

The Influence of Food and  
Temperature Upon the Growth  
and Development of the Green Bug

by Ruby Cornelia Hosford

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AND TEMPERATURE UPON  
THE GROWTH AND DEVELOP-  
MENT OF THE GREEN BUG

RUBY CORNELIA HOSFORD

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A THESIS.

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## PREFACE.

The Green Bug, Toxoptera graminum , which is a serious pest on small grains, was first found in Kansas in the Spring of 1907. It appeared then in such great numbers that great harm was done to the wheat crop in some places. In order to combat this pest successfully it was necessary to study the problem fundamentally. Insects were, therefore, brought into the laboratory and bred through successive generations. Many interesting biological phenomena were noted and problems suggested.

This paper gives the results of experiments performed with a view of determining the effects of food and temperature upon the growth and development of the green bug, paying especial attention to the question of the probable cause of the change from the parthenogenetic to the sexual mode of reproduction.

It was at the suggestion of Professor S. J. Hunter that this work was undertaken and the writer wishes at this time to thank him for his kindly interest and criticism and many helpful suggestions.

The writer also desires to express her sincere appreciation of the help rendered by all others of the Department of Entomology, especially by Mr. H.

B. Hungerford in keeping the records of the experiments and Miss Hazel Hall and Mr. Roy Fraser in carrying on the check series.

The colored plate and the figures showing the Intermediate forms of the green bug, and the chart showing the relation between temperature and the rate of reproduction were taken from the Bulletin, "The Green Bug and Its Natural Enemies".



THE INFLUENCE OF FOOD AND TEMPERATURE  
UPON THE GROWTH AND DEVELOPMENT OF THE GREEN BUG.

"Many volumes have been written upon the habits and life histories of plant-lice; enough has been written upon the grape Phylloxera alone, to fill a small library. And yet we have much to learn about plant-lice. I believe they present as varied, peculiar, interesting, and wonderful phases in their habits and life histories as do any other insects."

Thus wrote Slingerland twenty years ago. Since then many more volumes have been added; enough to fill a large library, and still no satisfactory solution has been obtained of one of the most interesting biological problems illustrated in this group of insects, viz., the transition from the parthenogenetic to the sexual phase of the life cycle.

Many investigators have studied this question, have experimented, have discovered factors that influence the growth and development of these

insects and have advanced theories as to the solution of the problem. It was to corroborate the work of some of these experimentors, to obtain, if possible, more definite results and perhaps through them to throw some light upon the solution of this mystery of Nature, that the writer undertook experimental work on the influence of food and temperature upon the growth and development of the green bug, (Toxoptera graminum). It was at the suggestion of Professor S. J. Hunter that the writer undertook this work and she is greatly indebted to him for his aid and suggestions throughout.

The life cycle of aphids briefly is as follows: in the spring the stem mother hatches from the overwintering egg; she gives birth to wingless agamic females which in turn reproduce parthenogenetically, the progeny being either wingless forms or winged ones capable of perpetuating the species by their ability to fly to new fields. In the fall the true males and females appear, mate and the overwintering eggs are deposited.

It has been demonstrated, however, that this cycle can be altered by changing the attendant conditions.

Kyber found that by keeping the insects in a warm room a series of agamic generations was produced which extended through four years without the intervention of the sexual forms. However, no record was kept of the number of generations produced during this time. This seems to indicate that temperature is a factor in the production of sex forms.

Slingerland furnished further data on this point. He produced under constant temperature conditions in the insectary at Cornell, sixty-two generations in two years and ten months, with no males or females and no winged forms. He also found that the reproductive power of the agamic females did not decrease through nearly sixty generations.

To learn whether winged females might not be produced if the plants became overcrowded with the aphids, he allowed in several instances, reproduction to go on undisturbed in his cages. These experiments proved nothing definitely for in each case, when several hundred had accumulated on a small plant, the overcrowding was checked by a fungous growth, which set in and destroyed a majority of the insects.

Clarke, in California, states that he has been able to produce a winged generation at will by simply changing the chemical constitution of the sap of the host-plant on which the aphids were reared in his laboratory.

Kellogg believed that extrinsic influences, such as crowding the host plant and hence lessening the food, or an unusual humidity or lack of humidity, an early lowering of temperature in autumn, etc., seemed to be very potent in producing or acting as effective stimuli for adaptive variations of the usual course of life.

Davis in his studies on the Corn Root-Aphis, found that bisexual forms might appear in any generation, providing the environmental conditions were such as to favor their development. In his work, in the insectary, sexual forms appeared in October and November from 12 different generations, varying from the eleventh to the twenty-second, inclusive. This seemed to indicate that the appearance of the sexes might be conditioned by temperature. A further illustration of this was the occurrence of sexual forms on September 5, 1905, at which time the



weather was quite cool for that time of the year, while in 1906 the sexual forms did not appear until October 2, the weather up to that time being milder than in 1905.

Mr. Davis also recorded numerous instances in which the first young of a generation were viviparous and the last oviparous. In these cases it was noticed that after the production of viviparous forms the aphids would rest a few days before beginning to produce sexual forms.

This was not a new observation, for Buckton, in his "Monograph of British Aphids," says that several early observers had stated that the female aphid is at different periods of her life both viviparous and oviparous. He, however, did not agree with this view, stating that, "it may be pretty certainly asserted that the viviparous aphid is never oviparous, and that the converse also is true."

The results obtained by Davis prove that the early observers may have been correct in their belief that an aphid might be both oviparous and viviparous, and that Buckton was wrong in his denial of the possibility of such a thing, at least as far as the

Corn Root-Aphis is concerned.

All of the aphides which Davis reared individually, in vials, were wingless. Other aphides, however, of the same mothers, and placed in cages containing many other aphides as well as a less abundant food supply, often became winged. "From these and other evidences obtained," he states, "it may be inferred that the development of the winged forms among aphides is largely caused by an insufficient food supply."

Tanreuther (19)7) thought that though the conditions of food and temperature were very important in aphid development. they influenced only in an indirect way the appearance of the sexual forms. With the aphides used in his experiments, normally, the sexual females appeared about the middle of September., after the production of six parthenogenetic generations. These six included the stem mother and the pre-sexual generation. Favorable conditions would retard growth and lengthen the time for any given generation, thereby causing the sex forms to appear later. The presexual generation, which is produced by the fifth parthenogenetic

generation, gave rise to either all male or all sexual females. According to his observations it appeared that an egg must be frozen before it would complete development. The greatest number of winged forms appeared in the second generation, especially when food was abundant.

Judging from the observations of these various men, it would seem that environmental conditions, particularly food and temperature, have a great influence upon the transition from the parthenogenetic to the sexual phase of the life cycle. Indeed, several years ago it was the general opinion of zoologists that there was a possibility that sex in aphids was determined by external conditions.

With the idea in mind that on this interpretation it might be possible to regulate sex in aphids by controlling the conditions under which they were kept, Professor T. H. Morgan and Miss N. M. Stevens began work on the group. The experimental work was done conjointly while Miss Stevens took up the histological side. The aphid used was the rose aphid. The work gave only negative results on the experimental side. None of the external

conditions to which the aphid was subjected produced the change from the parthenogenetic to the sexual forms. A long series of experiments, was tried, in which twigs of the rose with aphids on them were kept in solutions of various salts, magnesium, calcium, potassium, lithium. It was hoped that the solutions, drawn up into the stems by the evaporation from the leaves would be imbibed by the aphids which procure their food by sucking the juices of the plant and a change in the mode of reproduction brought about. The results, as stated above, were negative.

Concerning the effects of temperature on the cycle of this rose aphid, it was found that the sexual forms might appear in the late summer before cool weather began. Furthermore, late in the autumn parthenogenetic individuals could always be found on the ends of the young twigs of the rose. In one case a potted rose was kept outside of a window and aphids remained on it until December, even after freezing temperature outside. When brought into the green-house, these terminal aphids might continue to multiply throughout the winter without



reproducing sexually. These facts seemed to show that temperature need take no direct part in the change in mode of reproduction; also that the conclusions drawn from Kyber's experiment were doubtful.

Morgan states, "The continued parthenogenesis of aphids brought into the green-house need not mean that the result is due to removal from the effects of cold, but that those individuals having escaped, so to speak, the influences, whether internal or external, that cause the cyclical change, continue to reproduce by parthenogenesis. Whether, having escaped at the critical period they could ever subsequently be caused to produce the sexual forms, is not known, but there is nothing that we know opposed to such a view."

When the sexual forms appear the leaves have in many cases begun to dry up, or at least to harden so that nourishment may be more difficult to obtain. In the rose aphid the sexual forms are found on the lower, older leaves, while the parthenogenetic individuals are on the terminal young buds and younger leaves. If these are brought into the

green-house they continue to produce parthenogenetically; the leaves of the plants grown under such conditions remain soft, many young leaves are present and the terminal buds continue to grow.

Judging from the results of his experiments, Morgan thought that temperature probably had no direct influence on the life-cycle in the aphids, but that perhaps the change might be connected with conditions of nutrition.

Pursuing this line of investigation, he had an analysis made of the leaves of the rose and of maples in June when the young aphids had just emerged and another late in the autumn when the leaves were old and the sexual forms had appeared. It was found that there was no great difference between the two sets of leaves. In June there was more water, in October, more starch and also a greater amount of ash. Of course there might be many other substances present that differ in amount not brought out by an analysis of this kind.

In spite of the negative results obtained, Morgan sums up his discussion by saying, "The foregoing discussion is not intended to imply that external

conditions are not potent factors in the life cycles of species with alternation sexual and parthenogenetic reproduction. On the contrary, I am prepared to accept such a view despite the negative result of the experiments; but one fact of capital importance has been, I think, overlooked in the interpretation that has been applied to the facts. The results show that whatever the conditions are that bring about the transformation, the change involves the production of both sexual forms, the male and the sexual female; hence the conditions do not determine sex in the sense of producing either males or sexual females., but bring to an end parthenogenetic and introduce sexual reproduction. It follows, I think, with probability that we are dealing with two different things here, and that confusion has resulted from supposing them to be the same."

Morgan's work then has served to show those who are interested in the question of sex determination, that it would be more profitable for them to follow other lines of investigation, but has left the problem of the cause of the change from the parthenogenetic to the sexual cycle practically as it was

before.

In consideration of this question comparisons are made with two other groups of animals, the daphnians and the rotifer, *Hydatina senta*, in which the relation between sex and parthenogenesis is very similar to that in aphids.

