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DISEASES OF WINTER LINSEED: OCCURRENCE, EFFECTS AND IMPORTANCE

Diseases of winter linseed: occurrence, effects and importance

by

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Contents

Abstract

In 1998, a survey of the incidence and severity of diseases was carried out on 30 crops of winter linseed at early flowering and again at crop maturity. Five crops each were selected in south west, east, east Midlands, west Midlands and north of England and from Scotland. Crops were predominantly cv. Oliver (90% crops), grown from certified seed (83%) and sown in September (97%). Pasmo (*Mycosphaerella*) was the most important disease, affecting leaves of 73% crops at early flowering and 90% crops at maturity. Powdery mildew (70% crops), *Alternaria* (30% crops) on leaves and *Botrytis* on capsules (70% crops) were also common. Regional differences were apparent for powdery mildew, which was present in all regions except the southwest, whilst *Alternaria* predominated in the Midlands. Half of the crops surveyed had received fungicide sprays, but this appeared to have made limited impact on disease severity. Pasmo is a new threat to UK linseed crops and this raises concerns about the threat it poses to spring linseed.

In 1999, a survey of the incidence and severity of diseases was carried out on 30 crops of winter linseed at early flowering and again at crop maturity. Five crops each were selected in south west, east, east Midlands, west Midlands and north of England and from Scotland. Crops were predominantly cv. Oliver (93% crops), grown from certified seed (70%) and sown from mid September to mid October. Pasmo (*Mycosphaerella*) was the most important disease, affecting leaves of 83% crops at early flowering and 80% crops at maturity. Powdery mildew (24% crops), *Alternaria* (13% crops) on leaves and *Botrytis* on capsules (83% crops) were also common. Regional differences were apparent for powdery mildew, which was present mainly in the west Midlands and Scotland and much less common in the east than in 1998. *Alternaria* predominated in the south west. There was an increase of 30% in the use of fungicide sprays and 73% of crops surveyed had been treated. Tebuconazole plus MBC during flowering was the most widely used fungicide treatment. This appeared to have made some impact on disease severity. Pasmo was less severe in 1999 than in 1998 and this contributed to higher yields. This disease became established more slowly in the autumn and winter than in 1997/98 and understanding this phase of the epidemic could lead to improved control strategies.

In 2000, a survey of the incidence and severity of diseases was carried out on 30 crops of linseed at early flowering and again at crop maturity. Because of the rapid decline in winter linseed cropping, samples were taken in equal numbers from winter and spring linseed crops in England. Sampling reflected the areas of production and comprised six crops (five spring linseed) in the south west, nine crops (five spring linseed) in east, five crops (two spring) in east Midlands, five crops (one spring) in the west Midlands and five crops (two spring) in the north of England. Winter linseed crops were all cv. Oliver and spring linseed was represented by eight cultivars. Certified seed was used for 70% of crops and sown during mid September to mid October for winter crops and early March to early May for spring crops. Pasmo (*Mycosphaerella*) was the most important disease, affecting leaves of 70% crops at early flowering and 80% crops at maturity. Powdery mildew (43% crops), *Alternaria* (13% crops) on leaves and *Botrytis* on capsules (90% crops) were

also common. Regional differences were apparent for powdery mildew, which was most prevalent in the east at early flowering and in the south by crop maturity. *Alternaria* was confined to the south. Fungicide sprays were used on 47% crops, of which 40% was on winter linseed. Treatments were applied mainly during the early to mid flowering period and appeared to have made a limited impact on final disease severity. It is clear that pasmo is a threat to spring linseed crops and further monitoring is advisable to see if the disease declines in the absence of winter linseed cropping.

In winter linseed experiments at Rothamsted in 1997/98, 1998/99, and 1999/2000 different fungicides were applied in autumn and at pre-flowering, mid-flowering or capsule development stages to control diseases. In 1997/98, pasmo developed early in the season and became very severe in June/July after high March/April and June rainfall. Pasmo was well controlled by a single application of benomyl at mid-flowering and yield was more than doubled; a two-spray programme provided little additional control. However, in 1998/99 and 1999/2000 pasmo developed later, there was less rainfall in March/April and June and pasmo did not become as severe as in 1997/98. Fungicide applications did not decrease disease severity and there was little yield response in these two seasons. Regression analyses suggest that yield responses could be related to the control of pasmo on leaves in June and on stems in July. Therefore a simple model using the stem pasmo severity at crop maturity (x) as the explanatory variable was selected to estimate yield loss (y_r) retrospectively for each season. These models were applied to five regions in England to estimate regional and national losses.

The estimated natural costs of yield losses caused by this disease were £28M in 1998, £1M in 1999 and £0.5M in 2000 in the UK. Correctly timed fungicides can provide good control in years when pasmo is serious, but in some years there was no evidence that fungicides improve yields of winter linseed. Since the incidence and severity of pasmo varies between regions and seasons, a decision-making aid would help predict in what crops there might be an expected effect of pasmo. A model can be used in spring to estimate the development of the disease to predict the possible yield loss due to pasmo and hence aid fungicide decision-making.

Results suggest that application of fungicides to winter linseed to increase yield by disease control may be justified in one year out of three when pasmo epidemics are severe (in two years of this three year study pasmo did not become sufficiently severe). When pasmo disease was first observed on leaves later than January, it did not become sufficiently severe to reduce yields, even on untreated plots. Data from untreated plots indicate that in 1997/98, when the pasmo epidemic on leaves started earlier, stem disease was first observed in March. By contrast, it was not observed until May in 1998/99 and 1999/2000 when it did not become sufficiently severe to cause yield loss. Therefore, the results suggest that growers should only apply pre/mid-flowering sprays if stem disease is present in March.

Summary

Winter-sown linseed was introduced commercially to the UK in 1995 as an alternative to spring-sown linseed. Spring linseed can pose problems for harvesting because of its late maturity so that it is difficult to include in arable rotations. When this project was started in 1997, there had been little research into diseases of winter linseed but surveys had shown widespread, severe epidemics of pasmo (caused by *Mycosphaerella linicola*) in many commercial crops, causing considerable yield losses. In 1997, there were indications that diseases would be an important constraint to the success of the winter linseed crop in the UK, with widespread severe attacks of pasmo causing serious yield losses on winter linseed (at all ADAS centres and on many commercial crops) suggesting that the most damaging diseases on winter linseed may be different from those on spring crops (on which *Botrytis* and *Alternaria* had been the predominant diseases). However, in 1997 good control of diseases and lodging was achieved in ADAS winter linseed trials, with yield responses in the region of 25%. As the area of linseed grown was expected to expand, the incidence and severity of diseases on the crop were also likely to increase and this series of field experiments were done to investigate the effects of disease on crop growth and yield.

This project included a three-year survey of diseases of winter linseed co-ordinated by Dr. Peter Gladders (ADAS, Boxworth), data analyses and a three-year programme of field experiments at Rothamsted co-ordinated by Sarah Perryman. The overall aims of this project were:

1. To determine the occurrence of diseases on winter linseed crops in the UK (ADAS);
2. To quantify effects of diseases on growth and yield of linseed crops, using fungicides;
3. To identify factors affecting the incidence and severity of diseases on linseed;
4. To evaluate the importance of diseases in winter linseed crops in the UK.

1. Disease survey 1998-2000

The objective was to determine the incidence and severity of diseases on winter linseed and identify factors that affect the occurrence of disease problems.

Methods

In 1998, a total of 30 crops of winter linseed were selected for the survey with five crops being selected in each of the following six regions: South west England, Northern England, Eastern England, East Midlands, West Midlands, Scotland. Crops were selected by ADAS in England using growers known to ADAS and/or Semundo. Sites for sampling in Scotland were identified by Semundo. In 1999, there were few crops in Scotland and three samples were taken from the Borders region to augment two crops in Scotland. Winter

linseed cropping declined sharply in autumn 1999 and the survey in 2000 comprised 15 crops of winter linseed and 15 crops of spring linseed, all collected from farms in England.

Samples of 50 plants were collected at early flowering (late May/early June) and at crop maturity (as capsules turned yellow) in early July by ADAS and by local agronomists or farmers in Scotland and the Borders. A sub-sample of 25 plants was examined in detail, with records of the incidence and severity of individual diseases and other symptoms being recorded on the leaves, stems and capsules on each plant. Disease assessments were carried out locally by ADAS Plant Pathologists and samples from Scotland were assessed at ADAS Boxworth. Agronomic and cropping details were collected for each site and data was collated and stored at ADAS Boxworth.

Key results

1998

- Pasmo was the most common disease in winter linseed crops in 1998 and it was found on leaves of 73% crops at early flowering and 90% crops at maturity.
- Pasmo was the most common stem disease affecting 63% crops at early flowering and 87% crops at maturity.
- Powdery mildew was found in all areas (70% crops affected at early flowering) and was more common than pasmo at early flowering in the north of England and Scotland, but was less common at crop maturity (50% crops affected).
- *Alternaria* leaf spot increased from 13% crops affected at early flowering to 30% crops affected at crop maturity.
- *Botrytis* caused some leaf spotting in 7% crops at both early flowering and crop maturity, stem rotting in 10% crops and capsule rots in 70% crops.
- Minor stem diseases included *Phoma* spp. (1 crop), *Sclerotinia* (1 crop) and *Fusarium* spp. (2 crops).
- Crop lodging was severe in many crops and averaged over 60% crop area in the east and east Midland areas.
- Weed cover averaged less than 5% area affected, except in the south west and north of England, which averaged 30% and 11% area affected, respectively, at crop maturity.
- Invertebrate pest damage was limited and frequently below 1% leaf area affected. Pigeons gave cause for concern with late and severe grazing in the spring.
- The main cultivar was Oliver, grown predominantly from certified seed.
- Fungicide sprays were used on 50 % of crops and appeared to have a limited impact on disease severity. Tebuconazole and MBC products were the most frequently used fungicides.

- The combination of severe lodging and high disease contributed to low yields in 1998. Fungicide sprays have the potential to overcome disease and increase yields by at least 1 t/ha.
- Reports of pasmo on spring linseed are of concern and the disease appears to have become prominent since (probably as a direct result of) the introduction of winter linseed.

1999

- Pasmo was the most common disease in winter linseed crops in 1999 and it was found on leaves of 83% crops at early flowering and 80% crops at maturity.
- Pasmo was the most common stem disease, affecting 55% crops at early flowering and 90% crops at maturity.
- Powdery mildew was less common than in 1998 and was found mainly in the west Midlands and Scotland (24% crops affected at early flowering) and was slightly less common at crop maturity (20% crops affected).
- *Alternaria* leaf spot increased from 7% crops affected at early flowering to 13% crops affected at crop maturity.
- *Botrytis* caused some leaf spotting in 3% crops at early flowering and 13% crops at crop maturity, stem rotting in 23% crops and capsule rots in 83% crops.
- The minor stem diseases, including *Phoma* spp., *Sclerotinia* and *Fusarium* spp.were not recorded in 1999.
- Crop lodging was severe in a few crops and averaged 35% crop area in the eastern counties and <10% in other areas.
- Weed cover averaged less than 5% area affected in the north of England and west Midlands, but averaged 31% at crop maturity in the south west.
- Invertebrate pest damage was limited and below 1% leaf area affected in all except two crops at early flowering. Pigeons gave cause for concern with late and severe grazing in the spring.
- The main cultivar was Oliver, grown from predominantly from certified seed.
- Fungicide sprays were used on 73 % of crops and appeared to have some impact on disease severity. Tebuconazole and MBC products were the most frequently used fungicides, mainly applied as single sprays during flowering.
- The combination of limited lodging and much less severe pasmo disease contributed to improved yields in 1999 compared with 1998.
- Crop monitoring in winter may be a useful early indicator of disease risk.

2000

The monitoring in 2000 was confined to England and included equal numbers of spring and winter linseed crops.

- Pasmo was the most common disease in linseed crops in 2000 and it was found on leaves of 70% crops at early flowering and 90% crops at maturity.
- Pasmo was the most common stem disease, affecting 57% crops at early flowering and 73% crops at maturity. Pasmo showed a higher incidence in winter linseed than spring linseed on leaves at early flowering (85% and 16% plants affected respectively) and crop maturity (63% and 30% plants affected respectively). Similar differences were apparent on stems.
- Powdery mildew was found in all areas except the west Midlands and appeared after early flowering in the north (overall 20% crops affected at early flowering, 43% crops affected at crop maturity). It was more severe than pasmo at crop maturity, affecting up to 41% leaf area in the south. Powdery mildew was only found at early flowering in spring linseed and this difference was largely maintained at crop maturity when 4% of winter linseed plants and 51% spring linseed showed foliar symptoms.
- *Alternaria* affected leaves and capsules at crop maturity in 13% crops in the south.
- *Botrytis* caused some leaf spotting in 10% crops at early flowering and 33% crops at crop maturity. *Botrytis* stem rot occurred in 7% crops (both crops were spring linseed) and *Botrytis* capsule rots in 90% crops. No other stem diseases were recorded.
- Fine black spotting was very prevalent in winter linseed at early flowering (59% plants affected) and persisted on winter and spring crops up to crop maturity.
- Crop lodging was only significant in two crops in the east Midlands at early flowering and affected >10% of crop area at five sites by crop maturity. Lodging was predominantly in winter linseed and associated with the tallest crops.
- Weed cover averaged less than 5% area affected, except in the south and north of England, which averaged 17% and 18% area affected respectively crop maturity.
- Invertebrate pest damage was limited and frequently below 1% leaf area affected, reaching 5% damage in occasional spring linseed crops in the east.
- For winter linseed only the cultivar Oliver was grown, whereas eight different spring linseed cultivars were used spring cropping. Crops were grown predominantly (70%) from certified seed.
- Fungicide sprays were used on 47% of crops and appeared to have some impact on disease severity. Tebuconazole and MBC products were the most frequently used fungicides, with early to mid flowering timing. There was a large difference in fungicide use between winter and spring linseed, with 80% and 13% crops respectively receiving foliar sprays.
- Confirmation of severe pasmo in spring linseed is of concern and fungicide decision-making on spring crops will need to take account of the increased risk of yield loss from this disease.

2. Effects of diseases on growth and yield of linseed crops

These experiments provide opportunities to compare and contrast the effects of diseases on yields of winter and spring linseed crops at Rothamsted in three seasons (1997/98, 1998/99, and 1999/2000). Data analyses to establish relationships between disease incidence/severity and crop growth/yield loss were investigated with existing data from spring linseed (1988-1998) and with the new winter linseed field experiment data.

Methods

Field experiments were done at Rothamsted in three seasons (1997/98, 1998/99 and 1999/2000) using the cultivar Oliver. Plots received experimental treatments of different fungicides at different timings to manipulate the severity of diseases: - tebuconazole (Folicur), benomyl (Benlate), iprodione (Rovral Flo) and thiophanate-methyl plus iprodione (Compass). They were applied in autumn (tebuconazole) or at pre-flowering, mid-flowering or capsule development stages. Regular assessments were made of the disease symptoms on leaves, stems and capsules and of effects of diseases on crop growth, thousand seed weight and yield. Detailed weather information (temperature, rainfall, leaf wetness/duration) was collected using an automatic weather station and numbers of pathogen spores being dispersed were monitored with a Burkard spore sampler. Data analyses to establish relationships between disease incidence/severity and crop growth/yield loss were applied to existing data from spring linseed (1988-1998) and to the new winter linseed field experiment data.

Key results

Winter linseed:

- The only disease to occur at more than trace levels was pasmo.
- In 1997/98, pasmo symptoms were evident earlier in the season than in 1998/99 and 1999/2000.
- Pasmo was well controlled in the first season and consequently yield was more than doubled.
- The best treatment in this first season was a single application of benomyl at mid-flowering; a two-spray programme provided little additional control or yield response.
- An autumn application of tebuconazole did not have a long-term effect on disease or yield.
- There was insignificant disease control and little yield response in the later two seasons; however, untreated yields in these two seasons were significantly higher than those in the first season.
- When pasmo occurred late in the season, resulting in lower % area of stems affected, flowering treatments did not decrease disease levels and increase yields.
- Regression analyses suggested yield responses could be related to the control of pasmo on leaves in June and on stems in July.
- Thousand seed weight was related to yield, indicating yield gain at flowering/ post-flowering due to seed formation.

- These results therefore suggest that application of fungicides to winter linseed to increase yield by disease control may be justified in only one year out of three when pasmo epidemics become sufficiently severe.
- Decisions about whether to apply fungicides or not may be made in March; if there is a 20% area of stem affected by pasmo disease it is recommended to apply a pre or mid-flower spray of benomyl.

Spring linseed:

- Analyses of data from spring linseed field experiments for 1988-1998 suggests that substantial yield losses occurred in three years and only slight losses in other years.
- These yield losses were related to decreases in yield components (TSW and numbers of capsules).
- Percentage leaf area with browning was the disease factor most consistently related to yield losses (in five years) and for each 10% increase in leaf area with browning there was a yield loss of 0.10-0.18 t/ha.
- Yield losses were greatest in years when the period of flowering and early capsules development in June and July was wetter than average.
- The predominant disease was grey mould (*Botyrtis cinerea*) in wet years up to 1996, whereas pasmo (*Mycosphaerella linicola*) was most important in 1997 and 1998.
- Observed yield losses were small in hot dry years when powdery mildew (*Sphaerotheca lini*) and verticillium (*Verticillium dahliae*) were the predominant diseases.

3. Factors affecting severity of diseases on linseed

Weather, sowing date, previous cropping and air-borne spore numbers may affect the severity of diseases on linseed crops. Effects of weather were examined for existing spring linseed data since 1988 and for winter linseed experiments from 1997/98 –1999/2000.

Methods

Detailed weather information (temperature, rainfall, leaf wetness/duration) was collected using an automatic weather station and numbers of pathogen spores being dispersed were monitored with a Burkard spore sampler. These were recorded and examined using regression to identify which factors have the greatest influence on severity of different diseases. Incidence of fungal pathogens on linseed was investigated using culture on agar of seeds from infected plants.

Key results

Winter linseed:

- In 1997/98 when the linseed was sown in September, pasmo disease developed earlier and was subsequently severe, with a resulting loss in yield, than when the seed was sown in October in 1998/99 and 1999/2000.
- There was no definite relationship between the weather pattern in 1997/98 and the early outbreak of pasmo. However, in 1997/98 pasmo became very severe in the spring when there was high rainfall in March/April.
- In 1998/99, there was less rainfall in March/April than in 1997/98 and pasmo did not become so severe.
- *M. linicola* was not detected in seed harvested from field experiments in 1997/98 and 1998/99. There was a very low incidence of *M. linicola* on the seed in 1999/2000.
- *B. cinerea* was well controlled by benomyl and iprodione treatments in1997/98.

Spring linseed

- Yield losses were greatest in years when the period of flowering and early capsule development in June and July was wetter than average.
- The predominant disease was grey mould (*Botryrtis cinerea*) in wet years up to 1996, whereas pasmo (*Mycosphaerella linicola*) was most important in 1997 and 1998.
- Observed yield losses were small in hot dry years when powdery mildew (*Sphaerotheca lini*) and verticillium (*Verticillium dahliae*) were the predominant diseases.

4. Importance of diseases in winter linseed in UK

Methods

Results from the ADAS linseed disease survey were combined with the yield loss relationships derived from field experiments to estimate, retrospectively, the losses from pasmo disease severity nationally to determine the economic importance of the disease.

Key results

- Estimated national losses were c. £2M in 1998, £1M in 1999 and £0.5M in 2000.
- These losses represented 44% in 1998, 31% in 1999 and 47% in 2000 of the total possible net gain in linseed yields.

5. Conclusions and implications for growers

- Introduction of winter linseed has brought a significant new disease threat to linseed cropping. Pasmo is capable of causing >50% yield loss and contributed to poor performance of winter linseed crops in 1998-2000.
- Pasmo became established in all regions where linseed was monitored even when linseed was grown for the first time. It could be seed-borne but air-borne ascospores from crop residues in autumn are now implicated in early disease establishment.
- Spring linseed is also affected by pasmo and fungicide strategies need to be adjusted for spring crops.
- Fungicides can be very cost-effective when pasmo and other diseases are controlled. Aim to protect the upper leaves and capsules. A broad-spectrum treatment such as tebuconazole + carbendazim has proved cost-effective at early to mid flowering.
- Epidemiology of pasmo is poorly understood - rain is required for spore dispersal and infection and the latent period could be 3-4 weeks in spring.
- Powdery mildew is common in winter and spring linseed but economic damage is thought to be small.
- *Botrytis* is common on capsules and also as stem and leaf rot in a few crops, causing limited losses in most crops. *Alternaria* leaf spot was found in the wetter areas of the south west and west Midlands but is likely to be masked by severe pasmo.
- *Sclerotinia* and *Phoma* spp. stem rots were only found in single crops in1998; *Fusarium* spp.occurred in two crops.
- Lodging was a common problem in 1998 and occasionally severe in 1999 and 2000. The most severe lodging was associated with tall crops (>80 cm tall).
- Weed problems were most severe in the south west and north where >10% ground cover was recorded.

Technical detail

Introduction

The increase in the area of new winter-sown cultivars of linseed (*Linum usitatissimum*) since their introduction into the UK in 1995 has brought new disease problems for the linseed crop (Gladders *et al*., 1999). Surveys on winter-sown linseed crops in 1996/97 suggested that the most damaging diseases differ from those on spring linseed, with widespread severe epidemics of pasmo, caused by *Mycosphaerella linicola* (anamorph *Septoria linicola*), reported in many commercial winter crops. Although pasmo was recorded as early as the 1940's, it has been a minor disease in spring linseed (Mercer *et al*., 1994), which had previously been the only type of linseed grown in the UK. The most important disease on spring linseed in the UK has often been grey mould (*Botrytis cinerea*), which causes damage to the capsules following initial infection of flower buds and is favoured by periods of wet weather between flowering and harvest (Fitt & Ferguson, 1993; Harold *et al*., 1997).

Pasmo, a leaf and stem blotch, starts on lower foliage of young plants, progresses upwards, and can eventually cause complete leaf browning and subsequent defoliation. *M. linicola* is reported to be seed-borne and may survive on debris; wet weather and increasing temperature favour the development of the disease (Turner, 1987). Pasmo affects all above ground parts of the linseed plant, spotting the leaves, blighting flowers and capsules, weakening the pedicels, and causing elongate (hence name 'pasmo' which is Polish for 'stripe') brown lesions on the stems. The stem lesions enlarge and coalesce to produce the bands that circle the stem and alternate with unaffected green areas to produce the mottled appearance characteristic of the disease. The diseased plants ripen and die prematurely. The fungus causing pasmo was first described in Argentina in 1911 as *Phlyctaena linicola* and Pasmo was found outside South America for the first time in 1916 then in Europe in late 1930's/early 1940's. It is not clear how yield loss in winter linseed is related to the severity of pasmo epidemics and seasonal weather.

There is no information about relationships between measurement of disease severity, such as percentage area of leaves, stems or capsules affected by disease at different time of the season, and plant growth or yield loss. Such measurements are very time consuming to make and it would be beneficial to determine which of them a grower could use to be consistently related to effects of diseases on yields. In addition, the development of appropriate control strategies may be helped by ascertaining which components of yield these diseases affect. If consistent relationships between disease factors and yield loss can be established, it may also be possible to use them to guide decisions about control strategies, including the use and timing of fungicide sprays. Fungicide sprays applied at specific growth stages can provide effective control of grey mould and other diseases on spring linseed crops (Harold *et al*., 1997). In some seasons, the weather did not favour disease development and yield benefits from fungicide applications to spring linseed were not always achieved (Perryman & Fitt, 2000). It is not clear whether fungicide spays can provide effective control of diseases on winter linseed crops and increase yields. There is evidence that the influence of weather on occurrence, severity and effects of diseases on spring linseed is considerable. High rainfall, especially between flowering and harvest, can encourage diseases on these spring crops. There is a need for information about how weather factors can affect the growth and yield of winter linseed, in relation to the effects of diseases on growth and yield.

ADAS surveys from 1998-2000 were designed to determine the extent of disease problems in commercial crops of winter linseed and to examine factors that might influence the incidence and severity of disease attacks. Results from these surveys can be combined with yield loss relationships derived from Rothamsted field experiments to estimate the losses from different diseases nationally and consequently the economic importance of these diseases. Prior to this project, the 1997 value of linseed production in the UK was *c.* £21.7M; estimates in 1997 were of 30,000 ha of winter linseed, with an average yield of 2 t ha^{-1}, plus seed premium of £500/ha on *c.* 10% of area. If the disease constraints on winter linseed production could be overcome through improved strategies for disease control, there was the potential to double the total area of linseed (£21.7M) and to increase the average yield by 10% (an additional £4.3M). Furthermore, better disease control will improve the quality of seed produced and increase the number of crops which produce seed which meets UK seed certification standards, and decrease the need to import seeds from abroad.

Overall objectives:-

1 To determine the occurrence of diseases on winter linseed crops in the UK (ADAS).
2 To quantify effects of diseases on growth and yield of linseed crops, using fungicides.
3 To identify factors affecting the incidence and severity of diseases on linseed.
4 To evaluate the importance of diseases in winter linseed crops in the UK.

I. Survey of diseases on winter linseed crops (ADAS)

Methods

In 1998, a total of 30 crops of winter linseed were selected for the survey, with five crops being selected in each of the following six regions: South west England; Northern England; Eastern England; East Midlands; West Midlands; Scotland. Crops in England were selected by ADAS using growers known to ADAS and/or Semundo. Sites for sampling in Scotland were identified by Semundo. Samples of 50 plants were collected at early flowering (early June) and at crop maturity (as capsules turned yellow) in early July by ADAS and by local representatives in Scotland. A sub-sample of 25 plants was examined in detail, with records of the incidence and severity of individual diseases and other symptoms being recorded on the leaves, stems and capsules on each plant. Disease assessments were carried out locally by ADAS Plant Pathologists and samples from Scotland were assessed at ADAS Boxworth. Agronomic and cropping details were collected for each site and data was collated and stored at ADAS Boxworth.

In 1999, the same methodology was used, except that three crops from the Scottish borders were added to two crops from Scotland to form the 'Scottish' region. This followed a major decline in winter linseed cropping in Scotland from 1998 to 1999. There was a further decline in the area of winter linseed sown in England in autumn 1999 and the 2000 survey was modified to allow comparison of winter and spring linseed. A total of 30 crops, 15 of winter linseed and 15 of spring linseed were selected for the survey in 2000 with crops being selected as follows:

South and south west England (6 crops - 5 spring crops)
Northern England (5 crops - 2 spring crops)
Eastern England (9 crops - 5 spring crops)
East Midlands (5 crops - 2 spring crops)
West Midlands (5 crops - one spring crop)

Crops were selected by ADAS in England using growers known to ADAS and/or Semundo. An additional five sites (four in east and one in the south) were identified by Semundo. Disease assessments were mainly (not the south west) carried out at ADAS Boxworth.

Results

1998

Cultivars, use of certified seed and seed treatments

The 30 crops of winter linseed examined in 1998 comprised four cultivars, of which 90% were Oliver, 7% Nordica and 3% Antares. Most were grown from certified seed (83 %). The average seed rate was 55.3 kg/ha and, of those specifying a seed treatment, 62 % used a prochloraz seed treatment (as Prelude). Crops were sown in September, apart from one sown on 20 August in Scotland.

Disease incidence and severity

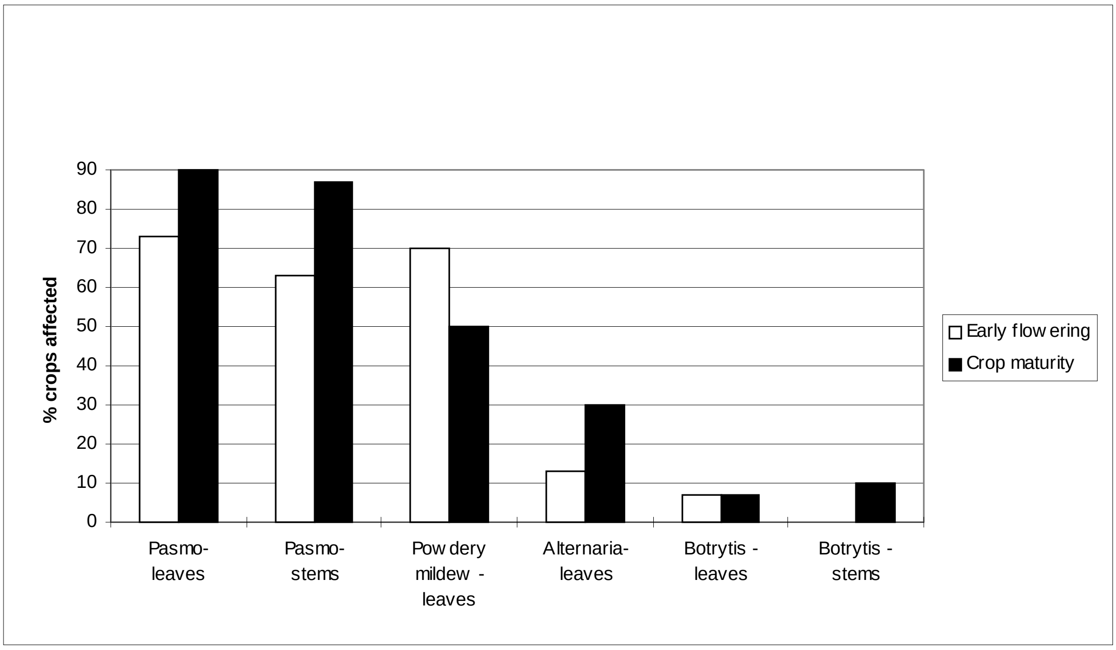

Fig. 1. Incidence of diseases (% crops affected) at early flowering and at crop maturity.

Pasmo was the most common disease, affecting leaves of 73% crops at early flowering and leaves on 90% crops at maturity. *Alternaria* leaf spot was common at both early flowering and crop maturity (13% and 30% crops, respectively), as was *Botrytis* leaf spot (7% and 7% crops, respectively) (Fig. 1). Several stem diseases were obtained, but only pasmo affected more than 10% crops, occurring on 63% crops at early flowering and 87% crops at maturity. *Sclerotinia* and *Phoma* stem rots were each only observed in single crops, whilst *Fusarium* stem rot occurred in two crops and *Botrytis* stem rot in three crops. Capsules were affected by *Botrytis* in 70% crops and pasmo affected the bracts surrounding the capsule in 83% crops.

The regional distribution of pasmo is shown in Fig. 2.

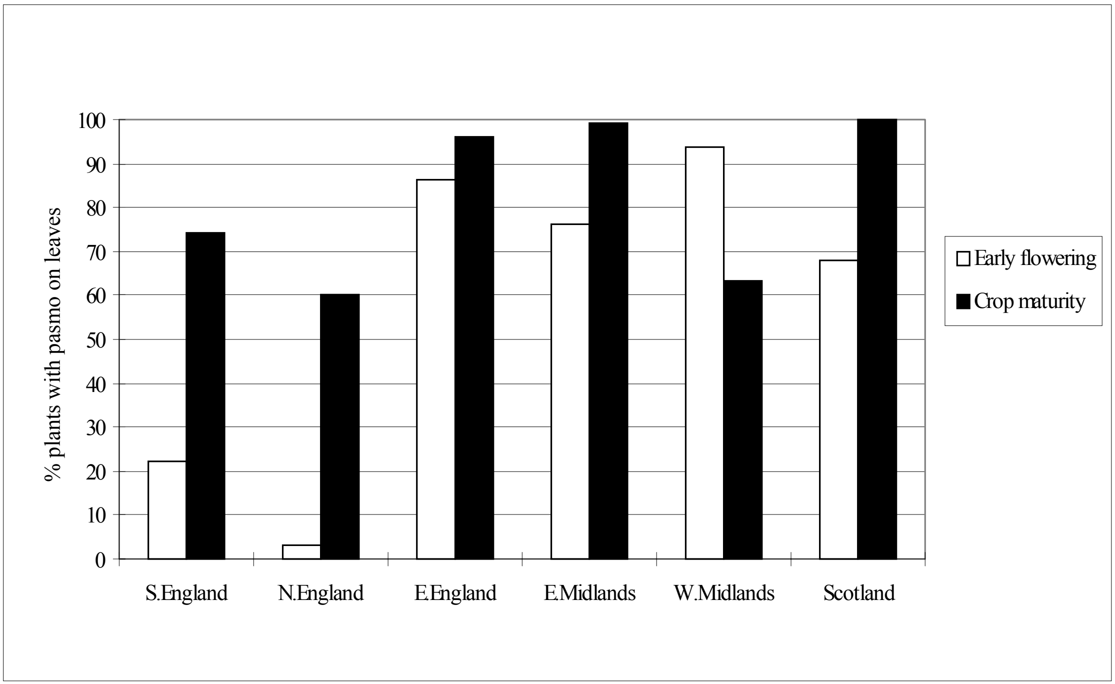

Fig. 2. Incidence of pasmo (% plants) on leaves by region at early flowering and at crop maturity.

