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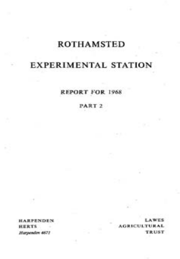
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EXPERIMENTAL STATION

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7. INSECT PESTS ON BROADBALK

C. G. JOHNSON, J. R. LOFTY AND D. J. CROSS

Entomological work on Broadbalk has been concerned mostly with the Wheat Blossom midges and the Wheat Bulb fly; the many other insects, including some pests, that occur there have been little studied. Wireworms are not a problem after the prolonged cultivation, and though they were recorded in large numbers in 1902–3 (The White Book, p. 332), this was an isolated record and the identification may have been wrong. Corn thrips and the leaf miner *Domomyza ambigua* (Fallén) damage the wheat, but have not been studied specifically on Broadbalk Field. There seems little to be gained at present from the old records.

This article therefore considers H. F. Barnes's work on Wheat Blossom midge on Broadbalk (C.G.J.), some further analyses of his data (D.J.C.) and the work on Wheat Bulb fly on Broadbalk by F. Raw and J. R. Lofty. Most of this work was of necessity observational, not experimental. The presence of a field permanently sown to wheat invites continuous records, and these have indicated problems that are better studied in detail elsewhere.

Wheat midges

Several species of gall midges (Cecidomyidae) have been found on the wheat on Broadbalk; a species of *Holobremia* (Kieffer) and one of *Plesiobremia* (Kieffer) infests the flowering ears, and *Haplodiplosis equestris* (B. Wagner) and *Mayetiola destructor* (Say), the Hessian fly, attack other parts of the plant. None of these species is abundant enough to be a pest. The percentage of ear-bearing straws and tillers infested with the Hessian fly in 1954, 1955 and 1956 ranged from 1·3 to 4·1 in different plots, but the infestation did not differ significantly from plot to plot or year to year (Stokes, 1958); the grain lost because of the pest was thought to be less than 6 lb/acre (Barnes, 1956).

The most numerous species are the Wheat Blossom midges *Contarinia tritici* (Kirkby) and *Sitodiplosis mosellana* (Géhin). Usually, though not in all years, *C. tritici* is the more abundant and its populations fluctuate more, and more rapidly, than those of *S. mosellana* (Table 7·1, Fig. 7·1). Over the 38 years up to 1964, *C. tritici* was nearly four times as common as *S. mosellana*. Most of the work on midges on Broadbalk has been with these two species.

Life histories of the Wheat Blossom midges. The lives of these midges are remarkable for the way they are adapted to synchronise with the growth of the wheat plant. The adult midges of both species emerge from their pupae in summer during a period of about five weeks from June to early July. Individuals live for less than two days and during that time lay their

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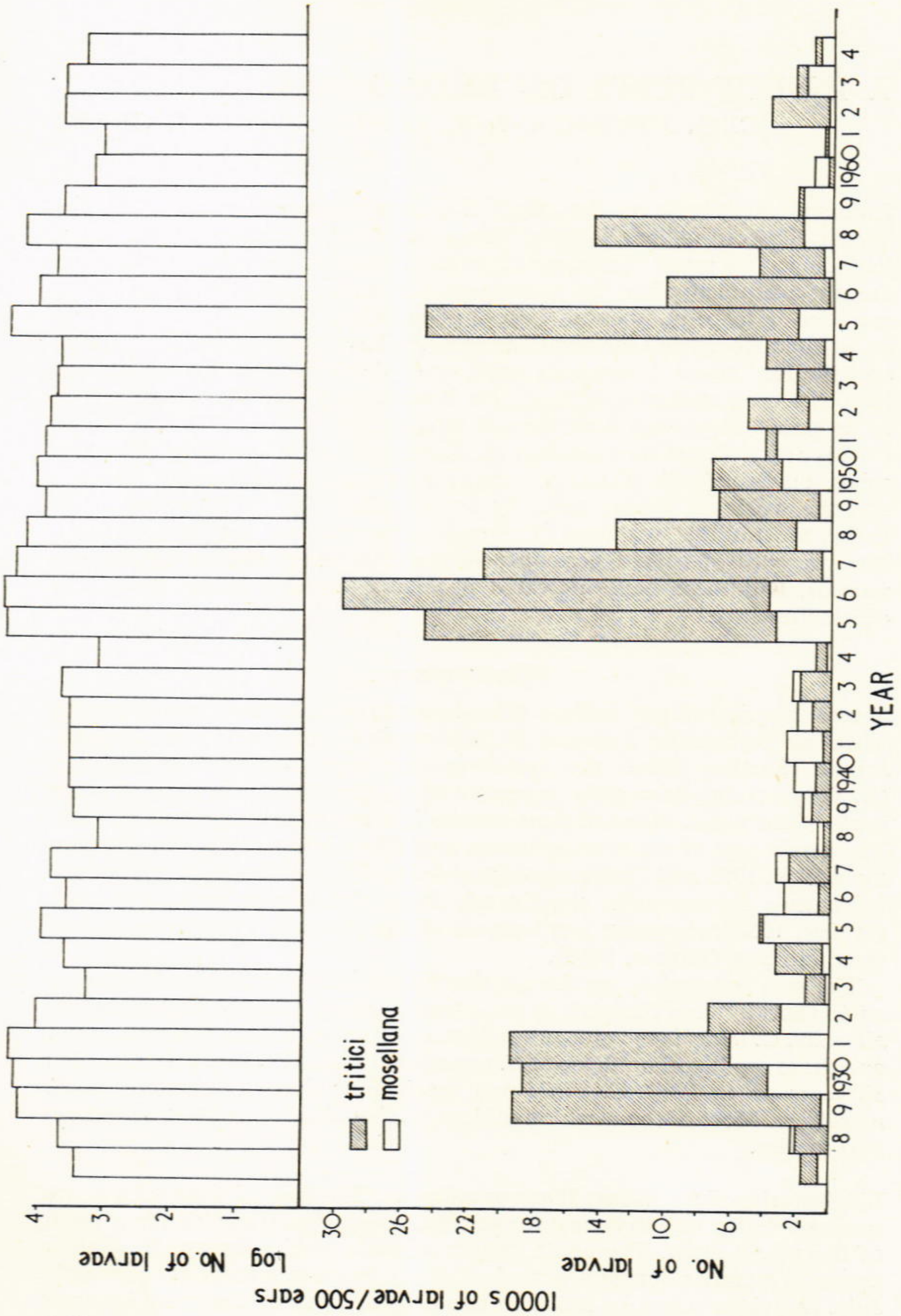

