Studies on the biology of Says Grain Bug (chlorochroa sayi stal)
by Lawrence A Jacobson

A THESIS Submitted to the Graduate Committee in partial fulfillment of the requirements for the degree of Master of Science in Entomology
Montana State University

Abstract:
The studies described are the result of laboratory and field investigations carried on at Lethbridge, Alberta, Canada, from 1936 to 1938, with supplemental data obtained at Montana state College, Bozeman, Montana.

Say'S grain bug (Chlorochroa sayi Stal) has been a recurrent pest in the southwestern states for some years, but it was not until 1932 that this insect was found in Montana in appreciable numbers, and from there the infestation probably spread into Alberta in 1934 and 1933. Since that time the insect has been spreading steadily northward, and in some localities has apparently become established in abundance.

The results of field observations on the hibernation of adults, oviposition, seasonal habits of nymphs and adults, host plants, proportion of sexes, and number of generations are given in this paper. These observations are supplemented by experiments with all stages of the insect at controlled temperatures.

Experiments on the effect of ultra-violet radiations on the change of color and resumption of activity are fully described.

Notes are given on the parasites and predators affecting C. sayi Stal. both in the older areas of occurrence and in Alberta.

Particular emphasis is given to the potentiality of this insect as a pest of grain, and several methods of control are suggested.

STUDIES ON
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(CHLOROCHROA SAYI STAL)

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Submitted to the Graduate Committee
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Approved:

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In Charge of Major Work

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Bozeman, Montana
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FOREWARD

At the time this thesis was written it was realized that the common name for *Chlorochroa sayi* Stal, as adopted by the Committee on Common Names of the American Association of Economic Entomologists, is Say's stink bug.

Since previous writers have used the common name, Say's grain bug, for *Chlorochroa sayi* Stal, and this name is universally used throughout the areas where this insect is present, its use is continued herein, pending possible approval by the Committee on Common Names at their next revision.

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ABSTRACT

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STUDIES ON THE BIOLOGY OF SAY'S GRAIN BUG (*CHLOROCHROA SAYI* STAL)

INTRODUCTION

Say's grain bug (*Chlorochroa sayi* Stal) is a new pest of economic grains in the western plains area. During the early period of its history, occurrence and economic damage was confined to the more southerly states of the United States. It is evidently one of those insects which extend their boundaries of distribution during periods of favorable climatic conditions.

The biology of this insect was studied in considerable detail during several years of severe infestation in New Mexico prior to 1919. In the years 1931 to 1937 this pest has been recorded from Utah, Montana, North Dakota and Nebraska in the United States and from various localities in Western Canada. Since it was found in appreciable numbers in this more northerly portion of the continent, there is some conjecture as to whether the insect was introduced or whether the abundance constituted an increase in numbers of one of the native pests. The nature of its rapid increase, both in numbers and in extent of territory, seems to lend strength to the introduction theory.

Since climatic conditions and length of seasons are very different in the Great Plains area from those in the state of New Mexico and other southern areas, a corresponding difference in insect development is to be expected. During the progress of investigations on this insect a considerable departure from the original findings was noted.

ACKNOWLEDGMENTS

All of the field observations and some of the laboratory experiments were conducted while the author was in the employ of the Entomological Branch, Dominion Department of Agriculture, at Lethbridge, Alberta, Canada. Other experimental investigations were conducted at Montana State College, Bozeman, Montana, U. S. A.

The writer wishes to thank the Entomological Branch, Ottawa, for permission to use the data obtained while in their employ for thesis purposes.

To Mr. H. L. Seamans, Entomologist in charge, at Lethbridge, Alberta, and other Branch officers, the author is indebted for sustained interest and encouragement.

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HISTORY AND DISTRIBUTION

Say's grain bug (Chlorochroa sayi Stal) belongs to the family Pentatomidae, order Hemiptera, the members of which are commonly referred to as "stink bugs". Chlorochroa sayi Stal is sometimes known as Say's stink bug, but its economic importance as a grain feeder tends to make the name "grain bug" more acceptable. The insect was first authentically named by Stal (1872)[1]. It is quite similar to another species of the same genus, Chlorochroa uhleri Stal, in general appearance and habits.

The history of the economic occurrence of this pest in the United States was set forth by Caffrey and Barber (1919). Sporadic outbreaks occurred from about 1904 in the states of Arizona, Colorado, California and Utah to the severe infestations in New Mexico in the years 1915 and 1916. Some time before this general period, Saunders (1898) reported crop losses in South Dakota due to a pentatomid described at that time as Uhler's green plant bug (C. uhleri Stal).

During the drought years from 1930 to 1936 this insect was noted again in appreciable numbers, considerably removed from the original centres of infestation. Knowlton (1931) stated that grain bugs were very numerous in northern Utah, often as many as four bugs being noted feeding on a

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1. Reference is made by year to literature cited.

single head in infested wheat fields. Shortly after, the apparent first occurrence in northern Montana was recorded by Strand (1934). In Hill County several wheat fields were attacked in 1932. The next year the damage was more severe and over a wider range. From 1934 to 1937, in the northern section of the state, several thousand acres of wheat were left uncut as a result of the feeding of this insect. The yield was too low to warrant harvesting. By 1936, reports were received from the states of North Dakota and Nebraska.

The present outbreak in the provinces of Alberta and Saskatchewan in Canada was apparently an extension of the infestation of the adjoining states in the United States. A single specimen was found in Alberta a few miles north of the International Boundary in the autumn of 1934. The next year C. sayi occurred over a wider territory and in appreciable numbers. The history of the Canadian invasion by this insect was reviewed by Jacobson (1936). Since that time the area of infestation in Alberta has steadily progressed northwards, and at the present time (in 1938) odd specimens have been found several hundred miles north of the boundary. In the last few years, also, localized infestations have been reported from various sections of southern Saskatchewan.

LIFE HISTORY

SEASONAL DEVELOPMENT:

The season history of Say's grain bug is not narrowly defined or regular. The individual generations, except a portion of the first, are not clearly demarcated, and seasonal activities are subject to some fluctuation depending upon climatic factors and their degree of yearly variation. The length of the various stages in the life history and the number of generations were determined by frequent observations of the insect in the field and by cage observations.

The winter is passed in the adult stage, the individuals hibernating in well sheltered quarters. With the rising daily mean temperatures in the spring, the adults gradually resume activity, and usually the emergence from hibernation is completed in the latter part of April and early May. Occasional fine weather before this period may result in a partial resumption of activity, particularly when hibernation has taken place in those locations which receive all the warming effects of the sun on these fine days.

Adults usually require several weeks of activity and feeding before oviposition takes place. During this preoviposition period a color change of the adults takes place, the drab winter coloration being gradually replaced by a bright green, which is characteristic of the active summer forms. Both forms were compared to Ridgway's color chart. The winter form is described as drab olive, which turns to a forest green towards the summer.

Caffrey and Barber (1919) mention that under New Mexico conditions the ovaries of overwintering females contain fully developed eggs and that only a few days of activity pass before egg-laying begins. This apparently is not the case under more northerly conditions such as occur in Western Canada. Dissections were made of overwintering adults at the time of the first emergence. There was no suggestion of egg development, but as time passed, this development was progressive, and it was not until about May 15 that all dissected females contained well developed eggs.

In Alberta, the first eggs are found about May 15. Oviposition by the overwintering adults apparently becomes general about June 1 and continues to about the first week in July. The eggs deposited during May and June require a long period of incubation, probably as much as twenty days. As mean temperatures increase, the length of the incubation period is shortened proportionately.

The nymphs pass through five instars from the time of hatching until the adult stage is reached. Under field conditions the duration of the nymphal period varies from 42 days to over 60. The length of the nymphal period is directly proportional to temperature. In midsummer, development is very rapid and in early autumn considerably slower.