In the daphnians the fertilized eggs produce only females while either males or sexual females may be produced from parthenogenetic eggs. Many investigators have worked with this group of animals. Kurz found that by slowly evaporating the water in which a colony of daphnians lived, sexual forms were caused to appear. Schmankewitsch suggested that this was brought about by an increase in the salt content of the water. Weisman concluded that the life cycle in its extent and various phases is the result of an internal mechanism that has become adapted, so to speak, to those conditions that each species is most likely to meet with. Issakowitsch, however, thought that the phases of the life cycle were materially affected by external conditions; that environment largely affected the internal mechanism.

In his experiments, Issakowitsch found that by



keeping the daphnians at a low temperature (24° C.) a great percentage of parthenogenetic females was produced, while at a higher temperature the tendency was to produce more males and winter eggs.

Although his results seem to show that temperature determines sex-production in these animals, Issakowitsch thinks that it acts only indirectly, that these results are brought about in its action in connection with food conditions. He kept two sets of animals under the same temperature conditions, but starved one and fed the other. The starved set produced males and sexual females at once. He concludes then that food rather than temperature alone is the sex-producing factor. From the results of his temperature experiments his conclusion is, "that since at a low temperature the assimilatory activity of the cells is lessened, and since the activity of the growing egg is more intense than that of any other cell, we must conclude that at a low temperature the conditions are unfavorable for nourishment of the egg in the ovary. We expect, therefore, to develop a winter egg or a small male egg."

Keilhack and Strohl rejected Issakowitsch's

conclusions. The Langhans found that external agents did have an effect on the life cycle. Among these agents they placed the excretions of certain daphnians themselves. Woltereck discovered that different species and different lines behaved differently. Some were affected by external conditions easily, while in others the cycle seemed to be determined almost entirely by internal factors.

McClendon believed that starvation, temperature differences, and excretions modified the life cycle. Papanicolau thought that both internal and external factors were responsible for the phases in the cycle. There are, he stated, three different periods in each cycle of the two genera with which he worked. The first generation counting from the resting egg, and a few first broods of later generations are purely parthenogenetic, not to be influenced by external conditions. Some of the late broods of late generations make up another period in which the females have a sexual tendency and no external conditions can make them parthenogenetic. The period of "transition from parthenogenesis to sexuality" comes between these other periods.

During this time warmth induces parthenogenesis, and cold, sexuality.

The life cycle of the rotifer, *Hydatina senta*, resembles in many ways that of aphids. In this all fertilized eggs become females, and these females produce by parthenogenesis a succession of parthenogenetic individuals.

Maupas, in his experiments with this species, concluded that temperature was the factor that controlled the proportion of male-producers. Nussbaum, testing out this theory, obtained negative results and came to the conclusion that temperature was but an indirect factor, food being the chief one. His experiments showed, he thought, that starvation increased the proportion of male-producers.

Punnett, later, trying out both these conclusions could obtain only negative results, but found evidence, as he believed, of strains, each yielding a rather definite proportion of male-producers. He concluded, then, that neither food nor temperature, -external conditions-, influenced the sex of the offspring, but that this was determined by an internal factor, the zygotic constitution.

Whitney made a great many experiments, concluding that Punnett was right in his assertion that food and temperature had no effect on the production of male-producers, but he, Whitney found no evidence of constant strains. He decided that male-producers appeared chiefly in the early part of the family.

Since the results of these various investigators were so conflicting, A. Franklin Shull decided to make a careful reexamination of the whole question. He took up the subject first in a general way. In order "to ascertain the nature of the fluctuations in percentage of male-producers, which might occur without intentional alteration of the conditions by the experimenter" he bred a series under as nearly normal conditions as possible. He found that there was a considerable fluctuation in the percentage of male-producers appearing in one generation and the next, also that there were long-continued periods in which few male-producers appeared, followed by equally long periods in which they were abundant.

In order to fix a standard amount of variation to regard as influenced by any factor it was necessary to find the amount of variation between even closely

related strains reared under the same conditions. He found that the ratio of the higher to the lower percentage of male-producers is often as great as 1.1 to 1.0, therefore, unless the ratio is greater than this it is not safe to infer from a single experiment that the agent in question has any influence. "In case of an agent having but slight effect, this effect should be shown by numerous experiments giving small differences of practically uniform sign."

With these points determined, Shull then set out to prove or disprove the work of his predecessors in the field. He discovered that certain chemical substances were capable of reducing the proportion of male-producers but that their effect is felt only during the growth period of the egg. "Once the egg has reached its full growth, or at least after it has been laid, chemical substances which, when applied throughout life, exclude male-producers are powerless to change the nature of the female hatching from the egg. In like manner, these substances are powerless to affect the nature of a female before the egg from which she hatches begins its growth. So far as these chemical substances are concerned, the fate

of an egg is irrevocably determined in its growth period."

Experiments to determine the influence of temperature gave negative results.

It appears from this review of the work on daphnians and the rotifer, *Hydatina senta* that much more definite results have been obtained with them than with the aphids. This is not strange for it is a much more difficult matter to control the conditions surrounding aphids. Since Aphids live upon the the juices of plants it is no easy task to get different chemical substances into these juices. It is also quite difficult to confine aphids, as they will leave the food plants when the temperature is raised or the food supply is scarce. When they are placed under glass, it is hard to supply enough moisture for the plant without starting a fungous growth which destroys the aphids. By careful watching, however, the latter difficulties may be surmounted. The former, though, that of changing the sap content, can only be experimented upon.

APHID USED, GREEN BUG.

The aphid used in these experiments was Toxoptera graminum, (the green bug, Spring Grain Aphis, etc.). In order to determine the results of these experiments it was first necessary to know the various forms of this aphid, especially the intermediate or transitional forms which appear at or before the time that the sexual forms are being produced.

The best description of these, extant, is given in "The Green Bug and Its Natural Enemies", by S. J. Hunter.

"Ordinarily the only forms present are the apterous agamic females and the Winged migrants; but at the time when the sexual forms are being produced, marked variations take place, and aside from the forms above mentioned, and the males and the true females, three more or less distinct intermediate forms appear.

The chief characteristics which distinguish the different forms are: the number of sensoria on the hind tibia, and on the third, fourth and fifth joints



of the antennae, the presence or absence or degree of prominence of the ocelli, the shape of the hind tibia, the contents of the body, and the presence, absence or degree of development of the wings.

Based on these characteristics, for the purpose of this discussion, eight forms are named, five of which are distinct and three of which are intermediate forms. They are as follows:-

1. Apterous agamic females.
2. Winged agamic females,
3. Winged intermediate females, resembling the winged agamic females in antennal characteristics.
4. Winged intermediate females, resembling the true female in antennal characteristics.
5. Apterous intermediate females.
6. True females.
7. Males.
8. Stem mothers.

From a series of tables compiled from the study of a great number of specimens of each of the first seven forms it was found that all forms had a single (large) sensorium on the sixth joint of the antennae with a cluster of from four to six smaller ones about its margin; one (large) terminal sensorium on the

fifth joint, and , with the exception of the males, have no sensorium on the fourth joint.

The apterous agamic female has no sensoria on the third joint of the antennae, no sensoria on the hind tibia, no ocelli, has the hind tibia slender, and young in various stages of development are plainly visible in the body, when mounted under a cover glass.

The winged agamic female has from four to seven sensoria on the third joint of the antennae, has none on the hind tibia, three prominent ocelli, the hind tibia are more slender than in the apterous agamic forms , the wings are normal, and the young are plainly visible in the body under a microscope.

In these two forms the characteristics are surprisingly stable throughout the greater part of the year when we consider the great variations which suddenly occur in the fall when the intermediate and sexual forms are being produced. At this time, the fall, notable irregularities appear in the otherwise regular structure of the two above described forms. These irregular aphids are here known as intermediate forms.

These intermediate forms, though divided into three classes, present nearly all gradations between the agamic and the oviparous forms.

The winged intermediate form, resembling the winged agamic form in antennal characteristics, has from two to five sensoria on the third joint of the antennae. The hind tibia vary in form; they may be thickened, as in the true female, or be slender, as in the winged agamic form. When the tibiae are thickened they possess from none to thirty-nine sensoria. This form has three ocelli, nearly or quite as prominent as in the winged agamic female. The body in some individuals contains only young, but in others both young and winter eggs. The wings are reduced; in some cases only one branch of the third discoidal is lacking, in others the wings are crumpled or rudimentary.

The winged intermediate form, resembling the true female in antennal characteristics, is similar to the one above described, except that the resemblance to the true female is more marked. There are no sensoria on the third joint of the antennae. The posterior tibia are all thickened and have from

5 to 66 sensoria. The ocelli are usually inconspicuous or wanting, the body may have only young or both eggs and young, and the wings are greatly reduced, being in most cases only rudimentary.

The apterous intermediate form resembles the true female in all external characteristics, but is distinguished from the true female by the fact that the body contains only young or both young and eggs.

The winged intermediate forms stand between the winged agamic form and the true female, and the apterous intermediate form stands between the apterous agamic form and the true female.

The true female resembles the apterous agamic form in external characteristics, except that in the true female, the hind tibia are conspicuously thickened and possess from thirty to fifty-five sensoria. The body is more robust than in the viviparous forms and the eggs showing through the body wall give the body a lighter color. The bodies of all the intermediate forms are robust, as in the true female, but are not so light a green owing to the fact that the body contains young as well as eggs.

The male which was described by Professor Glenn resembles in a general way the winged agamic form, but is smaller, the abdomen does not exceed the thorax in width, and is nearly uniform in width throughout its length. The third joint of the antennae bears from twelve to twenty-two sensoria the fourth from nine to sixteen, the fifth from nine to twenty-seven.

The stem mother is wingless, resembling somewhat the oviparous female. The body is robust, the abdomen somewhat distended, the color is a velvety yellowish green, darkened in spots by the eyes of the young which show through the body wall. The antennae are nearly a third shorter than those of the other forms."

#### Food Plants.

The green bug feeds upon quite a variety of plants among which are, wheat, oats, rye, barley, spelt, corn and a number of grasses. It is also reported as having been found on sorghum.

STUDY OF INFLUENCE OF FOOD.

The problem first taken up was to determine what effects food, both in quantity and character, has on the growth and development of the so called green bug, *Toxoptera graminum*, with special reference to the change from the parthenogenetic to the sexual mode of reproduction.