Pasmo was most common in the east, Midlands and Scotland at the early flowering stage and increased between then and crop maturity in all areas except the west Midlands. The south west and north of England appeared to be less severely affected than other areas. A similar pattern emerged with disease severity data, highlighting the highest pasmo disease at early flowering in the east Midlands (11.7% leaf area affected) and west Midlands (6.8% leaf area) which was overtaken by the south west (26% leaf area) and east of England (14.4 % leaf area affected) by crop maturity (Fig. 3).

Powdery mildew was not recorded in the south west on either visit, but was common in the east (62% plants affected), Midlands (50% east, 58% west) and Scotland (73% plants) (Fig. 4) at early flowering, declining as leaves senesced by the second visit. Average severity remained below 5% leaf area affected in all areas (Fig. 5), being absent from the south west and most severe (4.8% leaf area affected) in Scotland.

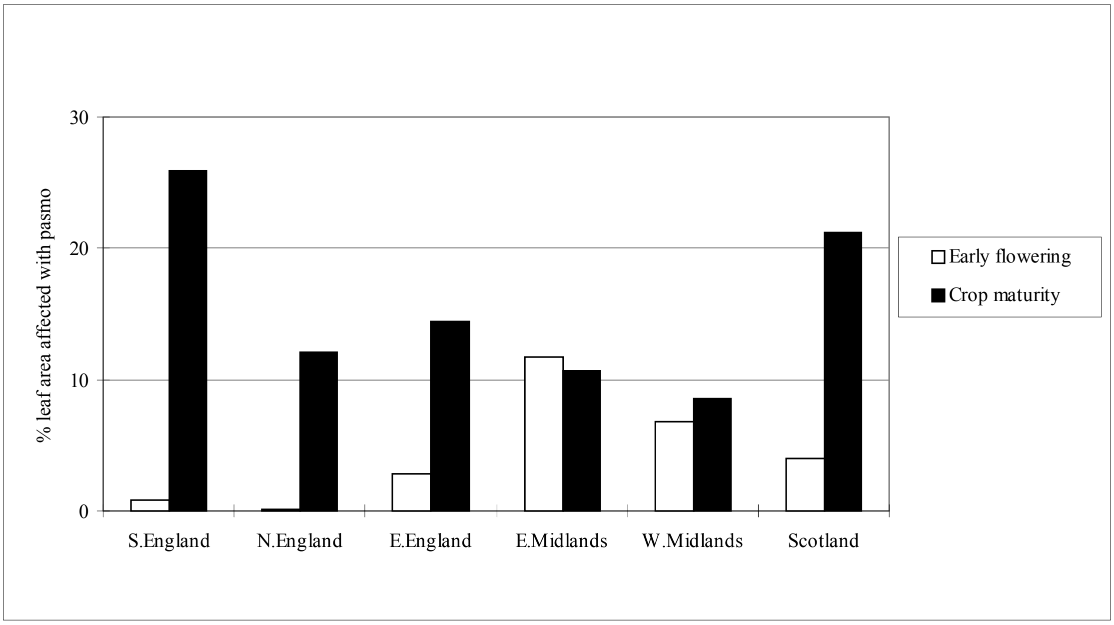

Fig. 3. Severity of pasmo on leaves (% area affected) in different regions at early flowering and at crop maturity.

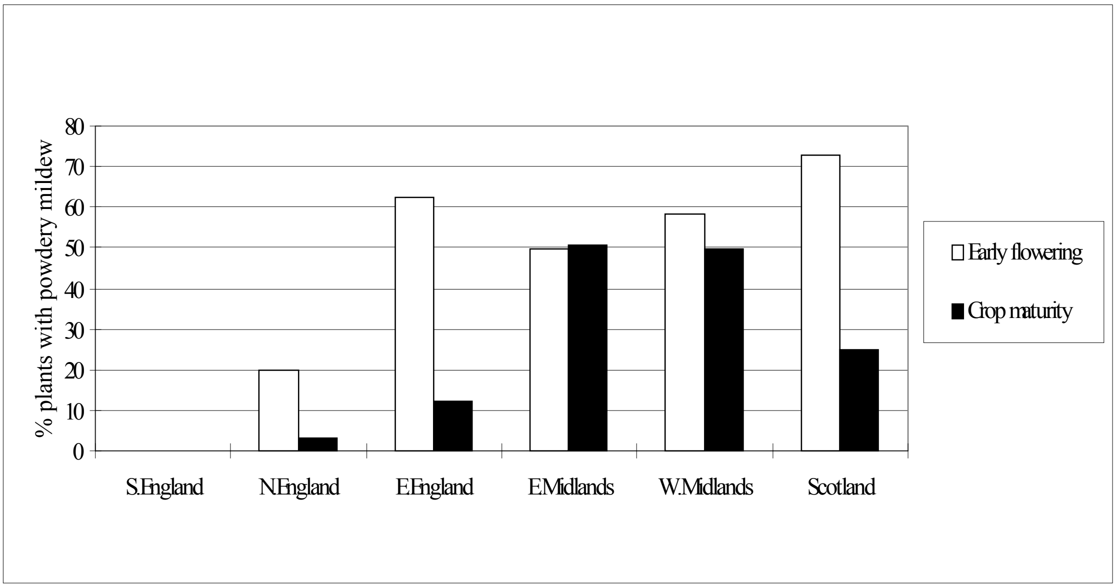

Fig. 4. Incidence of powdery mildew on leaves (% plants affected) in different regions at early flowering and at crop maturity.

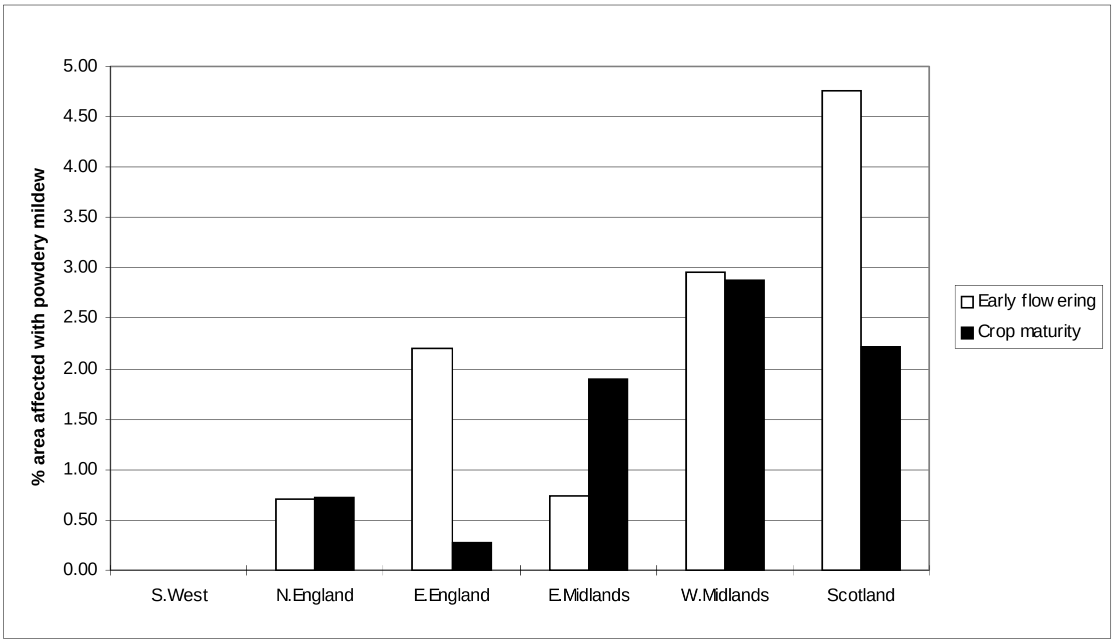

Fig. 5. Severity (% leaf area affected) of powdery mildew on leaves in different regions at early flowering and at crop maturity.

Pasmo was the most common stem disease and had affected stems by early flowering in all areas except the north of England (Fig. 6). It was particularly common at crop maturity in the east (97% plants affected), east Midlands (92% plants) and Scotland (78% plants) (Fig. 6). The severity of pasmo was greatest in the east and south west and lowest in the north of England at crop maturity (Fig.7). Pasmo undoubtedly accelerated leaf senescence and contributed to yellow and dead leaves and leaf loss. The proportion of the stem which had defoliated is expressed as the percentage bare stem (Fig. 8). Most regions had up to 10% defoliation at early flowering, considerably lower than the 25% bare stem recorded in south west. At the second assessment, disease and natural senescence combined to give about 70% bare stem in England, much higher than recorded in Scotland (20% bare stem), where some crops showed high retention of dead leaves.

Alternaria leaf spotting (*Alternaria linicola*) was only recorded in four crops at early flowering and these were confined to Scotland (1.6 % plants affected) and the east Midlands (27.2% plants). By the second assessment, nine crops showed *Alternaria* on leaves and these were from the east (16.0% plants) and the west Midlands (64.8% plants), the latter affecting 6.9 % leaf area.Stem rots were generally of minor significance with *Sclerotinia* being confined to a single plant in the north and *Botrytis* stem rots effecting up to 2% stems in west Midlands and south west England. *Phoma* stem rot was found in one crop in the Midlands and *Fusarium* stem rots were present in two crops from the south west (2% plants affected).

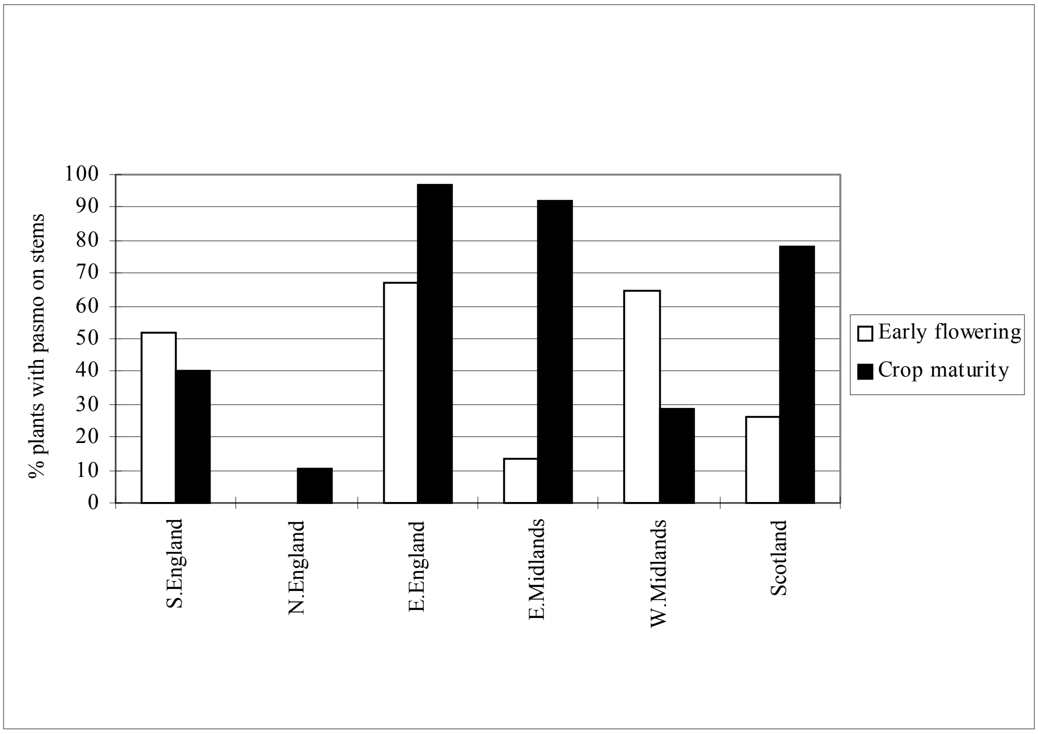

Fig. 6. Incidence of pasmo on stems (% stems affected) in different regions at early flowering and at crop maturity.

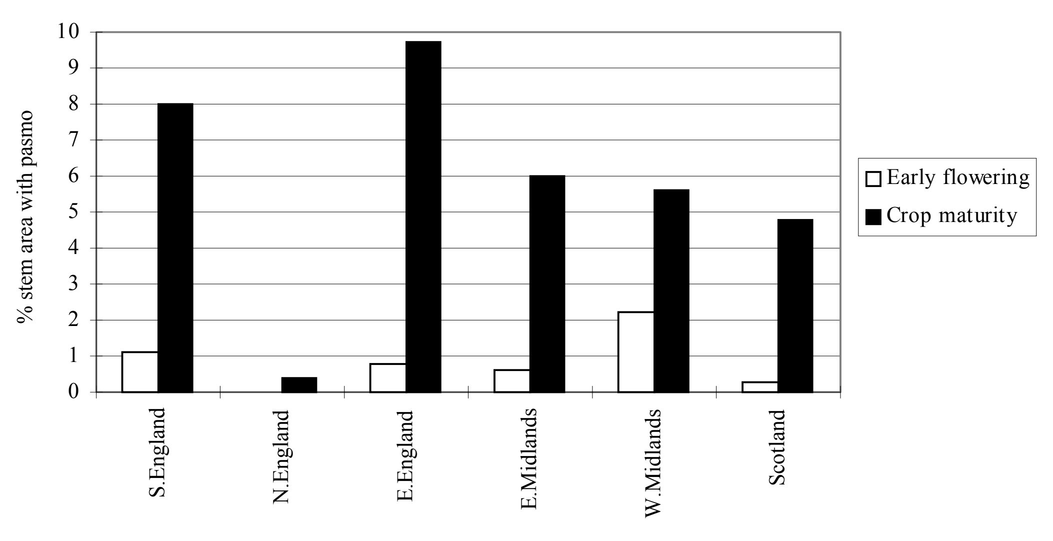

Fig.7. Severity of pasmo on stems (% area affected) in different regions at early flowering and crop maturity.

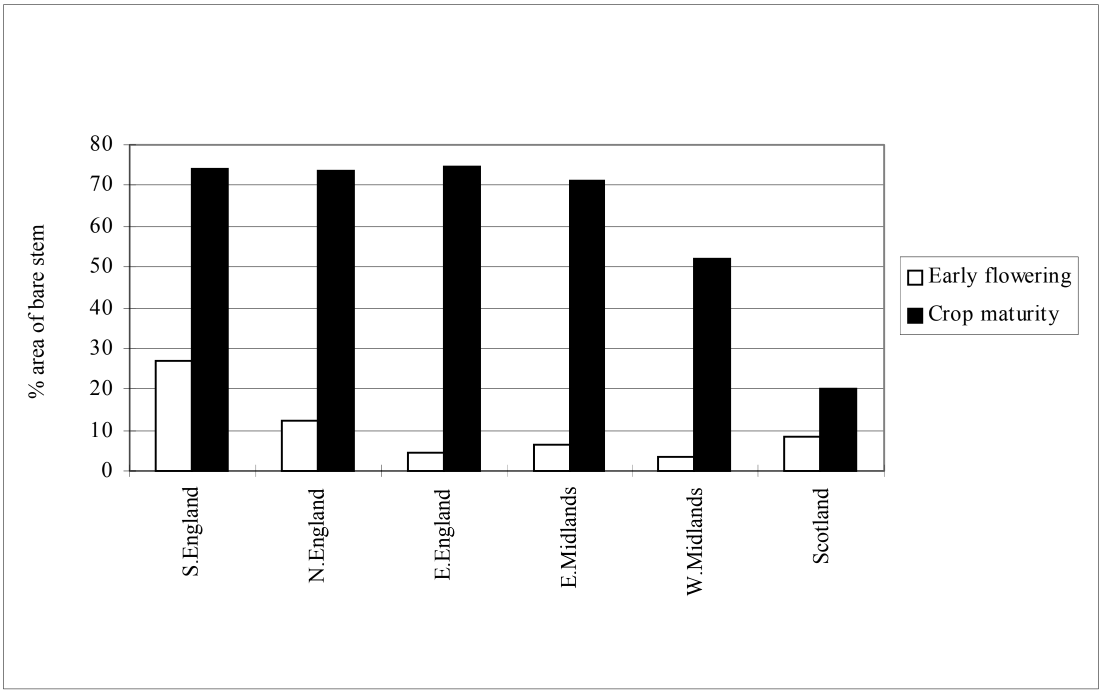

Fig. 8. Extent of leaf loss from stems (bare stem) (% area affected) in different regions at early flowering and crop maturity.

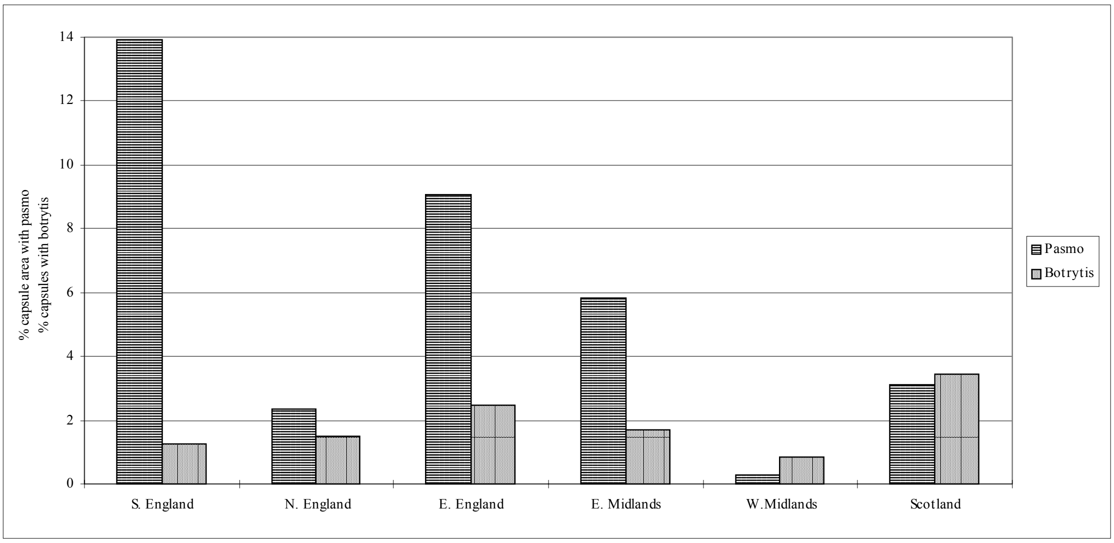

Fig. 9. Severity of pasmo on capsule bracts (% area affected) and % capsules with *Botrytis* in different regions at crop maturity.

Pasmo was commonly found on the bracts surrounding the capsule in all areas except the west Midlands (Fig. 9). It was most severe in the south west, affecting 13.9% capsule area and least severe in the west Midlands (0.3% area). *Botrytis* was found on capsules on an average of 39% plants in the east Midlands, 50% plants in Scotland and 30% plants in the south west, all considerably higher than the north (6%).

Botrytis affected 3.5% capsules in Scotland and up to 2.5% capsules in England, where it was most severe in the east.

Effect of fungicide treatments

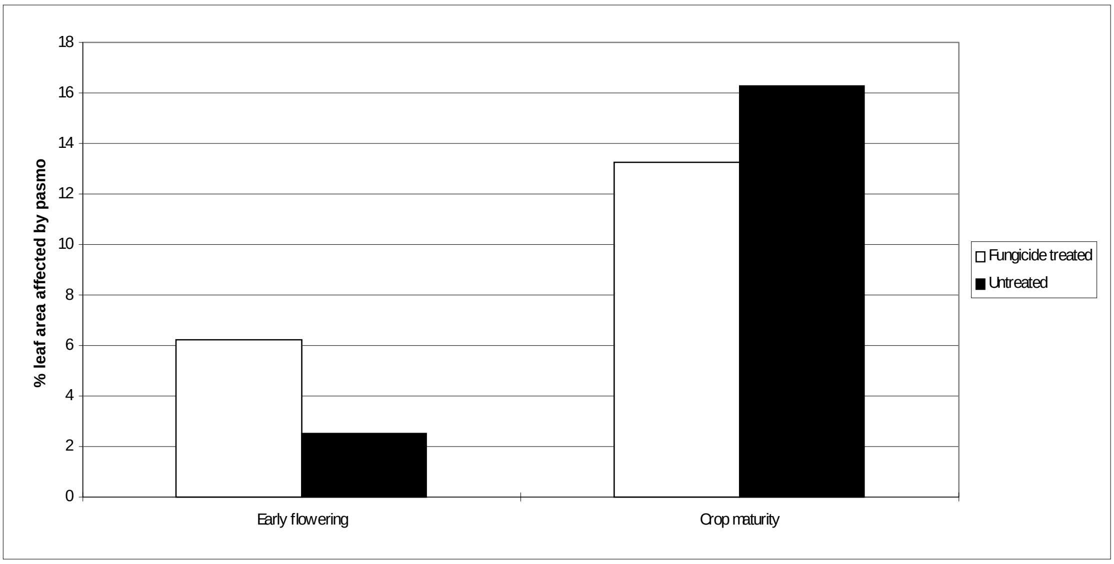

Fig. 10. Pasmo severity (% area affected) in untreated and fungicide-treated crops

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A total of 15 out of 30 crops received fungicide treatment during the growing season. Pasmo severity was higher at early flowering in crops that received fungicide than in those which remained untreated (Fig. 10). This position had been reversed by crop maturity, though differences were small (16.5% leaf area affected by pasmo in untreated crops, 13.2% in treated). However, stem pasmo affected 4.9% stem area in untreated crops and 6.9% in treated crops. On capsules, pasmo was less severe in treated (4.6% capsule area affected) than untreated crops (7.5% area).

There was little evidence that fungicides had controlled *Botrytis* on capsules as there was more infection in treated crops: 0.8% on untreated crops, 2.2% on treated crops. Powdery mildew was more prevalent in fungicide treated crops at both assessments: 0.7% leaf area affected in untreated, 3.0% in treated crops at early flowering, 1.2% in untreated and 1.6% in treated crops at crop maturity. Fungicide treated crops showed significantly lower areas of yellow and dead leaves and defoliation (bare stem) than untreated crops. Treatments were mainly applied during flowering (May/early June) and two crops received only a single spray in March.

The most frequently used fungicides were:

tebuconazole (as Folicur)	11 crops (5 used in tank mixture with MBC)
carbendazim (various products)	7 crops
iprodione + thiophanate methyl (as Compass)	2 crops
chlorothalonil (as Bravo)	1 crop
carbendazim + chlorothalonil (as Bravocarb)	1 crop

Lodging

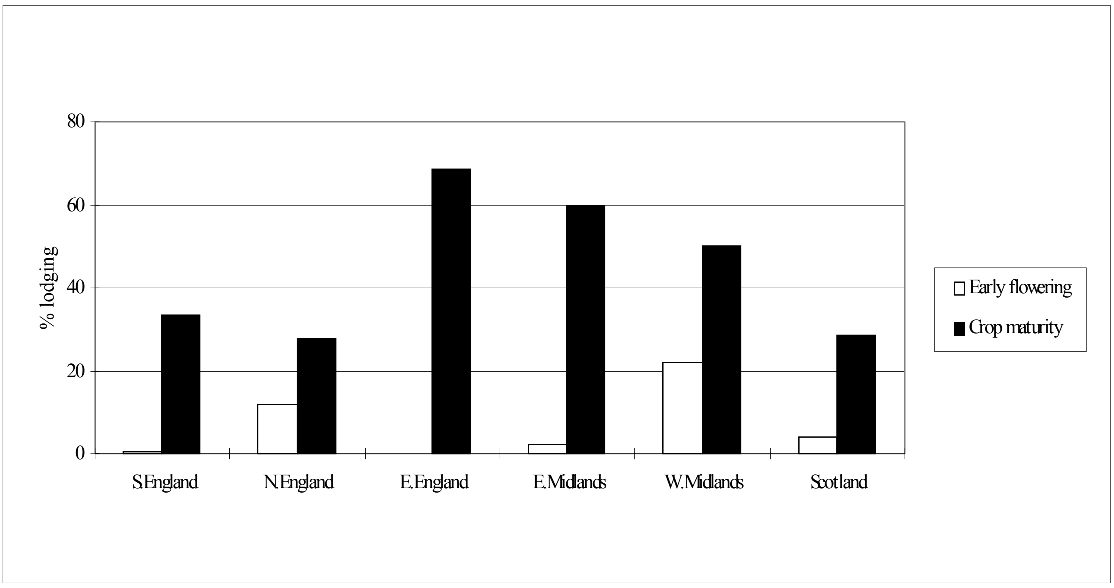

Fig. 11. Lodging severity (%) in different regions at early flowering and at crop maturity.

Lodging occurred in many crops at the early to mid-flowering stage following heavy rain on 20 May and again in early June, averaging 6.7% crop area affected at early flowering and 44.7% at maturity. Regional differences may therefore reflect differences in sampling relative to these rain events rather than inherent differences between crops or different areas. At crop maturity lodging was most serious in the east, east Midlands and west Midlands, almost twice the severity seen in the south west, north and Scotland (Fig. 11). Crops were tall and often dense in 1998 and, with plant height averaging 73 cm at early flowering and 80 cm at maturity; this is likely to have contributed to lodging problems (Fig. 12). In Scotland, plant height increased from 65 cm to 85 cm between assessments. Crop growth was vigorous and dense providing over 90% ground cover from early flowering, except in south west and north of England (Fig. 13).

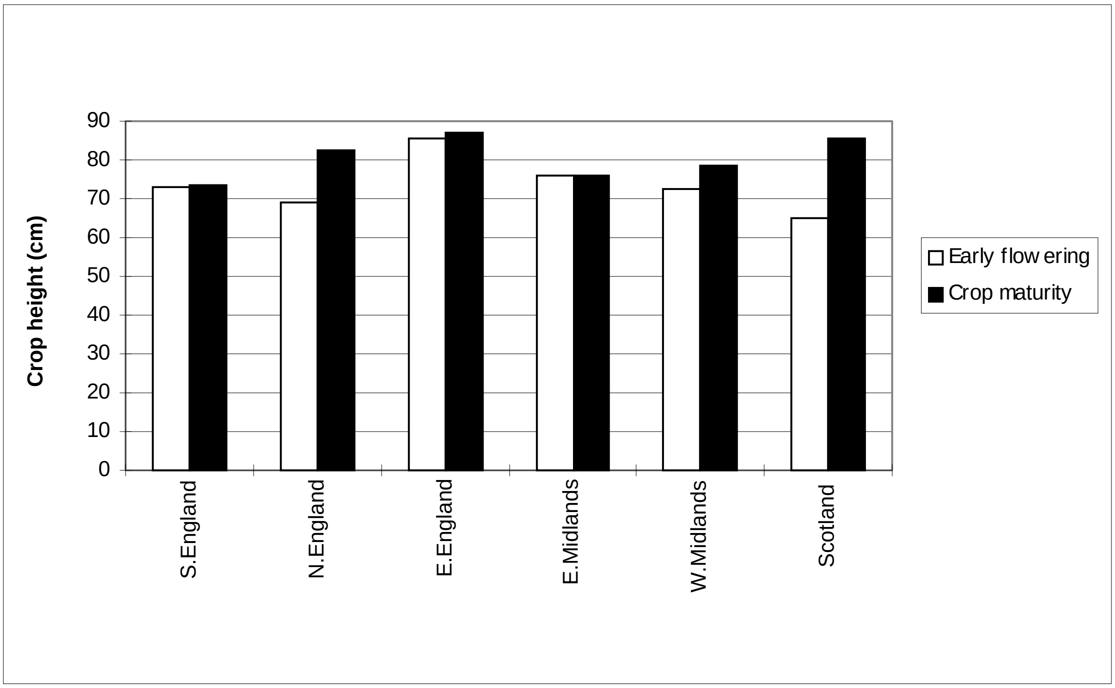

Fig.12. Mean crop height (cm) in different regions at early flowering and crop maturity.

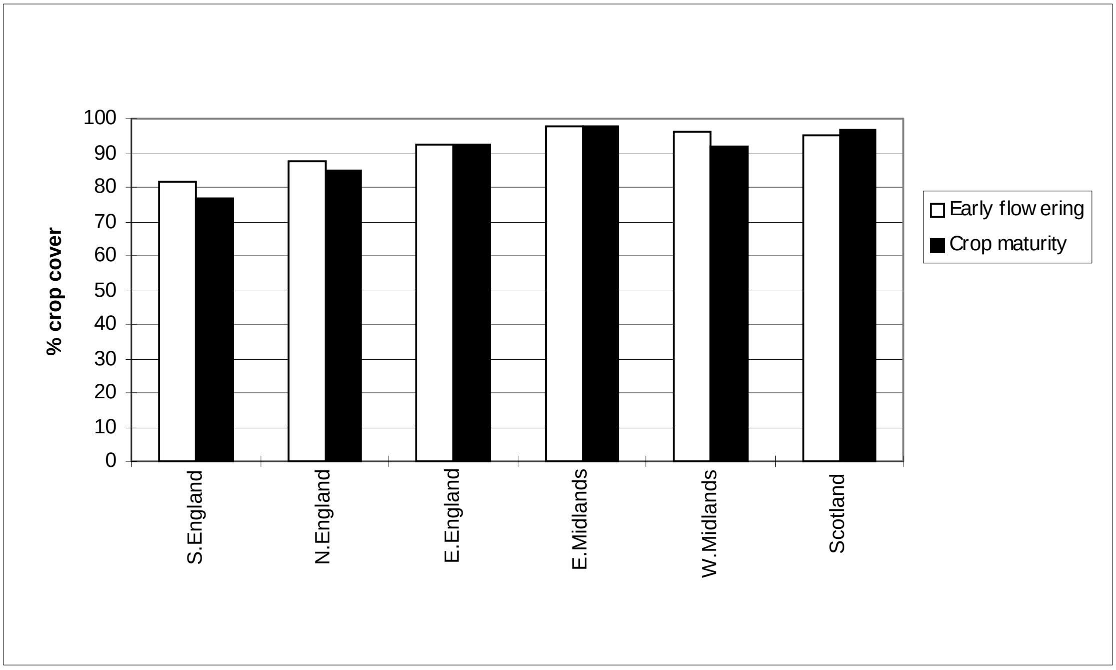

Fig. 13. Mean crop cover (%) in different regions at early flowering and crop maturity.