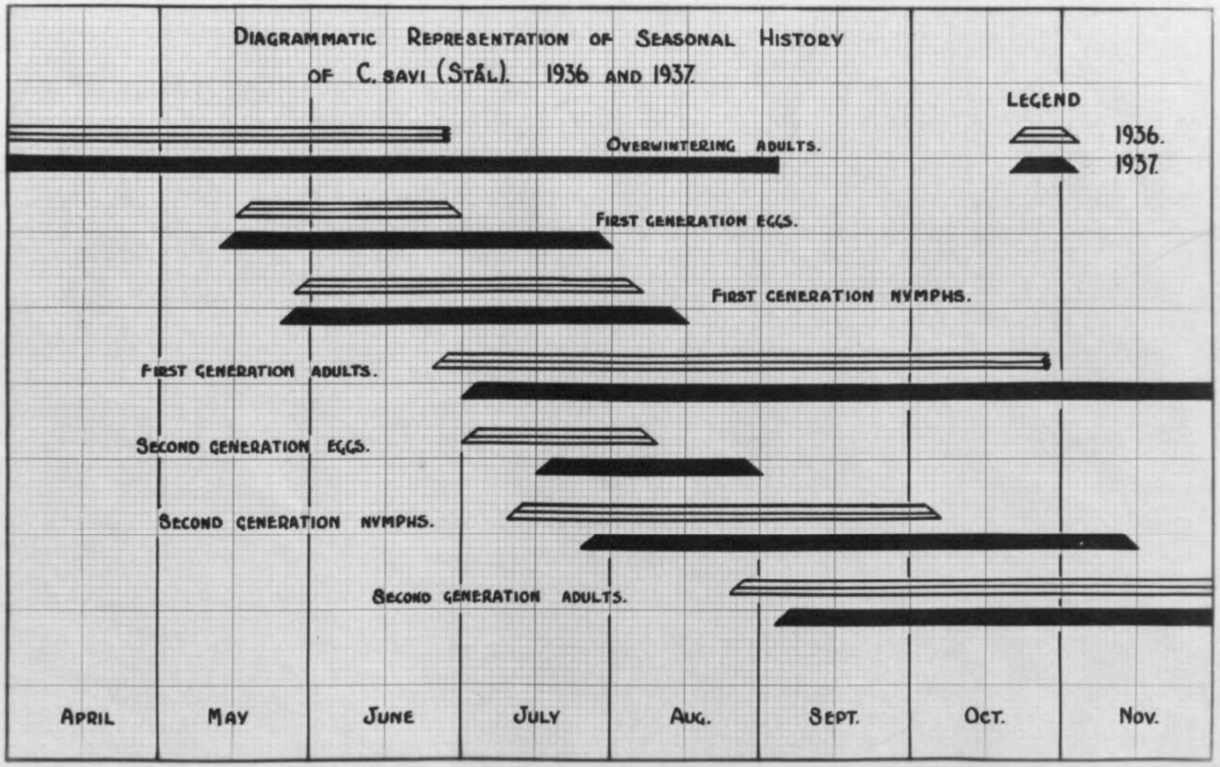
The eggs laid by overwintering adults begin hatching about June 1, and the first nymphs mature about the first week in July. Overwintering adults are still ovipositing by the time the first nymphs have reached the adult stage, indicating a marked overlapping of generations.

The first-generation adults begin oviposition about July 20, and eggs from this generation are found as late as September 1. The first nymphs from these eggs mature about the middle of September and the last as late as November 15. There are only two generations in Alberta compared with three and a partial fourth in New Mexico, as reported by Caffrey and Barber (1919). This is probably due to the shortness of the active season in Alberta and the comparatively short period of very high temperatures.

A diagrammatic representation of the seasonal history is shown in fig. 1. The overlapping of generations is very evident in this figure. In July, eggs of both overwintering and first-generation adults are present, and for several weeks all stages of nymphs, overwintering and first-generation adults are found at the same time.

HIBERNATION:

As mentioned before, *C. sayi* passes the winter in the adult stage. Nymphs are unable to survive the winter,



DIAGRAMMATIC REPRESENTATION OF SEASONAL HISTORY
OF C. SAYI (STÅL). 1936 AND 1937.
LEGEND
1936.
1937.
OVERWINTERING ADULTS.
FIRST GENERATION EGGS.
FIRST GENERATION NYMPHS.
FIRST GENERATION ADULTS.
SECOND GENERATION EGGS.
SECOND GENERATION NYMPHS.
SECOND GENERATION ADULTS.
APRIL
MAY
JUNE
JULY
AUG.
SEPT.
OCT.
NOV.

Fig. 1.

although on many occasions the later nymphal stages were found in hibernation quarters with the adults. However, they lived for only a short time.

Grain bugs are found in hibernation in many types of shelter. Usually the winter is passed under piles of weeds, stubble, and debris accumulated in ditches, along fences, in depressions along road allowances, and in abandoned fields. Hibernating individuals were often found among uncut tufts of native grasses. In cultivated areas a favorite location is an untilled fence corner where tillage implements cannot reach the weeds and where weeds and trash have been deposited by the wind. Hibernating adults have been found under rocks, horse droppings, scraps of loose paper, and on one occasion under a section of thresher draper canvas, several feet square, that had blown into a corner of an infested field.

In certain areas of Western Canada growing crops have been threatened by soil drifting. Several methods of control for this menace are now in practice, the more recent of which is the use of ploughless summerfallow. The basic principle of this method, as outlined by Hopkins, Palmer and Chepil (1937), is the keeping down of weed growth without burying the stubble or other trash. Implements such as one-way discs, double discs, duck-foot cultivators and rod-weeders are being used in fields of heavy stubble or dense weed covering. In many cases, particularly where the stubble is very long and dense, the trash is deposited on the surface in loose bunches. Where the stubble and weed growth is lighter, the trash in course of cultivation is more or less incorporated with the soil, with small clumps extending above the surface.

This trash on summerfallowed land, which is left to lie on the surface untouched during the winter months, has provided an ideal hibernation cover for overwintering grain bugs. In strip farming, migration of the bugs takes place from the infested grain to the adjoining strip of trash cover. The hibernating adults are usually found on the soil surface under loose bunches of trash where the covering is quite thick. Where the trash is lighter and partly bound with the soil the bugs are found burrowed into the small clumps, often below the actual soil surface.

During the winter, snow accumulates around this trash cover and provides extra insulation from the cold for the hibernating insects. When the snow melts, drainage and drying is rapid. This is of considerable importance, particularly during midwinter thaws, since very little water is allowed to accumulate in close proximity to the insects. Trash cover provides an ideal type of hibernating quarters for grain bugs compared with the other types chosen.

During the early period of hibernation the grain bugs do not remain completely inactive. Some measure of activity is resumed during the warmer portions of the day, and at night the individuals congregate. This habit of congregation is one of the preparations for actual hibernation. Cold weather, usually accompanied by a snow storm, marks the beginning of the actual hibernation period. Once such a storm has taken place and snow has drifted around the spots where the insects have congregated, the bugs usually remain inactive until spring. This congregation is often very marked, particularly along edges of infested fields where close to a hundred individuals have been found in a small area. When hibernation takes place in trash cover the habit of congregation is not as marked as under weed piles. The bugs are found singly and usually dispersed over a greater area.

Some time before actual hibernation the color change of the adults takes place. The bright green of the active insects is replaced by a drab olive coloration, characteristic of the overwintering adults, and the green coloration does not return until after the period of spring activity. Nymphs exhibit some change in coloration in the autumn, usually marked by a gradual darkening to almost black of the legs and scutellar regions.

The resumption of spring activity is just the reverse of the entrance to hibernation. Early activity takes place during midday, the insects tending to congregate again during the cool nights. The return to activity is sometimes hastened in the spring by winds which tend to dry out the hibernating centres and warm up the soil.

In 1936 hibernation was general about October 20, following a severe snowstorm. Even though the weather was quite mild after that time, the actual hibernating sites did not warm sufficiently to stimulate further activity. The autumn of 1937 was very mild, and since no snow fell until quite late, adults and nymphs remained active after the first week in November. Actual hibernation took place a few days later. The grain bugs had left their hibernating quarters in the spring of 1936 and 1937 about April 20, and activity and feeding was quite general. On plotting mean temperatures over 10-day periods against activity, it was found that the cessation of activity in the autumn and the resumption in the spring occurred during periods when the mean temperature was approaching 45 to 55° F.

The adults in hibernation include adults of the first and second generations. Cages were stocked with overwintering adults and first- and second-generation fifth-instar nymphs. In this way adults of each generation were assured. From these cage observations the certainty of the first- and second-generation adults entering hibernation was established. There was also a possibility that the occasional overwintering adult entered hibernation with the others, since several caged individuals were still alive as late as October.

BIOLOGY

COPULATION AND OVIPOSITION:

Oviposition studies were based on field observations and on eggs recovered from the adults of each generation placed in separate cages. The first dates and duration of oviposition were determined accurately from cage observations, and other data were obtained from field observations.

Copulation:

Say's grain bug adults are found in copulation at any time of the day on food plants, under rubbish, or around the bases of plants. In the early spring, copulation is confined to periods when the temperature is above 65° F. The mating pair face in opposite directions, and the time of copulation varies from a few minutes to several hours. On several occasions when copulation took place on their food plant, feeding continued during the act.

Oviposition:

Oviposition was observed at all times of the day and quite often at night. When ovipositing, the legs are strongly braced and the abdomen is inclined at an angle. As each egg is forced through the tip of the ovipositor, the tip of the abdomen bends and the egg is deposited in its appointed position. Adults have been observed in the act of oviposition, and the time required for the deposition of each egg takes about one minute.

Duration of the Oviposition Period:

The adults emerged from hibernation about the last week in April. Copulation took place soon after, and oviposition was general about the last week in May. In both years of observation the first eggs were found in the field about May 15. First-generation adults commenced egg-laying about 10 days after they reached maturity. Second-generation adults did not lay eggs, but entered hibernation to copulate and oviposit the next year.

The duration of the oviposition period of overwintering and second-generation adults is shown in fig. 1. In 1937 eggs laid by overwintering adults were recovered from cages as late as August 1. First-generation adults continued oviposition in 1936 until about August 10 and in 1937 to September 1. The length of the oviposition period appears to be dependent upon the weather. In 1936 July was extremely warm and oviposition ceased soon after the temperature became more moderate. The period was longer in 1937, the weather being average in July and August, and the decline in temperature was not marked until about September 1. In that year, oviposition ceased about the same time. Dawson (1931) found that the decline of mean temperatures limited the number of generations of *Telea polyphemus* Cramer in different isothermic regions. The temperature decline in August may govern the cessation of egg-laying by *C. sayi*. It was also noted that eggs laid later in the season failed to hatch, for reasons at present unknown.

