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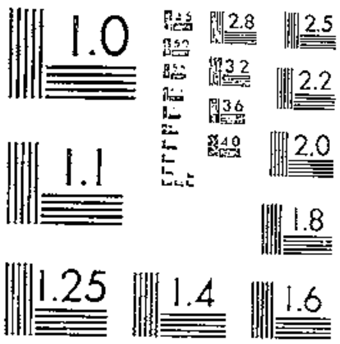

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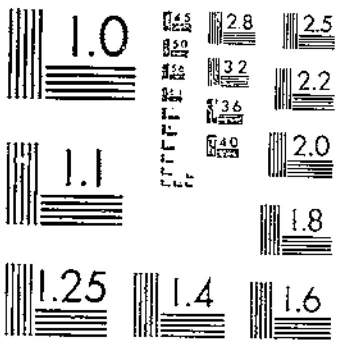

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THE HESSIAN FLY IN THE PACIFIC NORTHWEST

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INTRODUCTION

In the Pacific Northwest the Hessian fly (*Phytophaga destructor* Say) is known as an important wheat pest in the territory west of the Cascade Mountains and north of the Umpqua River. Although this territory produces but a small fraction of the wheat crop of the Pacific Northwest, wheat has always been one of the principal crops of the general farming districts west of the mountains, particularly in the Willamette Valley. It is estimated[1] that in 1927 this territory produced approximately 4,220,000 bushels of wheat on about 189,000 acres.

In this territory the Hessian fly is not so serious a pest as it is in many other areas. This may be attributed to the fact that the prevailing practice of late fall preparation of the land and consequent late seeding, which have been brought about by climatic conditions and the abandonment of the early-day practice of summer fallowing, have avoided infestation of fall-sown wheat in the fall. Hence Hessian-fly damage to young stands of fall-sown wheat has

[1] From data on Oregon crop production, 1927, by F. L. Kent, agricultural statistician, U. S. Department of Agriculture. The estimate given above includes western Washington, as producing 200,000 bushels on 8,500 acres (*19*).[2]
[2] Italic numbers in parentheses refer to Literature Cited, p. 21.

been prevented and the fields have been kept remarkably free from early volunteer wheat. Hessian-fly infestation of planted wheat has been limited, almost without exception, to that occurring in the spring.

As the Hessian fly is now well known to many farmers in this territory, numerous complaints of injury to wheat are made, especially in years when the insect is more abundant than usual. Some of the failure of wheat to fulfill expectations can doubtless be attributed to Hessian-fly injury. But this readily discernible factor is often given all the blame, whereas combinations of other factors often contribute much more to the reduction of the wheat crop than does the fly. The main factors overlooked are the weather conditions at critical periods in the growing season. Weather, of course, is an uncontrollable factor, but injury by the Hessian fly can be controlled, or at least greatly reduced. The purpose of this bulletin is to give information on methods of combating the Hessian fly in the Pacific Northwest.

The seasonal history of the Hessian fly and the factors affecting it in this territory are of considerable importance in the nation-wide study of the problem. The climatic conditions peculiar to the Pacific Northwest seem to have brought about some modification of the seasonal history of the fly as reported for eastern localities. It is believed, therefore, that the relation of these climatic conditions to the Hessian fly, as shown herein, will contribute important data on this phase of the problem of controlling this well-known wheat pest.

The effects of the environment on the important Hessian-fly parasite *Platygaster hiemalis* Forbes seem to be even more marked, as the parasite appears to have normally two generations a year in Oregon, whereas it has but one in Pennsylvania (*7*). The seasonal history and status of *P. hiemalis* and of other parasites, some of which are not known in the East, warrant further investigation of this phase of the problem.

WHEAT CULTURE IN THE PACIFIC NORTHWEST

Wheat culture in the Pacific Northwest was introduced at the Hudson's Bay Co.'s post at Fort Vancouver about 1825 (*3, p. 278*). John McLoughlin, the chief factor of this company, reported a yield of 1,800 bushels of wheat there in 1832 (*3, p. 792*) and 5,000 bushels in 1835 (*3, p. 791*). The sections of the "Oregon country" where wheat was first grown by settlers were: French Prairie (1833) (*3, p. 792*), the Chehalem Valley, Sauvie's Island, the Tualatin Plains (1843), and the Cowlitz Valley.

Soft white varieties of wheat were grown from the first. The typical wheat berry of the Willamette Valley is still soft, plump, and white, as were the kernels in a cargo said to have been rejected in New York in early days because it was believed that the wheat had swelled during the voyage (*3, p. 792*). This soft, white wheat, often weighing more than 60 pounds to the bushel (*6, p. 72; 14, p. 37*), is usually in good demand for export.

Wheat was grown continuously, sometimes alternating with oats or, after 1865, with occasional summer fallow (*8, p. 2*). Winter wheat was seeded from August to December (*6, p. 72*); usually earlier (August and September) (*14, p. 50*) on summer-fallowed fields than on cropped fields. Wheat was not infrequently allowed to volunteer for subsequent harvest without additional seeding (*14, p. 51*). Wheat of a true winter habit of growth was sometimes seeded in May, pastured during the year of planting, and harvested the following year (*15*). Average yields per acre up to 1869 have been variously reported (*2, 6, 14, 15*) as 20 to 30 bushels, with exceptional yields as high as 48 bushels or even more (*14, p. 45*). When wheat yields for Oregon were first reported by the United States commissioner of agriculture, there was an average yield of 18.8 bushels per acre the first seven years, 1869–1875 (*14, p. 42*). As computed from the census figures for 1880 (*25*), the average yield for the Willamette Valley counties was 15.4 bushels per acre, with a low of 12.1 bushels for Linn County and a high of 19.5 for Multnomah County. This was the low point of reported yields.[3]

With the introduction of successful clover culture in the late eighties and early nineties (*8, p. 3*), a wheat-clover rotation, with occasional alternation with oats or with oats and vetch, was generally adopted in the best agricultural districts and has prevailed to this time. Since the practice of summer fallowing has been abandoned, fall wheat is seeded, as a rule, in October or later. This practice has been brought about by climatic conditions. The rainfall in July and August is usually very scant, and most farmers now await sufficient precipitation to enable them to work the soil up into a good seed bed before seeding their fall wheat. Under this system of agriculture and with better farming methods in general, the average yields of wheat per acre have returned to approximately those of the early days, notwithstanding the activity of the Hessian fly.

HISTORY AND DISTRIBUTION OF THE HESSIAN FLY

The date of the first appearance of the Hessian fly in the Pacific Northwest has not been determined. Motley (*15, p. 352*), in 1853, said: "The Hessian fly and the weevil are not known in this country." Moseley (*14, p. 45*), in 1878, stated that "there is no insect or mildew of any kind to injure the crops of cereals in Oregon." Lang (*10, p. 550*), in 1885, said, "there were no insect depredators." The first definite record[4] of the occurrence of the Hessian fly in Oregon was made December 9, 1897, on material from Scappoose, Oreg., according to unpublished records of the Oregon agricultural experiment station. Cordley (*4, p. 26*), of that station, reported its occurrence in Washington County, Oreg., and Clarke County, Wash., in 1899.

