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BUREAU OF ENTOMOLOGY.

L. O. HOWARD, Entomologist and Chief of Bureau.

THE SPRING GRAIN-APHIS OR SO-CALLED "GREEN BUG."

(*Toxoptera graminum* Rond.)

By F. M. WEBSTER,
In Charge of Cereal and Forage-Plant Insect Investigations.

The early history in America of the spring grain-aphis (figs. 1–4), which has come to be generally known as the "green bug," was published in Circular No. 85 of this Bureau, and need not be reproduced

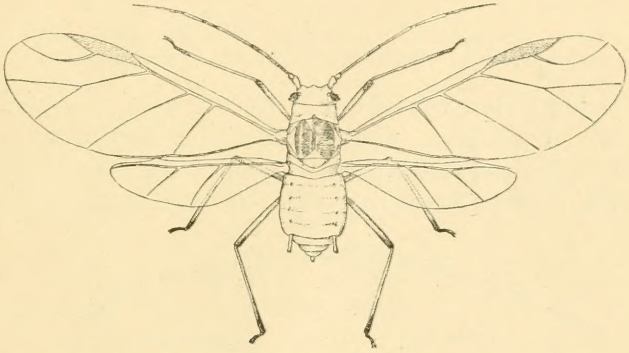

FIG. 1.—Spring grain-aphis (*Toxoptera graminum*): Male. Greatly enlarged. (Original.)

here. Suffice it to say that it is an imported species, long known to be destructive to growing grain in Europe, but not known in this country prior to 1882, and not as a destructive insect until 1890. The literature relating to this, the third and perhaps most destructive outbreak of the pest, is so misleading that this publication seems necessary in order to prevent misapprehension among farmers, and to afford them all possible helpful information in advance of future similar outbreaks.

DISTRIBUTION IN THE UNITED STATES.

The insect is usually common, and is found from New Mexico, Colorado, and Montana to the Atlantic coast, approximately covering the area south of latitude 41°, excepting New York, New Jersey, and New England, and east of longitude 105°. Within this territory its area of destructive abundance, as well as the severity of its attack during any year, will be regulated by two factors: First, the

presence of young growing wheat, oats, barley, or rye; and, second, weather conditions favoring its rapid increase and unfavorable for the development of its natural enemies. It will breed freely in the fields from an altitude of less than 20 feet above sea level on the At-

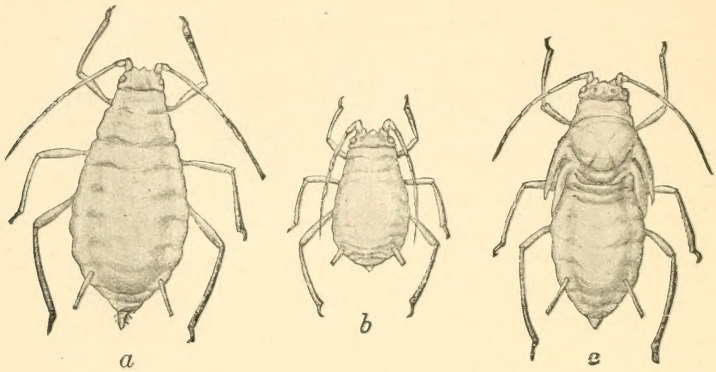

FIG. 2.—The spring grain-aphis or "green bug" (*Toxoptera graminum*): *a*, Wingless female; *b*, larva; *c*, pupa. Much enlarged. (From Pergande.)

lantic coast to an elevation of nearly 8,000 feet in New Mexico, and from eastern Washington, southern Montana, northwestern Minnesota, southern Wisconsin, northern Ohio, and southern Pennsylvania southward to extreme southern South Carolina, southern Texas, and

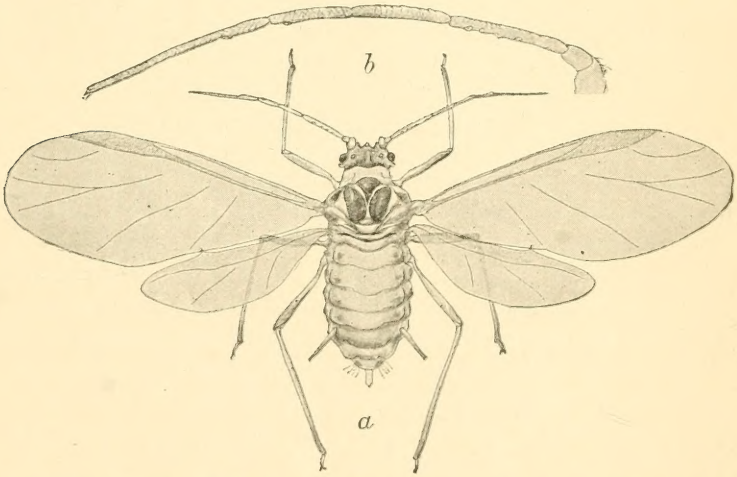

FIG. 3.—The spring grain-aphis or "green bug" (*Toxoptera graminum*): *a*, Winged migrant; *b*, antenna of same. *a*, Much enlarged; *b*, highly magnified. (From Pergande.)

New Mexico. Yet, with normal weather conditions during the first four or five months of the year, these facts signify absolutely nothing, for this insect will not be abundant enough to attract any attention by its injuries.

This insect, as with other closely allied species of aphides, reproduces in two ways. As cool weather approaches in autumn there occur in greater or less numbers both males and females, the latter depositing eggs (see fig. 4), and it is in the egg state only that, under normal weather conditions as to temperature, the "green bug" passes the winter, and from these eggs it originates in the spring. But from spring to fall there are neither eggs nor males; all are females, and these give birth to living young in a series of generations. With the normal cold of early winter these females gradually disappear and the winter eggs remain; but if the winter temperature is mild, and the temperature of the following spring abnormally cold, the summer method of reproduction continues throughout the winter and during spring. Indeed, it is not improbable that males and egg-laying females may be found in spring, especially in the South.

The "green bug" will breed freely in temperatures ranging from above 100° to below 46° F. As the young mature in eight days and themselves begin to give birth to young, it will be seen that an exceptionally mild winter followed by an abnormally cold spring offers the best possible conditions for the excessive increase of the pest, which would ordinarily begin breeding only in spring, and from the eggs.

