Kansas State Agricultural College.

EXPERIMENT STATION—Bulletin No. 188.

*ED. H. WEBSTER, *Director*.

TECHNICAL BULLETIN.

Department of Entomology.

GEO. A. DEAN, *Entomologist in Charge*.

The Hessian Fly

BY

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Manhattan, Kansas,
July, 1913.

* Resigned December 31, 1912.
† Resigned October 1, 1912.
‡ Resigned November 30, 1910.

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ANNOUNCEMENT.

SINCE this manuscript was submitted the following important changes in the station staff have occurred: Ed. H. Webster, director of the experiment station, resigned December 31, 1912, to become associate editor of Hoard's Dairyman, and has been succeeded by W. M. Jardine. Prof. L. E. Call has succeeded W. M. Jardine, as head of the agronomy department. Dr. T. J. Headlee resigned as head of the departments of entomology and zoölogy, to become entomologist of the New Jersey Experiment Station, and has been succeeded by Prof. Geo. A. Dean, in the department of entomology, and by Dr. R. K. Nabours, in the department of zoölogy.

DEPARTMENT OF ENTOMOLOGY.

GEO. A. DEAN .... Entomologist in Charge.
J. H. MERRILL .... Assistant Entomologist.
J. W. MCCOLLOCH .... Assistant Entomologist.

OTHER DEPARTMENTS OF THE DIVISION OF AGRICULTURE.

Agronomy	L. E. CALL in charge.
Animal Husbandry	W. A. COCHEL in charge.
Bacteriology	L. D. BUSHNELL in charge.
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Chemistry	J. T. WILLARD in charge.
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Poultry Husbandry	W. A. LIPPINCOTT in charge.
Veterinary Medicine	F. S. SCHOENLEBER in charge.
Zoölogy	R. K. NABOURS in charge.

Summary.

1. During the forty-one years of its known residence in Kansas, the Hessian fly has produced six different outbreaks, the last and greatest of which destroyed ten million bushels of the wheat of the 1908 crop.

2. The length of the fly's life cycle is variable, ranging, under field conditions, from forty-five days to twelve months or more. Dry weather and cool weather lengthen it, and moist weather and warm weather shorten it.

3. The number of broods is variable. In 1908, main-spring, supplementary-spring, midsummer, main-fall, and supplementary-fall broods were determined. In dry summers, it is likely that midsummer and supplementary-fall broods would not appear, and it is likely that in very dry years, particularly when the drouth begins early, the supplementary-spring brood might be eliminated.

4. The measures of control must be of such a nature as to effect the prevention or destruction of *all* of these main and supplementary broods; for while in many cases only part of them appear, there is always a chance that they may all develop.

5. The sources of the flies which form each of the broods are variable, for the members of a single brood came from as many as three different places--old stubble, regular crop, and volunteer wheat. The measures of control must be of such a nature as to close up all these sources of supply.

6. Temperature and moisture are the only climatic elements that appear materiaIly to influence the fly. Low temperature or low moisture, or both acting simultaneously, always retard its development, and may, if extreme, destroy it. High temperature and high moisture are universally favorable to its development.

7. Although both predaceous and parasitic enemies always reduce the fly, their action is so irregular and so rarely sufficient that dependence upon them for protection is folly.

8. It is the maggot stage that does the damage. In the fall the central shoot of the young plant is stunted and killed; if

the attack be serious enough, the whole plant and the whole field may be destroyed. Ordinarily, the slow destruction of the central shoots causes the tillers to grow vigorously, giving the field a dark green appearance. In the spring, the maggots interfere with the sap flow, cause the heads partly or completely to fail to fill, and so weaken the stalks that many break and fall before harvest.

9. The fly infesting the old stubble can best be destroyed by plowing the stubble under so carefully and deeply that when the ground is packed down into a good seed bed for wheat, there will be at least four inches of soil between the stubble and the surface.

10. The growth of volunteer wheat is a menace, and should not be tolerated before the regular crop is sown.

11. In average years, with proper preparation of the seed bed, the date of safe sowing is at least as early as the date on which wheat should be sown to make a maximum yield if no fly were present.

12. The schedule of procedure outlined on pages 135-138 is one which, if conscientiously followed, will, we think, enable the farmer to escape serious fly damage and give him the best possible chance to obtain a maximum crop.

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THE HESSIAN FLY.

By T. HEADLINE and J. B. PARKER.*

INTRODUCTION.

ALTHOUGH the Hessian fly is an insect capable of inflicting on Kansas wheat injury resulting in the loss of ten million bushels in a single year, no complete and separate treatise on it has been issued from Kansas sources during the forty years of its residence in this state. Some complete treatments have appeared from the pens of United States entomologists and from entomologists of some of the states, more or less nearly complete discussions have been published in the reports and press bulletins of this Experiment Station and in the repoyts of the Kansas State Board of Agriculture, and numberless notices and statements relative to this subject have been printed by the agricultural and general press.

There is need for a relatively complete and separate statement of the Hessian fly and its work. This bulletin purposes to set forth such available facts about the fly as are important from the standpoint of its control, and for this purpose the authors have drawn freely upon the findings of othey students of the fly as well as upon the information accumulated by the study of the fly at this station.

History and Distribution.

Like three-fourths of our serious insect pests, the Hessian fly is a foreigner. Having made its first appearance in 1779 in Long Island, in the vicinity of a Hessian soldier encampment of three years previous, it has spread north, south, and west, until most of the wheat-growing regions of the United States suffermore or less damage through its depredations. It seems able to vary its habits in accordance with the climatic conditions of North Dakota or Texas, Pennsylvania or fornia.

* This bulletin was planned and written by the senior author and confirmed by the junior. The illustrations, unless otherwise indicated, are original with the authors.

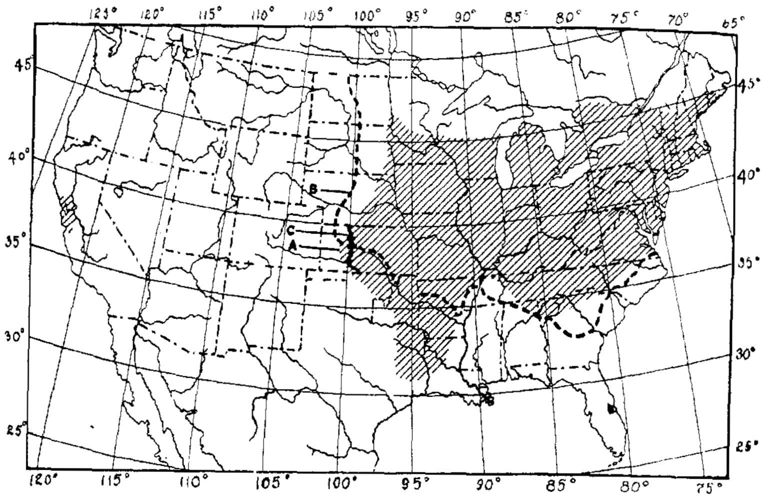


FIG. 1. Map of the United States showing the distribution of the Hessian fly. A. Western Kansas limit according to Osborn. B. Limit according to Webster. C. Limit according to authors' investigations.

The Hessian fly was first reported damaging wheat in Kansas in 1871[1], ninety-two years after its first serious ravages in Long Island. In 1877 it again became abundant enough to receive notice. Not again until 1880 did it do noticeable harm. From this date its damage increased until in 1883 and 1884 the harm was widespread and generally recognized. At this time Snow[3] presented to the State Board of Agriculture

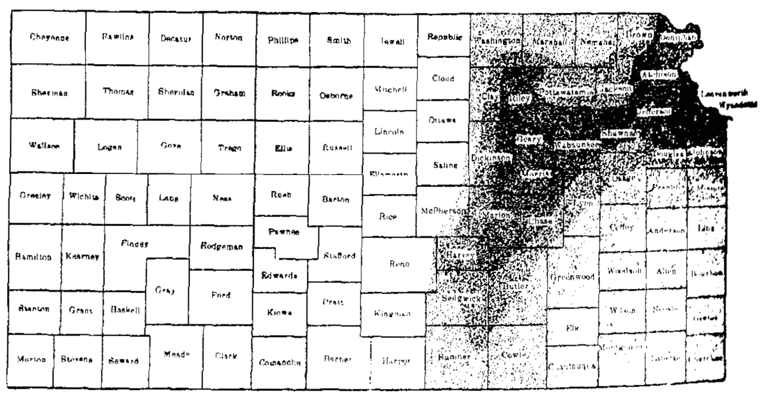


FIG. 2. Map of Kansas showing the infestation described by Snow in his report to the State Board of Agriculture for the years 1883-'84. The Hessian fly did damage throughout the shaded area, the relative amount of damage being indicated by the depth of shading.

1. Packard, A. S., Third Report of U. S. Entom. Com. (1883). 201.

3. Report of the Kansas State Board of Agriculture for 1883-1884. 605-609.

an account of its work. He said that twenty-one counties reported the fly to be present to an extent varying from slight indication to very serious occupation. The accompanying map, based upon his report, will serve to give an idea of the distribution and extent of damage. Between this date and 1907 the available data on the fly's history in Kansas have been meager. Thinking our agricultural papers,[4] reflecting as they do the agricultural conditions of the state, would be likely to show the presence of the fly by articles on that subject, we examined the files, and our account of the creature's ups and downs for the period between Snow's report and 1907 is drawn from this source.

By 1886 the damage of the fly became so slight as to receive very little notice, and by 1887 it had dropped from sight altogether. Not until 1891 is there any indication of its work. In that year both Popenoe and Snow published articles indicating slight but general damage through the wheat district. No further indication of its presence is found until 1898, when an unknown writer mentions the "urgent need" of combating the fly. In 1900 the articles, by number and character, especially the former, indicate a considerable outbreak, but no estimate of the extent of damage was published. More or less harm is indicated by constant publication until 1904, when, except for mention of damage to Oklahoma wheat, the fly drops from sight until 1908. In the fall of 1907 the senior author found the fly ovipositing freely and abundantly on wheat in the southern part of the state, and during the following winter complaints of fly damage were received from many parts of the state.[5] In many instances, particularly in the southern part of the state, the entire crop was destroyed before spring, and the fields were listed to corn. When harvest time arrived, the damage was found to be widespread and large, aggregating at least ten million bushels.

The accompanying map will serve to show the distribution

4. The Kansas Farmer files were the ones available and consulted.

5. Infested wheat was received from the following places: Anson (Sumner county), Argonia (Sumner county), Arkansas City (Cowley county), Arlington (Reno county), Caldwell (Sumner county), Chetopa (Labette county), Conway Springs (Sumner county), Elk City (Montgomery county), Enterprise (Dickinson county), Great Bend (Barton county), Harper (Harper county), Hazelton (Barber county), Hutchinson (Reno county), Isabel (Barber county), Marysville (Marshall county), Leavenworth (Leavenworth county), McPherson (McPherson county), Milton (Sumner county), Sedgwick (Harvey county), St. Paul (Neosho county), Sylvia (Reno county), Wakefield (Clay county), Wamego (Pottawatomie county), Wellington (Sumner county), Wichita (Sedgwick county), Williamsburg (Franklin county), Winfield (Cowley county), Worden (Douglas county), and Strawn (Coffey county).

of the damage in 1908. Growers throughout the infested district were anxiously asking for measures to prevent damage to the following year's crop. Press Bulletin No. 163 was issued in response to this desire, and not less than twenty thousand copies were distributed among farmers, millers, elevator men, and grain dealers generally. During the summer, which was very wet and marked by an unusually strong growth of volunteer wheat, the fly formed a supplementary brood and destroyed much of that wheat. The oviposition on early sown

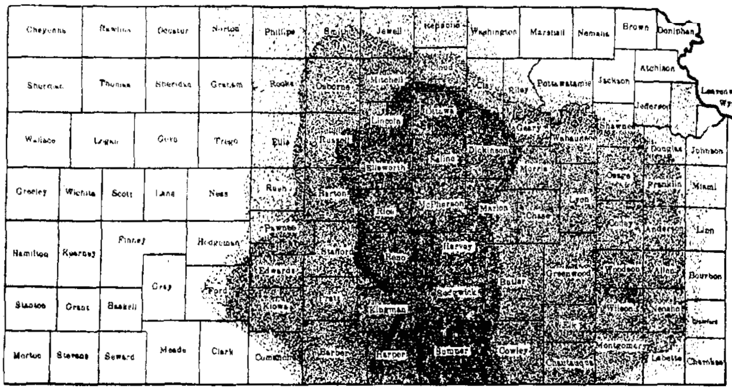


FIG. 3. Map of Kansas showing the territory damaged by the Hessian fly in 1908. The relative amount of damage is indicated by the depth of shading.

wheat in the succeeding fall (1908) was very large, and large numbers of the resulting larvæ became flaxseeds and passed the winter successfully. The following spring (1909) saw a large emergence and heavy deposition of eggs, but the dry and windy weather either prevented them from hatching or destroyed the larvæ after their escape from the eggs. In fact, so thorough was the work of destruction that the fly did not until 1912 attract the farmer's notice, although it had been present in small numbers everywhere.

Since its first appearance in Kansas as an important factor in wheat production, the fly has alternately disappeared and reappeared. In some years, its ravages destroyed thirteen or more per cent of the crop; in others, its work was so small as to pass unnoticed. The explanation of this peculiarity appears to lie in the fact that unfavorable weather conditions or an undue abundance of natural enemies may almost eradicate it. The years when the Hessian fly is hardly heard of are the ones that follow its wholesale destruction by unfavorable weather. conditions or natural enemies, while years when Hessian fly is abundant and does large damage, are the ones that follow the presence of favorable weather and the wholesale destruction of the fly's natural enemies. Both agencies frequently work together, and it is difficult to say, without a complete record at hand, which has been the more important.

