a relationship between the number of oviposition punctures per ten stems and total number of eggs recovered.

Total punctures, oviposition punctures and total eggs all indicated no significant differences between fields during 1981. Means are presented in Table 16. The difference between the high and low total punctures was greatest at harvest. The results were similar to the 1980 results in both order and magnitude of the populations encountered (Table 14). It was found that both Fields 4 and 6 showed consistently high populations based on feeding and oviposition punctures and total eggs per ten stems during both 1980 and 1981. It was Field 4 that was cut early in 1980 presumably to disrupt weevil development. However, ample adults returned in 1981 to result in crop damage. Field 5 reflected the previous season high population of larvae and subsequent adults with a large number of punctures. These trends held between years as confirmed in the following analyses.

<u>Split-plot analysis of variance for 1980 and 1981 samples</u>. A split-plot in time was used to determine if there were differences between replicates, fields, dates and years. Interactions between the factors were also important in the further analyses. Covariates, stem density, stem length, accumulated degree days and lodging, were included to adjust for factors that influence field sampling procedures. The means were first set to zero then ranked. Therefore some means assume negative values.

Table 16. Mean separation of the total (TPUN) and oviposition (OPUN) punctures and the total eggs (TEGG) per ten stem bouquets for 1980 and 1981.

	1980				1981			
FIELD	N	TPUN	OPUN	TEGG	N	TPUN	OPUN	TEGG
1	89	2.03 ab*	0.63	6.91	45	2.07	0.60	6.16
2	90	2.50 abc	0.68	5.51	45	1.98	0.56	4.64
3	90	2.74 bc	0.73	7.11	45	1.91	0.60	5.84
4	80	2.28 abc	0.79	7.89	45	2.91	1.09	9.44
5	91	1.81 a	0.59	5.79	45	2.04	0.98	6.51
6	90	2.98 c	0.98	9.22	45	2.91	1.18	11.53

Means not followed by the same letter are significantly different, *=P>0.05%. N=number of observations per mean. See Appendices B11 for ANOVA.

The data are presented in the logical sequence of occurrence. The adult sweeps are followed by stem punctures, Berlese funnels and finally larvae and Bathyplectes curculionis in sweeps. Some transforms of data were used but not included because there was no difference in results of analysis, and problems are avoided. Analyses based on physiological time, accumulated degree days were also performed but did not lead to greater understanding of the underlying mechanisms.

Split-plot analysis of the adult weevil captures for 1980 and 1981. The central issue revolved around separation of the fields according different populations sufficiently early in the season to prevent damage by larvae. Based on the results, it should be possible to forecast an outbreak of larvae based on an earlier component of the larval population.

There were differences between the fields, dates and years mean separation for adults (Table 17). Fields 5 and 6 had the lowest populations of adults and Field 4 has the highest. Separation by date across both years was achieved. The alfalfa development was affecting the capture rate, but it looked as if the dates were all separate events. The population appeared to expand as the season continued. Alfalfa growth 'adjustment' accounted for the large weevil numbers. The difference between years was large also. The 1981 collections had twice the population of adults as that seen in 1980.

The differences in field adult populations also depended on behavior which was strongly influenced by the weather during the previous day(s). If the day before was cool, the females spent their time on the lower 15 cm of the plant ovipositing. Warm spells were spent both feeding and oviposition. During early season, late March and April, warm weather strongly influenced later egg maturation rates. Cool weather retarded the development of eggs without stopping it entirely. The weather (Parks, 1914) also influenced the rate of egg maturation and oviposition.

Split-plot analysis of total punctures and oviposition punctures. As with captures of adults, the weather strongly influences the rate at which adults feed and oviposit. Once started, the rate of egg maturation and deposition are essentially constant for the remainder of the season. The adjusted means for the total punctures and oviposition punctures are presented in Table 17.

Separation of the total puncture means (TPUN) by field gave interesting data. The fields with the heaviest population of eggs were the fields with the lowest stem densities and stoniest soils. The stony soil probably has little direct effect on the number of punctures that were discovered. The thinner stands of alfalfa might be expected to warm or cool more rapidly than the fields with more densely packed

Table 17. Mean separation of adult weevils (ADULT), total punctures (TPUN), oviposition punctures (OPUN), Berlese funnel samples first instar and total instars (B 1 and B 1-4 respectively), weevil larvae (LARV) and <u>Bathyplectes curculionis</u> (BC) based on split-plot in time across both 1980 and 1981.

	ADULT	TPUN	OPUN	B 1	B 1-4	LARV	BC
FIELD							
1	17.1 b**	-12.06 b*	-2.75	7.28	19.34 a***	35.4 ab**	0.93
2	17.5 b	43.66 f	10.52	13.40	44.44 c	155.7 cd	0.89
3	17.7 b	23.19 e	5.66	13.55	43.20 b	15.4 a	0.91
4	26.4 c	-32.56 a	-7.39	6.14	14.86 a	66.6 a	0.45
5	7.9 a	-5.05 c	-0.50	6.47	19.94 a	85.4 a	0.92
6	11.5 ab	-3.40 d	-1.01	9.45	31.29 b	103.8 cd	1.16
DATE							
26 AP	26.8 c**	-11.71 a**	1.17 c**	33.25	56.27	3.81	0.92 b*
30 AP	20.1 b	—	—	22.32	37.91	11.40	1.26 b
5 MA		-3.25 b	0.51 a				
13 MA	20.3 b	0.70 c	0.49 b	-2.68	11.40	37.91	1.33 bc
19 MA		4.32 d	0.74 b				
26 MA		10.16 e	0.73 b				
30 MA	-1.7 a	13.56 f	0.89 b	15.36	3.81	56.27	0.03 a
YEAR							
1980	9.8 a**	-0.09	0.55	-1.64 a*		75.5	0.79
1981	22.9 b	4.68	0.97	20.41 b		78.6	0.98

Means followed by the same letter are not significantly different from each other; *=P>0.05%, **=P>0.01%, and ***=P>0.10%. See Appendix 2 Table 12 for ANOVA.

stems. Another effect that might have been operating was that the number of adults recovered in the sweep sample did not match the true order. Field 4 had the highest population of adults but the fewest total punctures per stem. Fields 5 and 6 had the lowest levels of adults recovered but intermediate levels of total punctures.

The steady increase of total punctures through the season corresponds to the growth of alfalfa. The low recovery of the total punctures in late April and early May indicated the difficulty of using simple population measurements alone, especially when the stem density and environment interacted with the number of adults in the field to produce different larval populations.

The number of adults during 1980 was low but the number of total punctures was relatively high. The large number of punctures in 1980 was followed by a larger overall population of adults the following year. But 1981, with a higher population of adults, did not result in heavier oviposition.

The punctures could be interpreted as a physiological response of the female weevil that integrates over the total season, not simply current conditions. Early season warm days allowing feeding to occur, resulted in more mature eggs. Cool weather retarded feeding and egg maturation, so early cool conditions retarded late season larval population development. The small difference in development temperatures between the alfalfa and weevil meant that early cool weather favored the plant.

Oviposition punctures (OPUN) were also analyzed. There were no differences among the fields or years although there were differences among the dates, Table 17.

There were no differences between either field or year. Mean differences existed but the F-tests were not significant. The field order was nearly the same for the total punctures each year, however Fields 5 and 6 became reversed in order. The differences between oviposition were of much smaller magnitude than the total punctures. The difference in oviposition punctures seemed to be affected by weather more than the populations of adults or total punctures.

The oviposition punctures did not increase as the spring progressed and did not exactly match the order of total punctures during either 1980 or 1981. The heaviest oviposition occurred in late April. The second highest number of mean oviposition punctures occurred on the final sample date, 30 May. The pattern of oviposition and feeding punctures did not correspond. This indicated that some unmeasured factors control oviposition. Parks, 1914, graphically indicated that one factor was the climatic conditions in the field 2-3 days prior to sampling. Conditions in March and April apparently interacted to produce the patterns seen. Early spring apparently affected adult development and maybe at temperatures below the weevil development threshold.

It has been reported that eggs, once deposited, will hatch after an appropriate number of degree days are accumulated (Hintz, et. al, 1974). Consequently, stems placed in a Berlese funnel for 24 hours were assumed to force hatching of eggs that were near eclosion.

Split-plot analysis of Berlese funnel captures of both first instar and total larval captures. The Berlese funnel assessed the populations of larvae before the sweep net could be used. On a per stem basis it was assumed to show an absolute density estimate of the larvae in the field. The stage of larvae captured was determined with ease and accuracy. All larval instars were subjected to a similar analysis but results were no easier to interpret than sweep samples. The first instars and total (B 1 and B 1-4) populations results were presented in Table 17. The F-test for fields and dates were not significant and the adjusted means were not separated. A much larger population of larvae occurred in 1981 than 1980, as seen in Table 17.

The fields with low levels of either total or oviposition punctures gave similar data to the captures of first instar Berlese. Fields with lower numbers of punctures were also low for Berlese captures. The fields with high oviposition levels had high populations of larvae in all instars. There were unmeasured interactions with the environment since high levels of oviposition punctures levels did not lead to corresponding levels of first instar larvae. The time the larvae were in the first instar was very short compared to later instars, making them unavailable for capture. High mean punctures did lead to high population of total larvae caught in the Berlese funnels. High early season populations of adults did not result in corresponding levels of total punctures, oviposition punctures or total larvae. At high populations, adults may compete in the search for oviposition sites. They also spent more time mating.

During April-June the highest population of first instar larvae occurred in late April and the lowest means occurred in late May. Environmental effects on adults probably reduce the late season populations of larvae. As reported in the literature, high temperatures reduce egg production during middle and late May with these effects occurring first in the low stem density fields (Parks, 1914). In this manner the stem density has profound effect on the physiology of the weevil and the resultant egg production. Notice the capture of adults and oviposition punctures followed no set pattern while the total punctures steadily increased through the season. The number of first instar larvae was the reverse of that pattern. This could have resulted if the larval hatching was influenced less by adult behavior than by the environment. Parks (1914) reported that adult behavior and oviposition were clearly influenced by current and proximal weather patterns.

Total Berlese captures of the alfalfa weevil larvae were easily counted and analyzed as above (Table 17). The F-tests were clearer but variable results did not allow mean separations by date, although a pattern of increasing populations existed. As before (Table 17), the highest populations of adults did not result in the highest populations of larvae. Field 2 had an intermediate population of adults but the largest population of total larvae.

Either total punctures or oviposition punctures were indicators of total larvae (Table 17), but not reliable in calculating later instar populations. There were more larvae produced relative to punctures in some fields than in others. More efficient recovery of young larvae occurred in late April and early May than in later May. This may have been due to an increasing plant volume and subsequent longer time required to drive larvae from the stems in Berlese funnels.

Split-plot analysis of alfalfa weevil larval populations captured in sweep samples 1980 and 1981. Larval alfalfa weevils in Northern Utah were not collected in large numbers until early May in sweep samples. By 10 May the number of larvae began to increase rapidly until the alfalfa harvest, about 10 June. By the time there were enough larvae to determine which fields could have high populations it was too close to the harvest date to take preventive actions. The best course to follow with damaging populations was to cut early then control the emerging adults in the second crop, see Table 17.

Comparing adult weevil populations to larval numbers, there were no consistent trends. There did not appear to be a simple relationship between the number of adults and larvae.

Comparison of either the total punctures or oviposition punctures to the resulting population of larvae was not simple and gave erratic results. Fields 2 and 3, with lower stem densities had the highest total number of punctures. However, Field 3 did not develop a high population of larvae but did have an intermediate population of adults. Fields 3 and 4 were managed by the same grower and both had lower populations of larvae. Fields 2 and 3 had the highest number of punctures. The openness of the canopy might have allowed early warming of the soil and temperatures above development threshold (9°C) and later above the threshold that caused the females cease or reduce oviposition (30°C). The eggs that were deposited would result in larvae before the alfalfa was harvested. This coupled with management could have resulted in the population patterns encountered.

Each of the two years had roughly the same number of weevil larvae regardless of the number of adults, total punctures or oviposition punctures. The number of larvae within a field appeared to be influenced by factors that affected adult activities and egg hatch. The most important factors might be cultural practices employed by a grower. The harvest and irrigation timings influenced the weevil populations in manners not easily tested by the techniques used in this study. We did not attempt to change harvest techniques or practices and did not change irrigation practices in the study area.

Split-plot analysis of Bathyplectes curculionis captured in sweep net samples 1980 and 1981. The alfalfa weevil larval parasite was found at low population levels in all fields. The populations were independent of numbers of adult weevils, punctures or larvae in all fields. The means for field and year were not separated based on the F-test results. There was a distinct population peak during the middle of May (see BC in Table 17). This was as expected based on previous studies and host stage preference (Doudu and Davis, 1974b). There was no difference in the population means of parasites, similar to the results seen in the larval studies.

Field 4 had the lowest Bathyplectes population. There were nearly twice as many B. curculionis recovered from Field 2, and intermediate populations occurred in the remainder of the fields. This may have been due to the different conditions the parasite was exposed to during the long overwintering period. They are exposed on the soil surface to predators and weather. Winter mortality can reduce the populations to very low levels despite the high levels of larvae parasitized by the end of first harvest. The population of adult parasites fell off as the harvest date approached. The two years had similar parasite populations without regard the larval population available (Table 17).

Analysis of variance of Berlese funnels samples.

An analysis of variance was carried out on the larval data obtained in Berlese funnels samples to determine whether there were significant differences among the fields.

Combined instars. The combined numbers of weevil larval instars (first + second + third + fourth) indicated highly significant differences between fields (Table 18). When instars were separated, only the fourth instar populations did not have densities that were significantly different between fields.

Berlese funnels were used to separate populations of alfalfa weevil larvae from alfalfa stems throughout the season (Table 18). The fourth instar larvae did not become numerous enough before harvest to distinguish the fields but the third instar larvae did. The second instars had the highest mean rate of recovery in Berlese samples. The best aspect of this sampling technique was the simplicity in counting all the larvae present without separating them into instars, thus saving time.

A comparison of Berlese funnel results with the larval sweep samples for 1980 (Table 15), showed similarities. Fields 2 and 3 were identified as high population fields. This could have been due to low stem density, resulting in skewed samples, or to the larvae in the field maturing more rapidly in the open canopy, or to the larvae being present in higher populations, or to a greater likelihood of being captured than in fields with higher stem densities, or to combinations of factors. Field 4 had a high stem density and did not have as many larvae present as would be expected. Field 4 was managed to reduce larval population levels.

The Berlese funnel results from the 6 fields indicated the field populations were significantly different. The means show separation in Table 18. The larval populations could be separated into low (a), medium (b), and high (c) for all instars, except fourth.