THE EGG:

Description:

The egg of Chloroachroa sayi Stal is ovoid in form, and as viewed from above, is characterized by three white circles enclosing a central dull-grey area and two circular bands of the same color. The egg is usually about 1.1 to 1.2 mm. long and 0.6 to 0.9 mm. wide. C. sayi eggs exhbit the usual hemipterous appearance and are deposited in definite clusters.

Location of the Eggs:

In the field, eggs laid by overwintering adults were found on the under surface of the lateral branches of dead Russian thistle and tumbling mustard, on wheat stubble, and on debris near the plants under which they had sought shelter. Later in the season, eggs were found on the under side of new growth of Russian thistle and other weeds. Often eggs have been found glued on the stems and leaves of growing wheat and occasionally on the glumes of headed grain.

In cages, eggs are usually found on the plants in the same position as in the field. Frequently eggs were found glued on the screen and wooden supports of the cage. Egg clusters have been observed on clods of earth and even on the hardened soil surface.

When laid on a branch or some other similarly restricted surface, the eggs were usually in a double row extending along the length of the branch. The arrangement was more staggered when oviposition occurred on the flowers of Russian thistle, on cage surfaces or on the soil. The clusters were usually four or more eggs wide and the eggs irregularly placed.

Number of Eggs Laid:

The number of eggs per cluster varies considerably. Clusters in the field usually contain from 14 to 30 eggs. Quite frequently as few as 2 or 4 eggs were found in a cluster, and the largest number observed was 58. Counts were made in 1936 and 1937 of the number of eggs per cluster collected in the field and in cages over the entire active period. The summary of the findings are given in table I.

TABLE I

Summary of Egg Counts in the Field and in Cages

	Field	Cage	Total	Mean
No. clusters	94.0	49.0	143.0	- .-
No. eggs	2,254.0	1,341.0	3,595.0	- .-
Mean no. eggs per cluster	23.9	27.4	- .-	26.5
Largest no. eggs per cluster	53.0	58.0	- .-	55.5

The average number of eggs found per cluster was 26.5, which is approximately the number reported elsewhere. An interesting point in regard to the number per cluster was the number of clusters which contained eggs in multiples of 7. Many of the clusters found contained 28 eggs. This is explained by the fact that the females possess 7 ovarian tubules.

The females normally do not deposit their full complememt of eggs at one time or in a single cluster. The length of the fertility period of females varies with different individuals, and the entire oviposition period is shown in fig. 1. Caged individuals retained their fertility for 30 days or more. The number of eggs deposited by each female was found to vary from a minimum of 9 to 68. Several clusters of eggs may be laid during the fertile period. Caffrey and Barber (1919) found the maximum of eggs laid by one female to be 107.

Duration of the Incubation Period:

The duration of the egg stage is apparently dependent upon the degree of temperature. Under field conditions the incubation period varied from as low as 4 days to as high as 2 weeks, or longer. The egg stage was much shorter during the middle of the summer than during early spring or late summer.

An experiment was set up to determine the duration of the incubation period at various controlled constant temperatures. Eggs were recovered daily from caged adults so that the exact date of oviposition was always definitely known. Five or more clusters were placed at each of the following temperatures: 32° C., 29° C., 25° C., 21° C. and 13° C. No eggs hatched at 13° C., although the first eggs were allowed to remain at this temperature for the entire period of the experiment. Table II lists the results obtained.

TABLE II

The Effect of Temperature on the Duration of the Incubation Period of Eggs of *Chlorochroa sayi* Stal

	32° C.	29° C.	25° C.	21° C.
Time (in days)	4.000	5.000	5.800	11.700
Rate of development	0.025	0.020	0.017	0.008

From the data presented in table II and represented graphically in fig. 2, the relation of the length of the incubation period to temperature is clearly seen. As the temperature decreased, the length of the incubation period increased. Humidity appeared to have little effect on hatching. Several clusters of eggs were placed at 25° C. with relative humidities of 50% and 80%. Hatching occurred at the same time under the two conditions of relative humidity.

The rate of development or velocity is defined as the reciprocal of the time required to complete the incubation

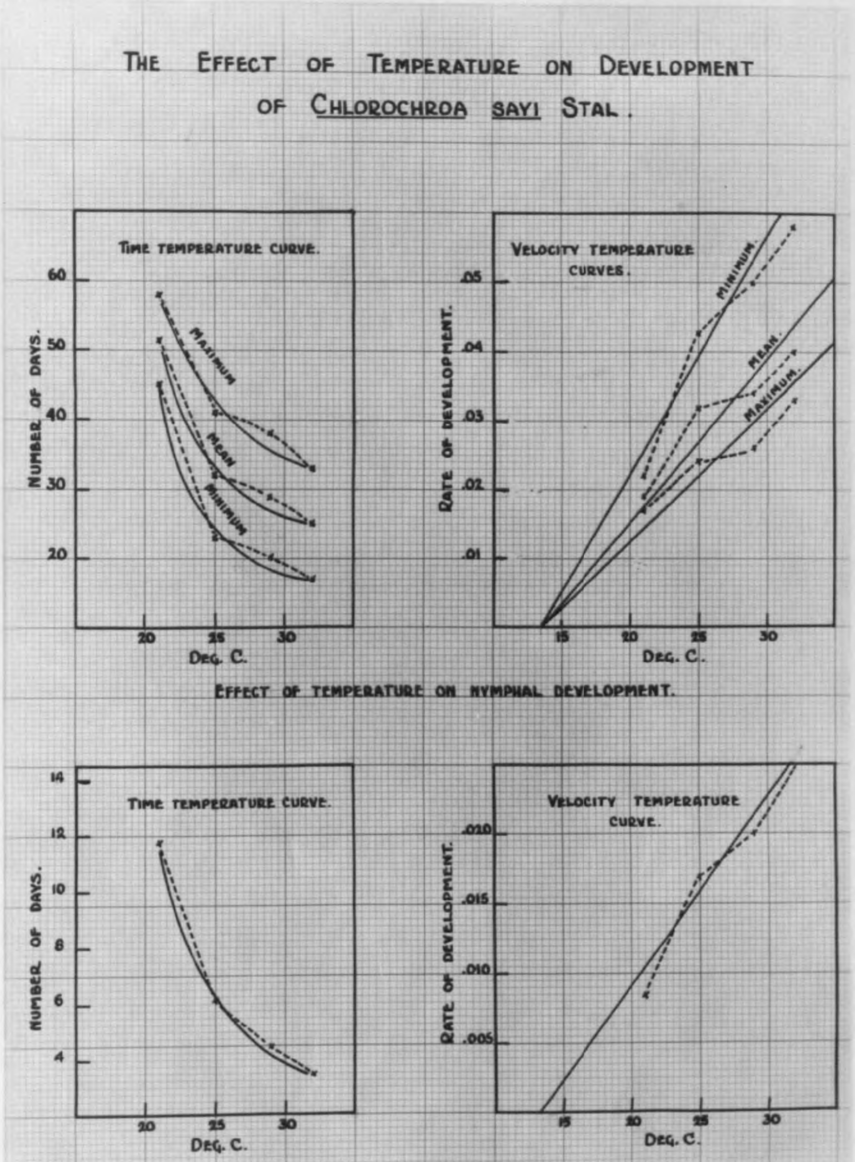

THE EFFECT OF TEMPERATURE ON DEVELOPMENT
OF CHLOROCHROA SAYI STAL.
TIME TEMPERATURE CURVE.
NUMBER OF DAYS.
MAXIMUM
MEAN
MINIMUM
DEG. C.
VELOCITY TEMPERATURE CURVES.
RATE OF DEVELOPMENT.
MINIMUM.
MEAN.
MAXIMUM.
DEG. C.
EFFECT OF TEMPERATURE ON NYMPHAL DEVELOPMENT.
TIME TEMPERATURE CURVE.
NUMBER OF DAYS.
DEG. C.
VELOCITY TEMPERATURE CURVE.
RATE OF DEVELOPMENT.
DEG. C.
EFFECT OF TEMPERATURE ON DURATION OF INCUBATION PERIOD.

Fig. 2.

period, or in this case, the value of one day at a given temperature. From the velocity temperature curve the regression line was computed, and it indicated that the threshold of development for grain-bug eggs was between 13° C. and 15° C. This was substantiated to some degree by the failure of eggs to hatch at 13° C.

THE NYMPH:

General Observations:

Newly hatched nymphs remain grouped on the parent egg-cluster for some time after hatching. Soon after the second instar is reached they wander away singly in search of food, but usually are found feeding very close together. During the later instars the nymphs become more solitary in habit. Frequently the entire progeny of one egg-cluster reaches maturity within a few feet from the place of hatching, particularly if the food supply is abundant. Dispersal is greatest among fifth-instar nymphs, as evidenced by the numbers found feeding in wheat fields, usually quite some distance from the nearest weeds.

Nymphs depend almost entirely upon weeds, principally Russian thistle and tumbling mustard, for food. This may not always be a question of choice, but rather a result of their immobility during this stage of development. This was shown to be the case in a field in which all stages of nymphs were found on wheat. A small portion of the field was severely infested with pale western cutworm (Agrotis orthogonia Morr.) and overgrown with Russian thistle, with the occasional wheat plant growing among the weeds. This weed patch was infested with adult grain bugs, and in due course practically every plant had egg-clusters on the branches. As the nymphs developed, all stages were found on the wheat plants as well as on the weeds.

