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The Hessian Fly in Missouri

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Entomology Department, Missouri Agricultural Experiment Station, and the Bureau of Entomology and Plant Quarantine, Agricultural Research Administration, United States Department of Agriculture Cooperating

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INTRODUCTION

The hessian fly is the most destructive insect pest of wheat in Missouri. While the loss of yield caused by the fly has not been carefully ascertained, it probably ranges upward from 1,500,000 bushels of wheat annually in the State. The specific information obtained from State-wide annual tests of the planting-date method of control of the hessian fly conducted over the years 1917 to 1935 in Missouri are presented in these pages. Owing to weather somewhat adverse, on the average, to the fly during this period, general outbreaks were infrequent. Local outbreaks occurred nearly every year, however, causing considerable losses of crop in individual fields. In years when infestations were above average the loss was much increased as, for example, in 1932 when a loss of 3,360,000 bushels of wheat was estimated from the reduced acreage harvested. Much of this loss was due to hessian fly damage. Infestation was above the average established by the field tests in about 37 percent of the years of test. Greatly increased infestation would be expected in years of recurrence of weather more favorable to the fly. Serious wheat-crop losses can best be prevented in such years by the concerted application of all the measures recommended for a date of planting control compaign. By following these same practices the individual farmer can greatly reduce his own losses.

NATURE OF INJURY

Damage to the wheat crop by the hessian fly begins with the first steady feeding of its minute maggots immediately upon obtaining anchorage within the plant. These maggots hatch from eggs laid by the adults, mostly on the upper leaf surface of the young wheat plants, and soon move down to positions between sheath and stem within the plant, where they extract the plant juices and in a few days impart a characteristic damaged appearance to the plants. The maggot-bearing central stem becomes dwarfed or disappears, and the ensheathing

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leaves fail to attain normal length but grow broader and become unusually dark green. The infested tiller remains undersized (Fig. 1). Where the young plant has more than one tiller the abnormal shade of green characteristic of infested tillers frequently is transmitted to other tillers on which there are no maggots. Often a single maggot is sufficient to kill the young plant before tillering, while several maggots may cause the death of even the well-tillered young plant. The normal, noninfested young wheat plant (Fig. 2) is light green, with a central shoot which normally unrolls into a new leaf, and an additional tiller.

Fig. 1.—Young wheat plant infested by hessian fly. Plant undersized, leaves shortened and widened, color abnormally dark.

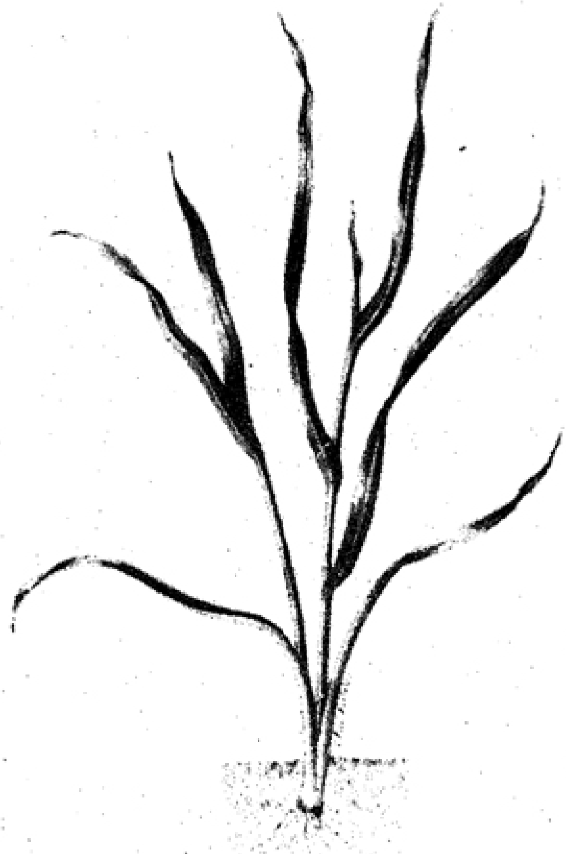

Fig. 2.—Typical noninfested young wheat plant.

The larvae of two and often three generations attack the same crop of wheat, one in the fall and one or two in the spring. Where the hessian fly population is high, much young wheat is destroyed by maggots of the fall generation. Again in early spring, maggots of another generation attack the wheat, increasing the injury, and those of a third generation occurring between mid May and harvest further intensify the damage. When the weather favors the fly at this time, this third generation becomes important and in some years increases greatly. In such seasons there is an increase of dwarfed stems, and of undersized, underproductive, and nonproductive heads. Frequently, also, there is increased lodging of matured stems which have been pinched or broken by clusters of "flaxseeds" (puparia) inside the leaf sheaths. Dwarfed and lodged wheat is missed by harvesting machinery, hence is a total loss to the yield, although it may still be salvaged by pasturing stock.

GENERATIONS AND LIFE CYCLES

An important feature in its life history protects the hessian fly from direct methods of control other than destroying its host plant. After the eggs have hatched and the maggots have left the leaf surface, all their immature life is spent within the plant. All the feeding of the insect and its transformations from maggot to flaxseed and to pupa, up to the emergence of the fly itself, take place behind the leaf sheath. The diagram, Fig. 3, illustrates the essential features of the life cycle of the two principal generations during the year.

Fall Generation

The fall generation, which usually inflicts the greatest damage to the wheat crop, begins with the deposition of eggs on the plants, when still young and most susceptible to injury, by adults which have emerged from stubble and volunteer wheat. The eggs hatch in a few days, the maggots crawl down into the plants for several weeks of feeding and growth during which they attain a length of about 3/16 inch, or an increase in length of about nine times that on hatching. After attaining full growth, the maggots transform into the inactive puparium, or "flaxseed," stage.

Feeding, growth, and transformations require about 3½ months, from about September 15 to December 31, after which the flaxseeds remain in position until the following spring. During March and April the maggots complete their development within the flaxseeds, change to the pupal stage or nearly matured flies, and finally emerge as mature winged flies. The fall generation thus remains in the plants for about 7 months. The flies emerge during late March and April and deposit their eggs, starting the first and principal spring generation.

Spring Generations

The spring generations are usually less damaging to the wheat because of the lush plant growth and nearer approach of the plants to maturity. The maggots enter the plants, grow and in part transform as before. The "flaxseed" stage is attained in April and May. The individuals, in large proportion, remain in this stage until early fall, then emerge to infest fall wheat sowings.

The small remainder, the proportion varying from year to year, complete their development and emerge in late May and June. These deposit eggs mostly on young tillers, immature plants, and available volunteer wheat, thus beginning a new, or second spring generation.

