HGCA

PROJECT REPORT No. 223

PROPERTIES OF NEW FUNGICIDES FOR WINTER WHEAT AND WINTER BARLEY

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PROPERTIES OF NEW FUNGICIDES FOR WINTER WHEAT AND WINTER BARLEY

by

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ABSTRACT

The objective of this project was to provide information on the biological properties of fungicides under development for cereals in the UK, such that information on how they compared with current commercial standards and how to make best use of them would be available at product launch.

Nine field experiments were undertaken in each of the 1996, 1997 and 1998 harvest years, six on winter wheat and three on winter barley. Sites and cultivars were selected to test the fungicides in severe epidemics of all the major foliar diseases of wheat and barley. Ten new fungicides were investigated during the course of the project. Of these, nine are now commercially available, representing seven active ingredients marketed during the course of the project, or subsequently. These were kresoxim-methyl (in Landmark and Ensign), azoxystrobin (in Amistar and Amistar Pro), metconazole (Caramba) tetraconazole (Eminent), cyprodinil (Unix), quinoxyfen (Fortress) and spiroxamine (Neon). The experimental design was to test single applications of each fungicide at the full recommended rate, at four or five growth stages between GS 30 and GS 59. This allowed the protectant and eradicant properties of each fungicide to be determined. A standard commercial two-spray programme (GS 31/32 and GS 39), designed to give full disease control, was also included, to show the yield potential of the crop in the absence of disease and to determine the contribution towards that yield that could be achieved with each single application.

The main advantage in disease control from Landmark compared with epoxiconazole (Opus) alone was in greater protectant activity on each leaf layer against *S. tritici* from sprays applied before emergence of that leaf layer, allowing greater flexibility overall in fungicide timing. There was also longer retention of green canopy, particularly on leaves 2 and 3, which resulted in consistently higher yields than those from Opus. Azoxystrobin, used alone as Amistar, showed good protectant activity against *Septoria tritici* and yellow rust on wheat, but its lack of eradicant activity was evident. When Amistar was used in mixture with Opus, its performance was similar to that from Landmark.

Although kresoxim-methyl, in mixture with fenpropimprph, gave good control of wheat mildew, this is likely to have limited commercial value for mildew control because of the occurrence of resistance to strobilurins, which has now been confirmed in wheat mildew in the UK, albeit at low frequency. The best wheat mildew control was given by Fortress, particularly when applied early. Unix and Neon both showed useful mildew activity, but should be used in mixture for best results.

The superiority of Opus over other azoles for *S. tritici* control was confirmed, but it showed little improvement over Folicur against yellow rust. One new azole fungicide, metconazole (Caramba) showed many similar properties to Folicur, with slightly greater activity against *S. tritici* but poorer control of yellow rust. Tetraconazole (Eminent) did not show any improvement over Folicur in activity against *S. tritici*, and was weaker against yellow rust.

On barley, the performance of Amistar against net blotch, a disease which has proved particularly difficult to control with older fungicides, was superior to that of any other fungicide, and brown rust control was comparable with that from the best azole, Opus. For *Rhynchosporium*, the currently available strobilurins are beneficial in azole or morpholine mixture but do not offer the advance in disease control that Amistar does for net blotch. Among other new fungicides, Unix has useful activity against net blotch, mildew and *Rhynchosporium*, but needs to be used in mixture for best effect.

SUMMARY REPORT

Objective

The objective of this project was to provide information on the biological properties of fungicides under development for cereals in the UK, such that information on how they compared with current commercial standards and how to make best use of them would be available at product launch.

Methods

Nine field experiments were undertaken in each of the 1996, 1997 and 1998 harvest years, six on winter wheat and three on winter barley. Sites and cultivars were selected to test the fungicides in severe epidemics of all the major foliar diseases of wheat and barley. Ten new fungicides were investigated during the course of the project. Of these, nine are now commercially available, representing seven active ingredients marketed during the course of the project, or subsequently. These were kresoxim-methyl (in Landmark and Ensign), azoxystrobin (in Amistar and Amistar Pro), metconazole (Caramba) tetraconazole (Eminent), cyprodinil (Unix), quinoxyfen (Fortress) and spiroxamine (Neon). One product included in the project is not commercially available, and is referred to in this report under the code by which it was identified in the field experiments (HGCA6). The identity of this fungicide has been made known to HGCA, so that information can be released upon product launch.

The experimental design in the first two years was to test single applications of each fungicide at the full recommended rate, at four or five growth stages between GS 30 and GS 59. This allowed the protectant and eradicant properties of each fungicide to be determined. A standard commercial two-spray programme (GS 31/32 and GS 39), designed to give full disease control, was also included, to show the yield potential of the crop in the absence of disease and to determine the contribution towards that yield that could be achieved with each single application. Opus Team was the standard fungicide on wheat, and Sanction plus Corbel on barley. In the third year, the number of application growth stages was reduced to three, GS 31/32, GS 33 and GS 39, with a two spray programme of each test fungicide in addition to the commercial standard two-spray programme. Disease data are presented as the area under the disease progress curve (AUDPC) which is an integration of the amount of disease and the time for which the disease affected the leaf layer. All trials were taken to yield.

Results

Examples of the results are included in this summary report to show the effect of new and standard fungicides against each of the main foliar diseases of wheat and barley, and to show the main properties of each new fungicide.

<u>Wheat - *Septoria tritici*</u>

The best control of *S. tritici* was consistently given by Opus, Landmark and a mixture of Amistar plus Opus. The example below (Figure 1) is typical, with little difference between Opus and Landmark for the applications around the time of leaf emergence (leaf 2 emerged at GS 33), but greater persistence of control from Landmark for applications prior to leaf emergence. The poor control from Amistar, used alone in 1997, showed its lack of eradicant activity. In 1998 experiments, mixtures of Opus with Amistar were comparable with activity. In 1998 experiments, mixtures of Opus with Amistar were comparable with Landmark. Folicur and Eminent were consistently less effective than Opus as either protectant and eradicant. Caramba was similar to Folicur, but showed slightly greater eradicant activity.

Figure 2 shows the greater persistence of green canopy that resulted from use of Landmark compared with Opus. This was observed at many sites, particularly on leaves 2 and 3, even though differences between these fungicides in disease control were very small, and Opus was sometimes slightly more effective than Landmark as an eradicant.

Landmark gave the highest yield in each of the *S. tritici* sites. Figure 3 shows that, at GS 33 and GS 39, Landmark outyielded Opus, and that the GS 39 application of Landmark gave similar yields to the standard two-spray programme (of Opus Team). Other fungicides showed a similar pattern in relation to timing, with a GS 39 optimum followed by GS 33, but gave consistently lower yields than Opus.

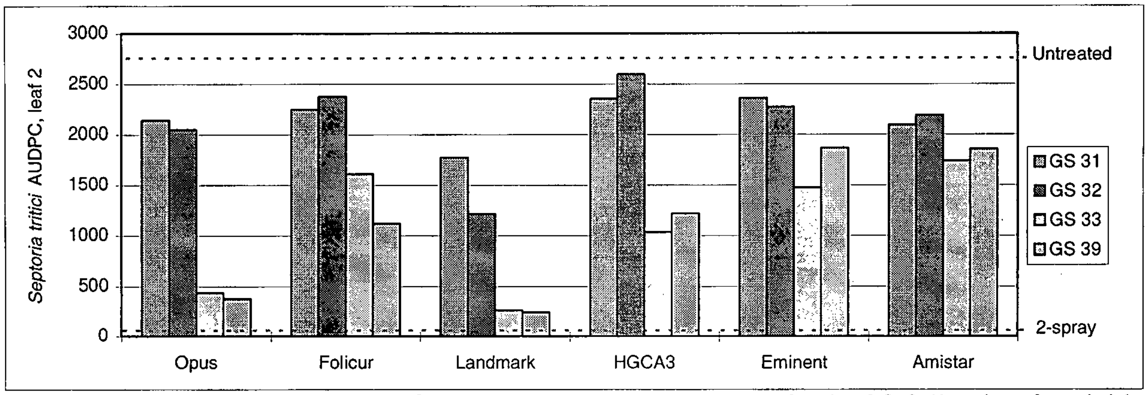
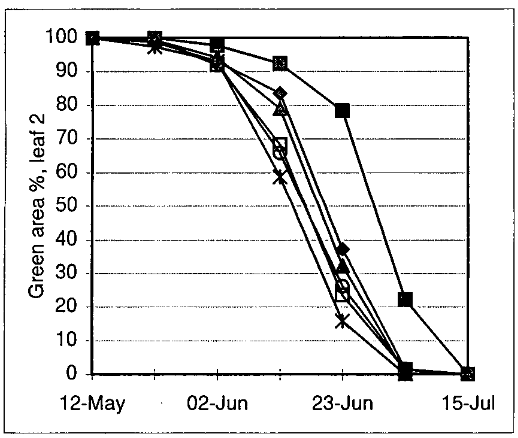


Figure 1. Area under wheat *Septoria tritici* progress curve for leaf 2 following fungicide application on four dates, West Bagborough, Somerset, 1997.



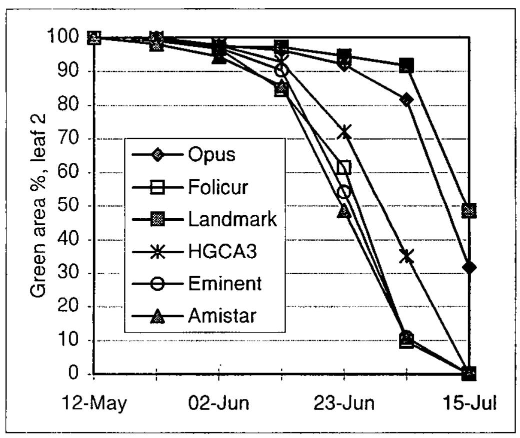


Figure 2. Effect of treatments on duration of green canopy on leaf 2, West Bagborough 1997; left: following GS 32 application; right: following GS 33 application.

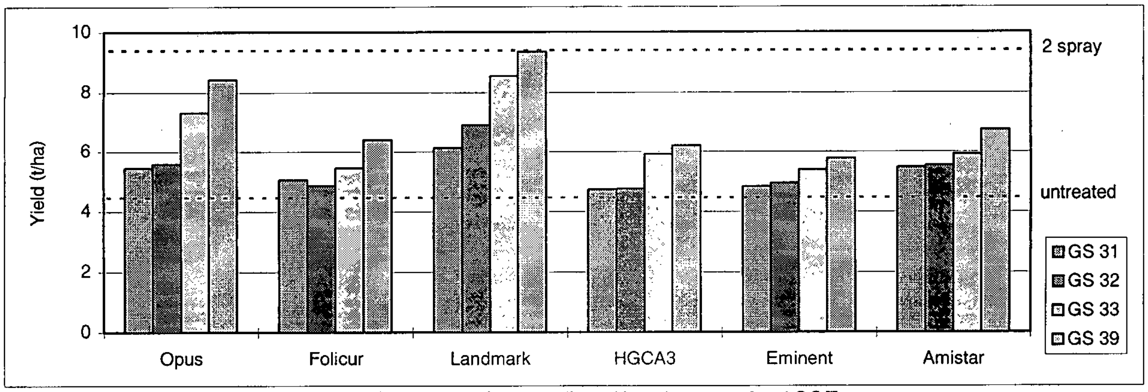


Figure 3. Effect of fungicides on yield, West Bagborough, 1997

Wheat yellow rust

The 1998 yellow rust experiment showed the importance of fungicide timing, with good control from GS 31 applications but little effect from those at GS 33 or GS 39 (Figure 4). Landmark and Amistar plus Opus gave best control, followed by Opus and Landmark. For each of these fungicides, the single GS 31 application was as effective as a two-spray programme. Ensign gave a smaller reduction in yellow rust from GS 31 application, but Neon had little effect.

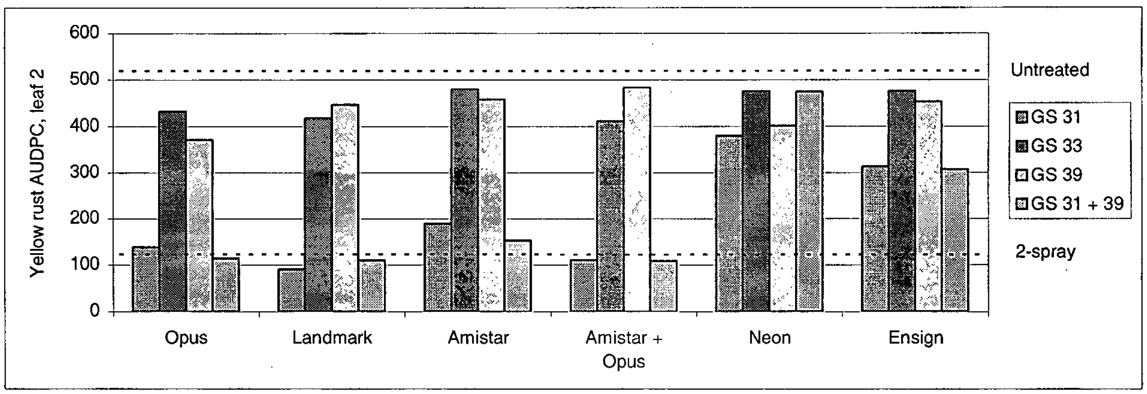


Figure 4. Area under wheat yellow rust progress curve for leaf 2 following fungicide application on four dates, ADAS Terrington, Norfolk, 1998.

Wheat mildew

Fortress and Ensign were the outstanding fungicides for wheat mildew control, as at ADAS Arthur Rickwood in 1997 (Figure 5). The long-established standard, Tern, gave good control, particularly as an eradicant, but could not match the protectant activity of Fortress and the combination of protectant and eradicant activity shown by Ensign. Unix also showed useful control of mildew. Neon, included only in 1998, was poorer than the other fungicides.