Frequently fourth- and fifth-instar nymphs were found feeding on wheat heads some distance from available weeds. This indicates that the later nymphs will migrate some distance for food. Saunders (1898) mentioned that in South Dakota fifth-instar nymphs were often seen migrating in large droves across fields to areas of more succulent food. This migratory habit has not been observed in recent years, but in times of very severe infestation the likelihood of this habit is not at all improbable.

The Effect of Temperature on Nymphal Development:

The atmospheric temperature is one of the most important factors in the development and rate of growth of the nymphs of Chlorochroa sayi Stal. Development of nymphs in the spring and autumn when the mean temperatures are low is considerably slower than at periods of higher temperature.

An experiment was planned to show the effect of temperature on development. Several methods of rearing were used. Mass rearing was used for the first instar, since all nymphs hatched at the same time. These nymphs were usually obtained from the eggs used in the incubation experiments. After the eggs had hatched at the experimental temperatures, the newly hatched nymphs were fed with sprouted wheat or sprigs of Russian thistle. When the second instar was reached the nymphs were transferred to individual containers.

For individual rearing each nymph was placed in a two-ounce, glass-topped tin box. Sprigs of Russian thistle, particularly those branches bearing the florets, were used for food. The food was changed when it began to wilt, which, at the higher temperatures, necessitated daily changing. In addition to the second-instar nymphs obtained from mass rearing, nymphs of all instars were collected in the field and reared. The date of each molt was recorded and the cast skin removed from the tin. In this way the duration of each instar was determined. This latter procedure was necessary since mortality under rearing conditions was excessive, and only rarely were nymphs reared through the entire nymphal period.

During the course of the rearing programme some variation in the length of time required for each instar at the same temperature was evidenced. This was more noticeable with the later than with the earlier instars, and may have been due to a seasonal variation in development. Nymphs were collected throughout the season, and it was noted that nymphs collected in the autumn developed more rapidly than those collected earlier in the season. For this reason, the maximum, mean and minimum rates of development for each temperature were computed. The results of this experiment are presented in table III.

TABLE III

The Effect of Temperature on the Rate of Development of *C. sayi* Stal Nymphs

	32° C.			29° C.			25° C.			21° C.		
Instar	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean
1	3.00	2.00	2.50	3.00	2.00	2.50	3.00	3.00	3.00	7.00	7.00	7.00
2	7.00	4.00	5.50	8.00	5.00	6.50	7.00	7.00	7.00	10.00	8.00	9.00
3	4.00	3.00	3.50	5.00	3.00	4.00	8.00	4.00	6.00	9.00	4.00	6.50
4	7.00	3.00	5.00	6.00	4.00	5.00	9.00	3.00	6.00	11.00	11.00	11.00
5	12.00	5.00	8.50	16.00	6.00	11.00	14.00	6.00	10.00	21.00	15.00	18.00
Total	33.00	17.00	25.00	38.00	20.00	29.00	41.00	23.00	32.00	58.00	45.00	51.50
Velocity	0.033	0.058	0.040	0.026	0.050	0.034	0.024	0.043	0.032	0.017	0.022	0.019

The data presented in table III show that the rate of development of the nymphs increased directly with an increase in temperature. However, since the temperatures used were constant, they are not wholly comparable with alternating temperatures such as are found under field conditions. Parker (1930) found that nymphs of <u>Camnula pellucida</u> Scud. and <u>Melanoplus mexicanus mexicanus</u> Saus., reared at alternating high and low temperatures, developed more rapidly at the alternating temperatures than at constant temperatures of the same mean. An acceleration at high temperatures was found by Cook (1927) to have taken place with larvae of <u>Agrotis orthogonia</u> Morr. when the larvae were brought from a low to a high temperature.

In fig. 2 the growth curves and velocity temperature curves are shown. The curves as depicted by the dotted lines are reasonably regular, the departure at 25° C. possibly being due to the differences in relative humidity at the other temperatures. Since no method of controlling humidity at these temperatures was available, no further check on this factor could be made. The regression line of the velocity temperature curves showed the threshold of development to be between 13° C. and 15° C. As was the case with the eggs, this was further substantiated by the inability of the nymphs to develop from one instar to another at 13° C. There was one exception, however, when newly hatched nymphs completed the first instar at 13° C. in 20 days. Since individual stages react independently of the entire nymphal period, this one exception does not alter the findings as presented. The difference in time required by nymphs to mature at different periods of the season is readily applicable to the data shown. The inability of the eggs to hatch and the nymphs to develop can be correlated with temperatures lower than the developmental zero during periods of inclement weather occurring in early spring and late autumn.

THE ADULT:

Host Plants:

A true host plant is taken to be one on which the egg, nymph and adult stages of an insect are found. It is sometimes impossible to ascertain whether the hosts recorded from various sources are true hosts or whether the insects found were there merely transitorily or hibernating. In general, nymphs of C. sayi are found on tender, succulent plants which are readily available. The adults prefer the same type of vegetation, and when plants are ripening, extend their feeding to include the seeds of many plants.

The following is a list of host plants of Say's grain bug which occur in Alberta, some of which were recorded by Caffrey and Barber (1919), and the others of which appear to be new hosts under Alberta conditions:-

Crop Plants

Alfalfa	# Oats
# Barley	# Peas.
# Beans	Potato
# Buckwheat	# Rye
# Cabbage	Sainfoin
# Corn	Sugar beets
Flax	# Tomato
# Lettuce	# Wheat

Wild and Ornamental Plants

Russian thistle (*Salsola kali* L.)
Tumbling mustard (*Sisymbrium altissimum* L.)
Hare's-ear mustard (*Conringia orientalis* L.)
Green tansy mustard (*Sisymbrium incisum* Engelm.)
Lamb's quarters (*Chenepodium album* L.)
Wild oats (*Avena fatua* L.)
Ground cedar (*Juniperus horizontalis* Moench.)
Goldenrod (*Solidago* sp.)
Sunflower (*Helianthus* sp.)
Perennial sow thistle (*Sonchus arvensis* L.)
Dandelion (*Taraxacum officinale* Weber)
Sage (*Artemesia frigida* Willd.)
Native grasses (species of *Agropyron*, *Poa*, *Bouteloua*)

Food plants recorded by Caffrey and Barber (1919).

Feeding Habits:

Adult grain bugs were introduced into cages in which wheat was growing in various stages of development. The insects fed readily on the developing wheat kernels, particularly when the kernel was in the milk and dough stages. Feeding punctures were easily located, and under a low-power magnification appeared as small holes about the size of a pin prick on the kernels and the outer glumes. In the wheat varieties in which a portion of the kernel was exposed, the site of the puncture could be easily seen with the naked eye, made more noticeable by a scab-like mass formed by the bleeding of the berry at the puncture.

As many as 6 bugs have been noted feeding on a single wheat head at the same time, the usual number being 2 or 3. The setae are forced through the glume near its point of attachment and into the kernel. Often an adult was seen with its mouthparts thrust downward through the glume opening to the kernel. Once the mouthparts are fixed for feeding, the individual will remain in that position for some time, often for several hours.

Wheat heads which have not begun kernel development show very positive symptoms of feeding. After several days' continued feeding, the head becomes noticeably lighter in color, but in other respects the appearance of the head is quite normal. This premature lightening in color is one of the few symptoms of grain-bug damage.

When the kernel is in the late milk or early dough stage no external symptoms are manifest. On close examination the site of the feeding punctures can be found, and the kernel exhibits a rather starchy appearance. This starchy color of the berry, accompanied by shrivelling, is probably due to the partial withdrawal of liquid content. When wheat is attacked soon after head emergence, kernel development is reduced to a minimum. On threshing out these heads only shrivelled vestiges of the original kernel can be found, although the glumes have apparently developed quite normally.

Because of the lack of definite field symptoms of grain-bug feeding, appraisal of the extent of damage incurred in a crop is very difficult by visual means. Infested and uninfested plants appear the same, and it is usually necessary to thresh out a number of heads in order to determine whether or not the infestation has produced harmful effects.

Field observations in the literature and investigations in Montana have shown that depredations can be very extensive. In Montana, according to Strand (1934), several fields in Hill County were left unharvested in 1933 because infestations had so reduced the yield that the grain was a total loss. Fields with an apparent yield of 25 bushels per acre or more were often found on harvesting to yield only about 4 or 5 bushels per acre. On one occasion in a field in southern Alberta which was the centre of a local infestation, 50 heads of wheat were chosen at random. When threshed out, only about 25 whole kernels were recovered, and these were very badly shrivelled. From such instances it is quite easy to determine the potentiality of this insect as a very definite menace to growing wheat.

Adult grain bugs have been reported damaging fields of seed alfalfa in Arizona by Lebert (1937) and also feeding on sugar beet seed in California (McKenzie 1936).

Migration and Flight:

Under normal conditions where food is readily available, nymphs and adults of Chlorochroa sayi Stal show very little tendency toward migration. As mentioned previously, Saunders (1898) reported large droves of nymphs, probably fifth-instar, migrating toward cultivated fields. This has not been observed in recent years, although there is no doubt that nymphs will more "on foot" several hundred yards in search of suitable food.