From the time of its appearance in Kansas in 1871 the fly followed the wheat plant westward until now the western limit appears to be a line passing through Ford, Ness, Trego, and Norton counties. In showing the westward movement it is interesting to note that Snow gave its western limit in 1883 and 1884 as a line passing through Sumner, Sedgwick, Harvey, Marion, Dickinson, Clay, and Washington counties.

Habits and Life History.

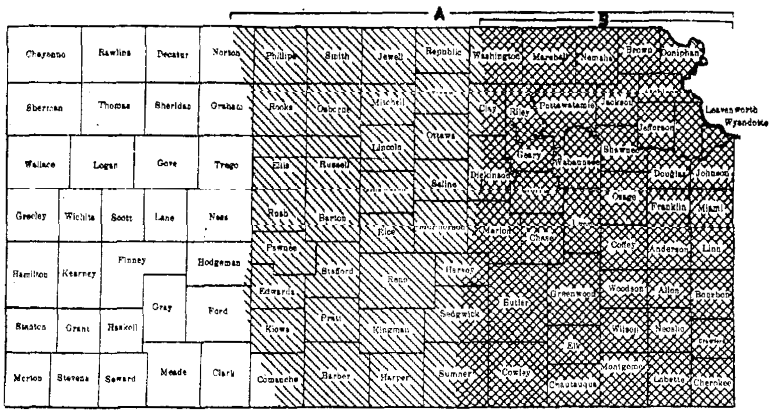


FIG. 4. Map of Kansas showing the progress of the Hessian fly toward the west. B, territory infested in 1883-'84. A, territory infested in 1908.

Like many other insects, the Hessian fly exhibits in the course of its development four different forms — egg, larva or maggot, puparium or flaxseed, and adult. So different is the creature in these stages that the average man would not suspect any kinship between them. The adult fly is a tiny, long-legged gnat not markedly different from other gnats commonly found in the wheat field. The egg, which is usually deposited upon the upper surface of the leaf, is so small and inconspicuous as barely to be visible to the unaided eye. The tiny maggots when first hatched are so small, and so quickly hide themselves between the leaf-sheath and the stem just above a node, that few people ever find them. Generally, by

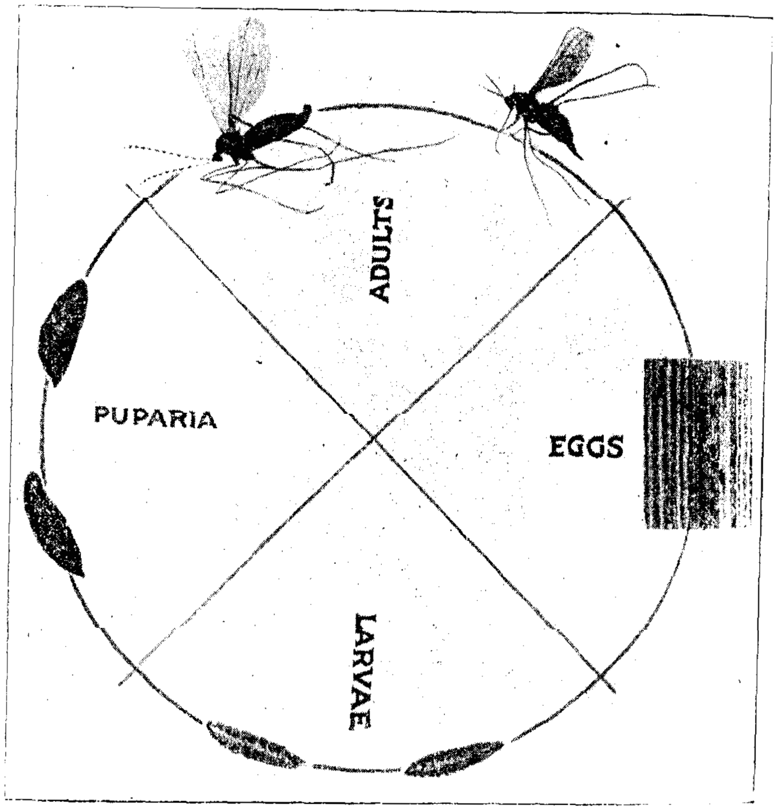
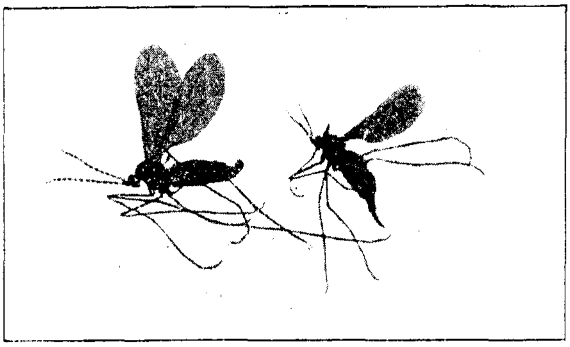


FIG. 5. Life cycle of the Hessian fly.

the time the injury has proceeded far enough to attract the grower's notice, the maggots have become fully grown and have transformed to flaxseeds. Consequently, the grower finds the flaxseed and concludes that it is responsible for the damage. Thus the flaxseed stage has become the stage of the fly with which the practical wheatgrower is most familiar. A little close observation, however, would suffice to acquaint him with all four stages.

In telling the life story of the fly it will be well to start with the tale at some one season of the year and follow it from that time until the same time the year following. Such a method will give the reader a view of its seasonal history, which, with variations due to different climatic and biologic conditions, is repeated year after year.

Starting with the fly about the middle of September, we find the adults on the wing. From this time forward, the members of this main fall brood will continue to appear until the middle of October, and members of a supplementary brood may continue the emergence for fifteen or twenty days longer. Each individual lives only a few days—long enough to deposit the eggs from which the young will develop. The fly comes out slowly when the ground is dry; rapidly where it is thoroughly wet from a rain.



A, male. B, female.

FIG. 6. Male and female Hessian fly, magnified six times.

The adult fly is about one-eighth of an inch from head to tip of abdomen. Some of its legs may be as long as one-sixth of an inch. It is dark in color, with a single pair of transparent wings. These, under the magnifying glass, are seen to be covered with hair-like structures and furnished with three lengthwise-running veins unconnected by cross veins. The male may be distinguished from the female with the unaided eye by the fact that while the abdomen of the male is slender and blunt-ending, that of the female is heavy and sharp-pointed.

Unless prevented by the absence of suitable plants or by untoward climatic conditions, the female begins to deposit her eggs soon after emerging. In fact, Mr. Kelley's notes[6] indicate

6. During the spring and early summer of 1908 Mr. E. O. G. Kelly became temporarily joint representative of the Bureau of Entomology and the Kansas State Experiment Station. The various facts attributed to Mr. Kelly were collected by him during this period.

that she deposits some before leaving the spot where she emerges. Finding a blade to her liking, she settles herself upon its upper surface with head facing the outer end, and with her pointed ovipositor deposits one or more eggs lengthwise in one of the furrows over which she is standing. She then places other eggs in the same or adjoining furrows, or flies away to other plants. Where more than one egg is placed in the same furrow, they are laid end to end either separated or with ends touching. Only rarely is an egg deposited upon the lower surface.

Although it is now generally conceded that the young develop only on wheat, rye, and barley, there is recent evidence to show that in some cases they may develop on certain wild grasses. On February 19, 1912, the following information from F. M. Webster, of the Bureau of Entomology, in charge of the cereal and forage crop insect investigations for the United States Department of Agriculture, reached the senior author:

"The best illustration we had of the breeding of Hessian fly in grasses, was in the fall of 1908, when there were fields of wheat along the railways in the vicinity of Wellington, Kan., literally ruined by Hessian fly. The railway authorities burned off the grass along their right-of-way at a time which enabled the young growth to shoot up at just the period when the Hessian flies were abroad in the fall. I could not see but that they laid their eggs as freely on this young grass, *Agropyron smithii,* as they would upon young wheat, and the effect of the larvæ on the growth of the leaf of the grass was just the same. These conditions were, of course, somewhat unnatural, as, ordinarily, the young grass would not have grown up as it did but for the fact that it had been burned off earlier. Thus, while we had an excellent illustration of the fact that the fly would breed in this grass freely under certain conditions, this must not be taken as implying that the pest does breed every year in this grass to the same extent that we observed it at that time. But it does prove that if there are fresh shoots coming up at the time the Hessian flies are abroad laying their eggs, they will place them on the grass precisely as they do on wheat, and develop adults thereon. Furthermore, we have absolute proof that the Hessian fly does breed freely in *Agropyon* in western Washington."

Statements as to the number of eggs a single female may lay vary considerably. Marlatt[7] states from 100 to 150. Gar-

7. Farmers' Bulletin No. 132, Bu. of Ent., U. S. Dept. of Agric., p. 15.

man[8] records the egg-laying of two specimens—one 195 and the other 215. We found that three females, kept in the insectary under an average mean temperature of 61° F. with an average mean relative humidity of 94 per cent, deposited an average of 74 eggs each, with 107 and 31 as extremes. Some of the eggs, which are deposited early, between harvest and the sowing of the following crop, hatch larvæ that turn to flaxseeds from which adult flies emerge from the middle to the thirtieth of October or later. These form a partial supplementary fall brood. On October 29, 1908, an examination of infested volunteer wheat at Wilson, Kan., showed that 48 per cent of the puparia either had already given up, or were ready to give up, adult flies. Eggs were found on the experimental sowings as late as November 15. Not all the flaxseeds that pass the preceding summer in the stubble give up adults at any time during the fall. In 1908, 10 per cent at Manhattan and 6 per cent at Wilson did not emerge in the fall, but remained over winter in the old stubble.

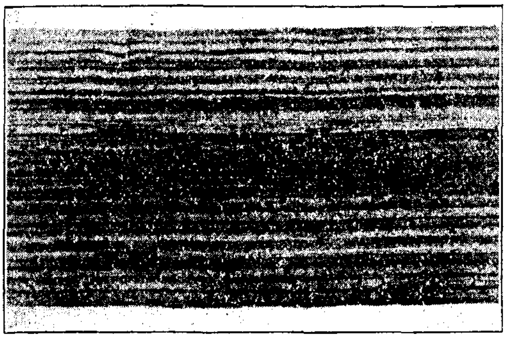


FIG. 7. Hessian fly eggs in natural position on wheat blade, magnified about eight times.

The egg of the Hessian fly is a long, oval, reddish object, about one-fiftieth of an inch in length, and small enough to lie easily in any of the lengthwise grooves that line the upper surface of the wheat leaf. Once the observer has become familiar with the shape, the location, and the reddish color, he can detect it easily with the naked eye.

When the larva hatches it is but little larger than the egg, and reddish in color. The maggot is rarely detected on the leaves. It seems to have various means of getting down into

8. Bulletin No. 111, Ky. Agric. Exp. Sta., p. 221.

the plant; some observations made by Mr. Kelly would indicate that in the presence of abundant dew it is washed down by the droplets of water. In other cases it undoubtedly crawls down, earthworm-like, following the groove until it reaches the

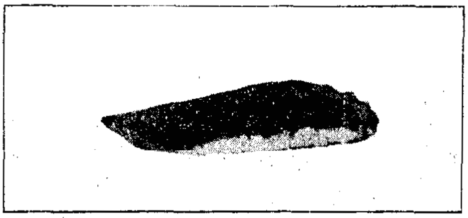


FIG. 8. Hessian fly larva almost grown. (Magnified eight times.)

place where the leaf-sheath winds tightly about the stem. Get down as it may, when once there it squeezes in between the leaf-sheath and the main stem and continues its way downward until it nearly reaches the point where the leaf takes its origin, Just above this point it stops and begins to feed. As it grows, the red color disappears and the maggot becomes white. It is now below the surface of the ground and apparently safe. Here it reaches maturity, ranging from one-eighth

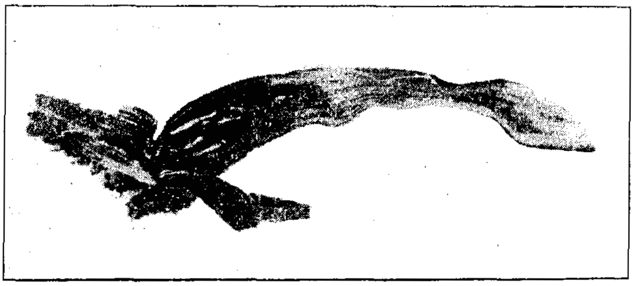


FIG. 9. Hessian fly puparia or flaxseeds in position in a wheat leaf. (Magnified two times.)

to one-fourth of an inch in length. Here it transforms to the flaxseed. The skin begins to stiffen and turn dark. The maggot, now enclosed in a new skin, shrinks and pulls away from the old skin. The old skin gets harder and turns darker until finally it becomes very resistant and of a pronounced dark-brown color. This flaxseed is long-oval in shape and about three-sixteenths of an inch in length. It is in this stage that most of the flies pass the winter. Whether any considerable number of the immature maggots overtaken by cold weather are able to live through is a matter of question. Gossard and Houser[9] observed that at Wooster, Ohio, in 1905, none of the immature maggots lived through, although the lowest temperature was 6° F. and the means for December and January were 33° F. and 33.9° F., respectively. Ordinarily our wheat sowings are examined for fly before the first of January, but in 1909-1910 several of them were not examined until the succeeding March. The minimum temperature at the stations ranged from 7° F. to 15° F.; in a few instances living maggots were found.

The first outward sign of fly damage in the fall appears in the deep green color of the infested wheat. An examination will show that the plants of such a field have the central shoot undeveloped and the leaves grown long, broad, and dark green. Later, the green color may be exchanged for a sickly yellow, and if the infestation be bad enough, the plants will die. In the fall of 1907 in some parts of the state much wheat was thus destroyed, and the fields were planted to corn the following spring.

