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ORANGE WHEAT BLOSSOM MIDGE: A LITERATURE REVIEW AND SURVEY OF THE 1993 OUTBREAK

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ORANGE WHEAT BLOSSOM MIDGE: A LITERATURE REVIEW AND SURVEY OF THE 1993 OUTBREAK

by

J. N. OAKLEY

ADAS Bridgets, Martyr Worthy, Winchester, Hampshire S021 1AP

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CONTENTS

Page

1 **Abstract**

2 **Glossary of terms**

3 **Introduction**

7 **Biology**
7 Orange wheat blossom midge
10 Yellow wheat blossom midge
10 Topics requiring further research

11 **Yield and quality effects of damage**
11 Orange wheat blossom midge
13 Yellow wheat blossom midge

14 **Natural enemies**
14 Parasitoids
15 Polyphagous predators
15 Opportunities for integrated control

16 **Cultural control**
16 Incoincidence
16 Physical measures
16 The effect of set-aside
16 Recommendations for control on organic farms

18 **Chemical control**
18 Recommended products
19 Spray action thresholds
21 Timing requirements

22 **Varietal susceptibility**
22 1993 varietal comparison experiments
23 1993 Cereals Quality Survey
25 Recommendations for future varietal comparison experiments

26 **Development of forecasting systems**
26 Case study I - the 1970s Yorkshire Wolds outbreak
31 Case study II - causes of the 1993 outbreak
34 Forecasting damage and spray need for 1994

36 **Conclusions and recommendations**
36 Main conclusions
37 Recommendations for further study

37 **Acknowledgements**

38 **References**

43 **Appendix**. Analysis of wheat grain samples from the HGCA Cereals Quality Survey for visible signs of damage due to the orange wheat blossom midge

ABSTRACT

A substantial outbreak of the orange wheat blossom midge occurred in 1993, affecting the wheat-growing areas of England, Scotland and Wales. The larvae of this species overwinter in the soil for up to 13 years before pupating and emerging as adults from late May to the beginning of July. Larval reactivation and pupation are stimulated by rising soil temperatures and rainfall. Mass emergence of adults can occur under suitable weather conditions which may lead to substantial damage if, as in 1993, the flight coincides with ear emergence of wheat crops and a favourable period of warm, still weather. The degree of coincidence between flight and the span of time during which susceptible florets are present in a crop are the main factors determining the degree of infestation. Adult midges are strongly attracted to susceptible crops, to which they will migrate from a distance of at least one kilometre. The eggs are laid in the florets of wheat ears between ear emergence and flowering. The larvae feed on the swelling grain, and can cause shrivelling, pre-sprouting and induce secondary fungal attack. A substantial reduction in Hagberg falling number and other quality measures can occur if these factors are already under pressure in the crop. Yield losses can be considerable where attacks are severe.

No effective cultural control methods are available, but the pests can suffer significant reductions due to various natural enemies. Although chemical control measures are available, their efficacy is dependent on precise timing of applications within 4-5 days of the adult midges arriving in a susceptible crop. Successful control depends therefore on predicting which crops may be at risk in relation to forecasts of midge emergence and in being prepared to spray at short notice in case of need. Forecasts can be given based on monitoring of pupation in the soil and linking pupal populations to weather data. Soil sampling can be used to estimate levels of midge larvae in the soil in advance and thus estimate the probability of a significant emergence at a critical stage.

Action thresholds for spray application have been revised to take account of recent research findings and current costings to one ovipositing midge per ear for feed crops and one midge per six ears for seed and milling crops, between growth stages 55 and 59. The insecticide sprays approved for use in the UK are broad-spectrum in action and care should be taken to time sprays accurately to minimise effects on the midges' natural enemies and other non-target insects.

Considerable differences in damage levels between varieties have been found in experiments, but are thought to be mainly due to patterns of coincidence at particular sites and show marked inconcistencies. Varietal traits of tightness of florets and hypersensitivity to midge damage have been identified which could merit further exploitation.

GLOSSARY OF TERMS

aleurone layer	a single layer of cells within the grain between the endosperm and the pericarp, rich in protein and fat deposits
glume, lemma and palea	parts of the wheat floret, the glumes are the outermost parts, a lemma and palea enclose each kernel
GS	growth stage
GS 51	the start of ear emergence
GS 55	mid-ear emergence
GS 59	all of ears emerged, but before the start of flowering
incoincidence	the degree to which adult midge flight fails to coincide with the susceptible crop growth stages
lemon wheat blossom midge	alternative name for the yellow wheat blossom midge
midges	flies of the family Cecidomyiidae: a general term for adult flies of this family
OP	organophosphorus insecticide
orange wheat blossom midge	*Sitodiplosis mosselana*
parasitoids	parasitic wasps whose larvae kill their host; in the case of wheat blossom midges they all belong to the superfamily: Calcidoidea (order Hymenoptera)
pericarp	several layers of cells enclosing the grain, the inner layers of which form a dense layer preventing water and moulds from affecting the grain
polyphagous predators	invertebrates which feed on a range of prey types
yellow wheat blossom midge	*Contarinia tritici*

INTRODUCTION

In July 1993 a widespread outbreak of the orange wheat blossom midge became apparent across a broad area of southern England. At the time of discovery, the larvae were nearly fully grown and the damage had been done. A few attempts at control were made, using triazophos sprays recommended for control of midge adults and eggs at the ear emergence stage, but these attempts proved to be futile. Subsequent midge-induced pre-sprouting and secondary fungal attack further enhanced the damage, and yield reductions of up to 30% were estimated in the most heavily infested fields.

The outbreak received a great deal of media attention. Some of the reporting was inaccurate and repeated various errors from standard text books based on older work, which added to the confusion. Some of the factors attributed to the orange wheat blossom midge in fact pertain to the distantly related yellow wheat blossom midge. This review attempts to bring together an accurate picture of the biology and control of these midges. It concentrates on the orange wheat blossom midge, responsible for over 99% of the damage caused in 1993, but draws comparisons with the yellow wheat blossom midge where necessary to prevent further confusion.

The orange wheat blossom midge is distributed throughout the temperate wheat growing areas in the Northern Hemisphere and has been responsible for serious outbreaks of damage from Canada (Wright & Doane, 1987), to France (Bouchet & Dagneaud, 1969), Germany (Lübke & Wetzel, 1984), Italy, (Concaro & Blanchard, 1989), Switzerland (Affolter, 1988), Sweden (Hjorth, 1992), Finland (Kurppa, 1988), the Netherlands (Nijvelt & Bokhorst, 1973), Belgium, Czechoslovakia, Poland, Hungary, Romania, Bulgaria, Yugoslavia, (Skuhrava, Skuhravy & Brewer, 1983), and to China (Chen, Li, Peng, Qi & Fu, 1988) and Japan (Katayama, Fukui & Sasaki, 1987).

The importance of the orange wheat blossom midge has increased since the introduction of the combine harvester, as crops are now left to stand for longer in the field, allowing more larvae to return successfully to the soil (Skuhrava *et al.*, 1983). Damage by the yellow wheat blossom midge has been restricted to Europe, with no significant outbreaks reported since the 1970s (Oakley, 1981, Lübke & Wetzel, 1984). This species is prone to greater fluctuations than the orange wheat blossom midge and tends to occur more occasionally, in intense, short-term outbreaks.

Barnes (1956 & 1958) conducted a long-term study of wheat blossom midge occurrence in the Broadbalk experiment at Rothamsted. This field was under continuous wheat cropping, with a rotational fallow strip (Figures 1 & 2). He found orange wheat blossom midge numbers to be relatively stable, with more than 5% of grain sites damaged in two thirds of the years between 1927 and 1955. The yellow wheat blossom midge showed three 'outbreak' periods within this time scale, ranging in duration from 4 to 6 years, with one extending beyond the period of study.

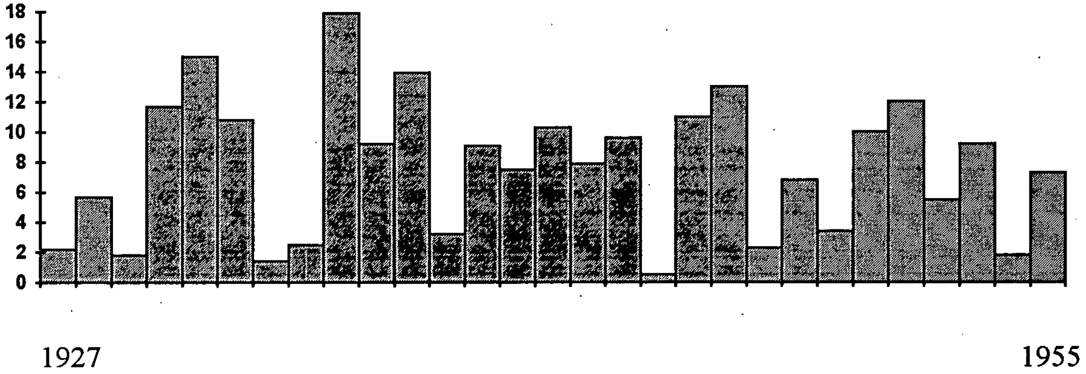

Figure 1. Percentage grain attacked by orange wheat blossom midge larvae in Broadbalk field, Rothamsted, after Barnes (1956)

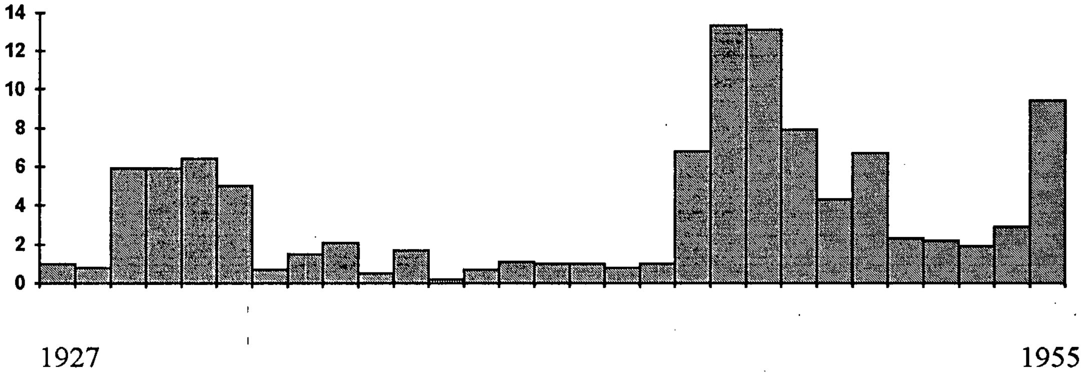

Figure 2. Percentage grain attacked by yellow wheat blossom midge larvae in Broadbalk field, Rothamsted, after Barnes (1956)

Previous recorded outbreaks of economic significance in the British Isles this century have been restricted to outbreaks due to both species in 1916, 1920 and in 1926, when all the eastern counties, Cheshire, east Devon and Kent were affected (Anon., 1928), one due to the orange wheat blossom midge only in Northumberland in the 1940's (Golightly, 1952), one mainly due to the yellow wheat blossom midge in Ireland in 1951 (Mullin, Fox & Brady, 1952) and one due to both species in the Yorkshire Wolds in the 1970s (Oakley, 1981). However, occasional observations and limited surveys have confirmed that both species occur in most wheat crops in most seasons, with the orange wheat blossom midge causing sufficient damage to affect quality quite frequently. Skuhrava *et al.* (1983) concluded that both species together probably caused yield losses of 5-10% across Europe as a whole.

The grain samples from the 1993 Home-Grown Cereals Authority Cereals Quality survey were examined for the extent of visible wheat blossom midge damage (Table 1). Thousand grain samples were examined under x2 magnifiers and damaged grain extracted and counted. The results of the examination are given in greater detail in Appendix 1.

Table 1. The distribution of orange wheat blossom midge damage as recorded by the Cereals Quality Survey, by HGCA region.

	Eastern	South West	Midland	Northern	Scotland	Overall
% damage						
mean	10.6	4.7	5.2	3.5	1.7	6.6
median	9.3	3.6	4.6	2.7	1.4	5.0
SD	6.27	3.75	3.43	3.99	1.24	5.64
maximum	35.6	17.7	13.6	29.2	5.3	35.6
minimum	0.7	0.7	0.0	0.3	0.2	0.0
Number of samples	142	59	102	66	24	393
% of samples						
< 5% damaged	19	68	51	82	96	50
5-10 %	40	20	37	15	4	29
>10 %	41	12	12	3	0	21

Of the 393 samples examined, all but two had some obvious damage present. The damage was generally greatest in the Eastern region. As explained in the varietal susceptibility chapter (page 22), examination of harvested grain samples may underestimate the actual level of damage in the field due to loss of badly damaged grain during harvesting and any subsequent cleaning. However, where more than 10% of damaged grain was found a significant yield loss of at least 2% would have occurred. Had an effective spray been applied, it would have been cost effective. Where less than 5 % of damage was found the damage would have been of little consequence, and where 5-10 % damage was found quality may have been affected if the crop was otherwise only just of acceptable quality.