There is no doubt of the ability of this insect to fly great distances under certain conditions. Usually, however, the flight is limited to short distances. As a rule, when adults are disturbed in the field, individuals which do not fall to the ground take wing and settle down several hundred yards away. On July 15, 1936, Mr. Seamans of the Lethbridge Entomological Laboratory noted a heavy flight of Say's grain bugs settling into a previously uninfested field. They were flying in large numbers from the southwest. Within a short time every plant over a considerable area had one or more of the bugs feeding on it. Another actual case of flight was reported by Mr. Mail, then of the Montana Experiment

Station, Bozeman. During July, 1936, a heavy flight of grain bugs settled in a wheat field in the irrigated section around Malta, Montana. The bugs fed there for a week or more and then disappeared. This one week's feeding was sufficient to reduce the yield from a probable 40 bushels per acre to fewer than 10. The nearest previously known infestation of grain bugs was almost 100 miles distant.

Activity and Temperature:

During the calm, pleasant weather of the summer months the adults of *C. sayi* are active and feeding throughout the greater part of the day and early evening. Nymphs are usually found near the ground or on the lower branches of their food plant and seem to avoid excessive heat as much as possible. During more moderate times of the day, nymphs can be found feeding on the higher leaves and branches. Adults, on the other hand, are usually found in the open and do not avoid excessive temperatures to the same extent as the nymphs. On one occasion when the air temperature reached 104° F., the bugs were found at the lower levels seeking all the available shade. Toward evening, as the temperature moderated, the individuals resumed their positions on the heads of the wheat plants. During periods of high wind, rain or hail storms, and when the nightly temperature is below 60° F., the insects cease their activities and seek shelter, generally under some object on the ground or around the bases of their food plants. Alberta and Montana nights are generally quite cool, and it was only rarely that adults and nymphs were found feeding during the night.

In order to determine the trend of insect response to a wide range of temperatures, adult bugs were caged over wheat in the greenhouse in the winter of 1936 and 1937. Greenhouse temperatures ranged from a minimum of 40° F. at night to as high as 110° F. at midday. Observations were made daily, and the data were summarized at the end of the winter period. Table IV gives a summary of the temperature range of various activities as determined under the above conditions.

TABLE IV

Activity of Chlorochroa sayi Stal Adults in Relation to Air Temperature

Temperature		
Fahr.	Cent.	Activity
Up to 55°	Up to 13.0°	Resting, inactive.
55° to 60°	13.0° to 15.5°	Beginning to move about.
60° to 70°	15.5° to 21.1°	Searching for food, some feeding
70° to 90°	21.1° to 32.0°	Optimum feeding range.
90° to 110°	32.0° to 43.3°	Flying in early part of range.

Tendency to flight became more marked as the temperature increased above 90° F. This was found to hold true under field conditions, since flight was observed only on very warm days and usually during midafternoon.

The optimum temperature of about 90° F. in the greenhouse was further shown by other experimental means. At Montana State College a temperature preference box was made available. This box consisted of a wooden enclosure fitted over a copper bar 4 feet in length, 4 inches wide and about 3/8 inch thick. One end of the bar was fastened to a refrigeration pipe coupling, and the other end extended from the box and could be heated with an alcohol lamp. A sheet of glass fitted into the box from above, resting on supports at a distance of about ½ inch from the copper bar. Ten adults were placed in this box for each series of readings. The box was covered with black cloth to minimize interference of light response with that of temperature. On the basis of several readings the optimum temperature preference was found to be between 25° and 31° C., or 77° to 87.8° F. During the course of several runs it was interesting to note that occasional individuals would move into either the hot or cold end, pass the critical temperature, and die there within a short time.

The Effect of Constant and Alternating Temperature on Activity and Oviposition of Hibernating Adults:

An experiment was set up to determine the effect of constant and alternating temperature on hibernating adults.

In the course of winter experimentation it was found that it was very difficult to induce oviposition of adults taken from hibernation. Apparently some combination of temperature conditions in the spring brings about the resumption of normal activity and ultimately oviposition. Based on this supposition an experiment was devised using one temperature in the optimum range and the other in the transition temperature range.

Thirty-two adults, an equal number of males and females, were used in each of the four series. The adults were collected from hibernation during March and kept inactive at 6° C. until the experiment was begun. The temperature conditions for each series were as follows:-

Series no. 1 - 32° C. constant.
2 - 16 hours at 32° C., 8 hours at 21° C.
3 - 8 hours at 32° C., 16 hours at 21° C.
4 - 21° C. constant.

The adults were confined in screen-cloth cylinders over 6-inch flower pots in which sprouted wheat was growing. Some difficulty was encountered in maintaining the wheat in a desirable condition for food, particularly at the higher temperatures. This was partly overcome by changing the food daily at the higher temperatures. Alternations were made at 9.00 a.m. and 5.00 p.m. Daily notes were made on mortality, copulation, oviposition and fertility. The eggs recovered were placed at 32° C. for hatching. The fertility rating was based on the numbers of eggs laid each day which actually hatched, and was computed in the following manner: for total hatch a rating of 1.0 was given; for partial hatch a rating of 0.5, and for no hatch, 0.0. A summary of the results obtained is given in Table V.

TABLE V

The Effect of Constant and Alternating Temperature on Hibernating Adults of Chlorochroa sayi Stal

	Series No.			
	1	2	3	4
Temperature	32° C.	32°-21°	21°-32°	21° C.
Color change after	4 days	5 days	6 days	7 days
First eggs after	7 days	8 days	10 days	No eggs
No. eggs after 10 days	66	61	14	"
No. eggs after 20 days	263	238	288	"
No. eggs after 30 days	268	259	298	"
Total eggs	268	259	298	"
Mortality after 10 days	5	3	2	2
Mortality after 20 days	17	11	6	7
Mortality after 30 days	32	29	29	17
Mortality after 40 days	32	32	31	21
Series finished after	28 days	37 days	41 days	64 days
Fertility rating	0.15	0.50	0.70	No eggs
Mean temperature	32° C.	28° C.	24° C.	21° C.
Degree-hours per day	768	680	592	504

It must be borne in mind that the data shown in table V are the results of one experiment, and because of this no definite comparisons can be made between the series until substantiated by additional experimentation. General trends can, however, be drawn with some accuracy.

From the summarized data, the rate of color change, the pre-oviposition period, and the duration of the experiment decreased directly with an increase in temperature.

The rate of color change is a variable factor, as other experiments have shown. It was found that the rate of change from the drab winter coloring to the bright green of the summer forms depended largely on the period of the year when the adults were taken from hibernation. Insects collected in the field during early winter required considerably more time to change color than did those collected a few weeks before the normal resumption of spring activity. Except for this seasonal variation, the rate under experimental conditions was always proportional to the temperature.

Temperature apparently had a very definite bearing on oviposition. Fertility increased with lower temperatures, and was lowest at the higher constant temperatures. The length of the pre-oviposition period was in direct relationship to changes in mean temperature. The number of eggs from each series was hardly significant, although the greatest numbers were recovered from the series with the highest fertility rating, namely, 8 hours at 32° C. and 16 hours at 21° C. No oviposition took place at 21° C. constant temperature. From miscellaneous observations it was noted that copulation generally occurred at the lower temperature and oviposition at the higher.

The most significant point in this experiment appeared to be that a high temperature preferably alternating with a low was necessary to induce oviposition.

The Effect of Ultra-violet Radiation on Hibernating Adults:

During recent years the effect of ultra-violet light has received considerable attention from investigations as a factor on various biological responses. Most noteworthy is the research in the field of medicine, utilizing ultra-violet in a successful therapeutic role.

The work on insects, in extent of experimentation and amount of results obtained, is inconsequential, particularly when compared with the other sciences. In common with investigations on plants, both stimulative and destructive effects have been found. Throughout all these investigations the point of demarcation between these two has not always been clearly determined. There has also been a lack of sustained effort toward standardized methods of experimentation, and as a result no equitable means of comparison is available between the different results obtained.

The position of ultra-violet light in relation to the remainder of the electromagnetic spectrum is shown in the following summarized tabulation adapted from Radley and Grant (1935):-

Cosmic rays	.0005	to	.005	Angstrom	units.
Gamma rays	.0050	to	1.000	"	" .
X-rays	.1000	to	1,000.000	"	" .
Ultra-violet rays	136.0000	to	4,000.000	"	" .
Visible rays	4,000.0000	to	7,000.000	"	" .
Solar radiation	2,900.0000	to	20,000,000	"	" .
Intra-red rays	8,000.0000	to	4 x 10^6	"	" .

From the above summary it can be readily seen that there is considerable overlapping between the various arbitrary classifications of the entire spectrum. For example, solar radiations include rays from the ultra-violet, visible and infra-red portions.

Previous to about 1926 very little had been written about the possible effects of ultra-violet radiations on insects. The subject of light had been generally considered in relation to insect behavior and tropic responses. From this the role of ultra-violet was evolved, first as a means of control with light-traps, and eventually as a definite factor of insect behavior and physiology.

Much of the work was an outcome of the effect of ultra-violet in producing mutations in genetic investigations with Drosophila melanogaster Meig. Geigy (1926) was the first to observe that irradiations caused certain mutations that were not inherited. The investigations of Promptov (1932) disclosed that the short rays of the ultra-violet spectrum were quite feeble in their ability to produce mutations, particularly when compared with Roentgen rays. Several years later Steen (1934) pursued this further and found that the radiations inhibited oviposition, particularly when administered in long exposures.