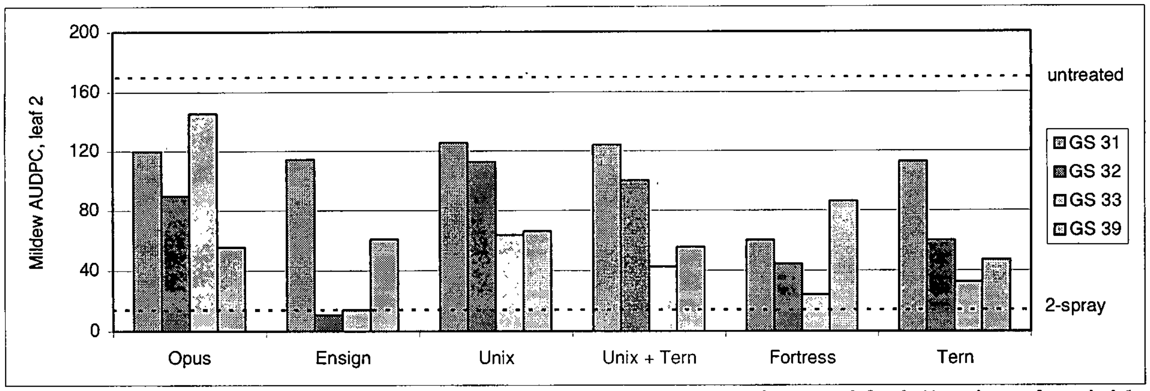


Figure 5. Area under wheat mildew progress curve for leaf 2 following fungicide application on four dates, ADAS Arthur Rickwood, Cambridgeshire, 1997.

Barley mildew

Landmark gave outstandingly good control of barley mildew , and the flexibility in timing is shown in Figure 6, where all four timings gave similar control. Opus was almost as effective from GS 33 application, which would have coincided with leaf emergence, which shows that the kresoxim-methyl component of Landmark was having long-lasting protectant effects from earlier timings. Unix was a good protectant, as shown by the effect of GS 31 application (10 days before full leaf emergence).

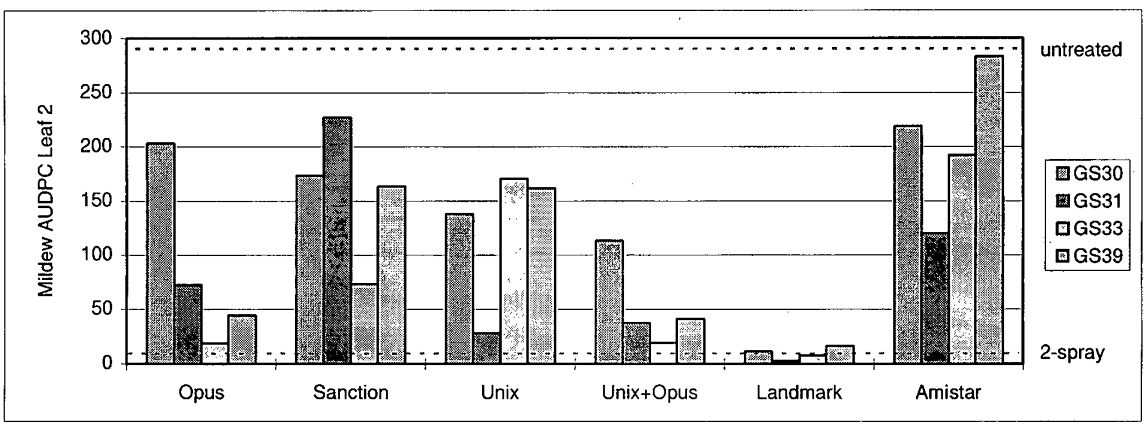


Figure 6. Area under barley mildew progress curve for leaf 2 following fungicide application on four dates, ADAS Rosemaund, Herefordshire, 1997.

Barley net blotch

The introduction of Amistar provides a more powerful fungicide against net blotch than any which were previously available, as shown in Figure 7. Landmark and Opus, used alone each gave good control as, to a lesser extent, did Unix. Sanction consistently gave poorer control than any of the new fungicides examined for net blotch control. GS 33 and GS 39 were generally the best timings for a single application.

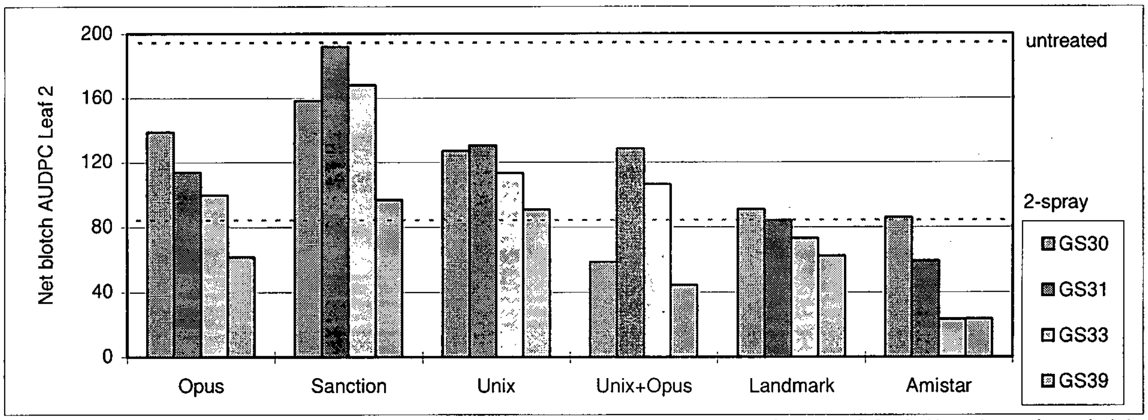


Figure 7. Area under barley net blotch progress curve for leaf 2 following fungicide application on four dates, Morley research Centre, Norfolk, 1997.

Barley *Rhynchosporium*

Strobilurin mixtures gave best control of *Rhynchosporium*, as in the 1998 experiment (Figure 8), where Landmark and Amistar Pro were most effective, followed by Amistar plus Opus. Unix also showed useful activity as a mixture partner for *Rhynchosporium* control. Timing was critical. In contrast with net blotch, early applications (GS 31) gave better control than later applications on all leaves except the flag leaves.

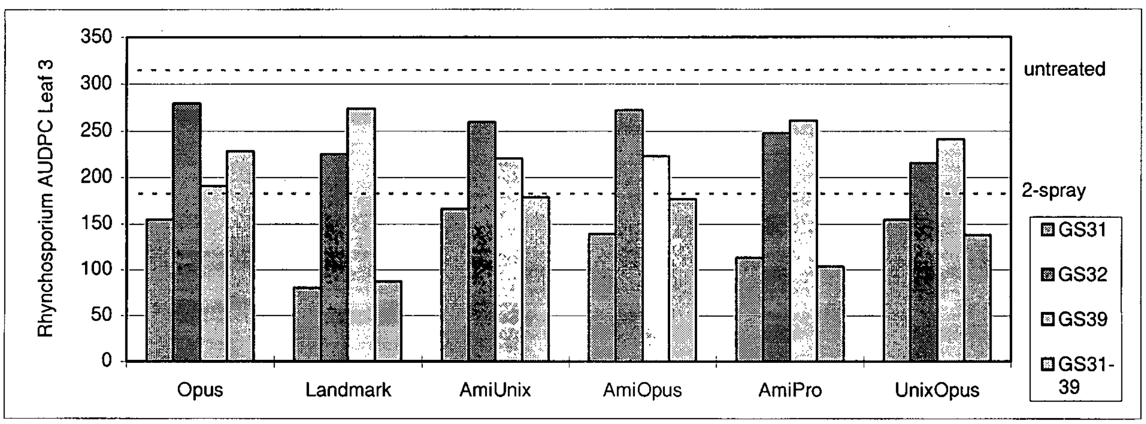


Figure 8. Area under barley *Rhynchosporium* progress curve for leaf 2 following fungicide application on four dates, Westward Arable Centres, Devon, 1998.

Conclusions

The two strobilurins introduced to the UK market during the lifetime of this project both showed considerable benefits for wheat and barley growers. Each of the other non-azole fungicides evaluated also showed promise, although use in mixture with an azole or morpholine was often required.

Kresoxim-methyl was available only in formulated mixtures with epoxiconazole (Landmark) and fenpropimorph (Ensign). The main advantage in disease control from Landmark compared with epoxiconazole (Opus) alone was in greater protectant activity on each leaf layer against *S. tritici* from sprays applied before emergence of that leaf layer, allowing greater flexibility overall in fungicide timing. There was also longer retention of green canopy, particularly on leaves 2 and 3, which resulted in consistently higher yields than those from Opus. Azoxystrobin, used alone as Amistar, showed good protectant activity against *Septoria tritici* and yellow rust on wheat, but its lack of eradicant activity resulted in disease control poorer than that of the best azoles, particularly against *S. tritici* which resulted in lower yields. When Amistar was used in mixture with Opus, its performance was similar to that from Landmark.

Although kresoxim-methyl, in mixture with fenpropimprph, gave good control of wheat mildew, this is likely to have limited commercial value for mildew control because of the occurrence of resistance to strobilurins, which has now been confirmed in the UK, albeit at low frequency. The best wheat mildew control was given by Fortress, particularly when applied early. Unix and Neon both showed useful mildew activity, but should be used in mixture for best results.

The superiority of Opus over other azoles for *S. tritici* control was confirmed, but it showed little improvement over Folicur against yellow rust. One new azole fungicide, metconazole (Caramba) showed many similar properties to Folicur, with slightly greater activity against *S. tritici* but poorer control of yellow rust. Tetraconazole (Eminent) did not show any improvement over Folicur in activity against *S. tritici*, and was weaker against yellow rust.

On barley, there were clear benefits from Amistar for control of net blotch and brown rust. The performance of Amistar against net blotch, a disease which has proved particularly difficult to control with older fungicides, was superior to that of any other fungicide, and brown rust control was comparable with that from the best azole, Opus. Although Ensign gave good control of barley mildew, resistance to strobilurins in barley mildew was found in Germany in 1999, and it is probable that this resistance will also develop in the UK , so it would be unwise to use Ensign where mildew is a prime concern. For *Rhynchosporium*, the currently available strobilurins are beneficial in azole or morpholine mixture but do not offer the advance in disease control that Amistar does for net blotch. Among other new fungicides, Unix has useful activity against net blotch, mildew and *Rhynchosporium*, but needs to be used in mixture for best effect.

INTRODUCTION

Fungicides are an integral part of UK cereal production and, since the late 1970s, azole fungicides have been the cornerstone of cereal disease control. The dependence on azole fungicides resulted from their broad spectrum of activity and the flexibility in timing and application rate. In the 1990s, a 'new generation' of azole fungicides was developed. These fungicides showed improvements in activity and, in some cases, a broader spectrum of activity compared with earlier azole fungicides. In addition, there were several fungicides under development, from new chemical groups with different modes of action, which offered good control of some of the important cereal pathogens and introduced the possibility of reducing the dependence on azole fungicides. Foremost among these were the strobilurin analogues, of which the first examples, azoxystrobin and kresoxim-methyl, were introduced to the UK market in 1997. Other important new non-azole fungicides introduced during the course of this project were cyprodinil, quinoxyfen and spiroxamine.

The development of new chemistry with alternative modes of action provides a powerful weapon against development of fungicide resistance. However, such new chemistry will only gain wide acceptance if the fungicides can provide activity and flexibility in use comparable with, or superior to, the best commercial standards. This requires a thorough understanding of the properties of the new fungicides.

PROJECT OBJECTIVES

To provide early information on how new fungicides, from new fungicide groups and new developments within established fungicide groups, can be used to improve the cost-effectiveness of disease control on winter wheat and winter barley.

MATERIALS AND METHODS

Nine field experiments were completed in each of the 1996, 1997 and 1998 harvest years, six on winter wheat and three on winter barley in each year. Target diseases at each site are detailed in Table 3.

In the first two years of the project, the treatment structure was to apply each new fungicide, together with appropriate standards, as single sprays on a series of dates. Untreated control plots were also included. In addition, there was a full protection programme consisting of two sprays. This was to show the potential yield from the crop where disease was controlled, so that the contribution of each of the single applications of experimental fungicides could be assessed in relation to the response of the crop to full fungicide protection. On winter wheat, the growth stages for single application in 1996 were GS 32, 33, 39 and 59, to provide applications at the times when each of the top three leaves and the ears emerged. In 1997, the timings on wheat were altered to GS 31, 32, 33, 39, in order to provide greater information on the period of protectant action of the fungicides. In each year, the full protection programme received two applications, at GS 32 and GS 39.

The barley timings in 1996 were five dates at 10-11 day intervals starting on 1 April, in order to cover the period between GS 30 and GS 39. To accommodate more fungicides in 1997, the number of application timings within this period was reduced to four. The full protection programme in each year consisted of sprays on the dates which corresponded most closely with GS 31 and GS 39.

The design of wheat and barley experiments was modified in 1998, to provide a two spray programme of each experimental and standard fungicide, to indicate the full potential benefit from each fungicide. This was compared with single applications of the fungicide on one of three dates, to show what proportion of the overall activity could be achieved at each timing. On wheat, the timings for single application were GS 31/32, GS 33 and GS 39, and on barley the timings were GS 30/31, GS 32 and GS 39/45. The full protection programmes of 2 sprays (GS 31/32 + 39 on wheat and GS 30/31 + 39/45 on barley) were applied using the same fungicides as in 1996 and 1997, to provide comparability between the years, and untreated controls were also included, as before.