The Hessian fly has been under more or less close observation by the staff of the United States entomological laboratory at Forest Grove, Oreg., since 1916.[5] In 1908 and 1909 some observations

[3] United States reports include eastern Oregon after 1875. Census reports give yields by counties.

[4] Osborn (*16, p. 10*) noted the title of an article in the Oregon Naturalist for January, 1896, entitled "Potato Bug and Hessian Fly" as indicating occurrence of the Hessian fly in Oregon. This article (which Osborn did not see) was found upon examination to be a general article by A. Gains, of Vincennes, Ind., and did not refer to Oregon.

[5] The following employees, other than the authors, have worked upon this problem and have contributed much to the mass of data upon which this paper is based. C. W. Creel, who directed the investigation up to 1919; Merton C. Lane, in 1917 to 1919; James M. Langston, who assisted in the period 1916 to 1919; Sadie E. Keen, who assisted from 1922 to 1927; and T. R. Chamberlin, who assisted in 1927 and 1928.

were made by George I. Reeves, of the Bureau of Entomology. His notes indicate that the Hessian fly was widely distributed at that time, as he found it in the lower Columbia Valley near Vancouver, Wash., and also at Albany and Corvallis, Oreg., near the center of the Willamette Valley. Before 1925 the workers at the Forest Grove laboratory found that this pest was present over all the Willamette Valley and the lower Columbia Valley in western Oregon, and in western Washington from the Columbia River to near the southern end of the Puget Sound district in King County. In 1920 (*20, p. 145*) the Hessian fly was discovered on the Saanich Peninsula of Vancouver Island. In 1926 it was reported by workers at the Oregon agricultural experiment station from northern Douglas County in the Umpqua watershed, and in 1927 the authors found infested wheat near Yoncalla in Douglas County. In the same year wheat infested by the Hessian fly was found in the upper Hood River Valley near Parkdale, Oreg. In 1932 the Hessian fly was found to be present from Seattle north to the Canadian boundary. This wheat pest has never been found east of the Cascade Mountains in either Washington or Oregon. Its known distribution in the Pacific Northwest is illustrated in Figure 1.

EXPLANATION OF TERMS

In view of the fact that "brood" and "generation" have been used by entomologists in more than one sense, it is thought best to define these and other terms as they are used in this bulletin.

"Generation" is used in its usual biological sense as a term for a body of Hessian flies of the same genealogical rank or remove from an ancestor. A generation begins with the eggs and is considered complete when the last living form of that generation becomes adult.

"Brood" is a term applied to a group of individuals of an immature stage of the fly of approximately the same age and present at approximately the same time.

"Emergence" is a term applied to the appearance of a number of Hessian-fly adults during approximately the same period. The emergences of regular occurrence in this section are called "the first spring emergence," "the second spring emergence," and "the fall emergence." Emergences which rarely occur are termed "supplemental emergences" and may occur either in the summer or in the fall or in both. The offspring of flies of each emergence constitute a brood of corresponding nomenclature.

"Young tiller" is a term applied to a young wheat shoot the nodes of which are not yet apparent.

"Culm" is a term applied to a jointed wheat stem which shows well-defined internodes.

"Fall-sown wheat," "winter-sown wheat," and "spring-sown wheat" are terms applied to wheat seeded during the indicated season without regard to the habit of growth. The mild winter climate of western Oregon usually permits seeding of varieties of wheat of a spring habit of growth in the fall and winter, and this is a common practice. Most of the wheat sown in the territory under discussion in the fall and winter during the progress of this investigation was of the spring habit of growth. An increase has recently occurred in the acreage seeded to the true winter wheats in this territory. This is especially true of such varieties as Wilhelmina (White Holland) and White Winter, but many of the wheat growers in the northern end of the Willamette Valley still plant wheats of the spring type.

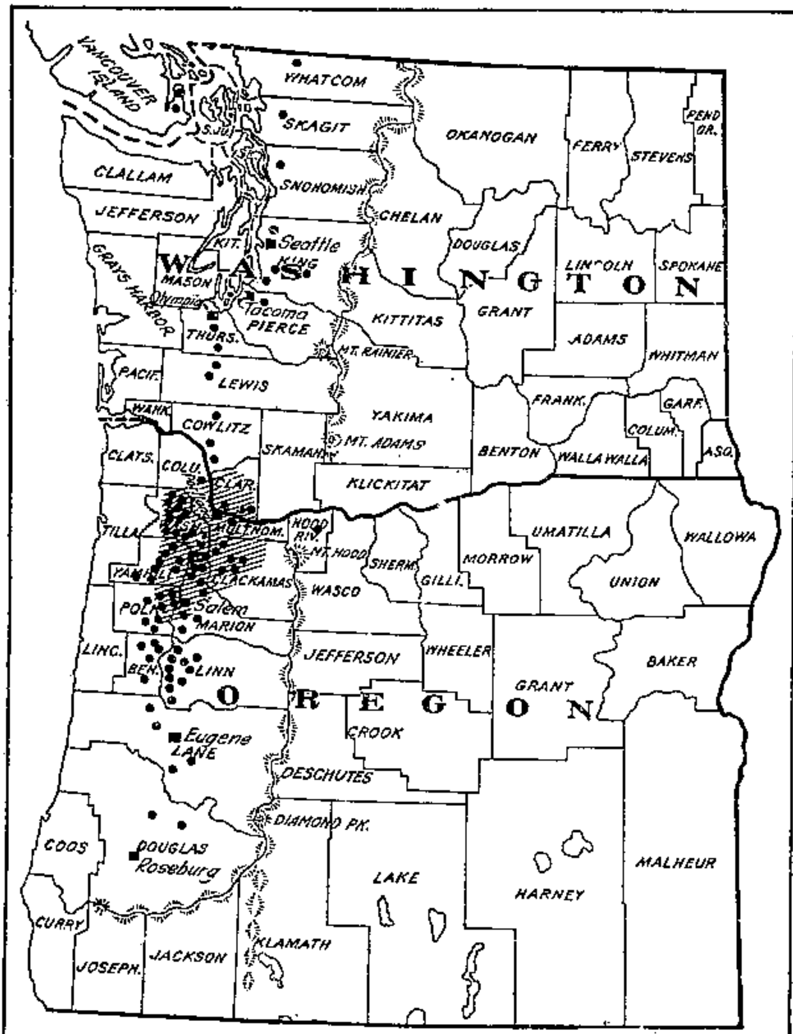

FIGURE 1.—Distribution of the Hessian fly in the Pacific Northwest. Dots represent localities where the fly has been found; shading represents sections most heavily infested

LIFE HISTORY AND HABITS OF THE HESSIAN FLY

MATING

The delicate mosquitolike flies of *Phytophaga destructor* mate soon after emergence from the puparia. M. C. Lane made some interesting observations at Forest Grove on the breeding habits in cages in 1917. He noted that the males are quick to locate females. In one instance, in a cage 3 feet square, a male was observed to enter the mouth of a small glass vial from which the observer was trying to coax a female. Free males in the field are attracted to females in wire-screen cages. The act of mating takes from 10 to 20 seconds. One male was observed to mate with three different females in one day. In another case a female mated twice with different males in rapid succession.