FIG. 7·1 Numbers of larvae of Wheat Blossom midges in annual samples of wheat from Broadbalk. Data in Table 7·1.

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TABLE 7·1

Records over 38 years of numbers of larvae and percentage grain attack in samples of 500 ears from Broadbalk, 1927–64

(Figures in brackets are corrected estimates (see text). From 1957 only 250 ears sampled annually.)

	No. of larvae			Percentage grain attacked	
	C. tritici	*S. mosellana*	Total	*C. tritici*	*S. mosellana*
1927	1780	715	2495	1·0	2·2
1928	2195	2403	4598	0·8	5·7
1929	19265	587	19852	5·9	1·8
1930	18595	3746	22341	5·9	11·7
1931	19273	6027	25300	6·4	15·0
1932	7356	3114	10470	5·0	10·8
1933	1474	319	1793	0·7	1·4
1934	3362	572	3934	1·5	2·5
1935	4297	4226	8523	2·1	17·9
1936	708	2872	3580	0·5	9·2
1937	2555	3420	5975	1·7	13·9
1938	378	827	1205	0·2	3·2
1939	1116	1615	2731	0·7	9·1
1940	977	2291	3268	1·1	7·5
1941	522 (2297)	2736	3258	1·0	10·3
1942	1143 (2286)	2064	3207	1·0	7·9
1943	1880	2363	4243	0·8	9·6
1944	1030 (2060)	133	1163	1·0	0·5
1945	24643	3557	28200	6·8	11·0
1946	29638	3853	33491	13·3	13·3
1947	21094 (29007)	599	21693	13·1	2·3
1948	13155 (17536)	2262	15417	7·9	6·8
1949	6897	801	7698	4·3	3·4
1950	7414 (13347)	3122	10536	6·7	10·0
1951	4191 (7118)	3383	7574	2·3	12·0
1952	5119	1462	6581	2·2	5·5
1953	2034 (3749)	3161	5195	1·9	9·2
1954	4179	500	4679	2·9	1·8
1955	24604	2232	26836	9·4	7·3
1956	10178	105	10283	7·1	0·4
1957	4596	602	5198	4·1	2·1
1958	14550	1968	16518	8·4	6·9
1959	2176	1964	4140	2·6	6·4
1960	324	1210	1534	0·6	3·9
1961	576	496	1072	0·5	1·2
1962	3876	320	4196	1·8	1·0
1963	2358	1728	4086	1·0	4·7
1964	1230	865	2095	0·7	2·7

eggs within the opening florets. The larvae from the eggs feed on the sap of the developing grain and become fully grown in about three weeks. Then, if the weather is dry, they lie dormant in the ears but emerge when it rains, fall to the ground, bury themselves and spin a cocoon within which they hibernate. Next spring they leave the cocoon, pupate and eventually the new adults emerge.

There is only one generation a year and its adults are active for less than a month, and this short period of activity must coincide with the opening of the ears and with a particular state of growth of the grain (which must not be too ripe) so that the eggs can be laid. The lives of individual midges are thus vulnerable to changes of weather and to growing conditions that upset the synchronisation of midge and plant; also the small and very delicate adults are easily blown away or disturbed while laying eggs.

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Little is known about the precise mechanisms that ensure this synchronisation.

Contarinia tritici and *Sitodiplosis mosellana* have similar life histories but differ in some details. *C. tritici* sometimes has a partial second generation on couch grass and, in contrast to *S. mosellana*, whose females lay single eggs in a floret, each female of *C. tritici* lays a cluster of ten or more eggs in a floret. Some larvae of either species that fall to the ground do not turn into adults the next year but remain dormant until a later year. *C. tritici* larvae can spend 3 or 4 years in the soil before emerging as adults (Barnes, 1943, 1952a) and *S. mosellana* may lie dormant for even longer, and pupae taken from Broadbalk have been recorded emerging after 18 years (*Rothamsted Report for 1959*, p. 136). The largest proportion of larvae of *C. tritici* become adults in the following summer but the largest proportion of *S. mosellana* may emerge one or two summers later (Barnes, 1958). Nevertheless, even after several years of dormancy, emergence synchronises with ear-burst.

Midges usually emerge during the evening and are sometimes seen drifting like smoke above wheat crops. The top part, or western fifth, of Broadbalk Field is usually more heavily infested than elsewhere, probably because the belt of trees on Broadbalk Wilderness provides shelter for wind-borne immigrants. (Lewis, 1967).