The food plant used was wheat.

The stock from which the aphids were taken was brought into the laboratory in the spring of 1907 and reared there under careful observation since that time. All forms have appeared. No progeny of stem mothers has been added to the stock, since its introduction into the laboratory, therefore, it may be said to be of parthenogenetic line.

Assuming that chemical solutions might be drawn up into the plant with the sap, the wheat was given various chemical solutions in place of the usual moisture.

These solutions were prepared by taking, for a normal solution, as many grams of the salt as its molecular weight to 1000cc of distilled water. For a decinormal solution the weight was divided by ten

to find the number of grams to be used, etc.

Following is the table used:

Solution	liters water	Grams. Salt.
NaCl solution (deci)	2	11.68
Sugar " (normal)	2	78.4
Ammonium nitrate (deci)	2	11.6
Lithium nitrate (deci)	2	13.7
Iron Sulphate (deci.)	2	15.2
Calcium nitrate (deci.)	2	8.25
Magnesium chloride( " )	2	9.53

The Nutrient solution strong was made by taking 8 grs. Ca No<sub>3</sub>, 2 grs. K No<sub>3</sub>, 2 grs. Mn So<sub>4</sub>, 2 grs. Potassium phosphate in 100 cc water and boiling till dissolved, then adding 2 liters distilled water.

### METHODS

Wheat was sprouted by soaking in hydrant water, then planted in pots of good clean dirt. As soon as the little green shoots appeared above the surface of the earth, the pots were taken, numbered to correspond with the experiments and watered from that time on with the solutions used in these experiments. When the work was begun 10cc of the solution was applied daily, but it soon became apparent that this gave too much moisture, causing a fungous growth which was fatal to the green bugs. Therefore, 15 cc. was given every other day or when it was hot and dry four times a week.

The breeding cages for the insects were composed of lamp chimneys that fitted down over the wheat stalks into the earth in the pots. The tops of these were covered with cheese cloth held in place by rubber bands. These chimneys were washed carefully each time before being used on a new experiment.

The pots were arranged on long tables in a first floor laboratory having a south exposure.



Two tables were used, one for each series of experiments. Back of each experiment was kept a second pot for a reserve food supply. This was treated just as the experiment. The sunshine was not allowed to come directly upon these plants, for it was found that the moisture which collected on the wheat blades and glass aided the injurious fungous growth. Plenty of light was admitted by shading the windows with white cloth curtains.

When the green bugs had sucked the juices from the plants until they began to turn yellow, the blades were cut off close to the ground and placed in the reserve food pot so that the insects might crawl on to the fresh blades. Then another pot of freshly sprouted wheat was placed in the reserve line. The dirt from the experimental pots was never used for a second experiment, and the pots were all carefully scrubbed before being used again.

The experiments were examined carefully each day and observation fully noted. In this paper, however, I have briefly summarized them by months, noting the general condition and anything out of the ordinary. The stock boxes were also observed daily

and comparisons made.

The first and second experiments deal with the quantity of the food. Number I, or the Drouth Experiment as it is called for convenience, was to test out the supposition that when the food plant begins to dry up and the supply becomes scarce, winged forms are produced.

Number II, or the Excess Moisture Experiment, might perhaps be more accurately called "The abundant food Supply experiment". The object of this was to see whether winged forms could be excluded by a superabundance of food supply.

The remiaining fifteen experiments were treated with the various recorded chemical solutions.

EXPERIMENT NO. I. -Drouth

Period of experiment, January 17, 1910 to  
December 19, 1910.

A newly born green bug was taken from the general stock and placed on wheat that had not been watered for several days. On January 25th five more young green bugs were added and on the 26th two more.

In this experiment hydrant water was used to moisten the plant. The water was applied very sparingly, barely enough to keep the blades of wheat from shriveling up at once.

When the food supply was entirely exhausted, the bugs were transferred to wheat that was already yellowing for lack of moisture.

Observations summarized by months:

- January. - Bugs matured very slowly.
- February.- Both winged and apterous forms present.  
Reproduction slow.
- March. - Both winged and apterous forms present.  
All normal.
- April. - Both winged and apterous forms present  
though not numerous.
- May. - Apterous forms very numerous. Some  
winged forms.
- June. - Both winged and apterous forms found.

- July. - Forms gradually became less numerous. Very few winged forms present.
- August. - Forms very scarce. A few winged ones present.
- September.- Number began to increase. Some winged forms.
- October. - Forms few in number but proportion of winged ones large.
- November. - Forms still scarce and proportion of winged ones small.
- December. - Forms very scarce. Very few winged ones present.

EXPERIMENT NO. II. - Excess Moisture.

Period of experiment, February 21, 1910 to December 19, 1910.

A number of green bugs were placed on a pot of wheat that had just been given as much water as the soil would absorb.

Hydrant water was used in this experiment and was applied two or three times a day, or as often as necessary to keep the soil soaked.

Under this treatment the wheat grew rank.

Observations summarized by months:

- March. - Green bugs reproduced rapidly. Very few winged forms were present.
- April. - Winged forms became very numerous.

- May. - Both apterous and winged forms were moderately numerous throughout this month.
- June. - Forms were numerous. Both winged and apterous forms were present.
- July. - The number varied during this month. At first they were numerous, then rather scarce, very scarce and increasing again to numerous. Both apterous and winged were present though percentage of apterous was greater.
- August. - At this time it was difficult to keep the stock alive on account of fungous disease.
- September.- Forms were numerous. Both winged and wingless were present in numbers.
- October. - Forms quite numerous. Winged and wingless, both present.
- November. - Still quite numerous.
- December. - Forms moderately numerous. Both apterous and winged present.

EXPERIMENT NO. III. - Cane Sugar Normal.

Period of Experiment, January 19, 1910 to  
December 19, 1910.

A newly born green bug from the general stock was placed on a stalk of wheat that had been sprouted and watered with hydrant water.

From the time the experiment was begun the solution used to moisten the plant was the Cane Sugar normal solution.

The wheat plants did not thrive very well on this solution.

Observations summarized by months:

- January. - Experiments well started. No winged forms.
- February. - First winged form found February 7th. Bugs not very prolific. Winged forms scarce.
- March. - Winged forms very numerous. Normal.
- April. - Both winged and apterous forms present. April 20th, on check, intermediate form found.
- May. - Forms numerous. Winged forms have shorter wings.
- June. - Forms very numerous. Proportion of winged forms not very large.
- July. - Forms small. Reproduction slow. Some winged forms present.
- August. - Adults were darker in color and almost ceased to reproduce.
- September.- Forms began to increase and became quite numerous. Some winged forms present.

- October. - Both winged and apterous forms numerous.
- November. - Many small migrants present.
- December. - Forms numerous. Both winged and apterous present.

EXPERIMENT NO IIIa. - Dark Brown Sugar, normal.

Period of experiment, May 10, 1910 to December 19, 1910.

Several half grown green bugs were taken from the Cane Sugar Normal experiment and placed on a pot of young wheat plants.

In this experiment Dark Brown Sugar solution was used.

The wheat did not thrive with the solution. It was difficult to keep the stock alive on account of the poor condition of the wheat.

Observations summarized by months:

- May. - Forms numerous.
- June. - Forms scarce.
- July. - Forms very scarce.
- August. - Forms small and scarce.
- September.- Very few forms present.

- October. - Few forms present. Both winged and wingless forms found.
- November. - Few forms present. Very few winged forms found.
- December. - Forms seemed to be in slightly better condition though not very numerous.

EXPERIMENT NO. IIb. - Beet Sugar 2x Normal.

Period of experiment, May 12, 1910 to December 19, 1910.

Some winged forms and some apterous forms were taken from those on wheat in Experiment III, Normal Sugar, and placed on a plant that had previously been sprouted and watered with hydrant water.

In this experiment Beet Sugar 2x Normal solution was used.

The wheat did not thrive with this solution.

Observations summarized by months:

- May. - Forms scarce. Very few winged forms present.
- June. - Forms small and not very numerous.
- July. - Moderately numerous. Both winged and wingless present.
- August. - Forms scarce, adults dark in color.



September.- Forms moderately numerous.

October. - Few winged forms present. Two or three intermediate forms found.  
Oct. 31, True female found.

November. - Forms small and scattered, very few winged forms present.

December. - Number increased. Both winged and apterous ones present.

EXPERIMENT NO. IIIc. - Cane Sugar 2x Normal.

Period of experiment, May 12, 1910 to December 19, 1910.

Removed several apterous and winged forms from experiment III in which the Cane Sugar Normal solution was being used and placed them on a pot of wheat that had been grown in the laboratory.

The solution used in this experiment was Cane Sugar 2x Normal.

The wheat did not thrive at all on this solution.

Observations summarized by months:

May. - Green bugs numerous.

June. - Forms scarce. Very few winged ones present. All normal.

July. - Forms moderately numerous. Proportion of winged ones large.

- August. - The adults dark in color. Winged forms small. All forms very scarce toward end of month.
- September.- Scattering at first of month but increasing until quite numerous. Both winged and apterous present.
- October. - Forms not very numerous, Oct. 12, found true female.
- November. - Moderately numerous. Many small winged forms.
- December. - Forms small, not very numerous. Very few winged ones present.

EXPERIMENT NO. IIId. - Beet Sugar Normal.

Period of experiment, May 27, 1910 to December 19, 1910.

A number of apterous forms of the green bug were taken from those in Experiment III, normal solution of Cane Sugar, and placed on some stalks of wheat.

The solution used in this experiment was Beet Sugar Normal.

The wheat in this as in the other sugar experiments did not thrive.

Observations summarized by months:

- May. - The experiment was but well started.

- June. - Green bugs rather scarce at first, but increased until moderately numerous.
- July. - Both apterous and winged forms present. Numerous and normal.
- August. - Both apterous and winged forms numerous. Adults darker in color.
- September.- Forms scarce.
- October. - Forms not very numerous. Both winged and apterous present.
- November.- Forms moderately numerous. Very few winged ones found.
- December. - Forms numerous. Winged ones small.

#### EXPERIMENT NO. IV. - Salt.

Period of experiment, January 19, 1910 to December 19, 1910.

A number of green bugs were taken from the general stock and placed on a pot of wheat.

A salt solution was used in the experiment.

Wheat thrived fairly well with this solution.