The larval populations during 1981 were higher than during 1980 and significant differences among fields were detected (Tables 18). The fourth instars were more numerous during 1981 and separation of all instar populations was possible. The 1981 season was warmer during May than the 1980 season.

Comparison of sweeps and Berlese samples. These results support earlier findings that the alfalfa weevil larval populations in fields tend to maintain their relative population level between years. The 1981 season had a 2- to 3- fold increase in populations over the 1980 season and the lack of interaction led to the conclusion that population increases caused changes in the field populations without appreciable shifts in the relative positions of the field population means in relation to other fields.

In 1980, Berlese stem samples were compared in detail with 20 sweep samples collected at the same time. Larvae were first counted from regular sweep samples (Table 18) and then they were subsampled

Table 18. Mean separation of alfalfa weevil larvae populations captured from alfalfa bouquets (ten stems per bouquet; five replicates per field) for Berlese first, second, third, fourth instars and total captures (I, II, III, IV, and TOT) captures for six fields near Hyde Park and Logan during 1980.

		INSTARS				
FIELD	REPS	I	II	III	IV	TOT
1980						
1	91	1.99 a**	9.00 a**	0.77 a**	0.00	5.79 a**
2	89	4.92 bc	19.50 c	1.54 ab	1.35	13.46 a
3	95	6.01 c	18.10 c	2.26 b	0.15	15.95 b
4	75	2.71 ab	10.37 a	1.35 a	0.01	7.40 a
5	87	2.43 ab	10.27 a	2.26 b	0.36	7.93 a
6	90	4.53 b	14.12 b	2.48 b	1.62	16.14 b
1981						
1	40	3.35 ab**	6.72 a**	1.91 a**	10.83 ab**	
2	40	5.14 ab	9.41 a	3.05 a	14.57 ab	
3	40	7.65 b	15.48 b	5.15 b	12.60 ab	
4	40	2.88 ab	6.63 a	3.25 ab	9.47 a	
5	40	2.03 a	6.00 a	3.58 ab	14.53 ab	
6	40	3.90 ab	13.65 b	5.38 b	18.37 b	
FIELD SWEEPS 1980						
1	87	1.87	19.53 a**	15.62 ab**	10.21	21.40 a*
2	90	2.22	47.15 abc	25.06 ab	3.45	49.37 ab
3	95	2.38	35.82 ab	22.23 ab	11.20	38.20 a
4	75	0.97	39.91 ab	12.57 a	2.71	40.88 ab
5	75	1.69	54.49 bc	46.85 bc	16.73	56.18 b
6	85	3.31	72.48 c	79.08 c	13.73	75.79 b

Note: Means not followed by the same letter are different, *=P>0.05%, **=P>0.01%.

using a head caliper to verify the ages of the larvae. The samples were compared according to instars captured by the two methods. There were several things noted when comparing Berlese samples and sweep samples. The number of first instars in sweep samples was low and were seen primarily during early May when the amount of debris and numbers of other insects was low. Later, the first instars were not readily dislodged by sweeps and those present tended to become mixed with the debris. The sweeps and Berlese samples showed the same basic patterns of larval populations. Fields 2 and 3 had higher total larval populations in Berlese counts than in sweep samples from the same fields. The two techniques sampled different phases of larval development and population distribution in a field.

The stem samples were estimates of limited areas in the field while the sweeps were averages of large areas. The Berlese samples measured the distribution of larvae in a few clumps of alfalfa. Comparison between the two means from each sample allowed an estimate of the sampling error of the sweep net compared to the absolute numbers of larvae per stem in the same field area. The differences between the numbers of second and third instars were less than differences between first and second instars. The relative positions of the population estimates were comparable using the two techniques. Using Berlese funnels, the differences among fields was detected somewhat earlier in the season due to sampling early instars. Use of the sweep net did not enable evaluation of first instars but was an indicator later (Table 15, Julian day 119). The sweep net dislodged and captured many large larvae but not as many smaller ones as it passed through the alfalfa. While the Berlese funnel was only a small sample from a large field. When taken carefully Berlese samples represented absolute population estimates. Many samples, with low numbers of insects were taken during early season with either techniques. Late spring samples had much larger numbers of individuals. Although there are remaining problems, early spring larval population estimates from either technique might be useful.

Array sweeps.

The mark-release-recapture arrays were used to designate distance from a central release site (Fig. 4 b). Using the stakes as markers, when the alfalfa in the arrays was swept. Five sweeps were taken at each stake and 100 sweeps total.

Adult and larval populations. The highest populations of weevil adults occurred in the second crop during the period of emergence and feeding by new adults. For 1981, Fields 1 and 4 had the lowest populations while Field 6 had significantly higher populations of adults and larvae recovered in sweep samples (Table 19). Adult populations were very similar to larval populations in the same fields.

There were large mean differences between the adult populations and subsequent larval populations. There was no difference in replicates for either adults or larvae (Table 14) within a field.

Pitfall trap analysis.

In each field the linear pitfall array was composed of twenty traps. These were divided into five treatments representing distance from the margin of the field.

Table 19. Mean separation of adult and larvae alfalfa weevil from the pitfall arrays from three fields in Hyde Park and North Logan during 1981.

		ADULTS	LARVAE
FIELD	No. of samples		
1	141	3.49 a	97 a
2	410	3.94 a	54 a
3	120	7.78 b	194 b

Note. Means not followed by the same number are different, all=P>0.01%.

<u>Distance from the margin</u>. The trap captures were analyzed using a contingency table. The treatments were set to columns with fields set into rows (Tables 20 and 21). The 1981 season had fewer trap days than the 1980 season (43 days in 1980 and 13 days in 1981) and the total captures were lower than the previous year. During 1980, the heaviest population of adults was in Field 4 and the lowest in Field 5. During 1981 the heaviest population of adults was in Field 2 and was lowest in Field 6. The pattern did not match the larval captures seen in sweep captures and Berlese counts. More weevil adults were captured in Fields 2 and 4 for both years. Adults were captured at an intermediate distance, 15 to 22 m, from the margin of the field. The fewest adults were captured near the margin (0 to 7.5 m).

The patterns during the 1981 season were similar to those of 1980. There was interaction between field and distance from the margin, but it was not possible to determine the cause.

<u>Rate of adult weevil capture throughout the season</u>. The Chi square analysis of total adult captures throughout the season was compared with a hypothetical constant capture rate of about 25, 50, 75 and 100 per cent corresponding to 25, 50, 75, and 100 per cent of days

Table 20. Chi-square analysis of pitfall captures of alfalfa weevil adults from different distances (meters) from the margin in six fields near Hyde Park and North Logan during 1980 (Julian days 110 to 155).

METERS	0-7.9	8-15.9	16-23.9	24-31.9	23-40	TOTAL
FIELD						
1	19	32	27	32	17	127
2	40	49	62	56	37	244
3	22	45	66	32	26	191
4	29	99	85	70	65	348
5	7	16	10	13	8	54
6	25	22	14	30	28	119
	142	263	264	233	181	1083

Chi-square= 49.11; df= 20= (6-1)(5-1)

Table 21. Chi-square analysis of pitfall captures of alfalfa weevil adults from different distances (meters) from the margin in six fields near Hyde Park and North Logan during 1981 (Julian days 110 to 155).

METERS	0-7.9	8-15.9	16-23.9	24-31.9	23-40	TOTAL
FIELD						
1	15	10	12	22	4	63
2	19	29	56	51	28	183
3	14	15	20	13	12	74
4	18	29	39	20	42	148
5	6	19	13	11	24	73
6	14	12	7	11	7	51
	86	114	147	128	117	592

Chi-square= 62.50; df= 20= (6-1)(5-1)   Chi-square = 62.50

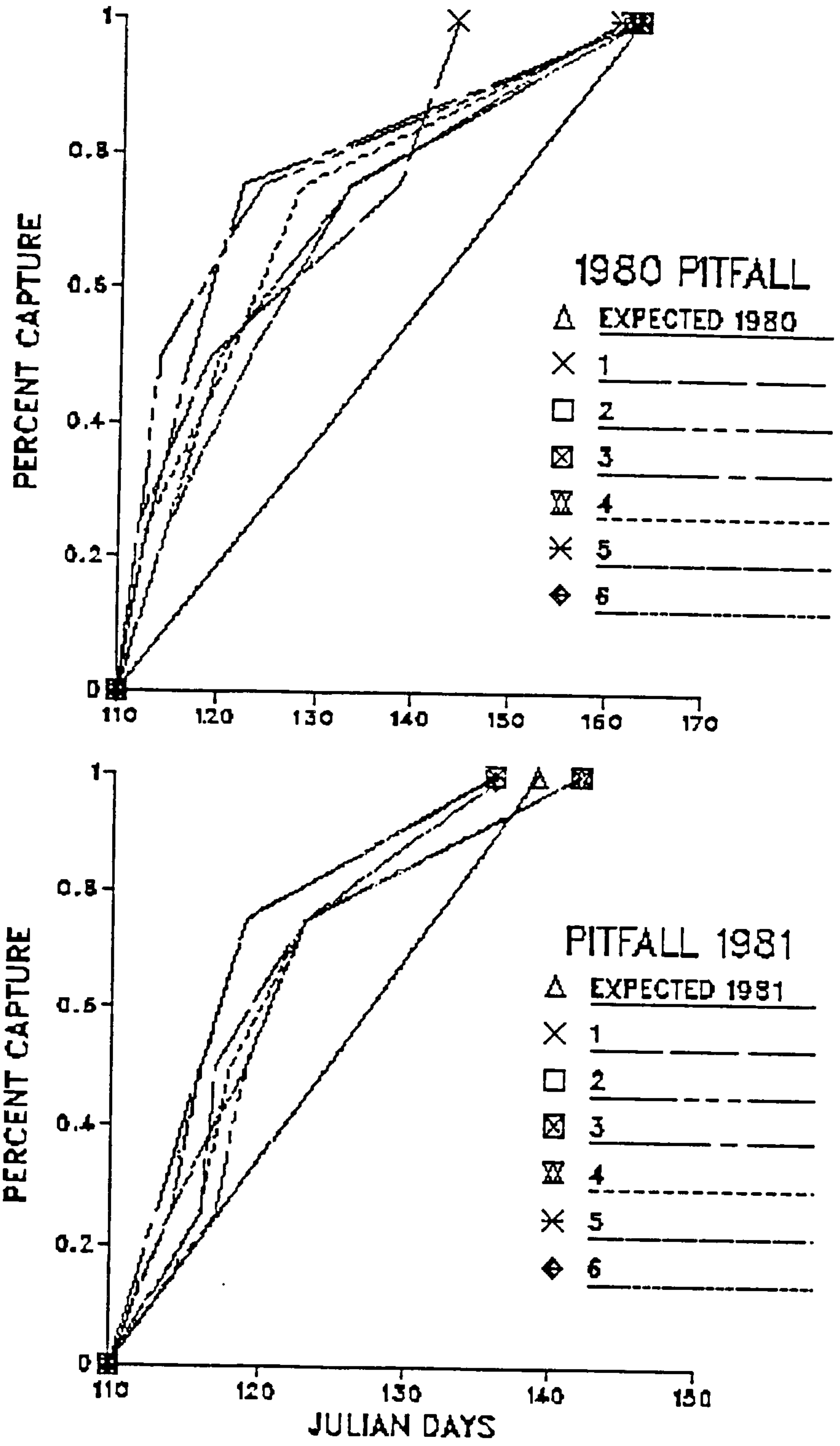


Fig. 17. The linear pitfall array observed capture rate in six fields near Hyde Park and North Logan and a hypothetical constant capture rate are plotted for the 1980 spring (Julian days 110 to 155).

the traps were exposed. This would indicate the traps captured insects at a constant rate (Fig. 17). In 1980 and 1981 there was a high capture rate early in the season. The rate leveled off as the crop matured. Most trap lines had 50% of the total captures within a few days of the being set in place. This reflects changes in the behavior as the mating, feeding and oviposition activities occur more frequently within the alfalfa plant canopy.

Analysis of variance for mark-release-recapture array. An analysis of variance was executed to learn if years and fields were interacting (Table 22). The field populations were either low or high for both years. Weevils within fields respond to the environment similarly across years. Even though the 1980 season had the greater number of trap days, no difference in the pattern of capture between the years existed (Fig. 18) and population means did not change their order.

The pitfall captures were totaled for each day and an analysis of variance completed on these totals. Data from the two years were combined for analysis. During 1981, there were fewer days with no captures and the means were higher. Separation of means was achieved. The differences were constant between years (Table 22).

Mark-release-recapture experiments.

Mark-release-recapture experiments were conducted in 1980 and 1981. The marked insects were released into the areas in which they had been captured. Only one marked weevil was recovered, in Field 4 during 1980. None of the results were satisfactory for estimating

Table 22. Mean separation of linear pitfall array captures (20 traps per array) of alfalfa weevil adults in six fields near Hyde Park and North Logan during 1980 and 1981.

FIELD	REPS	1980		REPS	1981	
1	44	1.48	a	14	2.46	a
2	45	2.78	ab	14	6.71	b
3	42	1.88	a	12	3.33	ab
4	43	4.88	b	14	6.15	b
5	41	0.68	a	14	2.50	a
6	43	1.65	a	14	1.43	a

Note. Means not followed by the same letter are different, all **=P>0.01%.

either absolute or relative populations of adults in the field for either year.

During 1981 an additional array (Fig. 4 B.) in Fields 1, 4 and 5 was set up and marked insects were released as discussed by Roe (1985). Except for release activities, the arrays remained undisturbed. Prior to harvest the arrays were intensively swept.

Of the 400 marked weevils released in each array only a few were recovered (Field 1 = 3%, Field 4 = 4.25% and Field 5 =2.75%), and the data would not support further analyses to determine the size of the population.

The question of how far the weevils moved within the field (Table 23) was examined. Half of the insects were released on 17 May (Julian day 138) and the rest on 25 May (Julian day 145). The sweeps were conducted between 1-4 June (Julian days 152 to 155). The highest mean capture occurred at the innermost sample sites. Since there were twice as many sets of samples (eight versus four) taken at the inner ring than at the others it seemed appropriate to divide the total recapture of the inner ring by 2 (22/2 = 11) . This brought the adults captured at all distances to similar dimensions (Table 23).