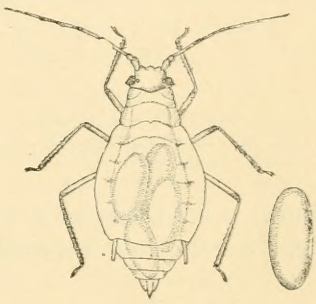

FIG. 4.—Spring grain-aphis (*Toxoptera graminum*): Egg-laying female with eggs in body, greatly enlarged; at right, egg, still more enlarged. (Original.)

With excessive reproduction and the destruction or aging of its food plants, this insect develops a corresponding abundance of winged migrating females, which are the means of the spread northward or outward from original centers.

The "green bug" in normal years—that is, when its breeding begins in spring—is effectively held in check by its natural enemies, and notably by a minute, black, wasplike insect, *Lysiphlebus tritici* Ashm. (see fig. 5) that deposits eggs singly in the "green bugs," the grubs hatching from the eggs feeding internally on the bug and destroying it (see fig. 6). Other natural enemies are the larvæ of certain predaceous flies, and the larvæ and adults of lady-beetles. The little wasplike parasite first mentioned, however, is the one that keeps the "green bug" in control in normal years, and in years when the latter is most abundant finally overcomes it, as was the case in 1907 in Kansas, North Carolina, and other States in the more northern part of the range of the pest.

Unfortunately this parasitic wasp—as with the other beneficial insects—is active only while the temperature is above 56° F., or at least 10° above that at which the "green bug" breeds freely; and

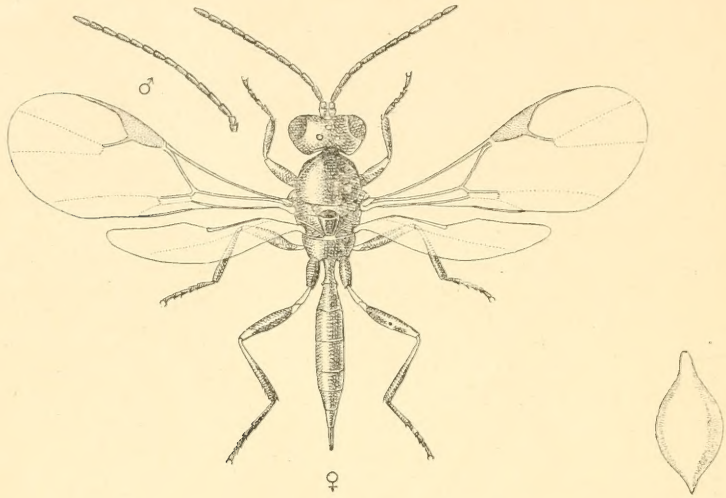

FIG. 5.—*Lysiphlebus tritici*, principal parasite of the spring grain-aphis: Adult female and antenna of male, greatly enlarged. Egg of *Lysiphlebus tritici* at right, highly magnified. (Original.)

herein is the whole secret of the irregular disastrous outbreaks of the "green bug" in grain fields. As accounting for the outbreak in the year 1907, the "green bug" had had a whole winter and the following late spring in which to breed and multiply unmolested, and it accomplished its principal damage, as in Texas and southern Oklahoma, before the weather was warm enough for the parasite to increase sufficiently to overcome it.

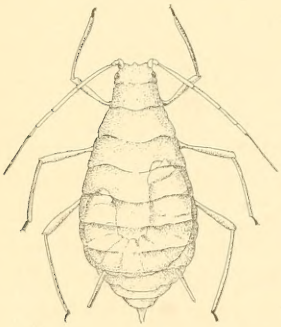

FIG. 6.—Wingless female of "green bug," containing larva of the parasite *Lysiphlebus tritici*. Much enlarged. (Original.)

As further illustrative of the important bearing of weather conditions, it is found that in the case of the three important outbreaks of this insect, namely, for the years 1890, 1901, and 1907, the temperature for the first five months of each of these years, including the latter part of winter and spring, was above the normal for the winter months and below the normal for the spring months; in other words, warm winters and cold, late springs.

The little parasitic wasp which is so useful in the control of this pest is native to this country, widely distributed, and every year does its work with the "green bug" and with other aphides. It is always

present in grain fields, as shown by its appearance every year, to war on these pests whenever the weather conditions make its breeding and multiplication possible, and its rate of breeding is so rapid (there being a generation about every ten days) that with a week or two of favorable weather it gains control over its host insects and destroys them.

FOOD PLANTS.

The spring grain-aphis is essentially a leaf-infesting insect, rarely being found on the stem. While preferring oats, it will readily attack wheat, rye, and barley, and may often be found on the underside of the lower leaves of corn. Corn excepted, its effect on the leaves of grain, when present in large numbers, is to cause the infested leaves to change to a red color, which seems to be very characteristic of Toxoptera and does not follow attacks of other species of aphides on these grains. The insect has also been found breeding upon a considerable number of grasses, any one of which may constitute its alternating food plant upon which it may survive the summer in different portions of the United States. It has been found breeding freely upon marsh foxtail (*Alopecurus geniculatus*) in Oklahoma by Mr. W. J. Phillips, and by Mr. C. N. Ainslie in Kansas; on *Agropyron occidentalis*, also in Oklahoma, by Mr. Phillips, and by Mr. E. O. G. Kelly and Prof. C. P. Gillette in Colorado. Slender wheat-grass (*Agropyron tenerum*) was found moderately infested by Mr. Ainslie at Las Vegas, N. Mex. The species was found breeding upon Bromus at Washington, D. C., and also upon Porter's chess (*Bromus porteri*) at Las Vegas, N. Mex., and on an undetermined species of Bromus at Mesilla Park, N. Mex., all by Mr. Ainslie. The writer observed it very abundantly on orchard grass (*Dactylis glomerata*) in Indiana in 1890, and again excessively abundant in a small isolated meadow of this grass near Midlothian, Va., in April, 1907. This meadow was located in a region not adapted to the growing of grain, and there was no field of growing wheat or oats within 5 miles. Mr. Kelly found it in Montana, inhabiting marsh spike-grass (*Distichlis spicata*) in such abundance as to be damaging this grass, which in that part of the country is known commonly as "salt grass." It was found inhabiting slender wild rye (*Elymus striatus*) at Las Vegas, N. Mex., by Mr. Ainslie. Mr. Phillips found it attacking little barley (*Hordeum pusillum*) at Beloit, Kans., and Kingfisher, Okla., while the writer found this to be of frequent occurrence throughout Kansas. Mr. Kelly observed it abundant on squirrel-tail grass (*Hordeum jubatum*) in Montana, while Mr. Ainslie found it moderately abundant on *Hordeum cæspitosum* near Cimarron, N. Mex. Wherever Kentucky blue-grass (*Poa pratensis*) grows, the insect will probably be found breeding upon it through-