The peculiarity of the infestation on Broadbalk. Wheat crops are infested by egg-laying blossom midges that either emerge from the ground, where the larvae dropped from a previous crop, or drift in from crops nearby. Wheat on Broadbalk differs from most other crops in being permanently on the same field, which therefore possesses a permanent population of midges and their parasites. The ears probably become reinfested each year largely from the larvae in the soil beneath the crop and infestation by immigrants is probably slight. However, the number of midges that enters the crop from outside has never been assessed and compared with the local population. Nevertheless, it is reasonable to suppose that the midges and their parasites on Broadbalk tend to form a fairly closed system and that the parasites exert a maximum 'buffering' effect on the midges, because populations of the two increase and decrease more or less reciprocally (Barnes, 1941, 1958). This perhaps explains why the infestations on Broadbalk, though continuous, are smaller than are sometimes seen in other places.

The hypothesis of a 4–6 years cycle of outbreaks. Surveys by the Ministry of Agriculture suggested that 1916, 1920 and 1926 were years when Wheat Blossom midges were particularly abundant (Barnes, 1932b). Barnes therefore sampled ears of wheat on Broadbalk Field for larvae annually for 34 years from 1927, to study changes in abundance, and sampling was continued for another 4 years after his death in 1960 (Table 7·1). This record is exceptional for its length and probably unique in entomological literature for its consistency of method over so many years. Barnes (1956) obtained his Broadbalk records to test the idea that there were major outbreaks about every 5 years; he thought that such fluctuations

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were generally determined by climate (or even by a periodic variation in the amount of ultra-violet radiation; Barnes 1958). However, local weather sometimes causes the population fluctuations in one locality to deviate from the general rhythm and 'although the peak years appear to have been 1931, 1936, 1941, 1946 and 1951, the years 1936 and 1951 were not actual peak years on Broadbalk Field' (Barnes, 1956; see also Fig. 7·1). For example, in 1936 very heavy rain fell just at the time of maximum emergence; this seriously limited the number of eggs that were laid. Also the subsequent week of hot sunshine consolidated the surface of the ground and prevented many midges from emerging. There seems little doubt that these events seriously affected the midges on Broadbalk in 1936, but it is not certain that the fluctuations in the midge population on Broadbalk generally reflect those over the whole country, although the inverse correlations of Broadbalk midges with national yields suggests that they might (Barnes & Weil, 1944).

Weather can suddenly affect the abundance of midges in several ways; for example, midges usually emerge approximately when the ears burst and then can lay most eggs. When emergence and ear-burst are not synchronised, fewer eggs can be laid. For example, Barnes (1935, 1956) attributed the small population on Broadbalk in 1933 (Fig. 7·1) to the fact that ears burst two weeks and midges emerged three weeks earlier than usual, so the two events were not synchronized.

Data on populations of Wheat Blossom midges for 38 consecutive years. Each year Barnes took 13 ears from each of the four sections under wheat for each of the plots 2, 3, 5, 8, 10, 11, 12, 13, 14 and 16. Of the 52 ears from each plot, 50 were used to make a total sample of 500 ears. The sample was taken on the day when the population of full-grown larvae in the ears was estimated to be maximal. This date, usually about three weeks after the peak of egg laying, was also gauged by observing emergence in the insectary, but the exact day was finally chosen after examining successive small samples of ears from the field and observing the stages to which larvae had grown ('pre-sampling'). The main sample of 500 ears was then used to estimate the number of full-grown larvae. Thus the count was made at the peak of abundance of mature larvae; it did not estimate the integrated total of all larvae during the annual cycle of development and emergence. It is likely, therefore, that an unknown proportion of the larvae had already left the ears by the time the sample was taken.

Table 7·1 shows the numbers of larvae in 500 ears and the percentage of grains attacked by the two species separately. Pre-sampling also permitted the main estimate to be corrected when it was inadvertently made too late and after many larvae had left the ears. This correction was often large, and sometimes increased the estimate by as much as 4 times. During the last few years the practise of sampling 500 ears was abandoned and 250 were taken; but the final estimate was given as for 500 ears.

Table 7·1 and Fig. 7·1 show that the population can fluctuate from about 1 thousand to 34 thousand per 500 ears in consecutive years. However, the idea of a cycle with a maximum every 4–6 years is of doubtful validity, although the minima seem to occur fairly regularly; perhaps the factors that tend to lessen the numbers are more regular in their effect than those that allow the large potential population to develop.

The causes and prediction of outbreaks. The population in any year results from the balance of many opposing factors and not only major events such as sudden rain during egg laying, but other biological and meteorological factors can affect the synchronisation of oviposition and larval development with the stage of growth of the crop. Also, in a dry season larvae cannot leave the ears easily, so many are removed with the crop, which presumably affects the population the next year (Barnes, 1941).

D. J. Cross analysed Barnes's data and found that the date on which midges began to emerge, usually from the beginning of June onwards, was correlated with the average daily mean air temperature of the last week of May and the first week of June ($r = 0{\cdot}712$), that the date at which the peak of emergence occurred could be predicted more accurately than that of the onset, and that emergence of *C. tritici* was more predictable than that of *S. mosellana*. Temperatures before 22 May had an effect, but did not significantly add to the effect of the period between 22 May to 7 June.