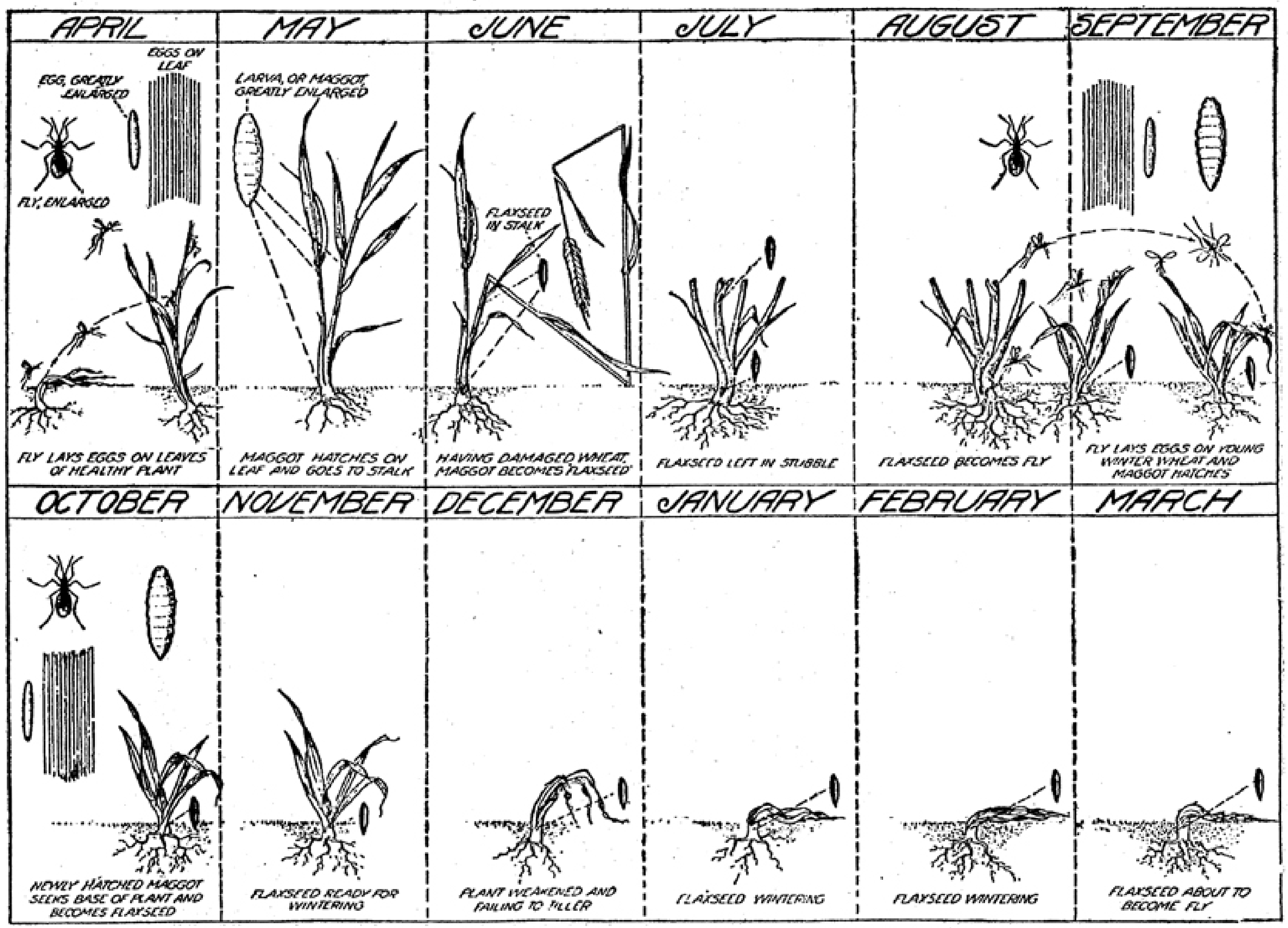

Fig. 3.—Diagram of outstanding features in the life cycle of the two principal generations of the hessian fly.

Although during the years of test this generation usually was not seriously harmful to the maturing crop, it does become so under the favoring conditions of frequent or timely rainfall, subnormal temperature, renewed growth in planted wheat, and plentiful volunteer wheat. Such conditions induce an early start and rapid increase of the second generation. There is an obvious increase of damage, manifested particularly in the failure of stems and even of entire plants to mature and in an increase of lodging. This warm-season generation has a short life cycle, being mostly in the flaxseed stage by harvest-time. The adults emerge in the fall. Damage to the wheat is increased in proportion to the shortness of life cycle and size of population of this generation. It is, however, exceptionally exposed and susceptible to attack by parasites.

Supplemental Generations

Supplemental generations, rarely complete or of abundant population, have become prominent in some years and localities. There may be one or two of these, depending on the weather. The first of these rare emergences occurs in late August or early September, after a period of drought followed by late summer rains and cooler weather. Their success in producing progeny depends upon the presence of wheat, volunteer or very early sown, as for pasturage, upon which to lay eggs.

The second unseasonable emergence occurs in late fall and early winter in response to overly prolonged mild weather in conjunction with ample moisture. In rare years, this delayed emergence is followed by a late brood of maggots which infests wheat sown during the ordinarily safe-sowing period. This brood has seldom been important in Missouri.

Growth Stages

The hessian fly passes through five unlike stages of growth, of which the last one is the fully matured, winged adult fly. It is small, about 1/12 to 1/6 inch long, with dark-gray to black body and two transparent wings, somewhat mosquitolike in general form. The male (Fig. 4) is smaller and much more slender than the female and is predominantly gray throughout. The female (figure 5) is very dark gray to almost black, the head and thorax shiny black, the abdomen distinctly reddish when distended with eggs, which most commonly is the case immediately after emergence.

The eggs are minute, ellipsoid, about 1/50 inch long and a little more than one-seventh that wide, so narrow that they fit into the grooves between the leaf ribs, mostly being deposited in these grooves. (Fig. 6.) Their orange-red color sharply contrasts with the green of the wheat leaf so that they can be seen, in direct sunlight, lying singly or end to end in strings on the upper leaf surface.

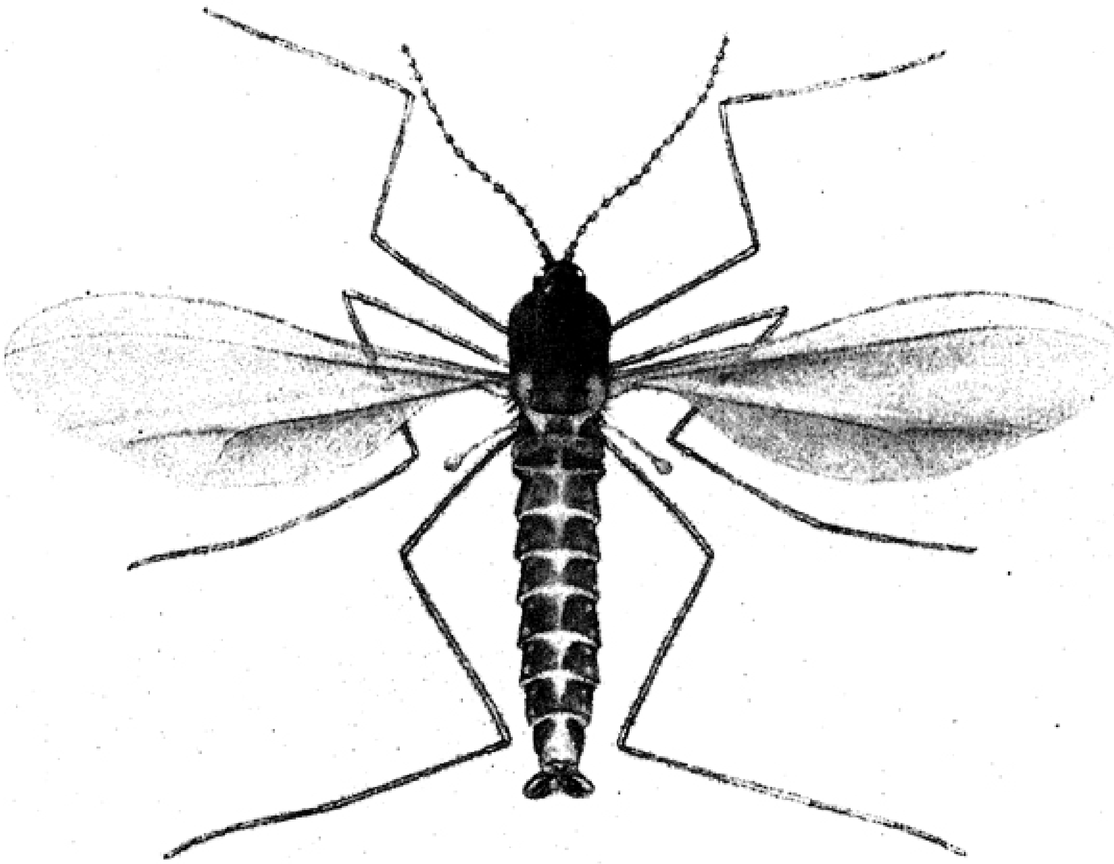

Fig. 4.—The adult male hessian fly. X 16.

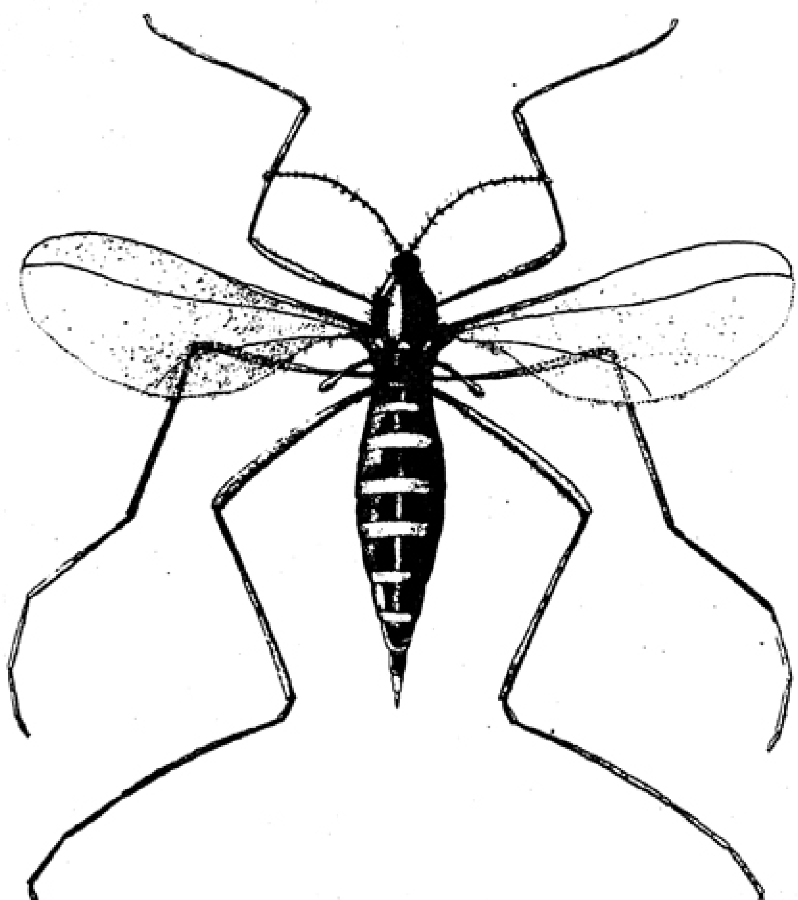

Fig. 5.—The adult female hessian fly. X 16.