out the entire summer. In fact, this has been actually observed to occur in the city of Washington. Mr. Phillips has observed the same thing in Indiana, and throughout the northern sections of the country where the Toxoptera occurs it is more likely to be found on this plant during summer than upon grain, excepting, perhaps, during seasons of excessive abundance. Mr. Ainslie also found it moderately abundant on beard-grass (*Polypogon monspeliensis*) about Albuquerque, N. Mex. It has been found breeding on yellow foxtail or pigeon-grass (*Ixophorus glaucus*) by Mr. Phillips at Richmond, Ind., and on green stipa (*Stipa viridula*) at Las Vegas, N. Mex., by Mr. Ainslie. In the latter case the grass was heavily infested. As one or more of these grasses will be found to occur in almost every portion of the United States, it would appear that the nonoccurrence of Toxoptera in any considerable section of country can not be due to a lack of uncultivated food plants. Of food plants other than grasses we have only the one observation made by Mr. Phillips at Kingfisher, Okla., April 23, 1907, where a species of ragweed growing up in a badly damaged wheat field was quite heavily infested with Toxoptera, at the time breeding freely on this plant.

The outbreak on the grounds of the Department of Agriculture was notable in some respects, in that the continued close cutting of the blue grass supplied a continual fresh, tender growth as food for the "green bug," thus preventing the development and escape of winged females; and especially is it notable in view of the total lack of *Lysiphlebus tritici*, the most important of the natural enemies of this aphis. The only natural enemy found in this case feeding upon the "green bug" was the diminutive black and yellow lady-beetle (*Hyperaspis undulata* Say), not previously known in connection with this pest.

When this outbreak became known to Mr. E. M. Byrnes, superintendent of Experimental Gardens and Grounds, he at once had the entire infested block sprayed with a solution of one-half gill of rose-leaf nicotine to each gallon of weak soapsuds. The application was, however, ineffective. Four days later a strip through this plat was thoroughly saturated with a strong solution of barnyard manure, made by soaking the manure in water. While there was no evidence that this killed any of the "green bugs," after nine days the pest was notably less on this area than where the application of manure solution was not made.

A series of experiments was then undertaken under the writer's direction by Mr. E. O. G. Kelly, as follows:

Tobacco dust was applied at rates of one-fourth, one-half, and 1 pound to each 100 square feet, but after over a week had elapsed

from the date of application no effect was to be observed and no dead insects were found.

Kerosene emulsion was applied at 8 and 10 per cent strengths. There was practically no difference in the effect of these two strengths, and at the end of nine days no "green bugs" were to be found on the areas so treated. Also there was no perceivable injury to the grass.

Whale-oil soap solutions, varying in strength from one-fourth of a pound to 2 pounds of soap to each 5 gallons of water, were applied to similar areas. In this case the stronger solution injured the grass slightly, but not permanently; in the case of the lesser strengths there was no injury whatever. The effect on the "green bug" was the same in every case. They were not only literally exterminated over the areas treated, but the applications seemed to protect from a reinfestation. In case of even the weakest solution an examination, five days after the application was made, revealed the "green bugs" in myriads and breeding freely on the untreated space, while but 8 inches away and on the treated area living bugs were scarcely to be found, though the dead were to be observed almost as abundantly as were the living on the space untreated. It must be remembered, however, that these experiments were carried out in grass kept closely cropped by frequent use of the lawn mower, and the results obtained in no way reflect upon similar experiments carried out by Messrs. Ainslie and Phillips in the grain fields of Oklahoma.

INVASION OF 1907.

A better appreciation of the interrelation of the "green bug" and its principal parasitic enemy can be conveyed by giving a chronological statement of our investigations of the very disastrous invasion of the "green bug" during the winter and spring of 1907.

The first rumors of injuries by this pest came to us early in January from east-central Texas, where the "green bugs" were reported to Mr. W. D. Hunter, in charge of cotton boll weevil investigations of this Bureau, as attacking fall oats. During this month in Texas, east of a line drawn from near Gainesville through Abilene and San Antonio to Galveston, the temperature was 9° above the normal. Within this area was a smaller one, the boundaries of which may be indicated by a line drawn from Texarkana to Fort Worth, Waco, and Joaquin. Over this latter area the temperature for the same month was 12° above the normal, and within this area the pest began its work of destruction.

Also, judging from data received later, the pest began to breed rapidly in fall-sown oats in southern South Carolina, where the temperature was from 6° to 9° above the normal.

During February all over the region west of the Mississippi River and the Great Lakes the temperature was above the normal, and in the Carolinas it was only slightly below. During this month much damage seems to have been done in Texas, and there is every probability that the pest was breeding freely in the Carolinas, though it had not yet been reported from the latter States.

Up to this time the outbreak in Texas was being investigated by Mr. E. C. Sanborn, an agent of this Bureau detailed to the Texas Agricultural Experiment Station. The first report of the insect outside of Texas was under date of March 6, from Mr. C. H. Drake, of Summers, Ark., who reported that "a small green bug" had destroyed the wheat in spots in the fields in his locality. This letter, received March 11, led to the prompt dispatching of Mr. C. N. Ainslie for the West, with full instructions to investigate the outbreak thoroughly, to experiment with measures for destroying the insects in the fields, especially over the spots where they seemed to be most abundant, and to determine what could be accomplished in checking the ravages of the pest by the early introduction of natural enemies into the infested fields. Arrangements were perfected with Mr. W. D. Hunter to ship to Arkansas living parasites (*Lysiphlebus tritici*), which were then abundant in Texas, and the same train by which Mr. Ainslie reached Summers brought several boxes of the parasites. These parasites were promptly placed in the infested fields and liberated March 18. But Mr. Ainslie found that both the lady-beetles and the little wasplike parasites (*Lysiphlebus tritici*) were already present at Summers and near-by points in greater numbers than could possibly have been introduced. The latter were simply everywhere, running about over the young grain plants and placing their eggs in the bodies of the "green bugs."