There is in this a suggestion that time of emergence depends at least partly on a cumulative effect of spring temperature, in addition to a critical threshold temperature for emergence. Emergence of wheat ears was also correlated with temperatures during May and early June, but unfortunately this event was recorded accurately on Broadbalk in only six years. Barnes also kept all the larvae he extracted from the main annual samples in an out-door insectary and recorded the percentage that emerged each year and the number of parasites that also emerged in subsequent years; not all of these parasites were identified. This information about parasitism of pupae in the soil and delayed emergence of midges has never yet been fully used in a hypothesis of population change in midges; and, at the time, it was also difficult to measure another basic parameter that affects population fluctuation, namely the number of larvae and pupae in the soil, although this was done later though only for one year (Aitkenhead *et al.*, 1955).

The effect of fallow and manurial treatment on infestation. From 1935 to 1940, Barnes (1941) studied the effect of fallow and found that the crop in the first year after fallow usually had fewer grains attacked by *C. tritici* than the 2nd, 3rd and 4th crops after fallow. The first two crops after fallow in total were less infested with *S. mosellana* than the 3rd and 4th crops. By the fourth year the effects of fallowing had disappeared. Fallowing therefore lessened subsequent populations and continued cropping increased them. Nevertheless the very large populations seen on some commercial fields have never occurred on Broadbalk.

Barnes (1932a, 1941) found no consistent differences in infestation between plots with different manurial treatments.

Damage. Between 1929 and 1943 the percentage of grains attacked by the two species of midge was negatively correlated with the yield of wheat. Correlation of greatest yields with years when infestations were small is

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not necessarily the outcome of the effect of midges on the wheat, and Barnes and Weil (1944) concluded that 'The weather and soil conditions which control the intensity of the midge infestations are to a large extent also those which control the development of the wheat plant'.

It is extremely difficult to assess the effect of the midges on the yield of grain on Broadbalk, partly because of the different kind of damage done by the two species, and partly because of the relatively small infestation and the consequent masking of loss by other factors.

Larvae feed on the sap of the growing grain and make it shrivel. Because several larvae of *C. tritici* usually feed on one grain, each attacked grain can be considered lost. *S. mosellana* has a less drastic effect because most attacked grains contain only one larva. However, it attacks more grains and therefore increases the number of small ones. Barnes estimated that grains attacked by *S. mosellana* lost, on average, about half as much weight as grains attacked by *C. tritici*. In addition to loss of weight, the milling quality and germination are also affected. Table 7·2 gives Barnes's estimates of grain loss.

TABLE 7·2

Estimated loss of grain, in cwt/acre, from attack by C. tritici *and* S. mosellana, *the effects of compensatory growth being neglected*

(Data from Barnes 1956)

% grain attacked	Loss: cwt/acre *C. tritici*	*S. mosellana*
1	0·2	0·1
2	0·3	0·2
3	0·5	0·2
4	0·7	0·3
5	0·8	0·4
6	1·0	0·5
7	1·1	0·6
8	1·3	0·7
9	1·5	0·7
10	1·6	0·8
11	1·8	0·9
12	2·0	1·0
13	2·1	1·1
14	2·3	1·1
15	2·5	1·2
16	2·6	1·3
17	2·8	1·4
18	2·9	1·5
19	3·1	1·5
20	3·3	1·6

When the percentages of ears and grains attacked by the two species on Broadbalk for 38 years are considered, the combined attack of the two species averages 10%. In one year it was about 27% (Table 7·1). Recorded populations of *S. mosellana* on Broadbalk only once reached 6000 larvae/500 ears when approximately 15% of grains were attacked. *C. tritici* never exceeded 30000 larvae/500 ears and then it attacked approximately 13% of grains; however, considerable proportions of ears had no larvae in them.

These are much smaller than populations of more than 100 000 larvae/500 ears of *C. tritici* and 25000 of *S. mosellana* reported from some

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commercial wheat crops (Barnes, 1956). Also, the proportion of grain attacked and the yield lost is less (Light, 1955).

Barnes considered that loss of yield on Broadbalk from Wheat Blossom midges was unlikely to be appreciable. Only when ears infested with *C. tritici* exceeded 70% were more than 5% of grains attacked, and then only when there were more than 7000 larvae/500 ears. D. J. Cross found no statistically significant correlation between Barnes's estimates of infestations by wheat midges on Broadbalk between the years 1930 and 1960 and the yields of grain over the same period. The major part of the yearly fluctuation in yield is caused by factors other than midges. Cross's work on midges and other factors affecting Broadbalk wheat largely confirms Barnes's (1958) statement that, considering the usually small infestation and the possibility of compensation 'there is scarcely ever likely to be a measureable loss . . .'. Whether this will still be true now that Broadbalk has been sown with crops other than wheat, and the supposed buffering effect of parasites on populations perhaps lessened, remains to be seen. More needs to be known about the different factors that affect yield of wheat on Broadbalk, such as summer rainstorms and errors in the grain yields from contamination by weed seeds (see Thurston, p. 200), before Barnes's records can be used to estimate any loss in yield caused by wheat midges.

Wheat Bulb fly

Wheat Bulb fly has been studied on Broadbalk mainly to provide an annual record of the populations of eggs and larvae and to compare populations on plots manured differently (Raw, 1954, 1955). Observations there also illustrate some important facts about Wheat Bulb fly; for example, that early germination allows many tillers to be produced and enables the crop to withstand attack, and by contrast, slow growth when the eggs hatch makes the crop liable to be damaged seriously. Experiments were also made to study the effect of Wheat Bulb fly on yield, by preventing oviposition in some plots while allowing it on others (Raw & Lofty, 1957). These observations enabled Raw (1967) to establish an important general fact, namely that the number of larvae that survived was directly related to the density of wheat shoots, even when there were four or five shoots available for each larva. From this he supposed that although fertilisers, or early sowing, would favour plant growth and early shoot development and so minimise the effects of attack, they would also promote survival of larvae and an increase in next year's adult population.