It can therefore be concluded that at least 21% of British wheat crops would have benefited from treatment against the orange wheat blossom midge in 1993. The consequent yield loss for Great Britain is estimated at 4%, allowing for one third of damaged grains being lost at harvest and a 20% size reduction in damaged grain in harvested samples.

Examination of samples from the survey, and varietal comparison experiments, have revealed significant overlooked patches of damage in the Lincolnshire Wolds and the West Midlands. The survey samples also revealed widespread damage in Scotland. All the Scottish samples examined had some damage but in no case did the amount exceed 5%. MacLagan (1957) recorded the yellow wheat blossom midge as one of the seven most important pests of Scottish wheat crops. Early records often failed to separate the species, so the orange wheat blossom midge may well have previously reached damaging levels in Scotland.

The highest levels found in the survey were considerably lower than the worst case reported to ADAS. 63% grain damage was found on a farm in Wiltshire under continuous wheat cropping, and similar levels were reported from Cambridgeshire. The incidence of such high levels of damage was too infrequent to have been picked up in the survey.

Soil populations following cropping are likely to pose a significant risk to crops in 1994 or 1995 wherever grain damage was above 10%. Given a favourable year in 1994 there could be some risk wherever damage levels exceeded 5%. The maximum area likely to be at risk in 1994 is approximately half the national wheat crop.

BIOLOGY

Two species of wheat blossom midge affect British cereal crops, the orange wheat blossom midge (*Sitodiplosis mosellana*: Géhin, 1857) and the yellow (or lemon) wheat blossom midge (*Contarinia tritici*: Kirby, 1798). Drawings of both species and methods for distinguishing them are given by Harris (1966), Pfeiffer & Brunet (1967) and Basedow (1971). Photographs showing the appearance of adults and larvae in the field are given by Oakley (1981; reproduced in Gratwick, 1992). At all stages the species can be separated by the differences in colour indicated by their common names. The adult midges are about 3 mm in length and fly at dusk, the general appearance of a female orange wheat blossom midge at rest on a wheat ear is shown in Figure 3. The eggs are laid within the florets of wheat, cereals and grasses and are cylindrical in shape. The larvae are about 3 mm long when fully grown and pass the winter curled up in circular cocoons of about 2 mm diameter.

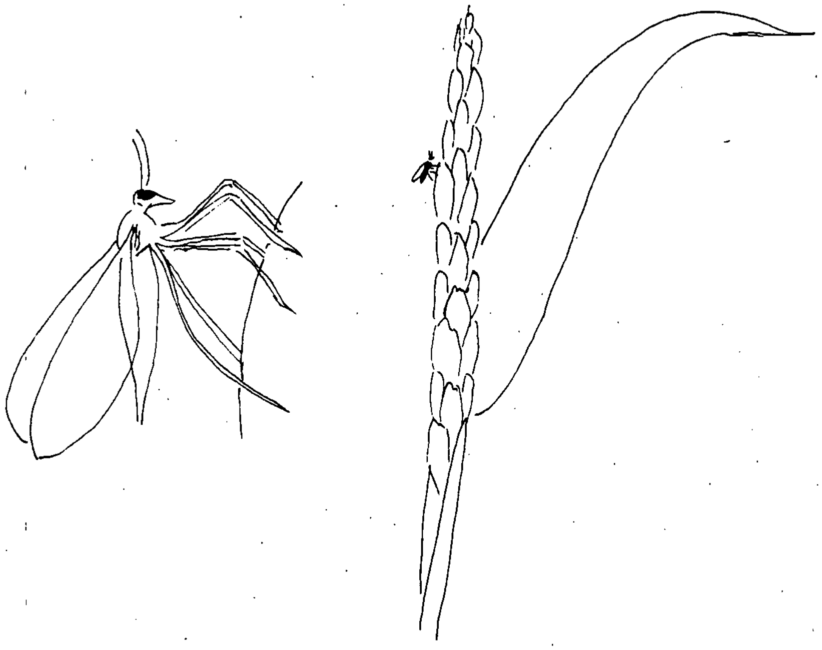

Figure 3 A female orange wheat blossom midge at rest on an emerging wheat ear. Shown magnified 10 times to the left, life sized to the right.

Orange wheat blossom midge

The larvae overwinter in cocoons in the soil. These are initially formed mainly in the top 50 mm but are later redistributed by cultivation. The larvae will not resume activity until after a prolonged period of cold weather followed by a period of warmer weather. The minimum vernalisation requirement is a period of 70 days with average temperatures below 10°C. For maximum potential reactivation, 112 days or more of cold weather are required. Where winters are too mild to provide the minimum requirement, the larvae will remain inactive for a further year or years to obtain the minimum requirement to break their diapause. Adults have been recorded emerging up to 13 years after the larvae entered the soil. No information is available on the cold tolerance of hibernating larvae, but as the pest does well in central Canada and Finland the tolerance range is unlikely to be significant in Britain.

If the vernalisation requirement is met the diapause is suspended after a period of warmer temperatures, sufficient to give 220 day degrees above a base temperature of 3°C after January 1. The period of diapause suspension lasts for about 5 weeks, during which time larvae will move to the soil surface and pupate if a further set of conditions are met. The principal requirement is sufficient rainfall to wet the top 25 mm of soil. Under British conditions a rapid rise in soil temperatures to above 13°C following a period of heavy rainfall seems to provide a particularly strong stimulus for larval reactivation and pupation.

The proportion of healthy larvae pupating each year under German conditions varies between 10 and 94% with a median of 47%. In the Yorkshire Wolds outbreak in the 1970s up to 98% of larvae pupated in one year. (Basedow, 1980; Oakley 1981; Basedow & Gillich 1982; Hinks & Doane 1988)

The duration of the pupal stage varies, according to temperature, between 2 and 4 weeks. The total heat sum required for first emergence after the end of diapause varies between areas and has been estimated as 450 day degrees above a base temperature of 6°C in Germany and 400 day degrees above 5°C in Finland (Basedow & Gillich, 1982; Kurppa, 1989a). The variation between these two estimates suggests that local adaptation to climate may occur and that these figures may not be applicable to British conditions.

Emergence of the adult midges from pupae is also stimulated by rising soil temperatures following rainfall. A rise to above 15°C is particularly favourable. The increasing strength of reactivation stimuli as the spring develops often produces a small early flush of adults, a "vols de préalerte", followed by a later emergence by the majority of those reactivated that season (Bayon, Ayrault & Pichon, 1983).

The midges mate at the emergence site. Following fertilisation the female midges make a host locating flight. The midges fly upwind in response to vapour gradients, towards susceptible crops at a suitable growth stage for oviposition. Directional flight can occur over at least one kilometre, and midges can transfer in large numbers over such a distance. Midges can be carried over longer distances when caught by thermal currents, or stronger winds. Flight usually starts 1 to 2 hours before dusk. The minimum temperature for flight is 15°C and the maximum wind speed 10 km/ha. Flight is inhibited by rainfall. During the day the midges rest in the crop close to ground level, flying up to the heads to lay eggs in the evening. Egg laying can continue until temperatures drop below 11°C and mainly takes place from 75 minutes before to 30 minutes after sunset. The midges then remain resting on the heads until temperatures rise above 15°C the next morning, when they return to the base of the crop.

The adult midges live for 6.6 days on average, laying most eggs on their third day of adult life. The eggs are laid in batches of between 1 and 9 with an average batch size of 2.4 eggs.

Eggs are laid on the glume, and also the lemma or palea of florets where the anthers have not dehisced. Florets are most favoured when about 25 mm clear of the flag leaf during the ear emergence process, but after all ears have passed this growth stage the midges will lay eggs on the least developed available florets. The attack may be centred on the upper or lower portions of earlier or late ears, or evenly distributed in those at mid-ear emergence, depending on the exact stage of growth at the time of peak egg laying. In good conditions each female will lay about 84 eggs on average, but lower estimates have been recorded under less favourable conditions. (Pfeiffer & Brunet 1967; Basedow & Schütte 1973; Oakley 1981; Mukerji, Olfert & Doane 1988; Pivnick & Labbé 1993).

Wheat is probably the most attractive crop for egg laying. In the absence of a wheat crop at a suitable growth stage within range, the midges will fly to crops of rye, triticale or barley or may complete their life cycle in weed grasses. Eggs may also be laid in florets after flowering, but the larvae fail to develop normally. Eggs laid close to flowering may be swept out by emerging anthers and lost (Basedow & Schütte, 1973; Kurppa, 1989a).

The larvae hatch within 4 to 10 days according to prevailing temperatures, taking 10 days or more at a mean daily temperature of 15°C and less than 4 days at 20°C. They crawl to a developing wheat kernel and commence feeding. The larvae feed by exuding enzymes through their cuticles which break down surrounding tissues. The resulting mush is then re-absorbed through the cuticle. During feeding the α-amylase level rises in the attacked grain, but it is not known whether midge larvae produce this enzyme, or produce another enzyme which induces the affected pericarp cells to release greater quantities. The larvae remain at their initial feeding site until fully grown. After 2-3 weeks feeding the larva retains its ecdysal sheath and enters a quiescent phase until triggered by rainfall to crawl to the outside of the ear and drop to the ground. Entry to the soil is eased by wetter conditions, under which reduced mortality occurs (Basedow, 1973; Oakley, 1981; Hinks & Doane, 1988; Mukerji *et al.*, 1988)

Yellow (lemon) wheat blossom midge

The yellow wheat blossom midge follows a similar life cycle, but is less persistent with larvae pupating within 3 years of entering the soil. Adults tend to emerge at a similar time to the orange wheat blossom midge, and are presumed to respond to the same stimuli, although they seem more inclined to pupate in drier soil conditions. The adult midges prefer to lay their eggs at a slightly earlier growth stage, preferring florets exposed by the boot cracking open at emergence and do not lay in florets once they are clear of the boot. The adult midge has a longer ovipositor and lays its eggs into the floret between the lemma and palea. Between 4 and 35 eggs are laid in a batch. The average batch size is 14. When the larvae hatch they feed on the stigma, causing damage which prevents pollination. They then feed on the anthers, which are retained within the floret. After 2-3 weeks feeding, the larvae jump from the floret during wet weather. Some larvae do not form cocoons, but pupate in September to form a partial second generation that feeds on couch grass. (Barnes, 1956; Pfeiffer & Brunet, 1967; Oakley, 1981; Bayon *et al.*, 1983)

Topics requiring further research

The mechanism of attraction of midges to crops is not known, other than that it is due to volatile substances that appear to be identified from at least a kilometre distance from the source. In the 1993 outbreak it was noted that more sheltered fields attracted more midges than more exposed fields, presumably because sheltered situations allow a greater retention of the volatile substance(s) involved creating a better vapour plume. A greater knowledge of this mechanism would allow a better understanding of the considerable difference in attractiveness noted between varieties of wheat, and perhaps the development of attractive traps for use in monitoring midge activity.

Very little is known about the mechanism of feeding, the enzymes released, or their effect on the plant. This lack of knowledge has prevented the formation of an accurate view of the nature of damage and the role of secondary fungal attack and midge induced sprouting in the reduction in quality of damaged grain.

YIELD AND QUALITY EFFECTS OF DAMAGE

Orange wheat blossom midge

The exact growth stage at which larvae start to feed on a kernel, the position of the larvae and the number of larvae feeding on each grain all affect the nature of the direct damage caused.

When one or two larvae feed on the dorsal side of the grain, starting at an early growth stage, the feeding causes a depressed area, which remains readily visible on the harvested grain. The pericarp is loosened around the area of feeding, with the aleurone layer folded or discontinuous in badly damaged grains. Where three or more larvae feed on a grain it is likely to be reduced to a small husk, and where feeding starts before the kernel starts to grow it may prevent any growth at all, giving the appearance of a sterile floret. One larva feeding on the ventral crack side of the grain may not cause an obvious depression but can cause the pericarp to loosen over the whole grain, giving it a whiter appearance. Where larval attack starts at a slightly later growth stage, there may not be a depression, and the only visible damage may be a loosened pericarp in the immediate area of the feeding midge larva. (Pelshenke & Schäfer, 1953; Miller & Halton, 1961; Bühl & Tietze, 1969; Lübke & Wetzel 1985; Dexter, Preston, Cooke, Morgan, Kruger, Kilborn & Elliott, 1987; Helenius & Kurppa, 1989)

Kurppa, (1989b) found differences in the average grain size reduction in Finnish spring wheat according to the date of ear emergence. These figures (see Table 2) illustrate the effect of growth stage at attack on damage. Some varieties were more sensitive to attack, allowing a greater proportion of damaged grain to be sifted out at harvest and reducing effects on grain quality.

Table 2. The average grain size reduction of Finnish spring wheat varieties according to earliness of ear emergence (after Kurppa, 1989b).