MacGregor (1932) irradiated larvae and pupae of Aedes eigypti L. and Culex pipiens Linn., and found that a peculiar fatal injury resulted. Similar abnormalities of the structure of irradiated eggs, larvae and adults of Bruchus (Mylabrus) obtectus Say were reported by Macleod (1933). The eggs were rendered infertile and the larvae were killed. Irradiated adults showed no particular injury, except that the eggs recovered from irradiated females were largely sterile.

An attempt was made by Bertholf (1933) to determine some method of irradiating honey bees which, by resultant increased honey production, would be of some commercial importance. He found that the ultra-violet rays of the shorter wave-lengths were definitely harmful to the larvae and adults. The longer wave-lengths, although not harmful, caused little difference in responsel The main conclusion of the investigation was that since ultra-violet radiations were harmful, no increase in honey production could be brought about by the commercial use of such radiations.

In the light of other investigations and since the adults of Chlorochroa sayi Stal emerged from hibernation in the spring when the solar radiation was increasing, it was thought that ultra-violet would be of some importance in stimulating normal activity and oviposition. The plan of the experiment was very similar to the previous one on the effect of constant and alternating temperature, except that ultra-violet radiations were added.

The source of the radiations was a mercury arc lamp manufactured by the Hanovia Chemical and Manufacturing Company, Newark, New Jersey. The tube was in the form of a helical grid, and was operated in conjunction with a transformer which supplied a secondary voltage of 5,000 volts. According to the manufacturer's measurements, about 92 per cent of the radiations were of 2,537 Angstrom units. Most of the remaining 8 per cent fell within the visible portion of the spectrum.

The insects were irradiated at a constant distance of 5 inches from the outer edge of the helical grid. The duration of the exposure was also constant for the irradiation of each series. An exposure of 3 minutes was used, timed for each series with the aid of a stop-watch.

The hibernating adults for this experiment were collected from the same observation fields during December and stored at about 4° C. until required.

Forty individuals, equal numbers of males and females, made up each series. The individual series were confined under celluloid sleeve cages with a cotton top over 6-inch flower pots of sprouted wheat. The same care in changing food as for the previous experiment was exercised.

The treatment of each series is shown in the following tabulation:-

Series No.	1 -	30° C. constant.
	2 -	16 hours at 30° C., 8 hours at 20° C.
	3 -	8 hours at 30° C., 16 hours at 20° C.
	4 -	20° C. constant.
	# 5 -	30° C. constant.
	# 6 -	16 hours at 30° C., 8 hours at 20° C.
	# 7 -	8 hours at 30° C., 16 hours at 20° C.
	# 8 -	20° C. constant.
	9 -	Check, room temperature.
	10 -	Check, greenhouse temperature.

Irradiated.

The alternations were made at 8.30 a.m. and 4.30 p.m. The irradiations were made at the same time each. In the irradiation period the unirradiated series were removed from the cabinets for observation. In this way the two sets of series received approximately the same treatment except for the addition of ultra-violet in one set.

The results obtained are summarized in table VI. The data are presented under approximately the same headings used in table V.

TABLE VI

The Effect of Ultra-violet and Temperature on Hibernating *C. sayi* Adults

	Series No.							
	1	2	3	4	#5	#6	#7	#8
Temperature	30° C.	30°-20°	20°-30°	20° C.	30° C.	30°-20°	20°-30°	20° C.
Col. ch., days	8	9	11	17	9	10	12	17
1st eggs, days	10	13	17	no eggs	8	16	26	no eggs
Total eggs	86	195	55	-	109	14	23	-
Mort., 10 days	9	9	3	1	4	11	4	0
" , 20 "	28	24	13	3	35	23	15	3
" , 30 "	40	34	24	7	40	40	31	8
" , 40 "	40	40	34	19	40	40	37	22
Finished, days	25	35	49	59	25	30	50	60

Irradiated with ultra-violet.

The two experiments summarized in tables V and VI are comparable since in both, conditions of constant and alternating temperature are used. In the experiment with temperature alone, 32° C. and 21° C. are used, and in the above experiment 30° C. and 20° C. The histories of the individuals used in the two experiments are different, and as a result have considerable bearing on the results obtained. In the former the individuals were collected during March, while in the latter the insects were collected during the month of December. Therefore, in the latter case the resumption of certain activities was considerably slower than when the adults were collected towards the end of the hibernation period.

The differences between the two experiments of the time required for the color change and the total oviposition may be attributed to the history of the two sets of individuals. The rate of color change in the individuals collected in December was greater than in those collected in March, although both retained the direct correlation with temperature. Similarly, the differences in oviposition and fertility encountered in the two experiments are due in all probability to the same condition.

The application of ultra-violet resulted in very little departure from the series which received no irradiation. At this time it must be noted that the output of the lamp was limited very definitely to only a small portion of the ultra-violet spectrum, namely, to 2,537 Angstrom units. Any response obtained would be due to this wave-length and would exclude any parallel comparison with solar radiations, since the ultra-violet in the sun's rays extend from 2,900 to 4,000 Angstrom units.

The color change of the irradiated series appeared to lag behind the unirradiated, as shown in table and fig. 3. This discrepancy was not sufficiently significant to draw any definite conclusions and may have been due more to individual variation than to the effect of the ultra-violet. A similar condition was found in comparing the eggs laid within the two sets of series. Some suggestion of inhibited oviposition is shown in the total number of eggs laid, 336 for the unirradiated series and 146 for the radiated. Further examination of the data in table VI shows that this does not hold true within the sets of series. In series no. 1, which was not irradiated, fewer eggs were found than in series no. 5, which was irradiated. In series nos. 2 and 6 there was a complete reversal of this finding.

The duration of each series was found to be directly dependent upon the temperature, and the addition of ultra-violet was of no significance. On comparing the duration of each series in tables V and VI the results were approximately the same. Comparison of the irradiated and un-

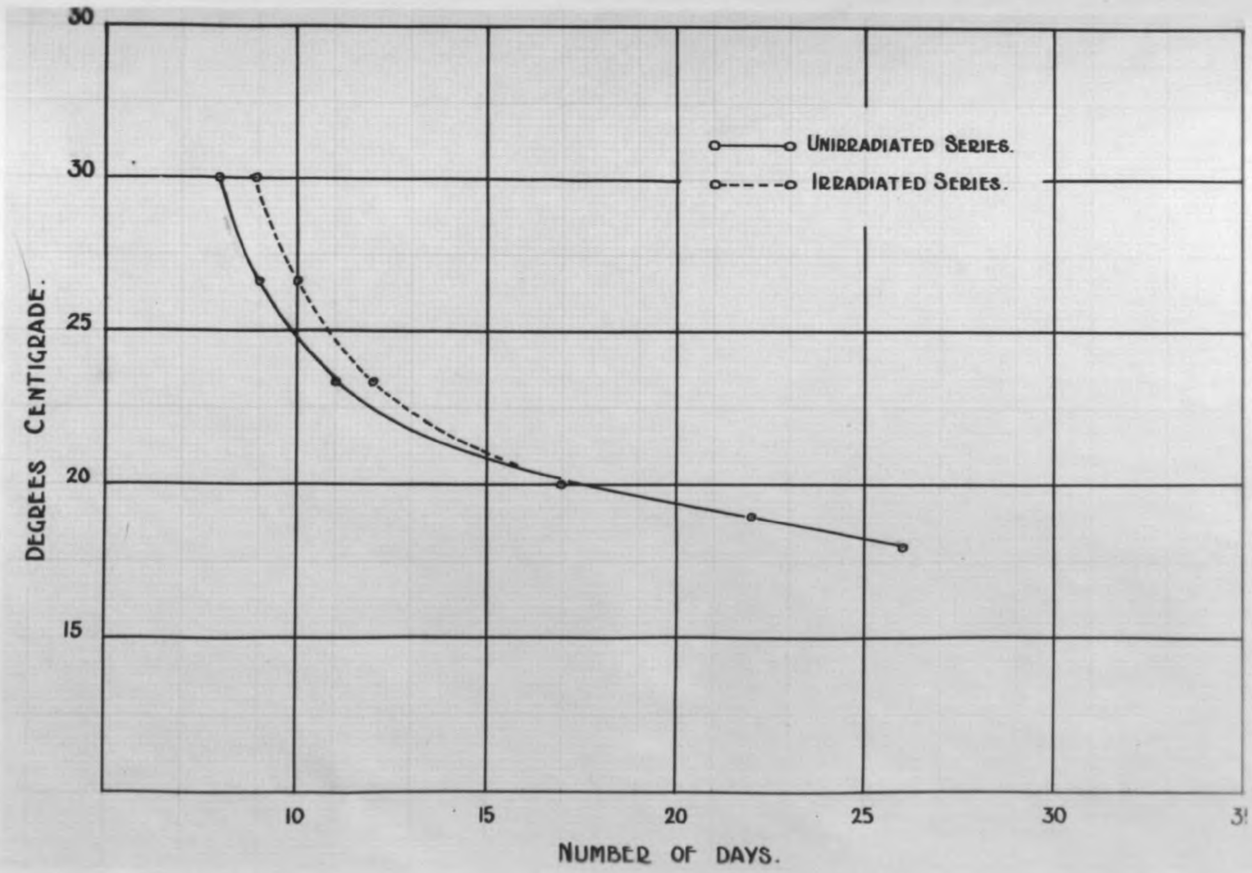


Fig. 3.