Clearly the importation of parasites would be useless under these conditions, and Mr. Ainslie, hoping to find a more favorable field for the introduction of parasites or direct experimental work with remedies, proceeded, on March 23, for various points in Oklahoma.

At Chandler and Guthrie, March 23 to 25, the pest was very abundant, but the conditions at these points were again even less favorable than in Arkansas for the introduction of parasites. For example, on one blade containing about 150 of the "green bugs" Mr. Ainslie counted 25 that were parasitized. He then proceeded to Kingfisher (March 26) and here found the parasites apparently less plentiful than at the other points visited, which were to the eastward.

Arrangements had been made with Mr. Hunter to furnish parasites from Texas fields when these were called for, and in response to a telegraphic request he dispatched a quantity of material collected by his assistants in Texas and in southern Oklahoma. When this was

received and the parasites liberated in the infested fields, native parasites were already issuing in great numbers. In other words, the parasite was already beginning unaided its active work of control. By March 27 the "green bugs" developed winged adults in great numbers, and these seemed to drift northward.

Mr. Ainslie was instructed to look for a region to the northward where the "green bug" was just starting, and he made his first stop, March 30, at Wellington, Sumner County, Kans., and found the conditions there such as to offer a favorable field for experimentation with parasites.

By April 1 the fields about Wellington were generally, though sparsely, infested with the "green bug," represented in many cases by winged females that had seemingly migrated to these fields and were giving birth to their young. Lady-beetles were common, but none of the Lysiphlebus was observed. After a couple of days spent in the vicinity of Wellington, Mr. Ainslie returned to Kingfisher to secure parasites for introduction into southern Kansas, but in the meantime severe weather, accompanied by heavy frosts, had prevailed, and the parasites formerly abundant at Kingfisher had become exceedingly scarce. By the 5th, however, he began again to find very many parasitized "green bugs," and by the 7th the parasites themselves began to appear again. A bushel of wheat plants, now nearly covered with parasitized "green bugs," was collected at Kingfisher and taken to Wellington April 9. At this time fully 12 per cent of the "green bugs" at Wellington were already parasitized, while on the 12th Mr. Ainslie counted as many as 11 parasitized individuals on a single blade of wheat.

About the middle of March an appeal came to this Bureau from the Texas Grain Dealers' Association, through their secretary, Mr. H. B. Dorsey, at Fort Worth, to investigate the "green bug." In response to this appeal Mr. W. J. Phillips, of the Bureau staff, was dispatched to Fort Worth, arriving on the 27th. Several days spent in examining fields in the vicinity of Fort Worth demonstrated that the "green bug" had totally destroyed the grain in that vicinity and disappeared, and there was no opportunity for experimental work. He then went, by instruction, to Hobart, Okla., and later relieved Mr. Ainslie at Kingfisher, and, in response to a telegram from Mr. Ainslie, sent an amount of parasitized wheat from Kingfisher to Wellington equal to or larger than the first shipment.

All of the material which Mr. Ainslie took with him from Oklahoma and that supplied him by Mr. Phillips was placed in a single wheat field near Wellington. It is safely estimated, from counts of average wheat blades, that upward of two and one-half millions of parasites were thus liberated in a single wheat field on April 9, and

by this time many were already there. This introduction of parasites was carried out in order to give a decisive test as to whether it was possible to aid in protecting fields in this manner along the advance line of invasion. The weather was still cold, and if the artificial introduction of parasites would, with the return of warmer weather, hasten the control of the "green bug," the introduction of such large numbers would clearly demonstrate this fact. And if such introduction on a large scale proved favorable, it would show reasonable ground for the more general introduction of parasites in lesser numbers.

There was a minor introduction of Lysiphlebus started at McPherson, Kans., April 18, though this parasite was already found in the fields in that vicinity at that time.

The weather during the whole of April was generally cold with, as on May 4, an occasional storm that is known to have killed many of the parasites, and though there were brief periods of warm weather during which the parasites would increase rapidly, the Lysiphlebus did not finally overcome the "green bug" in southern Kansas until about the middle of May.

As will be observed, this experiment was made under weather conditions almost uniformly unfavorable to the parasite and favorable to the development of the "green bug." There is no reason for supposing that the weather would affect the introduced parasites differently from those already present when the introduction was made.

Mr. Ainslie remained in the vicinity of Wellington, and more briefly at McPherson and Sterling, for the purpose of watching these experiments, and he was, moreover, in direct communication with Mr. Phillips in northern Oklahoma; and the two were therefore able to keep under their observation a wide range of country, thus eliminating the possibility of oversight or misconception on the part of either that might otherwise have occurred.

It was during this period of generally cold weather in late April and early May, interspersed by shorter periods of weather favorable to the parasites, that the latter increased generally throughout Kansas and, judging from reports, also in Missouri and Colorado. It wanted only the more extended warm spell that came soon after to enable them to get the upper hand and subdue the pest, as they did throughout the southern Atlantic coast section earlier in the season.

The field in which the two and a half million Lysiphlebus were introduced and liberated on April 9 did not, at the time of the overcoming of the pest in this and the adjacent country in May, indicate any benefit whatever above other fields, near or remote, where no

artificial introductions had been made. The result of the minor experiment at McPherson was, as reported by Mr. Knaus, no more favorable.

During the last two weeks of April a great many small lots of parasites were distributed over the southern and central counties of Kansas by Mr. S. J. Hunter, of the Kansas State University. The artificial sending out of these parasites by Mr. Hunter and the test of distributing an enormous quantity in a single field, described above, were legitimate experiments, but the evidence showed very conclusively that they resulted in no benefit whatever. In other words, as noted above, the parasites were already infesting 12 per cent of the "green bugs" at Wellington, Kans., April 9, when the artificial introduction was made, and 50 to 75 per cent at Kingfisher, Okla., at the same date, and they were only waiting for weather conditions to make it possible for them to do their work. Just as soon as the favorable weather arrived the parasites bred enormously and quickly overcame the "green bug." In no case was there a field of the hundreds examined in southern Kansas where the parasites natively present did not outnumber by many thousands or hundreds of thousands any number that could have been introduced artificially, at a time when weather conditions had become such that the liberations could have had any benefit. As shown by the careful investigations of the agents of this Bureau in the field, and independently of Prof. E. A. Popenoe, entomologist of the Kansas State Agricultural College, and his assistants, the parasites were equally abundant in all fields in May, when weather conditions became favorable, irrespective of whether distributions had been made or not.