	Percentage grain size reduction caused by:		
earliness of ear emergence	**1 larva/ grain**	**2 larvae/ grain**	**3 larvae/ grain**
early	22	53	72
mid	34	53	73
late	48	69	93

At higher levels of attack, where many florets have more than one egg batch laid in or by them, the proportion of grain attacked by three or more larvae increases. Where grain size is reduced by larvae feeding to maturity, the larvae act as alternative sinks for nutrients, leaving no scope for healthy grains to benefit. Where early feeding completely destroys kernels the remaining grain may increase in size to compensate for damage (Helenius & Kurppa, 1989).

In severe outbreaks yield losses can be considerable. Olfert, Mukerji & Doane (1985) estimated an average loss of 30% from 700,000 ha of wheat in Saskatchewan, Canada in 1983.

In addition to the direct damage caused, midge feeding may induce the grain to sprout prematurely in the ear. This seems more likely to occur under damper British conditions than in Canada; and this factor is given greater prominence by Miller & Halton (1961) considering damage to British winter wheat and by Helenius & Kurppa (1989) in Finland than by Dexter *et al.* (1987) working in drier conditions in Canada. Sprouting was a significant feature in the 1993 outbreak in Britain. Much greater effects on Hagberg falling numbers were caused in those crops where midge damage induced more sprouting. In addition to obviously sprouted grains, many grains were observed in 1993 samples where the germ had started to move, but had then stopped development due to the grain drying further. Such partial modification of the grain was associated with large reductions in Hagberg values. Earlier harvesting of midge damaged milling wheat crops should reduce such effects on quality.

Authors are not agreed as to whether sprouting is caused by the enzymes released by the midges, or by a loosening of the pericarp allowing an easier ingress of moisture. Looking at evidence from variety and chemical control experiments it would seem that the greatest midge effects on Hagberg values are seen at sites with lower potential values, later harvests, and in varieties more prone to sprouting. Sprouting generally commences after the midge larvae have left the ear, so is more likely to be due to physical damage than enzyme effects. At sites with marginal Hagberg levels due to other causes, a significant reduction in Hagberg levels can be caused if more than 5% of grain is damaged. Up to 20% damage may be tolerated without samples falling below tolerance levels, where Hagberg levels are otherwise high. The Hagberg falling number is a measure of α-amylase levels. During germination α-amylase is released, so a direct casual link between midge induced sprouting and this effect is probable.

In addition to reduced Hagberg falling numbers grain damage is associated with reduced flour yield, dark flour colour, increased flour ash, weak sticky dough properties, low baking absorption and poor bread quality. Quantities of protein and of α-amylase and proteolytic enzymes are not affected in damaged grain, but in heavily damaged samples a redistribution of protein to surviving grain may result in increased protein levels. The poor baking quality of damaged grain is associated with an unusually low sodium dodecyl sulphate (SDS) sedimentation volume. Severely damaged wheat exhibits inferior gluten protein quality (Dexter *et al.*, 1987). These additional changes in quality appear not to be as well correlated with premature sprouting as reduction in Hagberg values.

Damaged samples also show reduced germination when used as seed. A small survey of English seed lots failing germination tests in 1979 showed that midge damage was a major cause with up to 17% of grains visibly damaged.

Secondary fungal attack frequently follows midge damage under damper British conditions, although it is less important in crops grown on the continents of North America and Europe. Both pathogenic and saprophytic fungi find the midge feeding 'mush' a highly suitable medium for growth. Fungi associated with midge damage include *Septoria nodorum* and *Fusarium* spp. No significant direct effects of secondary fungal attack on quality have been observed, although the very high levels of *Fusarium* on British wheat in 1993 prompted concerns about both the health of seed samples and mycotoxin levels in feed samples (Miller & Halton, 1961; Welso & Freed, 1982).

It has been found that Hagberg values in attacked grain can be improved by gravity separation to remove the prematurely sprouted grains. This process has a lesser effect on the SDS values and baking characteristics, which are not directly linked to sprouting. As with grain damaged by other causes, midge damaged grain tends to disproportionately reduce baking characteristics when included in grists (Dexter *et al.,* 1987; Hook, Salmon, Greenwell & Evers, 1988).

Yellow wheat blossom midge

The yellow wheat blossom midge destroys nearly all attacked grain, so has no known effects on quality. Some partial compensation by increase in healthy grain size may occur at lower levels of attack (Basedow & Schütte, 1973), but at higher levels of attack the relationship between grain loss and yield depression is linear (Lübke & Wetzel, 1985).

NATURAL ENEMIES

Parasitoids

Both species of midge are attacked by parasitoid Calcid wasps that lay their eggs in the midge eggs or larvae in the ear. The eggs remain dormant in the midge larva until it reactivates prior to pupation, when the parasitoid larva develops and consumes the midge larva. The parasitoids then pupate within the midge larva's skin, the body contents being reduced to a small residue at one end by this time.

The orange wheat blossom midge suffers significant attacks from an unnamed *Platygaster* species (Hymenoptera: Platygastridae), *Pirene penetrans* (Hymenoptera: Pteromalidae) and *Euxestonotus error* (Hymenoptera: Platygastridae). An *Inostemma* species (Hymenoptera: Platygastridae) has also been found. The emergence period of the parasitoids lasts for about three weeks. The peak emergence is one to two weeks after the peak midge emergence. The adult parasitoids are mainly active during the day, when the small black wasps can be seen searching for midge eggs into which they lay a single egg. The parasitoids seem not to avoid midge eggs that have already been attacked and multiple parasitism occurs at higher levels of attack. A high mortality of midge eggs was observed in 1978 in the Yorkshire Wolds when midge eggs were very slow to develop and parasitoids were particularly numerous. This may be due to multiple "stinging" of midge eggs by ovipositing parasitoids causing death, as has been reported for other pests. Up to 40% parasitism has been recorded in reactivated populations of orange wheat blossom midge larvae in the UK, and up to 75% in Switzerland, during the decline phase of a midge outbreak (Affolter, 1988; 1989).

Barnes (1956) found parasitoid adults emerging from midge larvae after up to 6 years hibernation with a stronger tendency to develop after one or two winters. Parasitoid larvae hatch and commence feeding before the midge larvae pupate so that the moist conditions described by Basedow & Gillich (1982) for midge pupation to follow reactivation may not apply to parasitoid reactivation, giving the earlier bias noted. This potential unphasing of midge and parasitoid emergence leads to considerable fluctuations in the percentage parasitisation, further confounded by variations in the length of time taken for midge larvae to hatch according to prevailing temperatures, controlling the time for which they are available for parasitoid attack.

The yellow wheat blossom midge is attacked by a different group of parasitoids, a *Piestopleura* species, an *Isostasius* species and *Leptacis tipulae* (all Hymenoptera: Platygastridae) . The two former species follow a similar life cycle to the parasitoids of the orange wheat blossom midge. *Leptacis tipulae* lays its eggs in the midge larvae as they leave the ear, so its importance may have been underestimated in some studies. (Affolter, 1988 & 1989.) Only one parasitised yellow wheat blossom midge larva was found during pupation monitoring in the Yorkshire Wolds outbreak, whilst hundreds of parasitised orange wheat blossom midge larvae were recovered.

Polyphagous predators

Basedow (1973, 1975) found that ground beetles, money spiders and rove beetles, in that order of importance, could cause significant mortality to midge larvae returning to the soil. He found a wide range of mortality according to the rainfall during the larval migration, where 22 mm or more rain fell during this period the larvae were able to enter the soil easily and no mortality occurred. Mortality was lower for the orange than the yellow wheat blossom midge, the latter being more inclined to remain in the ear until a significant rainfall. Cocoons in the soil suffer a lower rate of predation through the winter, but larvae may be more exposed when they return to the soil surface to pupate.

Opportunities for integrated control

The slightly later activity of parasitoids renders them at risk to mis-timed chemical sprays applied to control the adult midges. All the insecticides approved world-wide for midge control are relatively broad spectrum in action and are likely to be toxic to adult parasitoids. Conversely the use of a shorter persistence insecticide at peak midge activity should spare the majority of parasitoids and increase the relative level of parasitism of the residual egg population.

Floate, Elliott, Doane & Gillott (1989) demonstrated a high initial toxicity to ground beetle predators from wheat blossom midge sprays, but found that numbers trapped had returned to pre-spray levels within 3-16 days, so that predation on larvae returning to the soil should not be affected.

CULTURAL CONTROL

The older literature contains various recommendations for cultural control that are summarised and considered by Barnes (1956).

Incoincidence

Sowing crops very early or late has been recommended as a means of avoiding midge flights. The extreme alterations required to guarantee this are quite inappropriate in relation to the unknown, but probably low, threat posed by wheat blossom midges in any one season. Much greater problems from other causes would be created by such an approach.

Selecting varieties and husbandry methods to ensure that ear emergence is completed over a short period has been suggested to reduce the time a crop is exposed to midge damage. This would only be helpful if all wheat crops on a farm could be fine tuned to emerge together, and again is too impractical for adoption.

Physical measures

Deep ploughing was once widely advocated, but as the midges can still reach the soil surface to pupate it was found that a greater depth of cultivation, by exposing larvae to different temperature regimes, simply resulted in an extended period of emergence, tending to increase the span of crops damaged.

Burning the winnowing residue was found to have some effect in the days when wheat was dried in stooks, and many larvae left the ear after cutting. With the advent of the combine harvester the crop was left to stand longer and the majority of midge larvae were safely buried 25 mm or more deep in the soil before straw burning could be carried out (Golightly, 1952, Skuhrava *et al.*, 1983). In Canada concern over the spreading of midge larvae in hay has led to the development of a thermal disinfestation process to kill midge larvae (Soskhansanj & Wood, 1989).

Disturbance of the soil at pupation time was also recommended as a means of destroying pupae, but would entail being able to cultivate the majority of emergence sites on the farm in early May, which would not be feasible even if the measure was proved to be effective.

The effect of set-aside

The lack of cultivation in rotational set-aside land is likely to leave the majority of midge cocoons formed after a following wheat crop close to the surface, subject to greater temperature fluctuations and therefore perhaps more liable to emerge in the season following. Once set-aside is established within a rotation this effect would be neutral, as fewer midges would emerge the following season when set-aside fields were returned to cropping. On balance the introduction of set-aside would be likely to have much less effect than any change in the proportion of wheat grown within the rotation as a result of policy changes.

Recommendations for control on organic farms

As earlier suggestions for cultural control have been found to be largely impractical, the control of wheat blossom midges on organic farms will have to be mainly through the rotation. Preferably no more than a quarter of the farm would be in wheat. However, reducing the amount of wheat on the farm for 1994 or 1995 would simply concentrate the existing midge population on a smaller area, increasing the level of damage. It is therefore suggested that current cropping patterns are maintained until after the outbreak has declined. Where damage levels are excessive, gravity table separation could be used to produce a marketable grain sample.

CHEMICAL CONTROL

Many insecticides have been developed for the control of wheat blossom midges. According to the mode of action of the insecticide they are effective against the adult midge only, or both the adult midges and eggs. No insecticides are effective against larvae once established within the ear.

The timing requirements for sprays are very precise, especially where the insecticide is only effective against the adults.

Recommended products

In the late 1970s three insecticides were given approval for use against wheat blossom midges after a single experiment (see Table 3) and observation of field scale tests by the author in 1977 confirmed efficacy known for some of the test materials from previous work in France (Bouchet & Dagneaud, 1969). The recommendations for chlorpyrifos and fenitrothion still stand. These chemicals are broad spectrum in action killing both adults and eggs and are best applied between GS 55 and 59 where the main target is the orange wheat blossom midge and between GS 51 and 53 for the yellow wheat blossom midge. Due to their high vapour pressure these materials are able to penetrate sufficiently far into the floret to kill eggs and hatching larvae, but are not able to penetrate far enough to kill larvae established on the kernels. This penetrative action allows the chemicals to be effective for up to 4-5 days after the start of oviposition (Elliott, 1988a).

Table 3. The percentage control of orange and yellow wheat blossom midge larvae and yield responses from selected treatments applied to an experiment at Grindale in 1977, all treatments but one applied on 30 June.

Treatment	**Percentage control of**		**Relative yield**
	orange wheat blossom midge	**yellow wheat blossom midge**	
chlorpyrifos	68	61	117
fenitrothion	66	74	120
" on 4 July	96	85	119
triazophos	74	65	114
demeton-S-methyl	63	0	109
dimethoate	48	38	107
pirimicarb	0	42	102
permethrin	54	51	111
SED (39df)	22	28	6

Of note within the 1977 results are the efficacy of the later application of fenitrothion, applied after the majority of eggs had been laid be both species, and the differential efficacy apparent between demeton-S-methyl and pirimicarb in relation to the two species. It was thought that demeton-S-methyl was only effective against the adult midges, giving a better control of the orange wheat blossom midges, which had yet to lay the majority of their eggs at the time of treatment. Pirimicarb was ineffective against the adults but appeared to have some effect on eggs or young larvae as they hatched, and gave some control of the yellow wheat blossom midge which attacked the crop at a slightly earlier growth stage. A similar result with pirimicarb was obtained in a further experiment in 1978.