Details of fungicides for each target disease, together with target growth stages in each year are given in Table 1, and rates of active ingredients in the products used are in Table 2. Details of active ingredients and rates are given, together with the code of the formulation tested and the current trade name, for those fungicides which were supplied by manufacturers prior to commercial launch but which are now available. Of the experimental fungicides which were used prior to registration, one (coded HGCA6) is not commercially available and, for commercial considerations, it is now unlikely that it will be marketed in the UK. The identity of this fungicide has been made known to the HGCA so that, in the event of commercial launch, information on its efficacy can be publicised.

Each experiment was a randomised block with three replicates of each treatment, except for the untreated control and full protection programmes, which were replicated six times. Plot sizes were in the range 24 m^2 to 48 m^2. Actual application dates and growth stages are given, together with a summary of site details, in Table 3.

Foliar diseases were assessed as percentage leaf area infected on each leaf layer on 10 tillers per plot from all plots at 10/11 day intervals from the date of the first fungicide application until all leaves were senescent. Percentage green leaf area was also estimated. To provide a cumulative measure of the effect of disease during the life of the stem leaves, the area under disease progress curve (AUDPC) was calculated for each treatment. This can be visualised on the graphs of disease progress (e.g. Figure 1.1), as the area under the line showing disease development for that treatment.

All trials were harvested and yields expressed at 85% dry matter.

Wheat mildew sensitivity to the morpholine fungicides fenpropimorph and fenpropidin was assayed at SAC Edinburgh by the following method. Isolates of mildew were collected each year from the two mildew sites, Aberdeen and Arthur Rickwood. Whole plants were collected from the untreated plots at both sites, and sent to SAC. Where possible, samples were collected prior to fungicide application but, in some instances, mildew severity was too low at that stage, so samples were collected from untreated plots later in the season.

Isolates collected from leaves from each plot were tested for sensitivity by bulking mildew pustules from ten to fifteen leaves on whole plants of the variety Cerco, which carries no known mildew resistance genes, and maintained on an isolation propagator to prevent cross contamination. To determine the sensitivity of isolates in tests, seedlings of Cerco were grown to the two true leaf stage and then fenpropimorph solutions were applied at concentrations of 0.058, 0.117, 0.234, 0.469 and 0.938 g a.i. l^{-1} in a spray cabinet using a Humbrol spray gun for ten seconds. Control plants were sprayed with water. Each spray treatment was replicated using the same spray cabinet. Treated sets of plants were kept apart for 24 hours before the preparation of leaf segments. Eight segments (2 cm long) were cut from the second true leaf of the treated plants from each concentration and spray cabinet combination and then plated on Davis minimal medium containing 80 mg l^{-1} benzimidazole and inoculated with the experimental isolates. Inoculation was carried out by dusting the mildew inoculum from the heavily infected plants evenly over the surface of the leaf segment using a fine, sterile paint brush. The percentage mildew cover after 14 days incubation at 18° C and 24 hours per day light was visually assessed and the data analysed using a Genstat 5 programme which fitted symmetrical logistic curves and allowed median efficacy (EC_{50}) values to be calculated. Some tests were repeated to determine the reproducibility of the results.

Table 1. Fungicides on wheat, 1996 & 1997

Year, crop & target disease	Treatment	Active ingredient	Product	Rate of product/ha
1996 Wheat				
Septoria & rusts	Standard	Epoxiconazole	Opus	1.00
	Standard	Tebuconazole	Folicur	1.00
	Experimental	Metconazole	Caramba	1.50
	Experimental	Tetraconazole	Eminent	1.00
	Experimental	Epoxiconazole + kresoxim-methyl	Landmark	1.00
	Full protection	Epoxiconazole + fenpropimorph	Opus Team	1.50
Mildew	Standard	Epoxiconazole	Opus	1.00
	Experimental	Fenpropimorph + kresoxim-methyl	Ensign	0.70
	Experimental	Cyprodinil	Unix	0.67
	Experimental	Cyprodinil + fenpropodin	Unix + Tern	0.67+0.50
	Standard	Fenpropimorph	Corbel	1.00
	Standard	Fenpropidin	Tern	1.00
	Full protection	Epoxiconazole + fenpropimorph	Opus Team	1.50
1997 Wheat				
Septoria & brown rust	Standard	Epoxiconazole	Opus	1.00
	Standard	Tebuconazole	Folicur	1.00
	Experimental	Metconazole	Caramba	1.50
	Experimental	Tetraconazole	Eminent	1.00
	Experimental	Epoxiconazole + kresoxim-methyl	Landmark	1.00
	Experimental	Azoxystrobin	Amistar	1.00
	Full protection	Epoxiconazole + fenpropimorph	Opus Team	1.50
Yellow rust	Standard	Epoxiconazole	Opus	1.00
	Experimental	Metconazole	Caramba	1.50
	Experimental	Tetraconazole	Eminent	1.00
	Experimental	Epoxiconazole + kresoxim-methyl	Landmark	1.00
	Experimental	Azoxystrobin	Amistar	1.00
	Full protection	Epoxiconazole + fenpropimorph	Opus Team	1.50
Mildew	Standard	Epoxiconazole	Opus	1.00
	Experimental	Fenpropimorph + kresoxim-methyl	Ensign	0.70
	Experimental	Cyprodinil	Unix	0.67
	Experimental	Cyprodinil + fenpropodin	Unix + Tern	0.67+0.50
	Standard	Quinoxyfen	Fortress	0.30
	Standard	Fenpropidin	Tern	1.00
	Full protection	Epoxiconazole + fenpropimorph	Opus Team	1.50

Table 1 (continued). Fungicides on wheat, 1998

Year, crop & target disease	Treatment	Active ingredient	Product	Rate of product/ha
1998 Wheat				
Septoria & brown rust	Standard	Epoxiconazole	Opus	1.00
	Experimental	Epoxiconazole + kresoxim-methyl	Landmark	1.00
	Experimental	Azoxystrobin	Amistar	1.00
	Experimental	Azoxystrobin + epoxiconazole	Amistar + Opus	1.00+0.50
	Experimental	Metconazole	Caramba	1.50
	Experimental	Fenpropimorph + kresoxim-methyl	Ensign	0.70
	Full protection	Epoxiconazole + fenpropimorph	Opus Team	1.50
Yellow rust	Standard	Epoxiconazole	Opus	1.00
	Experimental	Epoxiconazole + kresoxim-methyl	Landmark	1.00
	Experimental	Azoxystrobin	Amistar	1.00
	Experimental	Azoxystrobin + epoxiconazole	Amistar + Opus	1.00+0.50
	Experimental	Spiroxamine	Neon	1.50
	Experimental	Fenpropimorph + kresoxim-methyl	Ensign	0.70
	Full protection	Epoxiconazole + fenpropimorph	Opus Team	1.50
Mildew	Experimental	Epoxiconazole + kresoxim-methyl	Landmark	1.00
	Experimental	Fenpropimorph + kresoxim-methyl	Ensign	0.70
	Experimental	Cyprodinil	Unix	0.67
	Experimental	Quinoxyfen	Fortress	0.30
	Experimental	Spiroxamine	Neon	1.50
	Standard	Fenpropidin	Tern	1.00
	Full protection	Epoxiconazole + fenpropimorph	Opus Team	1.50

Table 1 (continued). Fungicides on barley

Year, crop & target disease	Treatment	Active ingredient	Product	Rate of product/ha
1996 Barley				
All diseases	Standard	Epoxiconazole	Opus	1.00
	Standard	Flusilazole	Sanction	0.40
	Experimental	Cyprodinil	Unix	0.67
	Experimental	----	HGCA6	----
	Experimental	Cyprodinil + epoxiconazole	Unix + Opus	0.33+0.50
	Full protection	Flusilazole + fenpropimorph	Sanction + Corbel	0.40+0.50
1997 Barley				
All diseases	Standard	Epoxiconazole	Opus	1.00
	Standard	Flusilazole	Sanction	0.40
	Experimental	Cyprodinil	Unix	0.67
	Experimental	Cyprodinil + epoxiconazole	Unix + Opus	0.33+0.50
	Experimental	Fenpropimorph + kresoxim-methyl	Ensign	0.70
	Experimental	Azoxystrobin	Amistar	1.00
	Full protection	Flusilazole + fenpropimorph	Sanction + Corbel	0.40+0.50
1998 Barley				
Mildew, brown rust & net blotch	Standard	Epoxiconazole	Opus	1.00
	Experimental	Epoxiconazole + kresoxim-methyl	Landmark	1.00
	Experimental	Azoxystrobin	Amistar	1.00
	Experimental	Azoxystrobin + epoxiconazole	Amistar + Opus	1.00+0.50
	Experimental	Spiroxamine + epoxiconazole	Neon + Opus	1.50+0.50
	Experimental	Cyprodinil + epoxiconazole	Unix + Opus	0.33+0.50
	Full protection	Flusilazole + fenpropimorph	Sanction + Corbel	0.40+0.50
Rhynchosporium	Standard	Epoxiconazole	Opus	1.00
	Experimental	Epoxiconazole + kresoxim-methyl	Landmark	1.00
	Experimental	Azoxystrobin + cyprodinil	Amistar + Unix	0.50+0.67
	Experimental	Azoxystrobin + epoxiconazole	Amistar + Opus	1.00+0.50
	Experimental	Azoxystrobin + fenpropimorph	Amistar Pro	2.00
	Experimental	Epoxiconazole + cyprodinil	Unix + Opus	0.67+0.50
	Full protection	Flusilazole + fenpropimorph	Sanction + Corbel	0.40+0.50

Table 2. Fungicide active ingredients and products

Fungicide product	Active ingredient(s)	Rate of a.i. in product
Amistar	Azoxystrobin	250 g/l
Amistar Pro	Azoxystrobin + fenpropimorph	100 + 280 g/l
Caramba	Metconazole	60 g/l
Corbel	Fenpropimorph	750 g/l
Eminent	Tetraconazole	125 g/l
Ensign	Kresoxim-methyl + fenpropimorph	150 + 300 g/l
Folicur	Tebuconazole	250 g/l
Fortress	Quinoxyfen	500
Landmark	Kresoxim-methyl + epoxiconazole	125 + 125 g/l
Neon	Spiroxamine	500 g/l
Opus	Epoxiconazole	125 g/l
Opus Team	Epoxiconazole + fenpropimorph	84 + 250 g/l
Sanction	Flusilazole	400 g/l
Tern	Fenpropidin	750 g/l
Unix	Cyprodinil	750 g/kg

Table 3. Site details, winter wheat sites, 1996

Site	West Bagborough	Rosemaund	Terrington	Arthur Rickwood	Morley	Aberdeen
Target disease(s)	Septoria tritici	Septoria tritici	Yellow rust	Mildew	Brown rust & S. tritici	Mildew
Site code	NWY1S1	NWY1S2	NWY1S3	NWY1S4	NWY1S5	NWY1S6
Grid ref.	ST 163322	SO 564485	TF 549189	TL 435830	TM 045967	NJ 907225
Soil type	SZL	ZCL	ZCL	Peaty loam	SCL	SCL
Previous crops						
1995	Potatoes	W rape	Linseed	Potatoes	Linseed	Potatoes
1994	W wheat	W wheat	W wheat	W wheat	W wheat	S rape
Cultivar	Riband	Riband	Slejpner	Apollo	Riband	Apollo
Sowing date	16 Oct	5 Oct	3 Oct	3 Nov	22 Sep	20 Oct
Application date & GS						
1	2 May 31	11 May 32	21 May 32	15 May 32	6 May 32	29 May 31
2	13 May 32	20 May 33	29 May 37	30 May 33	21 May 33	12 Jun 37
3	29 May 39	4 Jun 39	4 Jun 39	6 Jun 39	2 Jun 43	25 Jun 50
4	14 June 59	18 Jun 65	19 Jun 61	14 Jun 59	14 Jun 61	11 Jul 65
Harvest date	22 & 30 Aug	18 Aug	19 Aug	20 & 21 Aug	21 Aug	16 Sep

Table 3 (continued). Site details, winter wheat sites 1997

Site	West Bagborough	Rosemaund	Terrington	Arthur Rickwood	Morley	Aberdeen
Target disease(s)	Septoria tritici	Septoria tritici	Yellow rust	Mildew	Brown rust & S. tritici	Mildew
Site code	NWY2S1	NWY2S2	NWY2S3	NWY2S4	NWY2S5	NWY2S6
Grid ref.	ST 165332	SO 565476	TF 545188	TL 432817	TM 062990	NJ 909234
Soil type	SZL	ZCL	ZCL	Peaty loam	SCL	SL
Previous crops						
1996	S rape	W beans	Linseed	Potatoes	W beans	S rape
1995	W barley	W wheat	Potatoes	W wheat	W wheat	W wheat
Cultivar	Riband	Riband	Slejpner	Apollo	Riband	Apollo
Sowing date	28 Sep	10 Oct	1 Oct	7 Nov	19 Sep	17 Oct
Application date & GS						
1	11 Apr 31	10 Apr 31	18 Apr 31	27 Apr 31	14 Apr 31	15 May 31
2	21 Apr 32	21 Apr 32	1 May 32	14 May 32	27 Apr 32	23 May 32
3	2 May 37	2 May 33	14 May 33	19 May 33	7 May 33	29 May 33
4	12 May 39	24 May 39	29 May 41	28 May 39	19 May 41	13 Jun 45
Harvest date	16 Aug	27 Aug	8 Aug	16 Aug	15 Aug	8 Sep