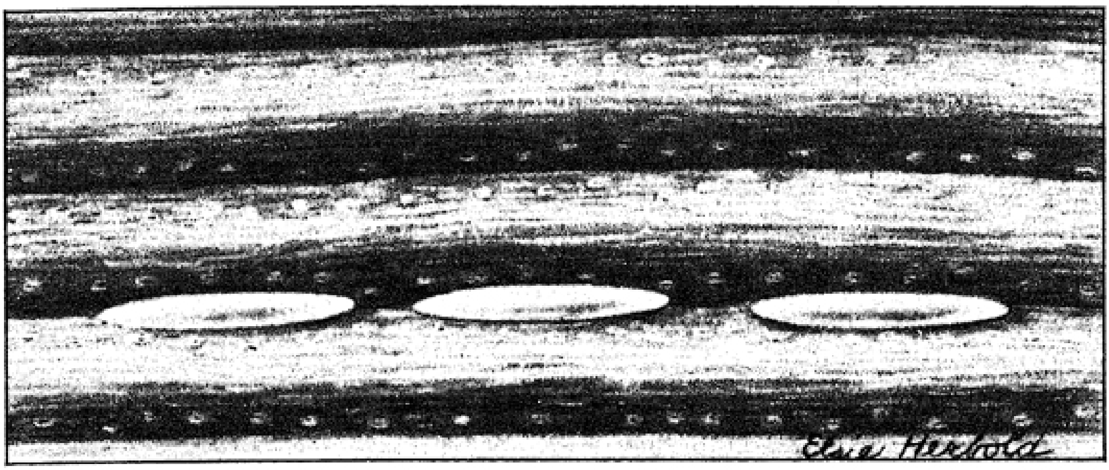

Fig. 6.—Eggs of the hessian fly on the surface of a wheat leaf. X 50.

At hatching time the minute larva issues from the eggshell as a reddish, legless maggot, finds its way into the plant between sheath and stem, soon increases in size, and becomes white throughout. As it grows larger, cloudy-white bodies of fat and green plant-food materials may be seen through the translucent skin. This is the only feeding stage of the insect, hence the only stage harmful to plants. The fully grown maggot, which is about 3/16 inch long, is illustrated in Fig. 7.

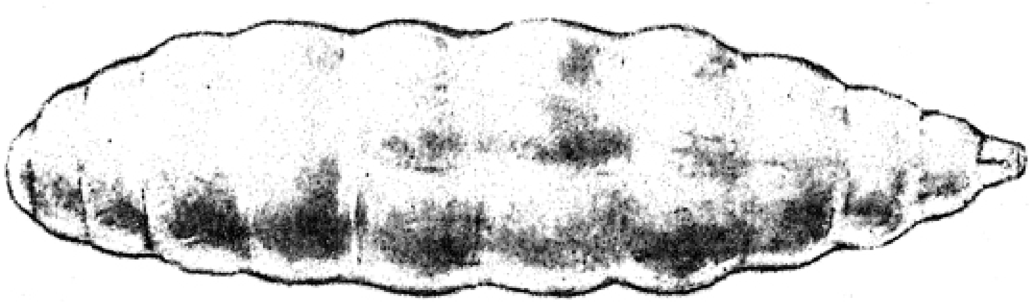

Fig. 7.—Hessian fly maggot before the puparium or "flaxseed" is formed. X 25.

When the maggot has fed for several weeks and attained full size it becomes ensheathed, while still in the plant, in its separate skin or puparium. This hardened skin, white at first, soon turns brown. In size and color it somewhat resembles the ripened seed of the flax plant, hence is known as the flaxseed. (Fig. 8.)

Within the puparium the maggot undergoes some further development, and turns about so that the head is directed upward to facilitate emergence of the adult from the plant. It next transforms into the stage known as the pupa, which somewhat closely resembles the

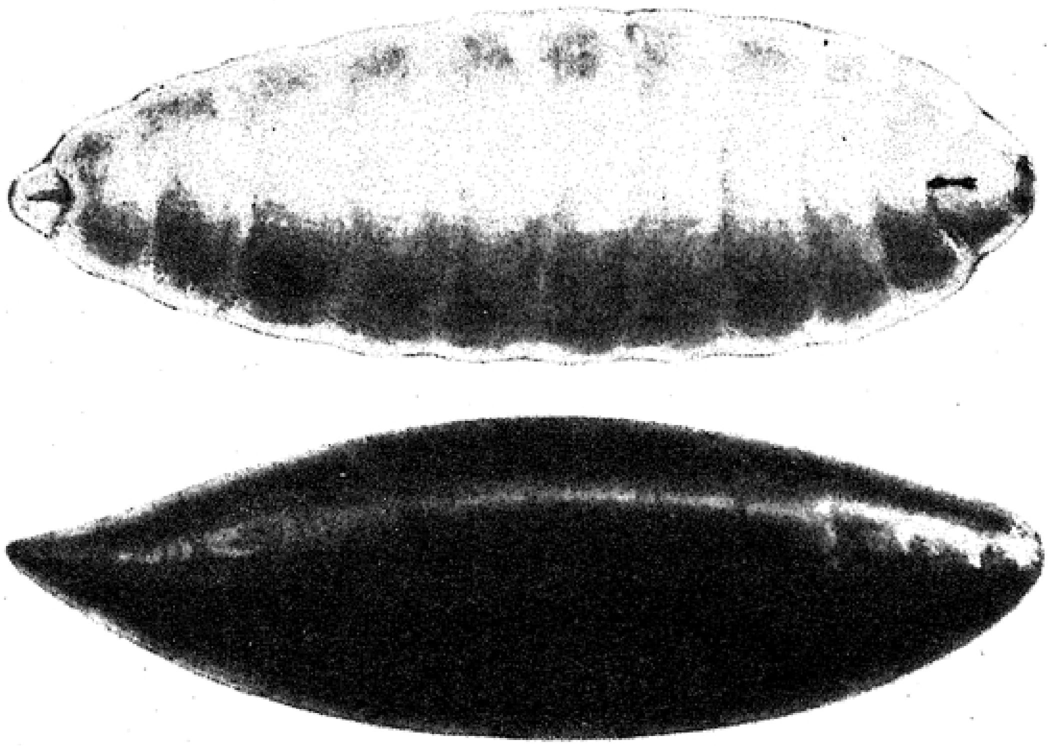

Fig. 8.—Hessian fly: a. The grown maggot, removed from the puparium. b. The puparial, or "flaxseed" stage. X 25.

adult fly itself. The pupa (Fig. 9), when fully developed, forces its way out of the flaxseed past obstructing leaf sheath and soil into the air. The pupal skin is then shed and the mature fly emerges.

Fig. 9.—Hessian fly: The pupa, removed from the flaxseed. X 25.

RELATION OF LIFE CYCLE TO CONTROL

The winter wheat plant is most highly susceptible to the hessian fly during its first 3 months from about mid-September to the end of December. The larvae of the overwintering fall generation are developing actively at this time when the plants are least able to withstand the injury. Therefore this period in the life cycle of the hessian fly usually is the most destructive. Another period of injury occurs in the spring, reaching its climax in late May or in June. (Figure 3.) It develops from attack by one or both spring generations of the fly, and the amount of damage depends upon the size of these populations and the susceptibility of the seedings in the spring. In the absence of spring weather especially favorable to the fly and because the plants are older and the amount of hardening straw is greater, damage by spring-generation larvae may be so slight as to go unnoticed. It may, however, be expected to increase sharply when a fall of fairly high infestation and damage is followed by a rainy spring. During the months from September of the planting year through June of the year following, nothing can be done toward controlling the hessian fly beyond destroying the crop of wheat in which it occurs.