Subsequent testing in other countries has led to additional registrations for OP and pyrethroid insecticides. Pyrethroids have been found to be effective against the adults only, two or three sprays being required to provide sufficient cover against the orange wheat blossom midge when the adult emergence period is prolonged. More recent registrations of interest for British conditions include dimethoate (Canada), deltamethrin (Finland & China) and lamda-cyhalothrin (France). (Elliott, 1988a & b; Kurppa 1989b; Kurppa & Husberg 1989; Pastre & Roa, 1989; Fougeroux, 1990)

Spray action thresholds

Action thresholds for use in Britain against mixed populations of orange and yellow wheat blossom midges were derived in the 1970s (Oakley, 1981). These assumed that sprays would be applied from the air, incurring contractors' application charges, and were based on a higher ratio of chemical costs to crop yield and value than prevails in the 1990s. The thresholds were set against Basedow & Schütte's (1973) estimate of 30 to 40 eggs laid on average per female. From these estimates, German action thresholds of one yellow wheat blossom midge per ear at the start of ear emergence, or one orange wheat blossom midge per three ears, when the ears were free from the flag leaf on both sides but not yet flowering, had been set. The British action thresholds were provisionally set at one wheat blossom midge per ear in relation to yield effects and one wheat blossom midge per two ears for seed crops to ensure that minimum germination requirements were protected.

Subsequent damage assessment work in Canada, Finland and Sweden in relation to infestations by the orange wheat blossom midge alone has led to the establishment of lower action thresholds of one midge per 3 ears, in relation to yield effects, and one midge per 6-7 ears to protect quality of milling wheats. This lower threshold is most appropriate to varieties and conditions leading to marginal Hagberg values. (Kurppa & Husberg, 1989; Larsson, 1992). Pivnick and Labbé (1993) have estimated that on average, under good conditions, 84 eggs are laid by each female orange wheat blossom midge. A recalculation of the action thresholds using this figure, and assuming a £6/ha spray cost plus £6.25/ha for ground application by the farmer (Nix, 1993), gives a revised action threshold for feed wheats of one midge per 3 ears. A minimum figure for milling wheats is harder to fix as the effect on quality is very variable in relation to effects on quality due to other causal factors. If a target maximum damage level in cleaned grain of 5% is set to take account of poor harvest conditions leading to marginal Hagberg values an action threshold of one midge per 10 ears would be required. A level of one midge per 6 ears would seem appropriate for most situations where satisfactory Hagberg values were anticipated.

In France no threshold levels are set for field use and sprays are recommended if any ovipositing midges are seen between ear emergence and the end of flowering, provided that temperatures at dusk are above 15°C and the air is calm (Fougeroux, 1990). The addition of similar weather parameters to a British decision making system could be considered provided that stable, unsuitable, weather patterns were likely to prevail for at least a week. At experimental sites in France, water traps are used to monitor midge activity and time treatment application. A threshold level of 80 midges in total per day in 10 traps is set. The protocol requires daily inspection of traps once the first midges are caught (Barr & Lescar, 1985).

The midges are most readily seen and identified in the hour before dusk when they move up to lay eggs in the ears. Assessments can also be made during the day by parting the crop, when the disturbance induces a short flight by the midges and they can be counted. These counts can then be related to the number of ears parted. As the males are much shorter lived no adjustment should be made to the number to take account of a possible component of male midges in a disturbance based count (Oakley, 1981).

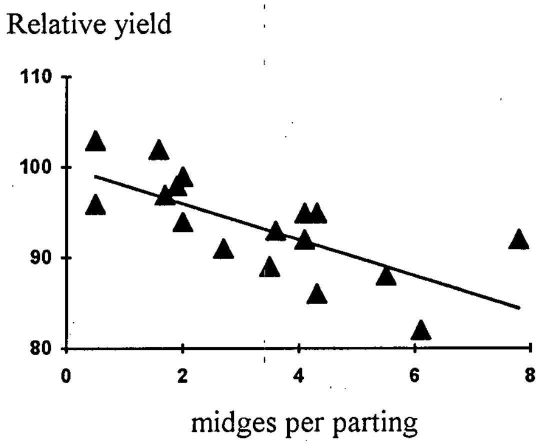

Figure 3. Relationship between relative yield and midges per parting at Grindale 1977.

Yield = 100 - (1.98 x midges)
accounts for 52 % of variance

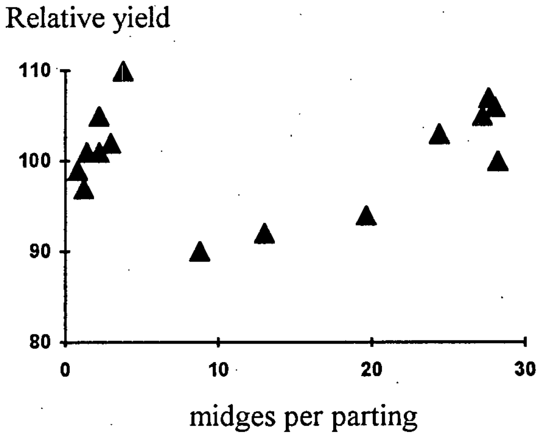

Figure 4. Relationship between relative yield and midges per parting at High Mowthorpe 1978.

No significant regression

The dangers of not taking the weather into account are shown by the strong correlation between surviving numbers of adult midges in sprayed plots and yield effects in 1977, compared to the lack of a relationship in 1978 (Figures 3 & 4). However the difference in weather between these two sites was restricted to one warmer interval occurring, against the run of prevailing weather, in 1977, compared to none in 1978, as explained under the development of forecasting systems (pages 27-29). The unsuitable weather in 1978 after midge emergence resulting in very little subsequent damage. Under changeable weather patterns, as tend to prevail in Britain, a fail-safe approach of spraying whenever threshold levels are exceeded is likely to be favoured. Counts of midges ovipositing on the ears help to overcome the problem, being a stage closer to crop damage, but will need to be repeated whenever suitable nights occur during the susceptible stages to take account of further migrations of midges to crops.

Timing requirements

Sprays of OP insecticides need to be applied within 4-5 days of the start of oviposition for full efficacy. Should pyrethroids become approved for use in Britain they will need to be applied within the first 2 days of midges arriving in the crop. The short available spray windows make it imperative that an effective warning system is in place so that farmers are able to obtain supplies of chemicals in advance, and assess crops at the correct time.

Late application of sprays is not only likely to result in poor control, but may kill many parasitoids and polyphagous predators resulting in increased risks in following seasons.

VARIETAL SUSCEPTIBILITY

Very large differences in levels of attack between varieties have frequently been reported in varietal comparison experiments. The main cause of this variation is thought to be due to the degree of coincidence between the susceptible growth stages over the whole span of ear emergence for a variety and the flight of the midges (Barnes, Miller & Arnold, 1959; Barnes & Arnold, 1960; Basedow & Schütte, 1974; Basedow & Gillich, 1982; Helenius & Kurppa, 1989; Kurppa, 1989b). Within varietal comparison experiments the small plot size used gives the midges a choice as to which variety to lay their eggs on, which is not available on a field scale. Varieties are also likely to receive disproportionate attention if their heading date is different to the majority and different to the crop in the surrounding area, concentrating the available midges in a small area. In field crops, even if the majority of ears have passed the susceptible stage, suitable sites may still be available in late secondary tillers. A migration to other crops is only likely if the midges fly before any ears have emerged in the field in question and other fields are at a susceptible stage nearby.

In addition to coincidence factors, Kurppa (1989b) considered that the tightness of the ear (in terms of a reduced gap between lemma and palea) could provide a level of resistance. She also identified hypersensitive varieties of Finnish spring wheat where damaged grains tended to be lost completely. Hypersensitivity was thought to be a positive characteristic, preserving the quality of the harvested sample, and allowing the potential for healthy grains to compensate by increased size. Varieties with a larger number of small grains are also likely to suffer a lower attack relative to varieties with fewer large grains.

Larger differences in coincidence do affect levels of damage on a field scale, and in any one season the differences between ear emergence of winter and spring sown wheat crops are likely to result in different levels of attack on the two crops. The span of ear emergence dates between an early heading wheat variety such as Soissons and later sown spring wheats is large, presenting at least some susceptible crops in an area whenever the main midge activity occurs.

The grain size reduction following attack is a function of the exact growth stage when feeding commenced as well as the number of larvae present and perhaps the sensitivity of the variety. Varieties differ not just in the number of grain sites attacked at any one site, but also in the proportion of attacked grains lost during harvesting and any subsequent cleaning (Kurppa, 1989b). A very different ranking of varieties in relation to susceptibility can therefore be produced depending on whether varieties are assessed on whole ear samples, grain taken directly from the combine, or grain subjected to further cleaning processes.

1993 Varietal comparison experiments

Samples of grain as harvested have been examined from 13 NIAB (Fenwick, pers. comm.) and 16 ADAS experimental sites in 1993 (Table 4). The sites were located in England, south of the river Tees, and in south Wales. Grain from all sites was found to be damaged by orange wheat blossom midge larvae, with at least 5% of the grain of some varieties damaged at all but one site and at least 10% of grain damaged at 24 sites. These levels are thought to be the minimum at which quality and yield estimates respectively may have been affected by midge damage. The ranking of varieties was not consistent across all sites with some obvious differences in coincidence pattern due to soil type, elevation and latitude.

Table 4. The average visible grain damage due to orange wheat blossom midge larvae found on harvested grain samples in 29 varietal comparison experiments in the affected areas of England and Wales in 1993.

Variety	**% grain damage relative to the mean of control varieties**			**Number of sites where grown**
	Mean	**Maximum**	**Minimum**	
Control varieties				
Beaver	120	168	74	29
Haven	153	201	57	29
Hussar	70	98	38	29
Mercia	68	150	16	29
Riband	88	155	8	29
Other varieties				
Admiral	102	254	33	29
Andante	80	238	19	29
Apollo	108	148	15	16
Brigadier	91	152	21	29
Buster	104	253	42	29
Cadenza	92	164	25	29
Estica	114	218	29	29
Flame	83	139	34	29
Genesis	121	190	8	29
Hereward	93	162	36	29
Hornet	152	344	97	3
Hunter	112	240	46	29
Lynx	165	397	71	29
Profet	79	142	26	29
Rialto	142	888	38	29
Ritmo	139	178	14	16
Sideral	124	293	46	11
Soissons	129	346	28	16
Spark	75	135	36	29
Torfrida	80	229	32	15
Wasp	107	127	18	16
Zodiak	110	210	26	29

Apparent differences in susceptibility may be due to either a greater proportion of damaged grain being lost during harvesting, or, higher level of attack. Care should also be taken in making comparisons between varieties due to the wide range of apparent susceptibility found, especially where the varieties were not represented at all sites. Loss of grain sites is more likely on the later heading varieties that would have been attacked at a relatively later growth stage. Monitoring of a few sites before harvest confirmed that later varieties had lost more grain sites, but also showed that larger differences in damage levels in harvested grain samples did still indicate the general trend in susceptibility. Further cleaning of the grain after harvest altered the ranking considerably and, together with differences in harvest dates and conditions, resulted in a poor correlation between Hagberg falling number assessments and assessment of midge damage on harvested samples.

Certain varieties at some sites may have suffered physiological damage due to temperature fluctuations, which could have had some direct effect on yield, and also increased the length of the pre-flowering period rendering the varieties more susceptible to wheat blossom midge damage (W. Angus, pers. comm.). This possibility further increases the caution that should be exercised in interpreting the results and in assessing any distortion in yield results caused by direct midge damage. What can be stated confidently is that at those sites with more than 10% of grain damaged on some varieties, yield reductions of more than 2% due to the direct effects of midge larval feeding will have occurred, significantly distorting the results of the experiment.

Between the control varieties there appeared to be a real difference in susceptibility between Haven and Beaver, which were generally more susceptible, and Hussar that was consistently less susceptible. The results for Mercia and Riband were more variable depending on the coincidence pattern at particular sites. Similarly large levels of variation were found among the other varieties with especially large variations found in Lynx, Rialto and Soissons. At some sites Lynx and Rialto suffered much higher levels of damage than other varieties, and the yield from these varieties was severely depressed, in relation to the rest of the varieties under test.

The variety Soissons was initially reported as being less affected on a field scale, being a week ahead of other varieties in growth stage. In the South the earlier growth stage resulted in less loss of grain sites, and less shrivelling of attacked grain in response to attack, but field scale crops generally had similar levels of damaged grains to other crops. The majority of damaged grains were attacked by initially overlooked larvae feeding mainly on the ventral crack side of the grain. A high proportion of these damaged grains pre-sprouted, and being normal sized were carried through into the harvested sample, severely reducing Hagberg values. In the North the earlier growth stage tended to lead to higher levels of damage than in other varieties.