Table 3 (continued). Site details, winter wheat sites, 1998

Site	West Bagborough	Rosemaund	Terrington	Arthur Rickwood	Morley	Aberdeen
Target disease(s)	Septoria tritici	Septoria tritici	Yellow rust	Mildew	Brown rust & Septoria tritici	Mildew
Site code	NWY3S1	NWY3S2	NWY3S3	NWY3S4	NWY3S5	NWY3S6
Grid ref.	ST 163322	SO 567482	TF 535193	TL 453892	TM 045967	NJ 909234
Soil type	SCL	ZCL	ZCL	Peaty loam	SCL	SL
Previous crops						
1997	Swedes	Spring OSR	Linseed	Onions	W beans	Potatoes
1996	W wheat	W wheat	Potatoes	W wheat	W wheat	W wheat
Cultivar	Riband	Riband	Brigadier	Apollo	Riband	Apollo
Sowing date	24 Sep	4 Oct	29 Sep	27 Oct	26 Sep	8 Oct
Application date & GS						
1	15 Apr 31	14 Apr 31	4 May 32	16 Apr 31	16 Apr 31	12 May 31
2	30 Apr 32	13 May 33	12 May 33	13 May 33	8 May 33	4 Jun 37
3	18 May 39	21 May 39	20 May 39	19 May 39	19 May 39	12 Jun 45
Harvest date	28 Aug	17 Aug	14 Aug	13 Aug	13 Aug	14 Oct

Table 3 (continued). Site details, barley sites, 1996 & 1997

Year	1996	1996	1996	1997	1997	1997
Site	Rosemaund	Morley	Salcombe	Rosemaund	Morley	Crediton
Target disease(s)	Mildew, brown rust	Net blotch	Rhyncho-sporium	Mildew, brown rust	Net blotch	Rhyncho-sporium
Site code	NBY1S2	NBY1S5	NBY1S7	NBY2S2	NBY2S5	NBY2S7
Grid ref.	SO 568486	TM 062995	SX 717389	SO 564485	TM 084999	SX 897986
Soil type	ZCL	SL	CL	ZCL	SL	SCL
Previous crops						
1 year before	W wheat	W barley	W wheat	W wheat	W barley	W wheat
2 years before	W oats	S barley	Linseed	W OSR	Sugar beet	Grass
Cultivar	Pastoral	Puffin	Willow	Pastoral	Puffin	Willow
Sowing date	23 Sep	21 Sep	25 Sep	1 Oct	18 Sep	12 Oct
Application date & GS						
1	1 Apr 26	1 Apr 25	1 Apr 29	4 Apr 31	1 Apr 30	9 Apr 31
2	11 Apr 30	11 Apr 25	11 Apr 31	15 Apr 33	10 Apr 31	21 Apr 33
3	21 Apr 31	22 Apr 31	22 Apr 33	22 Apr 37	22 Apr 33	2 May 45
4	4 May 32	2 May 33	2 May 37	2 May 49	2 May 45	13 May 55
5	13 May 39	13 May 39	13 May 49	NA	NA	NA
Harvest date	24 Jul	2 Aug	5 Aug	18 Jul	21 Jul	22 Jul

Table 3 (continued). Site details, barley sites, 1998

Site	Rosemaund	Morley	Crediton
Target disease(s)	Mildew, brown rust	Net blotch	Rhyncho-sporium
Site code	NBY3S2	NBY3S5	NBY3S7
Grid ref.	SO 565476	TM 084999	SX 895004
Soil type	ZCL	SL	SL
Previous crops			
1997	W wheat	W barley	W wheat
1996	W beans	Linseed	Grass
Cultivar	Pastoral	Puffin	Willow
Sowing date	23 Sep	16 Sep	19 Oct
Application date & GS			
1	12 Apr 33	7 Apr 31	2 Apr 31
2	25 Apr 37	16 Apr 33	1 May 37
3	9 May 45	4 May 43	14 May 45
Harvest date	24 Jul	21 Jul	26 Jul

RESULTS

1. *SEPTORIA TRITICI* SITES

There was a severe epidemic of *Septoria tritici* at West Bagborough in 1996, and no other diseases were recorded (Figure 1.1). Dissection of plants at GS 31 revealed that the leaf emerging at that stage was eventual leaf 3, not leaf 4 which usually emerges at GS 31. Consequently, the first two sprays were applied at GS 31 and GS 32 rather than GS 32 and GS 33; this change ensured that the first date coincided with emergence of eventual leaf 3 and the second with emergence of eventual leaf 2.

The optimum timing for control of *S. tritici* on leaf 3 for all fungicides at West Bagborough was the second application, which was at GS 32 (Figure 1.2). Landmark and Opus gave very good control, almost as good as the two-spray standard programme of Opus Team. Landmark at GS 31 and Opus at GS 31 or GS 39 also gave good control. GS 59 applications of all fungicides were less effective than the earlier timings. On leaf 2, the GS 39 timing was the most effective for all fungicides, although GS 31 or GS 32 application of Landmark or Opus was only slightly inferior. All fungicides were least effective at GS 59. On the flag leaves, GS 39 was the best timing for each fungicide. GS 59 was more effective than GS 31 or GS 32, except for Landmark which gave good control from GS 32 application.

Application of Landmark and, to a lesser extent, Opus at GS 31 allowed greater green area to persist on leaves 3 and 4 through late June and July compared with other fungicides (Figure 1.4). There was a similar effect on leaf 2 at the 1 July assessment which was no longer evident at the following assessment. Following GS 32 treatment, similar effects were noted, particularly on leaves 2 and 3.

The clear benefit from the GS 39 timing for *S. tritici* control was also evident in the yield advantage from the this timing (Figure 1.3). Landmark gave the highest yields, almost equalling the yield from the standard two-spray programme, followed by Opus at GS 39. Yields from Folicur, Caramba and Eminent were comparable with each other, but lower than Opus.

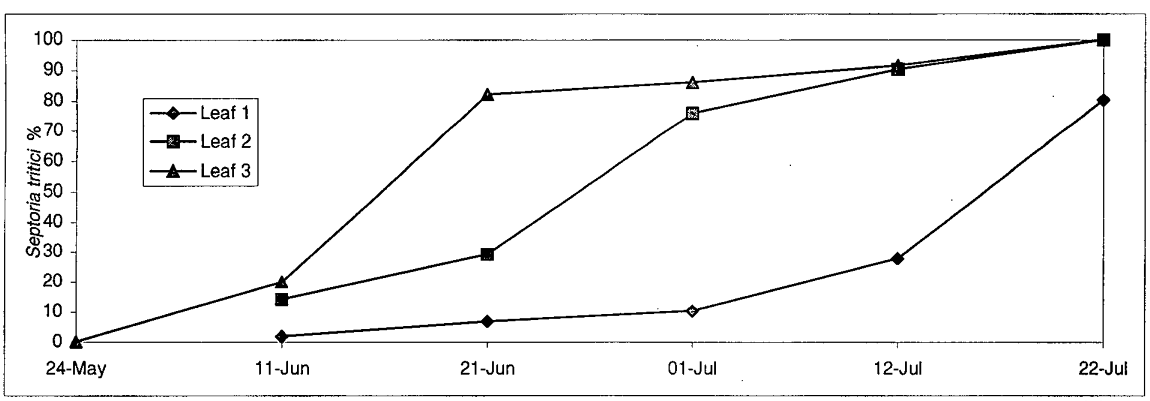


Figure 1.1. *Septoria tritici* development in untreated wheat plots, West Bagborough 1996.

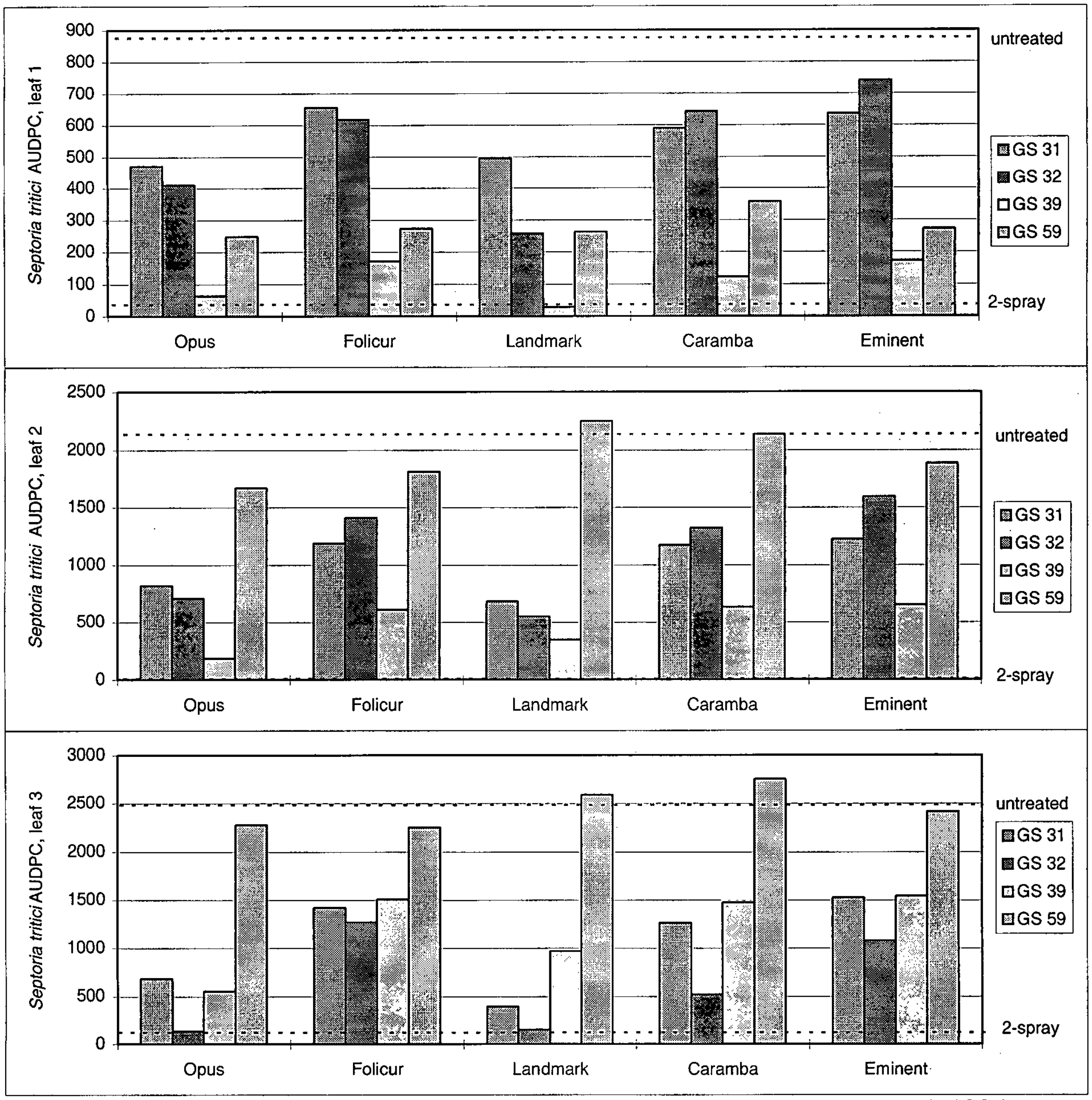


Figure 1.2. Effect of treatments on *Septoria tritici* AUDPC, West Bagborough 1996.

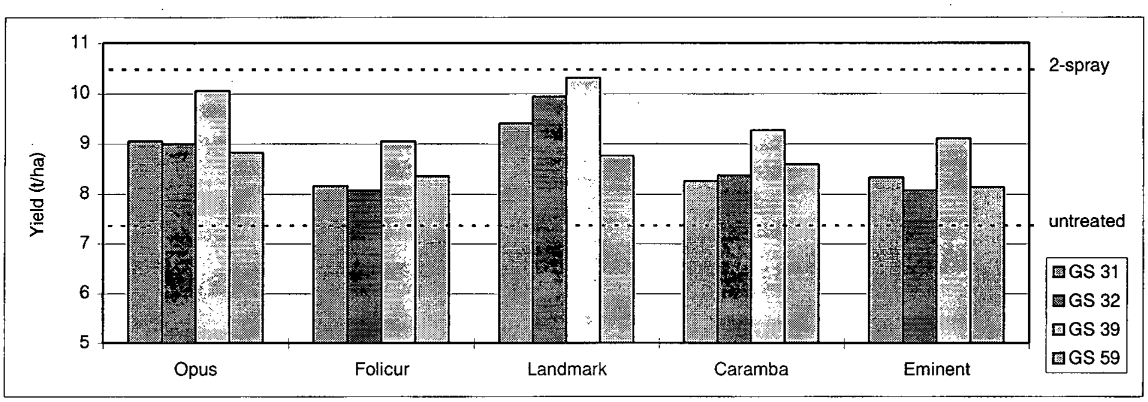


Figure 1.3. Effect of treatments on wheat yield, West Bagborough 1996.