#### Observations summarized by months:

January. - Experiment but well started.

February. - Both winged and wingless forms of greenbug present. Reproduction slow.

- March. - Both winged and wingless forms quite numerous.
- April. - Both kinds quite numerous.
- May. - Forms very scarce.
- June. - Forms still scarce.
- July. - Forms still scarce but increasing slowly. July 28, experiment removed to south east basement laboratory where temperature was 4 or 5 degrees lower than in first floor laboratory.
- August. - Forms scarce at first but increased rapidly. Returned to first floor laboratory on August 20th.
- September. - Forms numerous. Both winged and apterous present.
- October. - Forms very numerous. Winged forms very small.
- November. - Forms very numerous and small. Winged forms scarce.
- December. - Forms numerous. Winged ones scarce.

EXPERIMENT NO. V. - Soil Filtrate.

Period of experiment, January 25, 1910 to  
December 19, 1910.

Green bugs for this experiment were taken from  
the general stock.

The solution used was soil filtrate.

Wheat was always in good condition with this  
solution.

Observations summarized by months:

- January. - Experiment but well started.
- February. - Winged forms numerous. Reproduction  
slow.
- March. - Forms not normally prolific.  
Winged ones scarce.
- April. - Forms numerous. Proportion of  
Winged ones large.
- May. - Forms scarce. Almost no winged  
ones present.
- June. - Forms numerous but winged ones scarce.
- July. - Forms scarce. July 28th removed  
experiment from first floor laboratory  
to south east basement room where  
temperature was 4 or 5 degrees cooler.
- August. - Forms still scarce. Few winged ones  
present. On August 20th experiment  
was returned to first floor laboratory.
- September.- Number increased considerably.

- October. - Number few. Winged forms scarce.  
One intermediate.
- November. - Number few. Winged ones scarce.
- December. - Number increased rapidly. Both  
winged and apterous forms present.

EXPERIMENT NO. VI. - Lithium nitrate

Period of experiment, January 25th, 1910, to  
December 19, 1910.

Green bugs used in this experiment taken from  
general stock.

Lithium nitrate solution used to moisten plant.

Wheat appeared to be in good condition.

Observations summarized by months:

- January. - Stock well started.
- February. - Bugs seemed not normally prolific.  
Both winged and apterous forms  
present most of the time.
- March. - Normal in all ways. Both winged  
and wingless present all of time.
- April. - Winged forms seemed to be more  
productive than apterous.
- May. - Normal. Forms did not reproduce  
as rapidly as at some times and  
winged ones were not so numerous.
- June. - First week all forms disappeared from  
experiment and check though plants  
seemed to be healthy. Started

experiment again with more green bugs from general stock. Forms scarce throughout entire month. Difficult to keep stock alive.

- July. - Forms scarce throughout. Probably due in great part to heat.
- August. - Forms not at all numerous.
- September.- Number increased. Winged forms present.
- October. - All normal.
- November. - Forms all small. Few intermediates and one true female found.
- December. - Both winged and wingless forms moderately numerous.

#### EXPERIMENT NO. VII. - Nutrient solution.

Period of Experiment, January 26, 1910 to December 19, 1910.

Placed three young green bugs from the general stock on wheat grown on a sponge in solution.

Solution made of 150 grams of distilled water and 1 cc. nutrient solution.

Wheat strong and healthy.

#### Observations summarized by months:

January. - Experiment well started.

February.- Forms all apparently normal. Both winged and wingless ones present.

- March. - - Winged forms more numerous.
- April. - Both winged and apterous forms present and numerous. April 22, noticed one form with imperfect wing development.
- May. - Both winged and apterous forms numerous. On the 26th some winged ones seemed undersized.
- June. - Both winged and wingless forms very numerous.
- July. - First of month forms quite scarce but latter part quite numerous.
- August. - From 1st to 20th forms were numerous and normally reproductive. August 22nd forms were at a standstill, no winged ones, some of the apterous adults were dark colored. August 24, only a few adults remaining and they were dark colored. August 26th, the adults remaining were beginning to reproduce. August 31st, all forms had disappeared. Took several forms from check and started experiment anew.
- September.- Number gradually increased.
- October. - Forms normal, numerous. Many migrants present.
- November. - Both winged and apterous very numerous. Some of the winged ones seemed small.
- December. - Both winged and apterous numerous.



EXPERIMENT NO. VIII. - Ferrous amonium sulphate.

Period of experiment, March 30th, 1910 to December 19, 1910.

Several adult and young green bugs were taken from the general stock and placed on a pot of young wheat stalks.

Ferrous amonium sulphate was the salt solution used in this experiment.

Wheat appeared to grow normally with this solution.

Observation summarized by months:

- March. - Experiment started.
- April. - Forms normally reproductive. Number increased throughout month. At close both winged and wingless numerous.
- May. - Both winged and wingless present. All normal.
- June. - All normal, Both winged and apterous present.
- July. - First of month, forms very numerous. Last of month forms scarce.
- August. - Removed experiment to basement laboratory where temperature was 4 or 5 degrees lower than in first floor room. Forms began to increase, but scarce throughout month. August 20th removed plant to first floor laboratory again.

September.- All forms normal. Number increased.

October. - Did not reproduce so rapidly. On 31st on check experiment found four intermediates and one male.

November. - Winged forms scarce. Number gradually increased.

December. - Normal. Increase slow. Very few winged ones present.

#### EXPERIMENT NO. IX. - Amonium nitrate.

Period of experiment, January 27, 1910 to December 19, 1910.

Two adults and two young green bugs were taken from the general stock and placed on a pot of wheat stalks grown in the laboratory.

Amonium nitrate solution was used in this experiment.

Plants seemed to absorb this solution very rapidly, thus requiring more frequent moistening.

#### Observations summarized by months:

January, - Experiment well started.

February, - Bugs normally prolific, became numerous. Very few winged forms present.

March. - Reproduction less rapid. Winged forms present throughout month though not very numerous.

April. - Forms scarce, few winged ones present.

- May. - Increased slowly. Both winged and wingless forms present.
- June. - Not very numerous. Reproduction slow. Both winged and wingless forms present.
- July. - Both winged and apterous forms present though not very numerous. On the 28th removed to basement laboratory where temperature was 4 or 5 degrees lower.
- August. - Forms scarce. Increased slowly. August 20th returned again to first floor laboratory. Last of month forms very plentiful.
- September.- Apterous forms numerous but winged ones scarce.
- October. - All forms normal.
- November. - Forms numerous. Few winged ones present.
- December. - Forms numerous. December 9th took experiment to attic laboratory where nights were colder. Reproduction nearly ceased. Adults dark in color.

EXPERIMENT NO. X. - Calcium nitrate.

Period of experiment, February 8, 1910 to  
December 19, 1910.

Several young and partially grown green bugs were taken from the general stock and placed on a pot of young wheat stalks.

A solution of calcium nitrate was used in this experiment.

Wheat did not grow as well as when watered with hydrant water.

Observations summarized by months:

- February. - Forms all normal. Winged forms present.
- March. - All normal. Some winged forms throughout month.
- April. - Reproduction appeared less rapid. On the 22nd of the month found three forms with twisted wings.
- May. - Forms less numerous, small in size. Winged forms scarce.
- June. - Number gradually increased until last week when they became scarce. Winged ones present throughout the period though small in proportion to apterous ones.
- July. - Forms numerous. On the 28th of month removed experiment to basement laboratory where temperature was 4 or 5 degrees lower.
- August. - Forms numerous and normal. Some winged ones present. On 20th returned to first floor laboratory.
- September.- Still numerous. Both winged and apterous present.
- October. - Normal, less numerous.

November. - Forms few and small. Very few winged ones present.

December. - Number slightly increased. Dec. 9th removed one true female.

EXPERIMENT NO. XI. - Manganese sulphate.

Period of experiment, March 30, 1910 to December 19, 1910.

Several adult and some young green bugs were taken from the general stock and placed on a pot of young wheat stalks.

A solution of Manganese sulphate was used in this experiment.

Wheat seemed to grow normally with this solution.

Observations summarized by months:

- March. - Experiment started.
- April. - Many winged forms present.
- May. - Forms very numerous. Few winged ones present.
- June. - Forms moderately numerous. Few winged ones present.
- July. - For greater part of month forms very numerous. Last week reproduction ceased. Many adults died.
- August. - First week forms very scarce. Adults dark colored, reproduction slow, Last part of month increase in numbers.

September.- Increase more rapid.

October. - Forms moderately numerous. Winged ones scarce.

November. - Reproduction slow. Winged forms scarce.

December. - Increase more rapid. Winged forms still scarce.

#### EXPERIMENT NO. XII. - Iron sulphate.

Period of experiment, From May 5, 1910 to December 19, 1910.

A number of apterous forms of the green bug were taken from the general stock and placed on a pot of young wheat stalks.

In this experiment a solution of iron sulphate was used.

Wheat was generally in a poor condition.

#### Observations summarized by months:

May. - Both apterous and winged forms numerous.

June. - Forms numerous during first part of month, but last week they became scarce. Very few winged ones were found.

- July. - Forms increased but slowly. Almost no winged ones were found. On the 28th experiment was removed to basement laboratory where temperature was 4 or 5 degrees lower than in first floor laboratory.
- August. - Forms very scarce. August 20th returned experiment to first floor laboratory.
- September.- Number increased slowly.
- October. - Forms moderately numerous. On 21st on check one true female was found.
- November. - Forms scarce and small. Very few winged ones present.
- December. - Forms moderately numerous. Few winged ones present.

EXPERIMENT NO. XIII. - Magnesium chloride.

Period of Experiment, from February 8th, 1910 to December 19, 1910.

Several adult green bugs and a few young ones were taken from the general stock and placed on a pot of young wheat stalks.

A solution of magnesium chloride was used in this experiment.

Wheat fairly healthy with this solution

Observations summarized by months:

- February. - Forms moderately numerous. Both apterous and winged ones present,



- March. - Winged forms very numerous. Both apterous and winged forms. On the 1st, found one crumpled winged form.
- April. - First of the month winged forms few, After 27th they became numerous.
- May. - Forms scarce, gradual increase toward close of month.
- June. - Both winged and apterous forms moderately numerous.
- July. - Forms moderately numerous. On the 28<sup>th</sup> experiment removed to basement laboratory where temperature was 4 or 5 degrees lower.
- August. - Forms moderately numerous. Both winged and apterous forms present but winged ones scarce. On 20th returned to first floor laboratory.
- September.- Both apterous and winged forms extremely numerous.
- October. - Forms numerous. Proportion of winged ones large.
- November. - Forms few and small. Winged ones scarce. On November 1st found one true female.
- December. - Forms scarce and small.