Weed cover & pest damage

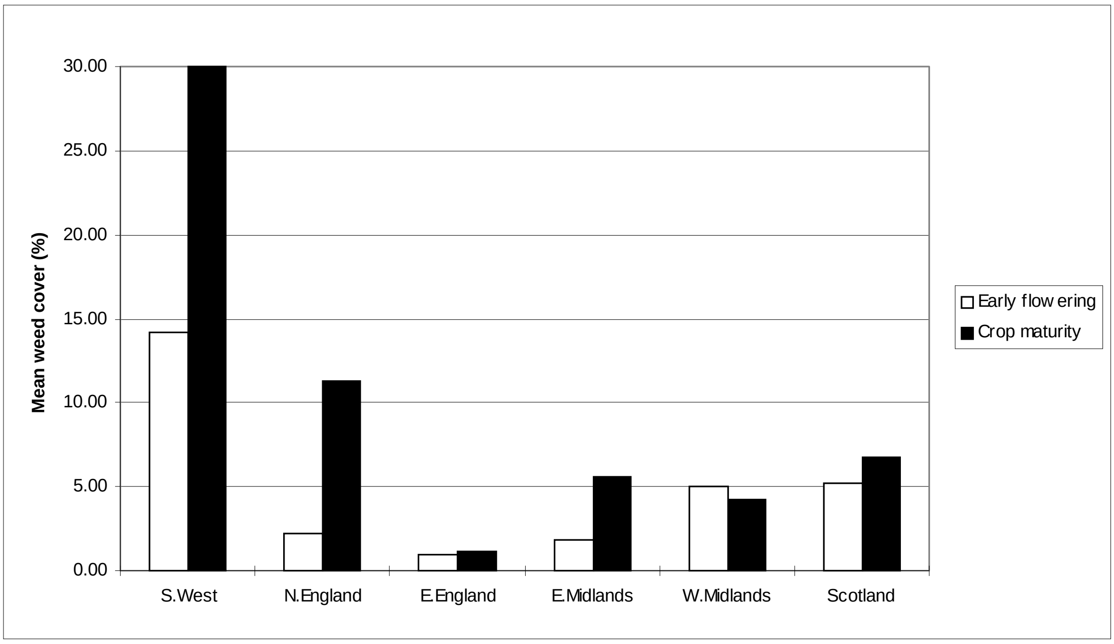

Fig.14. Mean weed cover (% area) in different regions at early flowering and cropmaturity.

Weeds were generally not troublesome, apart from some localised patches. Weed problems were most apparent in the south west and north. Weed cover increased between early flowering and crop maturity (Fig. 14) from 14% to 30% in south west and from 2% to 11% in the north of England. Slight leaf distortion or damage attributed to pests such as thrips, noted in low levels at early flowering in all areas, increased by crop maturity in the south west (0.6% area) and west Midlands (1.0% area) (Fig. 15), but damage remained slight.

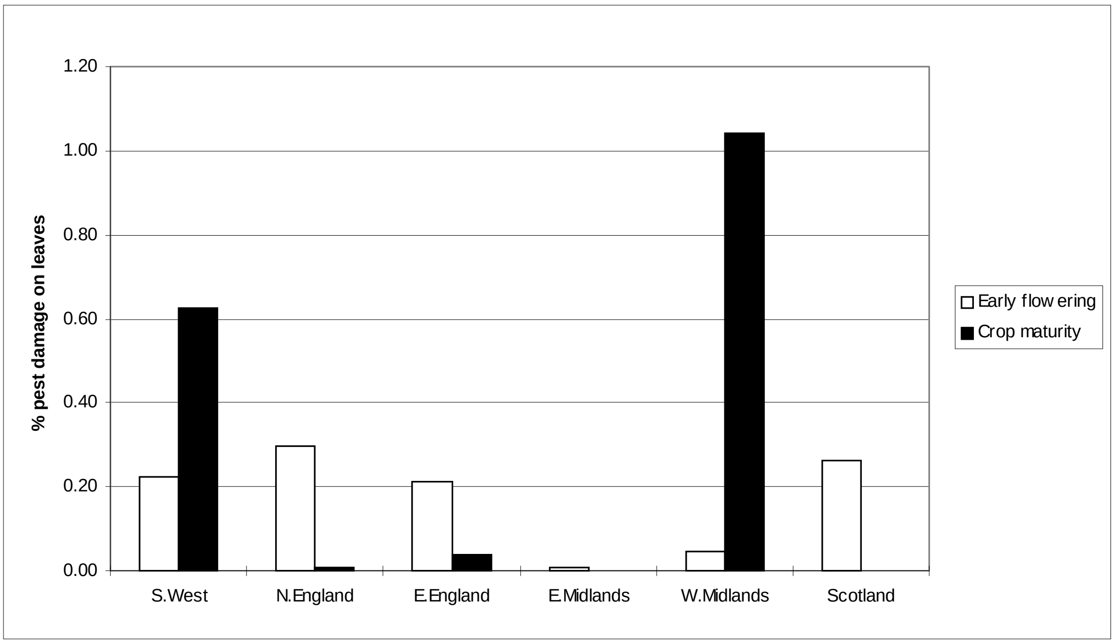

Fig. 15. Severity of pest damage on leaves (% area affected) in different regions atearly flowering and crop maturity.

1999

Cultivars, use of certified seed and seed treatments

The 30 crops examined in 1999 comprised only two cultivars; 28 crops were cv. Oliver and two crops in the south west were cv. Fjord. Most were grown from certified seed (70 %). The average seed rate was 52 kg/ha and those specifying a seed treatment used a prochloraz seed treatment (as Prelude). Crops were sown between mid-September and mid-October.

Disease incidence and severity

Pasmo was the most common disease, affecting leaves of 83 % crops at early flowering and 80% crops at crop maturity. Powdery mildew was much less prevalent at both early flowering and crop maturity (24% and 20% crops affected, respectively) and there were few cases of *Alternaria* leaf spot (7% and 13% crops, respectively) and *Botrytis* leaf spot (3% and 13% crops, respectively) (Fig. 16). Few stem diseases were found and only pasmo affected more than 25% crops, occurring on 55% crops at early flowering and 90% crops at maturity. *Sclerotinia*, *Fusarium* and *Phoma* stem rots were not found. *Botrytis* stem rot was found in 23% crops at maturity. Capsules were affected by *Botrytis* in 83% crops and pasmo affected the bracts surrounding the capsule in 63% crops. *Alternaria* was present on capsulses in 13% crops.

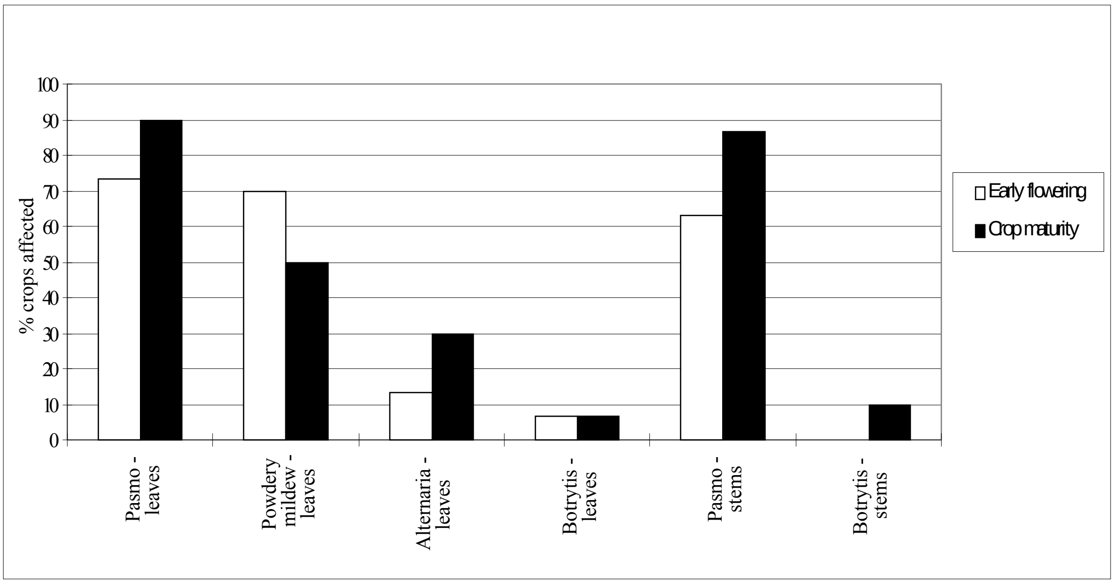

Fig. 16. Incidence of diseases (% crops affected) at early flowering and at crop maturity.

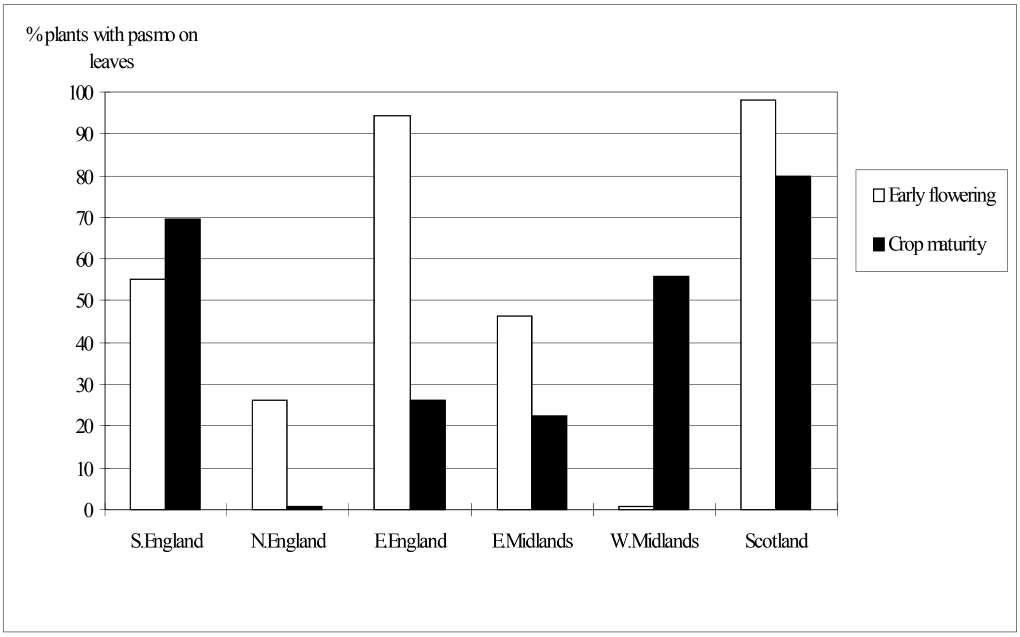

Fig. 17. Incidence of pasmo (% plants) on leaves by region at early flowering and at crop maturity.

The regional distribution of the major diseases is shown in Fig. 17. Pasmo was most common in the east and Scotland at the early flowering stage and its incidence on leaves decreased between early flowering and crop maturity in all areas except the west Midlands (Fig. 17). The south west and east Midlands had the lowest severity of pasmo, other areas had only the occasional severe problem (e.g. 87% leaf area affected in one crop in the south west and 37% leaf area affected in a crop from the Borders). Disease severity data, showed that pasmo severity was highest at early flowering in the east (3.5% leaf area affected) and Scotland/Borders (4.3% area). By crop maturity, the south west averaged 24.8% leaf area affected and Scotland/Borders 12.7% area, compared with 0.1% in East Midlands and 0.04% area in the north of England (Fig. 18).

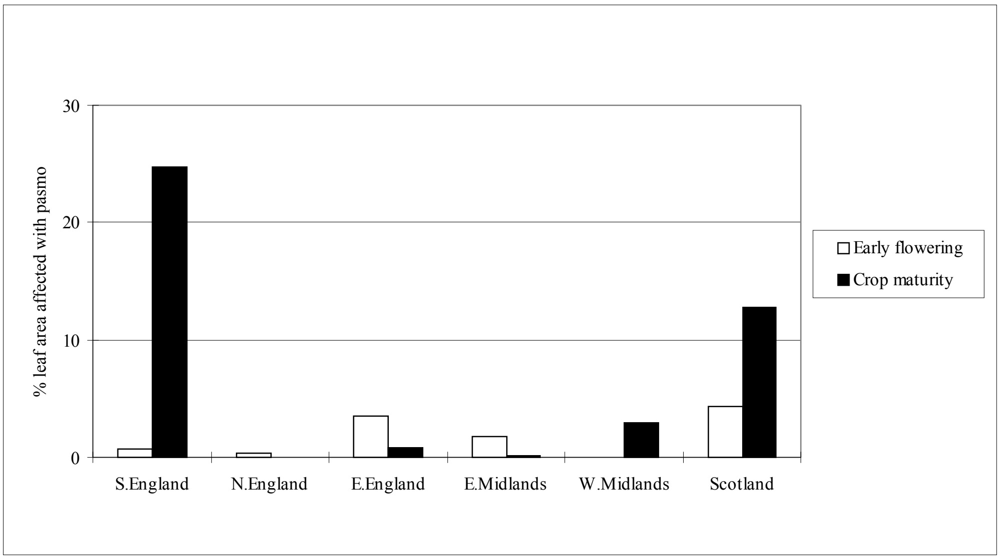

Fig. 18. Severity of pasmo on leaves (% area affected) in different regions at early flowering and at crop maturity.

Powdery mildew was much less prevalent than in 1998 and was not recorded in the south west on either visit or in the north and east on the first visit. It was common in the west Midlands (33% plants affected at early flowering, 10% plants affected at maturity) and Scotland/Borders (26% plants affected at early flowering only) (Fig. 19) at early flowering, declining as leaves senesced by crop maturity. Average severity remained below 1% leaf area affected in all areas, with maximum of 0.8% area affected at crop maturity in the north (Fig. 20).

Pasmo was less common as a stem disease in 1999 in some regions and was found in 55% crops at early flowering, whereas in 1998 all areas except the north of England had stems affected by early flowering (Fig. 21). In 1999, it was particularly common at crop maturity in the east (96% plants affected), east Midlands (94% plants) and Scotland (94% plants) as in 1998 (Fig. 21). The severity of pasmo was greatest in the south west (11.9% stem area affected) and lowest in the West Midlands (1.0% area) and north of England (1.3% area affected) at crop maturity (Fig.22).

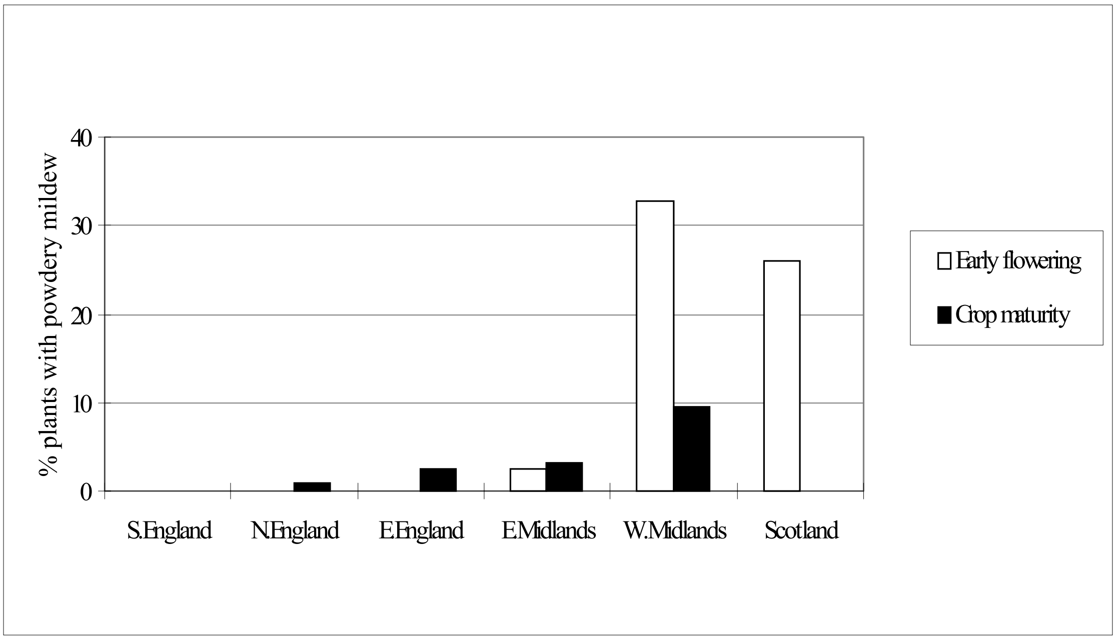

Fig. 19. Incidence of powdery mildew on leaves (% plants affected) in different regions at early flowering and at crop maturity.

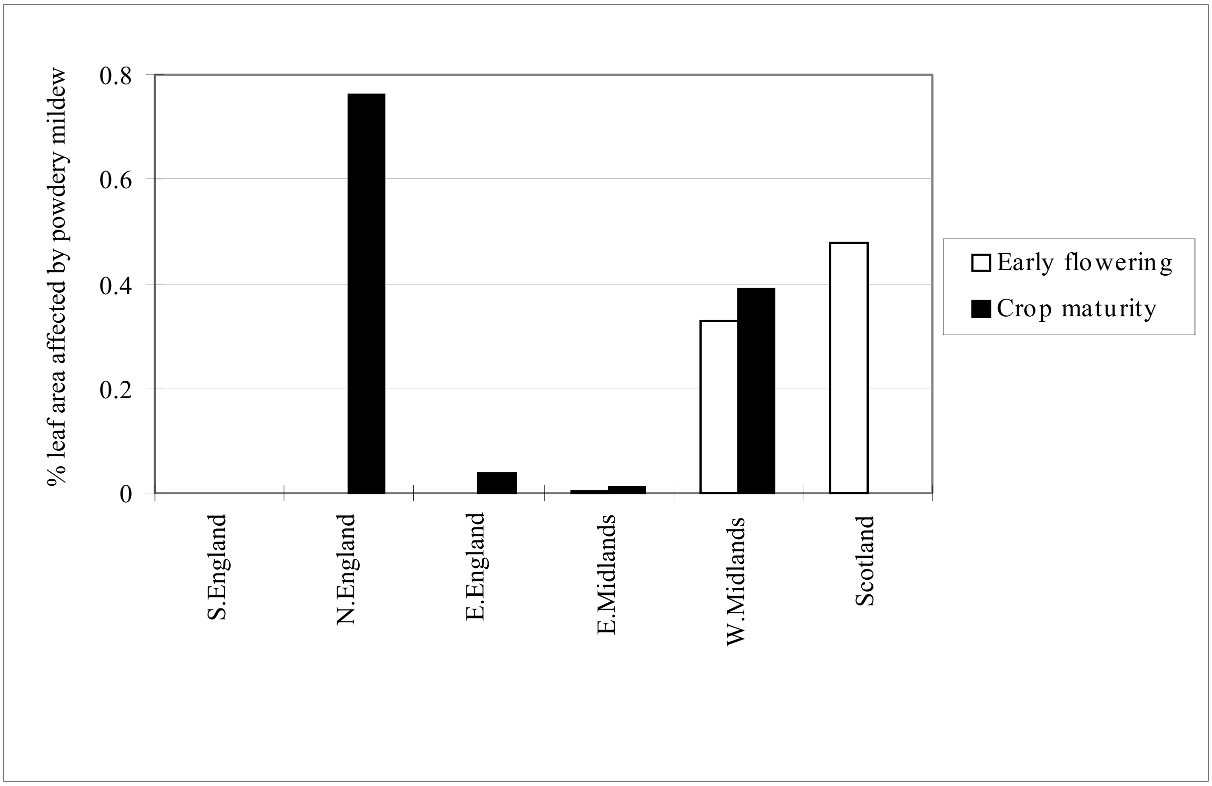

Fig. 20. Severity (% leaf area affected) of powdery mildew on leaves in different regions at early flowering and at crop maturity.

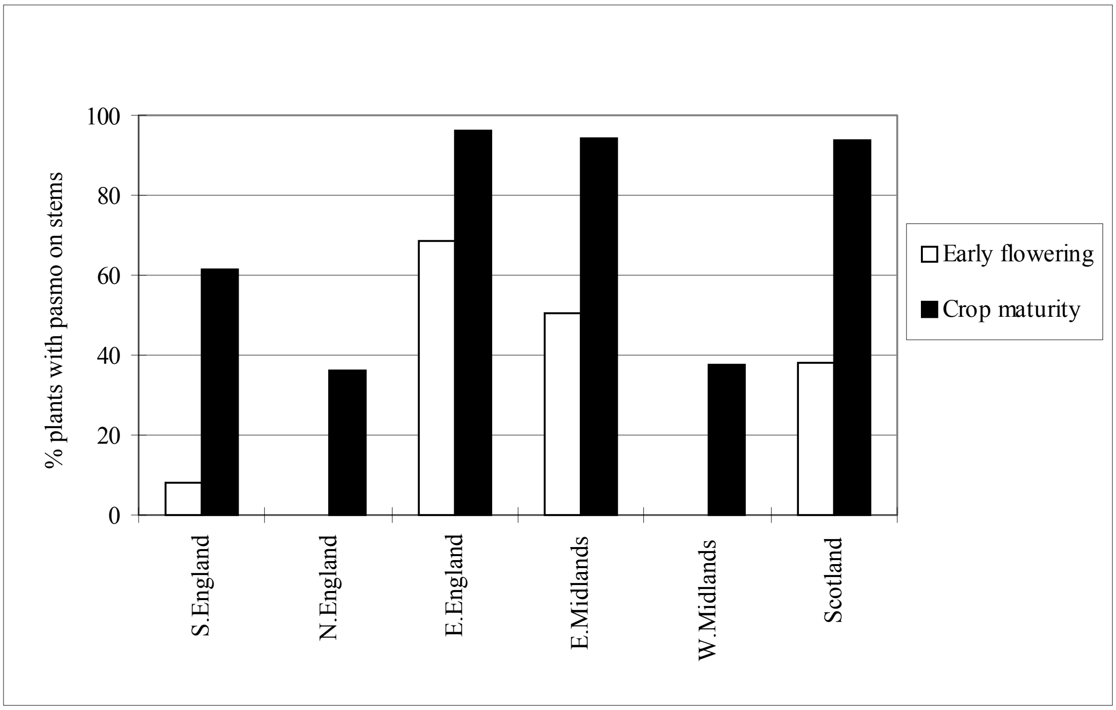

Fig. 21. Incidence of pasmo on stems (% stems affected) in different regions at earlyflowering and at crop maturity.

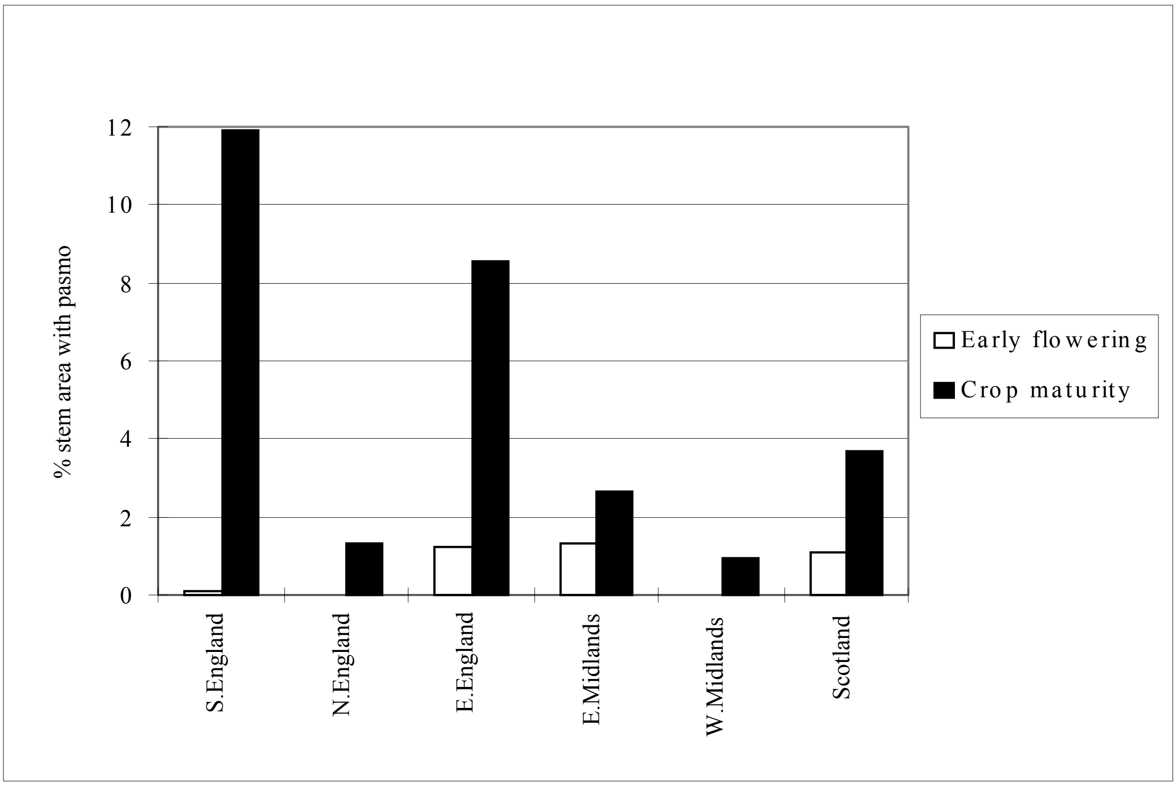

Fig. 22. Severity of pasmo on stems (% area affected) in different regions at earlyflowering and crop maturity.

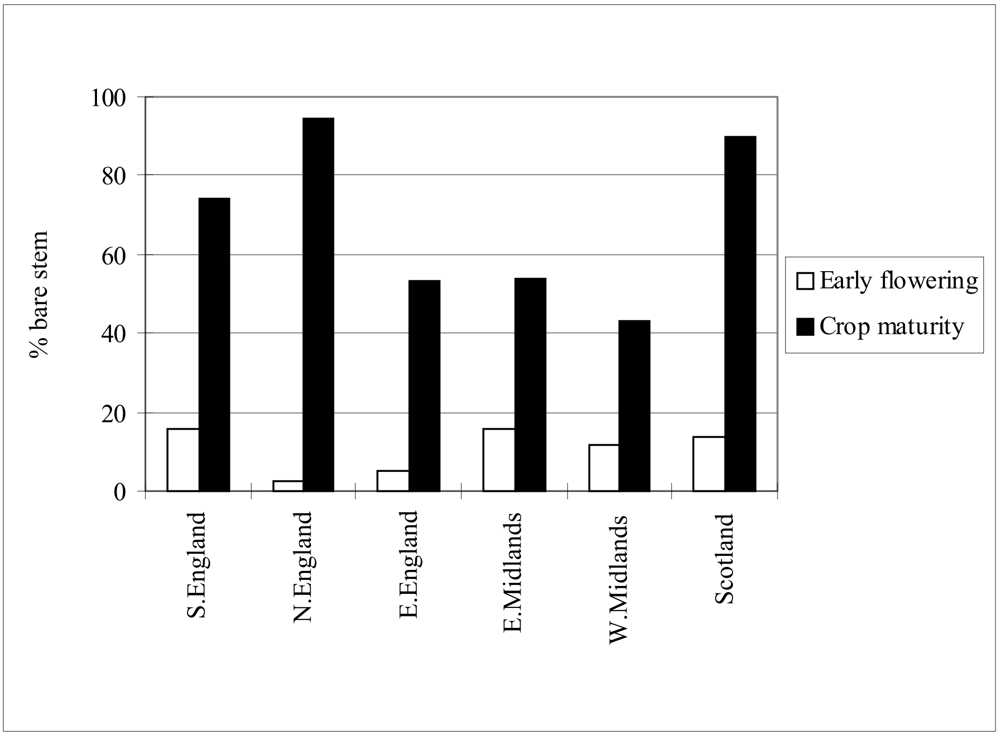

Fig. 23. Extent of leaf loss from stems (% area bare stem) in different regions at early flowering and crop maturity.

Pasmo contributed to leaf senescence and to yellowing and leaf loss, but its effects were less marked than in 1998, because spotting only occasionally reached the upper canopy. The proportion of the stem which had defoliated is expressed as the percentage bare stem (Fig. 23) and showed an average of 11% defoliation at early flowering (16% in south west and East Midlands). At crop maturity, disease and natural senescence combined to give about 68% bare stem in England, with most bare stem in the north (94%) and in Scotland (90% bare stem).

Alternaria leaf spotting (*Alternaria linicola*) was recorded only in two crops at early flowering and these were in the south west (4 % plants affected) and the west Midlands (12% plants). By crop maturity, four crops had *Alternaria* on leaves and these were from south west (53% plants) and showed 2.1% leaf area affected. Stem rots were generally of minor significance with no *Sclerotinia*, *Phoma* or *Fusarium* being confirmed. *Botrytis* stem rots affected up to 16% stems in Scotland and 4% stems in eastern England, the only English region affected.

Pasmo was commonly found on the bracts surrounding the capsule in all areas except the East Midlands (Fig. 24). It was most severe in the south west affecting 5.1% area and least severe in the East Midlands (0% area). *Botrytis* was found on capsules on an average of 32% plants, affecting 7% capsules in the east and 6% capsules in Scotland, considerably higher than the north (0.3%).

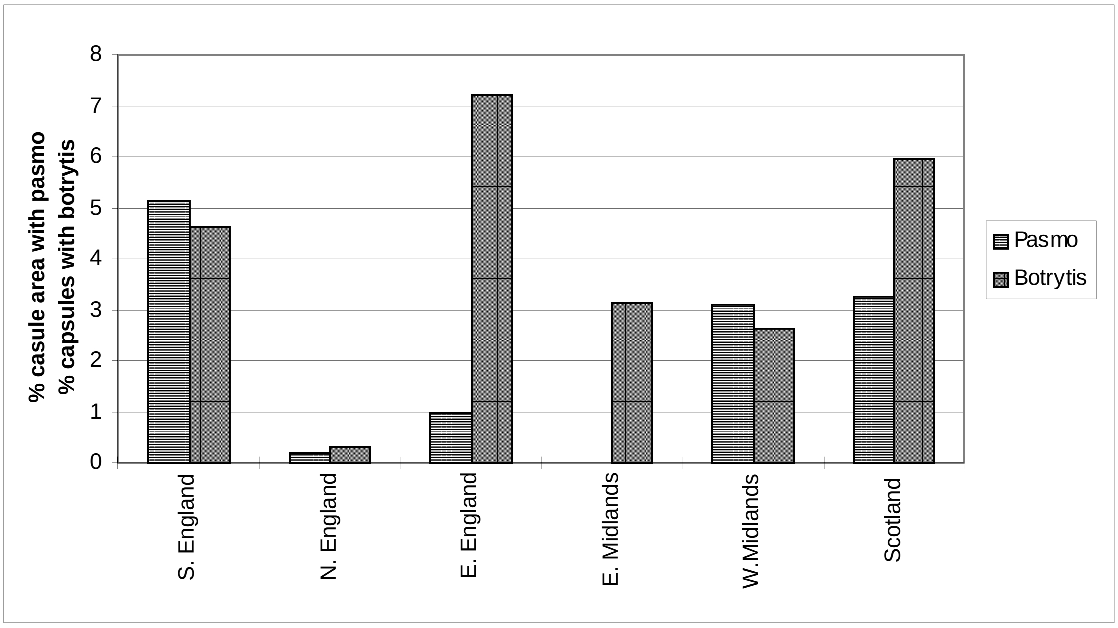

Fig. 24. Severity of pasmo on capsule bracts (% area affected) and percentage of capsules with *Botrytis* in different regions at crop maturity.

Effect of fungicide treatments

A total of 22 out of 30 crops received fungicide treatment during the growing season, an increase of 23% over 1998. Three crops received a two spray programme and two crops received three spray applications. Tebuconazole with an MBC fungicide was the most widely used treatment. There is limited data on which to base comparisons of untreated and treated crops. At crop maturity, however pasmo severity on leaves was higher in untreated crops (17% area affected) than in treated crops (5% area affected). There was more bare stem but less dead and yellow leaf retention in untreated crops.

The most frequently used fungicides were:

tebuconazole (as Folicur)	20* crops
carbendazim (various products)	16 crops
iprodione + thiophanate methyl (as Compass)	2 crops
chlorothalonil (as Bravo)	3 crops
carbendazim + chlorothalonil (as tank mix)	1 crop .