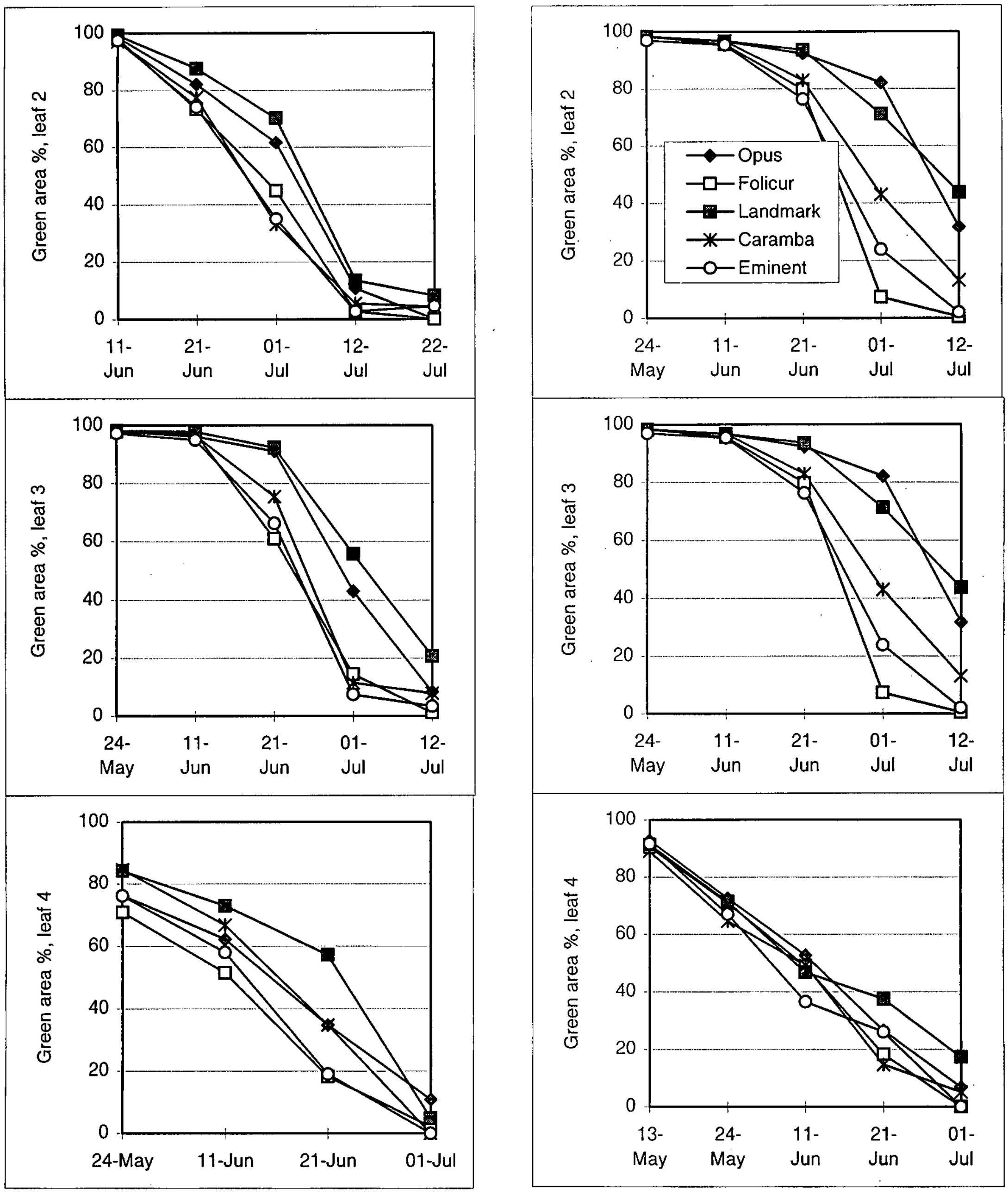


Figure 1.4. Effect of treatments on duration of green canopy on leaves 2, 3 and 4, West Bagborough 1996;
left: following GS 31 application; right: following GS 32 application.

At Rosemaund in 1996, eventual leaf 3 emerged at GS 32, so the spray timings followed the original schedule of GS 32, GS 33, GS 39 and GS 59. *S. tritici* was severe at Rosemaund (Figure 1.5). The only other disease recorded was mildew, at very low levels.

GS 32 was the optimum spray timing for disease control on leaf 3 for all fungicides except Opus, which was more effective at GS 33 (Figure 1.6). Landmark at either of these timings gave a greater reduction in disease than any other fungicide. GS 39 sprays gave good control, though not as good as the earlier timings, but the only fungicides which had much effect at GS 59 were Caramba and Eminent. On leaf 2, Landmark gave good disease control from each of the first three timings. Opus gave good control at GS 33 and GS 39, though inferior to Landmark at GS 33, and Caramba and Eminent also showed good activity at GS 39. As on leaf 3, the GS 59 sprays were the least effective, although all gave some reduction in disease compared with the untreated controls. Landmark gave very good disease control on the flag leaves from application at GS 33 or GS 39, with substantial control from the GS 32 spray. The other fungicides were most effective at GS 39 and the only one to give good control at any other timing was Opus at GS 33. GS 59 sprays gave poorer control than any earlier application for all fungicides except Folicur, for which GS 32 was least effective.

At Rosemaund, GS 32 application of Landmark increased green leaf duration on leaves 2 and 3, but Opus did not give a similar effect (Figure 1.8). GS 33 Opus and Landmark treatments also gave increased green leaf persistence on leaves 2 and 3.

Landmark at either GS 32 or GS 33 gave a yield slightly greater than the standard two-spray programme at Rosemaund, and Landmark at GS 39 and Opus at GS 33 were only slightly below (Figure 1.7). Among GS 39 applications, Landmark was the highest. There was little difference between the other fungicides, but Eminent was slightly higher than the rest.

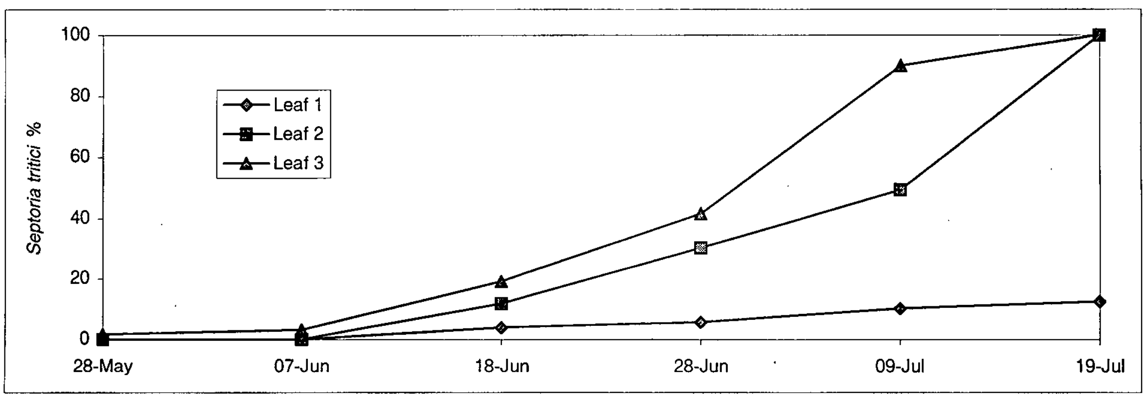


Figure 1.5. *Septoria tritici* development in untreated wheat plots, ADAS Rosemaund 1996.

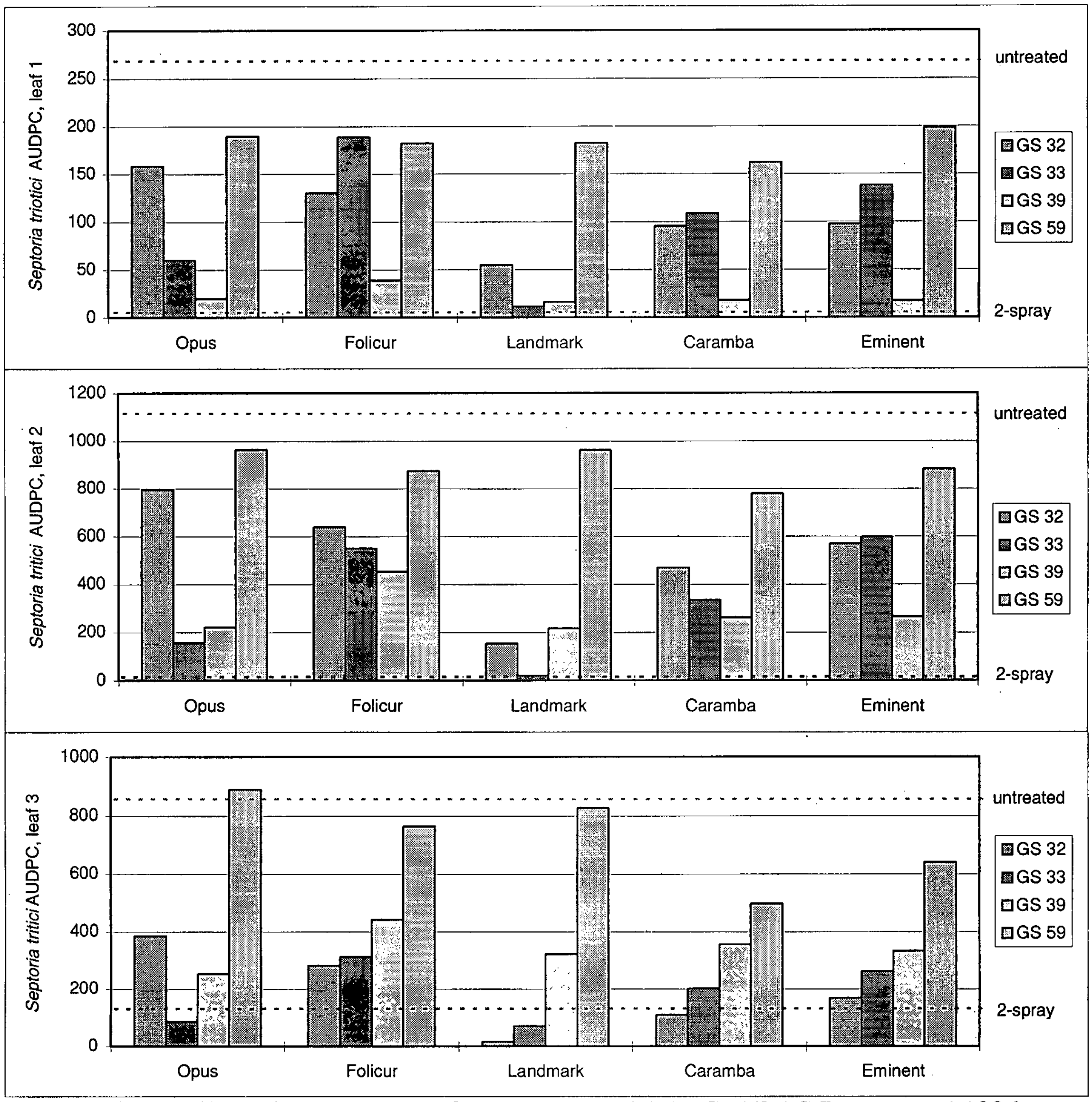


Figure 1.6. Effect of treatments on *Septoria tritici* AUDPC, ADAS Rosemaund 1996.

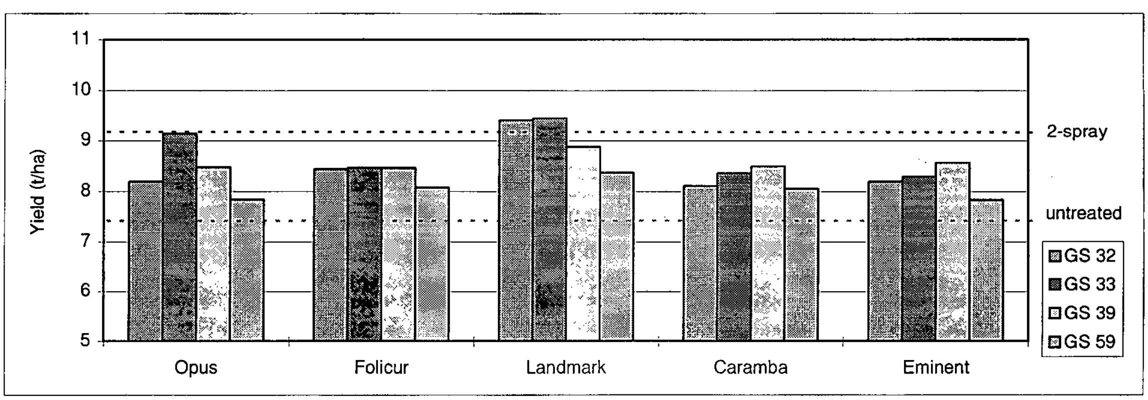


Figure 1.7. Effect of treatments on wheat yield, ADAS Rosemaund 1996.

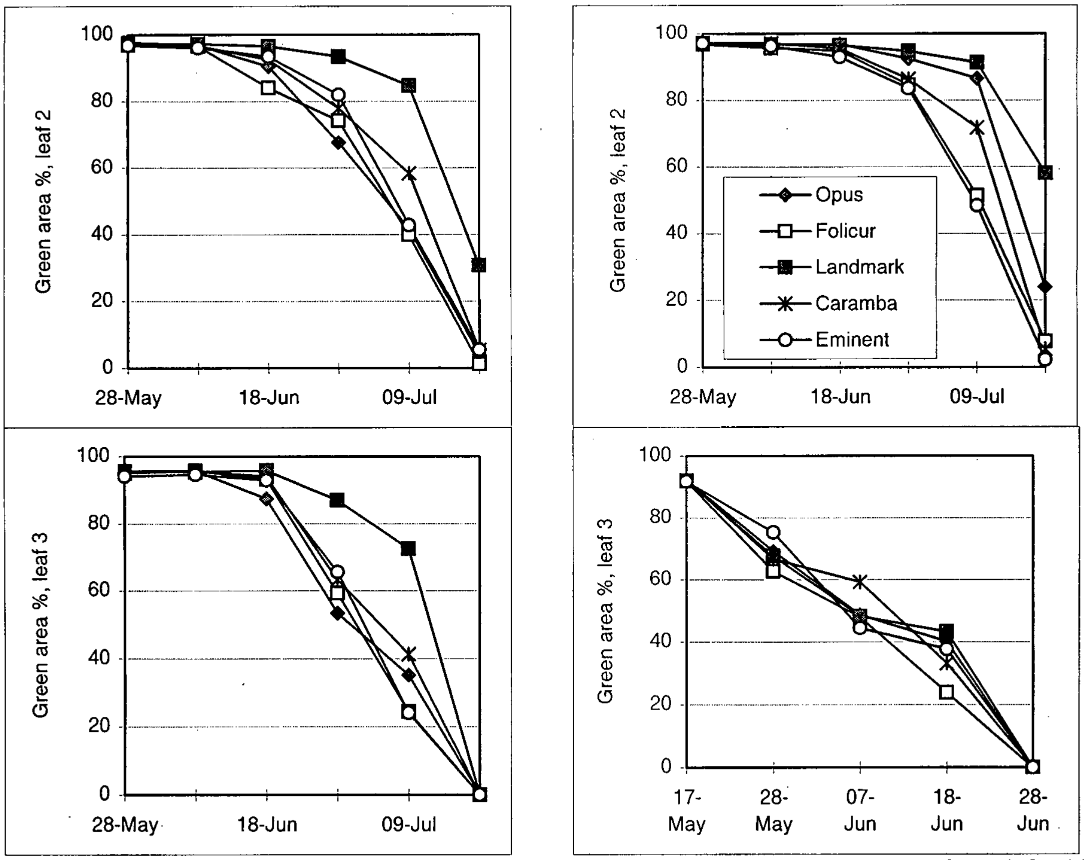


Figure 1. 8. Effect of treatments on duration of green canopy on leaves 2 and 3, ADAS Rosemaund 1996;
left: following GS 32 application; right: following GS 33 application.