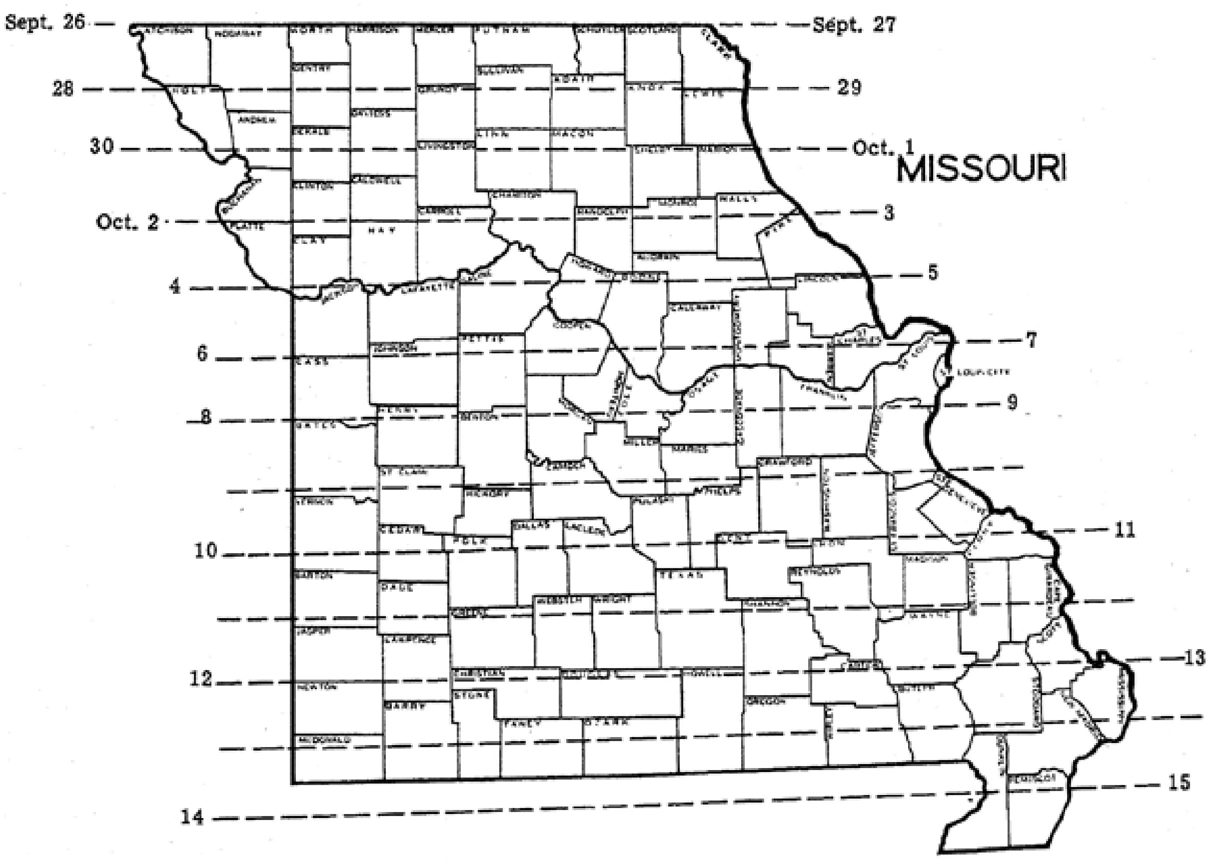

Fig. 10.—Approximate earliest safe dates for seeding winter wheat in Missouri to avoid the hessian fly. Average variation from these dates in time of disappearance of the fly, 4 days.

During the 2½ to 3 months after harvest, from July 1 to September 15 or later, emergence of flies from flaxseeds present in stubble and volunteer wheat may be largely prevented in many cases by summer or early fall plowing to bury the stubble, followed by thorough preparation of a well-tilled, compact seedbed. Finally, by delaying planting until the safe date some time between September 26 and October 15, depending on the locality (Fig. 10), fall infestation may be almost completely avoided.

NATURAL AGENCIES UNFAVORABLE TO OUTBREAKS

Insufficient Moisture

In years when the period between harvest and seeding is characterized by prolonged drought with only scant and unevenly distributed rainfall, the hessian fly population does not increase normally in the fall wheat sowings. Dry weather through July, August, and September interferes with pupation and emergence of the flies, with the work of land preparation and seeding, and with the germination of the wheat. Furthermore, at moisture levels only a little above the wilting point of the wheat plant, egg deposition, hatching, and migration of young maggots into the plants are reduced. In such seasons even those flies which are able to emerge cannot find wheat on which to deposit their eggs. It sometimes happens that summer drought is followed by rain and unseasonably cool weather in August and early September. The rain and cool weather result in emergence of the bulk of the flies in some localities even before the fall wheat has been planted.

Prolonged drought in the spring, also, sometimes adversely affects the increase of the fly at an important time. Emergence, egg deposition, and migration of the maggots into their feeding positions are retarded in much the same way as in the fall. In unusually dry spring periods, the wheat, whether volunteer or sown, ceases to produce tillers and leaves, and the plants begin to harden and become unsuitable to the fly. These conditions retard the growth and development of the principal spring generation and prevent the formation of a second spring generation.

On the other hand, in some years excessive local rainfall prevents seeding at the normal time, which, in turn, delays the emergence of sown wheat beyond the period for infestation by maggots of the fall generation.

As a rule, the seasonal weather fluctuations most unfavorable to the hessian fly occur in late summer and early fall, the spring period being, on the average, more favorable.

Natural Enemies

In its immature stages the hessian fly has many parasite and several predatory enemies. It may be stated with little exaggeration that fifty different insect and other enemies utilize the hessian fly as a part or most of their food supply. Less than half this number have been found in Missouri, however, and not a single instance has been observed or is recorded in which its enemies have succeeded in destroying all the current fly population. These enemies cannot be relied upon to assist materially in controlling the hessian fly in Missouri under conditions such as prevailed during the years covered by the field tests here reported. No practicable method is known for increasing either the number of enemy species or the number of individuals of any one enemy.

FOOD PLANTS

Common winter and spring wheats are the only crops seriously damaged by the hessian fly. It is known to attack barley, but rarely causes any considerable injury. Rye, emmer, and spelt have been listed as host plants. It has been found in small numbers on several grasses, including wheatgrass, ryegrass, bottlebrush grass, and little barley, and has been reared from some of these. No forthright evidence of important transfer from these minor hosts to wheat has been obtained.

TESTS OF CONTROL BY DATE PLANTING

Description of Test Plots

Seeding-date test strips for the principal wheat-growing areas of Missouri were located near Maryville, Bethany, Warrensburg, Columbia, St. Louis, Jefferson City, Cuba, Altenburg, Fredericktown, Cape Giardeau, Lebanon, Springfield, Mountain Grove, and Charleston. In general, wheat was planted in a single drill-width or drill-round, about 200 feet long, every 3 to 7 days during a period of at least 2 weeks before and after a central date which was assumed to be late enough to avoid injurious infestation. The strips were sown side by side, within 3 or 4 feet of one another, generally in the margins of wheat fields. After the initial years of trial the individual plots were sown on the same selected, uniform land in succeeding years. Wheat varieties seeded were those commonly grown in the neighborhood and by the cooperating farmers and experiment stations doing the planting. They were such ordinary wheats as Fultz, Fulcaster, Poole, Trumbull, Harvest Queen, Michigan Wonder, Red Prolific, and Kanred.

Test Plot Records

Records of infestation in the test plantings were obtained in early winter and again just before harvest, after adult activity of the hessian fly had ceased and its population had become stabilized in the wheat plants. The sample unit used to determine the amount of seasonal infestation was the entire plant including the primary shoot with all its tillers for the fall period, and the individual stem or culm for the spring period. The sample size was 100 or more units, assembled in lots of approximately equal number from 6 representative places in the plot. Plot yields in bushels per acre were obtained from a 5-square-yard sample assembled 1 square yard in a place from 5 representative places in the plot, at most localities; while at remaining localities plots were trimmed to equal size and full-plot yields taken.

Planting Dates Safe from Infestation

The best average seeding dates safe from the hessian fly obtainable for Missouri from these field-plot tests through the crop years 1917 to 1935 are given in figure 10. Having due regard for the facts that the yield of wheat sown too early may be reduced by the fly, while that of wheat sown unnecessarily late may be reduced by winter killing, these are the earliest safe planting dates. The safe dates represented by the test localities for different latitudes in the State are September 26 and 29 and October 3, 4, 6, 8, 10, and 11, which should be reliable to within about 4 days. The dates are a little earlier in the western part of the State than at the same latitudes in the eastern part. It is impossible to set more precise dates from available information because of the sporadic occurrence of fall outbreaks during the period covered by these trials.