(* 14 in tank mixtures with carbendazim products and 2 with chlorothalonil products)

Lodging

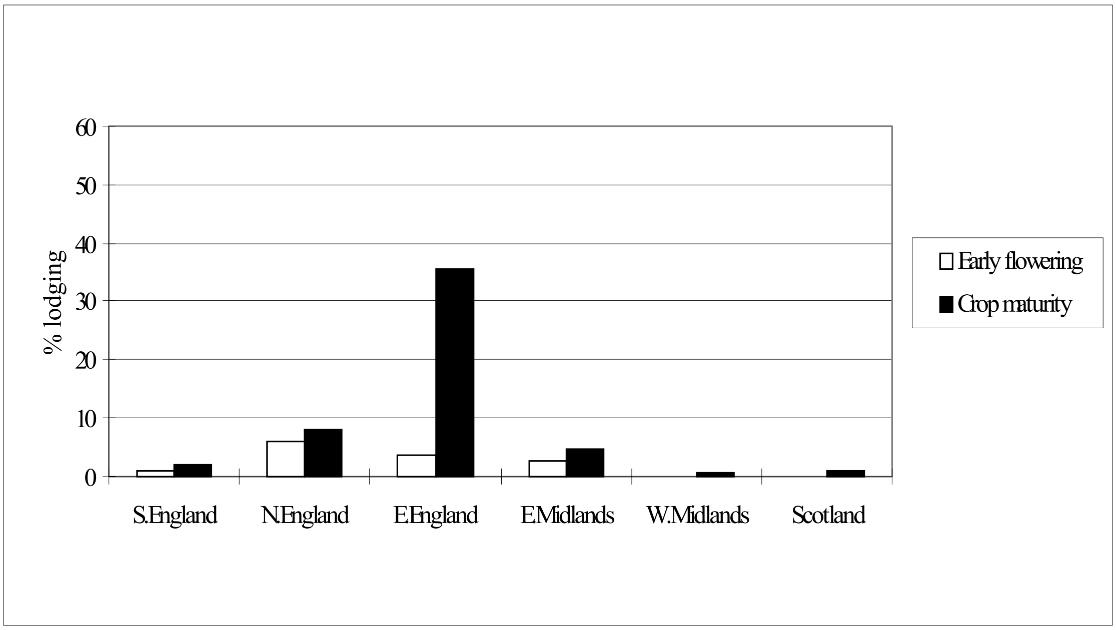

Fig. 25. Lodging severity (%) in different regions at early flowering and at crop maturity.

Lodging was much less of a problem in 1999 than in 1998 and problems were only serious in two crops in the east which had 80-85% crop affected (Fig. 25). Crops were slightly less tall than in 1998 with plant height averaging 65 cm compared with 73 cm in 1998 at early flowering and 67 cm (80 cm in 1998) at maturity. The shorter height of crops is likely to have reduced lodging problems (Fig. 26).

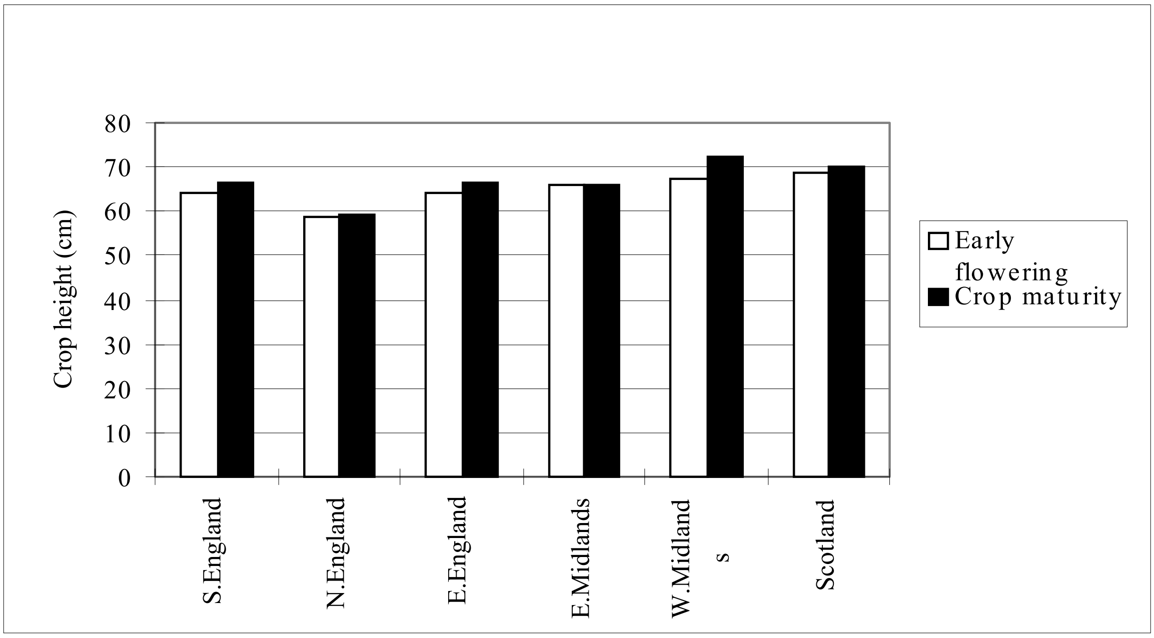

Fig. 26. Mean crop height (cm) in different regions at early flowering and crop maturity.

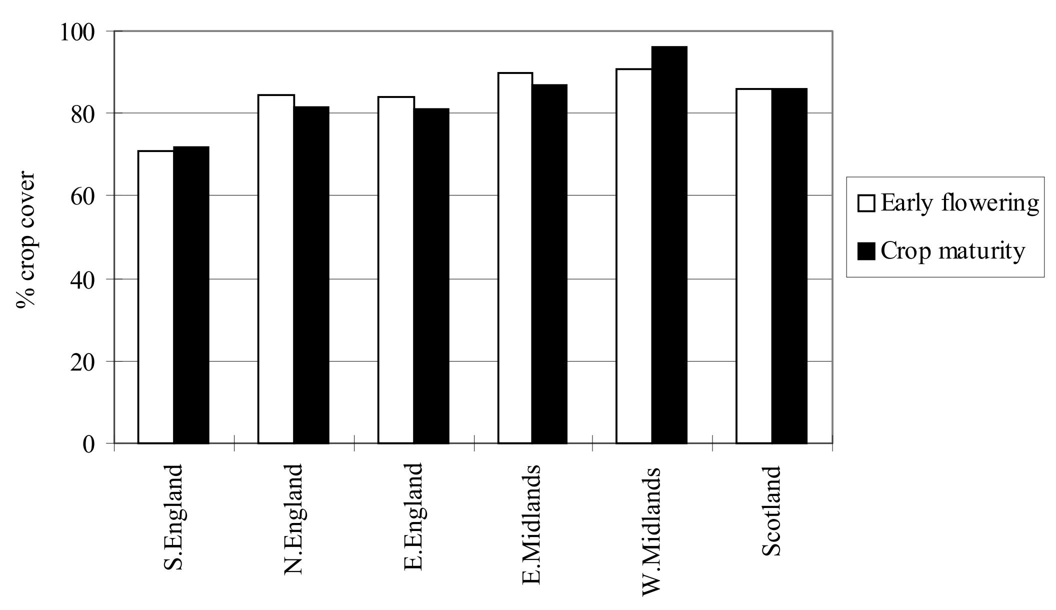

Fig. 27. Mean crop cover (%) in different regions at early flowering and crop maturity.

Crop growth was rather less vigorous and dense than in 1998 and provided 84% ground cover from early flowering. In south west England (Fig. 27), crop cover was only 71%, well below other regions.

Weed cover & pest damage

Weed problems were most apparent in the south west and Scotland and weed cover increased between early flowering and crop maturity (Fig. 28) from 20% to 31% in south west and from 5% to 11% in the west Midlands. Slight leaf distortion or notching damage attributed to pests such as thrips and flea beetles was noted at low levels particularly at early flowering in all areas. The most damage was recorded in the south west (0.2% area) and east and west Midlands (0.3% and 0.5% area, respectively) (Fig. 29). There was little damage at crop maturity as the upper leaves were less affected than those at the mid plant level.

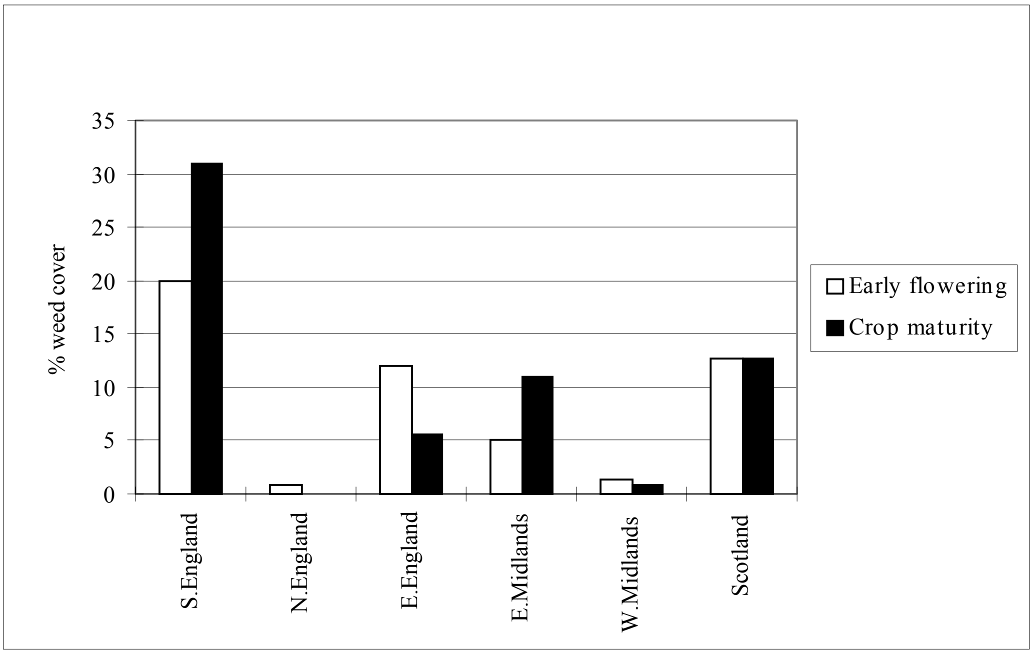

Fig. 28. Mean weed cover (% area) in different regions at early flowering and cropmaturity.

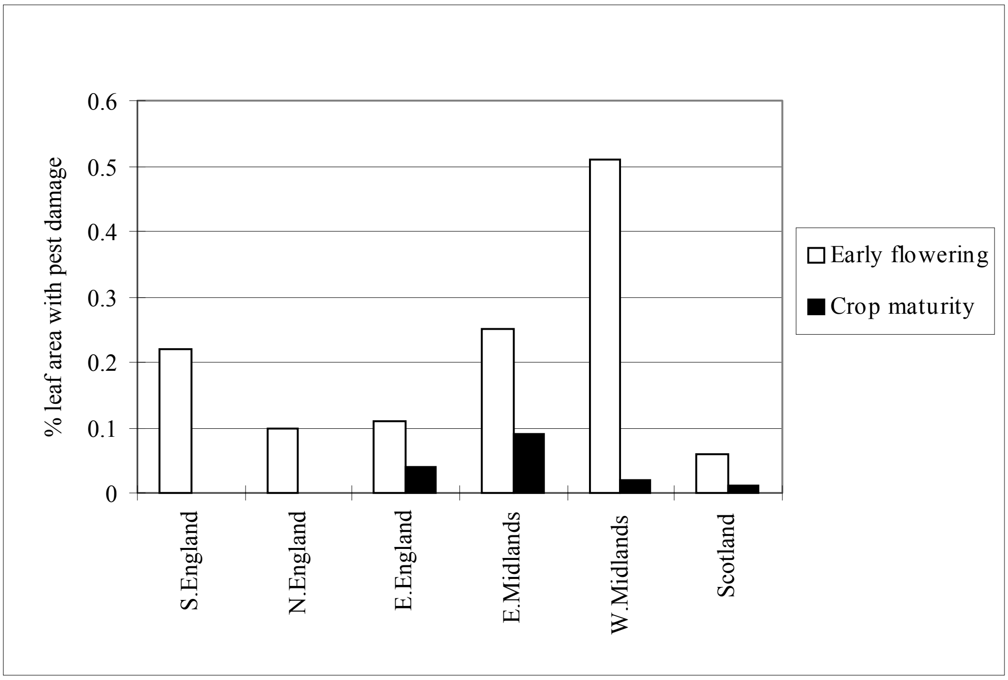

Fig. 29. Severity of pest damage on leaves (% area affected) in different regions at early flowering and crop maturity.

2000

Cultivars, use of certified seed and seed treatments

There were thirty crops examined in 2000, of which winter crops were cv. Oliver and spring crops included Baikal, Barbara, Jupiter, McGregor, Mikael, Oskar, Norlin and Taurus. Most were grown from certified seed (70 %). The average seed rate was 51.6 kg/ha and seed treatment was mainly prochloraz (as Prelude) with some carboxin + thiram (Vitavax) and imported insecticide (e.g. Lindex) use. There was some use of seed treatments on home-saved seed (6% crops). Winter crops were sown from mid-September to mid-October and spring crops from early March to early May.

Disease incidence and severity

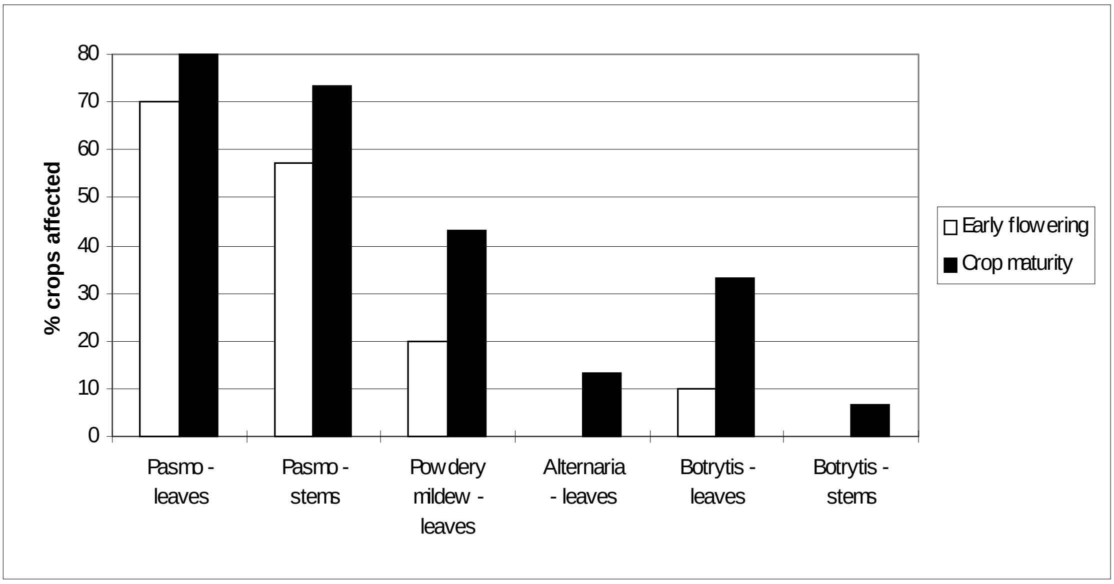

Fig. 31. Incidence of diseases (% crops affected) at early flowering and at crop maturity.

Pasmo was the most common disease, affecting leaves of 70% crops at early flowering and leaves on 80% crops at crop maturity. Powdery mildew was found in 20% crops at early flowering and 43% crops at crop maturity. *Alternaria* leaf spot was found only at crop maturity in 13% crops whilst *Botrytis* leaf spot affected 10% and 33% crops at early flowering and crop maturity, respectively (Fig. 31). Stem diseases were found and pasmo was the most important, occurring on 57% crops at early flowering and 73% crops at maturity. *Sclerotinia* and *Phoma* stem rots were not found in 2000 and *Botrytis* stem rot was recorded in only 2 crops in the east. Capsules were affected by *Botrytis* in 70% crops and pasmo affected the bracts surrounding the capsule in 83% crops. The regional variation in pasmo incidence on leaves is shown in Fig. 32.

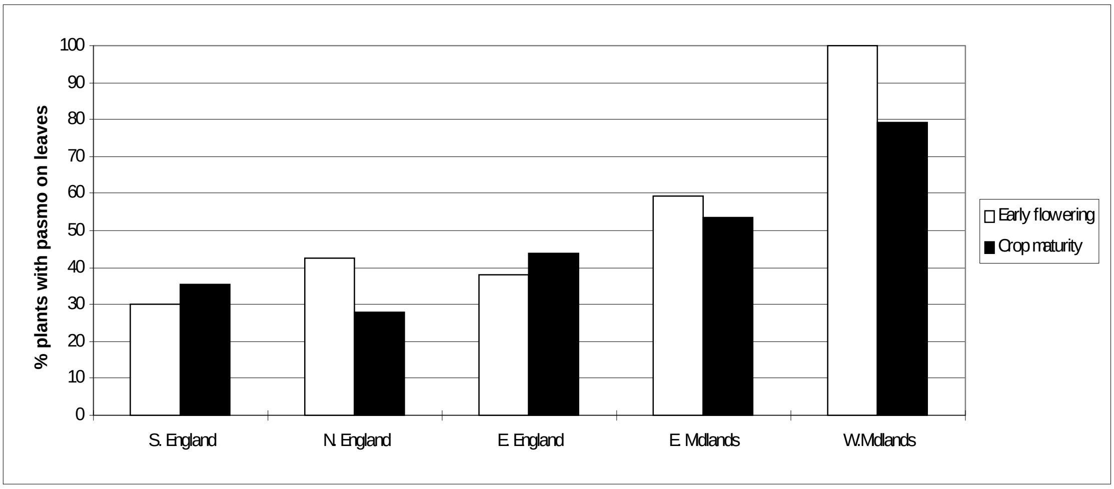

Fig. 32. Incidence of pasmo (% plants) on leaves by region at early flowering and at crop maturity.

Pasmo was common in all regions and most frequently recorded in the west Midlands, where all plants were affected at early flowering (Fig. 32). There was a decline in the incidence of leaf spotting by crop maturity compared with early flowering in the north and east Midlands brought about by extensive leaf loss. Pasmo showed large increases in severity on leaves between early flowering and crop maturity in the south, east and west Midlands (Fig. 33).

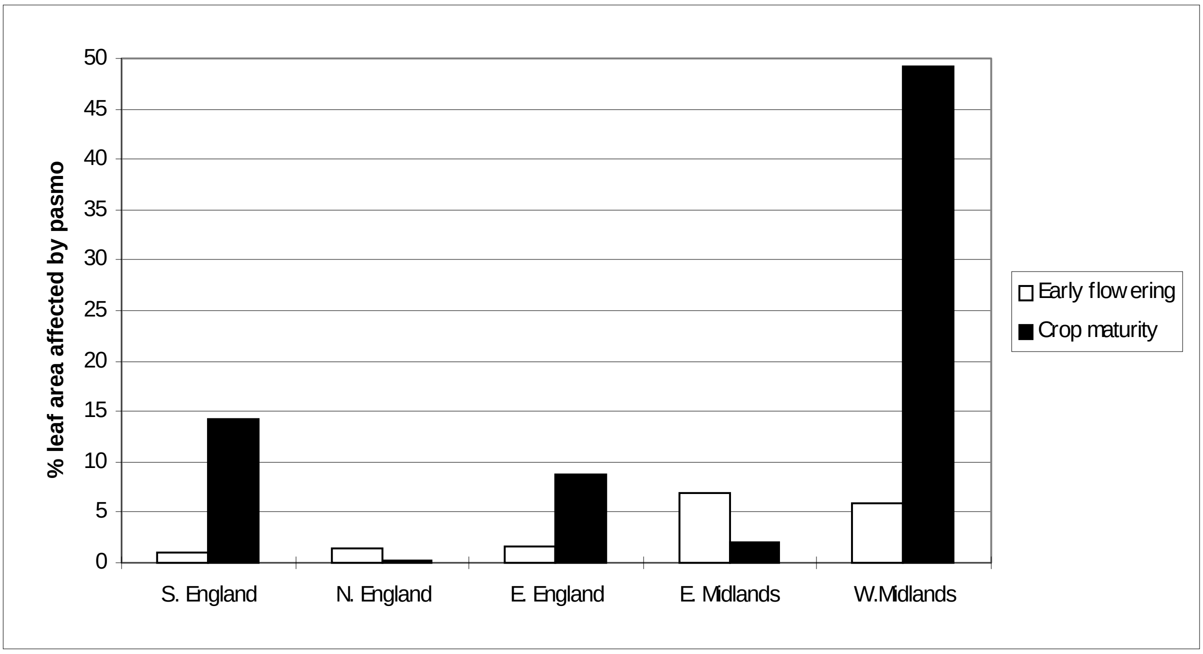

Fig. 33. Severity of pasmo on leaves (% area affected) in different regions at early flowering and at crop maturity.

Powdery mildew was not recorded in the north or west Midlands at early flowering, but was most common in the east (38% plants affected) (Fig. 34). By crop maturity, powdery mildew was present in all regions except the west Midlands and was most prevalent in the south and east Midlands. Average severity reached 15% leaf area affected in the south and east at early flowering (Fig. 35), with further increases being apparent in the south, east Midlands and north in the period up to crop maturity.

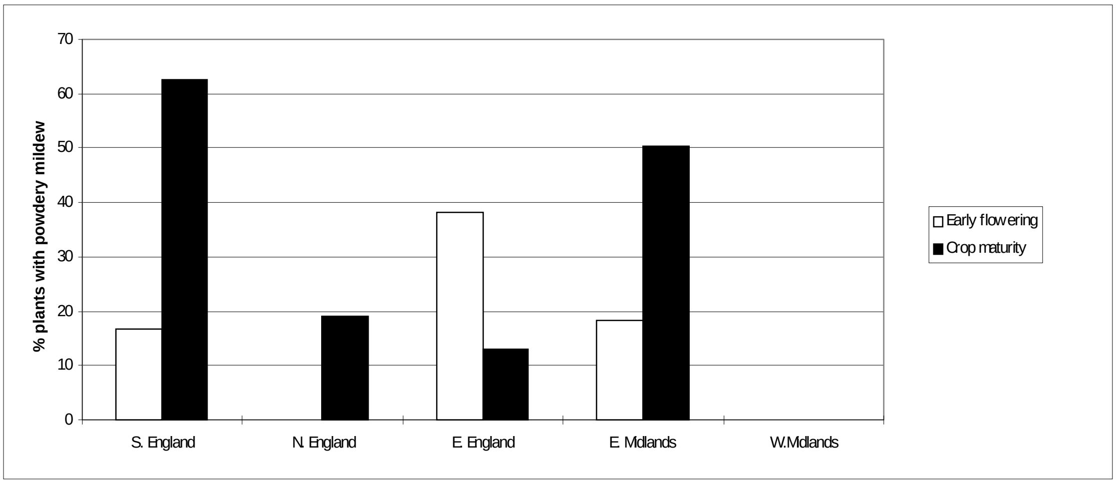

Fig. 34. Incidence of powdery mildew on leaves (% plants affected) in different regions at early flowering and at crop maturity.

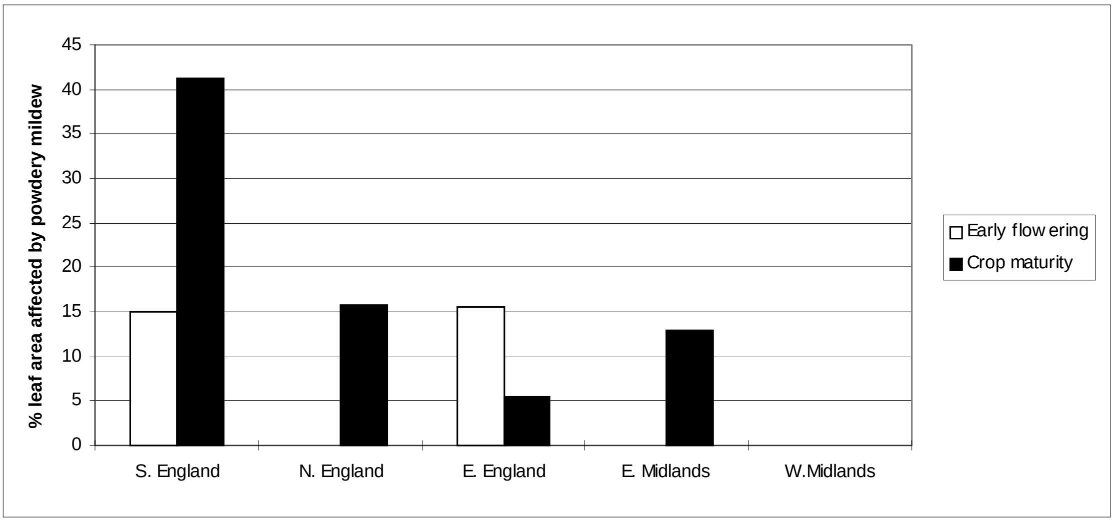

Fig. 35. Severity (% leaf area affected) of powdery mildew on leaves in different regions at early flowering and at crop maturity.

Pasmo was the most common stem disease and had affected more than 25% stems by early flowering in all areas except the south of England (Fig. 36). It was more common at crop maturity in all regions except the east Midlands by crop maturity, notably in the west Midlands (100% plants affected) and east (68% plants) (Fig. 36). The severity of pasmo on stems was greatest in the west Midlands and east and lowest in the north of England at crop maturity (Fig.37). Pasmo undoubtedly accelerated leaf senescence and contributed to yellow and dead leaves and leaf loss. The proportion of the stem that had defoliated is expressed as the percentage bare stem (Fig. 38). At crop maturity, disease and natural senescence combined to give about 44-84% bare stem, with most leaf loss in the west Midlands and east where pasmo was most severe on stems.

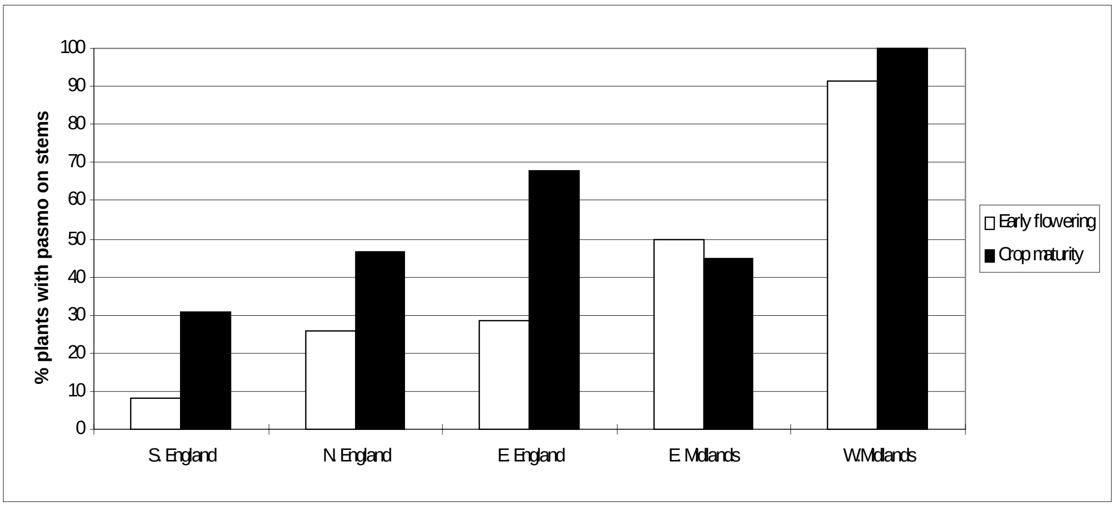

Fig. 36. Incidence of pasmo on stems (% stems affected) in different regions at early flowering and at crop maturity.

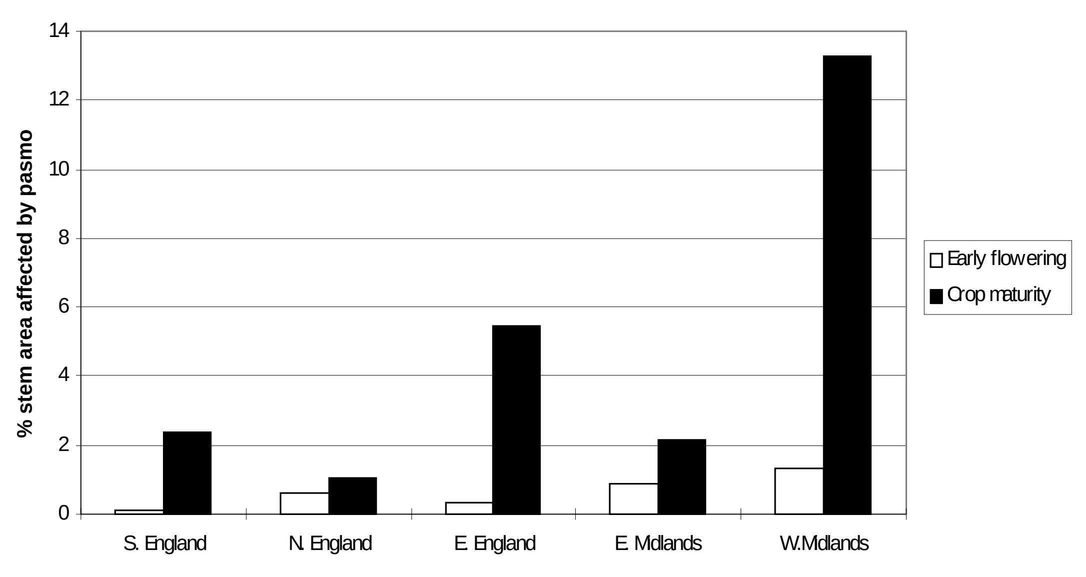

Fig. 37. Severity of pasmo on stems (% area affected) in different regions at early flowering and crop maturity.

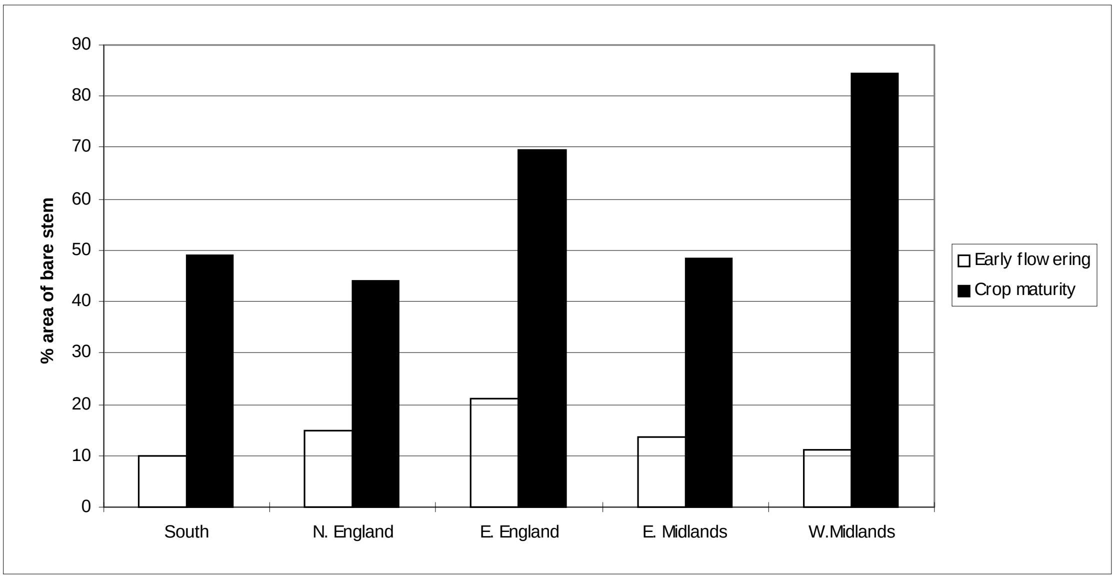

Fig. 38 Extent of leaf loss from stems (% area bare stem) in different regions at early flowering and crop maturity.

Alternaria leaf spotting (*Alternaria linicola*) was not recorded at early flowering. By crop maturity, four crops showed *Alternaria* on leaves and these were all from the south west (22.0% plants). Stem rots were generally of minor significance with no *Sclerotinia* being recorded, despite above average infection in winter oilseed rape crops in 2000. *Botrytis* stem rots affected two crops and these showed 16% and 20% stems affected. Interestingly, both of these were crops of cv. Mikael which did receive fungicide sprays. There were no records of *Phoma* or *Fusarium* stem rots.