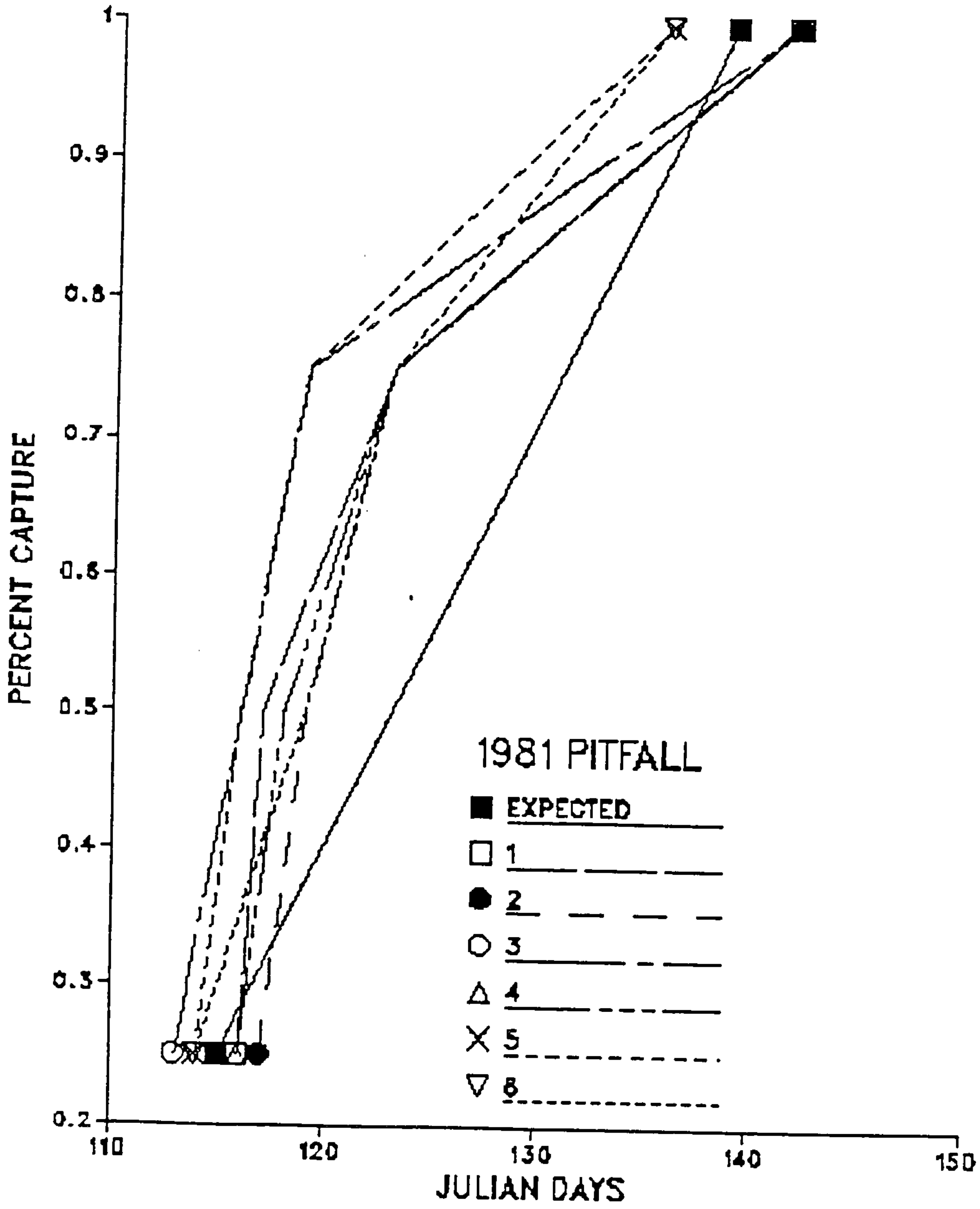


Fig. 18. The linear pitfall array observed capture rate in six fields near Hyde Park and North Logan and a hypothetical constant capture rate are plotted for the 1981 spring (Julian days 110 to 155).

The mean travel time to all distances was similar (near 10 days). The weevils released first (Julian day 138) were recaptured beyond 6 m at a lower rate than those released later. Adult weevils actively moved outward from the release site rather than distributing at random in the area.

Ring sample results.

To quantify survival through the critical harvest period a ring sample of the weevil population was taken with a 929 cm^2 ring. The ring was tossed and the number of living and dead larvae and pupae, along with parasite pupae, were counted before regrowth began after first harvest.

The number of larvae found alive in the samples was subjected to analysis of variance. The F-test was nonsignificant at the 5% level but was significant at the 10% level (Table 24). The LSD was applied at the appropriate level based on the number of observations. The number of larvae found dead was also analyzed.

The number of weevil larvae alive were not proportional to the number found dead (Table 24). Field 4 had the highest larval survival compared with the lowest numbers in the sweep captures. The analysis indicated Field 6 had the lowest mean population of living larvae; Field 4 had the highest population of living larvae and Field 5 was intermediate. The number of dead larvae was small in proportion to those alive. Based on comparison with 1980 adult populations, the number of live larvae did not correspond directly to the adults recovered the previous season.

Table 23. The analysis of alfalfa weevil adult recaptures to determine the distance traveled, from 400 marked weevils released in 3 alfalfa fields near Hyde Park and North Logan during 1981.

		DAYS SINCE RELEASE						
DISTANCE TRAVELED	# RECAPTURED	7	9	10	14	17	MEAN (DAYS)	S.E.
6.1 m	22 (11)	14	2	6			8.00	1.38
12.2 m	7	2	1	2	2		10.14	2.69
18.3 m	9	1	1	6		1	10.33	2.69
24.4 m	8	2		4	1	1	10.63	3.37
TOTAL	48	19	4	18	3	2		

Table 24. Mean separation of the alfalfa weevil larvae found alive, dead and pupae along with the parasite, Bathyplectes curculionis for 1981.

		ALFALFA WEEVIL LARVAE			
FIELD	REPS	ALIVE	DEAD	PUPAE	PARASITIZED
1	51	5.00 a	1.51 b	1.14 a	0.18
2	44	5.36 a	0.25 a	2.23 abc	0.48
3	32	7.72 b	0.19 a	1.84 ab	0.06
4	60	8.77 b	0.27 a	3.19 bc	0.08
5	16	7.24 ab	0.50 a	4.25 c	1.00
6	22	4.36 a	0.27 a	2.14 abc	0.41

Note: Means not followed by the same number are significantly different.

The alfalfa weevil pupae recovered from the same area within the field were also analyzed. Comparison of the survival between life stages and parasites within a field and between seasons was difficult. The number of B. curculionis cocoons was also tallied during the sampling for the weevils (Table 24).

Factors affecting survival of the different stages include: early harvest (Fields 3 and 4), low stem densities (Fields 2 and 3) and predators. Early harvest influenced the proportion of larvae entering the pupal stage. Late harvest (Fields 5 and 6) did not appear to result in more pupae surviving. Few dead larvae were found in any field. An undocumented number of weevil cocoons had neat circular holes in one side with no prepupae or pupae inside, indicating they may have emerged or been eaten. There were large numbers of potential predators found in the pitfall traps. Field 6 had a large population of carabid beetles (Calosoma sp). Long-term exposure of B. curculionis to heavy predation could result in a significant population reduction independent of other environmental factors.

Comparisons of the mean larval populations, either dead or alive, and B. curculionis, which were exposed or under the cover of the windrow, showed no significant statistical differences. However, more pupae were found under the windrow (Table 25). This could be explained by the behavior of either adults or larvae as they foraged or sought shelter.

The newly emerged adults and older larvae were mobile. While feeding, both distributed themselves evenly across a field. Before pupation, the unparasitized larvae sought the protection of the windrow

Table 25. Multiple regression of physical factors that may be useful in predicting populations of adults (ADULTS), total punctures (T-PUN), oviposition punctures (O-PUN), Berlese total capture (B TOT), larval alfalfa weevils from sweeps (LARV) and *Bathyplectes curculionis* (BC).

PREDICTORS	ADULT	T-PUN	O-PUN	B TOT	LARV	BC
INTERCEPT	25.07	-8.37	-6.05	-22.81	400.6	0.97
YEAR	17.94	-0.33	0.067	30.55	197.64	0.09
DAY	-0.40	0.09	0.053	0.21	-10.06	0.007
FIELD	0.18	0.06	0.067	0.37	25.11	0.023
STEM DEN	-0.02	-0.01	-0.002	-0.05	1.76	-0.010
HEIGHT	3.23	-0.0004	-0.0004	0.58	2.39	-0.034
ACC DD	0.03	-0.01	-0.005	0.03	1.76	0.007
LODGING	-24.42	1.23	0.44	0.46	184.22	-1.47
% VAR EXPLAINED	30.6	6.7	15.4	48.6	47.7	4.5

Note: INTERCEPT=overall mean value, YEAR=1980 or 1981, DAY=Julian day, FIELD=field for data source, STEM DEN=field stem density, ACC DD=accumulated degree days for the date of sample, LODGING=whether the alfalfa was lodged.

(3.3:1.8; windrow:exposed/929 cm^2). *B. curculionis* parasitized pupae were rare and evenly distributed between the two environments (sheltered 0.293 versus exposed 0.261/929 cm^2). This seemed to indicate that the parasite controlled the timing of pupation of the larvae and forced the formation of the pupal case when the parasite was ready, regardless of the environmental conditions. This would result in the random distribution of parasites.

Multiple regression analysis of factors affecting captures insects in alfalfa.

Multiple regression analysis, an extension of simple regression, allows the addition of independent variables that explain variability around the regression line and increase the correlation. These analyses were not used as a predictive tool, but were used to look at the relationship of factors to insect population sampled.

In these analyses, the year the samples were taken, Julian day, field sampled, stem density of the area in the field that was sampled, the stem length at the time of sampling, the accumulated degree days at the time of sampling and the state of lodging, yes or no, were added in the order presented. Their inclusion was based on earlier studies. Regression analyses are presented (Table 25).

Adult population captures could be modeled with only marginal success. Most of the variability was explained by the alfalfa lodging. The year in which the field was sampled was important in some of the population dynamics. Total punctures and oviposition punctures were not modeled well by any factor included. The multiple regression analysis was better if the independent variables contained unique sources of variability or could be correlated with factors such as days or lodging. It should be noted that both Berlese totals and sweep samples for larvae had relatively high correlations. This could be due to continued expansion of populations.

Multiple regression was performed on independent predictors of egg abundance based on the number of total punctures and oviposition; field number and stem density were included in the following equation:

# of eggs = -0.923 - 0.057 X total punctures + 9.88 X # oviposition punctures + 0.037 X Field number + 0.026 X field stem density.

% VAR = 84.9

This equation explained 84.9% of total variability in the number of eggs recovered. The equation produced a curve mimicking the egg population with good reliability if the number of oviposition punctures was known. This could be measured by counting the oviposition punctures in bouquets. The negative intercept indicated few eggs were detected early.

The following analyses were the result of stepwise multiple regression carried out on data from within two fields. The order of the importance of the factors changed with field but the most important measurable factor for determining the number of eggs in a stem was the total number of punctures in a bouquet. Each oviposition puncture was equivalent to an average of very close to ten eggs.

Field 4

$$\text{Total Eggs} = 1.38 + \underset{C}{0.154(\text{day})} - \underset{D}{0.266(\text{alfalfa height})} - \underset{B}{0.0063(\text{total punctures})} + \underset{A}{10.2(\text{total oviposition})} \qquad R^2 = 88.1\%$$

Field 5

$$\text{Total Eggs} = 0.53 - \underset{B}{0.071(\text{day})} + \underset{C}{0.143(\text{alfalfa height})} - \underset{D}{0.53(\text{total punctures})} + \underset{A}{10.1(\text{total oviposition})} \qquad R^2 = 86.8\%$$

The total number of eggs found in the stem samples was dependent on the total number of oviposition punctures. The letters indicated the order of the factors in explaining the variability. The number of eggs per oviposition was very close to the field mean for oviposition. This indicated the egg population may be easier to model than the ensuing larvae.

These results demonstrated that field egg and larval populations had distinct environmental factors acting on them at different times during the season. The larval population developed later in the season and larvae were seldom numerous in samples before the alfalfa was 35 cm tall. This indicated the early season forecasting of the late season larval populations depends on accurate measurement of the number of punctures early in the season. The forecast must then be updated to reflect current seasonal conditions relative to larval development and approaching harvest. An alternative would be to quantify the number of eggs per stem in a field. When the number of eggs per stem exceeded 1.0 per stem (1 oviposition puncture per ten stem bouquet) before the alfalfa reached 30 cm height, the larval population would likely reach outbreak dimensions. With lower egg densities, the late season development due to weather became more important.

Sticky board captures.

No adult weevils were captured on sticky boards during 1980. The only captures during 1981 were during early to middle April (Julian day 99 to 110). The total capture per day is presented in Fig. 18. The data were pooled from all 6 fields sampled. The number of captures per field was low (Field 1, 6 captured; Field 2, 5; Field 3, 14; Field 4, 1; Field 5, 3 and Field 6, 4). Field 3 had the highest number of captures and Field 4 had the lowest number of captures.

The weevil flight was expected to match either the adult captures in the field or to be evenly spread across all fields. The pattern indicated the foothill areas had more flight activity than the areas near the valley floor. The pattern matched neither the adult sweep net captures in the field nor any of the larval population levels. The adult behavior might have differed in fields if based on stem density or other physical factors not measured.