OVIPOSITION AND HATCHING OF EGGS

An hour or two after mating, the female begins active oviposition and exhausts her quota of eggs and dies in a short time, usually in 1 or 2 days, rarely 3, in cages. The small elongated reddish eggs are laid on the wheat leaves (fig. 2), usually in the grooves on the upper surface, but they may be laid on the smooth undersurface or, rarely, on the stem of the plant. The number of eggs laid by single females in cages varies considerably. The maximum number recorded by Lane at Forest Grove was from a female placed in a cage on May 17, 1917. This female laid 329 eggs in a little more than 24 hours and, on dissection, was found to have 32 eggs left in her ovaries. This indicated a capacity of 361 eggs for this female. The same observer secured a maximum of 280 eggs from a female of the fall emergence (which came out on September 28, 1917), and 159 eggs from a female of the second spring emergence (which came out on June 28, 1917). McConnell (*12*), working in southern Pennsylvania, has shown that the egg-laying ability of the female Hessian fly varies with the size of the individual. He found by dissection that the actual number of eggs per female ranged from 33 to 464, with an average of 287 for females of the spring emergence and 233 for those of the fall emergence. Unmated females appear to be sluggish. They lay but few eggs before death and these eggs fail to hatch.

The hatching period seems to depend largely on the temperature. In early May and in late September eggs hatched in five days at Forest Grove. Field observations indicate that the egg period is considerably longer in the cool weather of March and early April and probably appreciably shorter in June. McColloch (*11, p. 25*) recorded extremes of 4 and 12 days in a screened insectary in Kansas.

LARVAL DEVELOPMENT AND PUPATION

The young larvae, faintly red on hatching from the egg, migrate in the grooves of the wheat leaves to points beneath the sheath, either near the crown of the plant (when on young tillers) or near the nodes of culms. In rare instances they establish themselves almost midway between nodes and apparently develop successfully. When crowded on young tillers and culms, they may spread out over a considerable area on the plant stems. When once settled against the stem of the plant, the larvae are not known to move. The period of growth is variable—from three to six weeks—and is dependent, to a large degree, upon the temperature, although probably the quantity and quality of the food absorbed are also important factors. When the larvae have attained their growth they are whitish, with a glassy luster.

Soon after full growth has been attained the skin of the larva gradually becomes hardened and leathery and separates from the body. Inside this skin, according to Marchal (*13, p. 20*), the molted

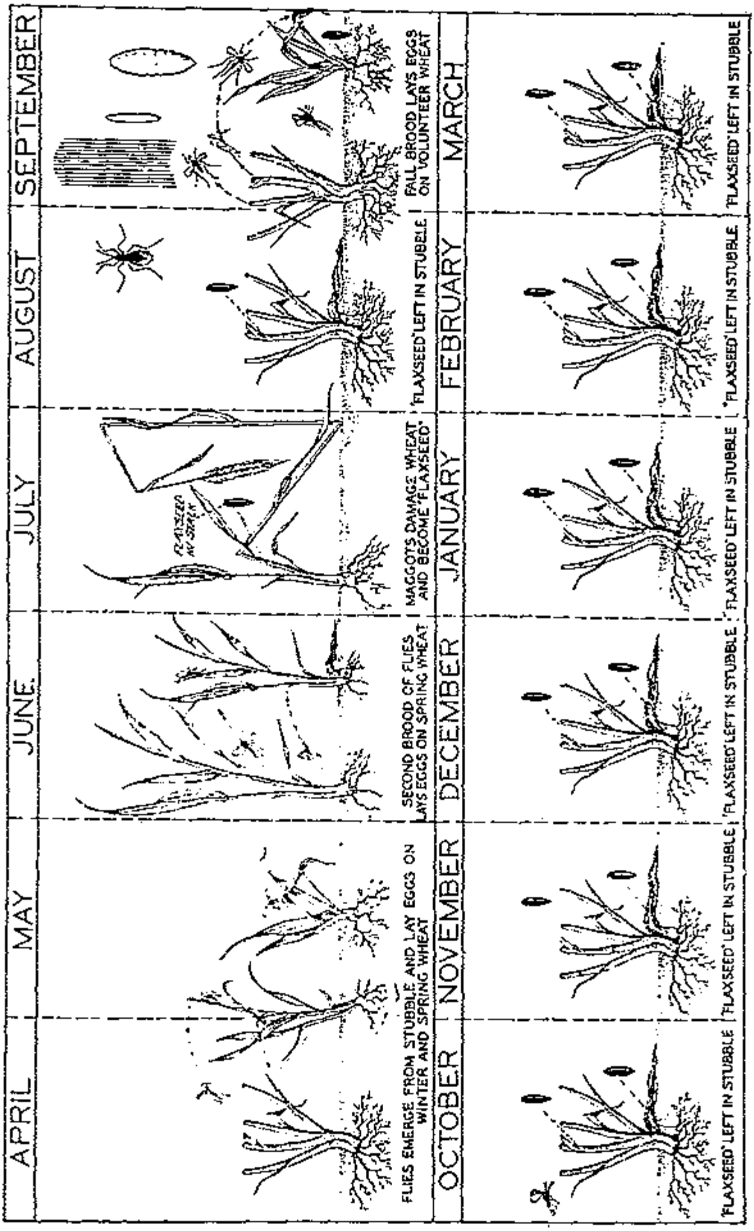

FIGURE 2.—Seasonal history of the Hessian fly in the Pacific Northwest

larva spins a thin silken lining, reversing itself during the process. The puparium thus formed is a dark brown, seedlike object about three-sixteenths inch long, and has been appropriately termed the "flaxseed." (Fig. 2.)

The nonfeeding larva may remain within the puparium for an indefinite period. If weather conditions are favorable some of the larvae pupate soon after the formation of the puparia and in a short time emerge as flies. Others remain as larvae to pupate and emerge later, perhaps in a year or more. The duration of the pupal period in September is about 12 days. Field observations indicate that this period is dependent largely upon the temperature, as it is longer in early spring than it is in May and June or in the first part of September.

SEASONAL HISTORY AND ITS RELATION TO WEATHER CONDITIONS

Since 1917 the seasonal history of the Hessian fly has been studied through field observations, including systematic periodical counts of various stages, within a 10-mile radius of Forest Grove and, less regularly, in other localities in western Oregon and Washington. More detailed observations were made at Forest Grove on wheat plots seeded at intervals all through the season. In conformity with the practice of cooperative observers of the United States Weather Bureau, climatological data have been recorded by the Forest Grove laboratory since 1916. In addition to these standard Weather Bureau records, the percentage of relative humidity has been recorded by a hygrograph since 1919. Observations on the stages of Hessian flies occurring on wheat under field conditions, especially the first and last appearance of each stage, have been plotted for each year on tables in which each month is divided into quarters large enough for placing identifying symbols in four positions in each quarter. These tables, which are too complicated to print, have enabled the writers to correlate, to a fairly close approximation, the seasonal history with the major climatic factors, which are averaged for each quarter of a month.