While some of the flies may emerge during prolonged warm weather in late winter, most of them remain as shrunken maggots in their dark-brown cases until the following March. During the latter part of March, the flies begin to emerge, probably reach their maximum during early April, and cease to come out in large numbers by the end of that month. In the spring of 1908, Mr. Kelly described them as being so abundant in the wheat fields about Wellington that they reddened the ground.

The females deposit their eggs in much the same way as in the fall, choosing the tender blades. The larvæ hatch and make their way down in the plants as in the fall. If the plants be well-grown, some of the maggots will locate in joints above the surface of the ground. In backward wheat most of the maggots produced by this spring brood of flies will be found below the surface of the ground.

Here the maggots feed, grow, reach maturity, and transform to flaxseeds. This feeding so weakens the stems that not only do heads partly or completely fail to fill, but the weakened stalks break in the strong wind and fall over, making it impossible to secure what little grain may have developed in

9. Bulletin No. 177, Ohio Agric. Exp. Sta. (1906). 6.

the head. Some of the earliest eggs produce maggots that transform to flaxseeds from which emerge flies during May, At Wellington, Kan., in 1908, Mr. Kelly found that 26 per cent of the flaxseeds of the main spring brood produced adult flies between May 7th and June 1st. The females of this supplemental spring brood laid their eggs upon the tender blades of sucker wheat plants, which had sprung up apparently from the bases of older plants. The maggots descended the blades and located, owing to the size of the plant, close to the forming head, which they utterly blighted. Here they obtained their growth and transformed into flaxseeds before harvest time. At harvest in 1908 the flaxseeds were to be found on the plants below the surface of the ground, just above the ground, and high up in the sucker plants. The use of the "header" left almost everything in the stubble. The use of the "binder" left only those that lay low down on the stalks in the stubble. This included most of the main spring brood and a part of the supplementary brood. While some of the flies emerge between harvest time and early September, especially during wet seasons like the summer of 1908, most remain over summer in the stubble. The wet summer of 1908 brought on a large growth of volunteer wheat and an unusually large summer emergence of flies. In parts of the infested territory, the wheat fields became as green as meadows, and much of the volunteer wheat was so badly infested that it died before the middle of September.

Seasonal History.

LIFE CYCLE.

As might be expected, the length of the stages included in the life cycle of the fly is subject to great variation.

Marlatt[10] gives the length of egg stage as from three to five days. Gossard and Houser[11] say that it ranges from four days to two weeks. In our own experiments the length of egg stage has varied inversely with the temperature and moisture. Low temperature and low moisture lengthen the time, and high temperature and high moisture shorten it, One hundred sixty-five eggs under constant temperature of 50° F. with constant relative humidity of 75 per cent hatched in an

10. Farmers' Bulletin No. 132, Bu. of Ent., U. S. Dept. Agri. (1901), 16.

11. Bulletin No. 177, Ohio Station (1906), 3.

average of nine days, while the same number of eggs under 70° F. and 75 per cent relative humidity hatched in an average of three days. Thirty-five eggs subjected to constant temperature of 107.6° F. under relative humidity of 100 per cent hatched in an average of 2.6 days. Of two groups of twenty eggs, each under constant temperature of 50° F., one was subjected to 100 per cent relative humidity and hatched in an average of eight days, while the other was inclosed in a calcium chloride desiccator and none of the eggs hatched, Of two other groups of twenty eggs, each under a constant temperature of 70° F., one was subjected to 100 per cent relative humidity and hatched in an average of three days, while the other, subjected to conditions in a calcium chloride desiccator, did not hatch at all. It seems, therefore, clear that the egg stage may be materially lengthened by either low temperature or low atmospheric moisture, and that the length of stage varies, inversely with these factors, from two to ten or more days.

The length of larval stage is likewise variable. Marchal,[12] as reported by Osborn,[13] found the fly able to pass through all its transformations in a period ranging from twenty days in the spring, through sixteen to seventeen in midsummer, to thirty-five in the fall. Mr. Kelly's notes indicate that the complete life cycle was passed by many individuals in the spring of 1908 in one and one-half months, or about forty-five days. The individual carried entirely through in our insectary under an average mean temperature of 67° F. and an average mean relative humidity of 67.2 per cent required sixty days, of which twenty-six were occupied in the period from hatching to formation of puparium. If in other cases, as in the last cited, the larval stages require about one-half the time occupied by the entire life cycle, the active larval stage would vary from eight to about thirty days. Such larvæ as succeed in passing the winter have a larval stage of approximately six months.

The puparium stage really involves two stages. It includes that part of the period from formation of puparium to transformation to pupa, and from formation of pupa to emergence.

12. Marchal, Paul. Les Cecidomyia des Céréales et leurs Parasites, Annales de la Société Entomologique de France, 1897, Premiere trimestre, 1-105.

13. Osborne. Bulletin No. 16, Bu. of Ent., U. S. Dept. of Agric. (1898), 20-21.

The first period may be called the quiescent larval or prepupal stage; the second, the pupal stage. The duration of this last part of the larval life is variable. That part of the early spring brood which emerges during May occupies a little less than twenty days for both prepupal and pupal stages. That part of the early spring brood which does not emerge until the following fall requires five months for the same transformations, while that part which does not emerge until the following spring requires eleven or twelve months for the same transformations. Although the data on which it is founded are not so full or as systematic as we could wish, it is our conviction that the creature transforms to a pupa only a short time before emergence, that the variation in the time of flaxseed stage is due principally to variation in length of prepupal stage, and that the pupal stage is not able to withstand great extremes of cold or drouth. In the fall of 1908, at Wilson, the junior author found the pupal stage to range, under field conditions, from ten days to two weeks.

The length of adult life appears usually to be limited to a few days. Gossard and Houser[14] showed that thirteen specimens of male and female flies confined in glass cages from time of emergence lived an average of less than five days. In our experiment eleven females without nourishment or fertilization lived an average of three and three-tenths days, while three males without nourishment or sexual activity lived two and seven-tenths days; on the other hand, three females without nourishment but with fertilization lived six days, while one male without nourishment but with sexual activity lived two days. Although this does not necessarily mean that flies in the field live so short a time, yet, when coupled with field observations to the same effect, it indicates that their life is short.

Marchal's work in France, as described by Osborn,[15] would indicate that during spring, summer and early fall the life cycle ranged from sixteen to thirty-five days. Mr. Kelly's records show that at Wellington, Kan., from eggs deposited during late March and early April came adult flies during the latter three-fourths of May. The one individual of several hundred started from eggs deposited by captive females on wheat in our insectary, that successfully passed all stages, required

14. Bulletin No. 177, Ohio Agric. Exp. Sta. (1906), 7-8.

15. Bulletin No. 16, Bu. of Ent., U. S. Dept. of Agric. (1898), 20-22.

sixty days from egg to adult, under an average mean temperature of 67° F. and an average mean moisture of 67.2 per cent. At both Wilson and Manhattan, flaxseeds which were present in the stubble shortly after harvest in 1908 and which must have come from eggs of the first spring brood, for they lay low in the plants, mostly below the surface of the ground, gave up adult flies from April 22 to May 3, 1909, at Manhattan, and before May 20, 1909, at Wilson. These flies required a period of more than twelve months to complete their life cycle. The length of life cycle is evidently extremely variable, ranging from sixteen days to twelve months or more.

NUMBER OF BROODS.

There has been so much difference of opinion among students of Hessian fly as to number of broods that a brief consideration of the varying conclusions is worth while.

Fitch[16] in 1847 said that Hessian fly has two generations and that individual specimens may have their growth retarded so much as to require even a whole year to complete their metamorphosis. Osborn[17] (1898), in summarizing our knowledge of this matter, says: "This cycle [the two-brood cycle] is doubtless the most universal and will apply particularly to a large section of winter wheat cultivation under normal conditions. It is especially the normal round in the eastern United States where all the earlier studies were made. . . . Nevertheless, recent studies have shown wide departures from this normal cycle, and these variations are of the utmost importance in determining the successful application of remedial measures." Webster[18] in 1899 held that in the territory between the Allegheny mountains and the Mississippi river and between the Ohio river and the Great Lakes there were only two broods, and that apparent supplementary broods were composed of either advance guards or stragglers resulting from acceleration or retardation as a result of weather conditions. He also held it probable that farther north the fall brood was eliminated, making the species single-brooded. Lugger[19] (1899) argues that

16. Transactions N. Y. St. Agric. Soc. for 1846-'47, vol. 6, 342, or in 1847 separate volume, 29.

17. Bulletin No. 16, Bu. of Ent., U. S. Dept. of Agric. (1898), 19.

18. Bulletin No. 107, Ohio Agric. Exp. Sta. (1899), 260-270.

19. Bulletin No. 64, Minnesota Agric. Exp. Sta. (1899), 351-357.

in the Red River valley there is only one brood. Fletcher[20] (1900) showed that the fly is two-brooded in Ontario and that some of the summer flaxseeds do not produce flies until the following spring. Washburn[21] (1903) holds that the fly in the Red River valley is two-brooded, because he found larvæ and flaxseeds in volunteer wheat growing in the stubble on October 18. Webster[22] (1899) places the beginning of the idea of more than two broods in 1820, when James Worth, writing in the American Farmer,* says: "It may then be said, that during the past year [1820] there have been three complete broods and partially a fourth." According to Osborn,[23] Lindemann, '87, concludes as a result of his work on the fly, that it has three well-marked broods in the latitude of Moscow, Russia. Marchal,[24] 1897, demonstrated that under outdoor conditions with an optimum of food supply the Hessian fly can at Paris, France, 'produce as many as six generations between the beginning of spring and the end of autumn. Of course, the abundance of suitable food provided by Marchal in the course of his experiments is not duplicated in nature, and the number of broods secured by him will not be found in nature. Marten[25] (1891) recorded the production of a second spring brood of adults in the course of insectary breeding experiments which were abundantly confirmed by field observations. Marlatt[26] (1901) summarizing our knowledge, says that "there are, however, supplemental broods both in spring and fall, particularly in the southern wheat area. . . ." Garman,[27] writing in 1902, reports three broods for Kentucky, but qualifies the report by suggesting that the third may be due to very favorable weather conditions. Webster,[28] writing again in 1906, says that, in addition to the regular spring and fall broods there appears in some localities, under some conditions, a supplementary second brood following the main spring brood, and a supplementary fall brood following the main fall brood. He further finds,

* American Farmer, 3:188; 213.

20. 31st An. Rept. Ent. Soc. of Ontario (1900), 62.
21. Bulletin No. 84, Minnesota Agric. Exp. Sta. (1903), 1-11.
22. Bulletin No. 107, Ohio Agric. Exp. Sta. (1899), 261.
23. Bulletin No. 16, Bu. of Ent., U. S. Dept. of Agric. (1898), 19.
24. Bulletin No. 16, Bu. of Ent., Dept. of Agric. (1898), 20-21.
25. Insect Life, 3:265-6 (March, 1891).
26. Farmers' Bulletin No. 132, Bu. of Ent., U. S. Dept. of Agric. (1901), 15.
27. Bulletin No. 103, Ky. Agric. Exp. Sta. (1902), 241.
28. Circular No. 70, Bu. of Ent., U. S. Dept. of Agric. (1906), 5.

from Reeves' work in North Dakota, that two broods of fly occur in that region.

In the spring of 1908, Mr. Kelly's notes show that at Wellington the adults of the main spring brood emerged during March and April, probably between March 25 and April 22. At Wilson in the spring of 1909 the adult flies of the main spring brood emerged from April 4 to April 25, the maximum emergence having occurred by April 16. Mr. Kelly's notes show that a supplementary spring brood of adult flies emerged between May 7 and June 1. That a large number, enough for a midsummer brood, emerged in 1908 between harvest and wheat sowing is demonstrated by the fact that in many fields, volunteer wheat, which sprang up in the wheat stubble after harvest, was totally destroyed by fly before the middle of September. Our observations at Wilson in 1908 show that first a main fall brood of adult flies emerged between September 22 and October 28. None of these produced progeny which reached the adult stage before winter. Of these that emerged and infested the volunteer wheat previous to the middle of September, 48 per cent either had produced or were just ready to produce adult flies on October 29, 1908. The flies of this supplemental fall brood emerged from October 15 to October 30 and probably later, for eggs were found on experimental sowings as late as November 15.

There would, therefore, appear to have been two main broods and as many as three supplemental broods in the year ending December 31, 1908. It must be remembered, however, that the summer of 1908 was exceptionally wet, producing a heavy crop of volunteer wheat in the wheat stubble and accelerating the fly. In normal seasons, or, more particularly, in dry summers, the midsummer brood might be almost entirely suppressed and no supplemental fall brood developed. It is plain, then, that the number of broods of fly in this state is bound to vary with the climatic conditions; and it is equally plain that where fly is present in large numbers, the measures of control must be such as will control both main and supplemental broods.

The source[29] of the individuals composing each brood is even

29. Bases for statements about composition of broods:

It should be said at the outset that the possible sources of flies in a country where much wheat and little barley and rye is grown must be old stubble, volunteer wheat, and regular crop. The infestation in the old stubble is practically exhausted in one year from the date of the harvest by which it is formed. The infestation in volunteer wheat is pracmore difficult to determine than the number of broods. Our notes distinctly show that the main spring brood is drawn from at least three sources: (1) puparia in the stubble of the preceding year's crop; (2) puparia that have passed the winter in the present year's crop; (3) puparia that passed the winter in volunteer wheat which grew up after harvesting the preceding year's crop. They also show that the supplemental spring brood is at least composed of individuals that come from: (1) puparia formed by the main spring brood; (2) puparia formed in volunteer wheat, which sprang up in the stubble after harvest of the preceding year; (3) puparia in the stubble of the preceding year's crop. Our observations do not afford us absolute proof as to the composition of the midsummer emergence, but it is probable that the flies come mainly from puparia formed by the main spring brood. The main fall brood appears to come mainly from puparia formed by the main spring brood. The supplemental fall brood at Wilson in 1908 came

tically exhausted by the time the regular crop is harvested. The regular crop becomes infested in the fall and remains so until by harvesting it is transformed into old stubble.