Apart from Hussar no other varieties were found which were consistently less susceptible than others. The variation found suggests that, given a slightly different timing in midge emergence relative to crop growth stages in a future year, a totally different pattern of relative susceptibilities would be likely. On the basis of currently available evidence, there appears to be no significant difference between the wheat varieties available in the UK in terms of their inherent susceptibility to the orange wheat blossom midge.

1993 Cereals Quality Survey

The results for the most frequently represented varieties within the HGCA Cereals Quality Survey (Table 5) show a measure of agreement with the varietal comparison experiment, confirming the significance of coincidence patterns on a field scale. Beaver and Haven were confirmed as having been generally favoured by the midges, with Hussar less favoured. Differences that did emerge between the survey results and experimental sites were mainly due to the proportion of the samples for a variety grown in the more heavily attacked areas, and the tendency for the variety to be grown as either a first or second wheat. The survey samples from Scotland were nearly all from crops of Riband wheat, averaging 1.7 % of grains damaged.

Table 5. The average visible grain damage due to orange wheat blossom midge larvae in the HGCA Cereals Quality Survey samples for 1993 and relative score for the varieties in relation to the mean for the control varieties as in Table 4.

	HGCA Region				England & Wales
Variety	**North**	**Midlands**	**East**	**South West**	**Relative damage**
Beaver	2.7	6.7	16.6	4.6	134
Haven	6.8	8.0	17.5	5.0	126
Hussar	3.5	3.5	4.0	-	51
Mercia	1.7	3.6	10.4	2.1	84
Riband	3.9	5.4	11.9	5.9	105
Admiral	3.8	4.3	8.8	-	86
Hereward	2.0	4.3	7.8	5.7	84
Hunter	1.0	3.3	9.1	4.6	91
Soissons	3.9	5.5	7.0	4.7	89

Recomendations for future varietal comparison experiments

Wheat blossom midge damage caused a significant distortion to the yield results from the 1993 varietal comparison experiments. Due to the overriding effect of coincidence patterns, no useful information on the susceptibility of the varieties to midge damage was obtained. It is recommended that in future wheat blossom midges should be controlled on experimental sites whenever a significant risk of damage is identified. It is recommended that all the 1994 varietal comparison experiments are sprayed with an appropriate insecticide if adult midges are found to be infesting the crop during the susceptible growth stages of any of the varieties under test. True differences in varietal susceptibility could only be assessed within specially designed experiments including a range of sowing dates to produce different ear emergence timings for each cultivar, a close monitoring of midge activity during susceptible growth stages, and with midge damage assessed in the ear and in cleaned samples of grain prior to quality assessment.

DEVELOPMENT OF FORECASTING SYSTEMS

A method of sequential soil sampling to monitor pupation was developed by Golightly, (1952). This method was further developed by the author in the 1970s. Basedow (1980) considered that the only reliable prediction of midge damage could be made from soil samples taken in April, by which time overwinter survival, parasitism and reactivation levels can be measured. Whilst a positive forecast of damage levels could not be made, a negative prognosis was possible. Significant damage could not occur if less than 6 million orange wheat blossom midge, or 13 million lemon wheat blossom midge larvae, were found per hectare. Soil sampling methods have also been tested in Canada (Doane, Olfert & Mukerji, 1987).

Pheromone based systems have not been developed for either species, but water traps are used to monitor adult activity at experimental sites in France, where a threshold level of 80 midges caught in total in 10 traps within a day is used to trigger spray application (Barr & Lescar, 1985). Qi and Guo (1987) correlated incidence with rainfall and windy days at the critical stages.

Basedow & Gillich (1982) attempted to forecast incidence but found that variations in parasitism, percentage pupation and coincidence of flight prevented the development of a viable forecast over a wide area. Bayon *et al.* (1983) found that suction traps could be used to monitor midge flight. However, because such flights were simultaneous with arrival in the field, this would not give prior warning on a useful time scale. Without other information it is impossible to tell whether a particular catch was the precursor of a larger flight, or the main movement for that season.

Case study I - the 1970s Yorkshire Wolds outbreak

Working in the Yorkshire Wolds in the 1970s the author found that pupation monitoring could provide one to two weeks warning of emergence. Soil samples taken during the winter allowed an estimate of the probability of a significant number of midges emerging during the critical growth stages and counts were reported to farmers in one of five categories ranging between a zero and a greater than 87.5% probability level. Where a significant risk was identified from winter sampling farmers were warned to obtain supplies of materials, and were given advanced warning, based on pupation sampling, of when to assess crops to determine which fields needed spraying and when to spray. Fields were then checked for midge levels, if passing through the susceptible growth stages during the period of flight, and sprays applied where threshold levels were exceeded. Within the limited geographic area involved this system proved to be accurate and enabled extremely effective spray application. A retrospective analysis of the causes of the Yorkshire Wolds outbreak, in relation to the monitoring done then and subsequent studies on midge biology, allows a further analysis of the causes of the more widespread outbreak in 1993, and possible parameters to utilise in a forecasting scheme.

Temperature and rainfall records were taken at the ADAS High Mowthorpe Research Centre in the Yorkshire Wolds. Pupation samples were taken with a trowel to 100 mm depth, so as to facilitate monitoring of the arrival of reactivated larvae in the upper soil profile. Midge larvae and pupae were extracted from bulked samples by a wet sieving and floatation process within 4 hours of collection and the float examined under a lower power microscope. Separate records were made of healthy larvae, pupae and parasitised larvae of both species of midge.

In 1975 (Fig. 5) a cool, dry period of weather in May ended with a significant rain and snow fall, followed by a rapid rise in temperatures that then remained above 15°C, in terms of both soil temperatures at 10 cm and mean daily air temperature, for the ear emergence period of all wheat crops. The same situation prevailed nationally, and is likely to have led to a significant increase in numbers of larvae in the soil. Reports of severe damage were received from two farms in the Yorkshire Wolds where continuous wheat cropping was being practised. The damage was first noticed during inspection for seed certification and the samples from both farms failed germination tests.

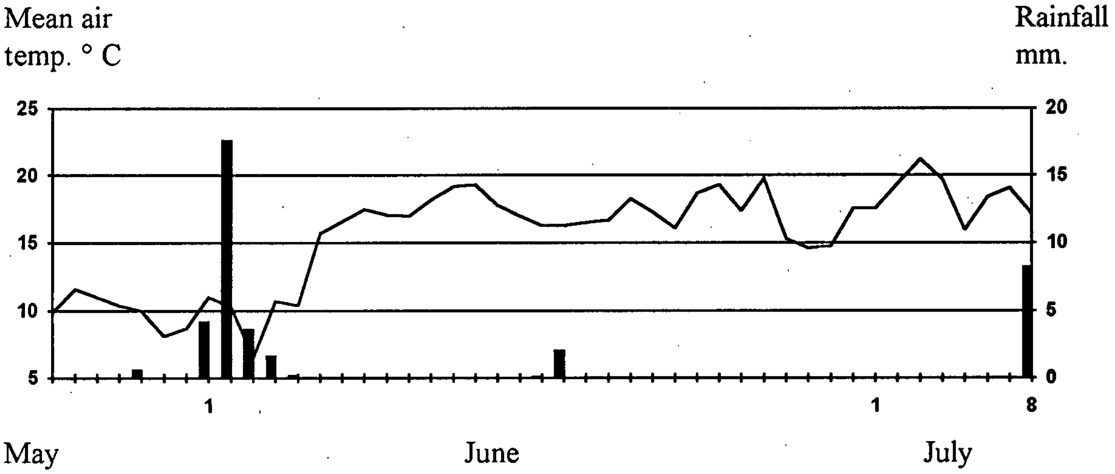

Figure 5. Mean air temperature and rainfall at ADAS High Mowthorpe in 1975.

In 1976 (Fig. 6) soil temperatures again rose above critical levels in early June, but air temperatures following any responding emergence were unfavourable until later June when rising temperatures caused a mass emergence of midges. This was followed by ideal conditions for oviposition and egg development. Similar conditions again prevailed across England. Apart from higher northern sites, such as the Yorkshire Wolds, winter wheat crops had passed the susceptible stages by this time. Damage levels in the Yorkshire Wolds continued to increase with significant damage found at three further farms.

In 1977 (Fig. 7) fluctuating soil temperatures in May gave a strong stimulus for reactivation and a wet period between 3 and 13 June ensured a high degree of pupation. In a field monitored at Rudston, 96% of larvae either pupated or were killed by parasitoids (Fig. 8). A few midges emerged around 9 June before ears were available for oviposition on winter wheat and when temperatures were unsuitable. The main emergence of midges occurred between 22 June and 4 July in response to rising temperatures. The evening of 24 June remained warmer than suggested by the mean temperature and was suitable for migration to crops. A warm spell starting on 3 July then induced oviposition.

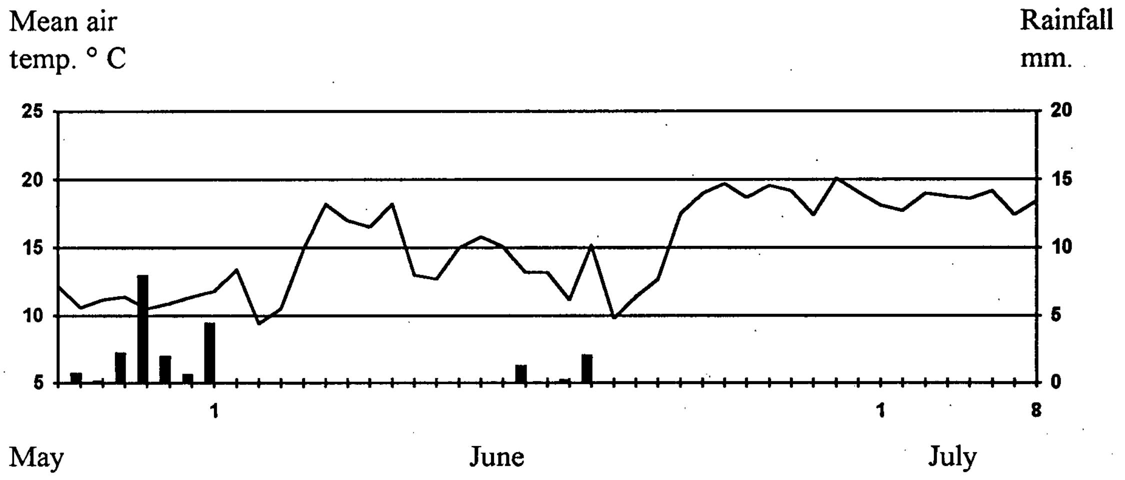

Figure 6. Mean air temperature and rainfall at ADAS High Mowthorpe in 1976.

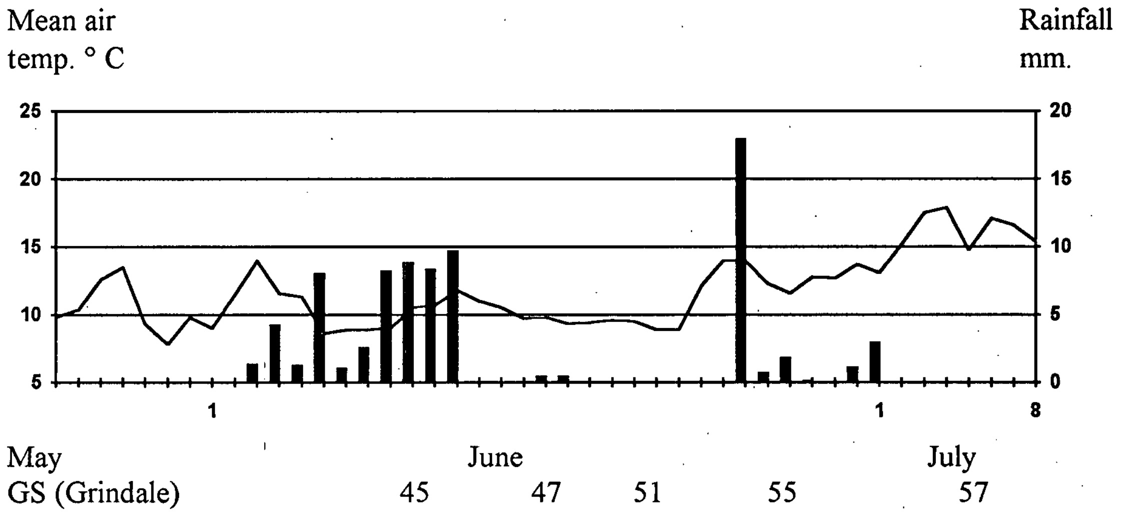

Figure 7. Mean air temperature and rainfall at ADAS High Mowthorpe in 1977.