OVERWINTERING

Hessian flies pass the winter as larvae in puparia on stubble, on volunteer wheat, and on wheat seeded in September, if any is available. The puparia on young wheat tillers killed by fall infestation of the fly may, on the disintegration of the plant material, become part of the débris at the surface of the soil. The puparia in the stubble, containing unemerged Hessian flies, are mostly of the spring brood, the offspring of flies of the first spring emergence. Examination of puparia from the stubble of wheat seeded in May, 1919 (and therefore infested by the second spring brood, the progeny of flies of the second spring emergence, only) showed, on October 27, 1919, only 5 per cent of prospectively overwintering larvae in the puparia that contained or had contained living unparasitized Hessian flies. At the same time, puparia from the stubble of a field seeded in March, 1919 (and therefore infested by both spring broods but principally by the first spring brood), showed 5[illegible] per cent of prospectively overwintering larvae in the puparia that were not parasitized. These are the "holdovers" that failed to produce flies for the fall emergence in the preceding September and October. These holdovers at times comprise more than 50 per cent of all puparia that have survived parasitization and mortality from other causes. In years of scant precipitation in September these holdovers are the principal source of flies of the first spring emergence, as was notably the case in 1929–30, when a mere trace of the fall emergence was found and that after the middle of October, 1929. In years of normal or excess precipitation in September and October there usually is a heavy infestation in volunteer wheat and in any wheat seeded in September, by the progeny of flies of the fall emergence. This was the case in 1920.

FIRST SPRING EMERGENCE

In the spring, the overwintering larvae begin to pupate in the puparia when the temperatures approximate a mean of about 45° F. Temperature appears to be the princial factor stimulating pupation at this time, as the rainfall and relative humidity are relatively high at this season. Some incipient pupae have been found as early as February (on February 14, 1920, after a mean of 46.7° F. in the last week of January, and on February 28, 1921, when the mean was 47.9° for the preceding 7-day period), but few are able to attain complete formation of the adult before the middle of March in years of an early spring, or before mid April, or even the end of April, in backward seasons. It is seldom that flies of the first spring emergence are on the wing in numbers before April. The mean temperature approximates 50° at the time when flies of this emergence are abundant. In the Pacific Northwest the first spring emergence is sometimes prolonged, or even broken up into well-separated fractions, by cold weather in March or April. In some years such conditions have produced very marked intervals in the development of the resultant brood. In one such case in 1919, progeny of the early flies of the first spring emergence produced a numerous and early flight of flies of the second spring emergence in early June, which occasioned serious damage to spring wheat in some localities. The cool spring of 1920 prolonged the first spring emergence over a period of eight weeks. Weather favorable to an early and continuous spring emergence leads to heavy infestation in fall-sown wheat, especially in late-sown fall wheat (*18*), and in wheat seeded in March. When the weather is favorable to a large second spring emergence following such an infestation, all wheat becomes more heavily infested than usual. This was the case in 1926, when the mean temperature for March was higher than the normal for April, and that of April higher than the normal for May. When the first spring emergence has been delayed or unduly prolonged, and the second spring emergence is so late as to be a negligible factor, there usually is little damage to fall-sown wheat. Such appears to have been the case in 1920 when, although the Hessian fly was more abundant than usual, the crop yields were above normal. For some unknown reason, flies do not emerge from all puparia of the same age at the same time, although apparently exposed to exactly the same conditions. Therefore, even under favorable conditions, the first spring emergence extends over a period of three weeks or longer.

SECOND SPRING EMERGENCE

The progeny of flies of the first spring emergence (the first spring brood) are located as larvae at the base of the young tillers on fall-sown wheat, winter-sown wheat, and spring-sown wheat and near the lowest nodes of the culms in fall-sown wheat. They develop to full-grown larvae and form puparia in from three to six weeks. Larval development is hastened by warm weather, as was the case in 1926, when it required but three weeks; or retarded by cool weather, as in 1920, when it was extended to six weeks. A part of the larvae in the puparia transform to pupae and emerge as flies of the second spring emergence. The number that develop to flies at this time appears to be somewhat dependent upon the precipitation while they are in puparia. The second spring emergence usually occurs in June and is early or late, according to the rapidity of development of the larvae and the time of precipitation. The earliest record for this emergence is May 13, 1926, a very exceptional year because of high temperatures in March and April. The latest records for the appearance of the first flies of this emergence are June 21, 1920, and June 30, 1922. The resultant second spring brood (fig. 2) is capable of causing serious damage, especially to spring-sown grain, in favorable years. Such an instance was found at Forest Grove in 1919 and 1926 and at Pleasant Hill, Lane County, in 1921. On the other hand, in years when the precipitation in June was scant the second spring brood was very small.

The authors' records show that most of the flies of the second spring emergence come from puparia of the first spring brood, but some of them come from overwintered forms in the stubble, having failed to emerge earlier. Cage experiments carried on by Lane in 1917 with single mated females showed that flies were produced in the latter part of June and early July by a large percentage of the first spring brood that survived to the puparial stage, although some were still larvae in puparia in late December. In a field of wheat seeded in February, 1921, at Pleasant Hill in Lane County, Oreg., 66 per cent of the puparia of the first spring brood contained pupae or had produced flies by May 28.

SUPPLEMENTAL EMERGENCES

Unusually heavy precipitation in July or early August brings out a suplemental emergence, as in 1918. This rarely occurs and is of of no importance in the Pacific Northwest. That some of the second spring brood may mature at once and produce flies is shown by the finding of an empty puparium and two pupae on July 26, 1920, on wheat seeded in May and infested by the second spring brood only. In 1926, 17 per cent of the puparia on wheat which had been seeded on May 13, and which was infested by the second spring brood only, were empty when examined on July 27. Further indications of emergence and continued propagation by flies after the second spring emergence and before the regular fall emergence are shown by the records of a plot of wheat seeded on July 29, 1918, after a rain of 0.95 inch that occurred between July 22 and 26. Considerable numbers of eggs were found on this plot on August 12. The resulting larvae were full grown on August 27. The first puparia were found on September 7, and three pupae and two puparia from which adults had emerged were found on September 26, at the time of the regular fall emergence from infested wheat stubble.

FALL EMERGENCE

A considerable percentage of the first spring brood remain as larvae in the puparia during the summer. The greater number of the second spring brood, many of which are near the nodes of the culms, also aestivate (as larvae) in the puparia. Stimulated to activity by the first heavy rain (0.5 inch or more) in the early fall, many such aestivating larvae pupate in the puparia and emerge as flies of the fall emergence, beginning approximately 12 days after the rain. In the Pacific Northwest this fall rain may occur in late August, in early September, or after the middle of September. In years of scant precipitation in September there is seldom very much volunteer wheat up in time for the flies of this emergence to oviposit on it, and the number of flies may be small and may emerge for only a short period. In the most heavily infested districts of western Oregon this emergence is of practically no economic importance, in so far as crop damage is concerned, because of the customary late seeding. Heavy frosts or low mean temperatures usually bring the fall issuance to a close about the middle of October. The larvae in puparia that fail to produce flies in the fall pass the winter in this form. There are often large numbers of these.