A. Reasons for thinking that the main spring brood comes from—
  I. Puparia in the preceding year's crop.
    1. At Manhattan, in 1908, ten per cent of the flies in the old stubble, and at Wilson six per cent, failed to emerge until the spring of 1909. At Manhattan this spring emergence extended from April 22 to May 3; at Wilson, from April 15 to May 20.
  II. Puparia in the present year's crop.
    1. All our observation confirms the general opinion that this is the case.
    2. Emergence started April 8, 1909.
  III. Puparia in volunteer wheat.
    1. Only forty-eight per cent of the flies infesting the volunteer wheat the summer of 1908 emerged during the fall of 1908.
    2. Emergence in the spring of 1909 started April 3.

B. Reasons for thinking that the supplemental spring brood comes from—
  I. Puparia of the main spring brood.
    1. In 1908 twenty-six per cent of the first spring brood emerged between May 7 and June 1.
  II. Puparia in the volunteer wheat of the preceding year.
    1. We had no chance to collect data, but it seems very probable that inasmuch as emergence began only five days before that from the old stubble, it did not stop long before the flies ceased to come from the latter, which time in 1909 was May 20.
  III. Puparia in the stubble of the preceding year's crop.
    1. In 1909 emergence did not cease until May 3 in one case and until May 20 in another.

C. Reasons for thinking that the midsummer brood comes mainly from—
  I. Puparia of the main spring brood.
    1. In 1908 a very large number of flies were on the wing and the puparia in the old stubble and volunteer wheat had been exhausted.
    2. The supplemental spring brood in 1908 was so heavily parasitized that few flies could possibly come from it. Considering the time during the spring when the parasites are on the wing, it seems likely that the high parasitism of this brood may be a common thing.

D. Reasons for thinking that the main fall brood comes mainly from—
  I. Puparia of the main spring brood.
    1. All other available sources, except the summer growth of volunteer wheat, were in 1908 practically exhausted, and the flies in the volunteer wheat did not emerge.

E. Reasons for thinking that the supplemental fall brood comes mainly from—
  I. Puparia in the volunteer wheat of the preceding summer.
    1. In 1908 forty-eight per cent of the flies in volunteer wheat either had emerged from October 16 to October 30 or were ready to emerge on the latter date.
    2. In 1908 none, or practically none, of the flaxseeds of the main fall brood of that year produced flies.

from puparia formed by the midsummer brood in volunteer wheat. These facts are represented graphically in the accompanying diagram.

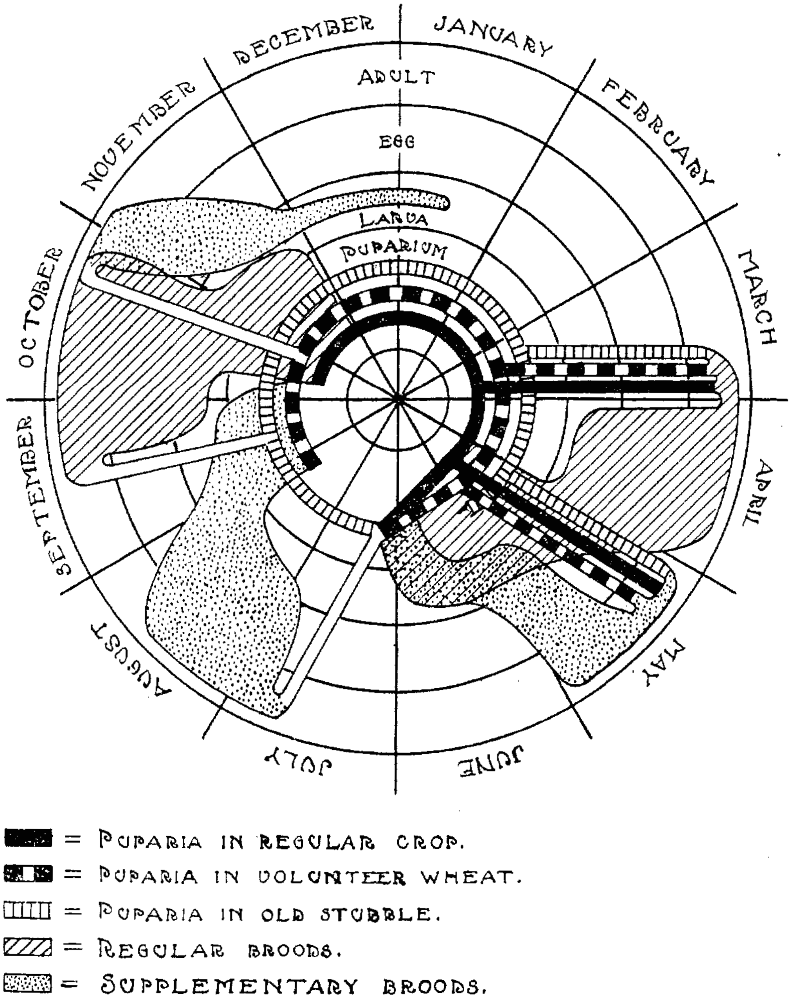


FIG. 10. Diagram to represent the number of broods of Hessian fly, the period of their appearance, and the sources from which they came.

Natural Checks.

Like most insects, the Hessian fly is dependent upon the environment in which it lives for the conditions that make its life economy possible: low temperatures and drought lengthen the span of its life cycle or, indeed, if severe at a critical stage, may almost eradicate it in limited localities; natural enemies always reduce its numbers.

CLIMATE.

It is probable that the climatic factors which exert the largest influence on Hessian fly are temperature and moisture.

TEMPERATURE.

Low temperature. The low temperatures of winter prolong the life cycle of the fly from thirty to sixty days to six months. Low temperatures at critical times may so reduce and hinder its progress that badly infested wheat may make a good crop. Bruner and Swenk[30] believe that a most serious attack of Hessian fly in Nebraska was in the spring of 1905 prevented by a sudden drop in the temperature just after the adults had emerged in great numbers. They say: "In the vicinity of Lincoln the flies appeared on April 8 in a period of warm damp weather, and continued a rapid emergence for four days, when there occurred a severe drop in temperature which was sustained for three days and attended with snow. On the 14th and 15th of April the highest temperature for the forty-eight hours was 45° F., the thermometer twice dropping to 24° F. and maintaining a mean temperature of 34° F." These investigators believe that the cold destroyed the flies and such eggs as had been deposited and so retarded the remainder of the brood that the wheat obtained a start sufficient to enable it to make a good crop, although forty to sixty per cent of it became infested.

Gossard and Housers[31] showed that a half-hour exposure of eggs to 25° F. did not affect their vitality, and that eggs brought in from the field after being subjected to a killing frost

30. Bulletin No. 96, Nebr. Agric. Exp. Sta. (1907), 8-9.

31. Bulletin No. 177, Ohio Agric. Exp. Sta. (1906), 30.

are not injured. The same investigators found that heavy frosts checked the egg-laying, but that it increased afterwards.

High Temperature During the hottest part of the year the bulk of the fly is in the flaxseed stage and in its most resistant condition, and there are no observations on record showing that summer heat has ever proved sufficiently fatal materially to reduce its numbers. Efforts to determine the fatal high temperature of the egg in moist atmosphere (practically saturation) showed that it could for three days easily withstand 107.6° F., which was about all the plants could resist. Thirty-five eggs were used, of which thirty hatched in between two and three days.

MOISTURE.

Low Humidity. Riley,[32] writing in 1877, says: "The prejudicial effect of drought has not been hitherto observed, that we are aware of, but was very noticeable the past year in part of Ohio, where the puparia literally dried up. . . . The intense heat had not only desiccated the Cecidomyia [Hessian fly], but what is still more remarkable, in most cases the parasites also." Forbes,[33] writing in 1890, says: "The history of the Hessian fly during the past two years exhibits anew the effect of drought upon the multiplication of that species. Many of the wheat fields of southern Illinois, in regions which had been free from the fly the preceding year, showed it in such numbers at harvest time in 1887 as to make it seem probable that the following crop would suffer heavily, bat a severe midsummer drought prevailing prevented almost entirely the growth of volunteer grain and very probably dried up the larvæ and pupæ of the fly in the field. As a consequence, these neighborhoods in 1888 were almost absolutely free from attack, although in adjacent counties where the drought was less severe the fly was noticeably abundant in the fall of 1887 and in the following spring." According to Osborn,[34] Paspelow in Russia showed that the emergence of the midsummer brood was prevented by the high temperature and great drought, and that the flies came out during the latter part of August and the first part of September.

High Humidity. Plenty of atmospheric moisture is as favorable to the fly's activities as drought is dangerous.

32. Am. Nat. 15 (1877), 916.

33. Sixteenth Rep. State Ent. of Ill. (1890), 10-21.

34. Bulletin No. 16, Bu. of Ent., U. S. Dept. of Agric. (1898), 22-23.

COMBINATION OF UNUSUAL TEMPERATURE AND HUMIDITY.

High temperature, when accompanied by low atmospheric moisture, always increases the length of life cycle, particularly if it find the fly a maggot in the puparium; if severe, it may prove fatal to any stage. High temperature, accompanied by high atmospheric moisture, does not seem either to retard development or to prove fatal. Such low temperatures as the fly may experience increase the length of its life cycle and prove fatal in most cases to all except the prepupal stage. Low atmospheric moisture, either with or without high temperature, increases the length of life cycle, or, if extreme, may destroy the fly in all stages. High atmospheric moisture is universally beneficial to its activities, The junior author found 83 per cent of the tillers in a field sown September 28, 1908, infested with the overwintering flaxseeds on April 1, 1909. By April 21 most of the flies from old stubble, volunteer wheat and early sown crop had emerged and 70 per cent of the tillers bore one or more eggs by April 29. Despite this large amount of egg laying, the field on May 20 showed only 7.2 per cent of the tillers infested. Fields of late-sown wheat examined at this time revealed no infestation whatever. Most of the early-sown fields showed less infestation in the higher ground, and more in the lower places. This condition was typical about Wilson. Clearly the fly must have experienced wholesale destruction between April 29 and May 20. No rain of consequence fell between the last of March and May 13. A very light shower fell in the morning of April 15. By the time the eggs were deposited in considerable numbers, the atmosphere was so dry that many could not hatch at all. By April 29 many of the eggs had begun to shrivel. On April 30 many eggs from which larvæ had escaped were found, but no larvæ could be found in the plants. By May 3 most of the unhatched eggs upon the plants were badly shriveled.

During most of this period the air was constantly in motion sometimes blowing furiously and carrying clouds of dust with it. It is highly probable, that many of the flies were destroyed by the winds and so failed to oviposit, and that most of the larvae which did hatch were unable to crawl down the leaves and were blown from the wheat blades.

It therefore seems that the continued absence of rain and dew, together with low temperature at the brief period when moisture was upon the wheat blades, coupled with an atmosphere continually dry and almost continuously in motion, almost exterminated the fly about Wilson. Later investigations showed that a similar destruction of the fly had taken place throughout the seriously infested portion of the wheat belt.

NATURAL ENEMIES.

Like other members of the insect world, the Hessian fly is preyed upon by parasitic and predaceous enemies. Osborn records for America six species that have been known to attack the fly and two other species that prey on its parasites.

PARASITES THAT DESTROY THE FLY:

Osborn's list of parasites.	Parasites taken in the course of this study.
Merisus destructor Say	*Merisus destructor* Say
Bœotomus subapterus Riley	
Pteromalus pallipes Forbes	
Eupelmus allynii French	*Eupelmus allynii* French
Entodon epigonus Walk.	
Polygnotus hiemalis Forbes	*Polygnotus hiemalis* Forbes
Platygaster herrickii Packard	*Platygaster herrickii* Packard

PARASITES THAT ATTACK THE PRIMARY PARASITES OF THE FLY:

Tetrastichus productus Riley	*Tetrastichus* sp.
Tetrastichus carinatus Forbes	

In the course of the study at this station, four of these species of primary and one of the species of secondary parasites have been found. Many other species of parasitic insects were discovered in cages which had been placed over infested wheat stubble — among them, two new to science. These new species have been determined by Mr. A. E. Gahan,[35] associate entomologist of the Maryland Station, and have been described by him. They are *Synaldis incisa* Gahan and *Hoplogryon kansasensis* Gahan.

Only one specimen of *Merisus destructor* Say was taken, and that on September 15, 1908, but this species was seen at Wilson, Kan., more frequently than any other. *Eupelmus allynii* French was reported.

RECORD OF PARASITE COLLECTIONS.

Merisus destructor Say. At Wilson, Kan., September 15, 1908, one specimen, (This species was found more frequently

35. The thanks of the authors are due Mr. Gahan for his kindly assistance in identifying the species of hymenopterous parasites taken in the course of this study.

on the wing at Wilson during the fall of 1908 than was any other.)

Eupelmus allynii French. (This species was taken in considerable numbers by Mr. Kelly at Wellington during the late spring of 1908, and one specimen emerged at Manhattan in field cage over infested stubble, July 23, 1908.)

Polygnotus hiemalis Forbes. (This species was reported by Mr. Kelly from Wellington in large numbers during May, 1908.)

Platygaster herrickii Packard. Manhattan, Kan., September 28, 1908, fourteen specimens. (These specimens were dissected from Hessian fly puparia and were perfectly formed adults having the usual dark color.)

Manhattan, Kan., January, 1909, three specimens. (These specimens were dissected from Hessian fly puparia and were perfectly formed adults having the normal dark color.)

Manhattan, Kan., April 10, 1909, one specimen.
Manhattan, Kan., April 13, 1909, one specimen.
Manhattan, Kan., April 16, 1909, four specimens.
Manhattan, Kan., April 22, 1909, one specimen.
Manhattan, Kan., April 24, 1909, six specimens.
Manhattan, Kan., May 3, 1909, one specimen.