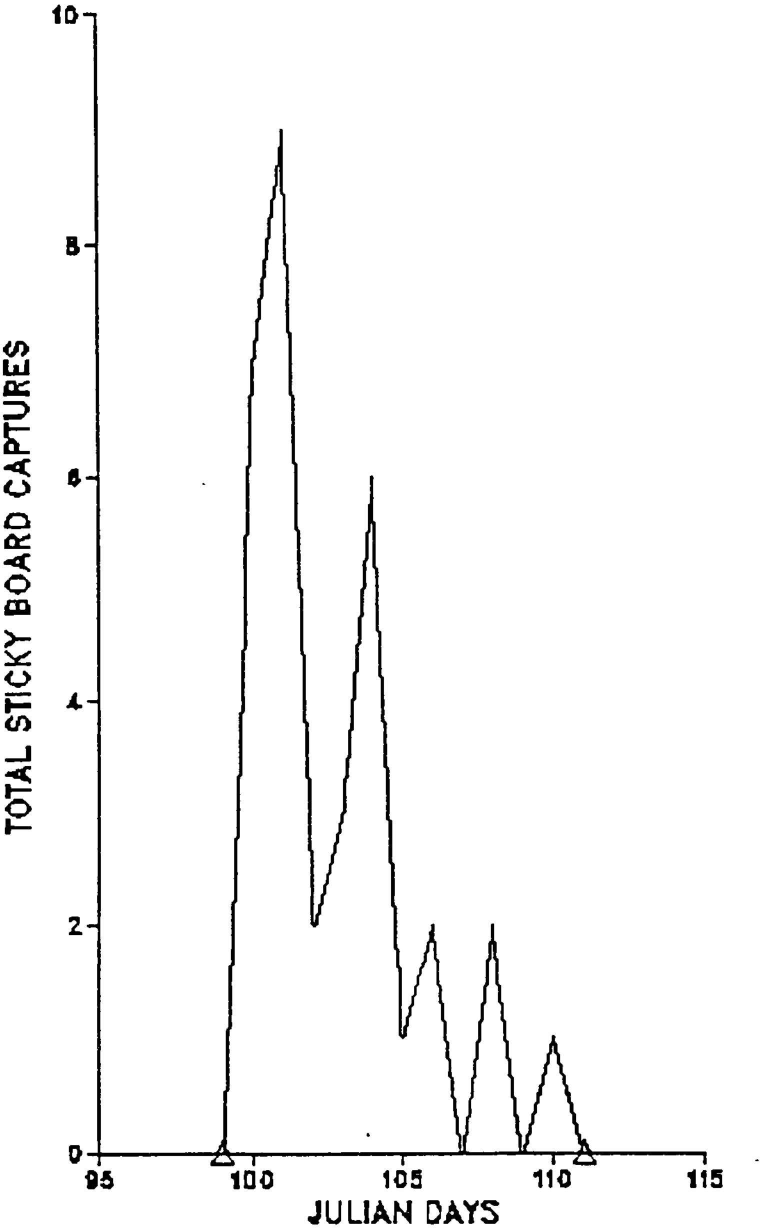


Fig. 19. Captures of alfalfa weevil adults in Hyde Park and North Logan on sticky boards plotted on Julian days during 1981.

Adults flew early in April in response to local conditions or the flights would have been evenly spread across the valley floor as well as the foothills. No captures occurred after 30 April. The spring flights were either small or sticky boards were not effective devices for capturing alfalfa weevils. Sticky boards captured an abundance of other insects.

DISCUSSION

It was assumed a relationship between early season adult alfalfa weevil numbers and later larval populations could be used to forecast outbreaks. It should be considered that the weevil is univoltine and once the season starts no further recruitment of adults into the field occurs. Also, it should be considered that weevil adults do not emigrate and mortality was expected to be low. Consequently, an index of the adult activity would likely be the best indicator of subsequent larval populations.

Analyses of accumulated degree days (DD) at different stations in Cache Valley at two threshold temperatures, (5°C) for alfalfa and (9°C) for weevil, was performed for the spring months. The effects of the DD were additive. Data indicated warm and cool areas existed in the valley. The season was divided into two segments, an early and late spring to reflect the different rates of DD accumulation.

Early spring (Julian days 60 to 109) degree day patterns were similar for Cache Valley locations for either alfalfa weevil or alfalfa during the study period. Areas that accumulated few DD at the alfalfa threshold (5°C) accumulated even fewer DD at the weevil threshold (9°C). The ratio of alfalfa accumulated DD to weevil accumulated DD for Trenton, the cool site, was (alfalfa DD:weevil DD) 6.5:1 and for USU, the warm site, was 4.6:1. A moderate season would have a steady accumulation at both thresholds while both lower and higher temperature regimes would have nearly the same ratio and favor the plant. However these analyses indicated the early spring differences were non-significant and no mean separation of areas was possible.

Low weevil populations were found in cool regions, Areas I and III, and seldom reached economic thresholds at peak populations (economic threshold = 18 to 21 larvae/sweep, Koehler and Rosenthal 1975) and growers probably experienced little or no economic loss due to larval feeding (Koehler and Gyrisco, 1963). Warm early season sites were likely to have damaging populations of larvae annually. Areas II, IV and V, on the east bench, the warmer region of Cache Valley often had damaging peak larval populations (> 21 larvae/sweep). High adult weevil populations during early spring were followed by higher larval populations, but not in proportional numbers.

In cool weather degree days necessary for weevil development accumulated slowly, while the alfalfa plant continued to develop. This was seen in Fig. 6. Also, the regression of weevil accumulated DD on alfalfa growth had a correlation coefficient of 82%-93%. This compared well with data used by Bula et al. (1975) whose calculations were based on 5°C (= 555 DD) for alfalfa. Similar conditions were seen in Cache Valley. The model tended to underestimate both the initial and final accumulations, but provided a good estimate of the weevil DD accumulated during the middle of May (Julian day 140).

One should note that the rate of accumulation of degree days for alfalfa (5°C) and alfalfa weevils (9°C) was nearly parallel during late spring and each could be used to accurately estimate the other. Eklund and Simpson (1977) were able to calculate the alfalfa height and DD and then check for the appearance of _Bathyplectes curculionis_ emergence at

194 to 222 DD or 25.4 to 35 cm growth. In Cache Valley the height of the alfalfa at 200 DD would be about 18-21 cm and second instar weevils would be available for the emerging B. curculionis.

Alfalfa growth was similar across the valley. The correlation in alfalfa growth even in the small areas, was near a mean of 0.01 cm/DD (9°C). Based on this relationship calculations were designed that converted the current alfalfa height to the estimated weevil accumulated DD (9°C) and projected to a hypothetical cutting date. Knowing the alfalfa height, it became possible to calculate dates when the alfalfa would be harvested. This would be used to estimate likely weevil populations for a projected interval; then one would manipulate the watering and cutting schedules to make the environment unsuitable for the weevil.

Hamlin et al., (1949) indicated that weevil larvae appeared near Salt Lake City after the first week in May. This is consistent with their appearance in Cache Valley. The estimated degree days required for an eastern weevil egg to complete development ranges from 150 to 260 DD (Evans 1959; Hintz, Wilson and Armbrust 1976; Harcourt, Guppy and Binns 1984; Harcourt 1981). An additional 355-382 DD is needed to complete development and pupate. Canadian weevils require fewer DD to hatch (110) and pupate after only an additional 294 DD, which is more like the conditions and weevil populations in Cache Valley (Peterson, 1960). The weevils that caused the majority of the damage in Cache Valley hatched after only 100-150 DD passed. This occurred when the alfalfa had grown to between 10 to 12 cm. Later eggs would not have sufficient time to complete larval development and later yield adults.

Therefore, early season temperature regimes (Julian day 60 to 109) become important in forecasting outbreaks of weevil larvae. It is during this period the female feeds, mates and oviposits resulting in damaging larval populations. If the month of May (Julian day 120) begins with either a significant accumulation of alfalfa weevil DD (near 100 DD) or by alfalfa height greater than 10 cm, there is likely to be larval damage. During the remainder of May there are nearly always sufficient degree days accumulated to mature the larval population (roughly 350 DD at 9°C). If warm conditions continue through May, growers should harvest early. This will control many of the larvae. This can be followed by an application of pesticides, if necessary, to the recently harvested field to control the newly emerged adults and hold-over larvae.

In contrast, when the temperature regime during early spring (April) is cooler with many periods between 5°C and 9°C, alfalfa growth proceeds with little weevil egg development. During such years, or in cool areas, weevil larvae seldom reach damaging levels by harvest. The method of following weather regimes and comparing them with alfalfa growth offers a substantial improvement over the current method of waiting for an outbreak to occur.

The pattern of adult sweep net captures was similar to those of Eklund and Simpson who plotted capture rate of adult weevils on alfalfa growth (1977). Hamlin et al. (1949) presented data similar to that shown in Fig. 11. In all plots, as the alfalfa approached 45 cm, the number of adults captured in a sweep net declined. Adult behavioral response to environmental cues, such the approach of a sampler, day length, or temperature increases causing the weevil to spend less time in the upper canopy, apparently contribute to the decline in mean captures. The density of matted alfalfa also prevents effective sweeping of the alfalfa canopy.

Bathyplectes curculionis capture patterns were also similar to those reported by Eklund and Simpson (1977) and Hamlin et al. (1949). B. curculionis were recovered coinciding with substantial populations of first and second weevil instars recovered in Berlese funnels. In Cache Valley the height of the alfalfa was 18-21 cm on Julian day 135 when second instar weevil larvae became commonly available for the B. curculionis. In earlier work with sweep nets, without extensive Berlese samples, B. curculionis adults were recorded before large populations of weevil larvae.

Lower than expected populations of B. curculionis were found in the southeastern and central portions of Cache Valley. There appeared to be sufficient weevil larvae for the B. curculionis populations but parasite numbers were low. Alfalfa in the south end of the valley was shaded by mountains and the central area tended to have cooler pockets. This may have affected B. curculionis development.

The alfalfa weevil larvae recoveries in Cache Valley followed the same patterns in all fields during the seasons of study. Sweep net captures were low until mid May. Prior to harvest during early June there was a rapid increase in the number of larvae captured. This coincided with the larvae reaching third instar. At the preferred harvest dates, more third instars than fourth instars were present in the sweep samples. Earlier discussions of the economic thresholds remain valid. The coolest location in the valley, Area III, had few fields where alfalfa weevils annually reached an economic threshold. Warmer areas in valley had many fields where weevils annually reached an economic threshold. These should have been treated with insecticides or harvested early, based on an economic threshold of 18-21 larvae/sweep (or 350-425 larvae/20 sweeps, Evans 1959, Koehler and Rosenthal, 1975). However, the interval between outbreak recognition by sweep nets and timing of pre-harvest control with insecticides was short. The available time was about ten days.

The use of alfalfa accumulated DD (5°C) to predict alfalfa weevil development was reliable and linked early growth of alfalfa with the development of the larval populations. During early May, the alfalfa was in a log growth phase that continued until harvest. The relationship of alfalfa growth and degree day accumulation was predictable and accurate and could be used as an index the development of the alfalfa weevil. When data were collected from specific fields, correlations increased.

The prime difference between this study and other studies of alfalfa weevil populations was the large number of fields visited and the temperature regimes studied within limited areas. Other reports have looked at either a few fields (2-6), or have sampled representative fields intensively, or only used limited sampling regimes. With repeated sampling in many fields the variability was reduced.

Measuring the populations of overwintered adults did not lead to estimates of the subsequent larval populations. Since there were no methods for accurate sampling of adult weevils, the oviposition and subsequent larval populations were erratic due to slight climatic variations. The number of <u>Bathyplectes</u> <u>curculionis</u> also did not indicate which areas would have a high larval populations. Location in the valley was the most consistent indicator of future high populations.

Based on earlier studies and reports, the detailed studies of 1980 and 1981 were conducted in the high population region (Area V) near Hyde Park and Logan. The six fields were planted with the same variety, Ranger, and the growers used sprinkle irrigation. The stem density was low in two fields (2 and 3) and these fields were also on the stony, poor soils. Maximum-minimum recording thermometers were placed in three fields (1, 4 and 6), and were correlated with the USU, KVNU and SW5 weather stations (Table 10). The differences in weather data obtained from these sources was minimal.

A sampling regime of 30 or more samples per site had been suggested by other workers. This was beyond our ability to process samples rapidly enough. Helgeson and Haynes (1972) used a similar regime with fewer samples under comparable conditions. Samples were collected and analyzed using regression analysis followed by analysis of variance. Some samples were collected over three consecutive days allowing repeated estimates of the same field populations. The same sampling intervals were followed using three techniques: stem, Berlese funnel and sweep nets. The number of stems required to accurately measure egg populations would have approached 200 samples per field for each date to reduce the variability below 20%. Guppy and Harcourt

(1977) counted between 64-128 stems two times each week for each field. Guppy, Harcourt and Mukerji (1975) used 16-20 sets of ten stem samples. These large numbers did not seem practical and would be of little value to integrated pest management personnel. Regression analyses were useful, but later a split-plot analysis of variance was also applied to data sets. To reduce the variability, these analyses included several covariates: stem density, alfalfa stem length, accumulated degree days and lodging.

A comparison of daily degree days among the field thermometers and National Oceanic and Atmospheric Administration weather shelters indicated the weather regime could be followed with considerable accuracy using simple thermometers. The correlation among the shelters was close to 1.00. Thermometers from Fields 1, 4 and 5 had similar readings to the weather stations, but correlations were slightly lower. This was due to primarily random effects of alfalfa shading the thermometers.

The field height at the time of thermometer emplacement was given as the intercept. The daily DD accumulations from the weather station was regressed on the alfalfa height starting on 1 April (Julian day 91). The negative height was interpreted as slow growth initiation in Field 2. The intercepts and slopes for all fields were similar. The degree days were estimated from readings of both the field thermometers and weather stations, and established that either could be used to predict the field height with high reliability.

The measured stem length was subjected to the same analyses as above. The combined (Comb.) slope was negative in only two fields (1 and 3) the rest were positive. The plant growth DD accumulation slopes regressed on either USU weather station or Field 1 thermometer readings, were similar to those shown in Table 11. Field 2 data in Table 11 was the only field with a negative slope. This supported later analyses that demonstrated Field 2 had more weevil larvae and adults per area sampled due primarily to the low stem density and early warming. Later the same warmth caused the females to cease egg production and oviposition sooner. Intercept and slopes for Field 2, were similar to others shown in Table 11. The high correlation coefficient should be noted. The alfalfa growth was measured readily using the field height or measured stem lengths. Since the correlation between the height and accumulated DD was high it was possible to estimate how many degree days had passed since the beginning of the season.

Analyses of punctures, using either feeding or oviposition punctures per ten stems were difficult due to the low numbers of actual punctures sample. This was also discussed by Harcourt, Mukerji and Guppy (1974), and Harcourt and Guppy (1976). The attempts to reduce variability by using a regression analysis were modestly successful. (See Figs. 14 through 16 for the seasonal population trends for feeding and oviposition punctures.)

Oviposition before Julian day 130 resulted in larvae that caused later damage, larvae emerging later did not have enough accumulated degree days by harvest time to become third and fourth instars unless rainy weather delayed harvest. Larvae from later ovipositions matured too late in the season to cause damage. An economic threshold, 1 oviposition puncture per ten stem bouquet by Julian day 120 would result in enough larvae to reach the economic threshold (Hamlin et al., 1949, Niemczyk and Flessel, 1970, Casagrande and Stehr 1973, Harcourt, Mukerji and Guppy, 1974). The coefficients of deviation for the intercept and regression coefficient were stable between fields and seasons. Larger samples did not decrease the variability of these estimates.

The number of punctures increased with both Julian days and the accumulated DD. This steady increase in the number of eggs and the similarity of regression coefficients and intercepts reinforced the observation that the adult population responded similarly in fields across the valley.