The weather, therefore, is the important influence. As demonstrated by the experience of this and other years, these parasites, always present in limited numbers, will overcome the aphis unaided as soon as weather conditions permit, and no artificial introduction, great or small, appears to hasten or increase their efficiency.

The writer left Washington for Kansas May 13 to take personal charge of the field work in relation to the "green bug" and to make a thorough survey of actual field conditions. The "green bug" at this time (May 15) had become abundant in oats as far north as Manhattan, Kans.; but wherever present there were numbers of parasites also already in evidence. Indeed, Mr. Phillips found this to be true at Kearney, Nebr., which point he visited about a week later. In no instance was a field observed, either in the vicinity of Manhattan or, during the next week or ten days, anywhere in Kansas, where the parasite was not present wherever the "green bug" occurred.

A further experiment, this time tried for the purpose of testing the possibility of hastening the work of the parasite during favorable weather by large introductions, was carried out as follows: The subjects of the experiment were two fields of oats, each containing 4 acres. In one of these it was determined to introduce enormous numbers of parasites artificially, keeping records of this field for comparison with the other field in which no introductions were made,

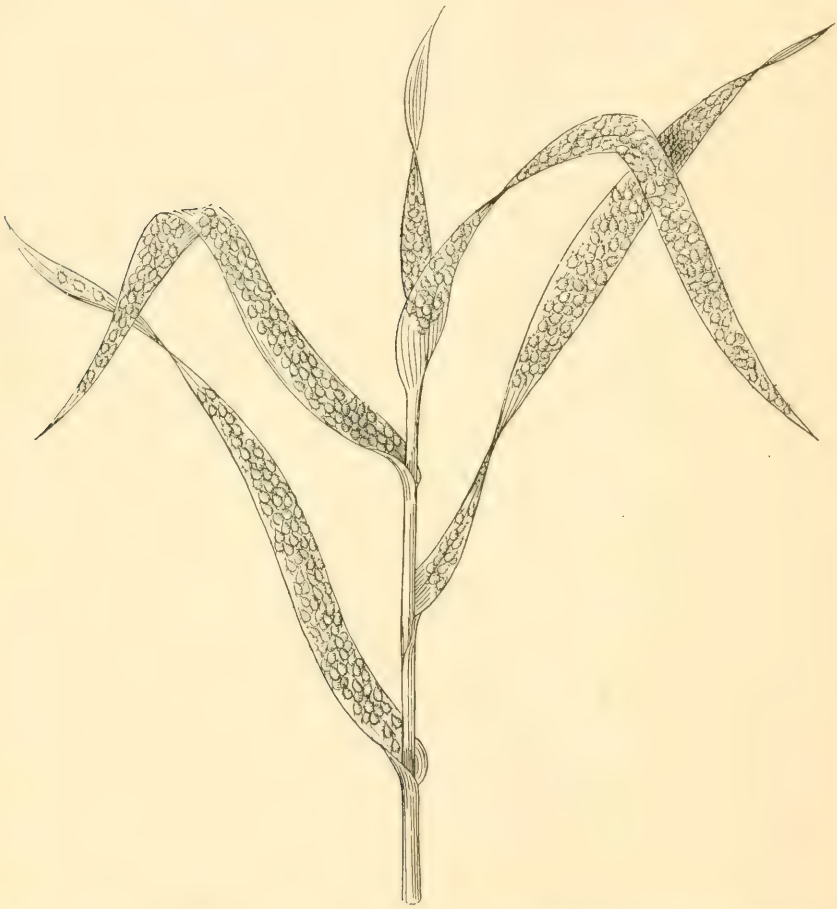

FIG. 7.—Stalk of wheat, the leaves covered with dead "green bugs" killed by the parasite *Lysiphlebus tritici*. About natural size. (Original.)

thus determining the measure of benefit, if any, which resulted from the artificial introduction. Mr. Ainslie was instructed by wire to ship from Wellington, Kans., 6 bushels of the wheat plants that had been destroyed by the "green bug" and which, in some cases, were literally covered with the parasitized bodies of the pest, upward of 500 having been found on a single plant. (See fig. 7.) Before taking up the ex-

periment, however, it was desirable to know just what the conditions were under which it was begun. As stated above, one of these oat fields was used for the experiment of introducing parasites, while the other was kept as a check. The fields were so widely separated that the introductions could not have spread from one field to the other. Six areas of a square yard each, selected for the examinations in different parts of each field, were gone over by Mr. Phillips and two of Professor Popenoe's assistants. Examinations of both of these fields, made on May 17 and 18, showed that the field in which the parasites sent from Wellington by Mr. Ainslie were to be liberated contained approximately fifty millions of the unparasitized "green bugs" and approximately one and three-quarter millions that were undoubtedly parasitized; in other words, approximately 3.5 per cent of the "green bugs" were at that time parasitized. In the check field the parasites were even more abundant, about 7.8 per cent being there found, by similar counts, to be parasitized.

On May 18 parasites from 12 packages, each containing about half a bushel of wheat plants, were liberated in one of these fields. Now, a count similar to that made before the parasites were introduced was made on May 23, and this showed that the percentage of parasitism in the field in which the experiment was carried out had increased only to 5.4 per cent, while in the field in which no parasites had been liberated it was 19.3 per cent. On May 27 a similar count was made, when the percentage of parasitism in the field where the introduction was made was 27.1 per cent, while in the check field it was 32.5 per cent. Clearly, under weather conditions favorable for their development, an introduction of these parasites to the extent of millions, carried out under field conditions, did not indicate enough efficiency to afford any encouragement for the use of this measure in the protection of the grain fields of the farmer in case of future attack.

With all the artificial introductions of this parasite that were made in the grain fields of Kansas and adjacent States and Territories, there is no probability that a single bushel of grain was saved thereby or that the United States harvested one bushel more of grain than it would have harvested had no introductions of parasites been made or attempted. In substantiation of this statement it is interesting to note the history of the "green bug" during 1907 throughout North and South Carolina, upward of a thousand miles from where any introduction of parasites had been attempted, excepting two that the writer himself conducted. A considerable amount of material was sent from Winston Salem, N. C., on April 20, to a point a few miles west of Richmond, Va., where it was introduced into a small meadow of orchard grass, with no grain field within 5 miles.