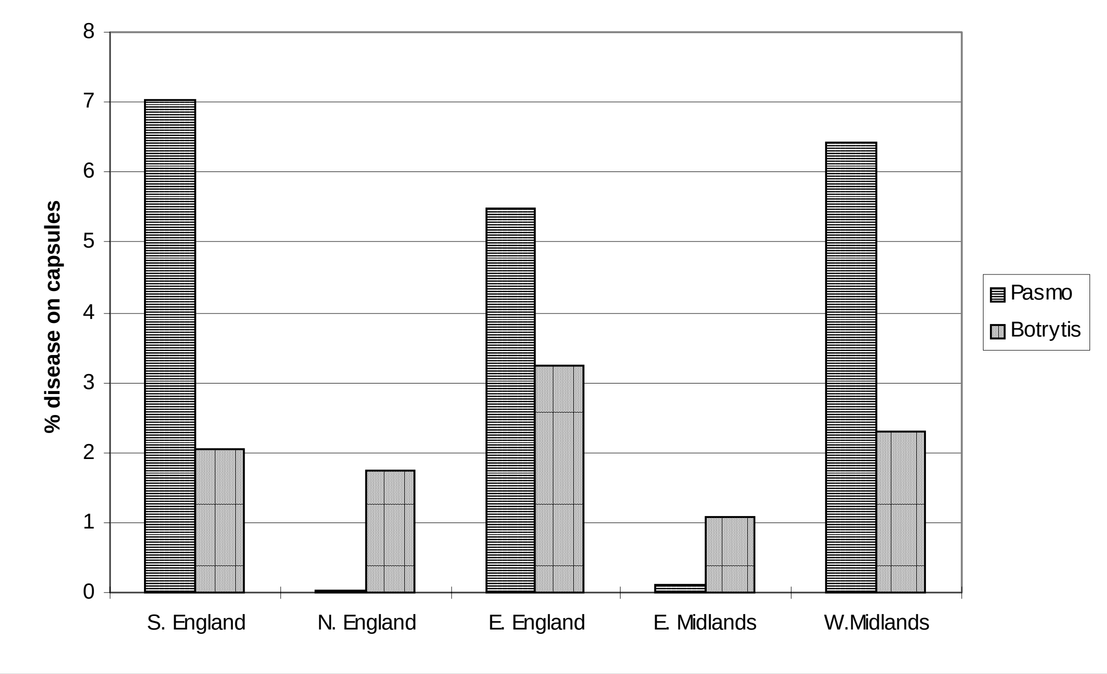

Fig. 39. Severity of pasmo on capsule bracts (% area affected) and % capsules with *Botrytis* in different regions at crop maturity.

Pasmo was found on the bracts surrounding the capsule in all areas, with the most severe infection occurring in the west Midlands, south and east (Fig. 39). *Botrytis* was found on capsules in all regions and showed the highest incidence (2-3% capsules affected) in the west Midlands, south and east.

Comparison of winter and spring linseed

Pasmo was much more prevalent in winter than spring linseeed at early flowering on leaves and stems and the contrast was less marked at crop maturity. Powdery mildew was present only in spring cultivars at early flowering. At crop maturity, a low level (94% plants) of powdery mildew was found in winter linseed. Fine black spotting was very common on winter linseed at early flowering and this declined by crop maturity, whilst spotting remained at low levels throughout on spring linseed (Fig. 40).

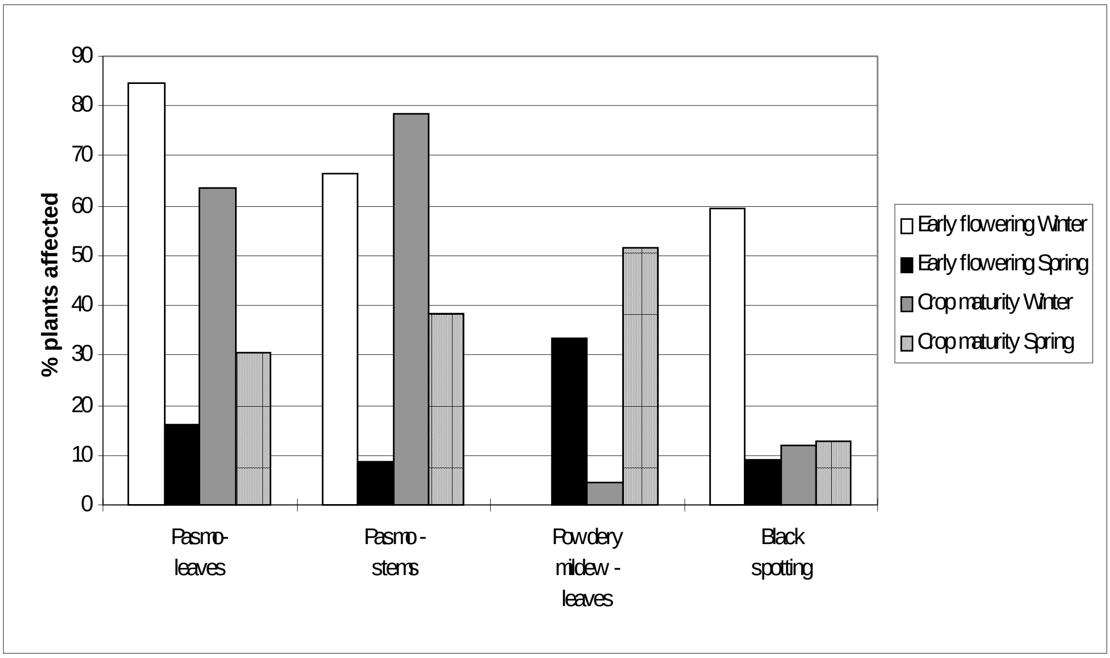

Fig. 40. Incidence of diseases on winter and spring linseed crops at early flowering and crop maturity.

Effect of fungicide treatments

A total of 14 out of 30 crops received fungicide treatment during the growing season, but there was a large difference between spring and winter crops. Fungicide sprays were applied to 12 out of 15 winter crops (80% treated) and to two out of 15 spring crops (13% treated).

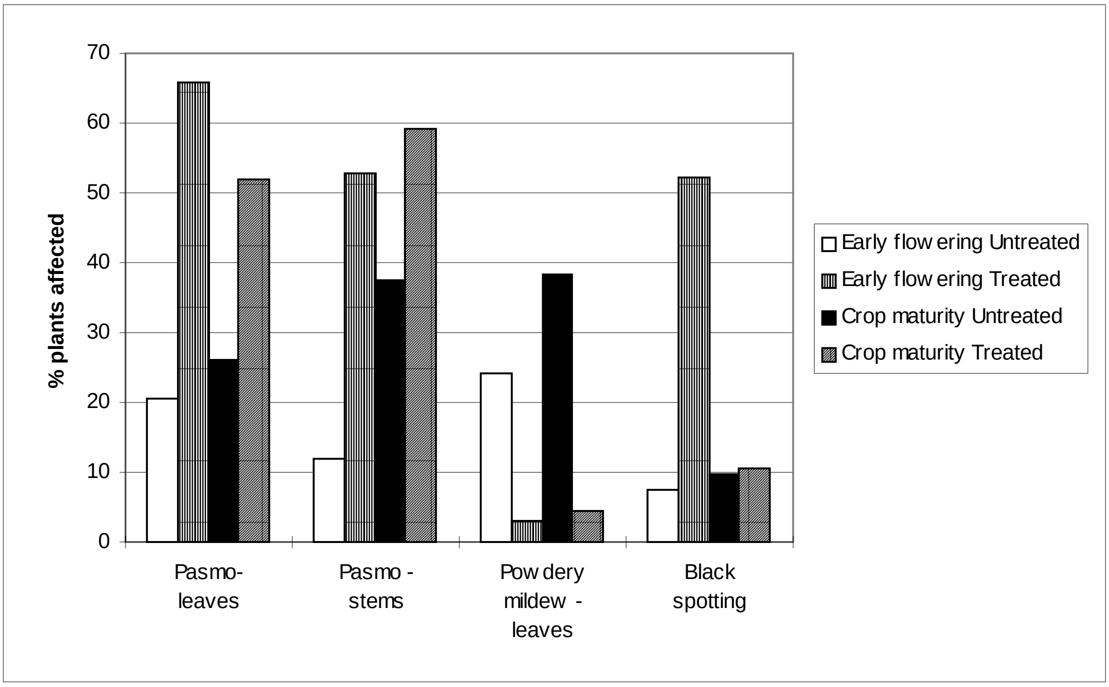

Fig. 41. Pasmo, powdery mildew and black spotting incidence (% plants affected) in untreated crops and in those treated with fungicide at early flowering and crop maturity.

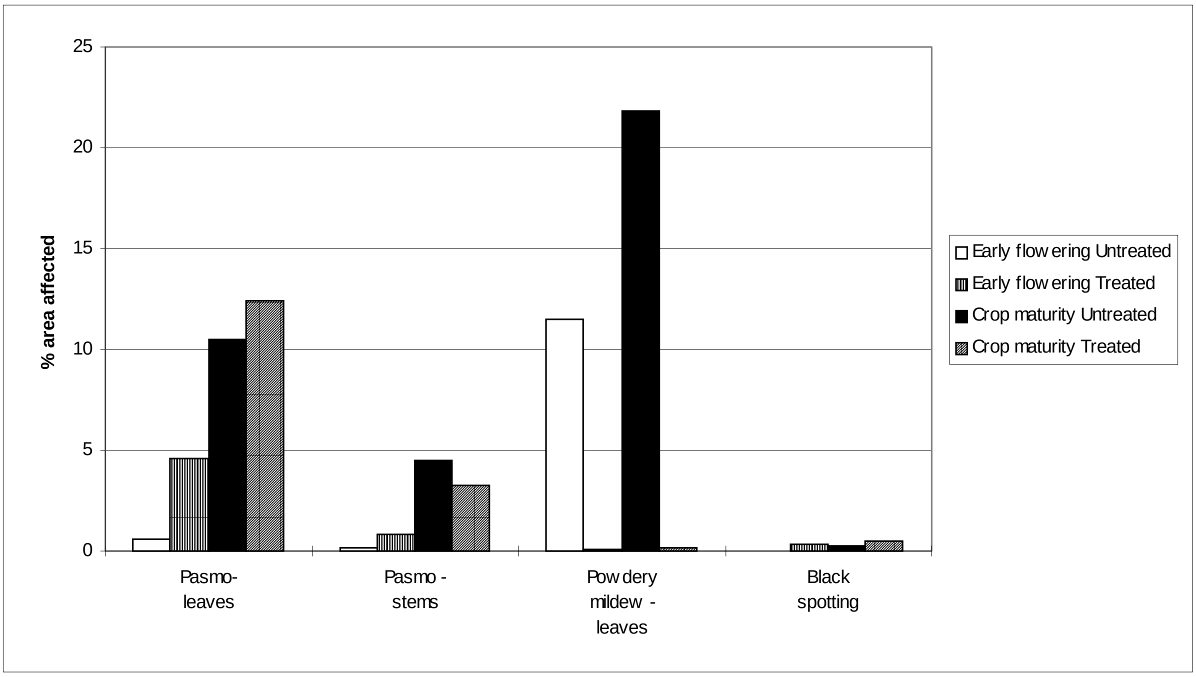

Fig. 42. Pasmo, powdery mildew and black spotting severity (% area affected) in untreated crops and fungicide treated at early flowering and crop maturity.

Pasmo incidence and severity was higher in crops which received fungicide than those which remained untreated (Figs. 41 & 42) at early flowering. The three untreated winter linseed crops had lower pasmo severity than all except one of the treated crops. Only one of the 6 crops of spring linseed with pasmo at early flowering had received fungicide sprays. This position had still not been reversed at crop maturity, though differences were smaller (26% leaf area affected by pasmo in untreated crops, 52% in treated). The same trend was found for stem pasmo, which affected 37% stem area in untreated crops and 59% in treated crops at crop maturity (Fig. 41). Disease severity records showed less stem pasmo after fungicide treatment (3.3% area) than in untreated crops (4.5% area), though leaf data provided no direct evidence of pasmo control. Black spotting was seven times more prevalent in treated crops than untreated crops at early flowering. On capsules, pasmo was less severe in treated (1.1% area affected) than untreated crops (3.2% area affected) (Fig 42).

There was a little evidence that fungicides had affected *Botrytis* on capsules; 2.1% on untreated crops, 1.5% in treated crops. Powdery mildew was much less prevalent in fungicide treated crops at both assessments: 11.5% leaf area affected in untreated, 0.7% treated crops at early flowering, 21.8% in untreated and 0.2% in treated crops at crop maturity. Fungicide treated crops showed slightly less dead leaf retention but rather higher leaf yellowing and defoliation (bare stem).

The most frequently used fungicides were:

tebuconazole (as Folicur)	11 crops (6 used in tank mixuture with MBC)
carbendazim (various products)	8 crops
thiophanate methyl + iprodione (as Compass)	2 crops
chlorothalonil (as Bravo)	2 crops
fenpropimorph (as Mistral)	1 crop

Treatments were mainly applied to winter linseed during flowering (May/early June), although two crops received a spray in early April and one had an autumn spray. One crop received a three-spray programme, two received two sprays and 11 crops had a single spray. The two fungicide-treated spring linseed crops received sprays at early to mid flowering in the second half of June

Lodging

Lodging occurred in a few crops (20%) at the early to mid flowering stage, notably in the east Midlands where one crop had 65% lodging. There were generally small increases in lodging after early flowering except in the west Midlands which showed 14% lodging at crop maturity after an absence of lodging at early flowering. In the east, lodging was slight, with only 2.5% and 4.4% crop area affected at early flowering and crop maturity respectively. No lodging was recorded in the south, though some leaning of stems was apparent (Fig. 43). Plants were much shorter than in 1998, averaging 53 cm at early flowering and 67 cm at crop maturity compared with 73 cm at early flowering and 80 cm at maturity in 1998 (Fig. 44). Crop growth provided at least 90% ground cover from early flowering in east and east Midlands and was lowest (67%) in the north of England (Fig. 45). There were only small differences of ± 2-3% between the two assessments at early flowering and crop maturity.

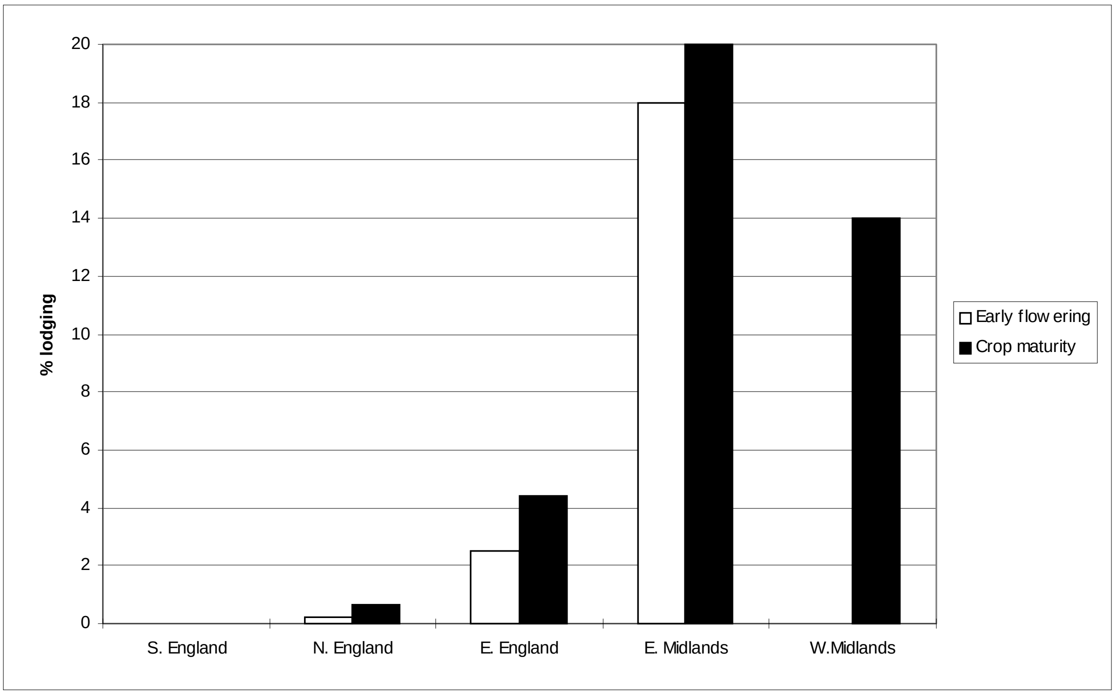

Fig. 43. Lodging severity (%) in different regions at early flowering and at cropmaturity.

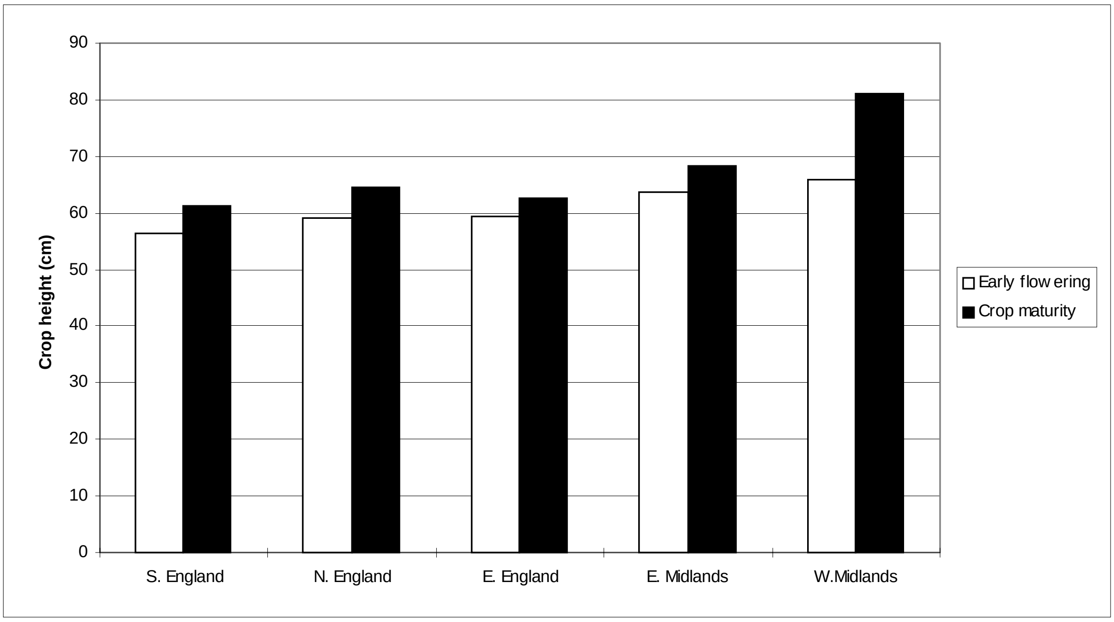

Fig. 44. Mean crop height (cm) in different regions at early flowering and crop maturity.

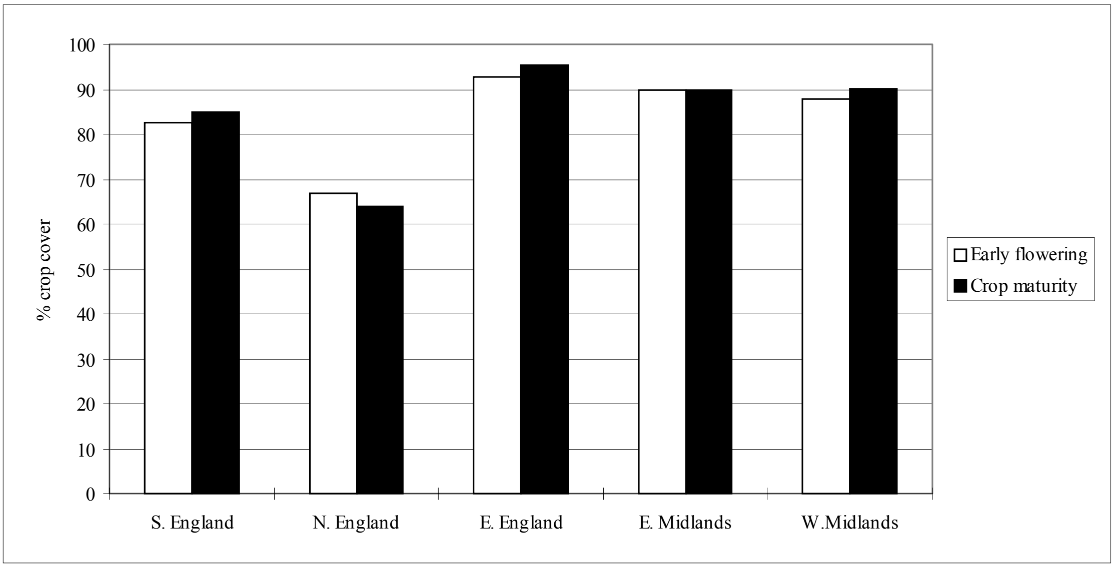

Fig. 45. Mean crop cover (%) in different regions at early flowering and crop maturity.

Weed cover & pest damage

Weeds were generally troublesome (>10% cover) in 23% crops at early flowering and 27% crops at maturity,of which 8.5% and 13%, respectively, were winter linseed crops. Weed problems were most apparent in the south west and north and weed cover increased almost two-fold between early flowering and crop maturity (Fig. 46) (e.g. from 10% to 20% in south west and from 11% to 18% in the north of England). Slight leaf distortion or damage attributed to pests such as thrips was noted at low levels but there was some notching of leaf margins on most plants at early flowering in all areas. This damage decreased between assessments, indicating less severe pest damage to the leaves remaining at crop maturity than earlier in the season (Fig. 47). Overall, pest damage remained slight.

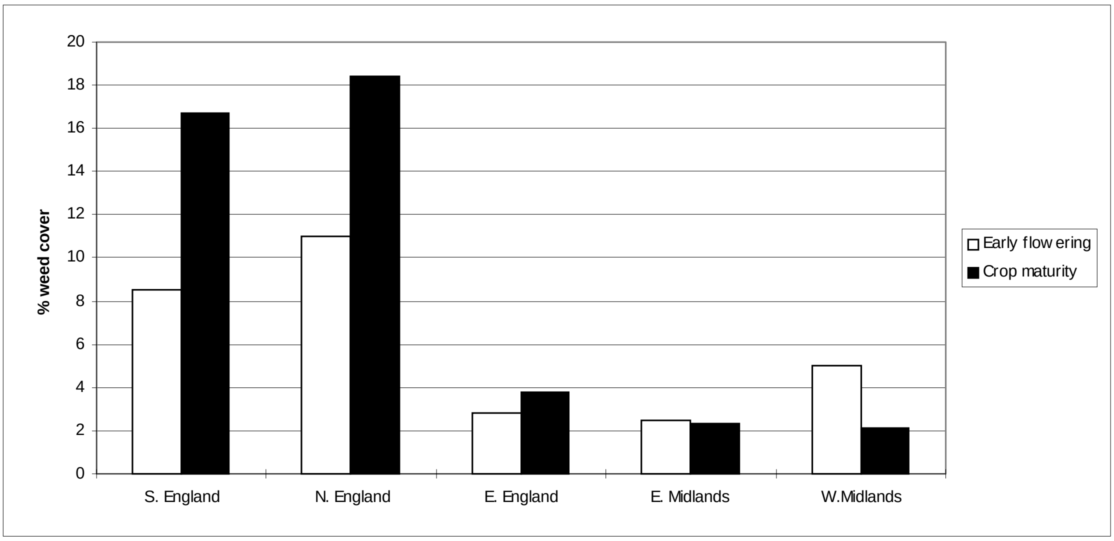

Fig. 46. Mean weed cover (% area) in different regions at early flowering and crop maturity.

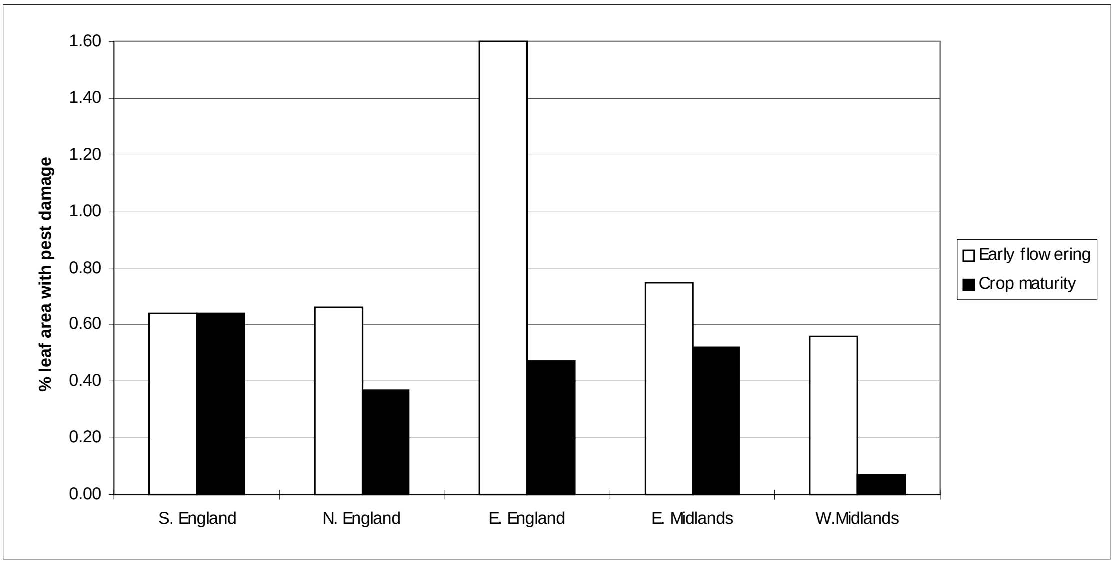

Fig. 47. Severity of pest damage on leaves (% area affected) in different regions at early flowering and crop maturity.

Conclusions

Summary tables of results from each sampling during 1998-2000 are shown in Tables 1-3. Pasmo was found to be present in all regions at each visit, affecting over 70% crops each year. Pasmo was the most common stem disease at early flowering, and its incidence increased subsequently as the disease continued to develop up to crop maturity (Table 1). Powdery mildew affected more crops in 1998 than in later years and declined after early flowering except in 2000 when spring linseed was included. *Botrytis* and *Alternaria* were only recorded in a few crops and mean incidence rarely exceeded 10% plants affected (Table 2). The most severe diseases were pasmo on leaves and stems and powdery mildew on leaves (Table 3). Pasmo spread up the plant and developed on stems after the first sampling to a greater extent in 1998 and 2000 than in 1999. Powdery mildew was most severe in 2000, which reflected the more severe infection on spring linseed (Fig. 48).

Botrytis stem rot was found in a few crops each year and was most widespread in 1999 when 23% crops were affected and average incidence was 1.9% plants affected. *Sclerotinia* was found in one crop, *Phoma* in one crop and *Fusarium* in two crops, all in 1998. Diseases affecting the capsules were *Botrytis* which caused a general rot or loss of capsules and pasmo which colonised the sepals. *Botrytis* affected capsules in 70%, 83% and 90% crops in successive years of the survey and 1.9%, 3.3% and 2.2% capsules, respectively.

Pasmo was slightly less widespread, affecting 83%, 63% and 70% crops, and slightly more severe overall with 5.8%, 2.1% and 2.7% capsule area affected.

Table 1. Mean percentage of crops affected by the major foliar and stem diseases of linseed in England and Scotland 1998-2000.

	% crops affected					
Disease	1998		1999		2000	
	Early flowering	Crop maturity	Early flowering	Crop maturity	Early flowering	Crop maturity
Pasmo - leaves	73	90	83	80	70	80
Pasmo - stems	63	87	55	90	57	73
Powdery mildew	70	50	24	20	20	43
Alternaria	13	30	7	13	0	13
Botrytis	7	7	3	13	10	33

Table 2. Mean percentage of plants affected by the major foliar and stem diseases of linseed in England and Scotland 1998-2000.

	% plants affected					
Disease	1998		1999		2000	
	Early flowering	Crop maturity	Early flowering	Crop maturity	Early flowering	Crop maturity
Pasmo - leaves	58	82	52	42	51	47
Pasmo - stems	37	58	27	63	38	58
Powdery mildew	44	23	10	3	18	20
Alternaria	5	13	1	9	0	4
Botrytis	0.3	0.3	0.1	2	8	10

Table 3. Mean percentage area affected by the major foliar and stem diseases of linseed in England and Scotland 1998-2000.

	% area affected					
Disease	1998		1999		2000	
	Early flowering	Crop maturity	Early flowering	Crop maturity	Early flowering	Crop maturity
Pasmo - leaves	4.4	15.5	1.7	6.9	3.0	14.0
Pasmo - stems	0.8	5.8	0.6	4.5	0.6	4.9
Powdery mildew	1.9	1.3	0.1	0.2	7.7	14.7

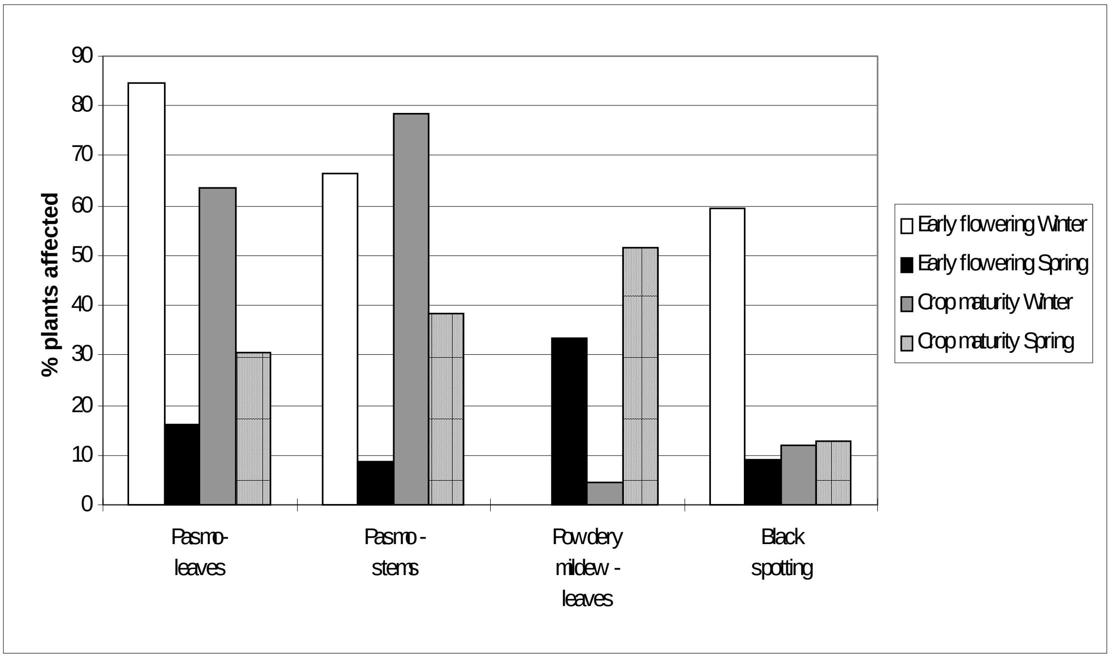

Fig. 48. Incidence of diseases on winter and spring linseed crops at early flowering and crop maturity.

Crops of winter linseed were predominantly cv. Oliver (90% crops in 1998, 93% crops in 1999 and 100% crops in 2000) sown from mid-September to mid-October. Eight different cultivars were encountered in spring linseed crops in 2000. Most were grown from certified seed (70-83%) which had been treated with fungicide. Regional differences were apparent in 1998 for powdery mildew, which was present in all regions except the south west, whilst *Alternaria* predominated in the Midlands. In 1999, powdery mildew was present mainly in the west Midlands and Scotland and much less common in the east than in 1998. *Alternaria* predominated in the south west in 1999 and 2000. Powdery mildew, which was most prevalent in the east at early flowering and in the south at crop maturity in 2000.