S U M M A R Y.

1. The wheat showed clearly the effect of the different treatments.
2. food plants were constantly being renewed so that the wheat never became as old as that in the fields in the fall.
3. Winged forms appeared throughout, apparently irrespective of the amount or character of food supply.
4. Sexual forms, with one exception, appeared on experiments at about same time as on the stock boxes in laboratory.
5. On April 20th, on experiment No. III (Cane Sugar normal) there appeared an Intermediate form, wings crumpled, sensoria on tibia, a few sensoria on antennae, tibia swollen, no eye-spots visible in body.
6. Sexual forms did not appear uniformly on all of the experiments but this can not be considered as significant since in the regular stock boxes, the same season, true sexes and intermediate forms were very few and could be found only after diligent search. It may be stated here that the number of

sex forms appearing on the stock in the laboratory has decreased with each year since 1907.

7. During the time of appearance of sexual forms, while the other experiments as well as the stock showed a marked decrease of agamic forms, the nutritive solution experiment and the excessive moisture experiment continued to reproduce in undiminished numbers.

8. Sex forms did not appear in any certain generation.

DISCUSSION.

The wheat plants in the various experiments showed clearly the effect of the different treatments. Those moistened with the several sugar solutions did not thrive, while those treated with the nutritive and soil filtrate solutions grew strong and abundantly. Most of the other experiments appeared quite normal. It would seem then that the various solutions might, in some degree at least, have netered into the sap of the plants.

It has been suggested that the aging of the food has a potent influence on the changes in the mode of reproduction of aphids. This factor can scarcely be considered as entering into the experiments performed, for the food plants were constantly being renewed. The aphids sapped the wheat so quickly that the plants never attained the age of those in the fields in the fall. This condition was likewise true of the stock boxes in the laboratory. However, every year since the stock was brought into the laboratory on these stock boxes and also on the experiemts sexual forms have appeared at practically the same season as in the fields.

It is true the sexual forms did not appear uniformly on all of the experiments but this can not be considered as a significant fact for they were scarce on the stock boxes as well. It seems that each year, since brought into the laboratory the number of sexes appearing has decreased and this season the true sexes and intermediate forms could be found only after diligent search.

During the time of the appearance of sexual forms it is noticeable that there is a marked decrease in the number of agamic forms. This was true in the experimental pots with the exception of the nutritive solution experiment and the excessive moisture experiment. In these reproduction continued in undiminished numbers., It will be noticed that the nutritive experiment was a suspension experiment and, therefore, might also be considered one in which an excess amount of moisture was used. The wheat in these pots was always young and tender.

It has been stated that winged forms appear when the food supply becomes scarce, in order to continue the species by their ability to fly to fresh fields. This statement, however, was not

substantiated in these experiments. Winged forms appeared throughout, apparently irrespective of the amount of food supply. On the excess moisture and nutritive experiments where the food was abundant winged forms were always to be found as on the other experiments.

All observations go to prove that Intermediate forms are produced at the same time and, therefore, probably by the same forces or conditions as the true sexes. On April 20th one intermediate was found on the Cane Sugar normal experiment. This one example is not sufficient evidence from which to draw any definite conclusions.

Apparently, after all these experiments, we are no nearer our goal, no nearer to finding out what factor is the potent one in causing the transition from the parthenogenetic to the sexual mode of reproduction. We know, though, that food can at most be but an indirect agent in this problem.

## STUDY OF INFLUENCE OF TEMPERATURE.

The bearing of temperature upon the growth and development of insects may be discussed from two points of view: first, its direct influence upon the insects themselves and, second, its indirect action in changing the food content of the host plant.

### Direct Influence of Temperature Upon Insects.

Sanderson in his paper upon the relation of temperature to the growth of insects reviews clearly the work which has been done on establishing a "thermal constant" that is "that accumulation of mean daily temperature above the 'critical point' of the species which will cause it to emerge from hibernation or to transform from any given stage."

From the work of others and his own experiments he shows that there is no uniform minimum above which the temperature may be accumulated as effective, but this varies with each species and phase of growth. As far as a mere accumulation of temperature is concerned there seems to be no "thermal constant". The velocity of reaction varies according to, the range of temperatures.

Sanderson reduced his reviews to curves showing the relation of temperature to the various stages in the life cycles of a great many insects and found that the eggs and pupae where they exist under similar conditions are similarly affected by temperature, while the active larvae is much more quickly influenced by changes of temperature.

In making exact determinations of the effect of temperature the moisture conditions must be kept constant for with many species moisture has as much or more influence than temperature in determining the optimum for development.

Standfuss produced moths in autumn from insect pupae which normally hibernate, by applying to the latter abundant humidity after they had been kept for a long period in a very dry condition. 200 to 400 pupae of Saturnia were kept from June to the end of September in a very dry atmosphere and then thoroughly moistened a few times at short intervals and about 1 % of such pupae emerged, which under normal conditions would not happen before the following May.



The various activities of insect life show their close relation to temperature when curves are platted. Bachmetjew has platted a number of these. Regener gave data of the amount of food eaten by the larvae of *Dendrolimus*, showing its connection with the temperature. Curves have also been made from observations by Tichomirow on the rate of the pulsation of the heart of the silk worm. These illustrate the same general relation of temperature to the rate of growth and activity.

Bachmetjew, in his *Experimentelle Entomologische Studien*, has made a great many observations on entomological phenomena. In the first part he took up only the relation of low temperatures to insect life, in the second part, however, he discusses the whole range of temperature as related to insect activity and "brings out the relation of the time and temperature factors with great clearness." Sanderson gives an excellent summary of his views thus:

"For every species there is a certain range of

temperature, K to W, in which it is normally active. At a certain point its growth or activity is most rapid, an increase or decrease of temperature from this point alike resulting in retarding the growth or activity. This point is the optimum. When the upper temperature limit of activity is passed, at W, heat-rigor ensues. If the heat be increased to a point A, death will result in a short time. This point is known as the maximum. A temperature above the maximum may be endured for a short time before death, but if the insect is brought to a temperature of B death is practically instantaneous due to the coagulation of certain proteids of the protoplasm. Although heat-rigor occurs at any point above W, the effect of it is due to the length of time of the exposure. Thus a varying length of exposure, according to the amount of temperature, as long as the temperature remains below the maximum A, will not kill the organism if it be returned to normal temperature, while it will die if it be maintained at a constant temperature above W. Metabolism does not necessarily cease during heat-rigor at temperatures above W, but

is greatly retarded."

"If the temperature is lowered, then at a point K, cold-rigor sets in and activity ceases. If it be cooled below freezing to a point T, termed the "critical point", the internal heat of the insect rebounds to a point  $N_2$ . But if the body temperature again falls below the critical point, as at  $T_3$ , then death ensues. If after the critical point has been reached and the rebound occurs, the insect be removed to normal temperatures, it will usually revive, depending upon the length of time it has been under-sooled. As in heat-rigor, metabolism does not cease at temperatures producing cold-rigor, though no activity is apparent, but below a point  $T_2$ , all metabolism ceases. Death at low temperatures is held to be due to molecular rearrangement and mechanical injury, whereas death at high temperature is due to chemical changes in the proteids. The relation of both excessive heat and excessive cold is, therefore, seen to depend upon the time involved and the rapidity with which the organism is cooled or heated and with which it is subsequently brought back to normal temperatures."

Davenport brought out these same facts in regard to both plants and animals. Other investigators, working independently have proven practically all of the points worked out by Bachmetjew but no one has brought them together as completely as he.

The question of the determination of minimum and maximum points for the various species of insects is of great importance to the economic entomologists, who seek thus to find a means of controlling insect pests.

Dr. L. O. Howard determined the points of cold-rigor and the minimum for several household pests with a view to turning this knowledge to practical account in the prevention of insect injury in cold storage.

Professor Dean has used the maximum or high temperature data in ridding mills of their insect pests. Indeed recent investigations seem to favor the idea that continued high temperatures are more uniformly fatal to insects than low ones. There is, however, a field for further investigation along both of these lines.

Since it is proven beyond a doubt that

temperature has a powerful influence on the length of the periods of development, upon the amount of food eaten by insects, on the very workings of the insect organism - on the pulsation of the heart - it seems not at all improbable that it may exert an influence on the more obscure mechanisms that take part in the change from parthenogenesis to gamogenesis.

The green bug, like all insects is greatly influenced by temperature. The history of all the destructive outbreaks of this insect when studied in connection with temperature records goes to prove that they are closely dependent upon the weather conditions. Professor P. A. Glenn gives a very complete discussion of this point in his paper on "The influence of climate upon the Green bug and its parasite". He concludes thus: "In conclusion, we may say that the green bug, aside from being at the mercy of its many natural enemies, has a very precarious existence on account of climatic conditions. It cannot endure the high temperatures which prevail in summer, or the low temperatures which prevail in winter in most of the

grain-growing sections. For this reason it is confined to the temperate zone, and then chiefly to those regions bordering large bodies of water, where the great extremes in summer and winter do not occur, rather than to inland regions."

"But it does manage to exist. However unfavorable the climatic conditions may be over a region in general, some local conditions somewhere will enable a few to survive here and there, and when more favorable conditions come these will soon be able to restock the depleted section, and when a cool moist summer is followed by an exceptionally mild winter they will, in the absence or scarcity of their natural enemies, be able to appear in such numbers the following spring as to merit the descriptive title, 'Destructive Outbreak'."

As was mentioned before the green bug has been under observation in this laboratory since the Spring of 1907. During this time a great many experiments have been performed along various lines. Professor Hunter has kindly allowed me to use all data bearing upon temperature in relation to the varied activities of the green bug.

In December many young were isolated for the purpose of ascertaining the length of the period of development in the winter months, but not one of them was reared to maturity. They either died, escaped or were lost before maturing. It is evident, however, that the period of development is greatly prolonged by cold weather. This was apparent from one of the experiments. Four young, born on December 17 were observed. One cast its first moult December 27, and the other three December 30. One cast its second moult January 20, another on January 25 and the other two January 27. February 7 two were lost while transferring them to a new plant. On February 10 one of the two remaining cast its third moult. On February 18 a storm blew the tent away and the bugs were lost. So in the case of these four we have:

Number of days from birth to first moult,  
minimum 10, maximum 13.