But even here the effect was uncertain, as the writer had found the parasite present in this locality before the introduction was made. In the other case a larger consignment was sent from the same locality in North Carolina to Sumter, S. C., to be placed in a field of oats that the writer visited in company with the owner on the 16th of April, when parasites were found in considerable numbers. In this case the owner of the field, writing under date of June 18 and reporting on the outcome of the experiment, said:

> I am sorry that the information to be derived from our experiments with the parasites is so indefinite. It just happened that other conditions probably overcame the aphis before the parasites had time to multiply sufficiently to get in their work. About the time that your box was received weather conditions changed somewhat from cool to warmer weather and the bugs seemed to disappear very rapidly. From the day the bugs disappeared, the oats, the only grain grown, began to improve, and while they will not make a full crop by any means, they are much better than we anticipated when you were here.

This is, as the writer personally observed, also the history of the disappearance of the pest in western North Carolina, where both fall wheat and fall oats are grown and where no parasites were introduced, but where they were literally swarming on April 20.

From all of this it would seem that throughout the greater areas over which this insect becomes injurious it has so far been impossible to assist the work in any way. We have apparently been wholly unable to aid the parasites in getting the upper hand. They accomplished their work earlier in the Carolinas than in the West, but reference to the records of the Weather Bureau will show that the weather conditions as regards temperature were precisely such as to bring this about.

The only possibility of accomplishing anything by the artificial use of natural enemies of the "green bug" seems to be in Texas and South Carolina, where the pest gets its start earliest, making its appearance in the fields in spots of greater or less area in the fall or early winter. If these incipient outbreaks can be stamped out by farm methods, as indicated further on, or by the encouragement of parasites, or if they can be so weakened as to prevent the "green bug" from developing in such enormous numbers, it will serve to protect the grain crops not only of these two States, but of all those to the northward over which the pest ravages in seasons favorable for its development. The Texas Agricultural Experiment Station is contemplating an experiment whereby they hope, by the artificial introduction at the proper time of a large number of the natural enemies of the "green bug" into these spots of early infestation, to forestall a future outbreak. If this can be accomplished it will prove of great benefit to the farmers. Whatever the outcome may be, the experiment seems worth trying.

DEVELOPMENT AND INFLUENCE OF LYSIPHLEBUS TRITICI.

Although there are several natural enemies of the "green bug," including one recently described by Dr. L. O. Howard as *Alphelinus nigritus*, yet all of them seem to be of little importance as compared with the one minute parasitic species, *Lysiphlebus tritici*. It is this species, or what we are at present terming as such, that normally holds Toxoptera in check in this country, and so long as its development and activity are not obstructed by adverse meteorological conditions it will probably continue to control it. Indeed, so important is this insect and so powerful is its influence that in a short space of from ten days to two weeks it can overcome a most serious outbreak of Toxoptera, and thus save from destruction vast areas of growing grain. The species winters over in the field in the body of its host. In many cases these parasites, having been prevented from emerging the previous fall by the advent of cold weather, hibernate as nearly developed or fully developed adults, ready to emerge when the temperature rises to about 56° F. and remains there for a sufficient length of time. This is clearly shown by the fact that Mr. E. O. G. Kelly found hibernating adults at Leavenworth, Kans., on November 13. In one lot of 50 dead, parasitized Toxoptera that had been washed or rubbed from the leaves of the young grain and taken from the mud about the wheat plants on February 28, after the winter was practically over, Mr. Kelly found 17 containing full-grown larvæ of the parasite, 12 containing pupæ of a light color, and 21 containing dark-colored pupæ, the latter evidently ready to develop promptly with the advent of warm weather. Mr. Kelly, on the same date, also secured a large number of Toxoptera in various stages of development that were hibernating in wheat fields near Leavenworth, Kans. The weather had been such as to preclude the possibility that these had been recently parasitized. Yet some of them soon began to show the yellowish color characteristic of Toxoptera parasitized by Lysiphlebus, and adults were afterwards reared from them. This shows conclusively that the Lysiphlebus parasites hibernate in advanced stages of development in the bodies of their host, which they have killed the previous autumn, and also as larvæ in those passing the winter from half to fully grown.

The female Lysiphlebus is even more prolific than the female Toxoptera. Mr. Phillips has found females which had upward of 400 eggs in their ovaries, and Mr. Kelly has reared in some cases 206 individuals from a single mother Lysiphlebus. The eggs are lemon-shaped and white. When excessively abundant this parasite will thrust its ovipositor into old and young aphides of both sexes, including the sexual female even though previously parasitized; and Mr. Phillips has observed that it will even oviposit in the dead bodies

of those that have been killed by fungous attack. When its numbers are not so great it shows more discrimination and seems to prefer half-grown individuals for oviposition.

This species of Lysiphlebus is parthenogenetic, as was first observed by Mr. Phillips at Richmond, Ind., and afterwards more fully elucidated by Messrs. E. O. G. Kelly and T. D. Urbahns at Wellington, Kans. The experimental breedings by Mr. Phillips in 1907 indicated that the offspring of virgin female Lysiphlebus were nearly always exclusively males. In a series of upward of 80 breeding experiments carried on indoors, in 1908, by Kelly and Urbahns, only 48 gave results of any kind. In only four of these were females produced, the others giving exclusively males. In the 4 exceptional cases the females remained virgin, and all finally gave birth to males alone, 2 with the first generation, 1 with the second, and 1 with the third. The mode of procedure was as follows:

Starting with a mated female, the females from among her offspring were isolated, even before emergence. On their appearance these were given Toxoptera reared under cover to preclude parasitism; the few females from among the second generation were again isolated in the same manner, the females in all cases being kept unmated. It was thus found possible to breed a limited number of females parthenogenetically to and including the third generation. Beyond this all offspring were males, this seemingly being the limit. Just why such a large percentage of these experiments should have proved abortive is not clear. The conditions under which they were carried out were of course unnatural but much more protected from the adverse elements of the open field.

The egg of the Lysiphlebus normally develops to the emerging adult in about ten days, during the first six of which the host insect remains alive, and at the end of which it commences to take on a yellowish hue, the larva of the parasite showing clearly through the skin of the abdomen.