The total number of eggs per ten stems per day was similar to the results reported by Harcourt, Mukerji and Guppy (1974). Manglitz and App (1957) and Norwood et al. (1967). The number of eggs per puncture per day changed little between early oviposition until harvest (1980 first counts were 11.80 and late counts 8.84; 1981 first counts were 9.36 and late 10.34). All environmental factors evaluated had little effect on the mean number of eggs per oviposition puncture. The number of punctures per day varied greatly. Cool periods were followed by heavy oviposition during ensuing warmer days. However, since the number of eggs per site was not affected by the environment, the mean could be considered a constant, as others have reported (LeCato and Pienkowski 1970, Hsieh and Armbrust 1974). This consistency simplified calculations. It also indicated that the females responded to the environmental conditions by ovipositing at more sites rather than more eggs per site.

Combined data for both years and mean two-year populations were checked against the annual means using a t-test. The data from 1980 and 1981 were indistinguishable. The fields tended to have the same number punctures each season. The fields that had high weevil populations one year had them the following year. Areas of the valley were also consistent, indicating broad environmental effects consistent between years.

An early season decline of oviposition rate occurred in Field 2, probably due to low stem density which enhanced egg production and larval development. Earlier and higher temperatures in the open canopy led to early cessation of oviposition. The upper temperature limit for female oviposition is 35°C (Bass 1966, Hsieh and Armbrust, 1974). High temperatures might also kill the eggs (Essig and Michelbacher, 1933). The above trend held for both years of research.

Early season weather can be quite different than later in the same season. The 1981 spring season began with a more rapid accumulation of degree days and ended with a cool spell. The cool late spring lowered the regression coefficients for 1981 but did not affect the intercept (Fig. 14). Although the number of eggs deposited in a site did not change, the female weevils laid more eggs per day during the warmer periods (LeCato and Pienkowski 1972a).

The number of eggs per oviposition site was statistically constant from season to season (Fig. 16). The correlation coefficient was 85% for both seasons and the field mean (number of eggs per puncture) varied from 9.9 to 10.2 eggs between years. This is similar to other data (Hamlin et al. 1949, 10.0; Harcourt, Mukerji and Guppy 1974, 10.1; Evans 1959, 9.9; Manglitz and App 1957, 8.8; Niemczyk and Flessel 1970 9.2).

Adult weevils and parasites responded similarly to temperatures in the field, and patterns compared well with published laboratory studies (Bass, 1966). The field captures of weevil adults and larvae along with the parasites are as reported by other workers (Eklund and Simpson 1977, Casagrande and Stehr 1973). The sweep net capture results for all alfalfa weevil stages, puncture records, and Bathyplectes curculionis catches were similar to records in the literature.

Adult alfalfa weevil sweep net captures were erratic and not predictive of later larval populations (Table 15). Adult captures varied greatly with temperatures and light intensity. Fields 6 and 4 had consistently high field populations until corrected for stem densities during later two factor analyses.

Larval weevil populations in the fields could be distinguished statistically by sweep samples when the alfalfa was about 34-40 cm tall and 200 DD had passed (5 May, Julian day 125). However, the predominance of early instars caused a high level of errors at this time. Sweep samples collected before Julian day 114 (24 April) were not useful in predicting late season larval populations. At 200 DD the mean captures were generally less than 1 per sweep (Table 15). After 200 DD, the field populations were separated with increasing accuracy on each sample date. The low stem density fields had low sweep net captures of larvae, reflecting fewer stems. Field 4 was cut early, and was an example of the effect of early harvest in preventing an outbreak of weevil larvae. It did not lower the number of adults for the next season, which was similar to findings by Morris and Miller, 1954. Fields 5 and 6 had delayed harvests and the weevil larval populations reached damaging levels during 1980.

The low frequency of punctures and eggs (Table 15) per stem made a separation of field populations difficult. Helgeson and Haynes (1972) used a regression technique to overcome similar problem. Analysis of variance of the daily adult and larval captures was not useful.

A series of split-plot analyses focused on smaller areas (northeast, northwest, southwest, southeast or center) in fields and related covariates. This assumed the variance associated with a population within a field was characteristic and could be measured (Federer 1975). There was very little error accounted for by the method of blocking chosen.

The split-plot analysis of variance of the punctures indicated there were no significant differences among fields for either 1980 or 1981, based on counted feeding punctures and oviposition punctures. Field 2 had the highest means for both total and oviposition punctures. These fields did not have the highest population of larvae based on 20 sweep counts. All fields had lower puncture means for 1980 compared with 1981.

Since the data on the number of punctures and the Berlese funnel samples were collected at the same time, they can be compared directly. The mean number of total larvae recovered in the Berlese funnels was 4-fold the number of eggs found in the ten stem bouquet (Table 17 BTOT vs

OPUN) for the fields. This confirms early observations (Titus, 1910a) that thin or old stands of alfalfa are more susceptible to weevil damage and must be closely managed to maintain fields in production.

A relationship between the total punctures and oviposition punctures plotted on Julian days (mean number of ovipositions and total oviposition) was evident in Fig. 16. The slopes were parallel and constant. This indicated that for every 3-4 total punctures at 12 cm growth stage there was roughly 1 oviposition puncture. For every oviposition puncture there were 9.99 eggs deposited, based on 1980 + 1981 combined data. Similar ratios based on the means were observed for each field each year.

From the data it was possible to estimate the number of expected oviposition punctures and total eggs based on the number of total punctures. For instance, if 10 punctures were found in a field sample there would be an average of 3 oviposition punctures and 30 eggs (3 oviposition punctures X 10 eggs per puncture = 30 eggs). Based on 1 oviposition puncture per ten stems, or 3 total punctures, there would be one larva per stem later on.

These estimates were based on the data from 1980 and 1981 and were fairly reliable when there was 12 cm alfalfa growth. This was also supported by regression analyses. However, there were other aspects of the physical environment which interacted, especially related to larval survival and success.

Split-plot analysis of the sweep net samples for capture of alfalfa weevil adults and larvae, and <u>Bathyplectes</u> <u>curculionis</u> were corrected for the stem density, stem length, accumulated degree days and lodging when samples were taken. The analysis adjusted for the covariates before the F-test was performed. The factor for interaction was significant but plotting the terms did not reveal significant deviations in most cases. There was little error associated with the where within the field the sample was taken in most cases. Five samples per field in this type of analysis detected significant differences among fields with no additional need for blocking. This would represent a major saving in time over other suggested techniques (Harcourt, Mukerji and Guppy, 1974; Harcourt, Binns and Guppy, 1983; Guppy and Harcourt, 1977; Blickenstaff, Huggans and Schroder, 1972). The data base would increase with every sample taken of the population. As the season progressed, the population ratings of individual fields in relation to others became apparent. This could be used as the basis for forecasting potential outbreaks, especially when combined with the egg sample.

The split-plot analysis of adults captured in a sweep net indicated the covariates accounted for significant errors during both seasons. The fields had the same order and magnitude of adult population means between years, but it did not match the larval populations.

The split-plot analysis of variance was applied to the results of the hand examination of the stems for punctures and number of eggs. These analyses used the same covariates as before. Again, there was no unexplainable interaction between the factors. For total punctures there were significant differences detected according to fields, dates and years. This was not expected since the raw data appeared to be similar, and the regression analyses were also very similar. The mean total punctures differences between the fields after adjustments, were large and indicated that a simple analysis was not useful in determining which fields were likely to have economic outbreaks of larvae based on this index of adult activity. Early season total number of punctures were low, then continued to increase during the season. The oviposition punctures followed a different pattern than the total punctures and appeared to respond more to field conditions. It should be noted that the highest and second highest mean number of oviposition punctures occurred during late April and late May while the highest total punctures occurred at the end of May after being low at the end of April. The adult weevils apparently oviposited in response to the prevailing conditions. This, coupled with the high mean populations of larvae found in the Berlese funnel samples during late April and the overall patterns seen in larval development, indicated that conditions during the period before the first of May were critical to later larval populations.

Total number of punctures were numerically higher during 1980 but the total number of oviposition punctures was not separable across years. This appeared to follow the pattern of adult captures more closely than the total punctures. Each field tended to have similar larval populations from year to year as seen in Table 12. This also applied to the parasite populations. The stability between seasons could be perturbed only with major management practices, such as late cutting due to rain at harvest. Otherwise, weevil populations tended toward stability between years.

The total number of eggs per oviposition site was nearly constant. This could be easily converted to the number of eggs per ten stems once the number of punctures was known. There was a slight increase in the number of eggs per ten stems from 1980 to 1981. The changes in alfalfa weevil egg population levels were not reflected in the total number of punctures. The number of punctures with eggs may vary but the mean total puncture to oviposition puncture ratio was consistent during late April and early May. This ratio should be considered as part of any stem sampling regime in integrated pest management practices.

The number of eggs deposited and the prevailing weather patterns within a season were the key factors to alfalfa weevil larvae numbers. The number of eggs per oviposition puncture was constant, near 10. If desired, the number of total punctures and the number of oviposition punctures could be determined by counting the total punctures and then splitting the stem to verify the number of punctures with eggs. Based on the data presented, fields with a total puncture mean greater than 3 per ten stems were likely to result in about one oviposition puncture per ten stems which in turn would result in a damaging population of alfalfa weevil larvae (1 or more per stem).

The two factor analysis on the number of larvae captured from the ten stems in Berlese funnel yield results was similar to that reported by Guppy, Harcourt and Mukerji (1975). Once the egg hatch began, the number of first instars captured from the ten stem bouquets in the Berlese funnels was nearly constant for the remainder of the season. This indicated the larvae passed rapidly through this stage.

Alfalfa weevil larval sweep net captures were analyzed as previously outlined. The covariates were significant and should be included in future studies. The main factors (field, date of sample collection and year samples were taken) were significant and can be used to separate larval populations. Field 2 stood alone with its high larval population during both years. Field 4 had an intermediate level of weevil larvae numbers compared to the number of adults found in the field. This may have been due to the early harvest practiced by the manager to reduce larval population. The various factors that influenced survival between successive stages, seasons and generations produced relative stability in the population means from year to year. There appear to be some techniques available to raise or lower the population of adult weevils or _B_. _curculionis_ by altering survival factors operating on those populations, rather than direct control of current larval populations (Morris and Miller, 1954).

The _Bathyplectes_ _curculionis_ adults numbers were analyzed in the same manner as the alfalfa weevil adults. The _B_. _curculionis_ were detected at low mean populations in all fields. Notice that Field 4 had a low population of _B_. _curculionis_ compared to the number of adult weevils. This may have been be due to the presence of factors acting differentially on one species or stage of the insect population. The overwintering parasites were exposed for long periods to surface feeding predators. _B_. _curculionis_ could have started with higher mean populations in Field 6 due to the high number of larvae or different management practices employed by the grower. The _B_. _curculionis_ responded similarly to conditions in Fields 1, 2 and 5. Field 4 had a low populations of *B. curculionis* which could have been due to management practices.

During the 1981 season, the sweep samples were subsampled and separated according to instars. These were analyzed using a two factor analysis. In earlier analyses, Fields 5 and 6 had the highest weevil populations while Field 2 was either low or intermediate. When corrected for stem density, the alfalfa weevil adults, eggs and larvae populations were higher in the thin stands of alfalfa than in higher stem density fields. The economic threshold based on sweep counts should be lower for fields with low stem densities than for those with dense stands.

Field 4 had a low larval population compared to adults. The field was managed to reduce the larval damage by early harvesting. This was successful and resulted in low larval populations but later high numbers of new adults. This was verified by both Berlese funnel and sweep samples.

The advantage of the Berlese funnel was that the results could be converted to unit areas (929 cm^2) and the fields compared. It was obvious, the sweep analyses were not directly comparable for the low and high stem density fields. For 1980 and 1981, the number of eggs per 929 cm^2 in the low stem density fields was generally lower than in the high stem density fields. Then they had more first and second instar larvae per stem than the high stem density fields. Field 6 was an exception. The number of larvae recovered in the sweep nets did not always reflect the absolute densities. Estimates from the low stem density fields were too low with sweep nets.

Given a choice between analysis of variance or a regression analysis, the regression gave better estimates of the population and was easier to interpret. More sample sets with fewer sweeps each increased precision of the estimates. Twenty 5-sweep samples per field would give more reliable information than five 20-sweep samples. The reduction in time to sort each sample would be worth the change.

Multiple regression analyses indicated the nature of the most important factors in determining the expected population levels. The results corroborated the analysis of variance conclusions that alfalfa height, stem density and DD accumulated were important in explaining the variability in the larval populations seen in fields. The height of the alfalfa was related to location in the valley and the degree days which was related to the current Julian day, harvest practices and variety of alfalfa grown. The best indicators of early season larval populations remained the ratio between the number of total punctures and oviposition punctures and the number of degree days that had passed between the first of March and the first of May. Once the current alfalfa height was known it was easy to forecast the height at some future date and then estimate the potential larval populations.

Ring samples of 929 cm^2 were revealing. It was apparent that the number of larvae found in the rings after the harvest in 1980 was not correlated with earlier captures of adults. This lack of correlation indicated that the conditions through harvest were not measured by the sweep sample. Survival of the larvae through harvest should be studied.

The number of pupae found in the 929 cm^2 ring samples were significantly different among the fields. The pupal survival could be influenced by the DD accumulated prior to and after harvest. The mean number of Bathyplectes curculionis cocoons found were also significantly different among fields. There were weak correlations between the parasites found in 1980 and the number captured in 1981.

The 929 cm^2 samples represented an absolute density estimate of the populations. The number of both stem and sweep samples taken was in relation to total field size. There was an error associated with the ability to search the sample areas. The technique was labor intensive and it was difficult to complete all planned samples during a season.

More alfalfa weevil pupae were found under the windrows than in the open areas after harvest, but living larvae were evenly distributed. Dead larvae, killed by the mechanical action of the harvester, tended to be concentrated.

The method of harvest can influence larval and pupal survival. Green chopping, cubing and old style moldboard harvester can destroy many larvae. The currently popular harvester types shade and protect the larvae under the windrow. Experiments designed to test the effects of early harvest should be designed and carried out to determine the effects of harvester and harvest dates. There were nearly twice as many surviving pupae under the windrow than in the open.

Stickyboards captured flying weevils in early April. More weevil adults were captured in traps near the foothills around Hyde Park and North Logan than in the central part of the valley. No information regarding field populations of either adults or larvae could be inferred from the captures. No additional captures were made during the remainder of the spring or summer.

The flights did not last long and did not supply data related to long range movements of populations. Reports of captures of marked weevils from other studies nearly 1 km from release sites were not verified in Cache Valley. The flight activity of the weevil was confined to the first few warm days of early spring.