Half of the crops surveyed had received fungicide sprays in 1998, but this appeared to have made limited impact on disease severity. In 1999, there was an increase of 30% in the use of fungicide sprays and 73% of crops surveyed were treated. Tebuconazole plus an MBC during flowering was the most widely used treatment and appeared to have made some impact on disease severity. Pasmo was less severe in 1999 than in 1998 and this contributed to higher yields. This disease became established more slowly in the autumn and winter than in 1997/98 and winter observations may have strategic value in decision making. In 2000, fungicide sprays were used on 47% crops, which comprised 80% of winter linseed crops and 13% spring linseed crops and again appeared to have made a limited impact on final disease severity. It is clear that pasmo is a threat to spring linseed crops and further monitoring is advisable to see if the disease declines in the absence of winter linseed cropping.

There were low levels of pest damage in crops and main agronomic problems were lodging and weeds. Lodging averaged 45% crop area affected at crop maturity in 1998 and was most severe in the east and Midlands. Lodging was much less of a problem in 1999 than in 1998 and problems were only serious in two crops in the east which had 80-85% crop affected. Crops were slightly less tall than in 1998 with plant height averaging 65 cm compared with 73 cm in 1998 at early flowering and 67 cm (80cm in 1998) at maturity. The shorter plants is likely to have contributed to reduced lodging problems. This was supported by observations in 2000 (which had slightly taller plants than 1999 - mean 73 cm at maturity) where seven out of eight crops which were at least 80 cm tall lodged significantly. In the east, lodging was slight with only 2.5% and 4.4% crop area affected at the two visits

Weed problems affected over 10% crop area in the south west and north in 1998. These problems continued in 1999 in the south west, where weed cover increased between early flowering and crop maturity from 20% to 31%. Weeds were generally troublesome (>10% cover) in 23% crops at early flowering and 27% crops at maturity in 2000. There were more problems in spring linseed than winter linseed, which showed 8.5% and 13% crops badly affected at early flowering and crop maturity, respectively. Weed problems were most apparent in the south west and north and weed cover increased almost two-fold between early flowering and crop maturity.

Discussion

1998

The 1998 harvest year was difficult for winter linseed growers. Severe pasmo disease affected foliage and stems and in experiments fungicide programmes were shown to increase yields by up to 1 t/ha, doubling seed yield. Yield increases were related to control of pasmo and increased green leaf area. For a second successive year, June had frequent and heavy rain and this caused extensive lodging (not such a feature in 1997) as well as favouring disease development.

As yield is produced from flowering onwards, the two survey assessments cover the most important period of yield formation. During this period, pasmo spread up the plant causing progressive defoliation and eventually affecting the upper leaves. At the same time, stem lesions were also becoming more extensive. Fortunately these were superficial and did not generally kill the upper part of the plant. Pasmo is known to have become established in winter linseed in the autumn (November) and it is thought that air-borne ascospores released from infected winter linseed residues of the 1997 crop were the main source of infection. Pasmo is also known to be seed-borne and seed could therefore be an important source of the disease, particularly if fungicidal seed treatments were not used or were ineffective. Given the severity of the current pasmo epidemic, use of home-saved seed could pose a risk to future cropping. Unfortunately pasmo is not assessed in current tests on stocks evaluated for use as seed. There is limited data available on the extent of pasmo infection on seed, disease thresholds and the effectiveness of seed treatments.

The establishment of pasmo in the UK appears to have been brought about by the introduction of winter linseed. There have already been some outbreaks in spring linseed and the disease now poses a threat to that crop. In winter linseed, pasmo develops slowly during the winter, which suggests it may have a fairly high temperature optimum. If this is the case, the disease, once established, could pose a bigger threat to spring linseed than winter linseed. Infection conditions need to be ascertained to establish the risk in wet and dry seasons so that fungicide spray treatments can be optimised.

Work to date indicates that MBC fungicides are very effective against pasmo with activity also apparent for tebuconazole, chlorothalonil and iprodione + thiophanate methyl. A fungicide mixture applied during flowering in a wet season should provide broad-spectrum disease control and substantial yield increases. More recently, winter linseed has given responses to spring and occasionally autumn sprays. Overall, pasmo has proved difficult to control and control was often less than 50%. As a result of experiments carried out in 1997/98, guidelines are available for fungicide use in 1999.

Other diseases in winter linseed are recognised more readily from experience in spring linseed. Powdery mildew, *Alternaria* and *Botrytis* were the most common, though diagnosis was difficult because of the extensive spotting from pasmo and these diseases may have been under-estimated. Lodging was a major problem in 1998; dense crops which continued to grow during mild winter conditions appear to have contributed to the problem. Pigeon grazing was severe in parts of the same crops but the shorter regrowth was less prone to lodging. Repeated heavy rains (10 mm or more) during June ensured that crops were unable to recover and the combination of lodging and disease accounted for the low yield. Crop density may have helped suppress weed growth as thinner crops in the south west and north showed increased weed cover between assessments. Weed control remained problematic in a few crops.

1999

The 1999 season was much more favourable for the crop than 1998, which had weather favouring both severe disease and crop lodging. Pasmo was again the most important disease. A range of other diseases in winter linseed was recorded, with powdery mildew, *Alternaria* and *Botrytis* being the most common. Diagnosis of diseases that cause dark spotting was difficult because of the extensive spotting from pasmo and some minor diseases may have been under-estimated. Rather less powdery mildew and more fine black spotting symptoms were found in 1999 than in 1998.

As yield is produced from flowering onwards, the two survey assessments cover the most important period of yield formation. During this period, pasmo spread up the plant to a limited extent in 1999 and only crops in the south west and Scotland showed serious pasmo affecting the upper leaves. Stem lesions were also less severe than in 1998 and were mainly confined to the base of the stem. Fortunately these are superficial and do not generally kill the upper part of the plant.

Pasmo is known to have become established in winter linseed in the autumn (November) and it is thought that air-borne ascospores released from infected winter linseed residues of the 1998 crop were the main source of infection. Pasmo is known to be seed-borne and seed could therefore be an important source of the disease particularly if fungicidal seed treatments were not used or were ineffective. It was noticeable that pasmo built up much more slowly in autumn 1998 than in autumn 1997 and there was little spread to the lower leaves by spring. Winter monitoring may therefore be a useful approach for assessment of disease risk and the need for fungicide treatments.

Most growers (47%) have used a mixture of tebuconazole + MBC during flowering and this follows a successful technology transfer of experimental work through collaborators in this project and through the farming press. There was a little use of fungicides before flowering and this is likely to have been for plant growth regulation as well as disease control.

Yield estimates were collated from survey sites and these appear to be higher in 1999 than in 1998. Fifteen farms provided yield estimates for both 1998 and 1999 and these averaged 1.57 t/ha and 1.79 t/ha, respectively, and were higher in 1999 on 10 farms. These yield increases can be related to lower disease pressure from pasmo and improved use of fungicides to control diseases. Lodging was much less of problem in 1999 than in 1998 and this may have helped reduce the impact of pasmo and contributed to the higher yields. Crop density may have helped suppress weed growth as thinner crops in the south west again showed increased weed cover between assessments. Weed control remained problematic in a few crops.

2000

The 1999/2000 winter linseed crop showed a limited development of pasmo during the winter (similar to 1998/99 winter), but wet weather from April onwards produced another high disease year. Severe pasmo disease affected foliage and stems and reached the capsules in many crops. Yield losses were undoubtedly incurred and these can be estimated from disease-yield loss relationships derived from fungicide experiments.

This is the first time direct comparisons can be made between winter and spring sown crops. Pasmo was present in all winter linseed crops at early flowering but only in 40% of spring linseed crops. Stem assessments showed pasmo affecting 93% crops of winter linseed and 20% of spring linseed crops and is an indicator of early and well-established infection. In spring 2000, wet weather undoubtedly favoured spread and infection of pasmo and the disease progressed up the plant. By crop maturity, pasmo affected stems and capsules of 93% crops of winter linseed and stems of 53% crops and capsules in 47% crops of spring linseed. It is clear that spring linseed can be as severely affected by pasmo as winter linseed with % stem area affected by pasmo reaching 21% in spring linseed and 31% in winter linseed.

Regional differences in diseases were apparent, though some caution is needed about using these in decision making in future years. Pasmo was most severe in the west Midlands and least severe in the north. The very severe pasmo may have influenced powdery mildew development in the west Midlands through competition for leaf surfaces and early leaf loss. The larger increase of pasmo on spring linseed can be partially attributed to the lower use of fungicides on this crop compared with winter linseed. Examination of disease incidence and severity data for untreated and fungicide treated crops suggest that fungicide treatments did have some impact on the severity of pasmo. In terms of targeting fungicides, it appears that at early flowering when decisions were made crops that were subsequently treated were more severely affected by pasmo than those which remained untreated. Subsequently untreated crops did show significant disease development and perhaps more should have been treated with fungicide.

In contrast to pasmo, powdery mildew was more severe on spring linseed than winter linseed. Powdery mildew was present in 40% spring linseed crops by early flowering and was not found until crop maturity assessments in winter linseed. Other diseases appeared to be of limited importance in linseed crops. *Botrytis* was present on flower buds and later on capsules, with rather more on spring linseed (mean 2.7% capsules affected) than winter linseed (1.8% capsules affected). A wet season is regarded as being most likely to generate responses to fungicides in spring linseed, yet only two crops out of 15 were treated. Lack of suitable conditions to apply sprays and assigning treatment of linseed a lower priority than other farm operations undoubtedly contributed to this.

Pasmo is known to have become established in winter linseed in the autumn (November) and it is thought that air-borne ascospores released from previously infected winter linseed crop residues were the main source of infection. Pasmo is known to be seed-borne though the contribution of this to the epidemic has not been established. The occurrence of pasmo in spring linseed suggests that air-borne spore spread has taken place after the emergence of spring crops. This could be ascospores from winter linseed debris (perhaps from infected winter crops in the current year as well as the in previous year) or conidial spores spread by rain splash from infected plants of winter linseed. The former is the more likely, if long distance dispersal is required. There was no clear influence of distance from previous linseed crops on pasmo severity in the survey. Severe attacks of pasmo have occurred in first linseed crops on the farm that suggests either long range dispersal of spores or rapid build up from seed-borne inoculum.

The establishment of pasmo in the UK appears to have been brought about by the introduction of winter linseed. Previous reports from 1998 and 1999 that pasmo is now present in spring linseed have been substantiated. Pasmo now poses a threat to the spring crop though it may not remain a persistent problem in the absence of winter linseed. Further monitoring will be required to establish its significance in spring linseed.

II. The effects of fungal diseases on growth and yield of winter linseed (*Linum usitatissimum*); factors affecting the severity of disease and national losses, 1997/98 – 1999/2000

Materials and Methods

Field experiments

Experiments to estimate the effects of diseases on the growth and yield of winter linseed were done on the Rothamsted farm from 1997/98 to 1999/2000. Seed (cv. Oliver), treated with prochloraz (Prelude) at 4g a.i. kg^{-1} was sown as first linseed (Table 4). Plots (15 x 3 m) were arranged in randomised block design with three blocks, either of eight (1997/98) or of ten plots (1998/99 and 1999/2000) with three replicates per treatment. Guard areas, 2 m wide, were sown between plots. Plots received experimental treatments (Table 5) or were untreated. The treatments were tebuconazole (Folicur) applied at 0.5 kg a.i. ha^{-1}, benomyl (Benlate) at 0.55 kg a.i. ha^{-1}, iprodione (Rovral Flo) at 0.25 kg a.i. ha^{-1} and thiophanate-methyl plus iprodione (Compass) at 1 kg a.i. ha^{-1}. They were applied in autumn (tebuconazole) or at pre-flowering, mid-flowering or capsule development stages by tractor-mounted boom. Benomyl has been used against grey mould in spring linseed, iprodione against leaf blight and thiophanate-methyl plus iprodione against both diseases. ADAS, Bayer and Semundo also did experiments, using many fungicide treatments and timings, to examine effects of diseases on yield of winter linseed. A Burkard spore sampler was sited in the crop in two seasons (1998/99 and 1999/2000) to provide daily records of air-borne fungal spore. An automatic meteorological station recorded hourly rainfall, temperature, relative humidity and leaf wetness. When the seeds were mature, crops were desiccated (with Enhance at 400 ml in 400 L or with diquat applied as Reglone at 3 L in 400 L) before harvest, combine-harvested and yields (t/ha), % oil and thousand seed weight (TSW) determined.

Table 4. Management data

	1997/98	1998/99	1999/2000
Sowing date	30 September	9 October	5 October
Sowing density (seeds m^{-2})	950	950	950
Desiccation date	25 July	9 July	26 July
Harvest date	5 August	24 July	1 August

Measurements

Plots were sampled monthly from October until April then twice a month from May to July. Five plants were sampled from each side at one end of each plot (10 plants per plot). Stems, leaves and capsules were assessed to record disease symptoms as % area affected. Incubation and isolation aided identification of pathogens causing symptoms; after incubation in damp chambers characteristic spores of *Botrytis cinerea* or *Mycosphaerella linicola* (in pycnidia) were produced.

Spread of fungal pathogens to linseed seed

Incidence of fungal pathogens on harvested seed was assessed as percentage of seeds affected. Seeds were surface sterilised by immersion in sodium hypochlorite (1% available chlorine) for 1 min and rinsed with sterile distilled water for 1 min. Seeds were placed on V8 or PDA agar (plus antibiotics) in Petri dishes and incubated at 20°C in darkness/NUV for 7 days. Pathogens were identified and number of colonies recorded.

Table 5. Fungicide treatments to winter linseed in experiments at Rothamsted, 1997/98 to 1999/2000

Fungicide treatment	Figure legend code		Application date	
		1997/98	*1998/99*	*1999/2000*
Untreated	None			
Tebuconazole	AF	26 November	9 Dec.^{s}	23 Nov
Tebuconazole ; benomyl x 2	APM		9 Dec ^{s}, 14 May‡, 7 June†	23 Nov, 22 Mar‡, 31 May†
Benomyl x 2 (pre+mid)	PM		14 May‡, 7 June†	22 Mar‡,31 May,
Benomyl	B1/BM	29 May†	7 June†	31 May†
Benomyl x 2	B2/BMC	29 May†, 25 June*	7 June†, 28 June*	31 May†, 26 June*
Iprodione	A1/AM	29 May†	7 June†	31 May†
Iprodione x 2	A2/AMC	29 May†, 25 June*	7 June†, 28 June*	31 May†, 26 June*
Thiophanate-methyl plus iprodione	C1/CM	29 May†	7 June†	31 May†
Thiophanate-methyl plus iprodione x 2	C2/CMC	29 May†, 25 June*	7 June†, 28 June*	31 May†, 26 June*

Growth stage (GS; Smith & Froment, 1998) for fungicide applications: ^{s} seedlings (GS 2); ‡ at pre-flowering (GS 3); † at mid-flowering (GS 6); * at capsule development (GS 7)

Statistical analyses

The effects of different treatments on diseases incidence and severity, crop growth and yield were investigated by analysis of variance. The relationships between yield and severity of diseases were examined using linear regression. For each disease factor, linear regression analysis was used to determine the time in the season when the relationship between that factor and decrease in yield was best. Estimated yield losses were calculated from yield loss coefficients from regressions of yield on disease. These were used to determine estimates of national losses when combined with ADAS survey disease data and based on price of £120 per tonne seed.

Results

Symptoms of disease observed

In these experiments on winter linseed at Rothamsted, the only disease that occurred at more than trace levels was pasmo. Pasmo lesions typically appeared on cotyledons in winter and progressed up leaves and onto and up stems during late spring/summer. Late in the season areas of crop very quickly became brown, eventually showing complete necrosis and defoliation. Pasmo (*M. linicola*) was observed on stems at the site of leaf scars as separate brown lesions, which eventually expanded to surround the stems; subsequently the disease would sometimes spread to sepals and capsules. Affected areas were light brown in colour and contained minute dark brown pycnidia. In the crop canopy, symptoms of grey mould (*B. cinerea*) were usually first observed on flowers, capsules or sepals as brown patches and then spread down the stems.

The pattern of pasmo disease across the field experiment points towards a background inoculum from a large number of distant sources, as there was a uniform distribution of disease with distance across the crops (no gradient in the field implying no local source of inoculum). Pasmo is reported as seed-borne in much literature, but only a very low percentage seed infection was recorded. It appears to be a polycyclic disease with wind-dispersed ascospores, which initiate epidemics at the beginning of the growing season, and splash-dispersed conidiospores, which are responsible for spread of disease up plants later in the season.

In damp weather, individual capsules (or whole plants if lodged) became covered with a dense mass of grey mycelium, conidiophores and conidia, which when washed off by rain left bleached capsules on brittle stems. Such capsules were often shed before harvest. Powdery mildew and *Verticillium dahliae* were not observed in any season in the field experiments. Very little *Alternaria* occurred and only in the first season. Some fungicide treatments decreased leaf and stem disease and therefore these plots senesced more slowly than untreated plots.

Disease progress on untreated crops

a) Cotyledons:

In 1997/98, the plants developed pasmo symptoms very early in the season (5 November) at the cotyledon stage. In 1998/99 and 1999/2000 seasons, pasmo was not evident on cotyledons until much later (6 January and 26 November respectively).

b) Leaves:

There was a broadly similar pattern of disease progress in each of the 3 seasons but the pattern differed in time-scale between the first season and the other two (Fig. 49). In 1997/98, the disease started on leaves in early November and increased slowly, over 3 months, up to approx 25% leaf area affected by early March. It then remained at this level until May when there was a rapid increase of disease symptoms with leaf area affected doubling to over 50% within the month (corresponding to the period of rapid stem extension). By the end of June disease increased to 100% leaf area affected on untreated plots. In comparison, in the next season, the disease symptoms did not appear until February 1999 and levels remained very low (2%) until the end of May, when 25% untreated leaves were affected. At the start of June 40% and at the end of June 70% leaves were affected, a significantly lower ($P<0.005$) level than the previous season. At the end of the season the most severely affected plants had only 90% leaves affected by pasmo disease. The final season, 1999/2000, the pattern of epidemic development on leaves was more akin to the middle season with pasmo leaf lesions appearing in February (approx. 10%) and remaining low until the end of May when 27% untreated leaves were affected. Levels rose from 35% at the start of June to 60% at the end of June. Levels continued to increase to 99% by mid July on untreated plots. Percentage green leaf area was recorded only in 2000 when there was no significant increase in green leaf area.

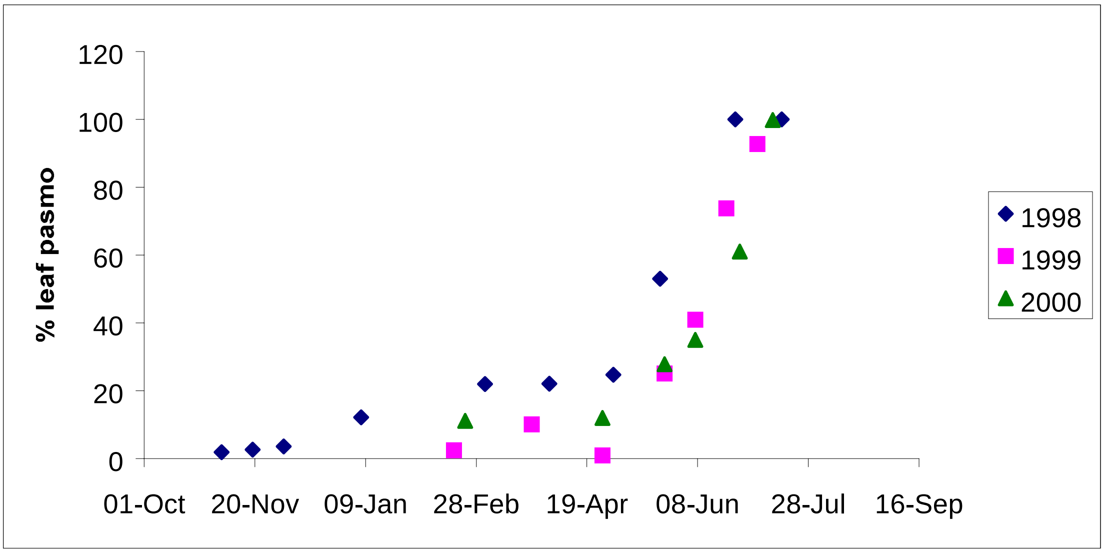

Fig. 49. Progress of pasmo on leaves of untreated winter linseed (cv. Oliver) at Rothamsted in 1997/98, 1998/99 and 1999/2000

c) Stems:

Pasmo disease symptoms typically spread from leaves and onto the stems later on in the season (Fig. 50). In 1997/98, it first appeared at the stem bases at very low severity (1%) at the end of May. It slowly increased to approx 15% at the end of JUne and then spread very rapidly to cover 80% stems by mid July. In 1998/99, it spread to stems at about the same time of year showing 3% severity at the end of May but did not reach levels any higher than 20% at the end of June, significantly lower (P<0.001) than the severity of the previous season. In the final season, pasmo lesions became evident in April (12%), remaining at this low level until the end of June when it was 17%. By mid July, this severity increased to approximately 35% on untreated plots.

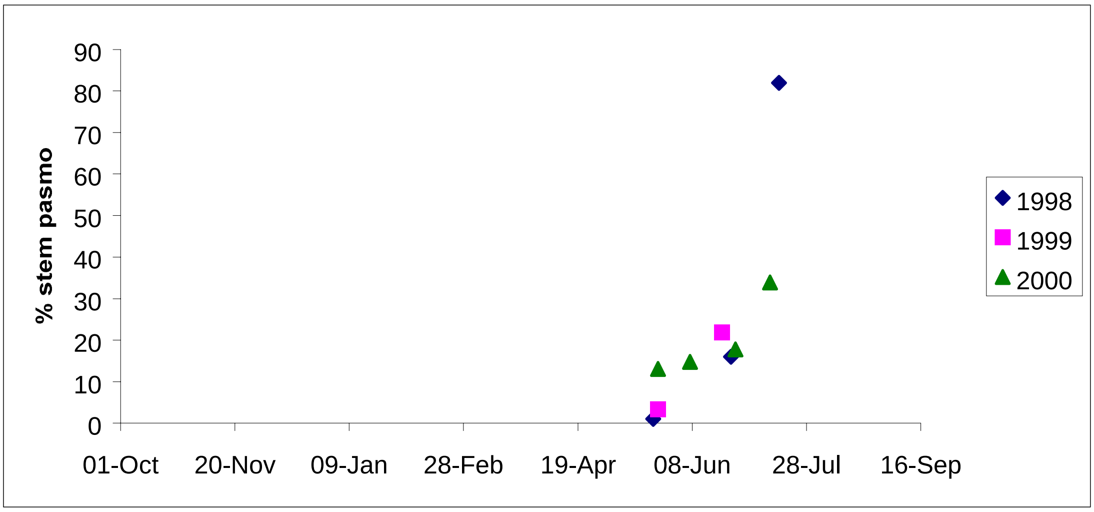

Fig. 50. Progress of pasmo on stems of untreated winter linseed (cv. Oliver) at Rothamsted in 1997/98, 1998/99 and 1999/2000

Effects of fungicide treatments on disease progress/severity:

a) Leaves and stems:

Fungicide treatments showed significant effects only in the first season. In 1997/98, the best fungicide treatments greatly decreased the % area of leaves with pasmo and subsequently the % area of stems with pasmo (Figs 51a, 52a & 53a). The autumn tebuconazole gave no decrease in disease; in fact treated plots had significantly more disease (18%) in February than untreated plots (2%). The mid-flowering application of benomyl decreased disease significantly (P<0.001) to 70% at the end of June (compared to 100% on untreated), and to 95% in mid-July. The capsule spray of benomyl had no effect. The other two sprays, iprodione and thiophanate-methyl, gave no control of disease in this season when disease levels were typically high. Consequently, these effects were seen in disease control on the stems with a mid-flowering spray of benomyl reducing disease to a quarter of that observed on untreated (4% as compared to 16%) at the end of June. In the middle of July a mid-flowering spray of benomyl decreased disease to 45%, a two-spray programme at mid-flowering and capsule development reduced disease to 28%, as compared to 80% levels on untreated plots. Two sprays of thiophante-methyl also decreased pasmo stem disease down to 34% (control not matched on the leaves). In 1998/99 (Figs 51b, 52b & 53b), the severity of pasmo was much less than in 1997/98. A pre-flowering spray of benomyl was introduced this year in addition to the mid-flowering and capsule sprays. There were some effects of fungicide treatments on leaf disease (eg. pre-flower plus mid-flower sprays of benomyl and mid-flower plus capsule sprays of benomyl), but none of these were significant.

In 1999/00 (Figs 52c, 52c & 53c), a two-spray programme of benomyl at pre-flowering and mid-flowering, a spray of tebuconazole in autumn plus a two-spray programme of benomyl at pre-flowering and mid-flowering both decreased pasmo disease on leaves and stems but not significantly. These spray programmes and one or two sprays of benomyl or thiophanate-methyl plus iprodione also decreased levels of pasmo on stems and these effects were significantly ($P<0.001$) different in mid July (decreasing pasmo on stems to 8-18% as compared to the 65% levels on the untreated plots).

c) Capsules and sepals:

In the first season (1997/98), the number of capsules per plant with lesions on the sepals at the end of June (Fig. 54) was significantly lower (5) in benomyl and thiophanate-methyl plus iprodione plots sprayed at mid-flowering than on untreated plots (10). This difference was not apparent in mid-July when all plots had approximately 10 capsules per plant with sepal lesions. The number of dead/diseased capsules in late June and mid July was lower (1) in benomyl sprayed plots than in the untreated plots (2). In the second season (1998/99) (Fig. 55) in mid June there were no effects of fungicides on numbers of capsules with lesions, sepal lesions or aborted buds. In early July there were also no effects of fungicides with the exception of a slight, but insignificant, decrease in % capsules with sepal lesions by all fungicide treatments. In the third season (1999/2000) (Fig. 56), there were no effects of fungicides on numbers of capsules with lesions in June or July, in the number of capsules with *Botrytis* in May, June or July or in the numbers of capsules aborted in June or July. However, some decreased controlled the numbers of capsules with sepal lesions but not significantly; including benomyl (pre or mid-flowering) on disease assessed in late June and mid-July.

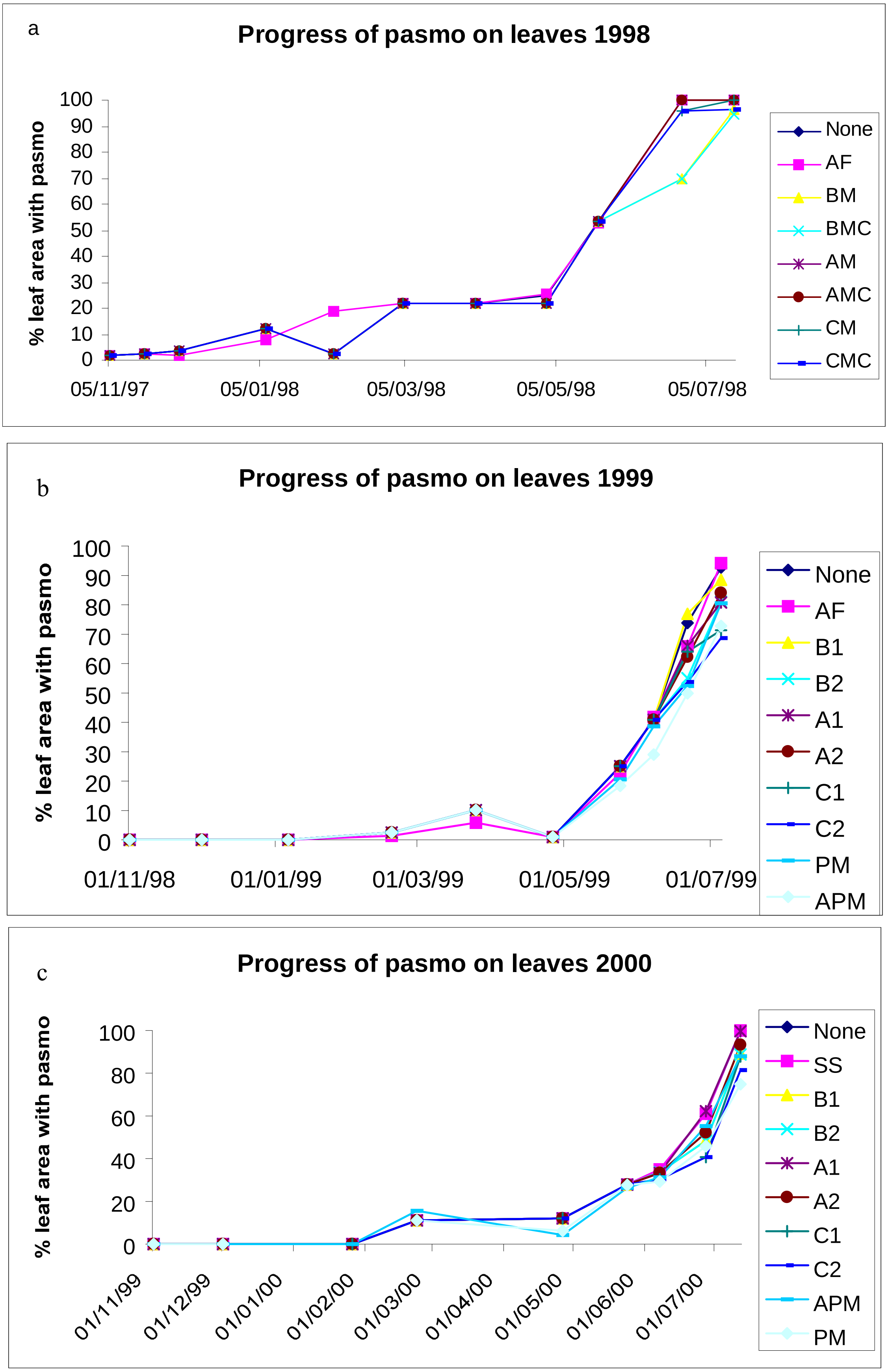

Fig. 51. Progress of pasmo on leaves of untreated and treated winter linseed (cv. Oliver) at Rothamsted

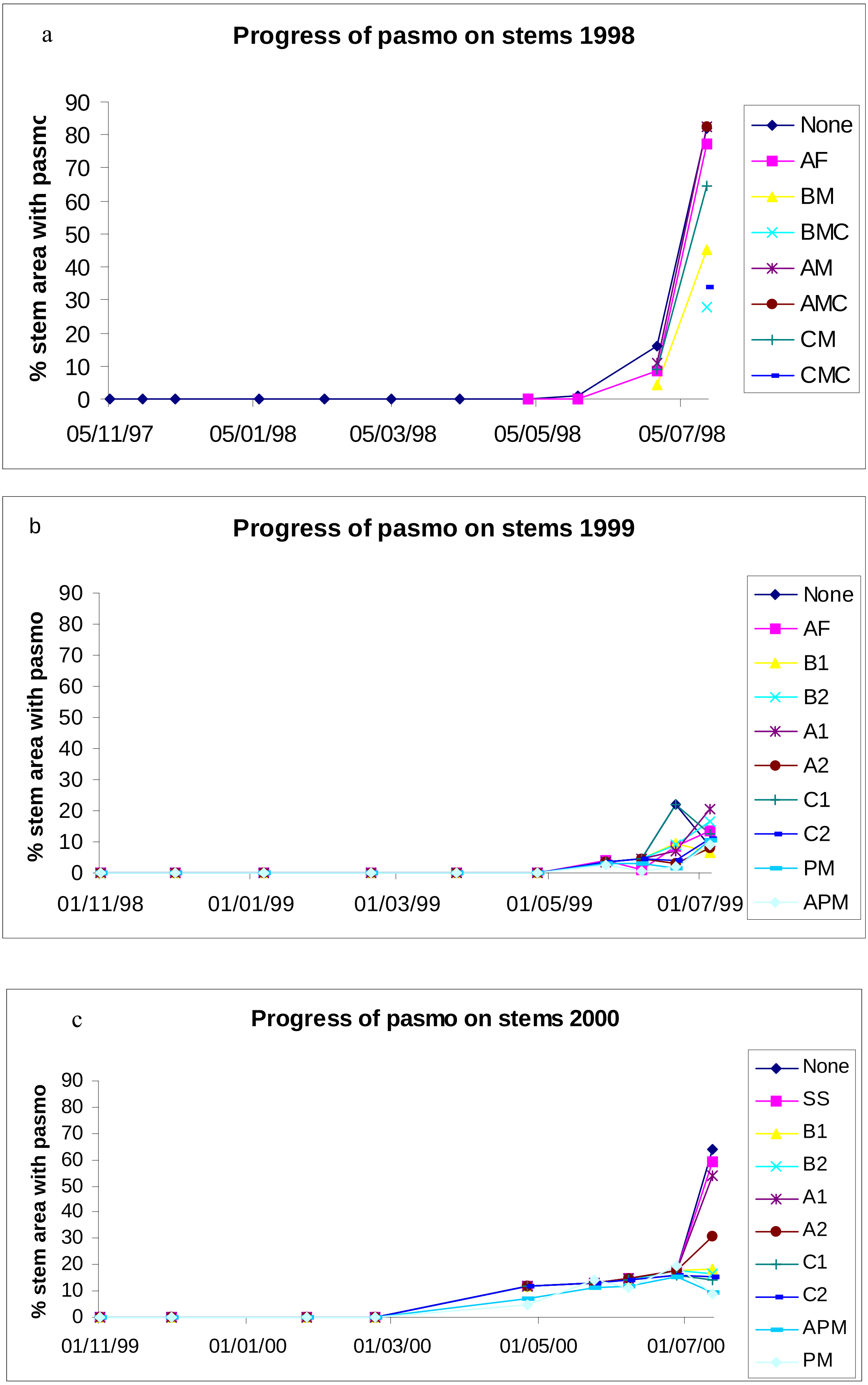

Fig. 52. Progress of pasmo on stems of untreated and treated winter linseed (cv. Oliver) at Rothamsted