Tetrastichus sp. Wilson, Kan., September 18, 1908, one specimen from Wellington in the late spring of 1908 in considerable numbers by Mr. Kelly, *Polygnotus hiemalis* Forbes was reported in large numbers during the late spring of 1908 at Wellington by Mr. Kelly; it was taken at Wilson during the early fall of the same year. *Platygaster herrickii* Packard was taken frequently at Manhattan during the spring of 1909, and perfectly formed adults were dissected from Hessian fly puparia in September and in the January preceding. It seems likely that *Platygaster herrickii* Packard passed the winter as an adult in the puparia of its host, for perfectly formed adults were dissected from Hessian fly puparia in September, 1908, and January, 1909, and although the cages in which the species were caught were set in August of 1908 and kept in place until the following June, specimens were taken only during April and May.

NOTE.—All individual parasites, unless otherwise labeled, were taken as adults, either in the field or in cages set over infested stubble or wheat in the field. All collections at Manhattan and at Wilson were made from field cages, and the dates given represent, within twenty-four hours of absolute accuracy the actual date of emergence.

With the meager data at hand it is hard to say which species has been the most effective check. At Wilson, in 1908, the junior author found *Merisus* most active, while at Manhattan *Platygaster* was easily first.

Repeated examinations of the stubble in the late summer and fall of 1908 showed that almost all of the flaxseeds above the ground had been destroyed by parasites, but that few of those beneath the surface were infested. Some idea of the extent to which parasitic enemies destroyed the fly during the outbreak of 1908 may be had by examination of the following table:

Counts of infested 1908 wheat stubble made at Wilson, Kan.

Date.	Number of plants.	Number of puparia.	Number parasitized.	Per cent parasitized.
Sept. 15, 1908	16	245	88	35.8
" 18, 1908	18	341	163	47.7
" 19, 1908	15	267	16	5.9
" 23, 1908	21	628	142	22.6
" 24, 1908	17	287	103	35.8
" 30, 1908	...	155	22	14.1
" 30, 1908	22	670	181	27.0
Oct. 2, 1908	...	365	191	52.8
" 6, 1908	22	633	204	32.2
" 15, 1908	18	456	114	15.0
" 22, 1908	19	402	106	26.3
" 23, 1908	21	557	127	22.8
" 30, 1908	15	232	38	16.3
Total	...	5,238	1,495	28.5

Counts of 1908 infested wheat stubble made at Manhattan, Kan.

Date.	Number of puparia.	Number parasitized.	Per cent parasitized.
Aug. 27, 1908	286	0	0
" 31, 1908	222	6	2.2
Sept. 4, 1908	203	11	5.4
" 9, 1908	169	4	2.3
" 14, 1908	157	5	3.1
" 19, 1908	91	6	6.6
" 24, 1908	181	15	8.3
" 29, 1908	167	22	13.1
Oct. 4, 1908	100	7	7.0
" 9, 1908	227	29	12.7
" 14, 1908	114	3	2.6
" 20, 1908	129	14	10.7
" 25, 1908	140	8	5.7
" 31, 1908	77	3	3.8
Nov. 16, 1908	100	6	6.0
" 30, 1908	106	16	15.0
Dec. 7, 1908	117	12	10.2
Mar. 17, 1909	92	17	18.4
June 19, 1909	24	0	0
Total	2,702	184	6.8

Thus it is seen that, while parasites were practically always present and destroyed a considerable per cent of the fly, they were totally unable to bring it into subjection. While working at Wilson, the junior author found the work of two predaceous enemies which he described as follows: "While digging up infested wheat, I frequently observed in plants entirely dead that the 'flaxseeds' had been destroyed, the puparia being in fragments. A close search showed that a larva that I take to be a 'wire worm' was the agent that did the work. I found several of them actually at work inside the plants. Where these larvæ are abundant in the soil, much of the fly has been destroyed. It is my belief, however, that the destruction of the fly is only incidental, since the interior of the plant is entirely eaten away and in some cases not all of the 'flaxseeds' have been destroyed. On April 13, I found numerous plants in which the 'flaxseeds' of the fly had been destroyed and in these were present small white dipterous larvæ pointed at the anterior end, blunt at the posterior end, and provided at that end with six bunches of short, small spines. I finally found one with its head thrust into a 'flaxseed.' I then took an infested plant (free from these larvæ) in which were two sound 'flaxseeds,' placed it with three more sound 'flaxseeds' in a bottle, and then introduced two of these larvæ. One Hessian fly and one of the dipterous insects emerged. Three of the five flies had been destroyed. The other dipterous insect was missing." By some unfortunate chance, specimens of the wire worm were lost and others could not be found. The dipterous insect proved to be a fungous gnat *(Sciara N. sp.*[36]*)*.

It was thought by Marchal that nematode worms might incidentally destroy some of the larvæ, and by Walsh and Pergande that thrips sometimes attacked the fly.

Despite the fact that there are cases on record where nine-tenths of the flies in a given area have been destroyed by parasites, they are, over the country as a whole, unable to reduce the damage below an average of ten per cent of the crop. No doubt it would be difficult to grow wheat at all were it not for the work of parasites against the fly, but with the parasitic and predaceous foes at their normal maximum efficiency the average loss is still very serious and the loss

36. This Sciara was submitted to O. A. Johannsen and by him h new species.

to large numbers of individual farmers is frequently total. Indeed, it seems that after the fly has been reduced by all the natural checks to which it is subject, there is yet much for the wheat grower to do. Of course, after unfavorable weather or parasites, or both, have almost eradicated the fly, the farmer needs to take no measures against it for a time, but sooner or later he must fight it or lose all his crop.

Injury.

NATURE OF INJURY.

It is the maggot that directly damages wheat, barley, and rye. It is the maggot that robs the plant of its sap and deadens the tissue where it feeds. The food for the nutrition of the plant is made in the leaves by the union of carbon from the air and of earth salts drawn up through the stem dissolved in the sap. The food manufactured in the leaves is carried down the stem for the nutrition of the parts below. The maggot not only takes all the sap which it can consume or get, but in killing the tissue of the stem interferes with the passage of food and material for making food and starves the plant. If the plant be weak or the infestation be great, it will die; if it be strong and the infestation slight, it may live to ripen and produce some grain.

The fall broods of maggots attack the wheat plants when they are young, and the infested stalks are always stunted and frequently killed, but other shoots, known as tillers, grow

FIG. 11. Effect of Hessian fly on the growth of the young wheat plant. (Adapted from Webster.)

-2

out from below the point of injury. Indeed, if only the central shoot be injured, the number of tillers produced may be so great that the injury will not be serious. If infestation is heavy and the plants young, with only one or two blades sufficiently developed to receive eggs, as was the case in some fields at Wilson in the fall of 1908, no stimulation to tiller occurs and the infested plants soon perish outright. In most instances that have come under our observation, only the shoot that is attacked is injured, but in some cases injury has been done to adjacent tillers, thus pointing to the possibility that the activities of the maggot initiated toxic effects even where its body was separated from the point of injury by the thickness of two leaf sheaths. The junior author found this type of injury at South Haven. One of the wheat plants which he collected showed four tillers, two of which were touching. Between the leaf sheath and the stem of a tiller, about one-eighth of an inch above the crown, lay a flaxseed. The point where this flaxseed lay was between the two touching tillers, but the flaxseed itself was clearly separated from the uninfested tiller by the leaf sheath of the infested tiller. Yet the uninfested tiller was as severely injured as the infested one at a point directly opposite the flaxseed. The injury to the two tillers, as far as external evidence would enable one to judge, was identical, and no other cause to which the injury to the uninfested tiller might be assigned was apparent.

The spring broods of maggots find the plants much larger and much better able to withstand their attacks. The attack is made in exactly the same way, but owing to the increased size of the plant, the point of injury is higher up on the stalk. The tissue of the straw which is subject to the maggots' attack appears to cease growth and allow the surrounding part to overgrow it, forming a niche just large enough for the maggot. Depending on the severity, the injury to the stem may kill it outright; may permit the heal to form and partly fill, but may so weaken the stem that it will break at the point of injury and fall over before harvest; or may permit the head to form and partly to fill and may leave the stalk strong enough to stand and be harvested with the rest.

It is only when the fall injury is such as to turn the wheat a sickly yellow or to destroy it outright, or when spring injury causes the wheat to break and fall over before harvest, that the average grower knows that the fly causes injury. Nevertheless, the other forms of damage, not noted because obscure, are real and important.

EXTENT OF INJURY.

In 1904 Marlatt,[37] in estimating the losses which this country experiences annually through the ravages of injurious insects, reached the conclusion that the Hessian fly taxes our wheat crop each year an amount equal to ten per cent of our total yield. This means that the 1909 wheat crop in the United States suffered a damage of 66,460,200 bushels. In 1908 forty-one Kansas counties reported injury ranging from 0 to 50 per cent of the crop and totaling 9,676,043 bushels. Large numbers of individual farmers lost 100 per cent. When we take into consideration the fact that these estimates do not include any of the obscure forms of damage, it is clear that ten million bushels would be a conservative estimate of the amount of Kansas wheat destroyed by the fly in 1908. The loss was progressively greater as one passed from the northern to the southern boundary of the state; this appeared to be correlated with the time of seeding. It is reasonable to assume that the wheat was in general sown at least as early in 1907 as in 1908, because during 1908 the warning had been sent broadcast to sow the wheat after certain fly-free dates. Assuming this to be the case, in 1907 thirteen or more per cent of the wheat in the northern half of the state was sown before the recommended fly-free date, while thirty-four or more per cent of that in the southern half of the state was sown before the recommended fly-free date. In 1908 when the crop was harvested, the north half of the state was found to have lost thirteen per cent of its wheat and the south half thirty per cent of its wheat through Hessian fly.

The importance of the fly's work to the individual farmer is not to be measured by its average annual damage, but by the percentage of his crop it may destroy. The importance of the fly to him is, accordingly, measured by the fact that it may destroy 100 per cent of his crop.

37. Yearbook, U. S. Dept. of Agric., 1904, 466-467.

Measures of Control.

Plainly, then, while natural checks to the fly's increase are of consequence, in our present state of knowledge they are so completely beyond our control and at best their work is so inadequate that dependence upon them would be pure folly. The wheat grower must, therefore, look to artificial measures as the best means of safeguarding his crop.

Students of the fly's habits and practical growers of wheat have in the past suggested many means for its control. Most of them prove unavailing under severe test, many extend a little help, and a few have proved of great and lasting value.

MEASURES OF LITTLE IF ANY VALUE.

So constantly do these misleading methods reappear, particularly in our agricultural papers, that they should be mentioned if for no other reason than merely to point out their useless nature.

GRAZING.

This method is generally practiced in certain parts of our state as a means primarily of obtaining forage during fall and winter, and, secondarily, of destroying the fly. Grazing must affect the fly either by consumption of the eggs while still on the leaves, or by trampling the maggots after they have got down into the plants. The eggs which will produce the larvæ that will injure the wheat are deposited between September 1 and October 15, for it is probable that eggs laid after October 20 even in extreme southern Kansas would produce larvae, very few of which would survive the winter. Our experience shows that the fly is not fond of wheat that has just emerged, but prefers that it show two blades. This period of oviposition and this preference mean that to destroy the eggs the wheat must be eaten off to the ground constantly from before it is two-bladed to the middle of October.

As a rule, men who pasture the wheat are accustomed to let it become good pasture before turning the stock upon it. The result of this procedure is that the number of eggs destroyed does not materially affect the abundance of the fly for the eggs have ample time to hatch and the maggots time to reach their places between the leaf-sheaths and the stems below the surface of the ground, before the wheat is closely trimmed.

This being the case, pasturing could hurt the fly seriously only by trampling. When we remember that the creature may be an inch below the surface, it is hard to understand how it could be crushed and the infested stalk remain unhurt. Moreover, it is entirely unlikely that all or nearly all the infested stalks would be trampled.

It would, therefore, appear that the habits of the fly preclude its control by pasturage. Actual observations made during the fall of 1907 showed clearly that while some of the eggs may be consumed and some of the maggots are destroyed by trampling, pasturage is totally insufficient to control the fly.

ROLLING OR BRUSHING.

These measures are directed against the eggs, and must operate in one or all of three ways — crushing, knocking off on the ground, and so bending the egg-bearing blades down that the maggots on hatching from the eggs will have to travel uphill, a thing they apparently can not do.

When we remember that the fly may lay its eggs from the time the wheat is two-bladed, that the eggs may hatch in three days, and that the period of possible oviposition extends from the time the early sown wheat gets above the ground to October 15 and later, it is plain that immense numbers of eggs may be laid and may hatch, and the maggots get down into the plant before, between, and after rolling or brushing.

MOWING.

It is sometimes said that mowing the wheat in the spring after the spring brood has got into the plants will prove an effective measure against the fly. This is supposed to destroy the fly by cutting the wheat stalk off below the point where it is at work. Fitch was inclined to consider this suggestion worth while in the state of New York, but when we consider the large number of the spring brood that lie low down on the plants and the difficulty the plants would experience in making the new growth after being cut off, especially if the weather were dry, the suggestion does not seem promising for our state.

FLY-PROOF WHEAT.

Fitch,[38] writing on this subject in 1847, said: "That there are many kinds of wheat which are perfectly 'fly proof' (to use a common expressive term), as has been sometimes stated, we wholly disbelieve. At times when the fly is so excessively numerous as to attack barley and rye, it is not probable that any of the cultivated species of the genus *Triticum* can entirely withstand its attacks." This is exactly where we stand to-day. No known strain of wheat is "fly proof." Some strains arc undeniably less injured by fly than others, but the difference, in view of the fact that the fly may be controlled by other measures, is not sufficient to render the growing of inferior wheat worth while just because it is more resistant to fly. It will pay much better to grow that wheat strain which, untouched by fly, will produce the largest amount of high-grade wheat, and to destroy the fly by other means.