Mark-release-recapture experiments were time consuming and yielded little new data. Attempts were made to avoid entry and disturbance of the release site to ensure that the adults distributed themselves amongst the native population. The low recapture of marked weevils did not allow the calculation of absolute populations (Lincoln, 1930). These calculations would have required at least 10% recapture for the confidence interval to be small enough to indicate the relative populations of the alfalfa weevil adults in the fields. The number of marked adults recaptured did not allow field population estimates. The marked weevils may have moved too far from the release site.

The measurement of true population densities of the adult weevils in fields seems to be beyond the ability of existing techniques. These experiments should be repeated using other techniques or more manpower. If attempted, it should be done in a single field or pair of fields.

The ground movement of the adult weevils was quite extensive. There were apparently different behavior patterns for certain individuals but the adult weevils ranged widely from the release sites within fields. Weevils were captured up to 24 m from the release sites. Of the recoveries 50% were made in 11 days or less. The adult weevils appeared to range freely over large areas within the field.

Chi-square analyses of linear pitfall arrays indicated the population distribution in the field was not even. No large waves of adults invading a field from the margin were detected in either 1980 or 1981. Fewer adult weevils were captured near the margin and center; the most were captured at the intermediate distances. Fields 2 and 4 had high adult populations both years. Fields 5 and 6 had relatively low populations of adults.

Many adult weevils were captured soon after the linear pitfalls were placed in the fields (Fig. 17; start: Julian day 103, 1980; 109, 1981). After alfalfa canopy closure, adult weevils spent much less time crawling on the ground. Short alfalfa had a substantial population of adults on the ground during early spring.

The linear array samples were also analyzed to determine if there was interaction between field and year. Even though trap arrays were placed in different locations within a field, populations maintain their relative mean positions between 1980 and 1981. The major problem with the data was the low capture rate per individual trap. The results did not aid in forecasting weevil larval numbers. The populations of adults trapped reflected the later sweep net samples of adults, but not larvae.

SUMMARY

The studies of the alfalfa weevil population response to environmental factors within Cache Valley demonstrate a connection between the local conditions, plant growth and population development. Daily degree-days from the first of January to the first of March produce few days that promote either plant growth or weevil activity. Early season accumulated degree-days (Julian day 60 to day 109) are not significantly different among sites within the valley. However, there are significant differences in weather regimes among years. There were no significant interaction between years and sites within the valley. The conclusions also hold for either alfalfa or weevil threshold (9°C or 5°C respectively). During either a cool or warm early spring, the alfalfa plant gains about 5 degree-days per average weevil degree-day. During an intermediate spring, the alfalfa gains only 4 degree-days per weevil degree-day. No measured relationship exists between the early spring temperature regime and later spring (Julian day 110 to 155), but interaction may be important in determining an outbreak of larvae. Throughout late spring, the fields receive increasing insolation. Air temperatures on the valley floor are cooler than the east bench. The lack of significant interaction between year and site within the valley indicate site specific stability for temperature regimes.

Since cutting of alfalfa is based on either pre-bloom or growth height, the cutting date can be predicted quite accurately by about May 5. Using either the alfalfa growth as an indicator, or comparing the current weevil development to the accumulated degree days for the alfalfa ($5^{o}C$ base), the dominant state of weevil development at harvest can be predicted. During the period from Julian day 109 to harvest, weevil development and alfalfa growth is nearly parallel in all areas of northern Utah which have been studied. Total expected weevil numbers can be determined by punctures prior to 20 cm growth and by sweeps later.

Comparison of the rates of daily degree accumulation between the alfalfa plant and weevil are nearly parallel during late spring. The weevil DD intercept can be thought of as an average value of degree days accumulated before 20 April. The height of the alfalfa can be used to predict the weevil population development in the field. Early spring warm spells will therefore add more degree-days to the plant growth than to the weevil but be very important for egg maturation and later population development. Cool spells on the other hand allow the plant to continue growing while the weevils do not mature eggs. Warm springs advance the weevil egg production relative to cool or average seasons. An early warm spring generally results in damage prior to harvest (see Fig. 20).

The valley has several distinct temperatures regions. Cool areas do not have high populations of either adults or larvae and alfalfa is harvested late. High population areas were often cut first. Both alfalfa plants and weevils respond to local environments. Warm areas, such as near Hyde Park and North Logan, have some fields that receive weevil damage every year. During a warm early spring damage can be prevalent in all areas in the valley.

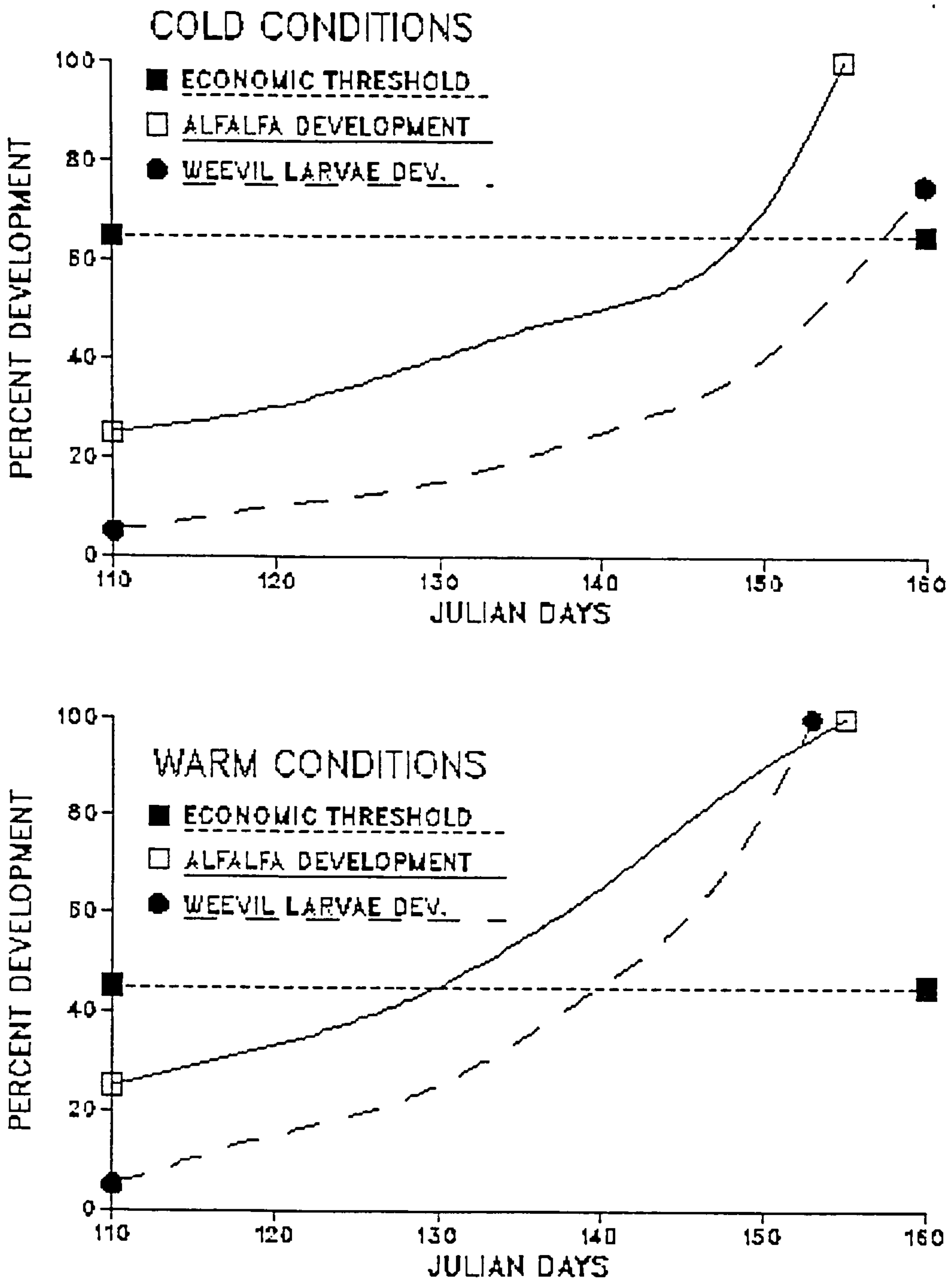


Fig. 20. Alfalfa plant and larval alfalfa weevil population response to warm springs or warm areas and cold springs or cold areas. cutting usually occurs between Julian days 150 and 165.

Field populations fell into regional patterns that reflected the temperature regimes in the valley. Cool areas had the lowest populations and the west facing slopes near Hyde Park and North Logan were identified as the high population areas for alfalfa weevil adults, larvae and B. curculionis. The low temperature areas of the valley floor had the lower weevil populations. Further analysis of the data set was not possible because of the low number of samples taken in some parts of the valley.

To remedy the problems and extend the data to determine which factors operated within a field, detailed studies of six fields on the east bench were carried out. The studies focused on analysis of the adult indices during the early season in relation to the larval population just prior to first harvest. Building on earlier studies, some additional factors were considered; stem length, accumulated degree days, stem density and lodging were observed and used as covariates in the analyses. Pitfall trap studies were added to follow adults during the early spring when the alfalfa could not be swept.

The field temperature regimes were compared with local weather stations. The accumulation of degree-days was followed with a high degree of reliability. The field height was regressed on both Julian days and accumulated degree-days. When the stem length in areas within a field were used, the correlations decreased. This was due to variability within soil and fertility. Analyses indicated the alfalfa does not begin rapid growth until after the first of May. The alfalfa then grew at a relatively steady rate until harvested in early June.

The number of punctures per ten stems occurred with a slowly increasing daily mean starting in mid April. There were significant differences among the regression slopes within the region. There were no differences in the number of punctures within a field but some differences existed among the six field in the study.

Fields with late high or low larval populations could be detected by the slope of the total number of punctures. The fields located on the benches near Hyde Park and North Logan had lower regression coefficients and correlations than the fields on the valley floor. This occurred because the feeding and oviposition begins earlier on the west facing slopes and lower stem density fields and continued with a steady daily average egg production. Fields with lower stem densities had slightly negative slopes. This was interpreted as allowing the weevil to start feeding and ovipositing sooner. They also had the highest population of larvae.

Weevils on the cooler valley floor had a delayed initiation of feeding and oviposition. The number of eggs recovered per day had a wide range and probably reflects the previous days weather regime. The overall high larval population field did not have the high total punctures. An intermediate larval population field had a high total mean number of eggs recovered. The analyses also detected fields with a low population of eggs and larvae.

The high larval population fields were high for both 1980 and 1981. When total oviposition was regressed on the Julian day, both high and low larval population fields were detected.

The fields were swept as soon as possible and the populations of weevil adults and larvae, and Bathyplectes curculionis were indexed to attempt to forecast late season larvae populations. The results of daily F-tests were compared to the late season larval counts. Sweeps were used as the standard of comparison. Early season adult population means could be separated, but the number of adults per field was not a reliable predictor of late season larval numbers. Intermediate populations of adults produced the highest number of larvae while high populations of adults produced only low mean populations of larvae. The mean number of early season punctures did not separate in the same order as the late season larval populations and could not be used as a predictor. The number of eggs per field per day did not predict the late season larval population either.

The number of feeding and oviposition punctures and eggs per ten stems were analyzed. More samples were taken during 1980, but the total number of punctures and total eggs per stem had the same pattern as the earlier larval sweep samples. The F-test did not appear adequate for this analysis. The number of stems sampled was too low on any one day and does not currently represent a reliable technique for predicting populations of larvae.

To account for as much variability within a field as possible, the stem density, stem height, accumulated degree days and lodging were declared covariates. This process adjusted for the covariates, then the analysis was continued. The adult captures were independent of larval captures during the same season. One field had a high density of adults and an intermediate number of punctures, eggs and larvae.

The total number of eggs recovered was below expected values for the number of adults present. The high larval population was produced by an intermediate population of adults in a low stem density field. The fields on the west facing foothills began May with more accumulated degree days due to height and slope aspect and the days began and ended at higher temperatures. The fields with low stem density were likely to accumulate more degree-days because the soil warmed more rapidly than the higher stem density fields. High populations of larvae did not produce the high population of adults or B. curculionis the following spring. The fields produced populations of the same dimensions from year to year. The intermediate population was able to feed and oviposit in sufficient quantity under the field conditions to produce the highest population of adults the following spring. The high population of adults might have been competing for oviposition sites.

The highest population of Bathyplectes curculionis was produced in a field with low stem density. The high populations of 1981 followed the high populations of larvae for 1980. B. curculionis survival was not in the same ratio as adult weevils, which might have resulted from increased predation by surface feeding insects. If the overwintering requirements were the same for the adult weevils as the parasite, then the same relative numbers would be expected to survive in a field. The parasite wintered best in the open canopy fields. All covariates account for significant variability in larval captures.

When punctures were combined across years, no significant differences were detected. Combined first through fourth instars and third instars counts from Berlese samples followed the same pattern as late season larval sweep captures. During 1981 there was no match between Berlese samples and field sweeps due to the reduced sampling regime. Careful comparison of the means indicated the fields on the west facing slopes would have been expected to have higher populations of larvae compared to the valley floor. The sweeps had more individuals taken in the final samples just before harvest. The Berlese funnels had a fairly constant, but low capture rate and measured the populations in small areas. When the sweep sample larvae were sorted using a head caliper, there were few first instar larvae recovered. Most numerous are the third instars. This could be due to differences between the seasons. None of the techniques tried and compared was totally satisfactory either by itself or in conjunction with another technique. The mean number of eggs per puncture was constant and could be measured. This along with puncture data could be used to determine a threshold to trigger more careful observation of the suspect field. When one egg per stem or one oviposition puncture per ten stems was encountered, an outbreak of larvae was likely, based on comparison with literature data and field observations. As this point was reached consideration should shift to the current field conditions. This was measured by either the current field height or Julian days.

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APPENDICES

Appendix A.

A1. Soil associations of Cache Valley from Soil survey.

Soil type	Description
	MODERATELY WELL DRAINED TO POORLY DRAINED SOILS OF THE LOW LAKE TERRACES
2	Trenton association: Strongly saline and alkali, somewhat poorly drained and moderately well drained, nearly level to sloping soils that have a silty clay subsoil
3	Greenson-Nibley-Collet association: Dominantly somewhat poorly drained, nearly level to sloping soils that have a loam to silty clay subsoil or underlying layer
	WELL DRAINED TO SOMEWHAT POORLY DRAINED SOILS OF THE MEDIUM LAKE TERRACES
4	Kidman-Lewiston association: Nearly level to gently sloping soils that are fine sandy loam throughout
	WELL DRAINED SOILS OF THE MEDIUM LAKE TERRACES
5	Mendon-Avon association: Nearly level to strongly sloping soils that have a clay loam and silty clay subsoil
6	Wheelon-Collinston association: Moderately steep to very steep soils that have a loam, silt loam, and clay loam subsoil

A2. Areas of Cache Valley and growers involved during 1977 to 1978.