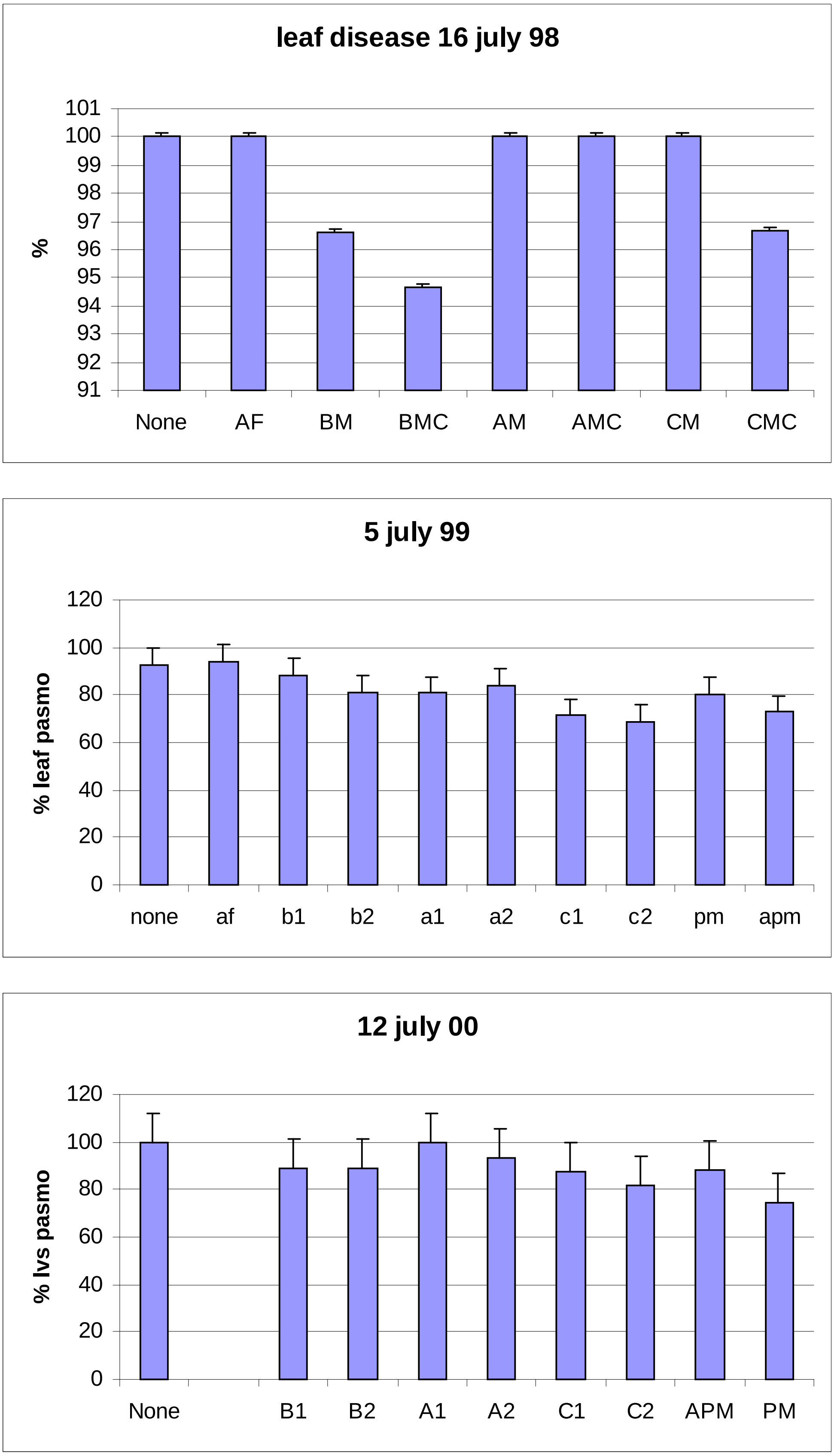

Fig. 53. Percentage leaf area with pasmo at crop maturity in winter linseed at Rothamsted in response to fungicide treatments in three seasons

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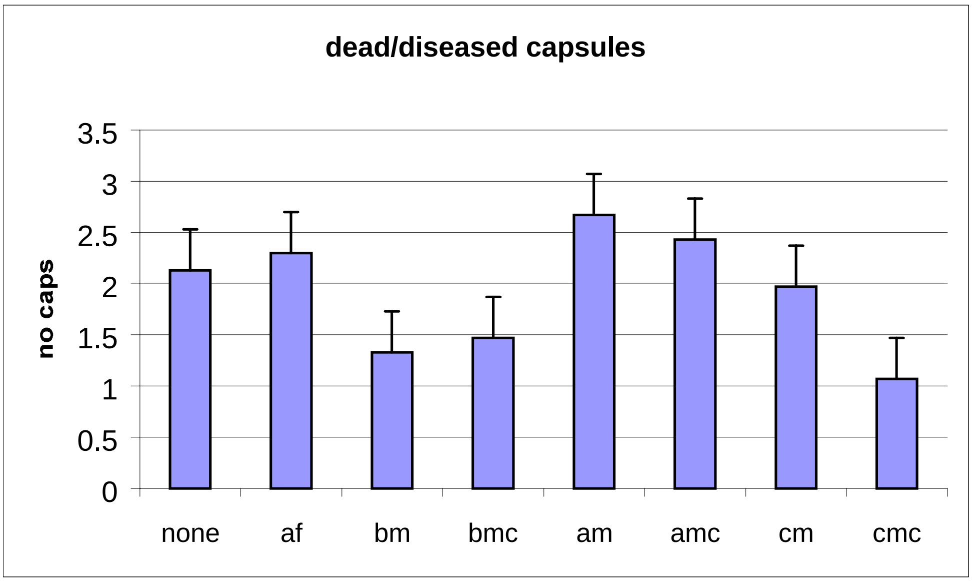


Fig. 54. Number of dead/diseased capsules at crop maturity in winter linseed at Rothamsted in 1998 in response to fungicide treatments

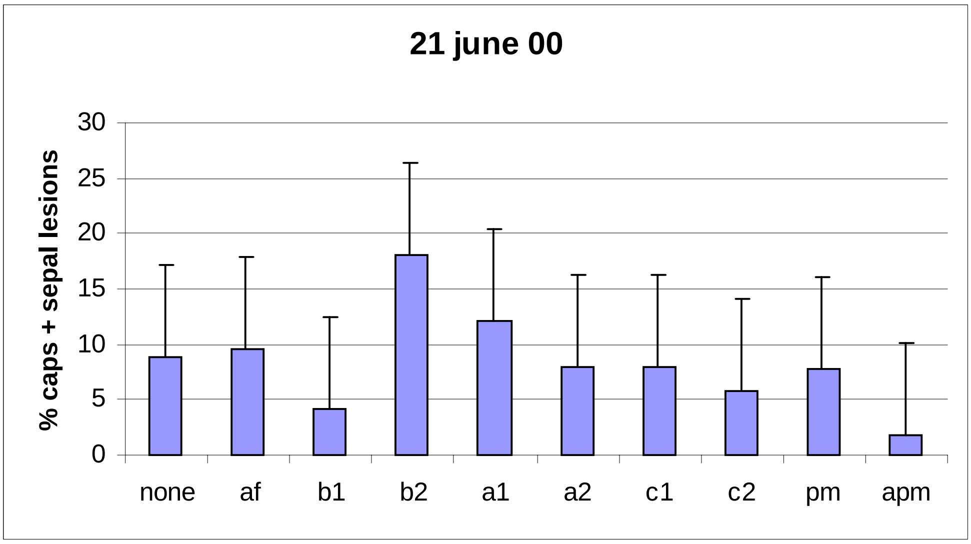


Fig. 55. Percentage of caspules with sepal lesions at crop maturity in 1999 in experiments at Rothamsted in response to fungicide treatments

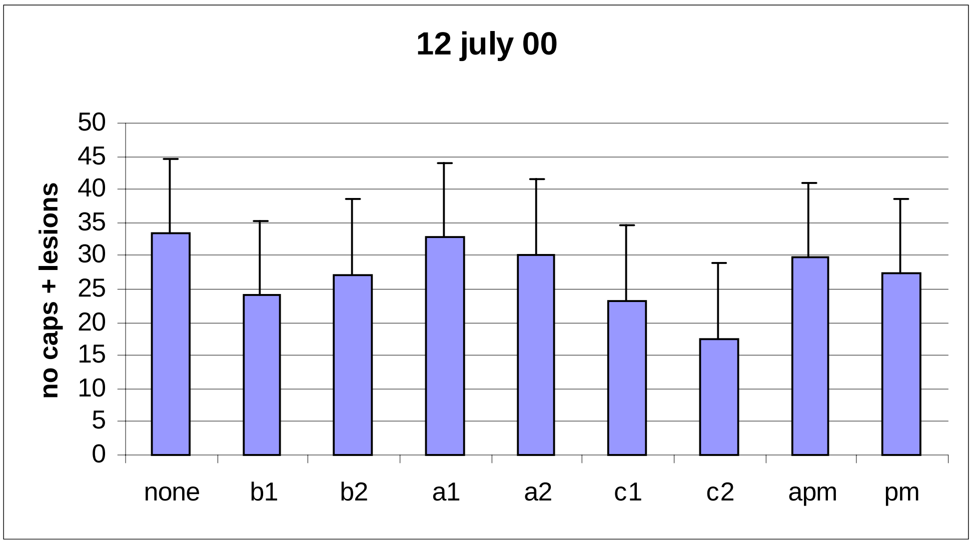


Fig. 56. Percentage of capsules with lesions in experiments at Rothamsted in 2000 in winter linseed at crop maturity in response to fungicide treatments

Plant growth:

Plants grew to a height of approximately 70cm but their height was greater in 1998/99 than in the other two seasons (Fig. 57) and this is likely to be due to a lack of a growth regulator (not applied due to adverse weather conditions). Plants were generally taller in plots treated with fungicides than in untreated plots. The period of rapid stem extension occurred between early March and late May.

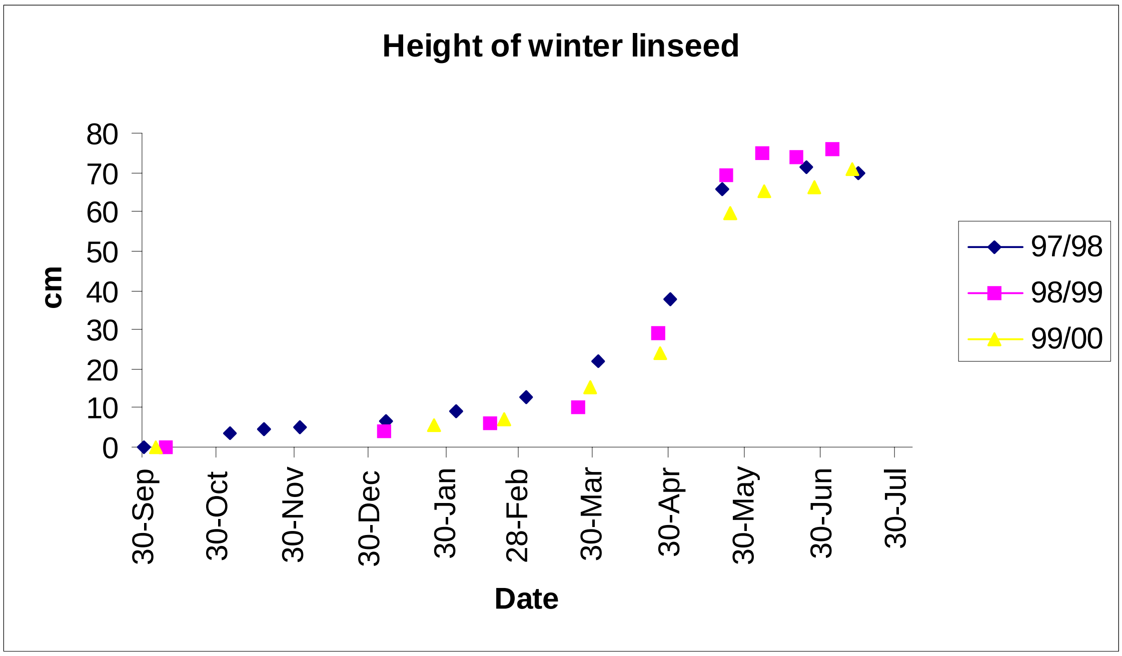


Fig. 57. Height of winter linseed (cv. Oliver) though three growing seasons, 1997/98, 1998/99 and 1999/2000 in experiments at Rothamsted

Yield responses

Fungicide treatments for disease control in winter linseed were associated with increased yields every season but only significantly in the first (Table 7, Fig. 58). In 1997/98 there were good yield responses ($P<0.001$) to fungicide treatments, with the best treatments (1.5 t/ha) more than doubling the yield of unsprayed plots (0.5 t/ha). A single spray of benomyl at mid-flowering achieved the most effective disease control and greatest yield. There was little additional benefit from the two-spray programme. In 1998/99, the severity of pasmo was much less than in 1997/98 and fungicide treatments did not significantly decrease pasmo severity in June. Yields (even on untreated control plots) were greater than 2.4 t/ha. A single spray of thiophanate-methyl plus iprodione at mid-flowering produced the highest yield but the yield was not greatly affected by pasmo in this season (R^2=12%). In 1999/2000, yields varied from 1.47 (two sprays of iprodione) to 1.97 t/ha (one spray of thiophanate-methyl) and there were no significant effects of fungicides.

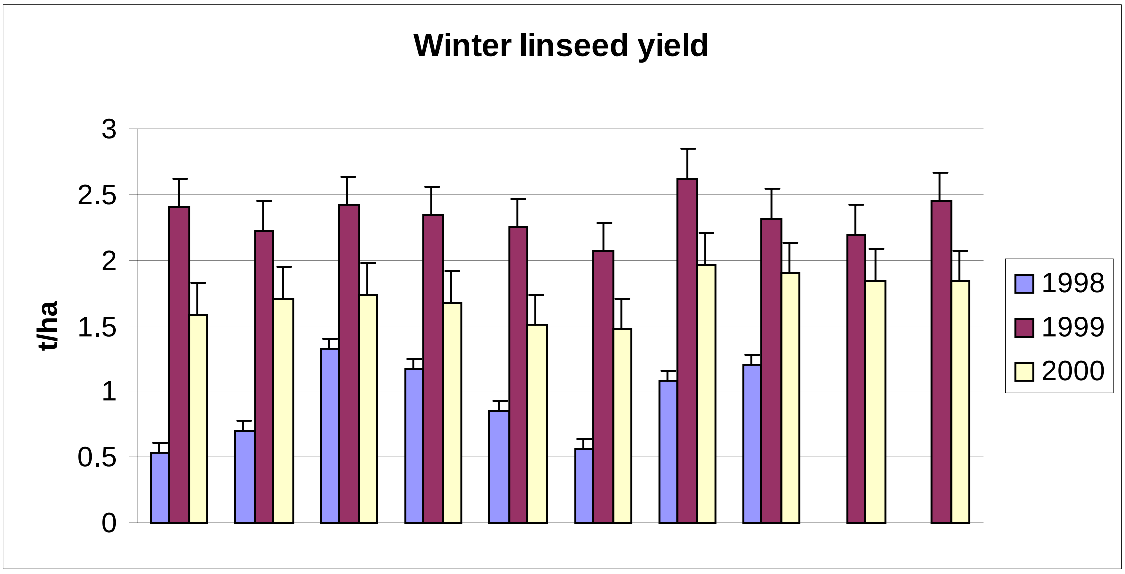


Fig. 58. Yield responses to disease control in winter linseed (cv. Oliver) at Rothamsted in 1998, 1999 and 2000

Yield components:

Numbers of capsules on main stems were not increased by fungicide treatments to control disease, but numbers did vary between seasons with least in the first season (9-11 per stem) and most in the last two (16-27) (Figs 55, 56 and 57). Fungicide treatments to control disease increased TSW, but significantly only in the first season (1997/98) and the greatest responses were with one or two sprays of benomyl (6.5g) (Fig. 59). TSW was significantly different over the seasons, being higher in the middle season, (1998/99), and lowest in the last (1999/2000) (5g). There were no differences in % oil in 1998/99 and 1999/2000 (Fig. 60) (not recorded in the first season).

Table 7. Seed yield (at 90% dry matter) of winter linseed (cv.Oliver) in experiments at Rothamsted, 1997/98-1999/2000, in plots with (+) or without (-) fungicide treatments

Fungicide treatments (spray timing)	Yield (t ha^{-1}		
	1998	1999	2000
None	0.53	2.4	1.35
Tebuconazole	0.7	2.23	
Tebuconazole + benomyl		2.2	
Tebuconazole + benomyl x 2		2.45	1.85
Benomyl – pre and mid		2.2	1.84
Benomyl – mid	1.32	2.41	1.74
Benomyl- mid and caps	1.17	2.34	1.68
Iprodione	0.85	2.25	1.51
Iprodione – mid and cap	0.56	2.07	1.47
Thiophanate-methyl + iprodione – mid	1.08	2.62	1.97
Thiophanate-methyl + iprodione – mid and caps	1.2	2.32	1.9

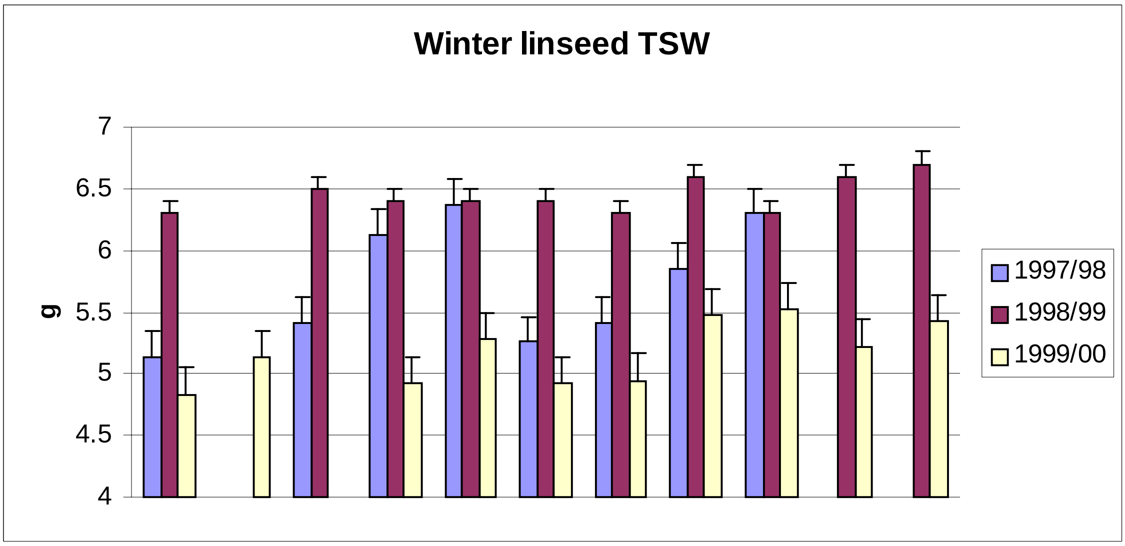


Fig. 11. Thousand seed weight of winter linseed (cv. Oliver) in experiments at Rothamsted in response to disease control 1997/98, 1998/99 and 1999/2000

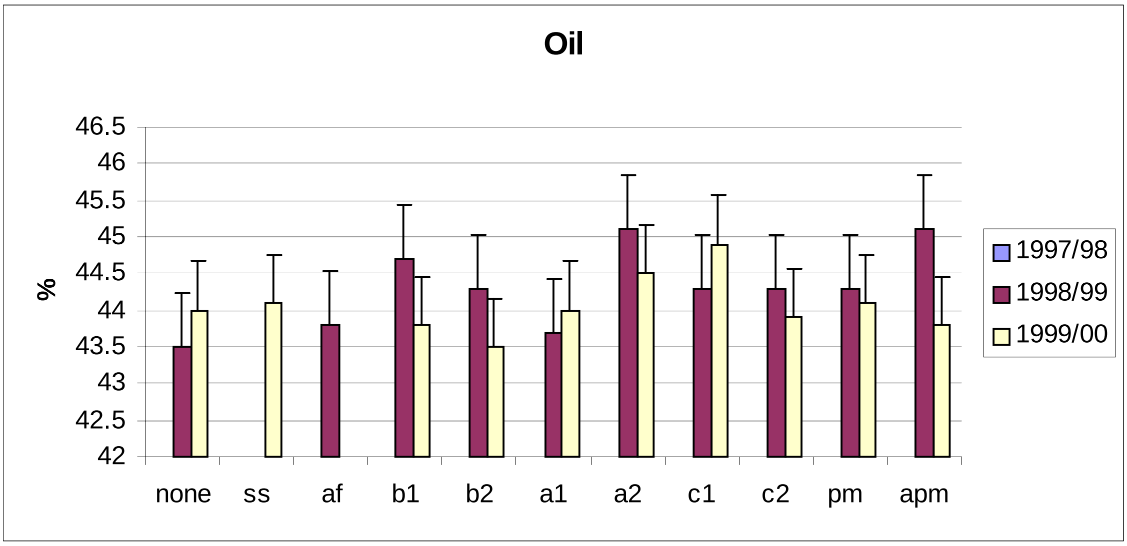


Fig. 60. Percentage oil in winter linseed (cv. Oliver) seed in experiments at Rothamsted 1998, 1999 and 2000

Incidence of fungal pathogens on seed

M. linicola was not detected in seed harvested from the Rothamsted experiment in 1998 and 1999 (Table 6). Incidence of *B. cinerea* decreased from 100% in seed from untreated plots to 30% in seed from benomyl or iprodione treated plots, but only to 80% in plots treated with thiophanate-methyl plus iprodione. There was a low incidence of *Alternaria* species on seeds from the untreated plots that did not appear to be influenced by any fungicide spray treatment. Pasmo was detected in some seeds from treated and untreated plots in 2000.

Spore numbers and meteorological data

In the 1997/98 season (data not presented), the daily concentrations of *M. linicola* ascospores fluctuated, with maxima in June (*c.* 400 spores m^{-3}) and mid-July 1998 (*c.* 500 spores m^{-3}). In 1998/99, concentrations of ascospores were low (1-20 m^{-3}) until early May 1999 and then increased to give maxima of 200-300 spores m^{-3} by late May/June and 600 spores m^{-3} in July (Figure 61). Maxima in numbers of spores coincided with the occurrence of spring rainfall (Fig. 62) and mean daily temperatures >12ºC. An important difference between the two seasons was that total rainfall in March/April was 178.0 mm in 1998 and 86.7 mm in 1999, and total rainfall in June was 102.8 mm in 1998 and 83.2 mm in 1999. In the last season, 1999/2000, the pattern exhibited in spore numbers was very similar to that of 1998/99. Relative humidity and wetness are shown in Fig. 63.

Table 6 . Incidence of fungal pathogens on seed harvested from winter linseed (cv. Oliver) at Rothamsted in 1998, 1999 and 2000 from plots that received different fungicide treatments

Pathogen	Year	Fungicide treatments									
		none	af	B1	B2	A1	A2	C1	C2	pm	apm
Alternaria spp	1998	6.7	26.7	53.3	33.3	20	20	13.3	13.3		
	1999	16.7	13.3	13.3	6.7	3.3	6.7	23.3	6.7	13.3	10
	2000	0	0	0	0	0	0	0	0	0	0
Botrytis cinerea	1998	100	86.7	33.3	100	33.3	33.3	73.3	86.7		
	1999	13.3	3.3	3.3	6.7	3.3	3.3	0	3.3	10	10
	2000	26.7		13	20	0	0	26.7	13	6.7	6.7
Mycosphaerella linicola	1998	0	0	0	0	0	0	0	0	0	0
	1999	0	0	0	0	0	0	0	0	0	0
	2000	13		20	26.7	13	0	0	13	0	0

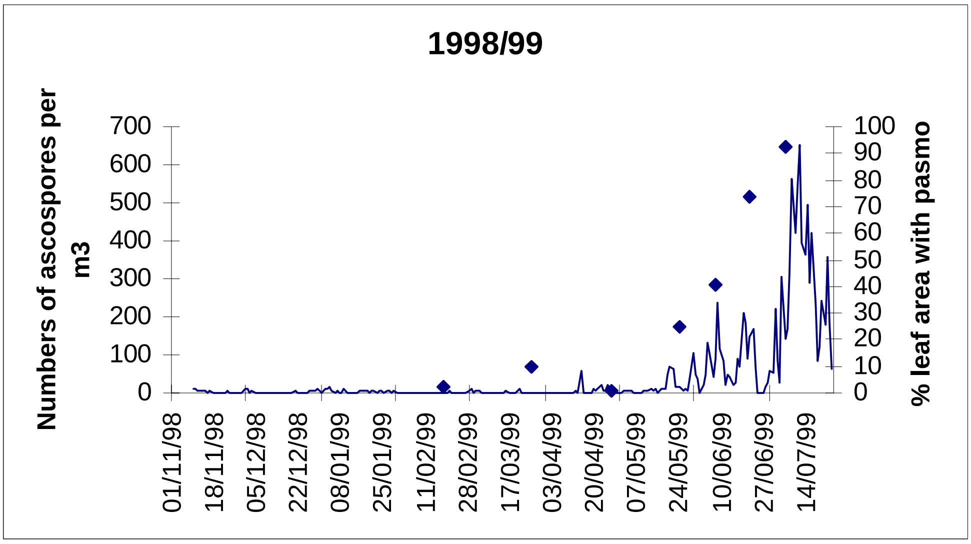
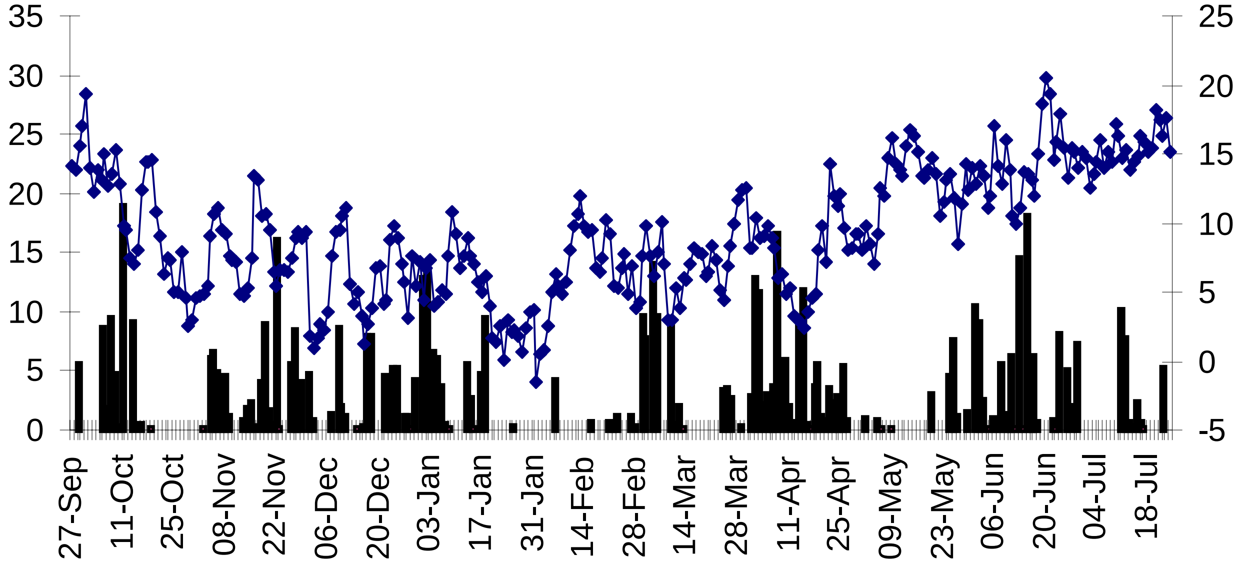


Fig. 61. *M. linicola* ascospores (per m^{-3}) collected daily by a Burkard spore sampler and progress of pasmo on leaves (% area affected) at Rothamsted in 1998/99

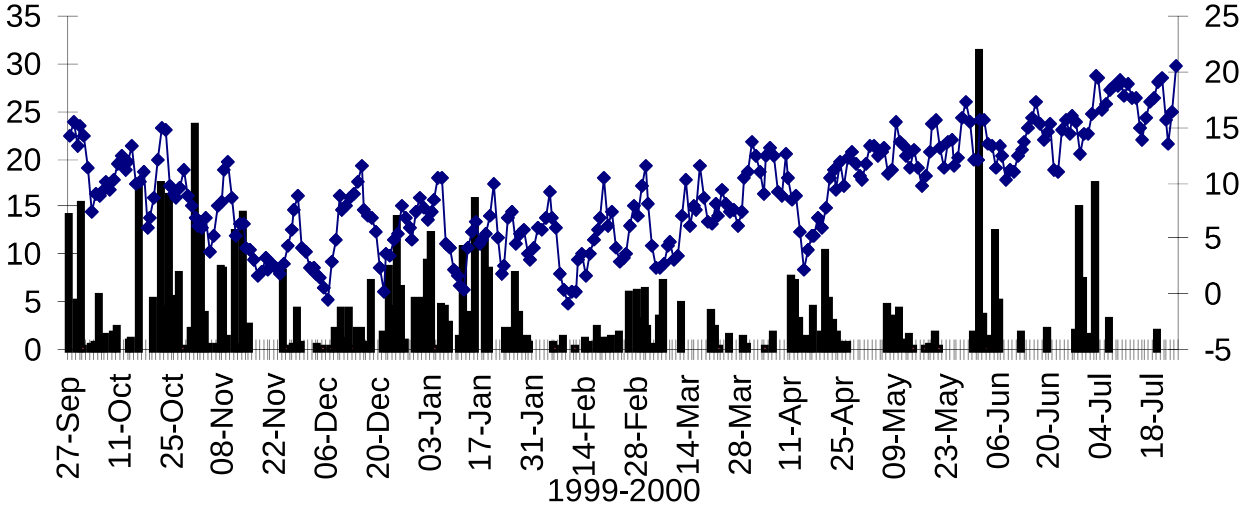
Mature ascospores were detected on the first Burkard samples in the autumn of each year (Fig.61) (observations on presence/abundance for first season not presented). However, these initial numbers were very low and may represent ascospores from the previous year's debris. Ascospores were first released (> 4 ascospores m^{-3}) in late March of 1999 and 2000 (no data for 1998) and numbers continued to increase until late May and then rapidly increased through June into July. This probably reflects the spores released by the senescing plant material during that period. The first spores released are very few in number but lead to a relatively high incidence of spotting. The numbers of ascospores then increase as the severity of pasmo disease increases. Leaf spotting/lesions in the field occurred in November in the first season (no spore numbers available) and in February in the second two seasons (when spore numbers were still only 0-8 m^{-3}). As leaf disease was earlier and became more severe in the first season it would be of interest to know if the maximum spore numbers occurred two months earlier also. If this was known, it could be used as a means of predicting early onset of disease and potential usefulness and application of fungicides.