At Morley in 1996, as at Rosemaund, eventual leaf 3 emerged at GS 32. Disease levels were lower at Morley than at the other sites, and *S. tritici* was the only disease recorded (Figure 1.9). Results on leaf 3 at Morley showed Landmark to be the most effective fungicide, when applied at GS 32 or GS 33 (Figure 1.10). For each of the other fungicides, GS 33 was the optimum timing. Disease levels on the top two leaves at Morley were relatively low. Landmark was the most effective fungicide on leaf 2, when applied at GS 32 or GS 33, but GS 33 was the optimum timing for each of the other fungicides, with indications that Opus and Caramba were more effective than the others. On the flag leaves, Landmark and Caramba had lowest disease levels, and GS 39 was the optimum timing for all except Landmark, which was more effective at GS 32 and GS 33 than GS 39. For each fungicide, GS 59 treatment gave poorer control than GS 32 or GS 33. Effects on green leaf retention were smaller at Morley than at the other sites in 1996, and are not shown.

The mean yield was higher at Morley that at either of the other sites in 1996, but yield responses to fungicides were smaller at Morley. Landmark at GS 33 gave the highest yield, and was the only single application to give a higher yield than the two-spray Opus Team standard (Figure 1.11). Differences between other fungicide treatments were small, but there was an indication that GS 39 gave the highest yields for Folicur, Caramba and Eminent, whereas Opus gave a higher yield at GS 33.

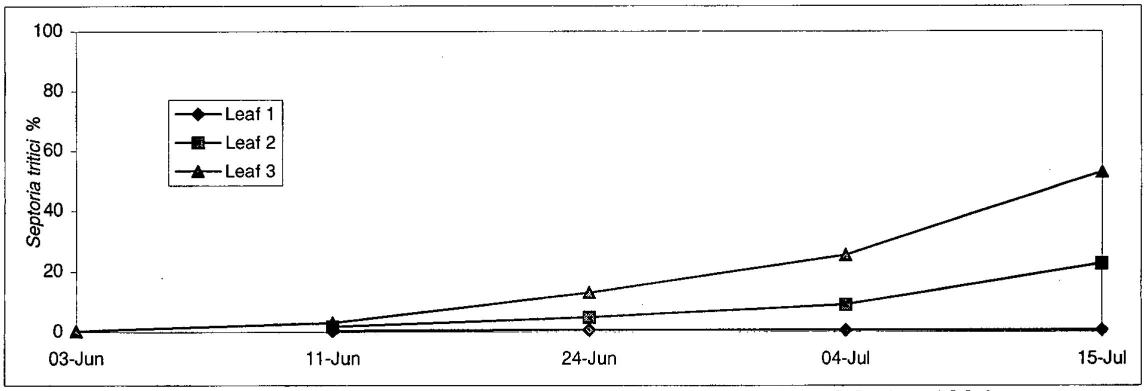


Figure 1.9. *Septoria tritici* development in untreated wheat plots, Morley 1996.

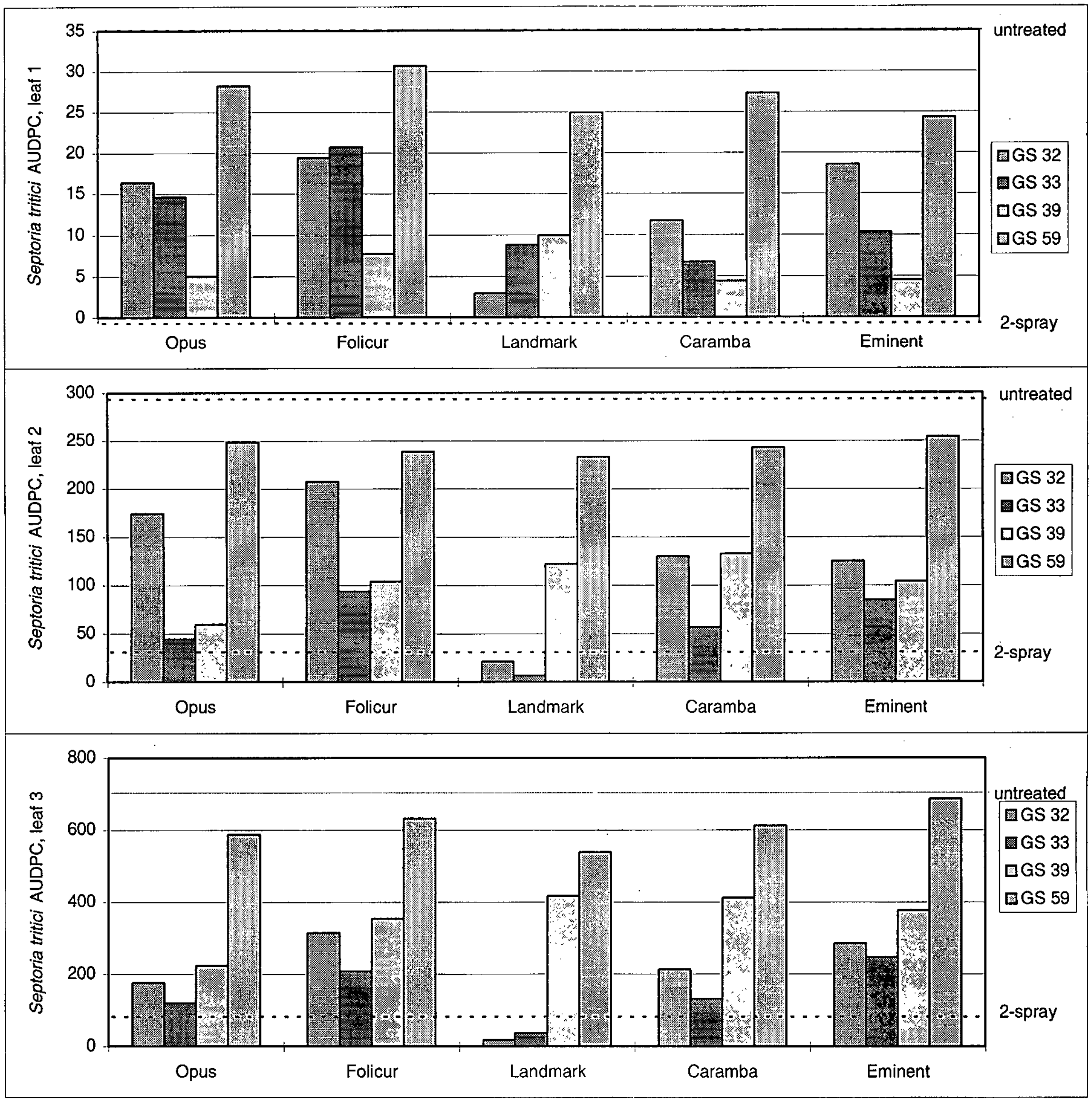


Figure 1.10. Effect of treatments on *Septoria tritici* AUDPC, Morley 1996.

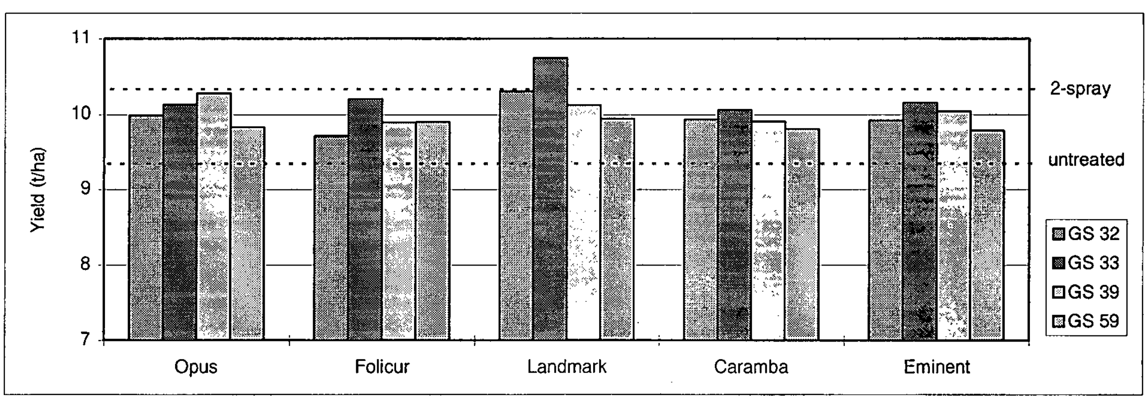


Figure 1.11. Effect of treatments on wheat yield, Morley 1996.

At West Bagborough, the *S. tritici* epidemic developed earlier in 1997 than in 1996 and was, consequently, more severe. GS 33 was the optimum timing for *S. tritici* control on leaf 3 for all fungicides except Landmark, for which GS 32 was equally effective (Figure 1.13). Opus at GS 33 and Landmark at GS 32 or GS 33 gave similar control to the two-spray Opus Team standard. Among other treatments, Folicur gave the best control and Amistar the poorest. On leaf 2, Landmark and Opus at either GS 33 or GS 39 were superior to any other treatment but, for each fungicide, performance at GS 33 was similar to that at GS 39. On the flag leaves, GS 39 was clearly the best timing, with Landmark giving best control, followed by Opus, then Amistar, Folicur and Caramba. There was a small effect from each fungicide at earlier timings, particularly Landmark at GS 33 and GS 32.

There was a striking effect on green leaf retention on leaves 2 and 3 from Landmark at GS 32 and, to a lesser extent, from GS 32 Opus (Figure 1.15). At GS 33, Landmark increased green leaf retention markedly on leaves 2 and 3 and to a smaller extent on leaf 1.

The two-spray Opus Team programme gave a yield increase of 4.85 t/ha over the untreated yield of 4.52 t/ha (Figure 1.14). Landmark at GS 39 was the only single application which equalled the two-spray standard. Landmark at GS 33 gave the next highest yield (4.04 t/ha increase), followed by Opus at GS 39 (3.91 t/ha).

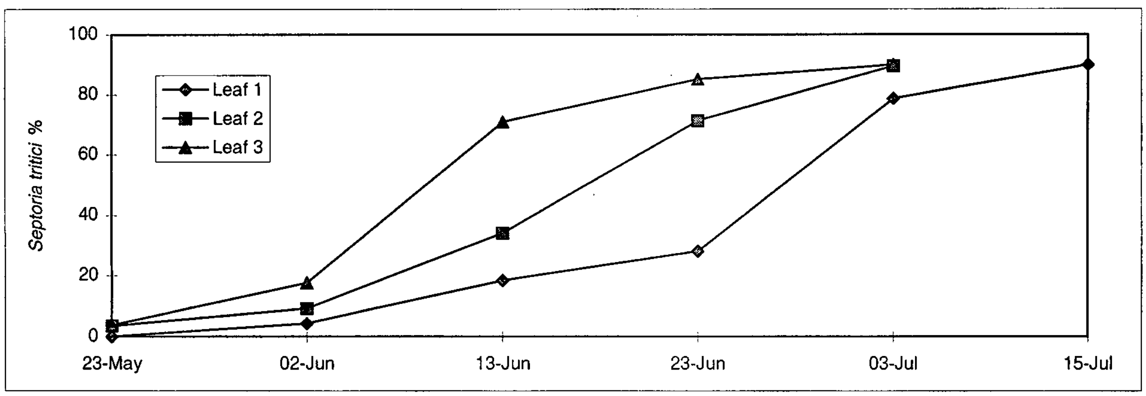


Figure 1.12. *Septoria tritici* development in untreated wheat plots, West Bagborough 1997.