Field#	Owner	Size	Age	Variety	Irrigation	Soil
AREA I						
1	Clair Allen	9	1	Resistador	Flood	3
2	" "	6	3	"	"	3
3	" "	7	5	"	"	3
4	" "	8	6	"	"	3
5	" "	10	5	Mixed 1	"	3
6	" "	7	6	Ranger	"	3
7	" "	15	4	Resistador	"	3
8	" "	5	3	"	"	3
9	" "	10	1	Unknown	"	3
10	Phillip Spackman	30	4	Ranger	Sprinkle	2
11	" "	12	2	Resistador	"	2
12	" "	40	3	Common	"	2
13	" "	20	3	Resistador	"	3
14	" "	13	5	"	Flood	3
15	Ray Sanders	5	4	Ranger	Sprinkle	8
16	Ivan Allen	11	3	"	"	8
17	" "	14	2	Ranger	"	6
18	Clair Allen	12	4	"	"	6
19	" "	10	6	"	"	6
20	" "	14	6	"	"	7
21	H. J. Griffin	16	5	Lahontan	"	7
Area II						
1	Norval Johnson	20	4	Ranger	Sprinkle	2
2	" "	18	3-5	"	"	2
3	R. Partington	20	10	Uinta	Dry	5
4	Vaughn Spackman	11	2	Lahontan	Flood	4
5	" "	11	2	"	"	4
6	" "	24	4	"	"	4
7	" "	10	2	"	"	4
8	" "	14	2-3	"	"	4
9	" "	25	1	"	Sprinkle	4
10	Robert Spackman	15	1	Ranger	Flood	4
11	" "	23	4	"	"	4
12	" "	12	3	"	"	4
13	" "	7	3	"	"	4
14	Keith Spackman	10	3	Intercross	"	4
15	" "	16	3	"	Sprinkle	4
16	" "	13	1	"	"	
17	" "	8	4	"	"	4
19	Valden Pitcher	15	13	Ranger	"	2

Area III

1	Fred Hardman	110	3-6	Ranger	Dry	5
2	" "	25	2-3	"	"	5
3	" "	14	5	"	"	5
4	" "	18	3-5	Uanna	"	5
5	" "	25	2-4	Ranger	"	5
6	Eldon Cooper	4	4	Lahontan	Sprinkle	5
7	" "	17	5	"	"	5
8	" "	4	5	"	"	5
9	" "	11	4	Thor	"	5
10	Vernon Bankhead	10	4	"	"	5
11	" "	7	3	WL-309	"	3
12	" "	8	6	Resistador	"	3
13	" "	9	1	WL-309	"	3
14	" "	5	3	"	Flood	3
15	Brent Parker	7	1	Resistador	"	3
16	" "	15	4	Common	Dry	8
17	" "	15	5	"	"	8
18	" "	18	5	"	"	8
19	" "	12	4	"	"	8
20	Lamont Leishman	8	4	Resistador	Flood	3
21	" "	8	3	Thor	"	3
22	" "	8	1	"	"	3
23	" "	8	5	Ranger	"	3

Area IV

1	Clair Allen	5	4	Resistador	Flood	3
2	" "	7	1	"	"	3
3	" "	11	4-5	Ranger	Sprinkle	3
4	" "	10	2	Resitstador	"	5
5	C. B. Hurren	6	4	Ranger	Flood	3
6	Wallace Buetler	5	3	"	"	7
7	" "	5	3	"	"	7
8	" "	10	4	"	"	7
9	Jesse Zollinger	10	3	Resistador	None	7
10	Homer Leishman	14	4	Ranger	Flood	3
11	" "	19	2	Resistador	"	3
12	D. Miller	12	5	Ranger	"	3
13	LeGrande Miller	6	1	"	"	3
14	" "	9	4	"	"	3
15	Carl Danielson	20	2	Thor	Sprinkle	7
16	Marion Olsen	30	2	Ranger	"	8
17	" "	20	1	"	Dry	7
18	Carl Danielson	25	1	Thor	Sprinkle	7
19	" "	20	4	Resistador	"	7
20	Frank Olsen	17	7	"	"	7
21	" "	20	2	"	"	9

A3. Areas of Cache Valley and growers involved during 1979.

Field#	Owner	Size	Age	Variety	Irrigation	Soil
				Area I		
1	Ray Pitcher	3	3	Ranger	Sprinkle	5
2	" "	2	10	"	"	5
3	Robert Spackman	15	5	"	Flood	4
4	" "	17	1	Washoe	"	4
5	" "	14	2	Ranger	"	4
6	" "	11	5	"	"	4
7	" "	7	5	"	None	4
8	Vaughn Spackman	4	3	Lahontan	Sprinkle	4
9	" "	3	3	"	"	4
10	" "	15	4	"	"	4
11	" "	15	4	"	"	4
12	" "	30	2	"	Flood	4
13	" "	15	4	"	"	4
14	" "	50	4	"	"	4
15	" "	8	1	"	"	4
16	" "	16	2	"	"	4
17	" "	10	4-5	Ranger	"	4
18	" "	15	4-5	"	"	4
19	Kieth Spackman	8	1	Intercross	"	4
20	" "	5	1	"	"	4
21	" "	5	2	"	"	4
22	" "	5	2	"	"	4
23	" "	22	3	"	Sprinkle	4
24	" "	11	1-2	"	"	4
			Area II			
1	H.J. Griffin	5	1	Ranger	Sprinkle	4
2	" " "	15	2	Lahontan	"	7
3	Clair Allen	35	3	"	"	6
4	" "	40	2	"/Ranger	"	6
5	" "	15	2	Lahontan	"	7
6	" "	20	2	"	"	7
7	Ivan Allen	11	6	Ranger	"	8
8	" "	14	5	"	"	6
9	Phillip Spackman	14	1	Resistador	Dry	2
10	" "	36	4	Common	"	2
11	" "	25	3	Resistador	Sprinkle	2
12	" "	28	5	Lahontan	"	2
13	" "	12	3	Resistador	"	3
14	" "	12	4	Common	"	2
15	Ray Sanders	15	4	Ranger	"	8

cont.

16	Norval Johnson	25	2-3	"	"	2
17	" "	20	6-7	"	"	2
18	" "	10	3-4	"	"	2
19	" "	55	4-5	"	"	2

Area III

1	Fred Hardman	110	3-6	Ranger	Dry	5
2	" "	25	2-3	"	"	5
3	" "	18	3-5	Uanna	"	5
4	Eldon Cooper	4	5	Lahontan	Sprinkle	5
5	" "	19	1	"	"	5
6	" "	11	4	Thor	"	5
7	" "	11	1	"	"	5
8	" "	10	4	"	"	3
9	Vernon Bankhead	7	4	WL-309	"	3
10	" "	5	5	"	"	3
11	" "	12	3	"	"	3
12	Brent Parker	12	5	Common	Dry	8
13	" "	12	4	"	"	8
14	" "	18	5	"	"	8
15	" "	8	3	Ranger	Sprinkle	8
16	Lamont Leishman	8	2	Thor	Flood	3
17	" "	8	6	Ranger	"	3

Area IV

1	Jesse Zollinger	4	2	Resistador	Flood	7
2	Marion Olsen	25	4	Ranger	Dry	8
3	" "	45	3	Resistador	Sprinkle	8
4	" "	30	3/7	"/Ranger	"	8
5	" "	30	6	Ranger	Dry	8
6	Carl Danielson	10	3	Resistador	Sprinkle	7
7	Lamont Leishman	30	1	Anchor	"	7
8	Carl Danielson	25	3	Thor	Sprinkle	7
9	Frank Olsen	19	10	Resistador	Sprinkle	9
10	" "	20	5	"	"	7
11	LeGrande Miller	15	5	Ranger	Flood	3
12	" "	9	5	"	"	3
13	" "	17	3-5	"	"	3
14	Homer Leishman	10	1	"	"	3
15	" "	14	4	"	"	3

Area V

1	Clair	Allen	11	3	Ranger	Sprinkle	3
2	"	"	5	1	Resistador	"	3
3	"	"	16	4	"	Flood	3
4	"	"	7	3	"	"	3
5	"	"	4	4	"	"	3
6	"	"	5	4	"	"	3
7	"	"	15	3	Common	Dry	3
8	"	"	7	1	"	Flood	3
9	"	"	5	6	Resistador	"	3
10	"	"	10	4	"	"	3
11	"	"	5	5	"	"	3
12	"	"	10	3	"	"	3
13	"	"	12	3	"	"	3
14	Wallace	Buetler	8	4	Ranger	Sprinkle	7
15	"	"	5	3	"	"	7
16	"	"	40	3	"	"	7

Appendix B.

B1. Summary of analyses of variances for degree days for the alfalfa plant (PLANT) and alfalfa weevil (WEEVIL) for the three years (1977-1979) and five weather stations in Cache Valley.

	Julian day 60-109					Julian day 110-155				
SOURCE		PLANT 5^{o}C		WEEVIL 9^{o}C			PLANT 5^{o}C		WEEVIL 9oC	
	df	MS	sig	MS	sig	df	MS	sig	MS	sig
YEAR	2	65.39	**	22.78	**	2	362.9	**	266.4	**
FIELD	5	2.90	NS	3.68	NS	5	118.0	**	68.3	**
FXY	10	2.08	NS	2.23	NS	10	5.4	NS	4.4	NS
ERROR	882	1.45		2.94		792	18.2		13.3	

Note: *=P<0.05%; **=P<0.01; NS=F-test not significant

B2. Summary of the two factor analysis of variance of the field and area within field stem density.

SOURCE	DF	MS	F	SIG
FIELD	5	801.1	5.60	**
AREA	4	209.9	1.47	NS
F X A	20	97.9	0.68	NS
ERROR	186	143.0		

B3. Field alfalfa height regressed on accumulated degree day (9^oC) using USU weather data (1 April to 10 June; Julian day 91 to 161) and Field 1 max-min recording thermometer data (1 May to 10 June; Julian day 121 to 161) during 1980.

	USU WEATHER STATION			FIELD 1 RECORDING THERMOMETER			
FIELD	INTER	SLOPE	%VAR.	INTER	SLOPE	%VAR.	DF
Comb.	2.42	0.178	88.4	18.8	0.097	85.4	350
1	0.62	0.190	96.9	15.2	0.094	92.8	63
2	-1.98	0.168	89.1	15.2	0.094	84.3	57
3	3.12	0.175	94.7	19.6	0.965	87.5	58
4	1.97	0.201	94.0	20.7	0.107	94.0	49
5	4.60	0.168	92.8	19.8	0.037	91.0	55
6	0.919	0.175	90.5	16.9	0.099	86.7	58

Note: DF = degrees of freedom; INTER = intercept height at initiation date; SLOPE = correlation coefficient between the accumulated degree day at the threshold and the Julian day; % VAR = the amount of variability accounted for by the relationship between accumulated degree days and growth; Comb.= combined data from all fields

B4. Measured alfalfa stem length regressed on accumulated degree day (9^oC) using USU weather Station (1 April to 10 June; Julian day 91 to 161) and Field 1 max-min recording thermometer data (1 May to 10 June; Julian day 121 to 161) during 1980.

		USU WEATHER STATION			FIELD 1 RECORDING THERMOMETER		
FIELD	DF	INTER	SLOPE	% VAR.	INTER	SLOPE	%VAR
Comb.	439	-1.74	0.198	73.9	14.8	0.102	68.8
1	77	1.61	0.170	78.8	17.4	0.091	74.3
2	72	-8.03	0.198	83.0	9.8	0.109	74.3
3	73	4.95	0.155	75.7	18.5	0.086	75.2
4	64	-0.56	0.198	69.7	17.6	0.107	66.6
5	70	-6.93	0.213	72.7	12.2	0.117	67.0
6	73	-5.56	0.193	81.5	11.4	0.107	75.2

Note: DF = degrees of freedom; INTER = intercept height at initiation date; SLOPE = correlation coefficient between the accumulated degree day at the threshold and the Julian day; % VAR = the amount of variability accounted for by the relationship between accumulated degree days and growth; Comb.= combined data from all fields

B5. Relationship between field alfalfa height (cm) and late spring days (Julian days 110 to 155) and accumulated degree days (9^{o}C, 0 to 400) from USU, during 1980.

	Julian days				Accumulated DD			
FIELD	DF	INTER	SLOPE	% VAR.	DF	INTER	SLOPE	%VAR
Comb.	676	-102	1.091	77.4	350	2.4	0.18	88.4
1	113	-109	1.033	85.6	63	0.6	0.19	96.9
2	113	-88	0.952	84.8	57	-0.2	0.17	89.1
3	112	-99	1.081	79.6	58	3.1	0.17	94.7
4	103	-135	1.381*	84.7	49	1.9	0.19	94.6
5	113	-98	1.065	80.3	55	4.6	0.17	92.8
6	112	-97	1.037	81.4	58	0.9	0.17	90.5

Note: DF = degrees of freedom; INTER = intercept height at initiation date; SLOPE = correlation coefficient between the accumulated degree day at the threshold and the Julian day; % VAR = the amount of variability accounted for by the relationship between accumulated degree days and growth; Comb.= combined data from all fields

B6. Analysis of daily total punctures per alfalfa stem bouquet (5 reps of 10 stems/field) regressed on Julian days (110 to 155) during 1980 and 1981.

	1980					1981			
FIELD	DF	INTER	SLOPE	%VAR.	F	DF	INTER	SLOPE	%VAR
Comb.	527	-6.32	0.065	16.0	3.18	286	-1.42	0.028	2.4
1	87	-3.30	0.041	5.0	(5,515)	43	0.51	0.018	0.0
2	88	-2.67	0.036	7.9	<----	43	-3.00	0.038	5.4
3	88	-4.56	0.055	17.3	---->	43	2.63	-0.005	0.0
4	78	-7.41	0.076	24.5	2.52	43	-4.68	0.058	6.7
5	88	-7.60	0.073	14.1	(5,252)	43	3.63	-0.012	0.0
6	88	-13.07	0.115*	32.6	(t=3.86)	43	-7.61	0.077	20.3

Significant differences are: * = <0.05, ** = <0.01; (DF for F-test)/(t=value at appropriate level); Note: DF = degrees of freedom; INTER = intercept height at initiation date; SLOPE = correlation coefficient between the accumulated degree day at the threshold and the Julian day; % VAR = the amount of variability accounted for by the relationship between accumulated degree days and growth; Comb.= combined data from all fields

B7. Relationship between the number of oviposition punctures per day per stem bouquet (5 reps of ten stems per field) and the Julian days (110 to 155) for fields during 1980 and 1981.