The Effect of Ultra-violet Radiation on the Rate of Color Change in *Chlorochroa sayi* Stal Adults irradiated series is shown pictorially in fig. 4, and here again the similarity is further borne out.

In conclusion, the addition of ultra-violet produced no definite additional response. There was some suggestion of harmful effect, which was in keeping with other investigations in which ultra-violet radiations of short wave-length were used.

Winter Mortality of Hibernating Adults:

In years of severe infestation the probable degree of injury would depend largely upon the percentage survival of hibernating insects. In order to become familiar with the winter hardiness of *Chlorochroa sayi* Stal and the factors affecting successful spring emergence, a course of hibernation studies was carried out during the winters of 1936-1937 and 1937-1938. Observations were made in a number of type fields, and mortalities were computed from collections made of different kinds of cover throughout the entire hibernation period. Supplementary investigations were conducted in the laboratory.

Patton and Mail (1935) made freezing-point determinations of hibernating adults and found that the temperature must decline to -13° C. and lower in order to have any lethal effect. Extensive temperature measurements by Mail (1935) showed that a snow covering provided adequate insulation

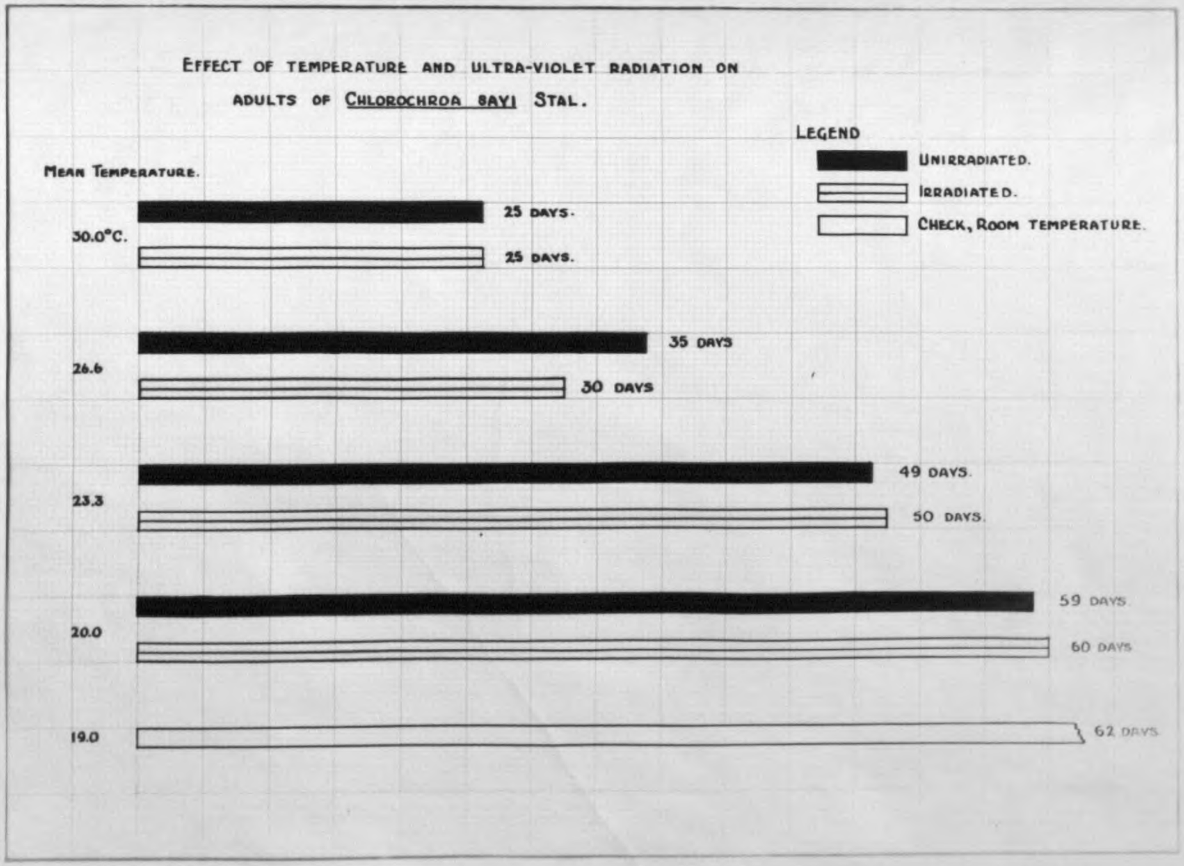


Fig. 4.

The Effect of Ultra-violet Radiation on Longevity at Various Temperature Conditions against extreme cold. Salt (1936) observed that when insects, including C. sayi Stal, were inoculated with water there was a definite tendency to reduce, or even eliminate, undercooling of the insects. From the above findings it would appear that under ordinary hibernating conditions grain bugs would not be affected by severe temperatures. On the other hand, during periods of alternate thawing and freezing, when the insects were inoculated with melting snow, or during sub-zero weather with no snow covering, the possibility of heavy mortality would be great.

During extreme cold weather, several series, wet and dry, were placed outdoors. A further check on previous work was obtained, as shown in table VII.

TABLE VII

The Effect of Low Temperatures on Survival of Adults of *Chlorochroa sayi* Stal

Minimum temperature	Percent Survival	
	Wet	Dry
- 6.7° C.	16	100
-16.7° C.	0	50
-23.3° C.	0	0

The freezing point of the dry individuals in the above experiment varied from -16.7° C. to -23.3° C., which was quite comparable with the ranges determined by Patton and Mail (1935) and Salt (1936). The ability of contact moisture to reduce the freezing points was evident, since the mortality of the wet series at all temperatures was practically 100 per cent.

The use of these principles is readily applicable to field conditions. As the adults usually hibernate in small depressions in the soil and have no other cover than the accumulated debris during periods of thawing, water could enter these locations. In such periods, particularly if followed by low freezing temperatures, field mortalities would tend to increase.

Winter Field Observations:

Definite observation sites in the field were chosen and periodic collections and counts of living and dead insects made. From these counts the percent survival was computed. Wherever possible, temperatures within the hibernating sites were taken and checked against the prevailing air temperature.

The autumn of 1936 was marked by intermittent snows and thawing weather. after October 20, the approximate date when hibernation commenced. From about December 10 to 24 the weather was very mild, and the snow was completely removed. Over a period of 44 days, from December 24 to February 6, 1937, the weather was extremely cold, unbroken by a thaw of any kind. Over 17 inches of snow fell, and the minimum temperature was -36° F. A period of moderate temperature followed, and no further sustained cold weather was experienced. In summary, temperatures during the winter were considerably lower than average, which was offset by more than average snowfall.

The autumn of 1937 was quite mild. No snow or cold weather was experienced until late in November. As a result, adult grain bugs remained active for almost a month longer than in the previous year. Considerable snow fell in the latter part of this month, but in the ensuing mild spell in early December the snow melted. There was a short period of cold weather from December 23 to 28, with only a light skim of snow, when minimum temperatures ranged to -22° F. January 1938 was very mild, almost approaching the same record month of 1931. Cold weather prevailed during most of February, followed by a dry, mild March and a wet April.

The observation fields were chosen to include the two types of cover, road allowances and field margins with weed covering, and trash-cover summerfallow. Collections were made whenever weather and passability of roads permitted. It was noted that mortalities increased after each mild spell.

This was particularly true during the winter of 1937-1938, when periods of mild weather were more frequent. As a result, spring survival was considerably lower in 1938 than in the preceding year.

In road-allowance and field-margin sites the increase in mortality was correlated with periods when snow as an insulating medium was absent and periods when the insects were exposed to low temperatures while they were in wet surroundings. This proved to be the case in one hibernation site, where the insects sought shelter along an ungraded road allowance in the furrows formed by a fire-guard and in small depressions. During the mild weather in the early spring of 1938 these locations were partly inundated with melted snow. Mortalities computed from collections made in this location were about 62 per cent, the highest recorded in the two years' observations.

The most remarkable finding of these observations was that trash-covered summerfallow provided an almost ideal hibernation site for grain bugs. The trash in this type of field provided more adequate shelter, since the insects could burrow into the trash to a point below the actual soil surface. In addition, since less snow accumulated in these fields and drying-out was very rapid in the spring, the possibility of wet surroundings was minimized.

A comparison of spring mortality from the two types of shelter is presented for the two years of observation in table VIII.

TABLE VIII

Spring Mortalities of Hibernating Adults of *C. sayi* Stal for 1937 and 1938

	Trash Cover Mortality	Other Shelters Mortality
Spring, 1937	10%	27%
Spring, 1938	6%	64%

It can be seen from the data presented in table VIII that in both years the mortality of hibernating adults collected from road allowances, under weed piles, and in similar sites, was considerably higher than in collections made in trash-cover summerfallow. The increase in mortality of adults collected in sites other than trash cover in 1938 over the previous year is remarkable in that this increase can be correlated with the milder winter. In the autumn of 1937 and the winter months of 1938 the weather was marked by many periods of alternated thawing and freezing, which was not the case the previous year.

The summer population of 1937 was considerably greater than that of 1936. This build-up occurred despite a spring mortality of about 26 per cent. It will be interesting to note whether a corresponding increase in numbers will be present in 1938 or whether the population will be limited by the greater spring mortality.