Broadbalk was not designed for entomological experiments and, although it illustrates the complex interactions between the insect and the crop, it cannot readily elucidate them. Also yield can be related to intensity of attack only in a gross way, because many other factors that affect yield are confounded with the effects of Wheat Bulb fly.

Life history of *Leptohylemyia coarctata* Fall. The flies that emerge in June do not lay their eggs on or near the plants on which the larvae will eventually feed; instead they lay on bare soil, or on sparsely covered soil,

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as in young potatoes or sugar beet. On heavy soils, such as on Broadbalk, they usually select bare soil. The eggs, which are laid in cracks in the soil, do not hatch until late January or early February when the newly-hatched larvae enter the young host plant, usually wheat; though sometimes rye and winter barley are also attacked.

Because part of Broadbalk is fallowed each year, the Wheat Bulb fly is always present, and the first wheat crop after fallow is always infested; crops on other sections are negligibly infested, and the following discussion is based on results from the first crop after fallow.

The relationship of infestation to the growth and density of plants and to yield. The effects of attack by Wheat Bulb fly larvae depend on several factors, some inter-related and some not. The sowing date, the weather and the temperature of the soil affects both the growth of the plants and the hatching of eggs; manuring affects germination and the growth of seedlings, and therefore the stage at which they are attacked. Growth of plants, density of shoots, number of eggs and number of larvae that infest plants can all influence the severity of the attack. Yield loss does not necessarily reflect the number of larvae or the number of shoots infested. Comparatively few larvae can cause severe damage when they attack plants that have only one or two shoots and are growing slowly. Conversely a crop can withstand attack by many larvae when growing conditions are good and the plants have tillered when first attacked (Bardner, 1968).

This article necessarily considers the effects of Wheat Bulb fly in terms of damage done to the growing crop rather than effects on yield. Only in years when the crop was ruined can loss of yield be related specifically to the attack. In other years the loss of yield is confounded with too many other factors for the effect of the Wheat Bulb fly to be distinguished.

The Wheat Bulb fly population

The number of eggs in the soil. Eggs were counted on Broadbalk first in 1954, then in 1959 and 1961 on fallowed plots 2, 3, 5, 7 and 10, and then annually from 1964, when they were counted on Plots 11, 12 and sometimes plots 13 and 14. The first five plots represent the extreme different manurial treatments. Plot 2 (FYM), plot 3 (unmanured); plot 5 (PKNaMg); plot 7 (N_2PKNaMg); plot 10 (nitrogen only). The other plots were sampled after it was noticed that some not given potassium failed completely in 1963. The greatest mean number of eggs per acre estimated from all plots was 3½ million in 1954, the first year Broadbalk was sampled. After 1954 one million eggs/acre was not exceeded until 1965, when there were more than 2·5 millions/acre (Fig. 7·2). Although estimates were not made in some intervening years, it seems unlikely that the mean population on the plots was ever fewer than 300 000 eggs per acre. Although more than one million eggs per acre is usually thought necessary to produce enough larvae to cause serious damage considerably fewer can be enough when plants grow slowly (Raw, 1967).

Several factors might influence the Wheat Bulb fly to select different plots in which to lay eggs. For example, although a recent single dressing

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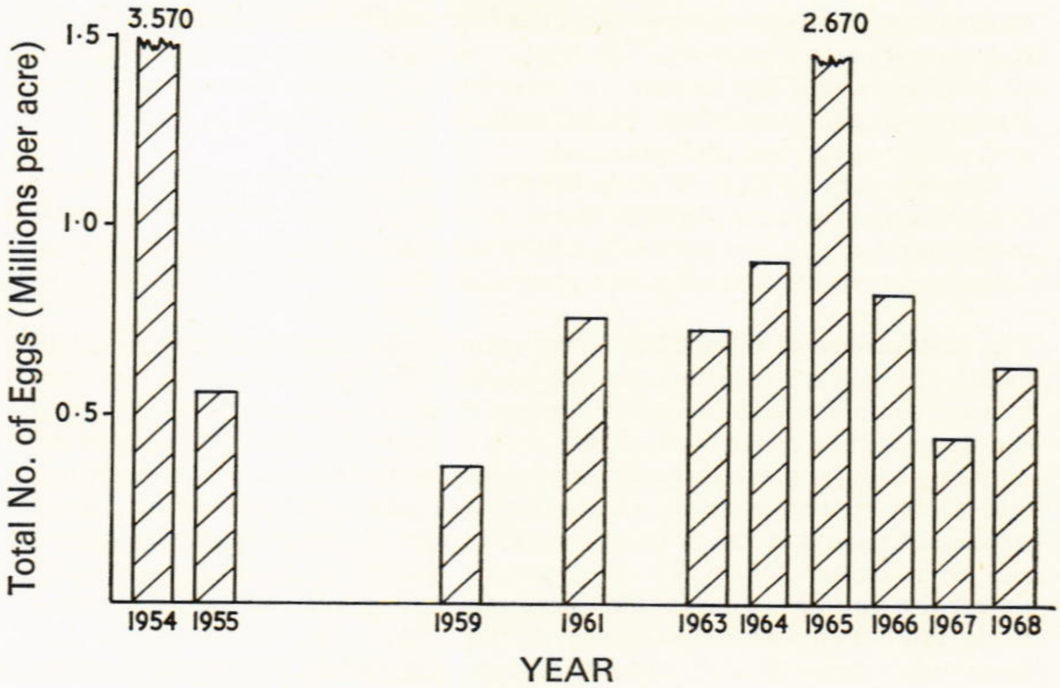

FIG. 7·2. Estimated mean number of eggs of Wheat Bulb fly from all plots, in millions/acre on Broadbalk. 1955 and 1963 were estimated indirectly from Life Tables (Raw, 1960, 1967): in other years numbers were estimated from soil samples.

of FYM did not affect numbers of eggs laid (Raw, 1955) the annual dressings to plot 2 have altered the texture, moisture-holding capacity and colour of the soil, and so might affect the number of eggs laid there. The position of individual plots in the field could also have an effect. However, in most years the mean number of eggs laid in different plots in the fallow section did not differ significantly (Table 7·3), but variation within plots was often great and the coefficient of variation ranged from 45 to 100%. Where there were significant differences there was no consistent effect of different manuring (Table 7·3).