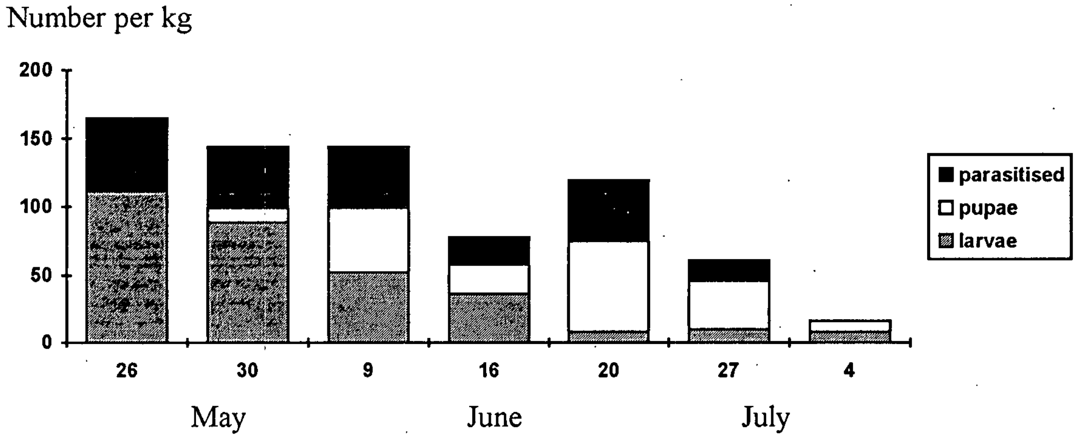

Figure 8. Pupation monitoring of orange wheat blossom midge at Rudston in 1977

A similar timing for pupation and emergence of both the orange and the yellow wheat blossom midges was found at nearby Grindale (Figures 9 & 10). The growth stages of the crop within which the chemical control experiment was situated at Grindale (Fig 7) show that this crop was at a suitable stage for both the orange and yellow wheat blossom midges at this time, and a significant attack due to both species developed. This short favourable period was sufficient to cause a significant increase in the area affected in the Yorkshire Wolds with at least 62 crops known to have been affected to a significant degree. Growth stages of winter wheat crops in the Yorkshire Wolds were generally closer to early ear emergence at this time and the population showed a marked shift towards the yellow wheat blossom midge.

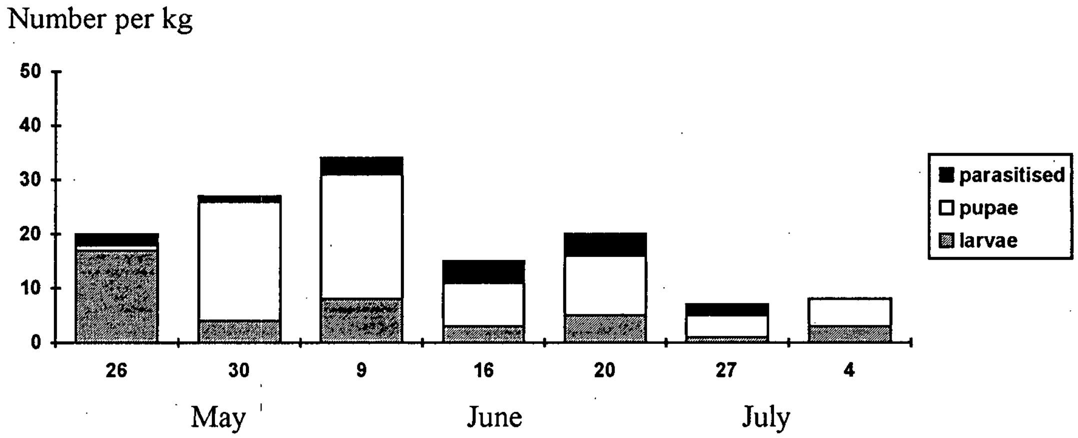

Figure 9. Pupation monitoring of orange wheat blossom midge at Grindale in 1977

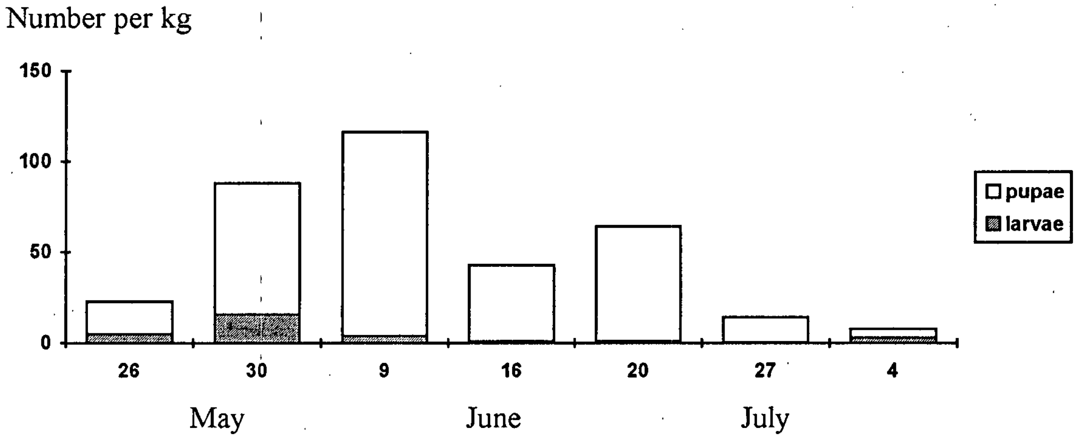

Figure 10. Pupation monitoring of yellow wheat blossom midge at Grindale in 1977

In 1978 (Fig. 11) soil temperatures were very high in May and a high proportion of larvae were reactivated. Parasitoid larvae developed in a considerable proportion of midge larvae (Fig. 12), fully accounting for the proportion of larvae extracted from soil samples in the winter found to contain parasitoid eggs (identified following smearing the larvae on a microscope slide and staining with cotton blue in lactophenol). Soil conditions were very dry and a relatively low proportion of reactivated larvae pupated. Adult midges emerged between 10 and 23 June, but conditions were unsuitable for oviposition and few eggs were laid. A water trap operated at the monitoring site caught only 14 orange and 78 yellow midges between 10 June and 3 July, but caught 4093 parasitoid adults between 23 June and 3 July. A very high mortality of midge eggs was observed, with 90% of eggs lost between 19 June and 3 July. This was seen to have been partly due to the anthers emerging from the floret after flowering sweeping away eggs that had been too slow to develop in the cool weather. Some mortality may also have resulted from multiple stinging by ovipositing parasitoids. Many fields were sprayed in the Yorkshire Wolds, in response to numbers of adult midges seen being above threshold levels. Had the length of the cool period been accurately predicted, the insecticide sprays applied to 2000 ha that year could have been omitted.

The remaining larvae overwintered to pupate in 1979, when few parasitoids were seen. Adult thresholds were exceeded in over 1000 ha of wheat, which were sprayed. Significant populations developed in unsprayed fields in favourable weather conditions. 1979 appeared to be a favourable year for orange wheat blossom midge over a wider area, with 10% of English wheat seed affected to the degree that germination was reduced. In 1980 midge emergence was delayed until after the wheat crops had passed the susceptible stages. Higher levels of infestation were found in spring barley than in winter wheat. Monitoring of the Yorkshire Wolds levels ceased in 1980, but sprays have been applied occasionally since, and sprays were applied in 1993 in response to threshold numbers of midges being seen on a previously infested farm.

It would appear that on farms growing continuous wheat there is the potential for accumulated soil populations to be high enough to cause damage in the first highly favourable season; but that for the majority of farms two favourable years in close succession are needed, one to build up populations to a potentially damaging level followed by a second in which the damage occurs. A year of low emergence, such as 1978, may reduce the parasitoid population and allow a more rapid build up of wheat blossom midge levels in the following year.

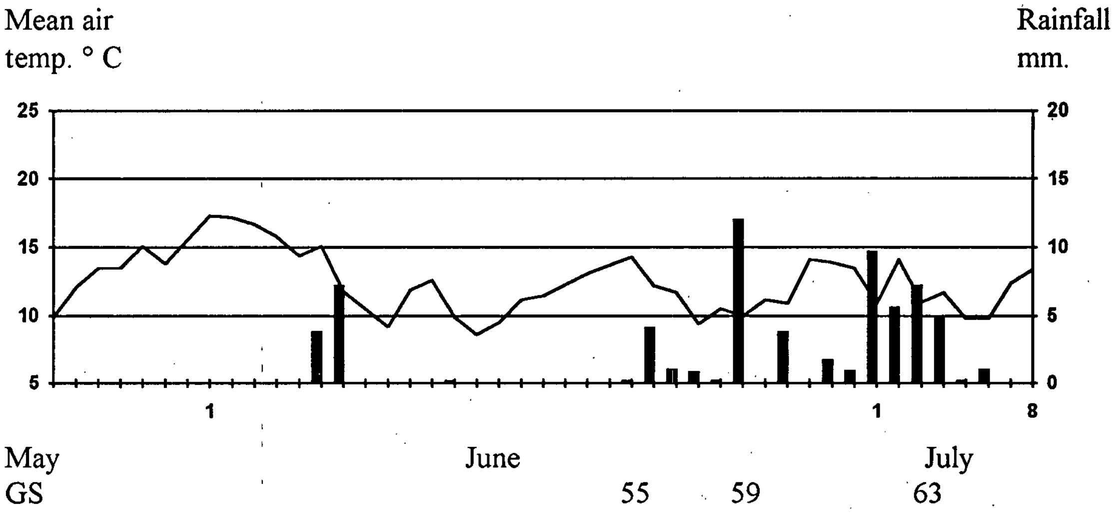

Figure 11. Mean air temperature and rainfall at ADAS High Mowthorpe in 1978.

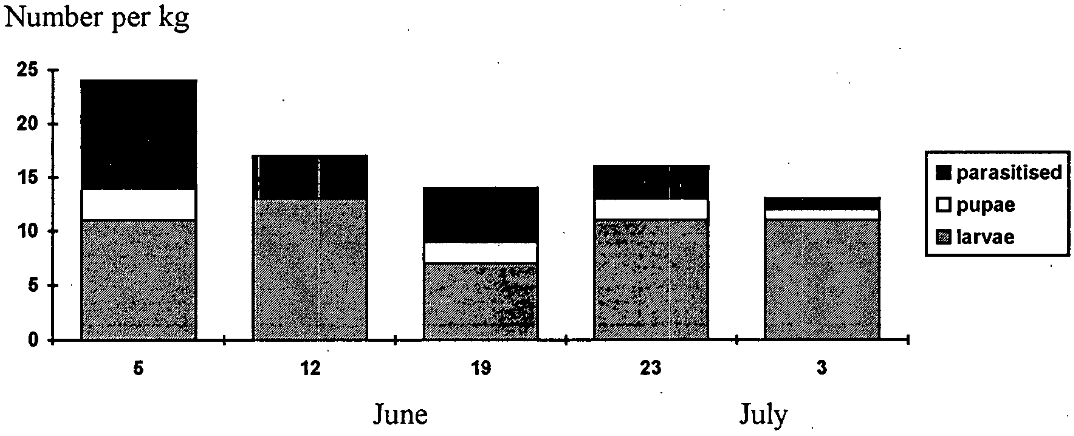

Figure 12. Pupation monitoring of orange wheat blossom midge at High Mowthorpe in 1978

Case study II - causes of the 1993 outbreak

Temperature and rainfall data for the ADAS Boxworth Research Centre near Cambridge have been assessed. In 1991 (Fig. 13) temperatures were suitable for reactivation in May but then remained unsuitable for wheat blossom midges throughout the ear emergence period in early June, which may have led to a wastage of parasitoids as occurred in 1978.

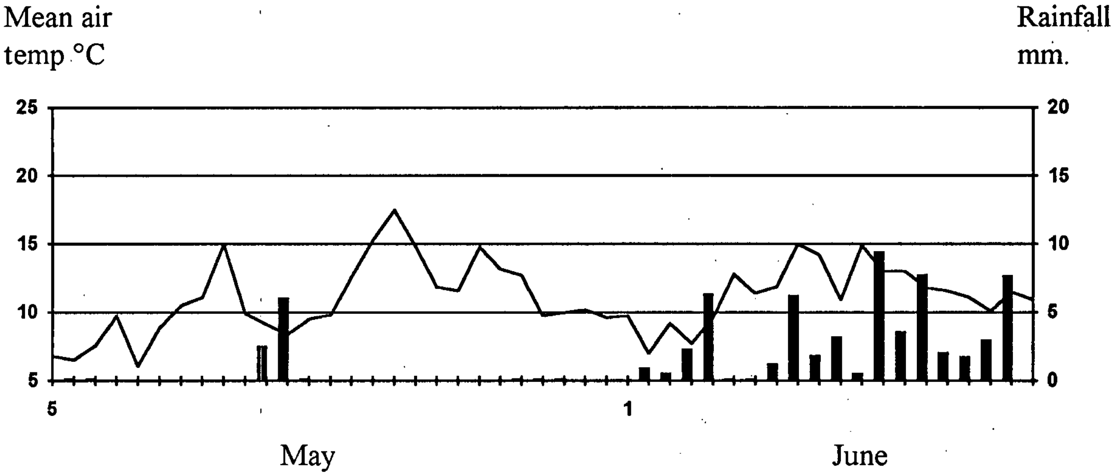

Figure 13. Mean air temperatures and rainfall at ADAS Boxworth in 1991.