Proportion of Sexes:

The proportion of sexes throughout the year does not vary greatly. Collections and counts were made in the last two years to determine the exact relation in numbers, if any, between the sexes and the seasonal proportion. Collections of grain bugs were made in the field on various hosts and in hibernation throughout the year, and counts were also kept of the sex ratio of adults reared in the laboratory. In all, 2,870 adults were counted, of which 1,211 were males and 1,659 females, which gives a ratio of 42.2 per cent males and 57.8 per cent females.

No seasonal variation of this ratio was found, and individual collections maintained about the same proportion. A reversal of sex ratio was found in collections made in a field from which migration was taking place, indicating that females were the first to migrate.

PARASITES AND PREDATORS

Several parasites and predators of *Chlorochroa sayi* Stal were found during the course of recent investigations. The findings were generally about the same as those reported by Caffrey and Barber (1919) and Strand (1937).

Eggs of *C. sayi* Stal found in the field were parasitized by a chalcid, determined by Muesebeck as *Telenomus messillae* Ckl. In June 1937, eggs laid by overwintering adults were found to be parasitized by this species. Observations in the field indicated that parasitism by this insect was greater on second-generation eggs than on first-generation. Under laboratory conditions, recently emerged parasites were confined with newly laid eggs of *C. sayi* stal. Oviposition by the parasites took place within a few minutes, flies emerging from these eggs about 15 days later. Because of this short life cycle, parasitism in July and August was considerably greater than earlier. Parasitism by this chalcid was estimated from counts made in the field to be from about 5 to 10 per cent. Eggs which had been parasitized were quite unlike normally hatched eggs in appearance. The round aperture through which the adult parasite had emerged was totally different in appearance from the lifted operculum of eggs from which nymphs had emerged. An egg parasite of the same genus (*Telenomus ashmeadi* Morril) was recorded by Caffrey and Barber (1919) in New Mexico and by Strand (1937) in Montana.

Two internal tachinid parasites were reared from adults, Gymnosoma fuliginosa Desv. and Cylindromyia armata Aldrich. Of the two, the former was found to be most abundant. The biology of these parasites has not been accurately worked out. It is known, however, that the parasite overwinters within the host. The larva emerges through the anal opening in the spring and pupates in the soil. The pupal period has been found to vary between 10 and 20 days. The parasitized host retains its activity and powers of feeding to within a short time of, and often after, the emergence of the parasite. The adults of these parasites were first observed in the field about the last week in May. They were most abundant during July and August, and were present in smaller numbers until the time of the first severe frosts. The larvae of the parasites were observed while making dissections on the host adults for ovarian development. The dissections were made from early spring until late autumn. From these observations it was found that the average parasitism for the entire period was about 18 per cent, with a maximum of 30 per cent in August.

The tachinid parasite, Octypteroides euchenor Walk., reported by Caffrey and Barber (1919, was found to be synonomous with Cylindromyia armata Aldrich. The correction was made by Aldrich (1926) from the reared specimens obtained from the original workers. A new tachinid, *Senotainia vigilans* Allen, which hitherto had not been reported as a parasite of *C. sayi* Stal, was reared during 1936 in Montana (Strand 1936).

Several insects were found preying on grain bugs in the field, and their predacious tendencies were confirmed in the laboratory. Carabid beetles of the genus *Calosoma* were often quite abundant in fields in which great numbers of grain-bug adults and nymphs were also present. In the laboratory these beetles fed avidly on adults and nymphs. Two hemipterous predators, *Sinea diadema* Fabr. and *Phymata erosa* Stal, were found to feed on nymphs in the field. The ground beetles were often observed feeding on eggs of *C. sayi* Stal, but the major portion of the feeding was probably done by a small melyrid beetle which was often found to be quite numerous.

METHODS OF CONTROL

Up to the present time the only accepted method of control was the spring burning of weeds and trash along road allowances, in field margins and in ditches. This method was first suggested by Saunders (1898) and later by Caffrey and Barber (1919) and Strand (1934). The spring burning applies particularly to the dead Russian thistle in abandoned fields and along irrigation ditches, check ridges and fence rows--in fact, all locations where the accumulations of weeds afford suitable hibernating quarters. In districts where the principles of good farming prevail, this method is a natural outcome of the accepted clean-up programmes conducted in conjunction with noxious weed control. On the other hand, abandoned fields and out-of-the-way, uncultivated lands are overlooked, and thus serve as reservoirs for future infestations. Such fields make the problem of concerted community action for pest control very difficult as past experiences with other insect pests have shown. The most serious objection to the burning method of control is that spring burning of stubble fields is very conducive to soil drifting. Since the problem of soil erosion and control is a very important one both in Western Canada and the United States, methods which would complicate this problem cannot be advocated.

The study of soil erosion and control has brought about another remarkable relationship with the control of this insect. Since hibernating adults utilize the recently introduced trash-cover summerfallow for hibernation, the situation is considerably altered. The insects are how capable of passing the winter with less mortality in a type of cover devised to curtail soil drifting.

Laboratory experiments were conducted which showed that nymphs and adults of Say's grain bug were unable to withstand burial in soil. When adults were buried to a depth of 2 inches or more, mortality was about 100 per cent. Nymphs were less able to make their way successfully to the surface than the adults.

Saunders (1898) mentioned that the adult insects were often found at a depth of several inches in the soil and concluded that they were able to burrow into the soil at will. This is probably not the case, but the insects to which he referred had probably taken shelter in cracks in baked soil, and natural weathering had trapped them below the soil surface. The interment of adults in soil by this means may possibly constitute some measure of natural control.

Future research on the control will be based on the inability of this insect to withstand burial in soil, particularly burial of several inches. Since trash-cover summerfallow has been utilized for hibernation and spring cultural operations usually begin at about the same time as spring activity of the insects, some method of cultural control may be evolved.

Early in the season the immature stages of the first generation are usually concentrated on the new growth of Russian thistle and other native host plants in certain areas of cultivated fields. At this time the multiplication of the species may be greatly restricted by spraying these areas with a strong herbicide, thus killing the insects and their obnoxious food plants in one operation. This means of control would be more advisable in areas of intensive farming, such as irrigated land, rather than under large-scale dryland conditions.

Mechanical means of control, such as hand picking and the use of dozers, would be of no value, except under very special circumstances.

SUMMARY

Say's grain bug (Chlorochroa sayi Stal) was first reported causing losses in 1904 in the states of Arizona, Colorado and California. Severe infestations occurred in New Mexico in the years 1915 and 1916. In recent years, marked by drought, the insect has appeared farther north, showing up in Montana in 1932 and in Alberta, Canada, in 1936, for the first time.

Known distribution records in North America include the states of Arizona, Colorado, California, New Mexico, Utah, Montana, North Dakota, South Dakota and Nebraska in the United States, and the provinces of Alberta and Saskatchewan in Canada.

The winter is passed in the adult stage, chiefly under shelter of weeds and other debris. In Canada, hibernation has taken place in trash-cover summerfallow, a cultural development devised for the control of soil drifting.

About the last of April the overwintering adults emerge from hibernation and resume activity and feeding. Egg-laying commences about May 15, and the first nymphs from these eggs mature in early July. There are two distinct generations each year, with considerable overlapping. The first eggs of the second generation are laid in late July, and oviposition continues until the last week in August. The first nymphs of the second generation mature in mid-September, and nymphs are present until late autumn.

The nymphal period varies in length from about 42 to 60 days, depending upon the season.

Adults enter hibernation in October or November, of both first and second generation. Nymphs are unable to survive the winter.

Oviposition is general throughout the entire period of insect activity. The eggs are usually laid on the under side of stubble and the branches of host plants. The average number of eggs per cluster was found to be about 26. Each female is capable of laying several clusters, the number of eggs varying from 9 to 68 or more.

Under field conditions the incubation period varies from 4 days to 2 weeks or longer, the duration being dependent upon the mean temperature. By laboratory experiments the threshold of development of eggs was found to be between 13° C. and 15° C.

Nymphs usually confine their feeding to weeds, and there is little movement from the place of hatching during the nymphal period.

The rate of development of nymphs increases directly with an increase in temperature. The theoretical zero point of development is about 13° C. to 15° C.

The host plant list includes many uncultivated plants and cultivated crops. The favorite hosts are Russian thistle and tumbling mustard, and the crop most commonly injured is wheat.

The primary injury done by C. sayi Stal is the withdrawal of the liquid contents of the developing wheat kernel, resulting in general shrivelling of the grain and reduced yield.

Apparently the adults are capable of flying considerable distances in search of more succulent food.

The adults are active between 55° F. and 110° F., the optimum range of activity being between 70° F. and 90° F.

Alternating temperatures are more conducive to oviposition by adults collected from hibernation than are constant temperatures.

Ultra-violet radiations of 2,537 Angstrom units have apparently no marked effect on hibernating adults.

Winter mortalities are lower in trash-cover summer-fallow than in other types of shelter.

The normal sex ratio of females to males is about 3 to 2.

Two internal tachinid parasites, Gymnosoma fuliginosa Desv. and Cylindromyia armata Ald., and one chalcid egg parasite, Telenomus mesillae Ckl., have been reared in Alberta. The chief predators are ground beetles of genus Calosoma and two hemipterons, Sinea diadema Fabr. and Phymata erosa Stal.

The spring burning of stubble and weeds is not a suitable method of control in Western Canada because of its tendency to increase soil erosion. Experiments have shown that adults and nymphs are unable to survive burial to a depth of several inches, by which means cultural practices may lead to future control methods.

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