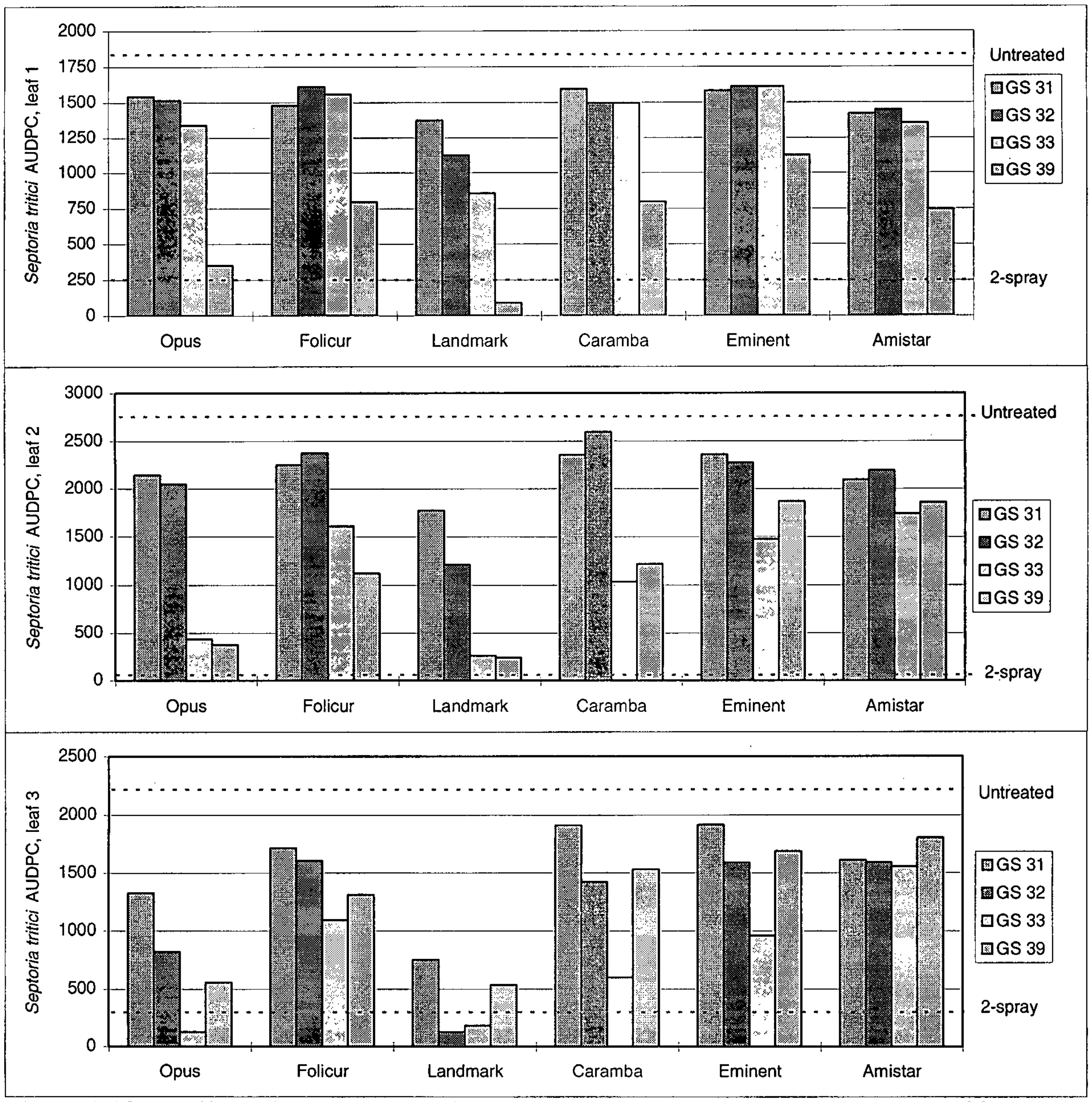


Figure 1.13. Effect of treatments on *Septoria tritici* AUDPC, West Bagborough 1997.

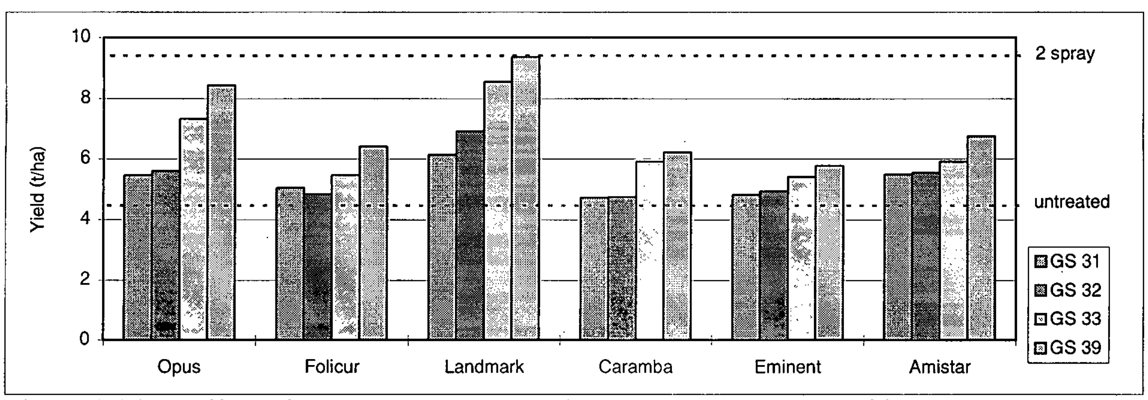


Figure 1.14. Effect of treatments on wheat yield, West Bagborough 1997.

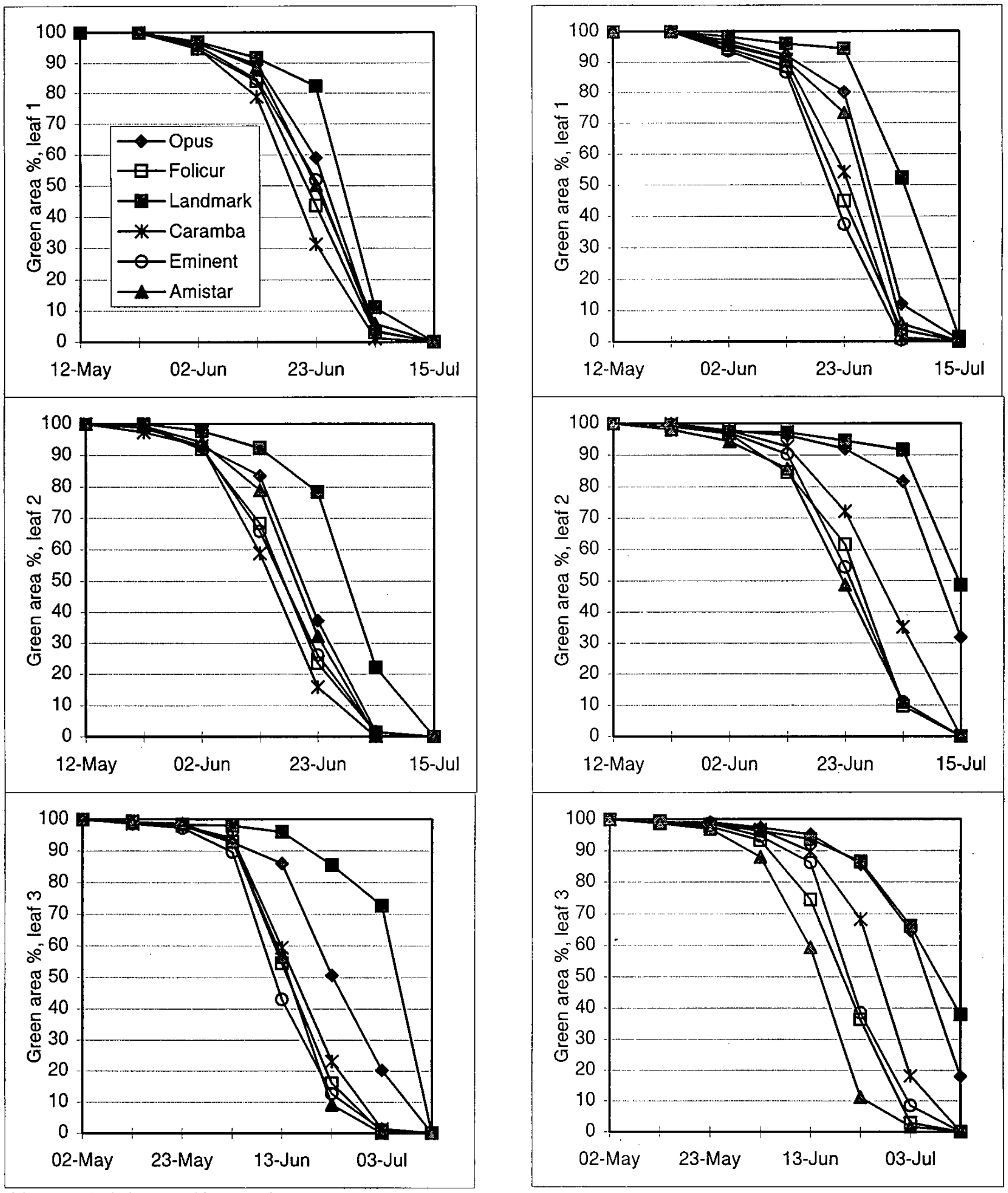


Figure 1.15. Effect of treatments on duration of green canopy on leaves 1, 2 and 3, West Bagborough 1997;
left: following GS 32 application; right: following GS 33 application.

At ADAS Rosemaund in 1997, GS 33 was the optimum timing for each fungicide for *S. tritici* control on leaf 3 (Figure 1.17). Landmark, Opus and Caramba at GS 33 all gave better control than the GS 32+39 Opus Team standard, as did Landmark at GS 32. On leaf 2, GS 39 was the optimum timing for all fungicides except Landmark and Amistar, for which GS 33 gave better control. Landmark at GS 33 and Opus at GS 39 were the best treatments. On the flag leaves, all fungicides performed best at GS 39. Opus and Landmark gave greatest reductions in disease, followed by Caramba and Folicur.

Effects of treatments on green canopy retention were similar to those at West Bagborough, with particular effects of Landmark at GS 32 on leaf 3 and at GS 33 on leaf 2 (Figure 1.19).

The two-spray Opus Team standard gave an increase of 5.15 t/ha over the unreated yield of 5.17 t/ha (Figure 1.18). Landmark at either GS 33 or GS 39, and Opus at GS 39 gave increases in the order of 4 t/ha, and other treatments all gave less than 3 t/ha. Among GS 31 and GS 32 treatments, Amistar was second highest after Landmark, whereas Amistar gave the lowest yields at GS 39.

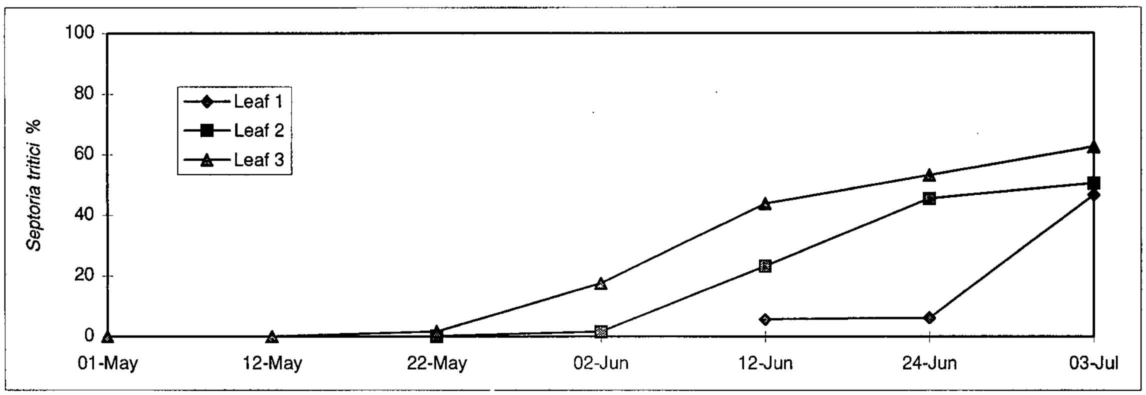


Figure 1.16. *Septoria tritici* development in untreated wheat plots, ADAS Rosemaund 1997.

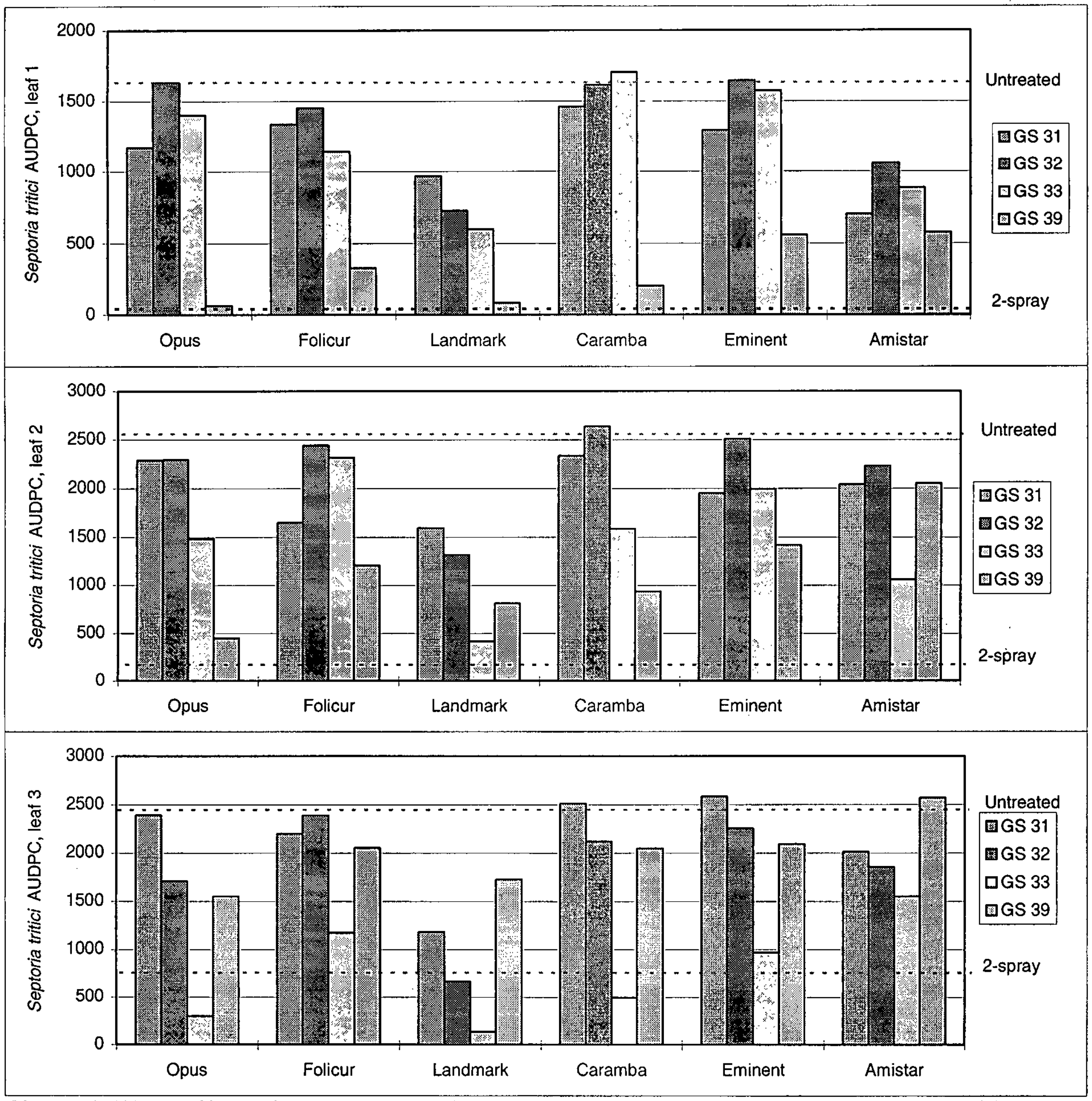


Figure 1.17. Effect of treatments on *Septoria tritici* AUDPC, ADAS Rosemaund 1997.