Yearly Variations in the Safe Planting Dates

The safe dates of sowing vary considerably from year to year in response to fluctuations in rainfall, ground moisture, and temperature. As heretofore explained, arid weather in July, August, and September delays the fall outbreak of flies, and consequently the arrival of the safe period of planting. When the weather is extremely dry, seeding and germination may also be delayed beyond the critical date for the fly. Local rains during August and September have the opposite effect of inducing the flies to emerge and die earlier than usual, making it safe to sow wheat a few days earlier. When the late summer rains and reduced temperatures cause a pronounced change of weather, the flies may emerge before any wheat is up. These and other less readily observed conditions profoundly influenced results from the test seedings, including the determination and variability of the safe dates. Usually the flies deposit their eggs and die early enough in the fall to allow ample time for planting during the best wheat-sowing period. Some years the fly is no menace, any date within the ordinary time for sowing wheat being safe.

Yearly Average Infestations in Test Plots

For reasons already stated, the average infestations in the date-test plots varied considerably from year to year. This is indicated

TABLE 1. YEARLY AVERAGE PERCENTAGE OF HESSIAN FLY INFESTATIONS AND WHEAT YIELDS, BUSHELS PER ACRE, IN ANTEDATE AND SAFE-DATE TEST PLOTS IN MISSOURI 1917-1935

Crop year	Fall infestations				Spring infestations				Yields			
	Antedate plots		Safe-date plots		Antedate plots		Safe-date plots		Antedate plots		Safe-date plots	
	Total plots no.	Infested plants percent	Total plots no.	Infested plants percent	Total plots no.	Infested culms percent	Total plots no.	Infested culms percent	Total plots no.	Bushels per acre	Total plots no.	Bushels per acre
1917	16	34	16	3	17	2	13	2	15	23.4	14	23.6
1918	20	0	22	0	21	0	19	0	20	25.1	20	21.4
1919	15	4	16	0	17	2	16	2	11	27.1	11	24.4
1920	15	40	20	1	10	32	13	9	12	16.2	17	18.3
1921	18	31	22	1	17	16	22	14	18	23.0	22	20.3
1922	16	21	27	2	16	8	27	3	14	20.4	24	19.3
1923	13	19	29	3	15	13	28	15	13	14.7	29	16.7
1924	5	3	14	0	8	6	18	11	9	13.3	18	17.3
1925	11	12	18	1	9	8	15	4	8	17.1	16	14.5
1926	10	0	17	0	10	1	17	1	10	29.1	17	22.0
1927	8	2	7	0	7	1	5	2	6	23.0	4	21.4
1928	12	38	10	5	11	16	9	5	8	14.1	7	25.0
1929	16	20	14	2	16	24	14	21	15	15.0	14	15.8
1930	21	20	18	2	20	19	15	16	19	23.0	15	26.4
1931	22	7	22	0	21	11	22	15	22	29.3	22	28.5
1932	25	43	12	18	29	31	14	28	29	15.4	13	18.7
1933	31	29	24	2	25	14	19	8	24	34.1	20	18.7
1934	27	16	18	0	23	16	14	6	19	18.5	11	23.5
1935	23	31	16	1	17	59	15	44	17	13.6	13	16.0

in table 1, which shows the fall plant infestations and spring culm infestations in all the years. Fall infestations were above the average established for the State by these tests in seven of the years; they were just moderate in five more, and almost negligible in the remaining seven years. The supernormal fall infestations occurred in the crops of 1917, 1920, 1921, 1928, 1932, 1933, and 1935; plots sown before the safe date had moderate to large infestations, whereas those sown on and after that date were almost free from the fly. Two of the crops sustaining more than average fall infestation—those of 1920 and 1928—followed fall infestations of only 4% and 2% and spring infestations of only 2% and 1% in the preceding crops, illustrating the potentially rapid increase of the fly. In such seasons it is impossible to foretell with certainty whether a damaging outbreak will occur. Nevertheless, the general trend of infestation from spring to fall was downward or remained unchanged in about 57% of the total years of record. On the other hand, the trend of infestation from fall to spring was upward in about 68% of the total years. This indicates that the summers from 1917 to 1935 were rather unfavorable to the hessian fly, whereas the winter and spring periods were more favorable, in either case about two-thirds of the time. This conclusion is based on the infestations of the antedate plots and may with little difficulty be observed in tables 4 and 5.

The yearly plot average infestations were influenced greatly by local outbreaks in response to increased moisture. For example, while there was no serious State-wide loss of crop due to the fly in the crops of 1918, 1919, 1924, 1926, 1927, and 1931 (table 1), serious damage occurred to the crop of 1924 at Maryville, following above normal rainfall. Fall infestations were zero in plot samples in the crops of 1918 and 1926, both preceded by exceptionally dry planting seasons; all months except April and August, 1917, were abnormally dry, while in 1925 there was general deficiency of rainfall during the first eight months, with pronounced drought effects during July to September, inclusive. Most of the sudden reductions

TABLE 2. AVERAGE PERCENTAGE OF PLANTS AND STEMS INFESTED IN THE FALL BY THE HESSIAN FLY, AND WHEAT YIELDS IN BUSHELS PER ACRE IN SOWING-DATE TEST PLOTS IN MISSOURI, 1917-1935, IN ALL LOCALITIES FOR ALL YEARS.

Localities: infestations (per cent) and yields (bushels per acre)	Antedate plots				Safe-date plots			
Maryville, (10 years) dates sown*	10-13	14-17	18.21	22-25	26-29	30-3	4-7	8-11
Plant infestation	0	42	1	11	7	4	1	0
Stem infestation	0	20	0	5	4	3	0	0
Yield	43.1	26.1	31.0	17.4	30.0	27.0	28.2	24.7
Bethany, (9 years) dates sown*	13-16	17-20	21-24	25-28	29-2	3-6	7-10	11-14
Plant infestation	23	18	13	6	2	0	0	0
Stem infestation	13	9	7	3	1	0	0	0
Yield	24.2	8.8	31.6	10.9	18.1	7.2	16.9	-
Warrensburg, (10 years) dates sown*	17-20	21-24	25-28	29-2	3-6	7-10	11-14	15-18
Plant infestation	-	19	20	10	3	2	0	0
Stem infestation	-	7	13	6	2	1	0	0
Yield	-	33.9	30.1	33.1	33.0	29.4	32.7	35.3
Columbia (18 years) dates sown*	18-21	22-25	26-29	30-3	4-7	8-11	12-15	16-19
Plant infestation	31	24	13	17	3	1	0	0
Stem infestation	17	12	5	10	2	0	0	0
Yield	33.1	28.5	20.5	26.9	23.2	23.7	23.2	18.1
Jefferson City (3 years) dates sown*	19-22	23-26	27-30	1-4	5-8	9-12	13-16	17-20
Plant infestation	-	12	29	22	8	-	0	-
Stem infestation	-	5	13	9	4	-	0	-
Yield	-	35.6	27.4	31.3	27.5	-	26.7	-
Cuba, (12 years) dates sown*	20-23	24-27	28-1	2-5	6-9	10-13	14-17	18-21
Plant infestation	3	26	22	10	3	1	1	0
Stem infestation	1	11	8	5	1	1	1	0
Yield	30.0	11.7	20.1	14.1	14.9	16.3	11.9	11.7
St. Louis, (15 years) dates sown*	22-25	26-29	30-3	4-7	8-11	12-15	16-19	20-23
Plant infestation	-	49	40	33	8	2	5	0
Stem infestation	-	29	23	23	5	1	1	0
Yield	-	13.1	17.4	19.9	22.0	16.3	18.5	19.5
Altenburg (6 years) dates sown*	24-27	28-1	2-5	6-9	10-13	14-17	18-21	22-25
Plant infestation	45	59	23	21	4	1	0	0
Stem infestation	22	30	11	8	2	0	0	0
Yield	14.4	12.5	16.0	16.8	15.9	15.5	16.6	13.6
Cape Girardeau (5 years) dates sown*	24-47	28-1	2-5	6-9	10-13	14-17	18-21	22-25
Plant infestation	-	15	11	7	2	1	0	0
Stem infestation	-	9	7	4	2	1	0	0
Yield	-	15.5	11.4	14.2	20.4	11.0	24.5	0