TABLE 7·3

Broadbalk Wheat Bulb fly egg populations

Mean number of eggs per sample (2 in. cores): (square root transformation)

Year	No. samples per plot	Plots 2	3	5	7	10	11	12	13	14	Mean	Standard error of plot estimate
1954	10	2·59	1·99	1·85	1·78*	2·69					2·21	1·01
1959		0·71	1·11	0·80	1·11	1·02					0·95	0·23
1961		0·90	0·71	0·66	0·72	1·25					0·85	0·15
1964	40	1·86	1·67	1·63	1·68	1·19	1·56	1·36	0·88	1·41	1·47	0·13
1965	20	2·12	1·54	1·94	1·54	2·17	1·88		1·84		1·86	0·19
1966	10	1·05	0·37	0·86	0·58	1·23	1·07	1·28	0·30	0·71	0·83	0·23
1967	10	0·10	0·89	0·44	0·38	0·64	0·87	0·44	0·75		0·56	0·19
1968	6	0·74	0·00	0·79	1·04	0·96	1·02	1·05	0·17	0·67	0·72	0·27

* Plot 8.

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Populations on Broadbalk and elsewhere. That populations of eggs and larvae on Broadbalk do not reflect those in other parts of the country was shown by comparing the mean egg populations from fields of heavy soil in Eastern England with those on Broadbalk (Table 7·4). Only in one of the

TABLE 7·4

Comparison of mean numbers of Wheat Bulb fly eggs (10^6/acre) *and degree of damage in the N.A.A.S. Eastern area and on Broadbalk*

	N.A.A.S. Survey				Broadbalk
Year	Number of fields	% fields with more than 1 million eggs/acre	Mean egg count in autumn 10^6/acre	Damage in spring	Mean egg count in autumn 10^6/acre
1954	9	33	0·64		3·57
1955	21	52	1·45		0·56*
1956	33	49	1·27		
1957	60	30	0·78		
1958	36	61	1·35		
1959	63	43	1·14		0·37
1960	35	71	2·27		
1961	40	23	0·63		0·76 (0·19)
1962	42	71	1·44	Light	
1963	55	76	2·20	Severe	0·73*
1964	66	65	1·84	Moderate	0·91 (0·17)
1965	44	84	3·08	Moderate-severe	2·67
1966	93	33	0·89	Severe	0·83 (0·22)
1967	63	19	0·61	Light	0·45 (0·06)
1968				Light	0·64

* Number of eggs estimated from number of larvae.
( ) = Empty eggs included in total.

peak years on Broadbalk (1965) was there a correspondingly large mean population over the Eastern Region. Sometimes populations of eggs were large elsewhere when they were relatively small on Broadbalk. In the peak year on Broadbalk (1954) populations were estimated by the N.A.A.S. on only a few fields elsewhere, but these showed the smallest populations of the whole period until 1967.

The effect of the attack on the crop. A large proportion of larvae that hatch from eggs may die before they can invade shoots. Nevertheless the number of shoots damaged by larvae each year is correlated with the number of fertile eggs laid in the soil during the previous autumn (Fig. 7·3). Also the more shoots there are, the greater is the number of larvae that survive (Fig. 7·4). However, serious damage to the crop does not depend only on there being large numbers of larvae; plants with several shoots withstand attack better than those with only one or two, indeed a plant that has only one shoot usually dies after a larva enters it. Therefore the relation between numbers of shoots, and the time eggs hatch is important.

In most years there are more shoots when the eggs hatch than there are larvae to infest them and the crop is not devastated. Little is known about the effects of such attack on yield. Many factors, including time of sowing, fertilisers and fallowing, affect the number of shoots at the time of attack; although much is known about differences between shoot numbers on

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different plots, little is known about the way effects of attack are related to factors affecting number of shoots.

Crops on some plots seem especially prone to damage, not because they are attacked by more larvae but because they are retarded, whereas crops on other plots withstand attack usually better. The analysis of such differences is complicated by the fact that fallowing increases yield, especially on plots 3 and 5 (Fig. 7·5), but also encourages Wheat Bulb fly. For