SPRAYING AND DUSTING INFESTED PLANTS.

Garman's work in Kentucky shows that regular treatments of infested wheat with kerosene emulsion, Bordeaux, lime and Paris green, and lime are not worth the trouble. Indeed, from the standpoint of the creature's life history and habits, it is difficult to see how any practical good could come from such treatments.

INTERMITTENT WHEAT CULTURE.

There is little doubt that if wheat, rye, and barley were discontinued for a couple of years, the fly would be almost eradicated. To be efficient, this plan would have to be accepted and carried out by all growers over a large territory, for a field here and there would keep up the supply of flies. Such a plan entails large losses, and, in view of present relatively satisfactory measures of combating the fly, would seem pure folly.

TRAP PLANTING.

Trap planting has been strongly recommended by various students of the Hessian fly, but in our present state of wheat culture, it seems hardly worth while. The volunteer wheat of

38. Transactions N. Y. St. Agric. Soc. for 1846-'47, vol. 6, or separate volume for 1847

39. Bulletin 103, Ky. Agric. Exp. Sta. (1902), 239-240.

the careless farmer will serve the same purpose, and save the grower the trouble of planting and later destroying the early bands of wheat, as usually recommended.

USEFUL METHODS.

DESTRUCTION OF FLY IN INFESTED STUBBLE.

Destruction of the fly in infested stubble has long been recognized as one of the best means of combating the fly. It is, of course, based on the fact that the fly rests from before harvest time to fall wheat sowing as a helpless puparium in the wheat stubble. Two general methods of accomplishing the destruction of the stubble have been suggested, burning and plowing under.

BURNING.

The relative efficiency of burning depends upon the location of the flaxseeds, whether they are all well above the surface of the ground or many of them are below it. In early August, 1908, four areas, each containing sixteen square feet, were selected in an infested stubble field, and each bunch of stubble was carefully searched for flaxseed. The wheat had been cut with a self-binder, and some of the infestation carried away with the straw. But almost all of that which remained lay entirely below the surface of the soil at depths ranging from just at the surface to one inch below it. The majority was found just above the crown of the plant, surrounded by the bases of the leaves of dead tillers, many of which were no longer above ground. On other plats from which the wheat had not been cut, the flaxseeds were found in the heads of sucker plants and in the first node below the heads of stunted stems, and this has been the general result of all examinations during 1908, 1909, and 1910. It is, therefore, perfectly plain that methods for destruction of fly in stubble must be of such a nature as to destroy flaxseeds located anywhere on the stalk from the head to an inch below the surface of the soil. In order to test the efficacy of fire as a means of destroying the flaxseeds, an area of considerable size was selected from stubble in which the check plats yielded an average of seventeen flies to the square yard. The selected plat was burned over, and one fly to the square yard emerged. In a similar experiment at Wilson, where the checks showed eighty to the square yard, the junior author found an emergence of fifteen to the square yard. It is therefore perfectly plain that while burning the stubble will destroy many of the puparia, it will not kill enough to keep the insect under control. Furthermore, it has been our experience that puparia which lie above the surface of the ground are the ones that are parasitized, while those below are relatively free. Burning has the additional disadvantage of depriving the soil of the stubble which, if allowed to rot in or on the ground, would increase the supply of humus.

PLOWING UNDER.

Of course, the reason behind this method lies in the idea that the infested stubble can be so deeply turned under and the ground so firmly packed that the flies emerging from the buried flaxseeds will perish before reaching the surface of the soil. With the idea of determining how much soil the fly could thus penetrate, thirty puparia, mostly containing pupa, were buried in each of six cages on April 9, 1909. They were buried in a dark, slightly sandy loam at depths ranging from one to six inches. The soil was watered from the top, and a surface mulch of pulverized soil was maintained. In the cage where flaxseeds were buried one inch, eight flies emerged; where the depth was two inches, two came out; where three inches, three came out; where four, five, and six inches, none emerged. In a field test of the seventy-seven flies emerging from ninety-five flaxseeds buried in the field beneath three inches of soil, only one was able to get through the covering soil. This would seem to indicate that where the plowed stubble is buried beneath four or more inches of well pulverized soil none of the flies can escape.

In the course of our search for a satisfactory method of destroying the fly in stubble, we have tried at Manhattan various combinations of burning, plowing, disking, and harrowing. After the treatment of each plat was completed, an India-linen-covered 3'X 3' cage was set over a typical spot and faithfully examined from day to day. All flies and Parasitic enemies were caught, recorded, and removed. The following table shows the effect of these treatments on the fly.

TREATMENT.

Plat No.	Treatment, the principal element of which in plowing 6 in. deep.	Number of flies emerging.
1	Burned, plowed, gone over once with an Acme and once with a smoothing harrow	0
2	Burned, disked, plowed, and gone over once with an Acme harrow	2
3	Burned, double disked, plowed, and gone over twice with an Acme harrow	0
7	Plowed, gone over once with an Acme and once with a smoothing harrow	2
8	Disked, plowed, and gone over twice with an Acme harrow,	0
9	Double disked, plowed, and gone over twice with an Acme harrow	2
	Average emergence	1
	TREATMENT FROM WHICH PLOWING IS OMITTED.	
4	Burned and double disked	5
5	Burned and disked	10
6	Burned	1
10	Double disked	4
11	Disked	20
	Average emergence	8
	UNTREATED.	
12	Untreated	30
13	Untreated	21
	Average emergence	25

This table serves to show that any of these treatments will reduce the total number of flies and that some of them will, if carefully carried out, reduce the number almost, if not quite, 100 per cent. The destruction of the fly in the infested stubble is rendered doubly important by the fact that not only do flies emerge from it in the fall, but they come from it the following spring in sufficient numbers[40] to do large damage to the growing crop. Thus it appears that although the crop of wheat may be sown in infested stubble so late that it will escape the fall brood, it will be attacked and injured by those flies which come from the old stubble the following spring.

DESTRUCTION OF VOLUNTEER WHEAT.

There is no doubt that volunteer wheat, especially in wet summers, serves to enable the fly to produce an extra brood and to carry it on in greater numbers to the regular crop. There is also no doubt that half or more of the flaxseeds formed in the volunteer wheat do not give up flies in the fall at all, but furnish a part of the destructive spring brood.

40. In the spring of 1909, from a quantity of the previous year's stubble that would scarcely half fill a quart fruit jar, seventy-one flies emerged. Ten per cent of the flaxseeds in the old stubble in 1908 at Manhattan and six per cent at Wilson did not give up flies until the spring of 1909.

Volunteer wheat is a menace to the succeeding crop and should not be allowed to grow.

LATE SOWING.

The earliest writers on Hessian fly recommended late sowing as one of the best means of escaping damage. Indeed, every recent writer on the subject, with the exception of Thorne,[41] has signified that late sowing is one of the most, if not the most, efficient of all measures for fly control.

Of course, the idea underlying the practice of late sowing is that wheat may be sown late enough to escape the damaging fall brood and yet make a good crop. Two main objections have been made to the practice of late sowing: (1) that when wheat is sown late the chances for winter injury are increased; (2) that sometimes the fall brood comes out late and more seriously infests wheat sown on the fly-free date than that which is sown earlier or later. The first objection can best be answered by examining, in relation to the fly-free date, such date-of-seeding-for-maximum-yield tests as are available, and by securing the opinion of large numbers of practical farmers.

41. Bulletin No. 136, Ohio State Exp. Sta. (1902), 23.

Relation of time of seeding to yield, Columbus, Ohio.

DATE OF SEEDING.	1879.	1880.	1883*a*.	1883*b*.	1884	1886.	1887	1888.	1889.	1890.
Aug. 22–25.....			24.1		35.8		31.7	12 8		16 8
" 29–31.....				40.0	51.8	41.2	31.6	11.2		16 8
Sept. 6–10.....	33 2	32.5	**34.9**		55.6	32.3	28.3	12.1	34 9	19 1
" 13–17.....	30.3	33 0		42 4	**57.2**	35.0	31.3	26.6	26.9	20.2
" *20–24*.....	*36 4*	*33 5*	*34 2*	*44.7*	*53 2*	*38.6*	*27.8*	*26 6*	*27 4*	*20.9*
" 27–30.....	32.7	29.5		**47.1**	54.6	**42.1**	26.1	26.1	42 4	22.5
Oct. 4– 8.....	26 2	26.2	34 7		56 9	36 5	**32.7**	28 2	**47.3**	**26 5**
" 11–15.....				38 0	44 4	38 0	30 6	**33.0**	33.8	22.6
" 18–20.....					43.6	29 9	20 9	20 8		23.0
" 25–27					35 6	18.9		27.7		

Italic figures date of safe sowing.

Black figures date of sowing to obtain a maximum yield.

Relation of time of seeding to yield, year, variety, and bushels per acre, Wooster, Ohio.

DATE OF SEEDING.	1902	1903.	1904.	1905.	1906	1907	1908	1909.	1910	Nine-year average.
	Valley.	Mealy.	Mealy.	Mealy.	Mealy.	Mealy.	Mealy.	Perfection.	Gypsy.	
Aug. 31–Sept. 1,	25 00	30.66	17 33	**26.16**	39.33	21.83	40 17	36 17	16 92	28 17
Sept. 7– 8.....	26.80	28 00	19 92	22.76	42.75	30 00	45 08	35 50	21.75	30.28
" 14–15.....	25 50	34.33	23 92	17.58	**48.75**	31.75	46.75	35 50	26 08	32 24
" 20.....	....	....	....	....	....	....	....	....	....	....
" 21–22.....	**28.50**	**36 83**	**24.33**	20 50	47.66	31 58	**47.12**	**38 67**	**26.08**	**33 61**
" 28–29	25.50	30 66	24 33	18.92	47 08	**33.50**	46 25	38 58	24 58	32.16
Oct. 5– 6	25.50	26.91	19.33	14.26	36 58	28 42	38.17	35.08	23.58	27 54
" 12–13	22 10	21.00	19.87	13 76	33 3[illegible]	25 08	33 50	36.08	23 42	25.35
" 19–20	15 50	15 25	00.00	10 50	28 08	17 08	25 25	31 25	22 54	18 38
" 26–27.....	9.33	12.41	00.00	8 58	25 16	11.25	24 17	15.67	23 33	14 43

Leaders show date of safe sowing.

Black figures date of sowing to obtain a maxmum yield.

At Columbus, Ohio,[42] where the safe-sowing date has been determined as September 25, in nine years' trials the best yields for eight years were obtained from wheat sown on or after that date, while the exception showed a yield from early sowing better by three-tenths of a bushel. At Wooster, Ohio,[43] where the safe-sowing date has been determined as September 20th, in nine years' trials the best yields for seven years were obtained from wheat sown on or after the safe-sowing date, while one of the exceptions showed a yield from early sowing better by six bushels and another a yield better by one bushel. To the question "Do you think sowing on the date recommended (October 1 in the northern third, October 7 in the central third, and October 15 in the southern third of Kansas) would with proper preparation of the seed bed seriously injure the farmer's chance for getting a maximum yield?" thirty-seven of the fifty representative farmers (these men were distributed throughout the state) who contributed to this point anticipated no injury, eight feared damage, and five were uncertain. Thus it becomes apparent that both the result of actual experiment and the weight of practical opinion unite to show that sowing on or immediately after the fly-free date does not injure the grower's chance for a maximum yield. Here it should be said that the terms "fly-free date" and "safe-sowing date" are used interchangeably in this bulletin, because: (1) the date of safe sowing has been defined by those who have used it as the date on which the bulk of the flies will have disappeared and consequently the date on or after which wheat may be sown to escape serious injury; (2) the date of fly-free sowing has been found by us to follow within one or two days the date on which the majority of the flies have emerged.

In answer to the second objection to late sowing, it may be said that, while at least one authentic case is on record, it is the rare exception which no general rule can take into account. The fact that such exceptional conditions may come any bad fly year is to be met by expert study of fly emergence at the time and by the issuance of timely warnings,

The most important step which the farmer can take to insure the production of the maximum yield from wheat sown late enough to avoid the fly is so to prepare the soil that the seed

42. Bulletin No. 136, Ohio Exp. Sta. (1902), 13.

43. Bulletin No. 231, Ohio Exp. Sta. (1911), 6.

will germinate without loss of time. That means that his late-sown wheat will go into winter in just as good or better shape than the early sown. Indeed, proper attention to this feature of wheat culture will eliminate most of the yield reduction for which late sowing is held responsible.

There is no doubt that the same climatic factors that encourage the growth of the wheat induce the fly to transform from a maggot into a gnat and to emerge for its brief aerial life. The majority of the flies generally emerge and lay their eggs, however, a week to ten days before the best time for wheat to come up is at hand, and the date on which wheat may be sown and come up after most of the flies are gone is the fly-free or safe-sowing date. As a matter of fact, although this fly-free date comes at such a time that the sowing comes up after the main brood of fly is gone, flies are ovipositing and continue to oviposit until early November. The wheat sown on or after the fly-free date is then free not only because the bulk of flies have disappeared before it becomes attractive, but because such eggs as are deposited fail to produce larvæ capable of maturing before cold weather comes on.

Subject as is fly emergence to the factors of climate, as shown earlier in this bulletin, and variable as are the fall and winter temperatures, variation in the fly-free date is to be expected. The best that can be done is to determine the fly-free date for a number of years and to take the average as the normal fly-free date for general use. The results of four years' tests are shown in the following tables.