	1980					1981			
FIELD	DF	INTER	SLOPE	%VAR.	F	DF	INTER	SLOPE	%VAR.
Comb.	527	-3.86	0.035	16.3	4.63	268	-2.58	0.0253	8.4
1	88	-1.88	0.019	5.0		44	-3.09	0.028	8.0
2	88	-2.15	0.021	7.9		44	1.59	-0.008*	0.0
3	88	-4.18	0.037	17.3		44	-1.77	0.018	7.1
4	88	-5.08	0.045	24.5		44	-53.62	0.049	21.1
5	88	0.18	0.032	14.1		44	-32.47	0.029	12.7
6	88	-0.38	0.058**	32.6		44	-3.48	0.035	10.2

Note:DF = degrees of freedom; INTER = intercept height at initiation date; SLOPE = correlation coefficient between the accumulated degree day at the threshold and the Julian day; % VAR = the amount of variability accounted for by the relationship between accumulated degree days and growth; Comb.= combined data from all fields

B8. Relationship of the total number of eggs per ten stem alfalfa bouquet (5 reps per field) with Julian days (110 to 155) for 1980 and 1981.

	1980					1981				
FIELD	DF	INTER	SLOPE	%VAR.	F	DF	INTER	SLOPE	%VAR.	F
Comb.	558	-35.8	0.322	12.3	3.13	258	-27.2	0.263	7.3	4.60
1	93	-30.4	0.279	5.7		44	-35.0	0.311	9.2	
2	93	-15.5	0.157*	4.1		43	27.1	-.171**	5.6	
3	93	-34.8	0.315	10.0		43	-12.0	0.136*	10.0	
4	83	-54.7	0.480	24.5		43	-61.7	0.542	25.4	
5	93	-32.9	0.289	12.4		43	-39.3	0.349	11.8	
6	93	-54.2	0.478	23.9		43	-41.9	0.407	9.0	

Note:DF = degrees of freedom; INTER = intercept height at initiation date; SLOPE = correlation coefficient between the accumulated degree day at the threshold and the Julian day; % VAR = the amount of variability accounted for by the relationship between accumulated degree days and growth; Comb.= combined data from all fields

B9. Relationship between the total number of eggs per stem bouquet divided by the total oviposition punctures on Julian days (110 to 155) during 1980 and 1981.

	1980					1981				
FIELD	DF	INTER	SLOPE	% VAR.	F	DF	INTER	SLOPE	% VAR	F
Comb.	210	16.9	0.052	1.5	3.45	214	16.6	0.024	1.5	2.77
1	30	7.9	0.018	0.0		13	-9.5	0.121	0.0	
2	31	19.5	0.075	4.8		17	24.7	0.129*	15.2	
3	34	23.4	-0.101*	3.3		20	20.4	-0.085	0.0	
4	38	1.7	0.059	0.0		22	-4.1	0.103	1.5	
5	26	5.1	0.064	0.0		17	-1.7	0.091	0.0	
6	41	27.6	0.126	11.3		25	2.9	0.053	0.0	

Comb = all fields through time period; *=P=<0.05; **=P<0.01%. Note: DF= degrees of freedom; INTER = intercept height at initiation date; SLOPE = correlation coefficient between the accumulated degree day at the threshold and the Julian day; % VAR = the amount of variability accounted for by the relationship between accumulated degree days and growth; Comb.= combined data from all fields

B10. Summary of analysis of variance of the different sample techniques used on the same day.

DAY	114	119	125	126	127	131	142	152
ACC DD	130	170	199	205	210	231	290	344
HEIGHT	25.6	30.9	36.8	37.8	38.2	42.9	55.1	63.7
F-TEST								
ADULT	3.63	5.10	12.0	4.78	5.46	20.5	6.98	3.06
LARVAE	NS	NS	9.6	4.79	6.26	10.5	13.3	21.9
T-PUN	NS	NS	NS	NS	NS	NS	3.17	3.18
T-EGG	NS	NS	NS	NS	NS	2.14	NS	3.60

Note: DAY = Julian day of the season; ACC DD = accumulated degree day; HEIGHT = measured stem length from Berlese samples; F-test results for adult and larval weevils, total punctures and total eggs per ten stem bouquet; NS = non significant results, otherwise the F-test result is shown.

B11. Two-factor analysis of variance for alfalfa weevil total punctures (T-PUN), oviposition punctures (O-PUN) and total eggs per ten stem bouquet (TEGG)(five replicates per field).

		T-PUN			O-PUN			TEGG		
SOURCE	DF	MS	F	SIG	MS	F	SIG	MS	F	SIG
YEAR	1	1.04	0.07	NS	2.26	1.12	NS	90.46	0.81	NS
FIELD	5	10.96	0.83	NS	3.48	1.73	NS	366.76	3.27	*
Y X F	5	13.09	2.02	NS	2.01	0.86	NS	112.07	0.62	NS
ERROR	787	6.47			2.34			181.05		

Note: NS = non significant; *=P<0.05%

B12. Split-plot analysis of the populations of adults, total puncutures (TPUN), oviposition punctures (OPUN), Berlese captures of first instar and total larvae (B 1 and B 1-4 respectively), alfalfa weevil larvae from sweep samples (LARV) and *Bathyplectes curculionis* (BC) for 1980 and 1981 with covariates: stem density (STEM DEN), measured stem lenght (BHT), accumulated degree days at 9^{O}C (ACCD), and whether the alfalfa was lodged or not (LDG).

	ADULT				TPUN				OPUN				B 1			
SOURCE	DF	MS	F	SIG	DF	MS	F	SIG	DF	MS	F	SIG	DF	MS	F	SIG
COVARIATES																
STEM DEN					1	4.88			1	0.28			1	8.00		
BHT	1	98.83			1	4.58			1	0.10			1	1.78		
ACCD	1	128.59			1	33.04			1	0.10			1	217.77		
LDG	1	16.53			1	5.25			1	0.44			1	2.96		
REPLICATE	4	41.11			4	5.11			4	1.48			4	65.81		
FIELD	5	1436.41	18.91	**	5	19.32	3.48	*	5	1.03	0.62	NS	5	141.76	2.07	NS
R X F	20	75.98			20	5.54			20	1.65			19	68.57		
DATE	3	946.33	9.72	**	5	17.47	7.80	**	5	1.78	5.11	**	3	79.09	1.18	NS
R X D	12	97.35			20	2.24			20	0.35			12	66.89		
F X D	15	686.25	10.17	**	25	7.08	2.09	**	25	1.33	1.35	NS	15	50.09	0.96	NS
R X D X F	60	67.50			125	3.39			125	0.99			60	52.03		
YEAR	1	3366.24	33.31	**	1	35.11	7.34	**	1	0.27	0.38	NS	1	946.17	13.12	*
F X Y	5	387.32	3.83	**	5	8.91	1.86	NS	5	1.60	1.60	NS	5	188.35	2.61	*
D X Y	2	113.82	1.13	NS	4	18.19	3.81	**	4	0.69	0.96	NS	2	19.85	0.27	NS
ERROR	110	101.09			166	4.78			166	0.72			109	72.08		

B12. CONT.

	B 1-4				LARVAE				BC			
SOURCE	DF	MS	F	SIG	DF	MS	F	SIG	DF	MS	F	SIG
COVARIATES												
STEM DEN	1	47.53										
BHT	1	701.56			1	65379.2			1	0.25		
ACCD	1	176.61			1	48266.8			1	0.37		
LDG	1	262.90			1	651677.9			1	0.50		
REPLICATE	4	337.70			4	6787.4			4	2.57		
FIELD	5	1093.94	2.71	0.10	5	53713.3	9.41	**	5	1.48	0.97	NS
R X F	19	403.77			20	5705.3			20	1.54		
DATE	3	603.17	2.26	NS	3	15427.5	2.32	NS	3	6.96	5.47	*
R X D	12	266.59			12	6645.7			12	1.27		
F X D	15	243.95	0.94	NS	15	43097.4	7.85	**	15	5.69	3.56	**
R X D X F	60	258.12			60	5492.3			60	1.59		
YEAR	1	4256.14	11.71	**	1	184.1	0.01	NS	1	0.74	0.37	NS
F X Y	5	1394.89	3.83	**	5	47169.3	4.79	**	5	10.62	5.30	**
D X Y	2	64.57	0.17	NS	2	38348.6	3.90	NS	1	0.06	0.03	NS
ERROR	.109	363.37			110	9842.7			110	2.00		

Note: *=P>0.05%; **=P>0.01%.

B13. Analysis of variance summary for Berlese funnel captures of first (B 1), second (B 2), third (B 3), fourth (B 4) and total (B TOT) for the six fields near Hyde Park and Logan during 1980.

		B 1			B 2			B 3			B 4			B TOT		
SOURCE	DF	MS	F	SIG	MS	F	SIG	MS	F	SIG	MS	F	SIG	MS	F	SIG
1980																
FIELD	5	235.38	10.61	**	392.20	7.51	**	35.02	2.95	**	45.41	1.66	NS	1893.7	9.94	**
ERROR	521	22.12			52.22			11.86			27.42			190.5		
1981																
FIELD	5	618.96	4.48	**	6536	10.24	**	717.04	34.27	**	789.04	11.95	**			
ERROR	219	138.05			638			20.92			66.02					
SWEEP 1980																
FIELD	5	49.42	1.17	NS	28270	3.72	**	54494	7.89	**	2503	1.27	NS	29610	3.57	*
ERROR	521	42.26			7604			6905			1960			8298		

Note: *=P>0.05%; **=P>0.01%.

B14. Summary of analysis of variance of alfalfa weevil adults and larvae analyzed by field and direction from mark-release arrays during 1981.

FIELD SOURCE	DF	ADULTS MS	ADULTS F	ADULTS SIG	LARVAE MS	LARVAE F	LARVAE SIG
FIELD	2	780.7	16.67	**	911244	30.92	**
ERROR	668	46.8			29469		
DIRECTION							
DIREC	3	4.7	0.07	NS	7946	0.25	NS
ERROR	666	64.3			32246		

Note: *=P>0.05%; **=P>0.01%.

B15. Analysis of variance of linear pitfall array captures (20 traps per array) of alfalfa weevil adults in six fields near Hyde Park and North Logan during 1980 and 1981.

SOURCE	1980 DF	1980 MS	1980 F	1980 SIG	1981 DF	1981 MS	1981 F	1981 SIG
FIELD	5	53.4	3.80	**	5	64.8	4.76	**
ERROR	249	14.1			75	13.6		

B16. Analysis of variance of the alfalfa weevil larvae found alive (ALIVE) and dead (DEAD), pupae (PUPAE) and Bathyplectes curculionis (BC) in 929^2cm in six alfalfa fields near Hyde Park and North Logan after first cutting during 1981.

		ALFALFA WEEVIL									BC		
		ALIVE			DEAD			PUPAE					
SOURCE	DF	MS	F	SIG	MS	F	SIG	MS	F	SIG	MS	F	SIG
FIELD	5	127.2	2.05	a.	12.34	2.92	**	56.8	3.18	**	2.95	4.74	**
ERROR	219	62.1			4.32			17.8			0.62		

Note a, 2.05 significant at p>0.10% and LSD applied at that level.

B17. Analysis of variance of the *Bathyplectes curculionis* pupae found in 929^{2}cm under the alfalfa or exposed between the windrows in six fields near Hyde Park and North Logan.

SOURCE	DF	MS	F	SIG.
WINDROW	1	125.3	6.87	**
ERROR	223	18.2		

VITAE

Larry Jech

Career Objectives: To develop, by research and modeling, new methods to manage pests and to implement them for crop protection.

Health: Good. Marital Status: Single. Age: 38 (born 5 May 1949).

Education:

Utah State University. Entomology with Statistics. PhD. 1986.
Mississippi State University. Entomology with Physiology. MS. 1974.
Southwestern Stat University. Biology with Chemistry. BS. 1971.
University of Oklahoma Biological Station. Entomology. 1968-9.
Gulf Coast Research Laboratory. Marine Zoology. 1967.

Experience:

Worked on the United States Department of Agriculture Animal Plant Health Inspection Service Plant Protection and Quarantine Mormon cricket survey and detection programs. This has included all aspects of the program from the field survey, presentation of the program to growers and ranchers to supervising the application of the pesticides to control the insects on the range and in the mountains. The release and monitoring of parasites for the biological control of the alfalfa weevil has been another project for which I am responsible. Conducted the preliminary survey for additional parasites of the alfalfa weevil in the state of Utah.

Taught laboratory section, conducted research and managed Dr. Don Davis' field work. Supervised up to seven workers who collected and sorted samples for pesticide trials and life history studies. Responsibilities included experimental design, analysis of data and grower contacts. Most of the pesticide work centered on irrigated crops, forage and seed alfalfa, apples, pears and cherries observing the effects of pesticides on population dynamics and interactions of the predator prey populations. Inaugurated the use of small computers for data analysis and word processing in addition to programming the automated environmental data acquisition computers.

In Mississippi, studied artificial diets for hemipterous insects and minored in toxicology. Helped initiate and Integrated Pest Management program on cotton. In off season worked at Buildings Unlimited. Starting as a laborer, eventually promoted to shop foreman and finally becoming a salesman on a new lot in a city about fifty miles from the original location. Eventually left Mississippi to come to Utah to pursue a Ph.D.

Extra Curricular Activities:

Active participant in departmental clubs and activities. Volunteer teacher in Upward Bound program, taught computer literacy to Freshman through Senior Highschool students. Elected as a student member to the Biology Department Advisory Council. Helped organize and served on the first campus wide Graduate Student Association and was the first representative to the Library Council. Student representative to the Pacific Branch of the Entomology Society of America. Organized and presented a Jobs Symposium to the 1981 nation meeting of the Entomology Society of America in Denver. Member of both American Association for the Advancement of Science (since 1971) and Entomological Society of America (since 1972).

Awards:

Recognized as an Outstanding Young Man in America by the Junior Chamber of Commerce for service to students while a student.

Letter of Commendation and cash award from United States Department of Agriculture for outstanding service while performing duties connected with the 1985 Grasshopper Control Program.

Letter of Commendation from the State of Utah Department of Agriculture for outstanding service during the 1985 Grasshopper Control Program.

List of References:

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