Number of days from birth to second moult,  
minimum 34, maximum 41.

Number of days from birth to third moult,  
minimum 55, maximum not ascertained.



From these facts it may safely be estimated that the period of development of these individuals would have been from seventy-five to ninety days had observation continued till they had cast their fourth moult. In other words, young born the middle of December would have matured from the first to the middle of March.

The first one reared in the field was born March 10 and matured March 28 or in 18 days. Three others, born March 31, matured April 17, or in 17 days.

The mean temperature from December 17 to March 1 was 35 degrees Fahrenheit. The mean temperature March 10 to April 28 was 56 degrees Fahrenheit, and the mean from March 31 to April 17 was 58 degrees Fahrenheit.

The length of life, period of reproduction, total number of young and average number of young produced daily by each individual for January and February, and also for March, April and May, are shown in the following summaries:



Summary for January and February.

A	Number of Experiment.					To- tals.	Aver- age.
	8B	9B	10B	11B	12B		
Length of life.....	34	69	69	51	38	261	52.2
Reproduction period	23	52	52	30	26	183	36.6
Total number young.	15	14	26	7	7	69	13.8

Average daily number of young for each individual during the reproductive period, 0.374.

Mean temperature for the period, 35° F.

Summary for March, April and May.

	Number of Experiment.										To- tals	Aver- age.
	13A	14A	15A	16A	17A	18A	19A	20A	21A	22A		
Length												
Life..	53	60	84	59	61	59	74	48	50	dis.	548	60;9
Period												
Repro..	30	50	49	46	45	41	42	24	29	31	387	38.7
Number												
Young..	59	60	45	66	81	42	53	30	55	84	575	57.5

Average daily number of young for each individual during reproductive period, 1.5.

Mean temperature for period, 58° F.

The individuals in experiments from No. 13B to 20A were reared in the laboratory, hence the period of development was much shorter than it would have been had they been reared in the field, and the length of life shown in the summary is less than it would be under natural conditions.

During summer temperature in the experimental laboratory the average length of life, based on continuous observation, from birth to death of 15 green bugs, was 35.22 days; average number of offspring, 55.42; average period of reproduction, 22.74 days; average number reproduced daily during reproductive period, 2.43; age at which reproduction begins, 7.1 days; number of moults, 4.

This data was corroborated in an observation upon 54 green bugs selected at various ages and kept under similar conditions.

The rate of reproduction in the winged forms appears to be about the same as in the wingless forms. The same ratio of reproduction and time of development attended those experiments conducted in the field and kept under observations during the same period.

During January and February, mean temperature 35 F., the average daily number of young for each individual during the reproductive period was .374; during March and April, mean temperature 58 F., 1.5 during the reproductive period. Laboratory experiments from January to May, mean temperature 62.32 F., gave results corresponding to those of summer temperatures in the field and laboratory.

The lowest temperature at which offspring appeared during a day recorded maximum 36 F., and minimum 4 F. Under artificial conditions offspring were produced during a day of temperature 65 to 103 F.

Experiments were made to test the effect of heat on the green bug. An electric heated chamber was used for these. When the temperature rose above 90 F., the green bugs began to get restless, becoming more so as the temperature continued to rise. They ceased feeding and ran actively up and down the blades of wheat, left the plant and endeavored to escape. It was difficult to keep them confined. In fact, in most of the experiments started they succeeded in escaping, or at least they disappeared

and could not be found, dead or alive.

In one experiment twelve adult wingless green bugs were placed in the heated chamber on May 2. The daily maximum temperature ranged from 99 F. to 103 F., and the daily minimum from 52 F. to 67 F. By May 11 four of the adults were dead and there were about seventy-five young on the plant. On May 12 the maximum ran up to 107 F., and as a result fifty-five dead bugs were found, three live ones and the others were missing. The fatality was found to be equally high in other similar experiments performed. The plants were watered daily in all of these experiments.

Summing up the data: the lowest temperature at which green bugs reared in the field produced offspring was maximum 36 F., minimum 4 F. Under artificial conditions, it was found that the green bug produced offspring between temperatures of 103 F. and 65 F., though both adults and offspring soon perished under such conditions. Temperatures of 107 F. are fatal to the green bug, though food supply is abundant.

Under natural conditions offspring which had appeared during a day when the temperature maximum was 95 F., the minimum 72 F. were observed.

Reducing the data to Bachmentjew's terms we find for Toxoptera the minimum of development is about 36 F., the "critical point" at which death occurs varies according to the amount of moisture but it seems that a mean temperature of about 34 F., with the minimum not lower than about 3 F., is about the limit of endurance in dry winters. The optimum of the species as shown by the rate of reproduction is about 68 F. From this point the rate gradually decreases, though it is known to occur at about 84 F. until the aphids cease feeding at 90 F. and death occurs at 100 to 107 F.

During the summer of 1911 no experiments were being performed but the stock was being kept and the general condition observed. This summer was exceedingly hot and dry and it was very difficult to keep the green bugs though the greatest care was taken to keep the food supply abundant and in the coolest part of the laboratory. Gradually as the summer progressed, the stock seemed to lose vitality

until in the latter part of August, in spite of all efforts, all of the forms disappeared.

Endeavors were made that fall to renew the stock but no green bugs could be found in Kansas. The high temperatures had evidently proven fatal to any such forms that might have escaped their enemies. Inquiries were sent out to various points where Toxoptera usually occurs, but it was not until the fall of 1912 that specimens were obtained. On November 5th, 1912 eight agamic forms were received from Professor E. C. Cotton, Knoxville, Tennessee. This number was soon greatly increased by rapid reproduction, under favorable conditions.

This stock was kept in the laboratory where the temperature was never very low. There was also no severe weather until in December. On December 9th males were quite numerous. They were observed mating with females. These females were isolated. One of these females produced one male, one true female and migratory and wingless agamic forms.

On December 13, a true female with eggs showing clearly in body was taken from the stock and isolated. That afternoon 2 eggs were deposited. In all this

female deposited six eggs. These eggs were evidently not fertilized for they remained brown in color never turning black and shining as the fertilized eggs do.

Males and true females were found quite numerous throughout December and January and until the middle of February. Many black, shining eggs were collected and kept in a breeding cage out of doors in order that natural conditions might obtain.

On April 7, the first tiny stem mother was found which had hatched from one of the eggs, had crawled on to the wheat and was already feeding.



Temperature as affecting the food content of host plant.

When we take up the question of the effect of temperature upon the composition of plants we enter a field that has been much explored. For many years numerous investigators have been studying the effect of environment upon the composition of grain. Quite contradictory results have been obtained and therefore there is a very wide divergence of opinion as to the factors which influence the composition of wheat.

The plan, in practically all these studies has been to transfer the seed from one point to another and grow it under a variety of conditions and from the results so obtained attempt to draw conclusions as to the influence of environment upon the composition of the grain. G. W. Shaw and E. H. Walters of the Experiment Station, Berkely, California, however, have conducted experiments under conditions which would eliminate all varying factors with the exception of the composition of the soil itself.

This condition was established by growing wheat from the same seed under the same conditions



on soils of widely different origin put under the same influences.

In 1905, the California Experiment Station, in collaboration with the Bureau of Plant Industry of the United States Department of Agriculture, undertook an investigation in growing wheat from the same original seed continuously in each of three localities.

The essential conclusions from analyses of grain thus grown was as follows:-

(1) "Wheats of the same variety when grown in the same locality and under the same conditions are, therefore, seem to vary but little in composition, although coming from seed differing widely in physical and chemical characteristics."

(2). "Wheat of any one variety, from any one source, and absolutely alike in chemical and physical characteristics, where grown in different localities, possessing different climatic conditions, yields crops of very widely different appearance and very different chemical composition."

(3) "The results so far obtained would seem to indicate that the soil and seed play a relatively

small part in influencing the composition of crops."

In 1907 Shaw undertook his experiment of neutralizing the effect of climate and having as a variable factor only the soil. To do this he had soil, on which wheat of a certain known composition had been produced, taken from Kansas and placed in a plat in California. A check plat of California soil was prepared and seed planted, endeavoring to make all conditions as nearly equal as possible. This same system was used in Kansas and Maryland. The conclusions arrived at were as follows:-

"It must be said that the results so far obtained do not shed much light on the question as to the influence of soil nitrogen upon the nitrogen content of the wheat. It is evident, however, that in neither of the series of trials has the grain carrying the larger nitrogen content been obtained from the soil plat having the heaviest total nitrogen content. In the light of the present data it seems quite certain that the soil nitrogen content has very little, if any, direct influence upon the nitrogen content of grain grown upon such

soil, and that some climatic factor is sufficient to entirely overshadow the soil factor. This is entirely in harmony with the well known wide fluctuation of the nitrogen content of wheat from season to season, although the grain be grown upon the same soil. It may be that certain physical factors, enabling the soil to hold moisture better at certain periods of the plant's growth are responsible for the difference, but of this we have no data as far as these plats are concerned."

"The results also show that a chemical analysis of a soil by the ten-hour hydrochloric acid digestion method reveals no definite relation between the chemical composition of the crop and the soil."

"Further, it appears that the nitrogen content of an original seed when grown elsewhere than in a climate within which it has been acclimated, has little or no influence upon its progeny, and that even though it be acclimated still some seasonal factor is sufficient to either lower the nitrogen content of a high-gluten wheat or raise the nitrogen content of a low-gluten original."

As a result of the work of Shaw and Walters and their correlation of conclusions of earlier investigators there seems to be strong grounds for the belief that the climatic factor is the chief one in producing changes in the chemical composition of wheat.

Of course this study had to do with the composition of the grain but it is reasonable to suppose that if the grain is thus affected the composition of the rest of the plant would be likewise influenced in some measure at least.

As has been said, this question regarding the effect of environment on the composition of grain has been much studied, but comparatively little work has been done in an attempt to correlate this phenomenon with that of the change in mode of reproduction of these sap feeding insects, aphids.

Many have thought that temperature was a factor in bringing about this change but the results of experiments thus far seem to show that it has but an indirect influence. Some, as Morgan and Shull,

have suggested that the aging of the food plant might have a bearing upon this problem. This suggestion, however, does not seem to be entirely satisfactory, for in the case of Toxoptera graminum the sex forms appeared in experiments where the food plant was never allowed to grow old, but was always young and tender.