Sowing in 1907 consisted of a single series of stations extending from the northern to the southern edge of Kansas. Sowings in 1908 consisted of a double series, one in the eastern and one in the western edge of the great central wheat belt. Sowings in 1909 were practically a duplicate of those in 1908. Sowings in 1910 were similar to those in 1909 except that the plats were much larger, each involving, with the exception of the ones at Manhattan, at least one acre. An area of at least one square yard was selected from each sowing, and every plant thoroughly examined, usually between November 15 and January 1. When more than one square yard was considered, the results have been reduced to that figure for the sake of uniformity.

1907.

MARYSVILLE.

Sep. 17, '07—No infestation.

MANHATTAN.

Date of sowing.	No. of plat.	Size of plants.	No. of plants.	No. of plants infested.	No. of tillers.	No. of tillers infested.
Sep. 9, '07	1	6-12 tillers	1,445	119	...	...
Sep. 19, '07	2	6-12 tillers	1,447	105	...	...
Sep. 29, '07	3	Not so large as 1 and 2,	903	30	...	...
Oct. 9, '07	4	Beginning to tiller ...	581	0	...	...
Oct. 19, '07	5	Leaf	211	0	...	...
Oct. 29, '07	6	Leafed	283	0	...	...
Oct. 9, '07	7	Just coming up	....	...	...	...

SEDGWICK.

Sep. 6, '07	1	4-8 tillers	824	196	...	...
Sep. 16, '07	2	5-8 tillers	969	215	...	...
Sep. 26, '07	3	3-5 tillers	634	0	...	...
Oct. 12, '07	4	....	658	0	...	...
Oct. 19, '07	5	2-3 bladed	221	0	...	...

CALDWELL.

Sep. 6, '07	1	5-7 tillers...........	839	11	...	...
Sep. 16, '07	2	5-7 tillers...........	862	21	...	...
Sep. 26, '07	3	Larger than 1 and 2 ..	1,031	31	...	...
Oct. 7, '07	4	3-5 tillers	895	46	...	...
Nov. 16, '07	5	Not tillering, 3-4 bladed,	475	0	...	...

1908.

MARYSVILLE.

Sep. 5, '08	1	....	182	101	...	...
Sep. 15, '08	2	....	129	48	...	...
Sep. 25, '08	3	....	137	69	...	...
Oct. 5, '08	4	....	....	0	...	...
Oct. 15, '08	5	....	....	0	...	...

MANHATTAN.

Aug. 29, '08	1	....	145	...	868	17
Aug. 31, '08	2	....	....	...	1,223	15
Sep. 7, '08	3	....	157	...	842	25
Sep. 10, '08	4	....	223	...	1,163	18
Sep. 14, '08	5	....	309	...	1,514	14
Sep. 17, '08	6	....	309	...	1,651	30
Sep. 21, '08	7	....	307	...	1,299	22
Sep. 24, '08	8	....	336	...	1,431	5
Sep. 28, '08	9	....	395	...	1,082	16
Oct. 1, '08	10	....	371	...	809	5
Oct. 5, '08	11	....	323	...	898	0
Oct. 8, '08	12	....	773	...	319	0
Oct. 12, '08	13	....	254	...	180	0
Oct. 15, '08	14	....	304	...	257	0
Oct. 19, '08	15	....	214	...	209	0

SEDGWICK.

Sep. 5, '08	1	....	118	118	...	...
Sep. 14, '08	2	....	170	170	...	...
Sep. 25, '08	3	....	170	168	...	...
Oct. 3, '08	4	....	251	51	...	...
Oct. 10, '08	5	....	....	0	...	...
Oct. 17, '08	6	....	....	0	...	...
Oct. 27, '08	7	....	....	0	...	...

CALDWELL.

Date of sowing.	No. of plat.	Size of plants.	No. of plants.	No. of plants infested.	No. of tillers.	No. of tillers infested.
Sep. 5, '08	1	....	98	98	...	...
Sep. 17, '08	2	....	105	105	...	...
Sep. 25, '08	3	....	138	138	...	...
Oct. 12, '08	4	2-3 leaves............	....	0	...	...
Oct. 27, '08	5	....	....	0	...	...

SAWYER.

Sep. 16, '08	1	....	226	23	1,127	30
Sep. 16, '08	1	....	226	126	981	219
Sep. 25, '08	2	....	280	21	1,301	26
Sep. 25, '08	2	....	145	145	451	276
Oct. 7, '08	3	....	....	0	...	0

GREAT BEND.

Farm of S. H. Gwinn.

Sep. 1, '08	1	....	0	0	0	0
Sep. 10, '08	2	....	76	35	169	56
Sep. 22, '08	3	....	167	109	417	220
Oct. 1, '08	4	....	232	29	...	...
Oct. 7, '08	5	....	....	0	...	0

Farm of Fred Moore.

Sep. 3, '08	1	....	0	0	0	0
Sep. 13, '08	2	....	97	41	213	69
Sep. 20, '08	3	....	143	67	500	106
Sep. 28, '08	4	....	205	29	...	...
Oct. 6, '08	5	....	....	0	...	0
Oct. 10, '08	6	....	....	0	...	0
Oct. 14, '08	7	....	....	0	...	0

NORTON.

Aug. 31, '08 to Sep. 20, '08 } No infestation.

1909.

MARYSVILLE.

Sep. 2, '09	1	....	390	239	1,801	277
Sep. 11, '09	2	....	380	101	2,397	103
Sep. 22, '09	3	....	366	5	1,742	5
Oct. 1, '09	4	....	280	0	995	0
Oct. 8, '09	5	....	307	0	899	0

MANHATTAN.

No infestation.

SEDGWICK.

Sep. 22, '09	1	....	231	0	736	0
Sep. 30, '09	2	....	274	3	467	8
Oct. 7, '09	3	....	302	0	458	0
Oct. 15, '09	4	....	331	0	570	0
Oct. 20, '09	5	....	398	0	710	0

CALDWELL.

Date of sowing.	No. of plat.	Size of plants.	No. of plants.	No. of plants infested.	No. of tillers.	No. of tillers infested.
Sep. 16, '09	1	....	177	10	899	10
Sep. 20, '09	2	....	257	133	1,690	165
Sep. 24, '09	3	....	239	103	972	123
Sep. 27, '09	4	....	253	23	1,584	26
Oct. 5, '09	5	....	265	61	969	67

Sowings were not completed.

PRATT.

Sep. 15, '09	1	....	581	19	2,132	20
Sep. 23, '09	2	....	185	1	938	1
Oct. 1, '09	3	....	221	23	1,024	25
Oct. 9, '09	4	....	195	24	985	24

Sowings were not completed.

GREAT BEND.

Sep. 17, '09	1	....	160	2	1,449	24
Sep. 20, '09	2	....	245	5	1,770	5
Sep. 27, '09	3	....	199	3	1,293	3
Oct. 4, '09	4	....	201	0	850	0
Oct. 11, '09	5	....	227	0	854	0
Oct. 18, '09	6	....	187	0	626	0

NORTON.

Sep. 1, '09 to Oct. 11, '09 } No infestation.

1910.

MARYSVILLE.

Sep. 12, '10	1	....	324	10	1,144	10
Sep. 19, '10	2	....	234	2	645	2
Sep. 29, '10	3	....	....	0	...	0
Oct. 3, '10	4	....	....	0	...	0
Oct. 10, '10	5	....	....	0	...	0
Oct. 17, '10	6	....	....	0	...	0
Oct. 24, '10	..	....	....	0	...	0

MANHATTAN.

No infestation.

MARION.

No infestation.

WELLINGTON.

No infestation.

PRATT.

No infestation.

WILSON.

No infestation.

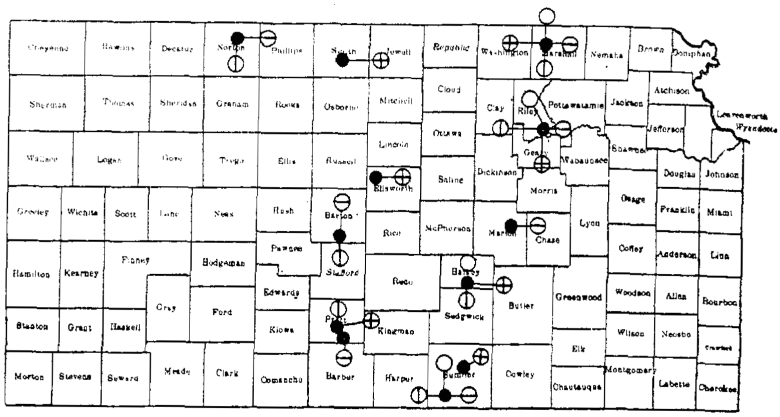
SMITH CENTER.

No infestation.

General Summary of Fly-free Dates.

Year.	Marysville.	Manhattan.	Marion.	Sedgwick.	Wellington.	Caldwell.	Sawyer.	Pratt.	Great Bend.	Wilson.	Smith Center.	Norton.
1907........	No infestation.	Oct. 9.		Sep. 26.[44]		Oct. 16.						
1908........	Oct. 5.	Oct. 5.		Oct. 10.		Oct. 12.	Oct. 7.		Oct. 6.	Oct. 12.		No infestation.
1909........	Oct. 1.	No infestation.		Oct. 7.		Not completed; infestation in sowing to Oct. 5.		Not completed; infestation in sowing to Oct. 9.	Oct. 4.	No infestation.		No infestation.
1910........	Sep. 29.	No infestation.	No infestation.		No infestation.			No infestation.		No infestation.	No infestation.	
Average of two or more years' sowing.	Oct. 2.	Oct. 7.		Oct. 9.		Oct. 14.			Oct. 5.			

44. The fly-free date at Sedgwick in 1907 the authors believe to be unduly early, and although the notes do not mention it, think that the planting was retarded because the number of tillers is considerably less than the number taken from the same amount of ground planted sixteen days later. It is, therefore, disregarded in making up the average.



O = Sowings 1907. ⊖ = Sowings 1908. ⦶ = Sowings 1909.
⊕ = Sowings 1910. ● = Location of sowing.

FIG. 12. Map of Kansas showing location of sowing stations.

Marysville, Manhattan, Sedgwick, and Caldwell, lying on the eastern edge of the great central wheat belt, and having much the same rainfall but differing in latitude and altitude, show average fly-free dates of October 2, October 7, October 9, and October 14 respectively. Great Bend and Sawyer, lying on the western edge of that part of the wheat belt infested with fly, differing from the preceding series in rainfall and altitude, but similar to each other in these respects, show average dates of October 5 and 7 respectively. Before attempting to show the ratio existing between these dates and climatic factors, the origin and development of the statement of this ratio should be described.

Through the medium of widely scattered seedings made throughout the normal period of wheat sowing, Webster[45] was able to show a distinct ratio between the dates of the disappearance of fall brood and the latitude, and this ratio was determined as about one day for each one-fourth of a degree—the fall brood disappearing one day earlier for each one-fourth of a degree north, and one day later for each one-fourth of a degree south, of a given point. One year later, Hopkins[46] confirmed in West Virginia the latitude ratio obtained by Webster in Ohio, and showed that wherever altitude was sufficiently variable to bring about difference in climate, there existed a

45. Bulletin No. 107, Ohio Agri. Exp. Sta., 1899.

46. Hopkins, A. D., Bulletin No 67, West Virginia Exp. Sta., 1900.

ratio between the disappearance of the fall brood and the height above the sea. He showed that a difference of one hundred feet in altitude made a difference of one day in the time of disappearance of the fall brood, the time being one day earlier if one hundred feet higher, and one day later if one hundred feet lower, than a given point. Although Hopkins did not attempt to state these ratios in the form of a law, he set them forth for the first time with sufficient clearness to merit such a designation. In substance he said that under normal climatic conditions the date of the disappearance of the fall brood of Hessian fly, and, consequently, the date of the safe sowing of wheat, varies with latitude and altitude, being one day earlier if north one-fourth of a degree or higher by one hundred feet, or one day later if south one-fourth of a degree or lower by one hundred feet, than a given point. This ratio may well become known in Hessian fly annals as "Hopkins' Law of Latitude and Altitude.''

Perhaps the easiest way to apply this law and to determine the theoretic date of safe sowing is as follows: (1) reduce the known safe-sowing date to the safe-sowing date of a point in the same latitude at sea level by adding as many days to the known date as the point is hundreds of feet above sea level; (2) add to this sum as many days as the point the safe-sowing date of which we wish to determine is quarters of a degree south or subtract as many days as it is quarters of a degree north of the known point; (3) subtract from this sum as many days as the new point is hundreds of feet above sea level.

Starting with October 2 as the fly-free date at Marysville, which is 39° 49' north latitude and 1153 feet above the sea, the theoretic date for Manhattan, which is 39° 11' north latitude and 1012 feet above the sea, is determined in the following way: The actual normal fly-free date at Marysville is October 2. Reducing this date to the date for sea level in the same latitude by adding as many days as Marysville is hundreds of feet (11.5) above the sea, we have October 13.5. Now, Manhattan is thirty-eight minutes south of Marysville. By adding one day for each fifteen minutes difference to the sea-level date for Marysville, we find the sea-level date of Manhattan to be October 15.8. Subtracting as many days from the sea-level date of Manhattan as Manhattan is hundreds of feet above the sea, we find the theoretic fly-free date at Manhattan to be October 6, which is within one day of the actual fly-free date as determined by experimental sowings. Taking the experimentally determined safe-sowing date of Marysville (latitude 39° 40', altitude 1153 feet) as October 2, the theoretic safe-sowing dates for Manhattan (latitude 39° 11', altitude 1012 feet), Sedgwick (latitude 37° 56', altitude 1375 feet), and Caldwell (latitude 37° 4', altitude 1107 feet), for which places we have the average of two or more years of sowings, are October 6, October 7, October 13, respectively, while the actual dates determined by the average of two or more years of experimental sowing are October 7, October 9, and October 14. Likewise, taking the experimentally determined safe-sowing date of Great Bend (latitude 38° 22', altitude 1843 feet) — in the western series only two stations have as yet given promising results — as October 5, the theoretic date for Sawyer (latitude 37° 29', altitude 1913 feet) is October 8, while the actual date by one year's test is October 7.