When the fall emergence has been early, and when the temperatures in October and the precipitation at the time the resultant brood form puparia have been higher than normal, a small supplemental fall emergence may take place after the middle of October. This sometimes happens in the Middle West. There have been no very definite indications of such emergence in the Pacific Northwest during the course of the present study. Meager traces of a supplemental fall emergence are indicated by records of eggs on October 30, 1925, October 19, 1926, and October 21 to 29, 1927. It is possible that part of this small emergence represents progeny of flies of the first fall emergence. A well-marked supplemental fall emergence is apparently very rare in the area under discussion.

NUMBER OF GENERATIONS

The number of generations that occur annually is undetermined, as the offspring of the flies of no one emergence (and of no individual female) develop to adult flies at the same time. An indefinite percentage of each brood is always retarded in the puparial stage. It is, therefore, possible that no one generation is completed within the course of one year. However, previous writers have noted several partial generations in one year. Marchal (*13*) and McColloch (*11*) have reared from five to six partial generations in one year under controlled conditions. The authors have found indications that at least three partial generations usually occur in western Oregon in the field. The adults of these generations combine to form parts of the following emergences: Second spring, supplemental, and fall emergences of the same year; and the first spring emergence of the following year.

The laboratory and field observations made in this study agree with those of McColloch (*11*) in indicating that temperature and moisture, while of primary importance, are not the only factors affecting pupation and emergence. In the field, puparia from the same location on the plants and, presumably, of the same brood, have produced flies at widely differing dates of emergence. The junior author kept a vial containing puparia collected on June 26, 1926, regularly moistened (except from November 19, 1926, to March 11, 1927, when they were stored in a cave of uniformly high humidity), and from these secured the ordinary fall emergence from August 4 to September 9, 1926. Yet one female Hessian fly issued from this material as late as June 13, 1927. McColloch (*11*) has observed that Hessian flies issued from material kept for four years under outdoor laboratory conditions. Such delayed emergence acts as a safeguard in perpetuating the species. It also permits transportation between regions that are widely separated and probably accounts for the wide distribution of the species during a period when human transportation facilities were much slower than now.

The factors involved in these seemingly irregular reactions to temperature and moisture on the part of the Hessian fly in the puparium are unknown. They may have to do with individual nutrition and development, with consequent variations in the ratio of fat to water in the larval tissues, or with heredity. It is also possible that some slight variation in the chemical or physical structure of the puparial envelope may render some puparia more permeable to moisture than others.

INJURY AND ECONOMIC IMPORTANCE

Hessian-fly larvae feed by sucking the juice from the tissues of the stem of the wheat plant. As a result of this feeding, the tissues of young and tender tillers become abnormal at the point of attack and eventually die. Wheat infested, before jointing, by the Hessian fly exhibits a characteristic stunted appearance. The leaves are broader, less spreading, and of a darker green color than those of healthy plants. On stems that have begun to form joints before they are attacked by the maggots the injury is less obvious and consists of a weakening of the culms at the points of attack. This weakening of headed culms causes direct loss in grain through the fallen, or lodged, wheat not gathered by the binder or combine. There is also direct loss of grain, owing to insufficient nourishment of the kernels, as the feeding larvae interfere with the supply of sap to the wheat heads. In severe infestations this form of injury causes shriveled grain that reduces the grade.

INFESTATION OF VOLUNTEER WHEAT

Volunteer and second-growth wheat plants often become very heavily infested in the fall. On September 26, 1917, M. C. Lane counted 277 eggs on one leaf of a volunteer wheat plant. The junior author counted 146 larvae on five tillers of one stunted second-growth plant on October 11, 1919, in a field of late-sown spring wheat. Such infestations, while of course fatal to the affected tillers, cause no direct economic loss in so far as the grain crop is concerned. However, the pest is carried over winter in this manner and is thus enabled to infest planted wheat in the spring.

INFESTATION OF FALL-SOWN WHEAT

Wheat seeded in August and September is very likely to become infested by the Hessian fly in the fall, and this usually causes considerable reduction in stand. It was noted that a field of wheat seeded about September 15, 1920, had the stand thinned approximately 25 per cent by an infestation that had killed many tillers and whole plants. In addition to this, the infested plants that had sufficient vitality to produce new tillers were greatly retarded, the new tillers that developed by December 17 being very small. On a wheat plot seeded August 11, 1922, and sampled by the linear-foot method (taking 10 separate linear feet) in January, 1923, 20 per cent of the young tillers out of a sample of 266 were found to be infested and dead, and of a sample of 211 tillers taken from a plot seeded on September 1, 8 per cent were in a similar condition. However, the soil of these plots was unusually fertile, and the wheat tillered freely after the infestation, more than compensating for those killed. Fortunately, in the Pacific Northwest fall-sown wheat is very rarely seeded early enough to become infested in the fall. Climatic conditions have led to the adoption of a general practice of seeding wheat in October or later.

Fall-sown wheat, if seeded early enough to get a good start before cold weather sets in, usually makes enough growth before the spring emergence of the Hessian fly to escape serious injury. When flies infest fall-sown wheat in April and May, their progeny attack the young tillers and the internodes of culms. The small tillers are killed before heading, but there appears to be a considerable mortality of these tillers at this time from other causes, as Packard (*17*) has noted. By the time of the second spring emergence such wheat is usually so far advanced as to be unattractive to the flies.

INFESTATION OF SPRING-SOWN WHEAT

Spring wheat, if seeded early enough to become infested by both spring broods of the Hessian fly, is sometimes considerably injured. Very late fall-sown (*18*) or winter-sown wheat is comparable to early spring-sown wheat in this respect. Late spring seedings of quickly maturing varieties of wheat sometimes escape any considerable degree of infestation, except in years of a heavy second spring emergence. Spring wheat is injured by a thinning out of the culms, owing to the death of tillers that might have headed had they not been infested before jointing; by the lodging of infested culms; and by the malnutrition of kernels, caused by the feeding of the larvae near the nodes of headed culms. Damage to spring-sown grain by the second spring brood was quite serious in 1919 and 1921. A field of wheat seeded in March, 1919, near Forest Grove showed, by the linear-foot count, an increase in infestation of 46 per cent of the plants and 40.6 per cent of the tillers and culms attributable to the second spring brood. The numbers of Hessian-fly forms found in 10 separate linear feet of drill row taken at random increased from 27 to 347. The heavy infestation resulting from the combination of the two spring broods caused an estimated reduction in yield of 7 bushels per acre, and the wheat was marked "Grade 3" because of shriveled grain.[6] In a field of wheat seeded in late February near Pleasant Hill, in Lane County, Oreg., in 1921, the second spring brood caused an increase of infestation amounting to 23 per cent of the plants and 19 per cent of the young tillers and culms. In the counts of 10 separate linear feet in this field the number of Hessian flies in all forms increased from 127 to 757.