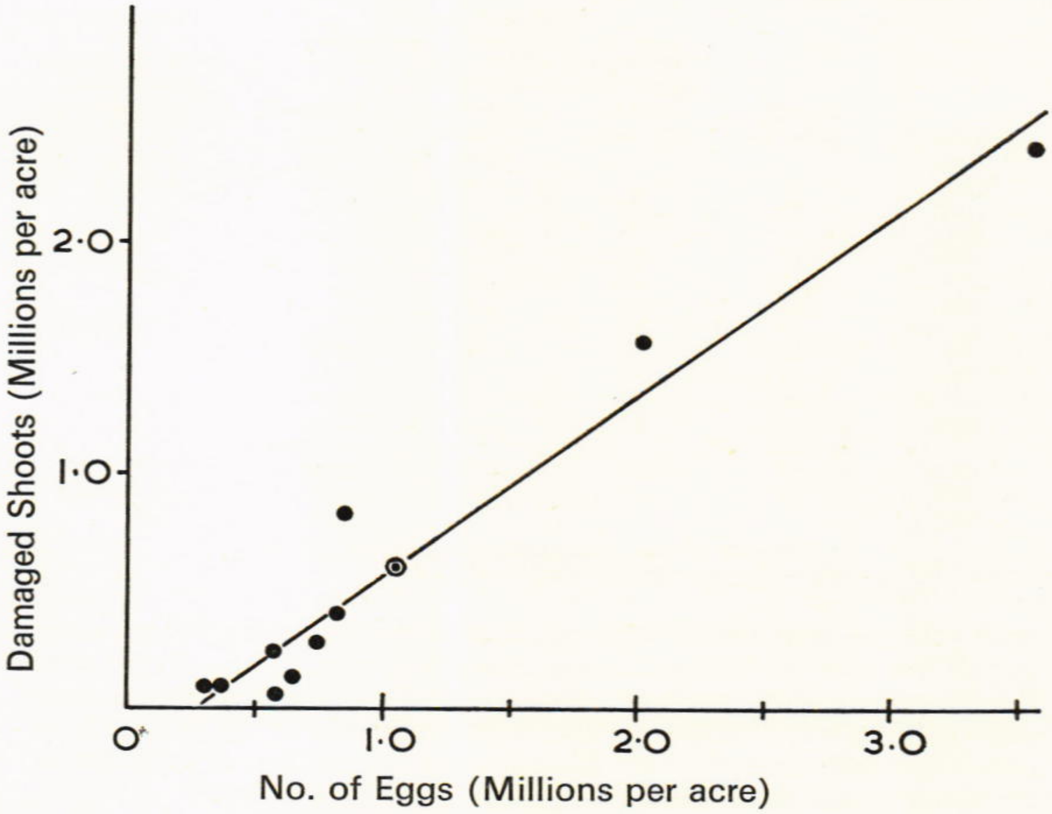

FIG. 7·3. The relation between mean number of eggs of Wheat Bulb fly and mean number of damaged shoots on Broadbalk. Each dot represents information for one year, for 1954, 1955, 1959, 1961 and 1963 to 1968.

example, plot 3 in 1963 and plot 5 in 1964 suffered severely and only in those years was the yield on the two plots less than on plots fallowed two years previously. Also plots 10, 11, 12 and 14 which get no potassium, suffered greatly from Wheat Bulb fly attack in many of the years when observations were made and yields from these plots tend to lessen rather than to increase after fallow (Fig. 7·5). In 1962–63 the severe winter retarded the plants and the crop on these plots was so damaged that it was ploughed in, although Wheat Bulb fly was not specially numerous (Fig. 7·2).

There can also be many eggs but little damage. For example, in 1954 and 1965 there were very many eggs in the soil (3·6 and 2·7 millions/acre respectively), but shoots were even more abundant (7·0 and 4·0 millions/acre

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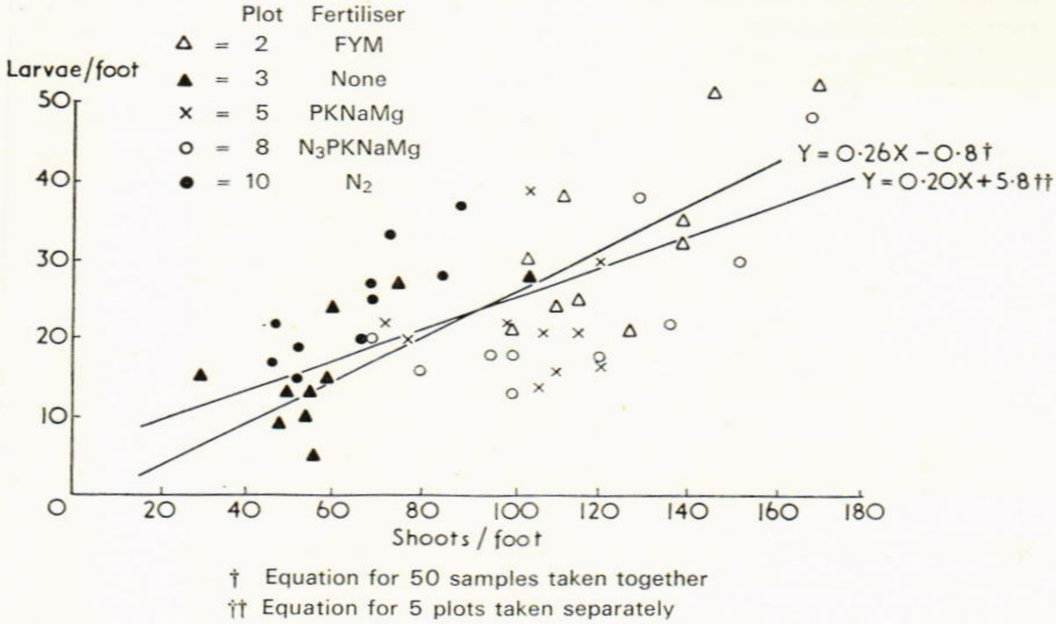

FIG. 7·4. The relation between number of shoots and number of larvae per foot of drill on Broadbalk in 1954; 10 samples of 1 foot per plot (from Raw, 1967).