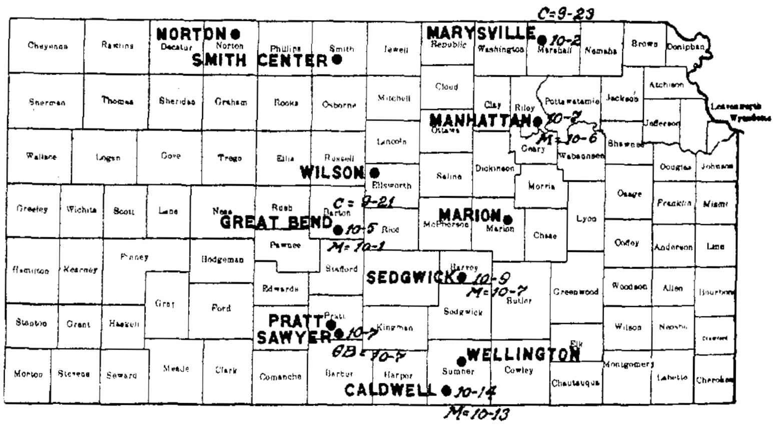


FIG. 13. Map of Kansas showing actual and theoretic dates of safe sowing. O, actual date of safe sowing determined by experimental sowings. M, theoretic date calculated by Hopkins' Law from actual date of Marysville. C, theoretic date calculated by Hopkins' Law from actual date of Columbus, Ohio.

The correspondence between theoretic and actual dates is so close that Hopkins' law may be said to apply to the eastern series and the western series when considered as separate units. Here, as in the case of Ohio and West Virginia, the only factor of climate sufficiently variable within the limits of the individual series to produce such variation in time of safe sowing in relation to latitude and altitude is temperature.

For the purpose of further testing the universality of this law, let us take the date of safe sowing at Marysville, as before, as October 2. Applying the law, the theoretic date of Great Bend (latitude 38° 22', altitude 1843 feet) is found to be October 1, whereas two years' sowing tests show the actual date to be October 5. No such discrepancy as this appeared between the actual and the theoretic dates in Ohio and West Virginia, according to Hopkins. For the purpose of further testing the law, taking the safe-sowing date at Columbus (latitude 40°, altitude 800 feet) experimentally determined as September 25, we find that the theoretic safe-sowing dates for Marysville and Great Bend are September 23 and September 21 respectively, whereas the actual dates by experimental sowings are October 2 and October 5 respectively. The actual date at Marysville is nine days, and at Great Bend fourteen days later than the theoretic. Evidently, this difference is the indication of another powerful factor.

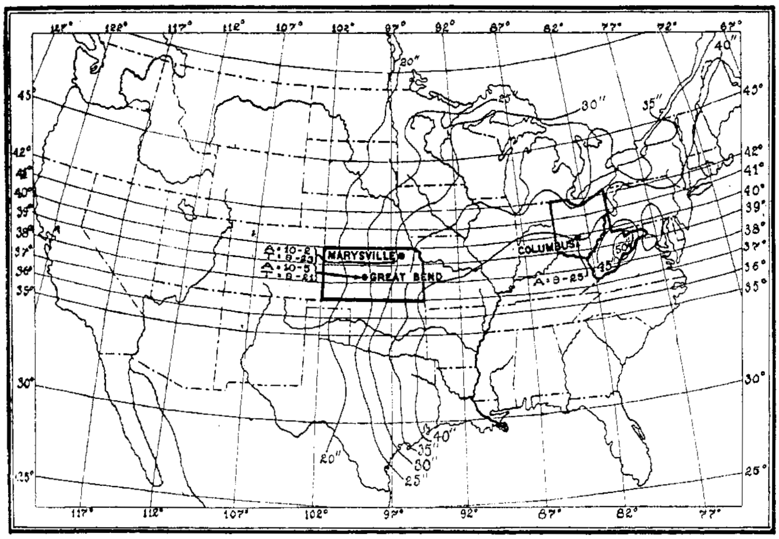


FIG. 14. Map of the United States showing the discrepancy between the theoretic and actual date of safe sowing in relation to normal annual precipitation. A, actual date of safe sowing as determined by sowing experiments. T, theoretic date of safe sowing figured according to "Hopkins' Law of Latitude and Altitude" from the actual date of Columbus, Ohio.

When we review the factors of environment known to retard Hessian fly, which do not vary enough to produce a material difference in Ohio and West Virginia, or in the individual stations of either the eastern or the western series, but which do vary enough to make large differences between Ohio and the eastern Kansas series and between the eastern and the western Kansas series, moisture stands out alone. The following table well serves to bring out the existence of a ratio between the difference existing between theoretic and actual date of safe-sowing and the difference in normal annual precipitation. The ratio appears to be about one day to the inch—the date being one day earlier if the rainfall is one inch greater and one day later if the rainfall is one inch less.

Correlation between Safe Sowing and Normal Annual Precipitation.

Place.	Actually determined safe-sowing date.	Theoretic safe-sowing date Columbus, being taken as Sept. 25.	Difference between actual and theoretic safe-sowing dates.	Normal annual precipitation.
Columbus, Ohio . . .	Sep. 25	. . . . . .	. . . . . .	40 in.
Marysville, Kan. . .	Oct. 2	Sep. 23	9 days	30 in.
Great Bend Kan. . .	Oct. 5	Sep. 21	14 days	25 in.

Of course, it is quite probable that this ratio between normal annual precipitation and the date of safe sowing may not hold where the precipitation reaches more than forty inches, but it is evident that it must be taken into consideration when the rainfall is less than forty inches. Hopkins' law of latitude and altitude must be modified to include the operation of moisture.

Even after the entomologist has by means of experimental sowings determined the normal date of safe sowing in his territory, his work is not done, for there have been and will be cases when, for lack of moisture or something else, the fly will be retarded, and, coming out later, will infest the wheat sown on the safe-sowing date just as seriously as, or more seriously than, sowings made either before or after. To avoid this, the entomologist should adopt as the normal safe-sowing date the average of dates on which the sowings of several years have been found absolutely free from fly and should, when an outbreak is anticipated, keep a close watch on fly emergence. The date of safe sowing as shown in the following table follows within a day or two the maximum emergence of the fly:

Relation of Maximum Emergence to Date of Safe Sowing.

Place.	Date of maximum emergence.	Date of fly-free sowing.	Difference
Wilson, Kan.	Oct. 10, '08	Oct. 12, '08	2 days
Manhattan, Kan.	Oct. 4, '08	Oct. 5, '08	1 day

The field men can thus check up the progress of emergence and warn the grower if the normal fly-free date is likely to prove either too early or materially later than necessary.

In the minds of some, the question may arise whether after the wheat sown on clean or cleaned land late enough in the fall to escape the fall brood may not be damaged by such of the flies as do not emerge during the fall but come out the following spring. While the studies at Wilson, Kan., on the farm of Mr. George Leavitt[47] have shown clearly that the fly sometimes does migrate this way as far as half a mile, investigations at this Station and elsewhere show that spring migration in sufficient numbers to do serious damage is rare and that wheat sown on clean land late enough to escape the fall brood is practically never seriously injured.

HOW TO PROCEED AGAINST THE FLY.

The Hessian fly's history in this country well exemplifies the general principle that insect success in struggle with man is attained through his ignorance. From first to last, the reduction and the prevention of fly damage are matters of using the proper measures at the right time. The understanding of both measures and time requires thought.

KNOWLEDGE NECESSARY.

The first thing the grower must know is whether he must choose between fighting the fly and suffering serious damage to his crops. There are many years during which the fly will not trouble him appreciably, and then will come years when it will do him great injury. He must be able, by the time harvest is finished, to tell whether the fly is abundant enough to damage next year's crop. Of course, to do this, he must be able to recognize the insect in its flaxseed stage; he must know where and how to look for it; he must determine how abundant it is, and whether it is healthy or nearly dead. If the grower does not know the flaxseed stage of the Hessian fly, he must learn its characteristic appearance from descriptions, pictures, and samples furnished him by his neighbors or by his state experiment station. After one becomes familiar

47. The junior author, working at Wilson, found on the farm of Mr. George Leavitt a field sown to wheat for the first time and removed from the nearest wheat field and stubble by about two hundred yards. This field was so large that the opposite side of the field was fully half a mile from the nearest wheat and stubble field. This wheat was planted after October 15, and although carefully examined, showed no trace of fly in the fall. The following spring eggs were found everywhere in the field, as thickly on the farther edge as anywhere. As the eggs were in no case apparently more than forty-eight hours old, it is not unreasonable to assume that migrant flies from adjacent fields had flown in and deposited them. The condition which probably led to this particular migration was prevalence of a strong wind blowing from the infested field across the uninfested field on the preceding day.

with the general appearance of the flaxseed, it is easy to determine whether the fly is present in wheat stubble. Just after harvest time the grower should go into his field and select a square yard of stubble. He should pull the stubble up by the roots and examine each carefully for flaxseeds. Our experience has led us to believe that the flaxseeds, if present, will generally be found between the old rotted leaf and the straw, below the surface of the ground; for in making examinations during that time, we have found the majority of flaxseeds in the rotted stems of plants which the maggots stunted and destroyed. At harvest time these rotted stems are entirely below the surface of the ground. No doubt in some cases, however, the flaxseeds are found between leaf sheaths and straws just above joints that are well above the surface of the ground. All flaxseeds found should be placed in a bottle or a tin can. At least two other square yards located in widely separated parts of the field should be examined and the flaxseeds preserved. The flaxseeds should then be taken to a magnifying glass and broken open. If each contains a white maggot not quite large enough to fill the shell, the grower may know that the flaxseeds are healthy and that those remaining in the field will produce healthy adult flies later in the season. The determination of the health of the flaxseeds is a rather difficult matter, and, if the gathered flaxseeds are sent to the experiment station accompanied by a request, they will be examined free of charge and the results of such examination will be forwarded to the sender.

If healthy flaxseeds are not shown by these examinations to be present the grower may proceed safely without regard to the fly. If, on the other hand, these examinations reveal the fly in any considerable numbers, the grower must take steps looking toward the prevention of injury to the following crop.

GENERAL PROCEDURE.

Having found the fly present in threatening numbers, the type of treatment adopted will depend upon the type of culture practiced. If wheat has been sown to clover, the infested stubble can not be destroyed without sacrificing the clover. In cases in which for any good reason the infested stubble can not be destroyed, the succeeding wheat crop should be planted as far as possible from the infested stubble, and sowing should be made on or after the fly-free date. If the stubble may be destroyed and wheat is to be sown in the field, we believe that the following series of steps will prove best for all fly-infested parts of the wheat belt.

CONTROL OF FLY WHEN WHEAT FOLLOWS INFESTED WHEAT.

.*Disking* The disk should follow the reaper as quickly as possible, because it conserves the moisture and makes plowing easier, because it causes many of the weed seeds and most of the volunteer wheat to germinate and renders their destruction more certain, and because it tends to bring about early emergence of the fly.

Plowing. The disked ground should be turned with a plow three or four weeks later. It should be plowed at least six inches deep. The work should be so carefully done that all stubble and rubbish are buried beneath at least four inches of soil. If the stubble and the rubbish are present in too great quantity to permit this type of plowing, the field should be thoroughly burned over before being plowed.

Packing down. By use of harrows and packers, the surface slice should be pulverized and packed down into a good seed bed. This means that the surface slice must become steadily more compact from surface downward until it passes almost unnoticeably into the subsoil. This will permit the subsoil moisture to penetrate and moisten the furrow slice. The surface must be left covered with a dust mulch, and the mulch must be remade after every rain which is heavy enough to crust the soil. Soil thus prepared will germinate wheat without delay whenever sown.

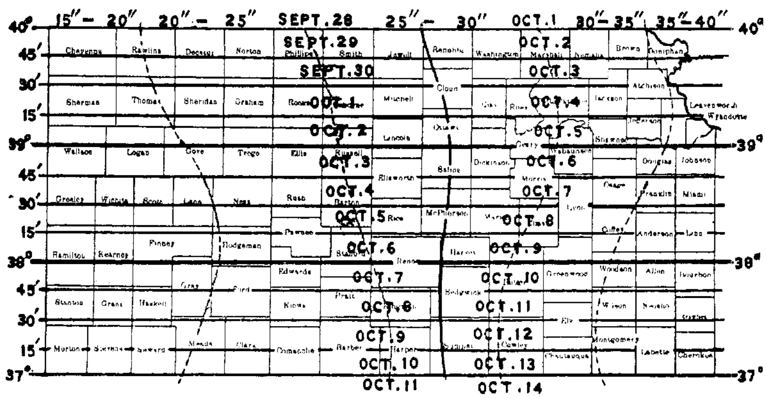


FIG. 15. Map of Kansas showing date of safe sowing calculated directly from 1907-'08, 1908-'09, 1909-'10 experimental sowings.

Sowing. The crop should not be sown until at least the safe-sowing date, which may be easily determined from the accompanying map.

Good seed and fertile soil. Good seed and fertile soil will produce thrifty, rapidly growing plants, which will show much less injury from fly.

CONTROL OF FLY WHEN WHEAT IS PLANTED ON LAND NOT IN WHEAT, RYE, OR BARLEY THE PRECEDING YEAR.

Proper preparation of the seed bed. Preparation of the seed bed is a matter of prime importance; for a properly prepared seed bed will sprout the seed as soon as sown, and wheat sown on the safe-sowing date will stand as good a chance as any to make a maximum crop.

Time of sowing. The crop should be sowh on or immediately after the safe-sowing date.

Good seed and fertile soil. Good seed and fertile soil are always important; for they produce plants of superior vigor that are better able to withstand the attack of fly.