ESTIMATE OF LOSS

The actual loss caused by the Hessian fly is difficult to estimate. Usually only young tillers are killed outright, and early fall-sown wheat on fertile soil produces a superfluity of these. This loss of tillers would be less likely to be compensated in the case of spring-sown wheat and winter-sown wheat. The principal loss of grain in the Pacific Northwest is probably owing to lodged culms and light heads on infested culms. In severe infestations where more than 50 per cent of the culms are affected the loss on fertile soil may amount to 6 to 8 bushels per acre, although the average loss, even in years of Hessian-fly abundance, is probably less than one-half as much. The grade of the wheat may also be reduced, and lower prices result. Most of the wheat acreage in the districts in Oregon most heavily infested by the Hessian fly is usually fall-sown. However, in some years there is a considerable acreage of winter-sown and early spring-sown wheat, both of which may be seriously injured by the fly.

TABLE 1.—*Relation of infestation by the Hessian fly to yields of wheat in Washington County, Oreg.*

Year	Average infestation by the Hessian fly in—						Average yields per acre	
	Winter-sown and spring-sown wheat		Winter-sown wheat [1]		Spring-sown wheat		Winter-sown wheat	Spring-sown wheat
	Plants	Young tillers and culms	Plants	Young tillers and culms	Plants	Young tillers and culms		
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Bushels*	*Bushels*
1920	49.5	24.5	46.7	23.7	55.0	27.3	28.0	25.9
1921	29.7	17.9	34.9	22.0	17.0	8.3	25.0	20.0
1922	23.9	10.8	29.1	12.1	18.6	9.6	22.0	12.9
1924	35.0	17.8	35.0	17.8	(2)	(2)	[3] 25.7	----------
1925	34.7	16.1	(4)	(4)	34.7	10.1	----------	25.0
1926	70.3	41.2	78.0	41.2	72.2	41.0	25.0	18.0
1927	24.4	8.9	20.3	7.3	30.6	11.2	25.0	20.0
1928	13.5	5.4	4.9	3.4	17.1	7.4	27.0	20.0

[1] Wheat seeded in fall and winter.
[2] Spring wheat near failure; no counts made.
[3] Both winter and spring wheat.
[4] Fall-sown and winter-sown wheat killed by December freeze.

The average percentage of infestation by the Hessian fly was determined by making counts in representative fields in Washington County. The average percentage of infestation for each year was then compared with the estimated final yields for that county as given out by F. L. Kent, agricultural statistician of the United States

[6] This estimate was arrived at by comparison with yields on fields which were seeded near the same date on similar land but were much less severely infested by the Hessian fly. Hence the reduction in yield can not be attributed with certainty to the fly.

Bureau of Agricultural Economics for the years 1920 to 1922, and 1924 to 1928. (Table 1.) No readily discernible correlation of average yields with Hessian-fly abundance is evident. It is obvious that other factors, fully as important as this pest, affect the yield of wheat in western Oregon. Doubtless the effect of Hessian fly infestation on wheat yields could be shown if records of data on the Hessian fly and other factors that affect yield were available for a long series of years.

HOST PLANTS OTHER THAN WHEAT

BARLEY AND RYE

Barley is often infested by the Hessian fly but usually less than wheat. A field of barley near Forest Grove, seeded in June, 1919, showed 20 per cent of the plants and 10 per cent of the young tillers and culms infested when examined on July 8. Wheat seeded on the same farm at about the same time showed 59 per cent of the plants and 25 per cent of the young tillers and culms infested on July 8.

Rye also becomes infested, but no infestations approaching those in wheat have been observed. As rye is rarely grown for grain in western Oregon, no counts have been made on that crop.

AGROPYRON REPENS (L.) BEAUV.

On October 25, 1909, G. I. Reeves found a species of Agropyron near Vancouver, Wash., infested by the Hessian fly. On December 31, 1919, the junior author found large numbers of Hessian-fly puparia on a species of Agropyron at Kelso, Wash. While on a second visit to Kelso on June 14, 1920, he made a thorough search of this grass and found only two puparia.

On November 5, 1929, near Vancouver, Wash., George I. Reeves and the junior author found scattering plants of couch grass (*Agropyron repens* (L.) Beauv.[7] in wheat stubble where no volunteer wheat had yet appeared because of a deficiency of rainfall in September and October. These plants were heavily infested with partly grown larvae. On careful examination of material collected at this time only one puparium was found. From this material adult flies indistinguishable from *Phytophaga destructor* were reared in early April, 1930. These flies were kept in cages and allowed to oviposit on *A. repens* and on young wheat. Where both wheat and couch grass were available in the cage at the same time, the flies showed a decided preference for wheat. Flies, the progeny of adults from *A. repens*, were reared in early June from both couch grass and wheat. Hessian flies that emerged from puparia collected from wheat stubble also produced offspring on *A. repens* in cages. Flies, the progeny of flies of couch-grass origin, but reared on wheat, were placed on *A. repens* and again produced offspring on this grass. A few males reared on couch grass were mated with virgin females that emerged from puparia taken from wheat stubble. Mating was successful, and progeny were produced by these crosses.

It is possible that *Agropyron repens* may be of some importance as a host plant for the fall brood of Hessian flies in some localities

[7] Determined by A. S. Hitchcock, of the Bureau of Plant Industry, U. S. Department of Agriculture.

where volunteer wheat or early-sown fall wheat are not available at the time the flies of the fall emergence are out. However, as many Hessian flies survive the winter as larvae in puparia on wheat stubble, when the rainfall in autumn is insufficient to bring up volunteer wheat, the fall brood on *A. repens* may not contribute very much to the number of flies in the first spring emergence of the following year.

CLIMATIC FACTORS

Climatic conditions have a potent influence upon the Hessian fly. Precipitation and relative humidity are probably the most important climatic factors, although temperature, in relation to these, is also of great importance.

EFFECT ON DISTRIBUTION

No occurence of the Hessian fly has been recorded in areas of the Pacific Northwest shown by Weather Bureau records (*5*, *21*, *22*, *23*, *24*) to have an average rainfall of less than 35 inches, except at Sidney, British Columbia (*5*), where the average annual precipitation is 27.7 inches; and the sections where the highest percentages of infestation are found year after year have an annual rainfall of 40 inches or more. However, as the Hessian fly is found in sections of the Middle West and of California and at Sidney, British Columbia,[8] where the average annual rainfall is less than 35 inches, it is probable that the time of precipitation and of high relative humidity in relation to effective temperature are determining factors in its distribution. The infested territory in Kansas receives most of its precipitation (18 to 30 inches) in the wheat-growing season (April to September), when the Hessian fly, if present, would be active (*9*). On the other hand, in the portion of California infested by the Hessian fly (*17*) temperatures are high enough for fly activity in February, March, and April, when the average rainfall is 7 to 14 inches. The great dry-land wheat-growing area of the Pacific Northwest has but 3 to 9 inches average precipitation in the period April to September, when temperatures are high enough to permit Hessian-fly activity.