In the middle of the season (when more ascospores were collected after stem extension than before), it appears that heavy rain results in spore release. Later on in the season, most spores are conidia which are released from decaying leaves lower down the plant and so there are less ascospores during heavy rain at this time. On drier days, it was observed that there was a diurnal periodicity, with release of ascospores when wind speed was increasing and relative humidity decreasing in the late morning. It may be that on dry sunny days the r.h. the night before is high, favouring sporulation. In autumn/winter, however, rainfall did not cause spores to be released from debris, as the current season's spores may still have been immature. It is important to note that, each year, pasmo lesions were detected by any major spore releases were detected before spore traps.

1997-98



1998-99



1999-2000

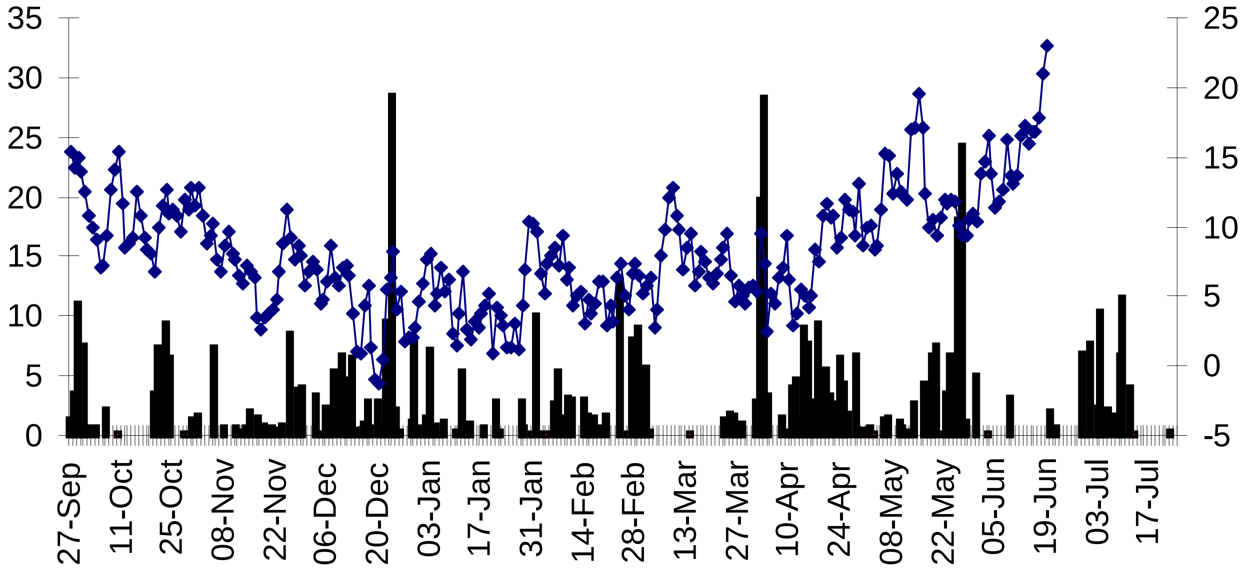


Fig. 62. Rainfall (mm) and temperature (^{o}C) at Rothamsted in three seasons

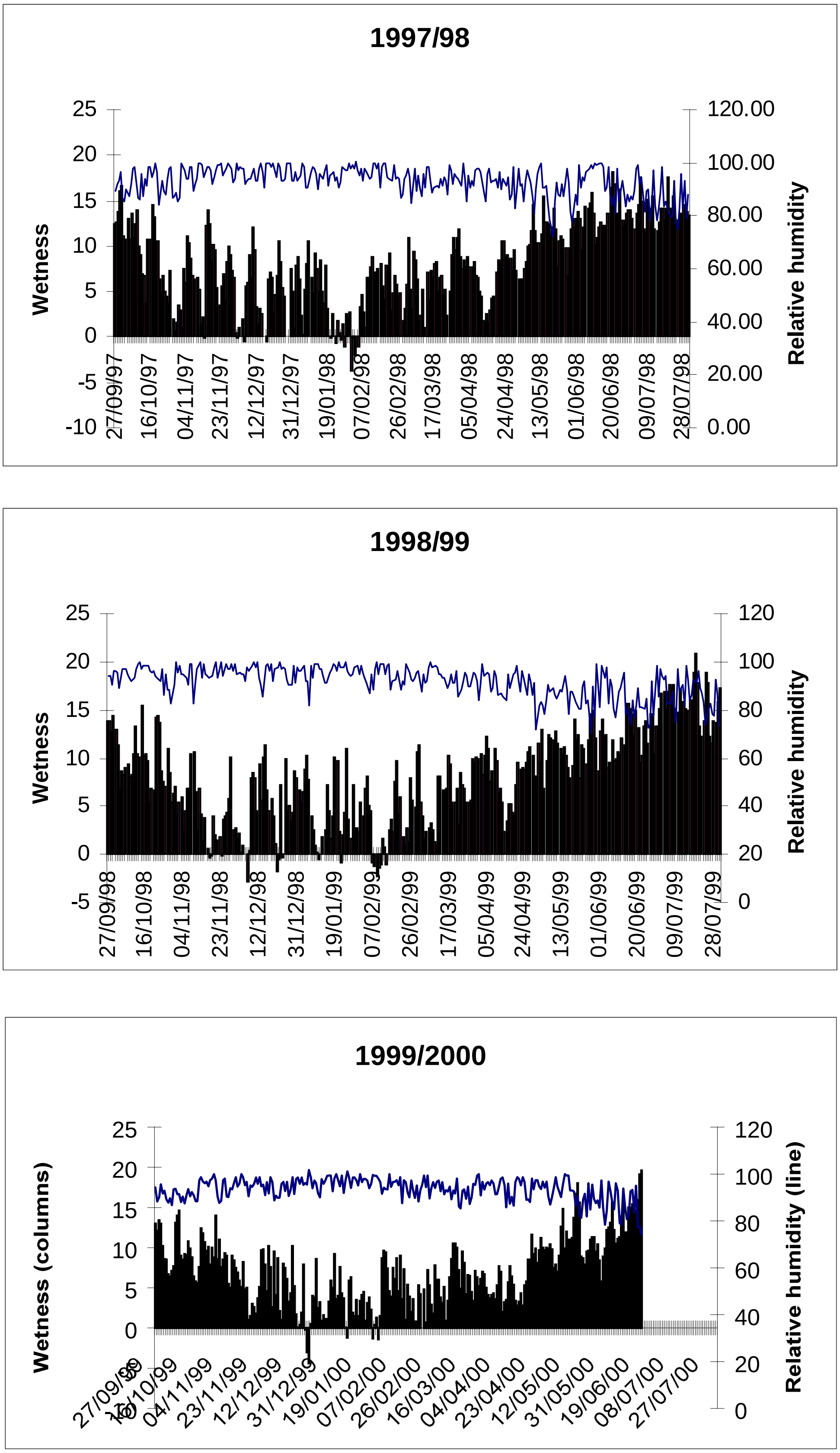


Fig. 63 Leaf wetness and relative humidity at Rothamsted in three seasons

Disease, yields losses and weather relationships

The early onset of pasmo in 1997/98 was associated with high autumn temperatures and rainfall and its severity in spring 1998 was related to the high spring rainfall. In 1999, spring was much drier and pasmo not so severe. In 1999/2000, autumn and winter temperatures were not so high as in 1997/98. Yield and yield losses associated with disease were greatest in warm wet years and smallest in the cooler than average years.

Yield loss relationships

In single point regressions of yield on disease factors at specific assessment dates in each year, several factors assessed accounted for varying % of the variance in yield (Table 7). Of these factors, % stem pasmo and % leaf pasmo showed a consistent negative association with yield over the three seasons. Factors were most significant in June/July (Fig. 64) when combined data for the three seasons results in the following models: $y = 5.86 - 0.046\ x_1$ ($R^2 = 57\%$) for % leaf area with pasmo (x_1) and $y = 2.34 - 0.02\ x_2$ ($R^2 = 75\%$) for % stem area with pasmo (x_2). Percentage capsules with sepal lesions (s) at crop maturity was significantly related to yield in 1998 ($y = 1.69 - 0.10\ s$ ($R^2 = 96\%$)) but less so in 2000 ($y = 2.32 - 0.008\ s$ ($R_2 = 52\%$)) (Fig. 65). The results demonstrated that greatest yield losses were generally associated with the largest severity scores. It can be deduced that the earlier that lesions with a high severity score are recorded on plants, the greater is the effect on yield, because lesions with a small severity score in early spring continued to become more severe. (Fig. 66). TSW was consistently positively related with yield, particularly in the first season.

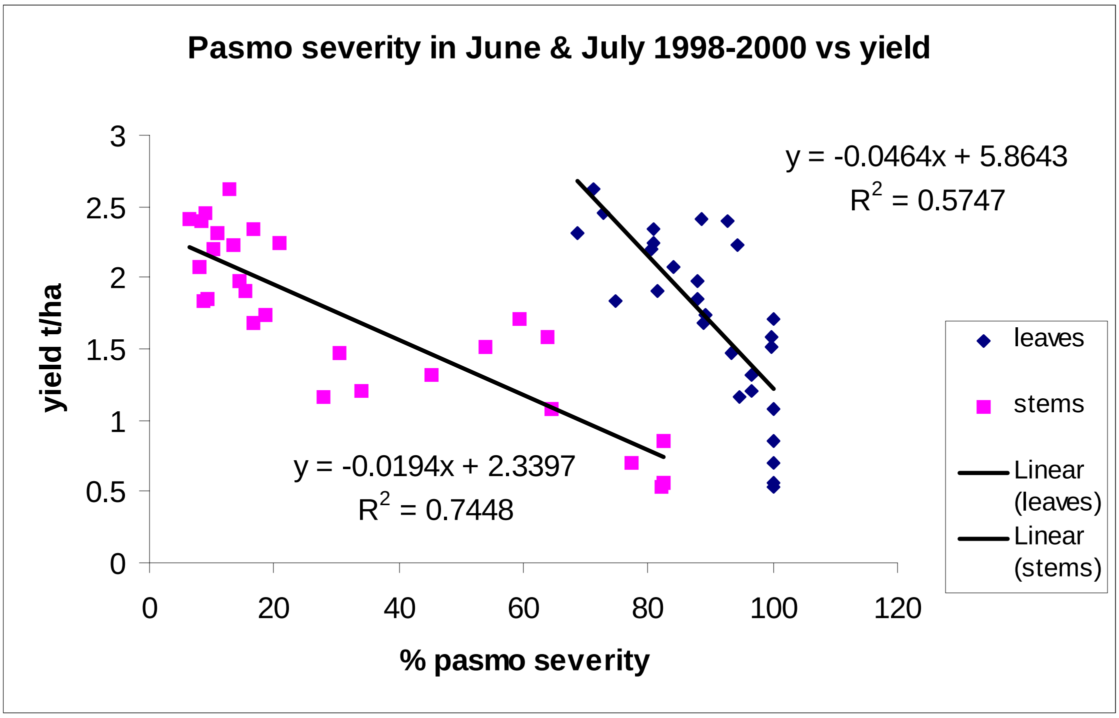


Fig. 64. Relationships between pasmo severity on leaves in June and stems in July and yield of winter linseed (cv. Oliver) at Rothamsted 1998-2000

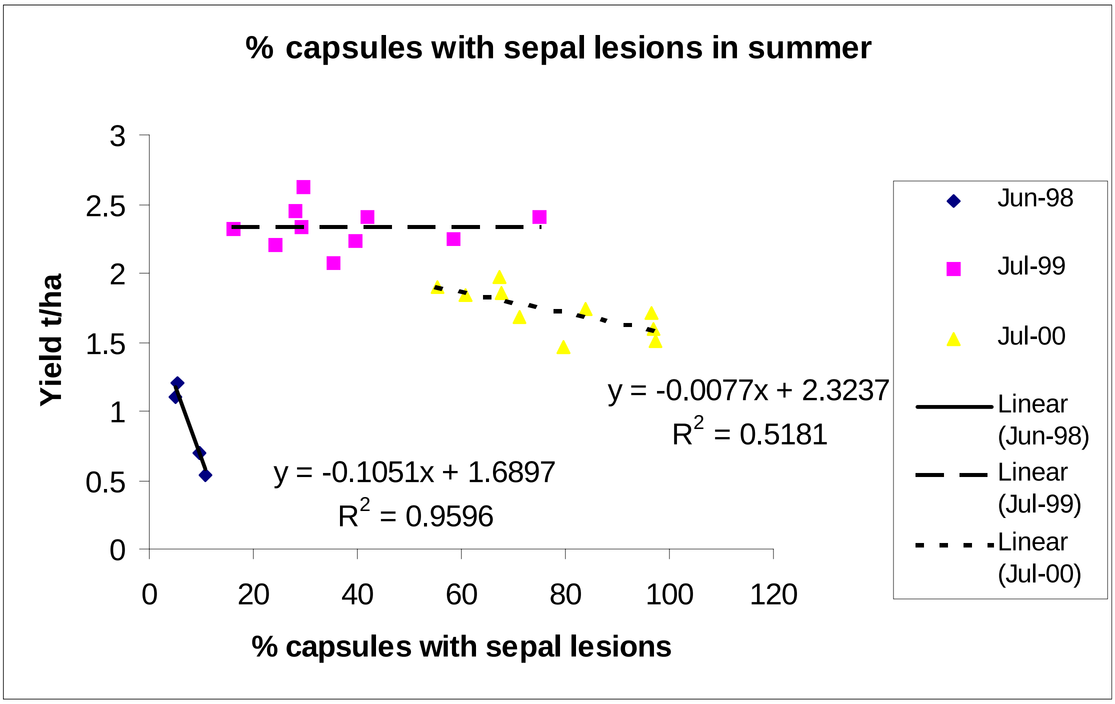


Fig. 65. Relationships between capsules with sepal lesions at crop maturity and yield of winter linseed (cv. Oliver) at Rothamsted in 1998-2000

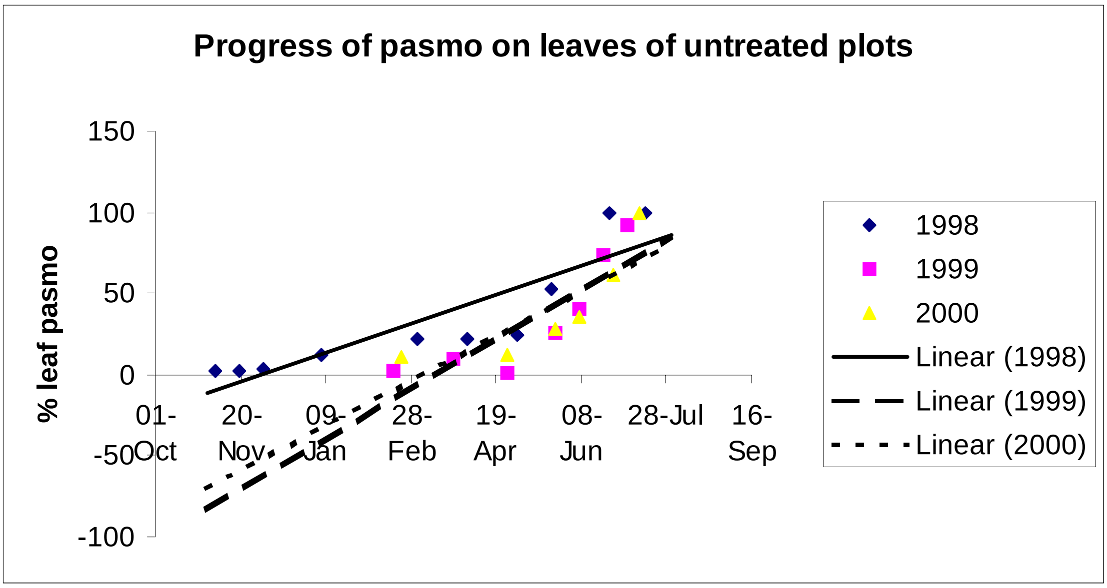


Fig. 66. Regressions of pasmo leaf severity against time in winter linseed (cv. Oliver) at Rothamsted

Table 7. Disease factors that accounted for a varying % of the variance (R^2) in the single point regression of yield (y) *on the factor* (d)*, for experiments at Rothamsted on winter linseed (cv. Oliver) 1997/98 – 2000. Regressions in the form* y = a – bd

			Leaves			Stems			Capsule	
		a	*b*	R^2	*a*	*b*	R^2	*a*	*b*	R^2
1997/98	3 Dec	0.91	0.10	100				1.74	0.11	82.8
	7 Jan	1.02	0.04	100				1.36	0.28	17.5
	4 Feb	0.51	0.01	100				3.01	0.22	41.0
	4 Mar							1.75	0.43	63.5
	2 April	94.2	4.25	100						
	1 May	-5.83	0.26	100			100			
	22 May	24.3	0.45	100	1.52	0.064	74.9			
	25 June	2.69	0.02	67.9	1.52	0.064	74.9			
	16 July	11.54	0.11	57.9	1.64	0.012	74.1			
1998/99	18 Feb	-2.01	0.16	100						0.72
	25 Mar	-2.01	0.04	100						0.65
	26 Apr	7.5	5.67	100			100			4.61
	24 May	2.42	0.01	1.12	2.69	0.113	42.3			0.25
	7 June	2.81	0.01	38.6	2.34	0.006	0.85			13.1
	21 June	-2.19	0.002	1.73	2.21	0.013	40.4			0.01
	5 July	2.8	0.006	12.6	2.35	0.002	0.37			
1999/00	12 Jul	-1.6	0.01	29.1						
	23 Feb	-0.16	0.11	100						
	29 Mar	-1.12	0.01	34.8	-1.16	0.01	33.4			
	26 Apr	2.20	0.07	92.7	2.28	0.075	90.2			
	24 May	7.75	0.22	40.1	2.0021	0.025	1.71			
	7 June	4.66	0.09	72.9	2.85	0.085	34.2			0.11
	27 june	2.92	0.02	73.4	1.94	0.009	75.7			84.4
	12 July	3.58	0.02	61.6						32.61
										59.2
										71.1

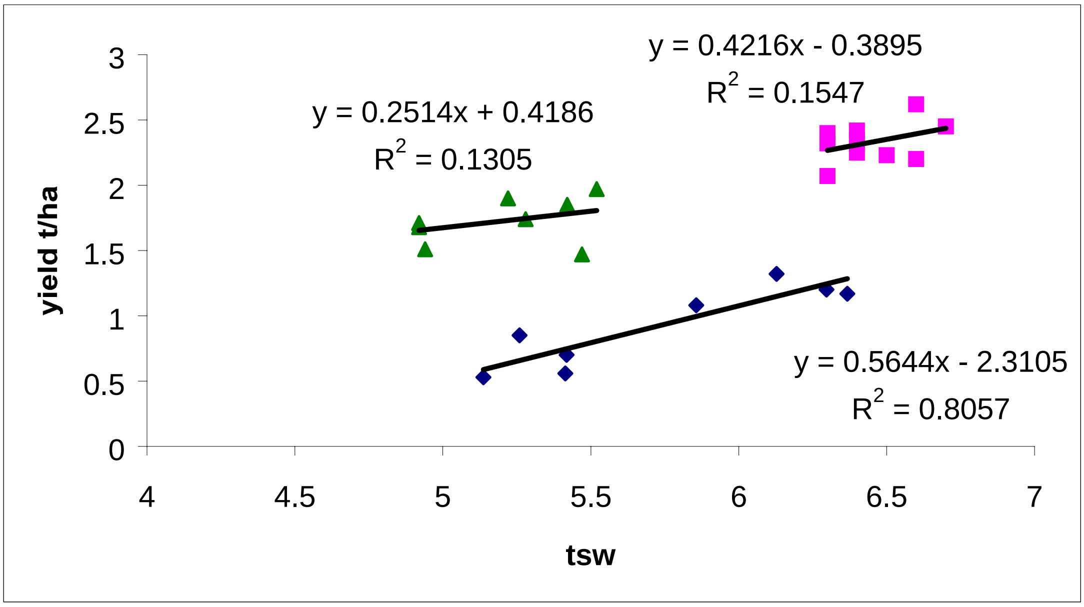


Fig. 67. Relationships between thousand seed weight and yield of winter linseed (cv. Oliver) at Rothamsted in 1998, 1999 and 2000 (● 1998, ■ 1999, and ▲ 2000)

Estimates of national yield losses

The formula relating yield loss to severity of pasmo on stems in July (crop maturity) are combined with the ADAS survey data to estimate, retrospectively, the national losses from pasmo and hence its importance (Table 8). Greatest losses were in the first season (1997/98), when the estimated yield loss over the UK was 1.2 t/ha due to disease. The greatest regional losses in this first-year were in England, with the exception of the West Midlands. Scotland had significantly lower levels of pasmo disease and hence only had losses of 0.4 t/ha. The estimated yield loss in the second season, (1998/99), was much less at 0.8 t/ha and again it was high over England but lower in the Midlands. However, in this second season the linseed crops in Scotland suffered severe levels of pasmo and had the highest losses (1.2 t/ha). In 1999/2000, the West Midlands had the highest losses of the whole study period (1.9 t/ha). Overall losses declined over the three seasons from approximately £2.8M to £0.5M, as the overall area of winter linseed grown in the UK declined drastically from 20,000 ha to 2,500 ha (Table 9).

Table 8. Estimates of regional and national losses of linseed yield due to disease, based on severity of pasmo in June on stems in 1998 ($y = 2.686 - 0.0192x$), in 1999 ($y = 2.811 - 0.013x$) and in 2000 ($y - 2.922 - 0.023x$) in UK.

Year	Region	% stem base/with pasmo	Estimated yield (t/ha)	Estimated yield loss (t/ha)
1988	S.England	75	1.25	1.44
	N.England	74	1.27	1.42
	E.England	76	1.24	1.46
	E.Midlands	71	1.32	1.36
	W.Midlands	52	1.69	1.00
	Scotland	20	2.30	0.37
	UK average	**61.3**	**1.51**	**1.18**
1999	S. England	75	1.83	0.98
	N. England	95	1.57	1.24
	E. England	55	2.09	0.72
	E. Midlands	56	2.08	0.73
	W Midlands	53	2.25	0.56
	Scotland	90	1.63	1.18
	UK average	**69**	**1.91**	**0.84**
2000	S. England	49	1.79	1.37
	N. England	44	1.90	1.02
	E. England	69	1.32	1.60
	E. Midlands	48	1.81	1.11
	W.Midlands	84	0.97	1.95
	England average	**58.8**	**1.56**	**1.06**

Table 9. Estimates of national disease losses in winter linseed from 1997/98 to 1999/2000

Year	Area grown in UK	Total production	Total value of crop produced	Average Loss due to disease	Total value of loss	Total loss due to disease
	(ha)	(t)	(£)	(t/ha)	(t)	(£)
1997/98	20,000	30,180	3,621,600	1.177	23,540	2,824,800
1998/99	10,000	19,070	2,288,400	0.841	8,410	1,009,200
1999/00	2,500	3,895	467,400	1.364	3,410	409,200

Discussion

These experiments suggest that pasmo is the most serious disease affecting yield of winter linseed in the UK; a conclusion supported by ADAS surveys of diseases in commercial crops across the country. It appears pasmo has replaced *Botrytis* and *Alternaria* as the major pathogen of linseed (winter and spring). Powdery mildew and *V. dahliae* were not observed in the field experiments at Rothamsted. The severe pasmo epidemic in 1997/98 was an important factor in the difference in yield between that and the other two seasons. Furthermore, the yield losses in the 1997/98 Rothamsted experiment could be directly related to the severity of pasmo on leaves and stems in June and July. The yield loss model was combined with survey data to estimate losses nationally. These loss estimates based on assessments in June/July can only be retrospective rather than predictive, as timing experiments fungicides must be applied earlier in the season to be effective.

These experiments also provide evidence that development of severe pasmo on leaves and stems is favoured by wet weather, since rainfall in March/April was much greater in 1998, when the severity of pasmo increased rapidly in May/June, than in 1999 and 2000 when the disease was less severe. However, the severity of the disease was also greater throughout the autumn/winter in 1997/98 than in 1998/99. The relative roles of the wind-dispersed ascospores and the splash-dispersed conidia in development of pasmo epidemics are unclear, and it would be valuable to confirm if numbers of air-borne ascospores in the spring were greater in 1998 than 1999 and 2000. The spread of pasmo in the spring from winter to spring linseed crops some distance away is evidence for the role of ascospores in disease spread at that time. It is possible that ascospores produced on crop debris may be responsible for initiation of epidemics in autumn, and pasmo is also reported to be seed-borne. Although infected seed may be important for distribution of the pathogen, *M. linicola* was not detected in seed harvested from severely affected crops at Rothamsted nor was the disease transmitted to seedlings and plants from seed from infected plants.

The results of these experiments also demonstrate the seasonal variability in winter linseed yields and yield responses to disease control. In 1997/98, yields were low but yield response to fungicide treatments was good whereas in 1998/99 and 1999/2000 yields were higher and were not greatly affected by the fungicide applications. This is in contrast to the surveys and so decisions should be made on an individual crop basis. The results demonstrate the advantage of well-timed fungicide applications when disease risk is high, with mid-flowering being the best spray timing. A single spray was as effective as a two-spray programme in controlling stem and leaf pasmo in 1997/98 in Rothamsted field experiments. However, the results suggest that in seasons with a warm dry spring (2 of the 3 years in this project) when pasmo does not become severe it is not necessary to apply fungicides. Thus, there is a need for a forecasting scheme based on weather and inoculum measurements to guide decision-making so that fungicide sprays are applied to winter linseed crops only when they are needed rather than prophylactically.

Observations on timing of appearance of initial symptoms can guide decision making on fungicide application. Infections of early leaves in the first season allowed the pathogen to spread to the stem by March (as compared to May in the second two seasons) and hence result in more damage to yields. In 1997/98, fungicide treatments, although not able to eradicate pasmo, did reduce the spread of the disease on the treated plants. Fungicides could be applied after lesions appear in the spring but before they become widespread on stems. These data analyses suggest that it is possible to predict potential yield loss and assess the need for fungicide treatment by estimating stem pasmo in March/early April. This may be the optimum growth stage for prediction of yield loss because pasmo severity then reflects the damage done by the disease over the winter period. The field experiments have shown that the optimum time for applying fungicides is pre-flower and mid-flower therefore this model can be used to guide decisions about these applications.

Correlation analysis indicated that yield losses from pasmo were related to disease severity at GS 6 in June/July, which is the seed development stage and a key stage for linseed yield production; hence this is the critical time for relating pasmo to yield loss. Results suggest that it is important for farmers to control early pasmo lesions. Ultimately, it is necessary to estimate risks that early, severe lesions on stems will develop to guide decision making for pasmo control during the period from early spring to early summer. Significant positive correlations between the data for seed yield and stem pasmo indicated that much of the loss in yield resulted from a reduction in the size of individual seeds.

The formulae relating yield losses to severity of disease factors, derived from these experiments, were combined with ADAS survey data to estimate, retrospectively, the national losses from diseases and assess their importance. Estimated national losses were *c*. £2.8M in 1998 £1M in 1999 and £0.5 in 2000. These losses represented 44% in 1998, 31% in 1999 and 47% in 2000, of the total possible net gain in linseed yields.

Further work is required to understand how climatic factors affect maturation of ascospores and timing of initial spore releases. Also of whether the spores are causing the disease or that the disease is the source of spores. It is unclear whether pasmo is seed borne or not and this requires further investigation The incubation period between spore release date and the appearance of cotyledon/leaf spotting in the field appears to be a few months. Further work could be done to evaluate effects of fungicides on established leaf infections in order to optimise fungicide use. The latent period between infection and symptom appearance affects the time of sprays; it is important to protect upper leaves and flowers, which means sprays need to be applied earlier. Therefore we need to understand infection periods and epidemiology of pasmo in more detail.

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References

Gladders P, Jones A M, Lockley, K D, Young C S & Turley D (1999).). Occurrence and importance of diseases in winter linseed. *In Protection and Production of Combinable Break Crops. Aspects of Applied Biology* **56**, 177-182.

Mercer P C, Hardwick N V, Fitt B D L & Sweet J B (1994). *Diseases of linseed in the UK. Plant Varieties and Seeds* **7**, 135-150.

Smith J & Froment M A 1998. A growth stage key for winter linseed (*Linum usitatissimum*). *Annals of Applied Biology* **133**, 297-306.

Publications, articles and presentations

Published papers

Gladders P, Jones A M, Lockley, K D, Young C S & Turley D (1999). Occurrence and importance of diseases in winter linseed. *In Protection and Production of Combinable Break Crops. Aspects of Applied Biology* **56**, 177-182.

Lane A & Gladders P (2000). Pests and Diseases of Oilseeds, Brassica seed crops and Field beans. Chapter 3, *BCPC Pest and Disease Management Handbook*, Blackwell Science, Oxford (ed. D V Alford), pp. 52-83.

Perryman, S A M, Fitt, B D L & Harold J F S (2001). Factors affecting the development of *Botrytis cinerea* (grey mould) on linseed buds, flowers and capsules. *Annals of Applied Biology – ready to be submitted.*

Perryman, S A M & Fitt, B. D. L. (2000). Yield responses to control of pasmo (*Mycosphaerella linicola*) in winter linseed. *In Proceedings Brighton Crop Protection Conference- Pests and Diseases*, 2000, 823-828.

***Perryman, S A M & Fitt, B D L** (2000). Effects of diseases on the growth and yield of spring linseed (*Linum usitatissimum*), 1988-1998. *Annals of Applied Biology* **136**, 197-207.

Perryman, S A M, Fitt, B D L & Gladders, P. (1999). Effects of diseases on the yield of winter linseed. *In Protection and Production of Combinable Break Crops. Aspects of Applied Biology* **56,** 211-218.

** This paper accompanies this report as it describes research funded by the HGCA and not presented in this report.*

Press articles

Gladders P (1999). Disease survey on linseed. *Oilseeds and Industrial Crops* **16** (4). (Semundo winter linseed briefing notes)

Perryman S A M & Fitt B D L (1999). The effect of fungicides on diseases and yield of winter linseed. *Oilseeds and Industrial Crops* **16** (4). (Semundo winter linseed briefing notes)

Perryman S A M –Winter linseed in ‘Rising stars look for a break’. *Crops 22*, January 2000, p29.

A feature was prepared in Bayer Four Seasons 1998, Volume 19, p.3 ‘Linseed viability under threat’

Occurrences of winter linseed diseases and control measures have featured regularly in ADAS Crop Action notes and some of these reached Farmers Weekly (e.g. Linseed leaf spot not worth spraying, Farmers Weekly **129** (25),p.45, 18 December 1998).

Progress of winter linseed crops and disease developments feature regularly in ADAS Crop Action Notes and these produced some press coverage.

An HGCA Fact Sheet was produced for diseases and weeds of winter linseed in Autumn 1999

Presentations and communications

Presentation given at conference at Cirencester Agricultural College, December 1999 'Protection and production of combinable break crops'.

Survey results were presented at the ADAS Crop Centres Conference, December 1998, Peterborough.

Informal contact with various farmers, agrochemical companies and advisers was undertaken, providing details of current problems, predisposing factors and general failure of fungicides to provide good control of pasmo.

Samples of pasmo were provided for a student project at IACR Rothamsted and this was reported to BSPP News (No. 38 Spring 2001).