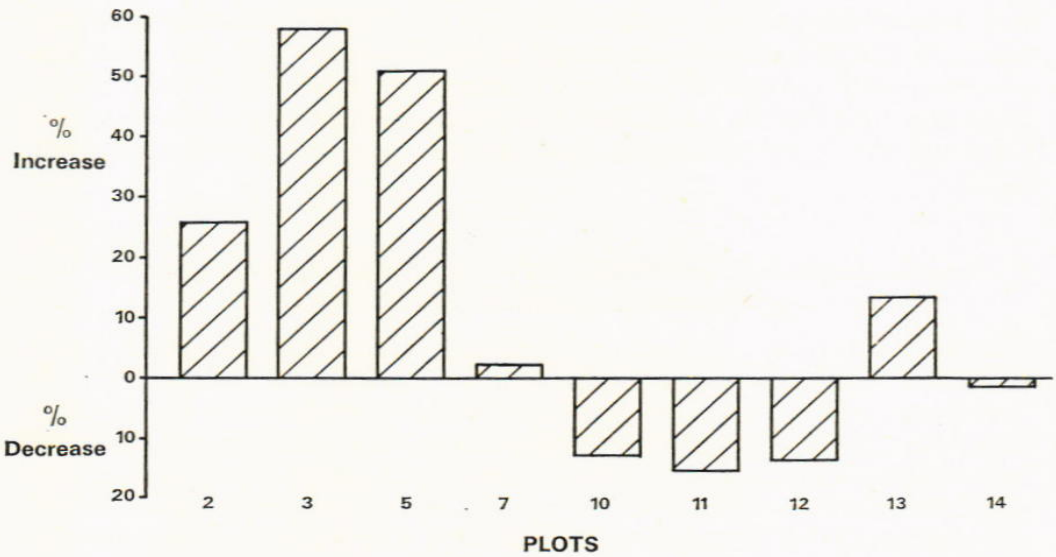

FIG. 7·5. The percentage increase and decrease in yield on different plots of Broadbalk one year after fallowing. Zero line refers to plots in corresponding sections fallowed two years previously. Data from White Book (means of yields from years 1953 to 1966 excluding 1963).

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respectively), and the crop was not severely affected. Had shoots been fewer, as they were in 1963 and 1966, damage might have been great; in these two years infestations were expected to affect the crop seriously and in 1963 the crop on some of the plots, expecially those with nitrogen but no potassium failed completely.

The 1966 crop was not sown until January and, although there were more than 800 000 eggs per acre, few plants were killed possibly because a very warm February speeded growth and compensated for attack; also some larvae may have hatched before the seeds germinated. Although numbers of shoots differ from plot to plot, the attack seems serious only in years such as 1963, when a cold winter and sparse shoots combined to increase the damage.

Attack by larvae kills some shoots or whole plants in each plot, but surviving plants may compensate and produce new ear-bearing shoots especially if they are well forward (Bardner, 1968). Such compensation undoubtedly occurs on Broadbalk, but its extent is unknown because shoots have not been counted when the attacks began.

The effect of winter temperature on damage to the crop. Sowing date and soil temperatures during winter strongly influence the size of a plant by the time larvae attack it. Those years when there were few shoots at the time of sampling, 1955, 1961 and 1966, were either years when the soil during the winter had been unusually cold, or when the seed was sown late (after the beginning of December), or both. In 1954 when the shoots were exceptionally numerous, the crop was sown during the third week of October, and the soil was unusually warm during winter; although many shoots were attacked by a large population of larvae, the effect on the yield was small. In 1962/63 winter was exceptionally cold and long and seed was not sown until the end of November. Attack occurred at the single shoot stage and on plots 10, 11, 12 and 14 (without potassium fertiliser) where the crop was very backward, most plants were killed and the wheat failed.

Gall midges and Wheat Bulb fly on Broadbalk indicate general problems in agricultural entomology

The work on Wheat Blossom midges and Wheat Bulb fly indicate two particular needs of current research in agricultural entomology. A permanent annual census of particular pests is needed with appropriate experimental work to predict damaging outbreaks. Such census work should be combined with studies of how the timing and intensity of attack affects yield. Work on both these pests illustrate, in different ways, the value and the deficiencies of a long-term census with and without supplementary work and, especially, how the effects of damage can be related to a census.

The populations of both pests fluctuate greatly from year to year; but even 39 years' recording provided only about seven 5-year cycles for analysis; in the 14 years of Wheat Bulb fly sampling there were only two peaks. Even with such long periods of sampling, evidence for regular cycles is

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difficult to obtain. The original hypothesis of a 5-year cycle for gall midges seems unfounded and the results cannot yet be used profitably; they do show, however, that prolonged monoculture has not produced damaging outbreaks as in commercial crops and this alone would justify Barnes's recording. The relation between damage to the crop by Wheat Bulb fly with stage of growth at the beginning of attack, and with numbers of larvae, may provide enough information for a sound hypothesis about the causes of crop damage and a continued census of this pest seems justified.

Entomological research in different parts of the world has concentrated much on analysing the fluctuations of populations of pests and the factors that cause outbreaks. Population dynamics is a fashionable subject, and with a perennial crop (e.g. trees) numbers of the pest may well be the most important thing to study. But with agricultural crops that last for only one season in any one place, it may be more feasible and desirable to try to relate the numbers of insects to their effect on the growth and yield of a crop and hence of the liability of a crop to be damaged rather than to try to predict only the abundance of the pest; indeed the prediction of the time of onset of attack may be relatively more important to some crops than the number of insects subsequently involved, as in the Wheat Bulb fly work on Broadbalk.

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