In 1992 (Fig. 14) temperature fluctuations were highly conducive to larval reactivation in May, with sufficient rainfall in late May and early June to induce a high rate of pupation. Temperatures then remained favourable throughout the ear emergence period for the majority of winter wheat crops. This weather pattern prevailed across a wide area and is likely to have caused a general increase in wheat blossom midge levels and a large increase in larval numbers overwintering in the soil. A retrospective analysis of a sample of Riband wheat harvested from the ADAS Bridgets Research Centre in Hampshire in 1992 showed 6% of grains damaged by orange wheat blossom midge.

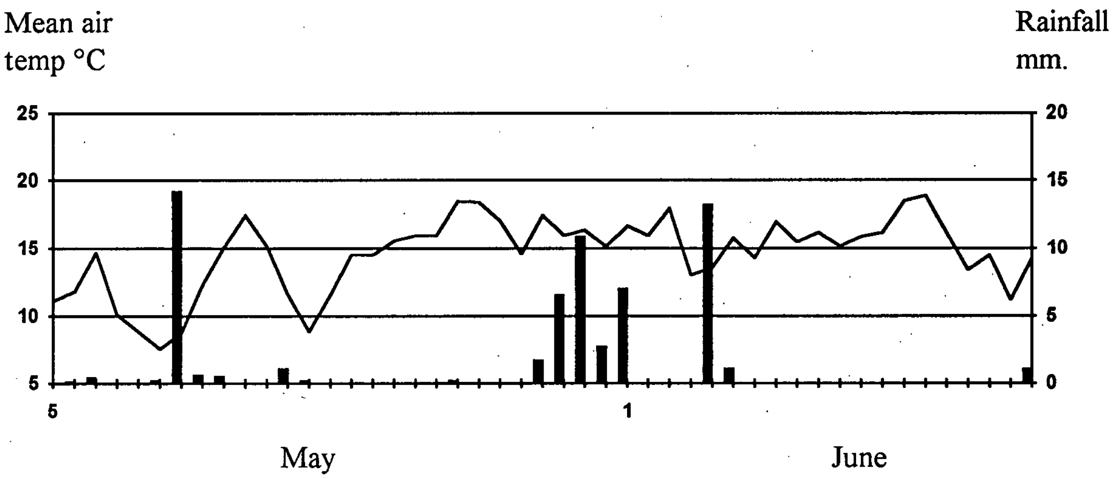

Figure 14. Mean air temperatures and rainfall at ADAS Boxworth in 1992.

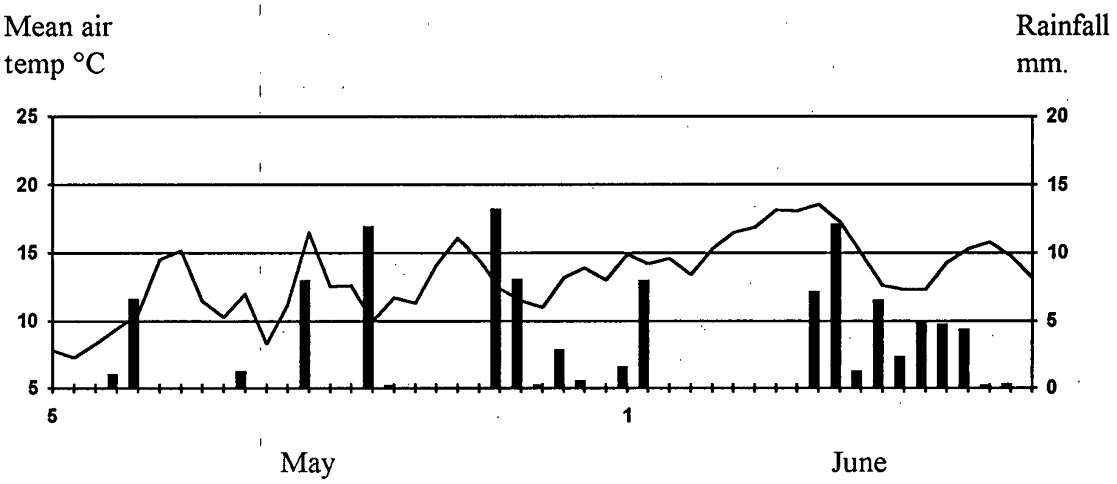

Figure 15. Mean air temperatures and rainfall at ADAS Boxworth in 1993.

In 1993 (Fig. 15) three "reactivation events" of significant rainfall followed by rapid increases in temperature occurred in May. Soil moisture levels remained suitable for pupation throughout the month. This was followed by a rapid rise in temperatures from 30 May to induce a mass emergence on about 4 June, followed by a period of highly favourable weather until 11 June. This weather pattern again prevailed across a wide area. The favourable period coincided with the ear emergence period of the majority of winter wheat crops. At the ADAS Bridgets Research Centre (Fig. 16) adult orange wheat blossom midges were first noted on sticky traps operated in a crop of Beaver wheat in the week ending 5 June. The ear emergence period was closely correlated to the period of midge activity and the crop developed a severe orange wheat blossom midge infestation.

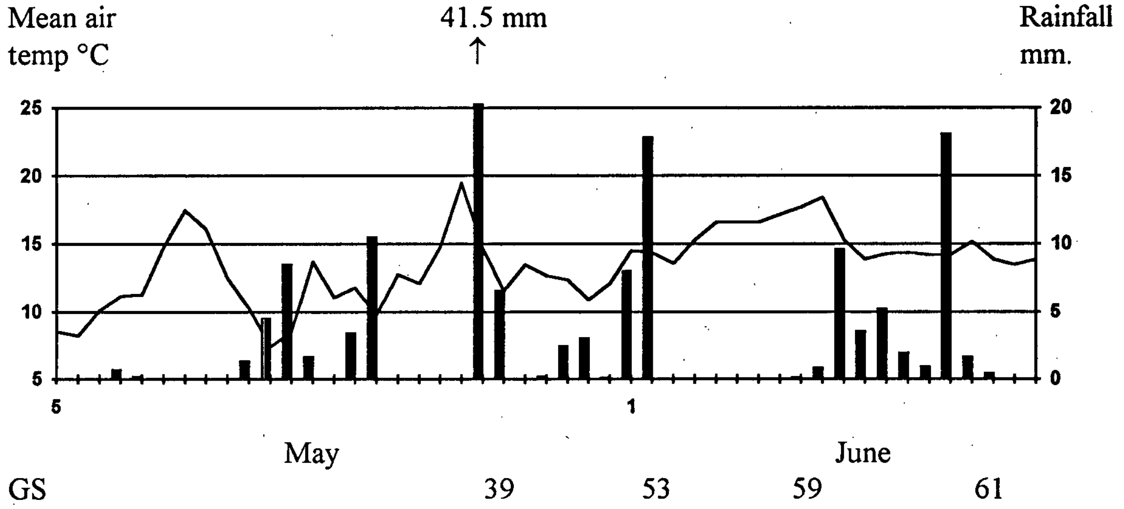

Figure 16. Mean air temperatures and rainfall at ADAS Bridgets in 1993.

In the majority of crops at Bridgets around 33% of grain sites were damaged by midge larvae, 15% of grain sites, were lost due to damage and 21% of harvested grain were visibly damaged by midge larvae (a 3.5 fold increase on 1992). Soil sampling in the autumn gave an average soil population of 42 million larvae per hectare. At a heavily infested farm in Wiltshire, where 70% of grain sites were damaged, autumn soil sampling estimated a population of 364 million larvae per hectare.

<u>Forecasting damage and spray need for 1994</u>

Given the high soil populations on heavily infested farms significant numbers of midges are almost certain to emerge in 1994. The probability that sufficient will fly within the ear emergence period to exceed spray thresholds is greater than 95%. The damage caused by these midges will depend on the prevailing weather pattern during the ear emergence period. If soil conditions in May are too dry for a high level of pupation the majority of larvae will go forward to pose a similar threat in 1995. At the site with the highest population level recorded in the autumn of 1993 where 364 million larvae per hectare were found, an average pupation of half the larvae per year could see threshold numbers of 6 million or more midges emerging from the soil each year until 1998.

If weather patterns in 1994 are again favourable during the ear emergence period, the majority of wheat crops in England and Wales may exceed the revised threshold levels and require spraying. A sudden demand for large quantities of insecticides over a very short period is likely to stretch both available stocks and delivery systems. These sprays will need to be applied within 5 days of midge population in affected fields exceeding threshold levels. Routine prophylactic sprays applied between GS 57 and 59, whether or not midges are found, can not be recommended as there is no guarantee that this timing would be effective in all cases. Mis-timed and unnecessary sprays could increase levels of damage in subsequent years by reducing the levels of natural control agents.

Conditions favouring the development of an orange wheat blossom midge attack can be summarised as:

winter:	vernalisation	a minimum of 70 days below a daily mean temperature of 10°C
	diapause	ideally 112 days or more below 10°C
spring:	pupation	220 day degrees above 3°C, ideally by the end of April
May:	reactivation	a rapid rise in soil temperatures at 100 mm to above 13°C
	pupation	sufficient rainfall to keep the surface 25 mm layer wet
June:	emergence	rainfall followed by a rise in daily mean air temperature to above 15°C
	flight & oviposition	temperatures above 15°C at dusk with wind speeds below 11 km/hour
	egg development	daily mean temperatures remaining above 15°C for at least a week

The following courses of action are recommended:

1. Where farmers are unsure of the levels of wheat blossom midge infestation on their farm, soil sampling should be used to establish the probability of risk.

2. Where soil populations are below 6 million larvae/ha, significant levels of damage are unlikely. Where an average of more than 12 million larvae/ha are found, the probability of damage to some crops is greater than 50%, and stocks of a recommended insecticide sufficient to cover at least half the wheat area should be obtained. If more than 25 million larvae/ha are found, sufficient insecticide to spray all the wheat area should be purchased.

3. Pupation monitoring should be carried out at a range of sites to provide information of the general level and timing of pupation. Such a system should provide at least a week's warning of hatch. Meteorological information should be used to extend the information derived from monitored sites on a wider basis.

4. Farmers, or their consultants, should inspect crops on receipt of warnings of hatch and apply sprays within 5 days if more than one midge per 3 ears in feed crops or one midge per 6 ears in milling or seed crops are found.

5. Sprays need not be applied if cool wet weather prevents application for a week or more after the threshold level is found, unless significant numbers of midges are still present and the crop has still not reached the flowering stage.

6. Where significant damage occurs to milling crops the crop should be harvested early to protect Hagberg values.

CONCLUSIONS AND RECOMMENDATIONS

Main conclusions

1. The high levels of midge larvae in the soil in the autumn of 1993 represent a threat to wheat crops for up to 5 further years, even if not reinforced during this period.

2. The short available spray window makes effective control over the potentially very large area involved impossible without forward planning.

3. Farms with a known, or detected, high risk of midge attack should obtain sufficient stocks of insecticide to meet the risk before the susceptible ear emergence stage is reached.

4. A representative pupation monitoring scheme would aid efficient crop walking and decision making.

5. Only correctly targetted insecticide sprays are likely to be cost effective. Fields should neither be sprayed in the absence of threshold levels of midges nor at the incorrect timing. Such treatment is likely be ineffective and could damage both the midge parasitoids and other non-target organisms.

6. Due to the broad spectrum nature of the approved chemicals, a conservation headland should be left wherever possible, and especially by field margins of value to wildlife and game.

7. Early harvesting of midge damaged milling wheat crops is advised to protect Hagberg falling number values.

8. No reliable degree of resistance is available within the currently recommended varieties of winter wheat. Large differences are apparent at particular experimental sites, but these are due to patterns of coincidence that were not repeated reliably across the country, and differences between varieties were less when grown in separate fields.

9. Due to the unreliable evidence of varietal susceptibilities obtained from varietal comparison experiments, and the distortion of results caused be differential levels of damage, sites should be sprayed in future to control midge attack where a risk of damage is identified.

Recommendations for further study

The following areas have been identified as meriting further study:

1. The mechanism of attraction of midges to susceptible crops should be established, so as to improve the understanding of varietal differences in attractiveness, and to develop an improved monitoring system.

2. The method of feeding and its effect on the grain should be established to allow a better understanding of the nature of the direct damage caused and the significance of premature sprouting and secondary fungi in enhancing this damage.

3. Chemical and cultural treatments capable of enhancing the control provided by parasitoids and predators should be developed as an alternative to the currently approved broad spectrum OP materials.

4. A forecasting system based on soil sampling in conjunction with temperature and rainfall based models should be developed to provide early warning of hatch each year and of possible outbreaks. Pheromone systems would aid detection of hatch on infested sites, but could not be developed in time to assist with the current outbreak.

The persistent nature of orange wheat blossom midge infestations, and the higher profile of the pest following the 1993 outbreak, are likely to lead to a significant ongoing concern and insecticide usage. The development of a rational approach to controlling the pest should be given a high priority.