The celerity with which an invasion of Toxoptera is overcome by Lysiphlebus is frequently a matter of wonder, as it hardly seems possible that this host alone could be the source of the swarms of parasites that make their appearance after a few warm days have elapsed in the midst of an unseasonably cool spring preceded by a winter abnormally mild.

In order to determine the origin of these myriads of parasites Messrs. Kelly and Urbahns began a long series of experiments at Wellington, Kans., to determine whether there might not be a multiplicity of host species from which great numbers of Lysiphlebus would emanate to fall upon and destroy Toxoptera whenever it becomes excessively abundant. The entire failure to introduce these

parasites in advance of an invasion of this character from the South, as was the case in Kansas in May, 1907, has indicated that such introductions were not possible and that to attempt it was veritably "carrying coals to Newcastle."

Female individuals of Lysiphlebus from the cabbage aphis (*Aphis brassicæ* L.) taken in the field were first allowed to parasitize Toxoptera and from the latter the adults were obtained. This experiment was several times repeated. Females of Lysiphlebus reared under cover from the corn root-aphis (*Aphis maidi-radicis* Forbes) were in two cases allowed to parasitize Toxoptera and adults obtained. Females of Lysiphlebus were taken from *Aphis setariæ* in the field and the issuing parasites in two cases allowed to parasitize Toxoptera and adults secured. This experiment also was repeated several times. Female individuals of Lysiphlebus were taken from the corn leaf-aphis (*Aphis maidis* Fitch) in the field and the adult parasites permitted to parasitize Toxoptera, from which finally the adults emerged. This experiment was repeated several times. Female specimens of Lysiphlebus were taken from the cotton or melon aphis (*Aphis gossypii* Glov.) from New Mexico and given Toxoptera as a host, the adult parasites developing successfully therefrom. Female specimens of Lysiphlebus were taken from *Aphis setariæ* in the field and given Toxoptera as a host, their offspring transferred to *A. maidi-radicis*, and the next generation transferred back to Toxoptera. Female individuals of Lysiphlebus were taken from *A. setariæ* in the field and allowed to parasitize Toxoptera, their offspring transferred to *A. setariæ*, the next generation to Toxoptera, and the following generation to *A. brassicæ*, from which adults were secured.

FIG. 8. Lysiphlebus depositing its eggs in the body of a grain aphis. Much enlarged. (Original.)

In many cases these breedings were reversed. The only cases of failure were in attempting to transfer Lysiphlebus issuing from Toxoptera to Chaitophorus and in transferring Lysiphlebus issuing from Toxoptera to *Macrosiphum rudbekiæ*. These experiments were reversed with the same results.

The female goes about, if in grain fields, among the plants, and when she finds an aphis she quickly throws her abdomen underneath her body and between her legs and with a springlike motion thrusts her ovipositor into the body of the aphis (fig. 8), leaving therein a

tiny egg. This egg hatches into a larva in a few days, and the usual position in the body of the "green bug" of the larva up to the time it becomes full-grown is shown in fig. 6, page 4. Up to this time it has fed within the body of the "green bug" without reaching any of the vital parts, but preventing to a greater or less degree the giving of birth to young. This is an important fact, for, as the parasite seems to prefer partly grown young, it begins to check the increase of the pest before the death of the "green bug" takes place. Mr. Phillips has found that females parasitized at this period of their development do not reproduce for more than a very few days. After about six days the larva of the parasite reaches full growth and becomes more active, working its way about within the still living body of its host, which now dies a seemingly terrible death. The motions of the parasitic larva within cause the skin of the "green bug" to become rotund in shape, as shown in fig. 9; the skin also becomes darker and hardens. Within four days (the life cycle in warm weather occupying about ten days) the adult Lysiphlebus emerges through a round hole in the dried skin of the "green bug," as shown also in fig. 9. In fields that have been destroyed the leaves become almost covered by their brown bodies, as shown in fig. 7. As stated, many of the "green bugs" are stung by the Lysiphlebus while quite young, and if these develop to winged adults, as they do at times in myriads and drift away to distant fields, they carry the parasite with them in their bodies. One of these parasitized winged females is shown in fig. 10.

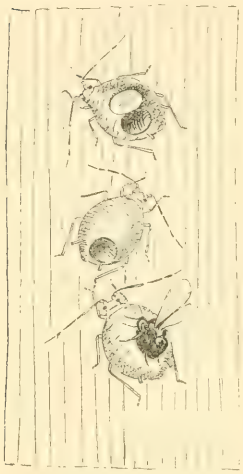

FIG. 9.—Dead "green bugs," showing hole from which the matured parasite of *Lysiphlebus tritici* emerges. The top figure shows the lid still attached, but pushed back; the bottom figure shows the parasite emerging. Enlarged. (Original.)

The very act of migration of the "green bug," therefore, brings the parasite, and there is no need of artificial introduction, for if the center from which the "green bug" is migrating has the parasites, as it always does, the latter are of necessity carried by their hosts, and, furthermore, the adult parasites fly with the latter with favoring winds.

During strong winds the Lysiphlebus does not use its wings, but crawls about over the plants and probably does not become scattered by gales. But in warm, comparatively still weather the writer has observed both winged "green bugs" and parasites crawling about on the windows of railway coaches many miles away from seriously infested fields of grain.

EXPERIMENTS IN DESTROYING "GREEN BUGS" OVER SMALL AREAS.

On leaving Washington both Mr. Ainslie and Mr. Phillips were instructed to place themselves in the position of a farmer whose grain fields were beginning to show the presence of the "green bug" by small deadening spots, and to leave nothing undone or untried that would seem to afford relief and save the crop.

Mr. Ainslie instituted some experiments in the use of a brush drag at Summers, Ark., and Mr. Phillips carried out similar experiments at Hobart, Okla., but in neither case was the measure sufficiently effective to warrant its recommendation. Experiments in rolling infested fields with heavy farm rollers were conducted by both of these agents, but it was invariably found that this measure was only effective on smooth lands. When the seeding is done with a grain drill, as most of it is, the plants grow up in the bottoms of slight furrows, and the roller comes in contact with the ridges only, leaving the young plants and their inhabitants almost wholly untouched. This measure, also, is therefore of little practical value.

FIG. 10.—Winged female of the "green bug," parasitized by *Lysiphlebus tritici*. Enlarged. (Original.)

Mr. Ainslie tried dusting with lime and also with sulphur, but both substances were ineffective.