TABLE 2 Continued

Localities: infestations (per cent) and yields (bushels per acre)	Antedate plots				Safe-date plots			
Fredericktown (2 years) dates sown*	24-27	28-1	2-5	6-9	10-13	14-17	18-21	22-25
Plant infestation	0	48	64	0	9	-	0	0
Stem infestation	0	34	26	0	4	-	0	0
Yield	26.7	25.5	28.2	24.5	34.6	-	22.7	23.9
Charleston (16 years) dates sown*	25-28	29-2	3-6	7-10	11-14	15-18	19-22	23-26
Plant infestation	20	35	25	10	4	0	0	0
Stem infestation	7	15	11	5	2	0	0	0
Yield	20.7	20.8	18.8	17.3	17.1	18.0	14.3	22.5
Springfield (19 years) dates sown*	25-28	29-2	3-6	7-10	11-14	15-18	19-22	23-26
Plant infestation	58	9	31	6	3	0	0	0
Stem infestation	30	5	22	5	2	0	0	0
Yield	13.6	22.5	16.5	16.1	20.1	13.9	16.6	9.8
Lebanon, (3 years) dates sown*	25-28	29-2	3-6	7-10	11-14	15-18	19-22	23-26
Plant infestation	10	45	3	95	0	10	0	-
Stem infestation	3	34	2	75	0	10	0	-
Yield	39.9	19.6	24.1	1.0	26.6	9.7	9.7	-
Mountain Grove (3 years) dates sown*	25-28	29-2	3-6	7-10	11-14	15-18	19-22	23-26
Plant infestation	16	38	5	10	2	0	0	0
Stem infestation	4	18	1	5	1	0	0	0
Yield	21.7	24.5	10.9	16.4	4.2	15.1	21.7	9.6
Averages --	Antedate seedings				Safe-date seedings			
Plant infestations per cent	22.2				2.2			
Stem infestations per cent	12.3				1.3			
Yield, bushels	20.0				20.1			

* Sowings in September and October.

of hessian fly population during the years of experiment were very largely due to weather conditions such as these. Rarely, the populations were reduced by unseasonable reductions of temperature during the critical weeks of egg deposition and hatching.

Despite these and other noncontrolled sources of variation, the yearly average fall infestations, as summarized for all localities over all years in tables 2, 3, and 4, clearly define the relationship between time of seeding and amount of fall infestation. Largest infestations occurred in the earlier sowings and decreased progressively, though with some irregularity, through successively later sowings up to the safe seeding period, when all (except in 1932, 1 year in 19) were practically noninfested.

Infestation by the spring generations of the hessian fly (table 5) depended much less upon the time of planting the test plots. More or less indiscriminate dispersion of the flies over all nearby wheat resulted in greater uniformity of infestation in all the plots at a locality. Spring infestations averaged only 5% greater while fall infestations averaged 21% greater in antedate than in safe-date plots over all years. Similarly compared, spring infestations were only

TABLE 3. YEARLY AVERAGE PERCENTAGE OF PLANTS INFESTED BY THE HESSIAN FLY IN THE FALL IN THE MISSOURI SEEDING-DATE TEST PLOTS, 1917-1935

Crop year	Succeeession of feedings, in 4-day intervals							
	Antedate plots				Safe-date plots			
	1	2	3	4	5	6	7	8
1917	76	38	24	7	6	1	1	0
1918	0	0	0	0	0	0	0	0
1919	10	7	4	0	1	0	0	0
1920	38	56	22	30	1	4	0	0
1921	34	41	41	22	3	1	0	0
1922	42	29	18	3	5	1	0	0
1923	23	45	9	16	7	2	1	0
1924	--	14	3	0	0	0	0	0
1925	--	29	4	4	1	0	2	0
1926	--	0	0	0	0	0	0	0
1927	4	4	--	0	0	0	0	--
1928	60	37	45	16	6	4	0	--
1929	--	33	23	12	4	0	0	--
1930	35	31	21	12	4	1	0	0
1931	3	15	5	0	1	0	0	--
1932	--	49	47	43	27	7	4	--
1933	31	48	23	26	5	0	0	--
1934	34	18	33	5	0	1	0	--
1935	74	2	34	10	1	0	0	--

TABLE 4. YEARLY AVERAGE PERCENTAGE OF STEMS[1] INFESTED BY THE HESSIAN FLY IN THE FALL IN THE MISSOURI SEEDING-DATE TEST PLOTS, 1917-1935

Crop year	Succession of seedings, in 4-day intervals							
	Antedate plots				Safe-date plots			
	1	2	3	4	5	6	7	8
1917	30	26	10	4	3	0	1	0
1918	3	0	2	1	0	0	0	0
1919	3	3	2	0	1	0	0	0
1920	31	43	13	27	0	3	0	0
1921	13	23	14	18	2	0	0	0
1922	9	8	5	2	1	0	0	0
1923	5	21	3	8	3	2	1	0
1924	--	35	6	0	4	4	0	0
1925	--	9	2	1	0	0	1	0
1926	--	0	0	0	0	0	0	0
1927	1	1	--	0	0	0	0	--
1928	32	17	32	10	4	4	0	--
1929	--	20	16	8	3	0	0	--
1930	26	16	13	10	3	1	0	0
1931	1	5	1	0	0	0	0	--
1932	21	22	22	20	14	7	2	--
1933	27	28	14	15	3	0	0	--
1934	15	9	16	3	0	0	0	--
1935	49	1	31	13	1	0	0	--

1. "Stem" is used for simplicity to denote the individual shoot, whether original stalk or tiller.

TABLE 5. YEARLY AVERAGE PERCENTAGE OF STEMS[1] INFESTED BY THE HESSIAN FLY IN THE SPRING IN THE MISSOURI SEEDING-DATE TEST PLOTS. 1917-1935

Crop year	Succession of seedings, in 4-day intervals							
	Antedate plots				Safe-date plots			
	1	2	3	4	5	6	7	8
1917	1	1	2	2	2	1	1	2
1918	0	0	0	0	0	1	0	2
1919	2	2	3	2	2	2	2	0
1920	31	36	23	34	11	8	10	9
1921	17	12	18	18	11	9	11	14
1922	15	9	7	3	3	4	4	2
1923	6	11	15	15	12	12	22	13
1924	--	2	10	5	10	18	6	4
1925	--	11	10	5	5	3	2	6
1926	--	0	1	1	1	1	1	1
1927	3	1	--	1	0	3	0	--
1928	31	11	17	10	6	6	0	--
1929	--	29	24	22	23	22	13	--
1930	10	17	22	19	14	18	14	--
1931	1	13	6	13	16	4	22	--
1932	51	23	35	30	26	35	24	--
1933	7	13	8	18	8	6	9	--
1934	36	5	30	14	3	22	6	--
1935	72	2	69	51	44	79	26	--

1. "Stem" is used to denote the individual shoot, whether original stalk or tiller.

11% greater while fall infestations were 43% greater in antedate than in safe-date seedings in the years and localities of more than average infestation. Infestation in the spring equaled or exceeded that of the preceding fall in early seedings in four-fifths of the years, indicating generally favorable conditions for the fly during that relatively moist period. Over the dry season, from spring to fall, the fly was able to increase moderately in less than one-fifth of the years. It is important to note here that spring infestations in post-date plot sowings would have been much less if these plots had not been exposed to flies emerging from nearby earlier sown fields and plots, and that concerted delayed sowing would largely prevent spring infestation as well as fall infestation.

The average yearly spring infestations in the successive seeding periods are given in table 5.

Yield in Relation to Infestation and Planting Date

Since the test plots sown before the safe date were fully exposed to attack by fall and spring generations, there was no control over the spring infestation. Its effect on yield is not readily separable from that of the total of factors adversely affecting yield. Reductions in yield which it undoubtedly causes in years of severe spring infestation are thus lost to the record. The effect of total infestation on yield, as shown by comparison of the yields from early with those from late-sown plots, is also somewhat obscured by the influx of flies in the spring into the otherwise fly-free plots.