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APPENDIX

Analysis of wheat grain samples from the HGCA Cereals Quality Survey for visible signs of damage due to the orange wheat blossom midge

Abstract

The degree of visible damage due to feeding by orange wheat blossom midge larvae was determined on 392 samples selected to be representative of the 1993 winter and spring wheat crops in England, Scotland and Wales. All but two of the samples were damaged to some extent with more than 5% of grains damaged in 50% of the samples and more than 10% of grain damaged in 21% of the samples. The highest levels of damage were found in eastern and southern England, but damage was recorded in all areas.

Introduction

The 1993 orange wheat blossom midge outbreak attracted a great deal of publicity, and damage was found in many crops in the main wheat growing areas of England. It was thought that the publicity, with its emphasis on the worst cases of damage, could easily have exaggerated the importance of the pest. There was a clear need to establish the general level of incidence so that an appropriate strategy for dealing with the problems created could be determined. Each year the Home-Grown Cereals Authority conducts a representative cereals quality survey to establish the quality of the British cereals harvest. The Cereals Quality Survey samples were seen as the best vehicle for such an analysis, being already available, and having quality measurements made upon them.

Materials and methods

Sub-samples of wheat grain from the Home-Grown Cereals Authority's Cereal Quality Survey were sent to ADAS Reading for wheat blossom midge analysis. These samples had been collected from field crops selected to be representative of the British wheat crop by HGCA staff. Thousand grain samples were extracted and spread out on a white tray. The grain was examined under a x2 illuminated magnifier for visible damage due to wheat blossom midge larval feeding. The grain was agitated several times and re-examined until no further damage was detected. For the samples from the Eastern region a note was also made of those samples showing pre-sprouting.

Results

The percentage visible grain damage for samples of each variety from each county were averaged (Table 1). The numbers of samples of each variety represented are shown in parenthesis. Summaries of the data by region and for the main varieties are given in the review (Tables 1 & 5, pp 5 & 24).

Table 1. Mean percentage visible orange wheat blossom midge grain damage by variety and county.

Variety	Cambridge	Essex	Suffolk	Norfolk	Northants
winter wheat					
Admiral			9	9 (2)	9
Apollo	20 (2)	15		8	
Avalon	12 (3)				
Beaver	19 (4)	18 (2)	13 (3)	23 (2)	
Camp Remy		2			
Estica			12	12	
Galahad					16 (2)
Hereward	12 (2)	9 (3)	7 (2)	5	8
Hornet			25 (2)		
Hunter	10	14 (2)	5		7
Mercia	12 (2)	7 (2)	11 (2)	12 (4)	11
Riband	14 (7)	9 (5)	12 (6)	11 (5)	10
Slejpner	15 (2)	5 (2)		10	11
Soissons		11	8	9	5
Spark		7 (2)	7		
Urban	9				
Wasp			7 (2)		
Zodiak			2		
mean for winter wheat	13	11	12	11	10
spring wheat					
Axona	3				3
Baldus			7		

Variety	**Bedford**	**Hertford**	**Bucks**	**Berkshire**	**Oxford**
winter wheat					
Admiral	8		9		
Apollo	8		7		4
Avalon				9	
Beaver	18 (2)	14	11		4
Estica				4	1
Galahad		15		2	
Haven					6
Hereward	5	8	6		6
Mercia	11				
Riband	27			8	9 (2)
Slejpner		9	21		
Soissons		7	5		
Talon					11
Torfrida		8			
mean for winter wheat	13	10	10	6	6
spring wheat					
Axona			5		1
Baldus		8			

Variety	**Wilts**	**Dorset**	**Somerset**	**Devon**	**Cornwall**
winter wheat					
Apollo	4			1	
Beaver	3	7		4	
Estica	2	3			
Haven	4				
Hereward	10 (2)	6	1		
Hunter	5				
Mercia			2	4	
Riband	6 (3)	6 (2)	2 (2)	2	
Soissons				4	3
mean	5	5	2	3	3

Variety	**Kent**	**Surrey**	**E Sussex**	**W Sussex**	**Hampshire**
winter wheat					
Apollo	1			4	12
Avalon				6	
Beaver		17			
Genesis	5			15	
Haven	26				
Hereward	6				4
Hunter	5				
Hussar	4				
Mercia					2 (2)
Riband			3		10 (3)
Slejpner	1			13	
Soissons	3		9		3 (IOW)
Spark					3
Zodiak	13				
mean for winter wheat	5	17	6	10	6
spring wheat					
Axona				1	
Baldus			8		
Canon	3				
Sunnan	3				
Tonic	4				

Variety	**Avon**	**Gloucester**	**Gwent**	**Hereford**	**Warwick**
winter wheat					
Admiral					3
Beaver		5		7 (2)	
Galahad				7	
Haven	5			8	
Hereward		4			
Hunter					2
Mercia		1	2	6	3 (3)
Riband		4 (4)		5 (4)	2
Soissons		7			6
Zodiak				2	
mean for winter wheat	5	4	2	6	2
spring wheat					
Axona					1

Variety	Leicester	Notts	Derby	Lincs	Humberside
winter wheat					
Admiral	10			1	5 (2)
Avalon	7			6	
Beaver	5	5		8 (10)	2 (3)
Brigadier				7	
Haven	8			10 (6)	12 (4)
Hereward	3 (4)			5 (2)	3 (2)
Hunter				4 (3)	4
Hussar	7			2 (3)	4
M.. Hunstman			3		
Mercia		6 (2)		3 (3)	5
Riband	12	6 (5)	3	7 (10)	6 (7)
Slejpner		4			
Soissons		2		7	
Talon					5
Zodiak				4	
mean for winter wheat	6	5	3	7	6
spring wheat					
Axona				1	
Baldus	2				
Tonic				3	

Variety	Stafford	Shropshire	Cheshire	Merseyside	Lancashire
winter wheat					
Admiral		4			
Beaver	4	1 (2)			
Genesis			7		
Haven		5 (3)			
Hereward	5 (2)				
Riband		0 (2)	6	3	2
Slejpner	1				5
mean	4	3	7	3	4

Variety	South Yorkshire	West Yorkshire	North Yorkshire	Clevland	Durham
winter wheat					
Albatross			3		
Admiral	6		1 (2)		
Beaver		3	3 (7)		1
Fresco				2	
Haven			1		7
Hereward	1		1 (3)		
Hunter			1		
Mercia	1		2		7
Riband			2 (6)	1	7
Soissons		4			
Spark	1				
mean	2	4	2	1	4

Variety	Tyne & Wear	Northumberland	Cumbria	Scotland
winter wheat				
Admiral				1
Beaver				1 (2)
Futur		1		
Haven		3 (2)		
Mercia		1 (2)		
Riband	3	5 (2)	5	2 (20)
mean	3	2	5	2

Discussion

The results confirm that wheat blossom midge damage was widespread in 1993 with all but two of the 392 samples affected to some degree. The highest levels of damage were found in southern and eastern England. Significant levels of damage were detected in other parts of England and low levels were found in Scotland and Wales.

Any crops with 10% or more visible grain damage are likely to have suffered yield losses in excess of 2%, and had an effective spray been applied it is likely to have been cost effective. On this basis it can be concluded that 21% of the British wheat area should have been sprayed against the pest in 1993.

Numbers of larvae returning to the soil after crops with more than 10% grain damage are likely to give rise to potentially damaging numbers of midges in two years out of 3. Numbers returning from crops with between 5 and 10% damage are likely to cause potential damage in one year out of three. The implications of the survey are that for 1994 there is a 33% probability that half of the wheat area will exceed spray thresholds and a 66% probability that 29% will require a spray.

The relative damage to different varieties followed the general trend established from examination of varietal comparison experiments (Tables 4 & 5), with Beaver and Haven showing higher levels of damage than Hussar and Mercia. The amount of damage found on the variety Riband was more variable. Some of the highest levels recorded were on this variety, reflecting its popularity for second and subsequent wheat crops which tend to have higher levels of midge damage. Riband also tends to be used as the main variety on mixed farms, growing a small proportion of wheat and suffering lower levels of midge damage in consequence.

The coincidence between the susceptible ear emergence period and midge flight varied according to sowing date as well as area, so comparison between varieties with only a few records in a particular county is probably not valid. The coincidence patterns observed in 1993 are unlikely to be repeated exactly in future years, so that a different distribution of damage between varieties is likely. There is no evidence of inherent differences in susceptibility between varieties of wheat currently available in the UK.

There was a poor correlation between midge damage and quality parameters such as Hagberg falling numbers. This is to be anticipated as the effect of the midge feeding varies according to the other parameters affecting quality. In particular Hagberg falling numbers were most reduced in those crops showing pre-sprouting. All the pre-sprouted grains found had been damaged by midge larvae, and it must be concluded that midge damage was a major pre-disposing factor causing pre-sprouting in 1993. In addition to variety, Hagberg falling number is also strongly influenced by maturity of the crop at harvest and pre-harvest weathering (Kettlewell, 1993); since these factors had not been measured it was not possible to exclude them from the analysis. Taking an individual variety for a single region, to eliminate as many other variables as possible, it was possible to identify definite trends. For example the variety Hereward in the Eastern region gave a significant correlation of:

Hagberg Falling Number = 314 - 5.70 x (% midge damage) which accounted for 41% of the variation (*p* 0.013, n 14) (Figure 1). The NIAB Hagberg rating for this variety of 277 in the 1994 list (HGCA 1993) may perhaps have been reduced by the midge damage to the experiments noted in 1993.

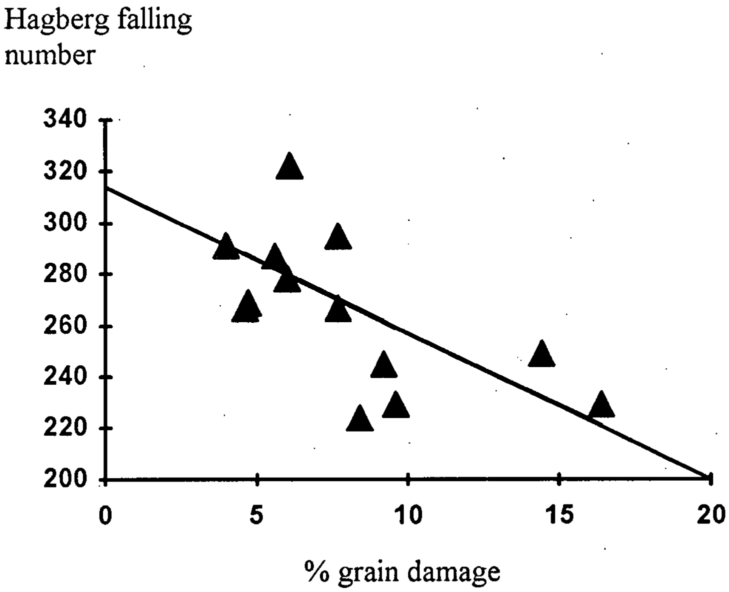

Figure 1. The relationship between Hagberg falling number of Hereward samples from the Eastern region and % of grains damaged by midge larvae

None of the samples in the survey had levels as high as the highest levels seen in advisory cases. Up to 63% damage grain had been recorded, on a farm growing continuous wheat in Wiltshire. The highest level found on samples within the survey was 36% grain damage from a sample of Beaver from Norfolk, and other high levels detected within East Anglia, included 29% damaged grain in a sample of Beaver from Cambridgeshire and 27% damage to Riband from Bedfordshire. Away from the main known area of infection, very high levels were occasionally detected, with 26% grain damage found in a sample of Haven from Kent and 29% damage found in the same variety from Humberside. It is thought that the Humberside sample may have been drawn from the northern end of the Lincolnshire Wolds where very high levels of damage were found in varietal comparison experiments. At a level of 30% damaged grain in the harvested sample yield losses are likely to have been in the order of 25%.

The analysis of survey samples confirms that overall the yield loss from British wheat in 1993 is likely to have been in the order of 4%. This estimate assumes that one third of damaged grains were lost at harvest, and that damaged grain in harvested samples had suffered a 20% reduction in size.

Some indication of the level of risk for 1994 can be drawn from these figures. Numbers of larvae returning to the soil where 10% or more of grains were attacked will be above 20 million per hectare. The probability that sufficient numbers of midges will hatch from these fields to exceed threshold levels during the ear emergence period is in excess of 66%. Between 5 and 10% grains damaged, numbers returning to the soil will be between about 6 and 20 million per hectare and the probability of a significant coincidence is greater than 33%.

It can therefore be deduced that there is a 66% probability that 21% of the UK wheat crop will be at risk in 1994 and a 33% probability that the figure could be as high as 50%. It is unlikely that more than 50% of British wheat will be at risk in 1994. The risk is not evenly distributed (Table 1 in the main review) and in the Eastern region up to 81% of crops may be at risk. However prophylactic sprays are unlikely to be fully effective and can not be recommended. The most successful strategy will be careful monitoring of crops during the ear emergence period, with well timed insecticide sprays applied where necessary.