Dewitz makes another suggestion thus, "The autumn season produces also other notable effects upon the insect life. During autumn males appear of many insects and other arthropods which are parthenogenetic in spring and summer, and then non-sexual propagation gives way to sexual. Hence to speak of a physiology of the seasons is perhaps not so unjustified as it may appear. Who can doubt that the numerous species of insects which live and thrive on plants, in particular plant-lice, are vitally affected by the changes which autumn effects in plants. The plant organism and its contents such as starch, sugar, albumen and enzymes differ greatly during the summer, autumn and winter seasons, and it is quite unthinkable that such material changes should be without effect upon the state of all insects which feed upon them."

CONCLUSIONS.

It is a rather difficult task to test out in a practical way the suggestions that have been made as to just what part temperature may play in the great problem of the cause of the transition from the parthenogenetic to the sexual mode of reproduction. In our study of the question with reference to *Toxoptera* we have found that ,

1. Temperature bears a direct relation to the growth and development of *Toxoptera graminum* as is shown by the length of life, and rate of development and reproduction .(see chart )

2. That it seems to be a potent factor in changing the composition of wheat and the plant organism and their contents, which differ from season to season.

Work along this line is at present under way, using recently installed apparatus by means of which temperatures ranging from  $110^{\circ}\text{F.}$  to  $10^{\circ}$  below zero  $\text{F.}$  may be maintained. No definite results with this have as yet been ~~re~~obtained.



BIBLIOGRAPHY.

GENERAL AND FOOD REFERENCES:

- 1.-Davis, John J.,-Two New Genera and Species of Aphididae; *Annals Ent. Soc. of Am.*, 1909, Vol.II, #3.
- 1-b.- Biological Studies on Three Species of Aphididae; *Tech. Ser.*, 12, Pt. VIII, U. S. Dept. Agriculture, Bur. of Entomology, 1909.
- 2.-Dewitz, J.,- The bearing of Physiology on Economic Entomology; -*Bul. Entomological Research*, Vol.III, Pt. 4, pp. 343-354.
- 3.-Doten, Samuel B.,-Concerning the Relation of Food to Reproductive Activity and Longevity in Certain Hymenopterous Parasites; *Tech. Bul.* 78, 1911, Agri. Ex. Station, University of Nevada.
- 4.- Hunter, S. J., and Glenn, P. A.,- The Green Bug And Its Natural Enemies; *Bul. University of Kansas* IX, 2, 1909.
- 5.- King, H. D.,-Studies on Sex Determination in Amphibians; *Biological Bul.*, XVI, 1909.
- 6.- Morgan, T. H.,-A Biological and Cytological Study of Sex Determination in Phylloxerans and Aphids; *Jour. Ex. Zoology*, Vol.,VII, No.2, 1909.
- 7.- Shull, A. F. -- Studies in the Life Cycle of *Hydatina senta*.
  - (a)- I-Artificial Control of the Transition from the Parthenogenetic to the Sexual Method of Reproduction.; *Jr. Ex. Zool.*, VIII, 3, 1910.
  - (b)- II-The Role of Temperature, of the Chemical Composition of the Medium, and of Internal Factors Upon the Ratio of Parthenogenetic to Sexual Forms.; *Jr. Ex. Zool.*, X, 2, 1911.
  - (c)- III-Internal Factors Influencing the Proportion of Male-producers.; *Jr. Ex. Zool.*, XII, 2, 1912.
- 8.- Slingerland, M. V.,-Some Observations of Plant Lice; *Science*, 21, Jan. 27, 1893, p.48.

- 9.-Tannreuther, G. W.,- History of the Germ Cells and Early Embryology of Certain Aphids; Zool. Jahr.,XVIV, 1907.
- 10.-Wheeler, W.M.,-The Origin of Female and Worker Ants from the Eggs of Parthenogenetic Workers.; Science, Dec. 1903.
- 11.- Whitney, D. D. 1910--The Influence of External Conditions upon the Life Cycle of Hydatina senta; Science, n.s. Vol.XXXII, no. 819, Sept.9, pp. 345-349.
- 12.- Webster, F. M. and Phillips, W. J.,- The Spring Grain-Aphis of "Green Bug". U. S. Dept. Agri. Bur. of Ent.- Bul. 110, 1912.



TEMPERATURE REFERENCES.

- 1.- Abbe, C.,- Thermal Constant for Locust Eggs.; 1st Report U. S. Entomological Commission, 1878, pp. 425-432.
- 2.- Duvel, J. W. T.,- Cold Storage for Cow Peas; U.S. Dept. Agric., Bur. of Ent., Bul. 54, 1905.
- 3.- Girault, A. A, and Rosenfeld, A. H., Psyche, XIV, pp. 45-57; 1907.
- 4.- Girault, A. A., Annals Ent. Soc. Am., I, pp. 155-178, 1908.
- 5.- Howard, L. O.,- Some Temperature Effects on Household Insects.; U. S. Dept. Agric., Div. Ent., n.s. Bul. 6, p.13, 1896.
- 6.- Hunter, S. J., and Glenn, P. A.,- The Green Bug and Its Natural Enemies.; University of Kansas Bul. IX, 2, 1909.
- 7.- Hunter, W. D., and Hinds, W. E.,- The Mexican Cotton Boll Weevil; U. S. Dept. Agri., Div. Ent., n.s. Bul. 45, 1904.
- 8.- Hunter, W. D., and Hooker, W.A.,- The North American Fever Tick; U. S. Dept. Agric., Div. Ent., Bul. 72, 1907.
- 9.- Jenne, E. L., The Codling Moth in the Ozarks., U. S. Dept. Agri., Bur. Ent., Bul. 80, pt. 1, 1909.
- 10.- Merrifield, Frederic, Systematic Temperature Experiments on Some Lepidoptera in All Their Stages.; Trans. Ent. Soc. London, Pt. I, pp.131-159, 1890.
- 11.-Newell, Wilmon, The Boll Weevil; Cir. 9, La. Crop Pest Commission. 1906.
- 12.- Newell, W.- The Cattle Tick; Cir. 10, La. Crop Pest Commission 1906.

- 13.- Quaintance, A. L., and Brues, C. T., The Cotton Bollworm, Bul. 50, Bur. Ent., U. S. Dept. Agri., 1905.
- 14.- Rau, Phil.,-The Period of Incubation of Eggs of Samia cecropia.; Psyche, XIX,2, April 1912.
- 15.- Riley, C. V.,- 1st Report U. S. Ent. Commission; pp.231,353, (1878).
- 16.- Sanderson, E. D., Some Observations of the Mexican Cotton Boll Weevil; Bul. 52, Bur. Ent., U. S. Dept. Agri., 1904.
- 17.- Sanderson, E. D.,- The Relation of Temperature To The Hibernation of Insects.; Jr. Econ. Ent., I, pp.56-65, 1908.
- 18.- Sanderson, E. D., - Influence of Minimum Temperature in Limiting the Northern Distribution of Insects; Jr. Econ. Ent., I, pp. 245-262, 1908.
- 19.- Sanderson, E. D. - The Relation of Temperature to the Growth of Insects.; Jr. Econ. Ent., Vol. III, 2, April, 1910., pp. 113-140.
- 20.- Simpson, C. B., The Codling Moth; Bul. 41, Div. Ent., U. S. Dept. Agri., 1903.
- 21.- Shaw, G. W., and Walters, E. H., A Progress Report upon Soil and Climatic Factors Influencing The Composition of Wheat.; Bul. 216, Agri. Ex. Station, California., 1911.

THE "GREEN BUG", Toxoptera graminum.

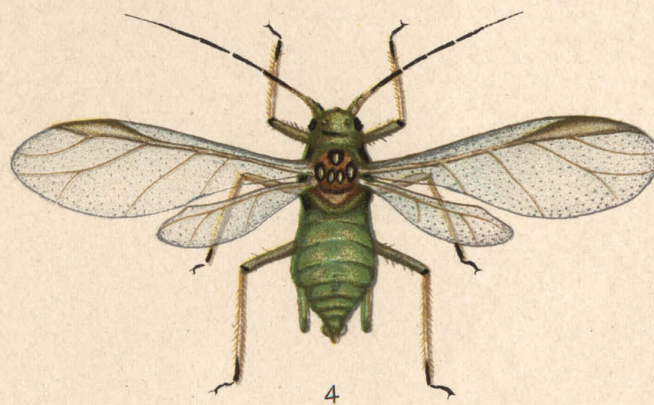
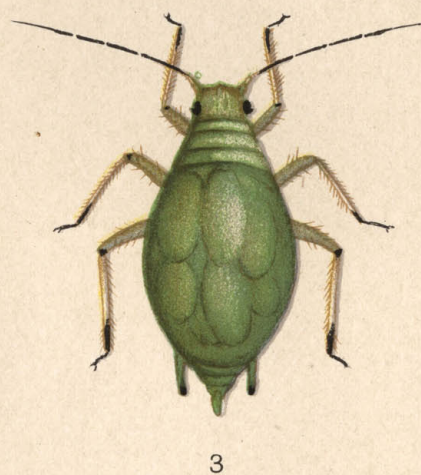
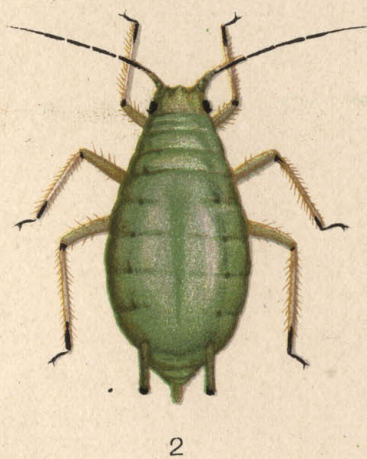
Fig. 1. Migratory form.

Fig. 2. Wingless form.

Fig. 3. True female.

Fig. 4. Male.





THE "GREEN BUG", Toxoptera graminum.

Figs. 1 and 2. Transitional forms,  
showing rudimentary wings.

Fig. 3. Winged form, producing both  
living young and winter eggs.  
The viviparous young are readily  
distinguished by the black ere  
spots.