The yearly average yields in bushels per acre for the seeding intervals nearest to the safe date for the years 1917-1935 are given in table 6. They may be compared readily with the fall and spring infestations in tables 4 and 5. On the average, over the 19 years, yields in the four ante- and post-date groups were almost identical, being only one-half a per cent greater in the late-sown plots, the respective fall plant infestation levels being 22% and 2% (table 2). This result was due to the 12 years of less-than-average infestations, some of which were zero. The important consideration for the wheat grower, however, is the severe loss that may be sustained from hessian fly attack on any one year's crop, and that the attack cannot be foreseen. For example, an early-sown plot at Maryville in the

TABLE 6. YEARLY AVERAGE WHEAT YIELDS, BUSHELS PER ACRE, FROM THE HESSIAN FLY SEEDING-DATE TEST PLOTS IN MISSOURI, 1917-1935

Crop year	Succession of seedings, in 4-day intervals							
	Antedate plots				Safe-date plots			
	1	2	3	4	5	6	7	8
1917	24.4	21.9	23.5	24.0	25.8	22.6	22.3	20.2
1918	25.0	27.9	21.8	25.1	23.9	17.7	21.1	20.2
1919	22.7	35.5	17.7	27.8	19.6	31.2	17.0	31.3
1920	21.3	6.6	29.0	13.1	21.9	17.0	17.4	17.0
1921	16.3	29.3	21.0	21.5	25.1	19.3	17.0	14.5
1922	21.7	25.1	18.1	19.3	23.6	19.5	21.3	13.4
1923	20.8	15.5	15.8	10.1	19.3	16.3	13.0	16.7
1924	---	5.0	18.9	13.2	15.1	15.9	17.7	36.6
1925	---	25.8	14.2	14.2	18.0	13.8	12.7	8.6
1926	---	49.8	21.8	26.0	23.6	19.5	22.0	22.3
1927	22.6	24.6	---	22.1	25.3	20.3	19.8	---
1928	6.1	20.0	11.4	16.1	23.8	24.4	31.4	---
1929	---	13.0	16.0	15.5	16.1	15.7	15.5	---
1930	30.8	14.4	27.3	23.5	25.3	26.2	28.7	---
1931	30.0	29.3	30.4	28.9	31.2	24.2	26.2	---
1932	5.4	11.1	18.9	16.0	19.9	18.5	16.0	---
1933	24.2	17.4	25.2	16.3	19.3	9.6	20.1	---
1934	8.6	24.3	13.3	20.2	26.5	10.9	26.2	---
1935	8.9	9.7	15.2	14.6	19.3	9.9	15.7	---
Average for all years	19.25	21.34	19.97	19.34	22.24	18.55	20.06	20.08

year of outbreak was nearly 100% infested, the wheat as a result being not worth harvesting. Field outbreaks of equal severity are common in this and other States.

TABLE 7. AVERAGE FALL INFESTATION, IN PERCENTAGE OF PLANTS AND STEMS, BY THE HESSIAN FLY AND BUSHELS-PER-ACRE WHEAT YIELDS IN SEEDING-DATE TEST PLOTS IN MISSOURI, 1917-1935, IN LOCALITIES AND YEARS OF SUPERNORMAL INFESTATION.

Localities	Antedate plots				Safe-date plots			
Maryville, (2 years) dates sown*	10-13	14-17	18-21	22-25	26-29	30-3	4-7	8-11
Plant infestation	---	92	---	48	42	16	0	0
Stem infestation	---	51	---	25	27	9	0	0
Yield	---	2.8	---	4.9	26.7	19.9	28.3	26.7
Warrensburg, (2 years) dates sown*	17-20	21-24	25-28	29-2	3-6	7-10	11-14	15-18
Plant infestation	---	48	39	38	17	12	1	---
Stem infestation	---	20	26	22	9	6	1	---
Yield	---	21.1	24.0	27.3	28.0	28.2	26.0	---
Columbia, (2 years) dates sown*	18-21	22-25	26-29	30-3	4-7	8-11	12-15	16-19
Plant infestation	96	71	---	40	4	0	0	---
Stem infestation	63	47	---	26	3	0	0	---
Yield	33.1	33.3	---	29.8	31.6	26.9	25.9	---
Cuba, (4 years) dates sown*	20-23	24-27	28-1	2-5	6-9	10-13	14-17	18-21
Plant infestation	---	42	52	25	9	2	1	0
Stem infestation	---	18	19	11	4	2	1	0
Yield	---	8.1	14.5	10.9	10.9	21.7	11.2	21.7
St. Louis, (7 years) dates sown*	22-25	26-29	30-3	4-7	8-11	12-15	16-19	20-23
Plant infestation	---	69	68	47	15	2	2	---
Stem infestation	---	42	40	33	10	2	1	---
Yield	---	10.9	17.9	17.1	18.0	15.3	17.7	---
Altenburg, (2 years) dates sown*	24-27	28-1	2-5	6-9	10-13	14-17	18-21	22-25
Plant infestation	64	90	62	26	11	3	0	0
Stem infestation	36	45	30	14	4	1	0	0
Yield	8.6	12.5	15.3	17.6	13.2	18.3	16.6	10.8
Cape Girardeau (1 year) dates sown*	24-27	28-1	2-5	6-9	10-13	14-17	18-21	22-25
Plant infestation	---	38	37	18	---	2	---	---
Stem infestation	---	20	19	10	---	2	---	---
Yield	---	3.2	10.3	10.7	---	10.4	---	---
Fredericktown, (1 year) dates sown*	24-27	28-1	2-5	6-9	10-13	14-17	18-21	22-25
Plant infestation	---	95	64	---	17	---	---	0
Stem infestation	---	68	26	---	8	---	----	0
Yield	---	22.5	28.2	---	46.3	---	---	29.5
Charleston, (4 years) dates sown*	25-28	29-2	3-6	7-10	11-14	15-18	19-22	23-26
Plant infestation	64	61	45	22	8	0	0	---
Stem infestation	30	30	19	12	4	0	0	---
Yield	8.2	16.0	18.3	14.5	18.5	23.6	14.5	---
Springfield, (5 years) dates sown*	25-28	29-2	3-6	7-10	11-14	15-18	19-22	23-26
Plant infestation	73	---	52	11	2	0	---	0
Stem infestation	42	---	38	11	2	0	---	0
Yield	8.7	---	11.5	12.3	15.4	9.6	---	4.2

Averages--	Antedate seedings	Safe-date seedings
Plant infestation, percent	48.6	5.8
Stem infestation, percent	28.7	3.4
Yield, bushels	14.8	18.8

Giving separate consideration to those localities in which the annual infestations were above average and minor outbreaks occurred, excluding for the moment all other localities, the average yield from safe-sown plots was 27% greater than that from antedate sowings, at the respective fall plant-infestation levels of 6% and 49% (table 7). Again, considering only the years of above-average infestations for the State, including all localities (table 8), the yield from safe-sown plots was 8% greater than from antedate sowings at respective fall plant-infestation levels of 4% and 35%. Complete consistency between yields and infestations is not to be expected because the amount of damage caused exclusively by the hessian fly cannot be isolated.

TABLE 8. YEARLY AVERAGE PERCENT OF PLANTS AND OF STEMS INFESTED BY THE HESSIAN FLY IN THE FALL AND BUSHELS-PER-ACRE WHEAT YIELDS IN DATE-TEST PLOTS IN MISSOURI, AT ALL LOCALITIES IN 7 YEARS OF SUPERNORMAL INFESTATION FOR THE STATE. [1]

Localities	Antedate plots				Safe-date plots			
Maryville, dates sown*	10-13	14-17	18-21	22-25	26-29	30-3	4-7	8-11
Plant infestation	0	16	1	0	1	1	0	0
Stem infestation	0	6	0	0	1	0	0	0
Yield	43.1	50.7	42.5	---	40.6	40.8	30.9	19.7
Bethany, dates sown*	13-16	17.20	21-24	25-28	29-2	3-6	7-10	11-14
Plant infestation	31	23	7	6	1	---	0	---
Stem infestation	18	11	4	2	1	---	0	---
Yield	24.2	11.3	31.6	10.9	22.9	---	22.2	---
Warrensburg, dates sown*	17-20	21-24	25-28	29-2	3-6	7-10	11-14	15-18
Plant infestation	---	27	27	38	7	7	0	---
Stem infestation	---	10	26	15	3	3	0	---
Yield	---	23.1	24.0	27.3	28.5	28.5	28.7	---
Columbia, dates sown*	18-21	22-25	26-29	30-3	4-7	8-11	12-15	16-19
Plant infestation	96	46	27	30	6	0	0	0
Stem infestation	63	27	12	17	4	0	0	0
Yield	33.1	24.3	22.2	26.9	26.7	20.0	19.7	14.5
Jefferson City, dates sown*	19-22	23-26	27-30	1-4	5-8	9-12	13-16	17-20
Plant infestation	---	9	33	44	11	---	0	---
Stem infestation	---	6	16	17	5	---	0	---
Yield	---	28.5	26.0	26.3	22.8	---	26.7	---
Cuba, dates sown*	20-23	24-27	28-1	2-5	6-9	10-13	14-17	18-21
Plant infestation	---	36	43	25	8	3	0	0
Stem infestation	---	19	19	11	3	1	0	0
Yield	---	8.1	14.5	10.9	10.8	21.7	11.2	21.7
St. Louis, dates sown*	22-25	26-29	30-3	4-7	8-11	12-15	16-19	20-23
Plant infestation	---	58	63	38	12	2	2	---
Stem infestation	---	35	35	25	7	2	1	---
Yield	---	11.9	19.8	17.1	18.5	12.3	15.7	---
Altenburg, dates sown*	24-27	28-1	2-5	6-9	10-13	14-17	18-21	22-25
Plant infestation	45	90	33	18	7	2	0	0
Stem infestation	26	45	17	10	3	1	0	0
Yield	10.5	12.5	13.1	15.4	13.9	14.6	16.6	12.7