McColloch (*11, p. 60*) has shown that in Kansas a relative humidity of more than 60 per cent is necessary for the sucessful hatching of the eggs and subsequent establishment of the young larvae beneath the sheath. This factor alone is probably sufficient to prevent the establishment of the Hessian fly as a wheat pest in the great dry-land wheat districts of eastern Oregon, eastern Washington, and Idaho, where the air is relatively dry except for some damp periods in winter (*23*, *24*). On the other hand, the humidity at Forest Grove, Oreg., a locality typical of the area west of the Cascade Mountains where the Hessian fly is most numerous, is relatively high in the spring and fall, as well as in winter, and is occasionally high for certain periods in the summer months. The mean monthly relative humidity at Forest Grove probably never falls below 60 per cent, even in the driest months of the summer, as 67 per cent is the average mean for July and August. Data of the United States Weather Bureau

[8] Sidney, British Columbia, is on the Puget Sound shore of Vancouver Island where the humidity is uniformly high.

(*23, 24*) for Baker, Oreg., and Spokane and Walla Walla, Wash., while not exactly comparable with those for Forest Grove, Oreg., indicate that the average mean relative humidity at these places (all east of the Cascade Mountains) would fall below 60 per cent during the period April to September, when the Hessian fly would be active. The data for the southeastern shore of Vancouver Island at Victoria (Gonzales Heights), British Columbia (*5*) (where the lowest monthly average of the mean relative humidity is 73 per cent, for June), show that the mean relative humidity is above 70 per cent in every month of the year, although the average annual precipitation is only 27.5 inches.

EFFECT ON EMERGENCE

Lack of moisture at critical periods stops the issuance of the flies; therefore, the periods of emergence are cut short, and the numbers of resulting offspring are greatly reduced. This is sometimes the case with the second spring emergence and nearly always with the supplemental, or summer emergence. Occasionally the fall emergence is either greatly delayed in the time of its issuance or restricted by lack of precipitation.

McColloch (*11, p. 58*) states that temperatures below freezing are fatal to the adult flies. In Oregon late frosts frequently interfere with the propagation of the Hessian flies during the flight of the first spring brood. Heavy frosts and low mean temperatures usually bring the fall emergence to a close about the middle of October.

EFFECT ON SUMMER MORTALITY

There is some indication that the prolonged dry periods characteristic of the Pacific-coast climate, usually occurring in July and August but occasionally beginning in June and extending well into September, cause a considerable mortality of Hessian-fly larvae in the puparia. Packard (*17*) has noted a similar mortality in California and attributes it to summer heat and desiccation. Records obtained in this study show a higher percentage of dead larvae in puparia in the 1917 counts (40 per cent of all puparia), when precipitation was below normal and the mean temperatures above normal in June, July, and August, than in the 1918 counts (17 per cent of all puparia), when precipitation was above normal and the mean temperature above normal in July and August. There must also be a very heavy mortality of first-stage larvae under unfavorable climatic conditions, as these small larvae are forced to migrate from the eggs on the leaves to the stems beneath the sheaths in order to have any chance for survival.

PARASITES

An important factor in natural control is insect parasitism. Periodical dissections by M. C. Lane in 1918 of 758 puparia from different fields showed a parasitization ranging from 16 to 75 per cent, with an average of 34 per cent for the year. In 1919, rearings from and dissections of 456 puparia showed variations in parasitization of from 15 per cent in wheat sown in May to 60 per cent in fall-sown wheat, with an average parasitization of 48 per cent. In that year more than 75 per cent of the parasitization was by species of Platygaster. In 1923, 900 puparia from various fields gave an average parasitization of 44 per cent.

The following species of hymenopterous parasites[9] have been reared in the course of this investigation: *Platygaster hiemalis* Forbes, *Platygaster herrickii* Pack., *Merisus destructor* Say, *Eupelmus allynii* French, *Pleurotropis epigonus* Walk., *Calosota metallica* Gahan, *Amblymerus* (*Eutelus*) *mayetiolae* Gahan, *Callitula bicolor* Spin., *Eupelminus saltator* Lind., *Eurytoma phoebus* Gir., *Eurytoma* sp., Eupteromalus (possibly two species), and *Tetrastichus carinatus* Forbes. One of the species of Eupteromalus has been found under circumstances indicating secondary parasitism on *Platygaster hiemalis*, and some of the others, while normally primary parasites, may be secondary at times. *Eupelminus saltator*, *Eurytoma* sp., and *Calosota metallica* are more commonly parasites of *Harmolita* sp. than of *Phytophaga destructor*, while *Eupelmus allynii*, also frequently reared from *Harmolita* sp., appears to be more commonly parasitic on *P. destructor*.

Platygaster hiemalis is probably the most important parasite. This species usually has two generations annually, the first appearing in May and parasitizing the offspring of the last individuals of the first spring emergence and those of the second spring emergence of Hessian flies, the second generation appearing in August and September and parasitizing the fall brood.[10] As this seasonal history differs radically from that found for this species in Pennsylvania (7), a further study of its seasonal history in the Pacific Northwest is being made. *P. herrickii* sometimes parasitizes considerable numbers of the first spring brood. It appears to be more susceptible to desiccation than either *P. hiemalis* or the host, *Phytophaga destructor*. Thus there is a platygasterine parasite working on each brood in this district, and the platygasterids, taken together, are probably more important than any other parasites.

The principal parasites of the puparial stage of the Hessian fly are *Merisus destructor* and *Eupelmus allynii*, although *Pleurotropis epigonus* and *Eupteromalus* sp. are quite abundant in some years. *Amblymerus mayetiolae* appears to be rare and distributed locally. It has so far been reared only from material from Kelso and Chehalis, in western Washington.

The seasonal history, the effects of environmental factors, and the rôle played by each species of parasite in the natural control of the Hessian fly in the Pacific Northwest are being further investigated.

CONTROL IN THE PACIFIC NORTHWEST

PLOWING STUBBLE FIELDS

The data given under seasonal history show that the stubble field is almost without exception the place where the Hessian fly passes the winter in this area. Wheat seeded early enough in the fall to become infested by the fall brood is now so rare as to be negligible in the infested districts of the Pacific Northwest.

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[9] All determined by A. B. Gahan.

[10] Specimens of both generations determined as *P. hiemalis* Forbes by A. B. Gahan and C. C. Hill.

The authors believe that Hessian-fly damage to the wheat crop of western Oregon and Washington could be practically eliminated if all wheat-stubble fields were plowed and the stubble deeply buried in the fall, as soon as possible after harvest. These stubble fields contain (as puparia on the straw, or as puparia or maggots in the volunteer wheat that has sprung up following the first fall rains) practically all the Hessian flies that are likely to attack wheat in the following spring.