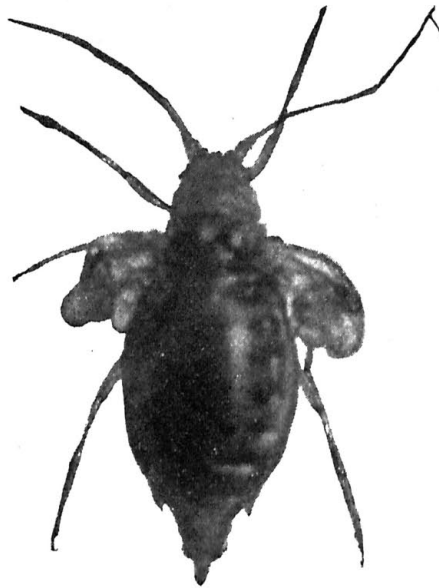


Fig. 1.

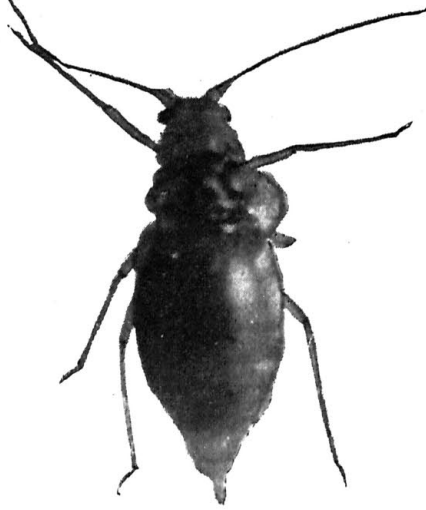


Fig. 2.

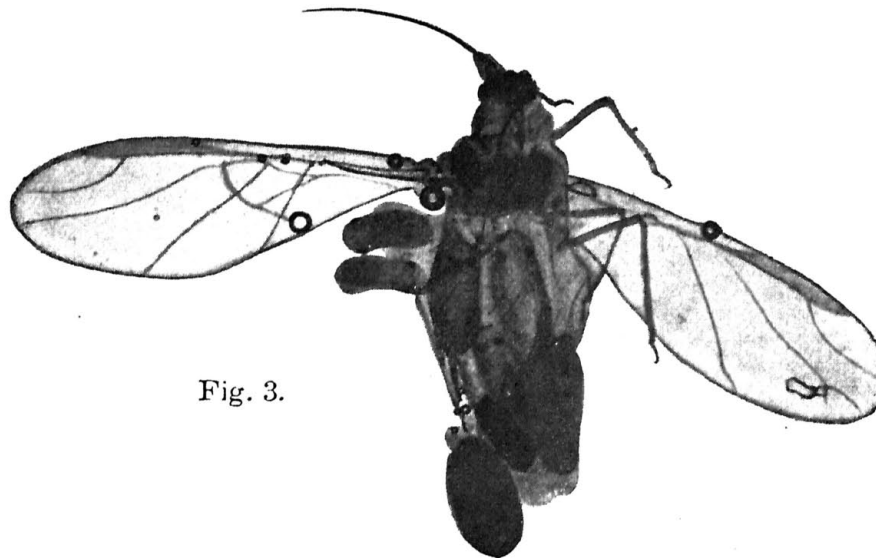


Fig. 3.

THE "GREEN BUG", Toxoptera graminum.

Fig. 4. Wingless forms, being both oviparous and viviparous.

Fig. 5. The same phenomenon is illustrated in both figures, the eggs are clean, the living young distinguished by black eye spots.

Fig. 6. A winged form, showing same condition.

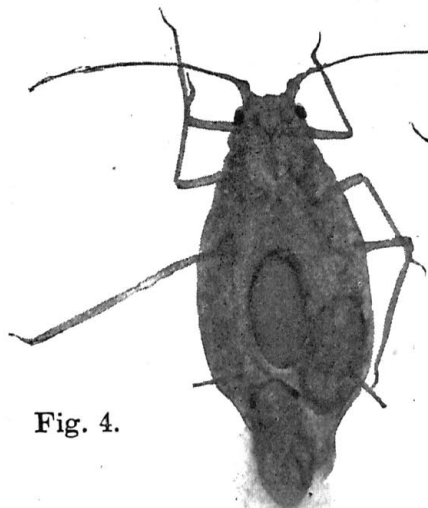


Fig. 4.

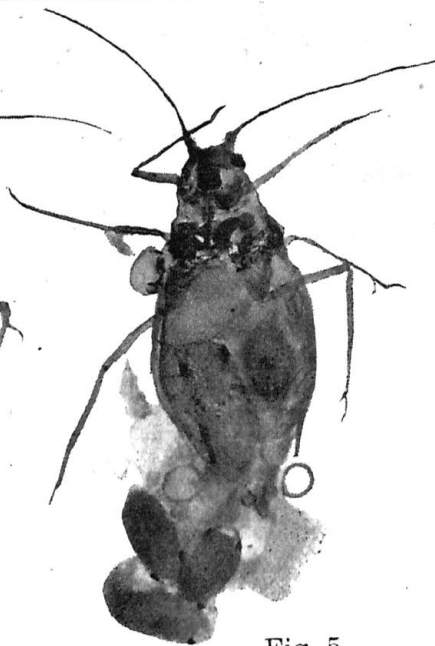


Fig. 5.

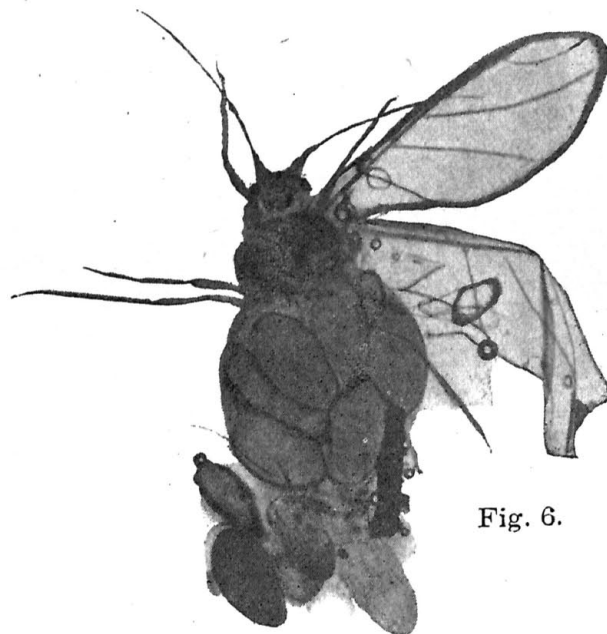


Fig. 6.



Chart showing relation between temperature and rate of reproduction, based on number of offspring of ten green bugs during the given period.

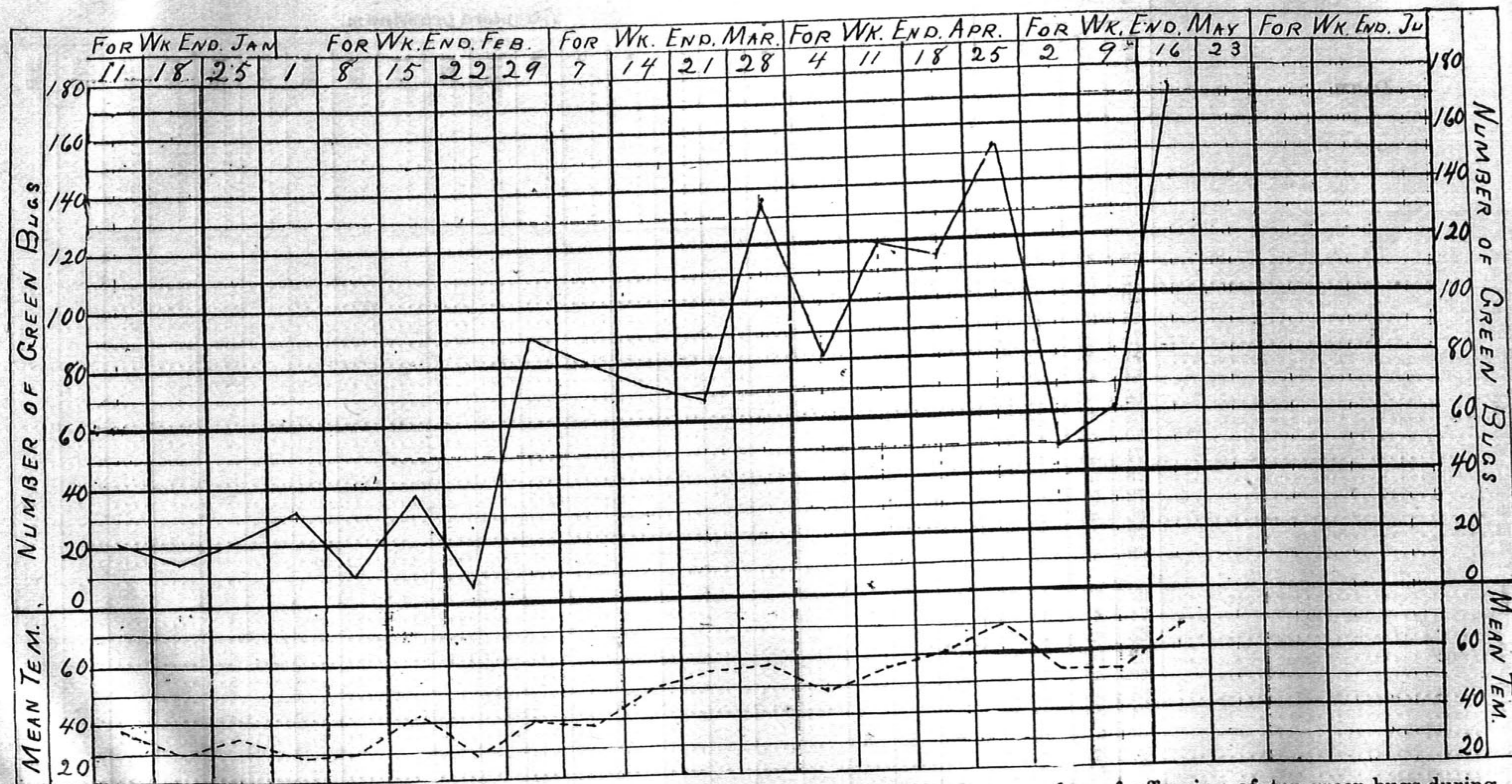


Chart showing relation between temperature and rate of reproduction, based on number of offspring of ten green bugs during the given period.

## FOOD EXPERIMENTS.

Showing table containing food experiments and back of it second table with check series.



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