TABLE 8. Continued

Localities	Antedate plots				Safe-date plots			
Cape Girardeau, dates sown*	24-27	28-1	2-5	6-9	10-13	14-17	18-21	22-25
Plant infestation	---	20	18	13	7	1	---	---
Stem infestation	---	10	10	8	7	1	---	---
Yield	---	9.4	13.8	12.5	20.3	12.5	---	---
Fredericktown, dates sown*	24-27	28-1	2-5	6-9	10-13	14-17	18-21	22-25
Plant infestation	---	95	64	---	17	---	---	0
Stem infestation	---	68	26	---	8	---	---	0
Yield	---	22.5	28.2	---	46.3	---	---	29.5
Charleston, dates sown*	25-28	29-2	3-6	7-10	11-14	15-18	19-22	23-26
Plant infestation	43	61	30	23	8	0	0	---
Stem infestation	17	31	19	11	4	0	0	---
Yield	8.2	16.0	18.3	14.5	18.5	23.6	14.5	---
Springfield, dates sown*	25-28	29-2	3-6	7-10	11-14	15-18	19-22	23-26
Plant infestation	78	7	45	15	2	0	1	0
Stem infestation	43	6	34	19	2	2	1	0
Yield	10.3	16.2	12.9	11.3	15.2	9.4	12.0	4.2
Lebanon, dates sown*	25-28	29-2	3-6	7-10	11-14	15-18	19-22	23-26
Plant infestation	---	91	---	95	---	20	0	---
Stem infestation	---	69	---	75	---	20	0	---
Yield	---	2.0	---	1.0	---	1.0	0.8	---
Mountain Grove, dates sown*	25-28	29-2	3-6	7-10	11-14	15-18	19-22	23-26
Plant infestation	---	38	---	19	---	0	---	---
Stem infestation	---	18	---	9	---	0	---	---
Yield	---	24.5	---	11.0	---	12.0	---	---

Averages ---	Antedate seedings	Safe-date seedings
Plant infestation, percent	35.0	3.7
Stem infestation, percent	20.7	2.3
Yield, bushels	17.8	19.2

1. Fall infestations for the State as a whole were above average in the years 1917, 1920, 1921, 1928 1932, 1933, and 1935. Fall infestations at some localities, nevertheless, were below average in these years but above average in other years. Consequently the supernormal infestations, by years and localities in which they occurred, are brought together in table 7.

CONCLUSIONS ON CONTROL

The field tests of seeding dates for the hessian fly summarized in these pages indicate that outbreaks of the fly in Missouri were sporadic and local during the years 1917 to 1935 and governed largely by the distribution and amount of rainfall. Outbreaks have been especially favored by ample moisture in the spring and in the summer following harvest. In about two-thirds of the years of experiment, infestations over the State were below the average for all the years, which markedly affected the average yields, making them almost identical in ante- and safe-date sowings (table 2). In dry seasons, when it is known that stubble infestations are slight, there is no need to depart from the usual wheat-growing practices, such as seeding early when local soil moisture happens to be sufficient for quick germination, or seeding very early for pasturage, or following wheat with wheat—merely as precautionary measures against the fly.

The data show, however, that infestations were above average over the State in about one-third of the years and even more frequently at some localities. Early-sown wheat received more infestation and produced less and poorer-quality grain than wheat which was not sown until the safe period. In the absence of yearly surveys to determine whether fly puparia prevail in threatening numbers in stubble and volunteer wheat to emerge and infest the fall sowings, concerted adherence to the control program of safe dates and related measures is the only way now available to prevent crop losses. Since the hessian fly flaxseeds usually survive the winter well, and have a high reproductive capacity, favorable weather and food conditions through the other seasons render it capable of an immense increase of population in a year's time. A measure of the average loss of crop from the hessian fly at the localities and in the years of highest infestations is given in table 7. The differences of yield cannot be taken strictly at face value as due solely to the fly because there is no way to isolate the amount of reduction of yield caused by the fly from that caused by other injurious factors. The loss of crop in early seedings fully exposed to the hessian fly in years of higher infestations at all localities is given in table 8, and must likewise be somewhat liberally interpreted.

In the case of extremely late seedings in complete absence of the hessian fly, the tests show decidedly depressed yields due to poor germination, rooting, and growth of the wheat, making it unable to withstand drought, freezing, and other causes of winter killing which, in some years, offsets the advantage gained through freedom from the hessian fly. For this reason it is best to commence sowing immediately upon the arrival of the safe date and finish it in the shortest time possible.

Control of the hessian fly in years when it threatens serious damage is relatively simple and practical, consisting almost wholly of preventing infestation in the fall. It is most important to know in advance when to expect an outbreak. One may be expected to follow a wet summer if the fly is prevalent in the stubble. This can be ascertained only by stubble examination. It is suggested that the wheat farmer might examine his own stubble field, and that the findings be then pooled with the county agent for use in determining whether a control campaign is needed and for organizing the same. The best time for the inspection is shortly before harvest. When the evidence indicates no real fly threat, farmers need not be urged to adhere strictly to the fly-control program, which stresses seeding on the fly-safe date. On the other hand, if the stubble contains a threatening abundance of the flaxseeds, with 10% or more infested, and there is normal to abundant summer rainfall, farmers should be urged to plow under all stubble fields not seeded to lespedeza or other pasture or hay crop, keep down volunteer wheat, and delay seeding until the fly-safe date. When the need for control is indicated, the methods usually recommended and in use should be applied, such as rotation of wheat with other crops, early plowing and thorough seedbed preparation, and planting immediately upon the arrival of the fly-safe date.

Rotation of wheat with other suitable crops, which requires that the stubble be plowed under soon after harvest, aids materially in preventing outbreaks of the hessian fly, hence is placed first among the methods to be considered and prepared for in years when fly control is important.

Plowing and seedbed preparation may be made important aids in controlling the fly where wheat follows wheat. Early stubble plowing where pasture or hay crop is not seeded in the stubble, turning under the flaxseeds, destroying weeds, allowing the seedbed to settle, conserving moisture, and promoting vigorous fall growth help materially to reduce the number of flies. Early plowing followed before seeding by disking and harrowing and, on some soils, by rolling with a packer makes a compact seedbed, reduces the number of flies to emerge from the stubble and reinfest growing wheat, and prevents the volunteer growth which becomes infested and serves to reinfest sown wheat in the fall and again in the spring. The prompt germination, strong rooting, and vigorous growth resulting from such land preparation also help the wheat to withstand winter damage from drought, heat, freezing, and other unfavorable conditions and thereby minimize these objections to delayed seeding. The early sowing of wheat for summer pasturage in the face of a threatened outbreak of the fly is not advisable; the substitution of rye or barley is safer for early seeding.

Delayed seeding of wheat properly timed to avoid the bulk of the fall emergence of the fly and thereby escape serious infestation is the most important single method of forestalling attack and consequent crop damage. In fact, with the growing tendency to seed lespedeza, clover, sweetclover, timothy, or other pasture or hay crop in wheat, thus preventing plowing under stubble, seeding on the fly-safe date is the all-important control for the fly available to most farmers in Missouri. The map, figure 10, shows the dates for Missouri on which in most years seeding may be started with practical certainty of avoiding destructive infestation. These dates should be closely observed in years when the preceding crop was damaged by the fly. It is important to begin seeding on or soon after the safe date and to plant the intended acreage rapidly, taking advantage of the fall and early-winter growing period to attain a sturdy growth of plants. Most winter hazards, including the hessian fly, may be avoided by moderately late sowing on a good seedbed. Too much delay in seeding results in winter injury, increased susceptibility to spring infestation, and reduced yields.

The breeding of fly-resistant strains of wheat has gone far enough to demonstrate the possibility of reducing fly damage through the use of resistant strains. However, until seeds of such strains are available and they have been fully tested for resistance in the different wheat-growing areas, farmers should continue to use the particular strain that is best adapted to, and gives largest yields in, his region, and apply the above control measures for protecting his crop from fly damage.