Both Mr. Ainslie and Mr. Phillips carried out a series of careful experiments in spraying with kerosene emulsion and with whale-oil soapsuds. From these experiments it was found possible to destroy 50 per cent or more of the "green bugs" at an expense of about $4 per acre. This treatment, of course, is intended for use only where, as seems to be more usual to the southward, the outbreaks of the pest originate in spots in the fields.

Mr. Ainslie also tried covering some of these spots with straw and burning it, thus destroying, of course, both grain and "green bugs." This, too, gave encouraging results, and probably would prove effective if applied earlier in the season, when the pest first begins to appear and the infested spots are small.

At Hooker, Okla., Mr. Phillips tried the efficiency of plowing these spots under, and as the field in which he was working was isolated and the "green bugs" did not make their way in from without, he was able to show conclusively that such outbreaks, under certain conditions, may be stopped.

In summing up these field experiments, then, it is found that these spots may be treated successfully either by plowing under and harrowing and rolling the surface of the ground, by spreading straw over them and burning, or by treating with a 10 per cent solution of kerosene emulsion. Except in the southernmost regions infested by this pest, however, the greatest difficulty does not arise from these isolated colonies, which seem to extend outward day after day, but from the fact that, after their food supply has become either largely destroyed or the grain too old and tough for them to feed upon, immense swarms of winged adults are produced, and these drift, in general, northward with the advance of the season and infest the grain fields of entire sections of the country much earlier and more completely than would be possible from the scanty stock natively present. This habit is also seen in the behavior of the pest in its original home in Europe. It may therefore prove that the country north of the Red River may be more or less protected if the pest can be early overcome in northern Texas.

AGRICULTURAL METHODS OF CONTROL.

The fact that the "green bug" in the South originates in spots in the grain fields has been alluded to, and also that from these fields come the vast swarms of winged females that develop and drift over the country, dispersing themselves in uninfested fields. Early sown fields or fields overgrown with volunteer grain seem especially to invite early attack in the more southern localities. Where these immense swarms settle down in a section of country, even the best fields of grain may succumb to their attacks. But usually, outside of an extremely limited area, there is a noticeable difference in intensity of attack as between different fields. In Oklahoma and northward, fields that have been late sown or that were pastured during the winter suffered worst and were the first to be destroyed. It has been frequently noticed that a field of grain may be totally destroyed, while an adjoining field, though seriously injured, will frequently produce a partial crop. An investigation of the history of these fields has invariably shown that the result in the latter case is due to fertile soil, proper cultivation, and seeding at the proper time. It seems to have been almost universally true, outside of the limited area of total destruction, that the best farmed fields have suffered the least. This does not apply alone to wheat, as the writer observed a field of oats near Hutchinson, Kans., that gave promise of a fair yield, where almost the entire crop would otherwise have been destroyed. The owner of this field, who had been obliged to plow up other fields where the cultural methods had been the same, expressed his opinion

that the reason the one field escaped the attack of the "green bug" to such an extent was that it had been for many years in alfalfa, only one crop, and that corn, having been taken from it since alfalfa had been turned under. He stated that the "green bug" was at one time as abundant in this field as in the ones which he had been obliged to plow under, but that in the one case the plants had withstood the attack better and were in better condition when the "green bugs" were overcome by the parasites, and thus able to start growth anew and yield to the owner a fair percentage of a crop.

In extreme western Kansas a field of 10 acres of oats lying adjacent to an irrigating ditch, but which had not been irrigated, showed very forcibly the effect of irrigation: Along this irrigation ditch was a ragged border of vigorously growing oats from 10 to 30 or 40 feet in width where the "green bug" had seemingly done no injury. Beyond this, where the moisture from the irrigating ditch had not penetrated, the loss was total. In another case in the same locality a part of the wheat in an unirrigated field came up in the fall and the rest not until spring; the former was uninjured by "green bugs," while the latter was killed. While late sowing in Texas will probably lessen attack in the fall, it is doubtful if this can be recommended north of the Red River. November-sown wheat was certainly less affected than others in North Carolina.

THE PRESENT "GREEN BUG" SITUATION IN THE SOUTHERN STATES, MAY 1, 1909.

The situation over the country with reference to a future invasion of this pest, though not alarming, is sufficiently serious to render a word of warning exceedingly appropriate. In widely separated localities from Western North Carolina to eastern New Mexico the insect has become sufficiently abundant during March and April to work considerable injury locally. This shows that the pest has recovered from the severe reverse given it by its natural enemies in 1907, and that a repetition of the mild winter of 1908–9 and the present cold, backward spring will be almost certain to precipitate a more or less disastrous invasion. Of course no one knows what the winter of 1909–10 and the spring of 1910 will be, but it stands the grain growers in hand throughout the country south of Virginia, Kentucky, Missouri, and Kansas to destroy, as far as possible, all volunteer grain coming up in the fields during the coming autumn; and where fall oats are sown, as is generally the case throughout this country, the sowing should be delayed as late as possible. These two measures have a tendency to prevent the pest from becoming so thoroughly established in the grain fields during the autumn months, and

are the only measures that can be taken that will have a tendency to ward off an impending invasion.

We have found that where serious damage has been done to fields of grain in late winter and spring such fields had become seriously infested during the preceding autumn. The carrying out of these measures in the southern portion of the country has a tendency to protect the grain fields farther north, for we have had additional illustration of the fact that winged individuals are, during the spring months, being almost continuously carried northward by the wind.

It is somewhat a question as to whether the spring-sown oats farther north would suffer to a less degree if there were no invasion in the South in fields of fall-sown grain, both of oats and wheat. While it is not possible for an insect to make its way or be carried by the wind from Texas to northern Kansas, Missouri, southern Illinois, Indiana, and Ohio, nevertheless continuous breedings to the southward certainly do influence the numbers over this last-mentioned territory.

If the farmers of the country, instead of being carried away by the highly colored newspaper reports of the effect of the introduction of a few parasites in their fields, will seek to evade the pest by the destruction of volunteer grain in the fall and late sowing in the extreme South and turn their attention to better farm methods, including not only cultural methods but by all means rotation of crops, watching for and stamping out the pest when it first appears in the South in the fall and winter, they will in all probability suffer far less from destruction of their crops when the next invasion of this pest occurs.

Approved:

JAMES WILSON,
Secretary of Agriculture.

WASHINGTON, D. C., *April 27, 1909.*

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