In some districts of western Oregon, because of local soil conditions, it may be impossible to plow the stubble under before the fall emergence in September. However, the offspring of the Hessian flies that have emerged from the stubble as the fall emergence are then located in the volunteer wheat in the stubble fields and can be destroyed by later plowing. It is important that all the stubble and volunteer wheat should be well covered so that it will not be raked to the surface by later harrowing. The flies on well-covered stubble and volunteer wheat are unable to work out through the covering soil in the following spring after the surface has been puddled by the winter rains.

A field of wheat near Forest Grove which showed 100 per cent of the plants and 80 per cent of the young tillers and culms infested in 1926 was plowed and harrowed late in the fall and seeded to oats and vetch. A few scattering volunteer wheat plants developed in this field. All the stubble was not completely buried, and a few partly buried straws containing Hessian-fly puparia were found on March 26, 1927. Yet when 10 volunteer wheat plants were examined on April 23, 1927, the only trace of the fly found on 50 tillers was one egg. These wheat plants were so few and scattered that they would have received a heavy deposition of eggs had many flies emerged in this field.

It has been observed that wheat stubble and volunteer wheat in young clover fields are the principal sources of the Hessian flies which injure near-by wheat in the spring. The practice, common in many sections of the Pacific Northwest, of seeding clover in wheat interferes with any general program for plowing wheat stubble under for control of the Hessian fly. It is doubtful whether, as a rule, the fly does enough damage to warrant a serious effort to induce farmers to abandon this usually economical practice. Should a locality suffer unusual Hessian-fly injury, it might be advisable, for a time at least, to abandon the practice of seeding clover in wheat until the Hessian fly has been controlled by plowing under the stubble. Eventually it may be found that some other method of planting clover, such as seeding alone or with some other crop, will insure better stands.

Where clover has been seeded in wheat and the stand is too good to plow up, little can be done to combat the Hessian fly. However, the farther a wheat field is located from the source of infestation, the less fly injury will develop. Hence it would be well for the farmer to plan to seed his wheat, especially very late fall-sown or spring-sown wheat (these plantings being more seriously injured by the Hessian fly than is early fall-sown wheat) as far away as possible from young clover fields containing wheat stubble. It has been observed that where a wheat field adjoins unplowed stubble, the infestation by the fly is much heavier on the side of the wheat field nearest the stubble than on the side farthest away from it, or even in the center of the field.

TIME OF SEEDING

Fall wheat should not be seeded, as a rule, until after the first week in October. The fall emergence of Hessian flies often continues until well into October, and hence wheat seeded in September becomes infested in the fall and carries the flies over winter in the planted field. Fortunately, however, because of soil conditions in the early fall, it is only rarely that any wheat is planted in the most heavily infested areas before October. This is an important factor in keeping down Hessian-fly injury in this area. It is to be hoped than an increased use of tractors, which make dry plowing and earlier seeding feasible, will not lead to an abandonment of this practice.

It has been reported (*1*) that the Oregon agricultural experiment station, at Corvallis, has found that wheat seeded about October 15 to 20 gives higher yields and is freer from weeds than wheat seeded earlier or later. Farmers should not be misled, by the idea of seeding wheat after the fall emergence of the Hessian fly is ended, into a practice of seeding at a much later date than that recommended by the Oregon experiment station. In fact, in most years wheat seeded about the first of October will have few or no Hessian flies in it in the fall, and seeding very much later than this gives no advantage to the farmer, as far as control of the Hessian fly is concerned. Wheat seeded in late November, December, January, and February has been observed to be as susceptible to spring fly injury as is early-sown spring wheat; and, as a rule, it does not yield as well as wheat seeded in October. A variety of wheat well adapted to the locality, seeded in a well-prepared seed bed at the right time, is seldom seriously injured by the Hessian fly.

In the Pacific Northwest early-sown spring wheat is usually more seriously injured by the Hessian fly than is fall-sown wheat. It has been observed that a quickly maturing variety of spring-sown wheat in a well-prepared seed bed is usually injured less than is a slow-growing variety seeded much earlier and often "mudded in." It would be advisable for those farmers who wish to plant spring wheat to secure seed of a variety that matures quickly, rather than to use seed of slowly maturing varieties, such as those commonly planted in the fall and winter.

IMMUNE OR RESISTANT VARIETIES OF WHEAT

It seems possible that profitable varieties of wheat immune or resistant to Hessian-fly injury may be developed. The variety known as Illini Chief, of a true winter habit of growth, was found to be practically immune in western Oregon in three seasons, during two of which home-grown seed was used. Although eggs of the Hessian fly were freely laid on this variety, the larvae failed to develop. However, this variety did not yield as well as a commonly grown variety, Rink, even though the latter variety was heavily infested by the fly. The variety known as Prohibition was lightly infested in experimental plots in 1919 and 1920 but did not yield as well as White Winter, Rink, or Foisy, all of which were infested to a much greater degree.

SUMMARY

In the Pacific Northwest the Hessian fly is found only in the humid area west of the Cascade Mountains. It causes some loss of grain every year, and in some years the damage, especially to wheat seeded in the winter and early spring, has been quite serious. The greatest injury occurs in years that are favorable to a large and early second spring emergence of Hessian flies.

The Hessian fly appears to have normally at least three partial generations a year in the Pacific Northwest. The adults of these constitute three usually well-defined emergences, the time, extent, and abundance of which are largely dependent on weather conditions. The emergences are as follows: The first spring emergence, in March, April, and early May; the second spring emergence, in late May, June, or early July; and the fall emergence, in late August, September, and early October. Rarely there is a small supplemental emergence in July or early August, and sometimes another very sparse supplemental emergence in late October. While moisture and temperature are important factors in determining the emergence of flies from the puparia, other factors, now undetermined, are also involved. It is thought that the dry conditions east of the Cascade Mountains will prevent the establishment of the Hessian fly as a wheat pest in the great dry-land wheat belt of eastern Oregon and Washington.

In the Pacific Northwest Hessian flies pass the winter as larvae in puparia on wheat stubble ("holdovers" which failed to issue in the fall emergence); on volunteer wheat (the offspring of flies of the fall emergence); or on wheat seeded in September, a practice of rare occurrence. The principal sources of flies for the spring emergences, the ones that lead to damage of planted grain, are the stubble and volunteer wheat in fields of young clover.

Thirteen species of hymenopterous parasites have been reared from the Hessian fly in this area. Of these the most important are probably the species of Platygaster. One of these, *P. hiemalis* Forbes, appears normally to have two broods in this area. The seasonal history and status of these parasites are being further investigated.

Hessian-fly damage to the wheat crop of western Oregon and Washington would be practically eliminated if all wheat stubble were plowed under and deeply buried in the fall. The practice of seeding clover in wheat interferes with the general adoption of such a program, but it is doubtful whether Hessian-fly damage is normally of sufficient importance to warrant for that reason alone the abandonment of the present practice. Wheat seeded about the middle of October is usually least injured by the Hessian fly. September seedings become infested by the fall brood of Hessian flies, and wheat seeded in the winter and early spring is usually the most severely injured by the spring broods.

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