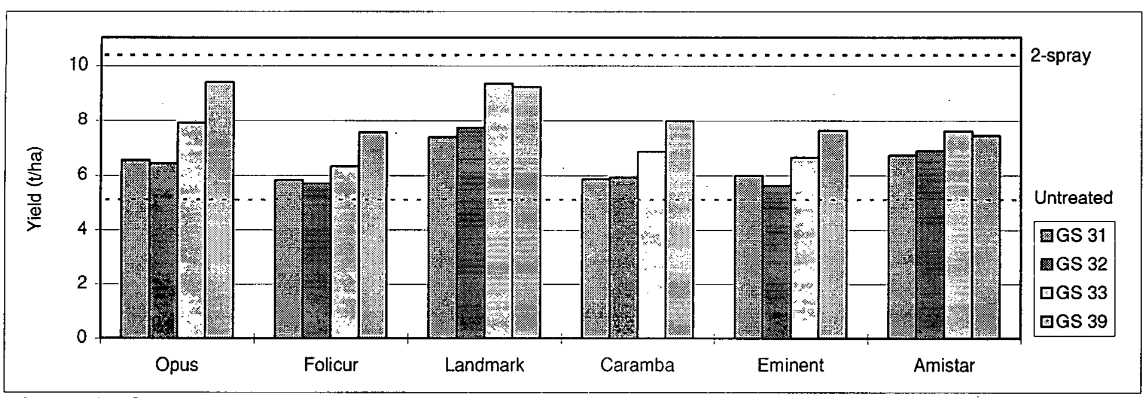


Figure 1.18. Effect of treatments on wheat yield, ADAS Rosemaund 1997.

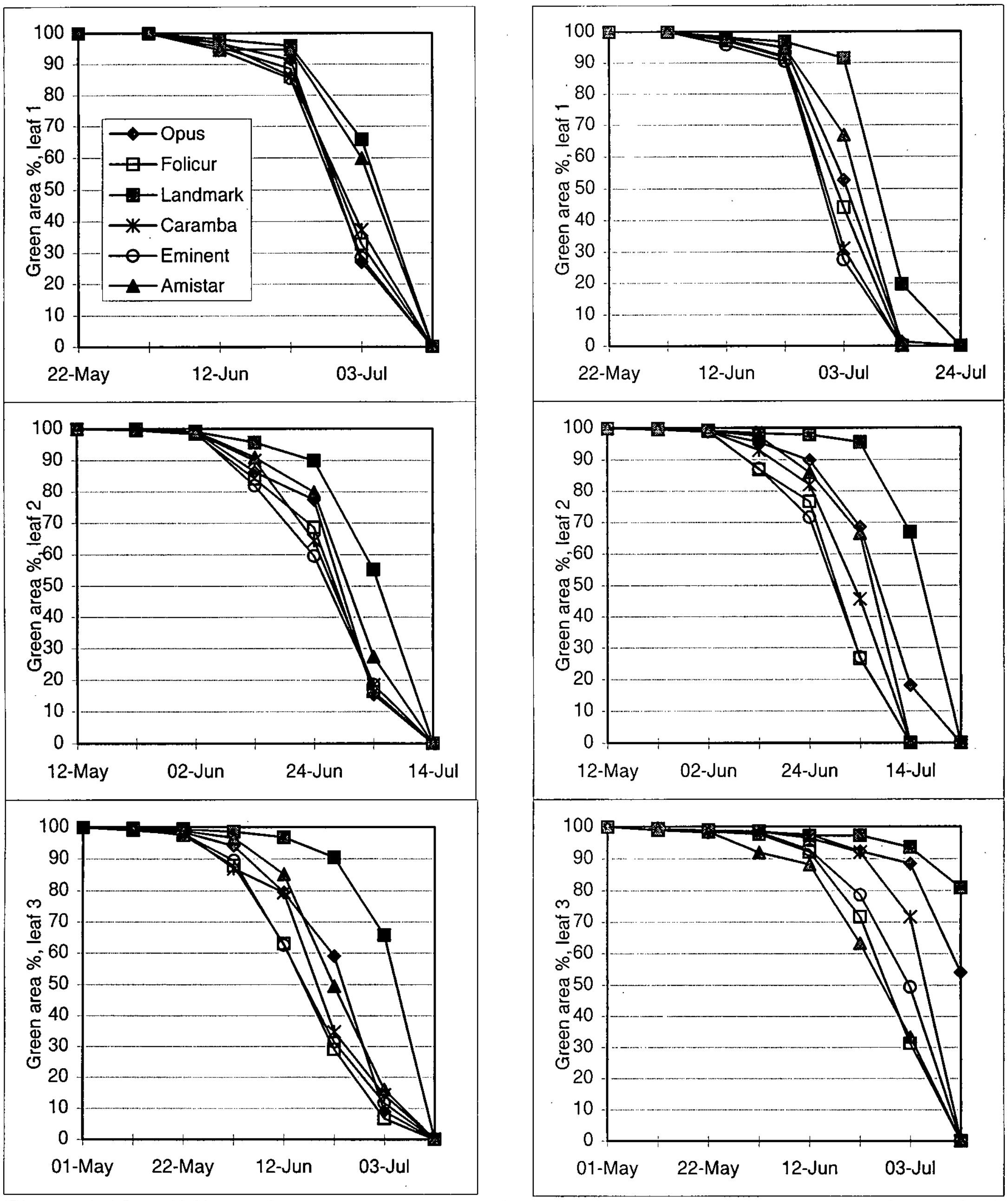


Figure 1.19. Effect of treatments on duration of green canopy on leaves 1, 2 and 3, ADAS Rosemaund 1997;
left: following GS 32 application; right: following GS 33 application.

At Morley in 1997, the epidemic developed more slowly than at the other two sites, but there was little difference from ADAS Rosemaund in final severity (Figure 1.20). GS 33 was generally the optimum timing for *S. tritici* control on leaf 3, with best control from Landmark and Opus (Figure 1.21). Landmark was as effective at GS 31 and GS 32 as at GS 33, but no other fungicide showed such flexibility in timing. Landmark at GS 33 also gave best control on leaf 2, followed by Opus at GS 33 or GS 39. The optimum timing of each fungicide on the flag leaves was GS 39, with Landmark and Opus superior to the others, followed by Caramba.

Effects on green leaf area were similar to those at the other sites in 1997 (Figure 1.23).

The two-spray standard Opus Team programme increased yield by 3.73 t/ha over the untreated yield of 5.76 t/ha (Figure 1.22). None of the single sprays matched the Opus Team programme, and the best single applications were Landmark at GS 33 or GS 39, followed by Opus at GS 39. and Caramba at GS 39.

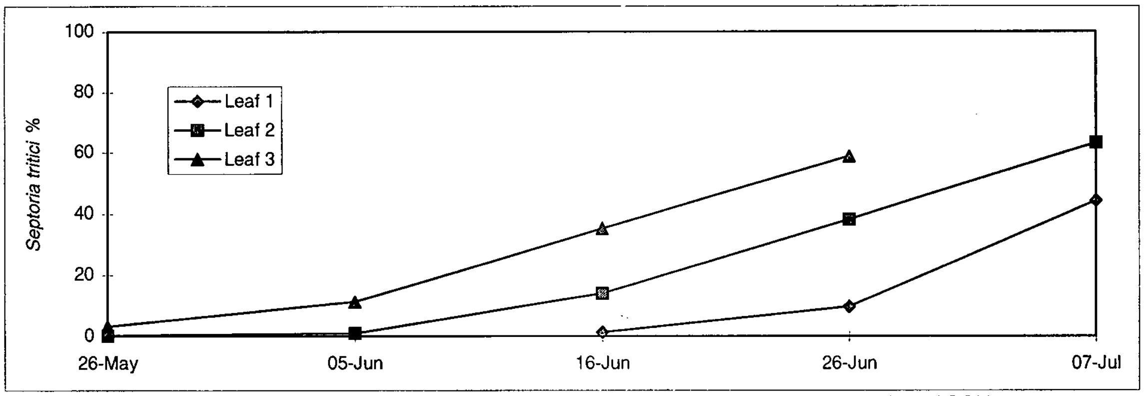


Figure 1.20. *Septoria tritici* development in untreated wheat plots, Morley 1997.

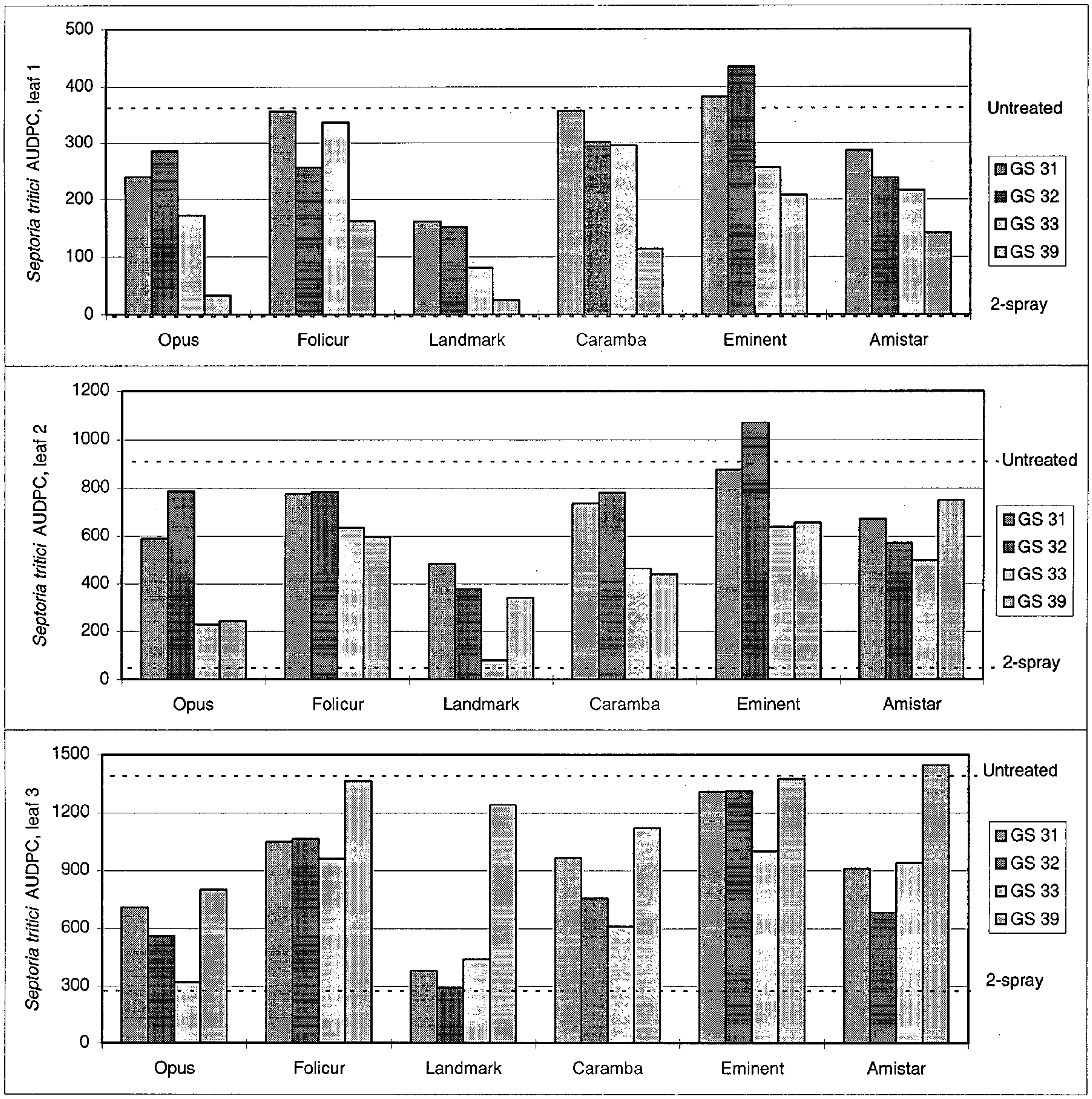


Figure 1.21. Effect of treatments on *Septoria tritici* AUDPC, Morley 1997.

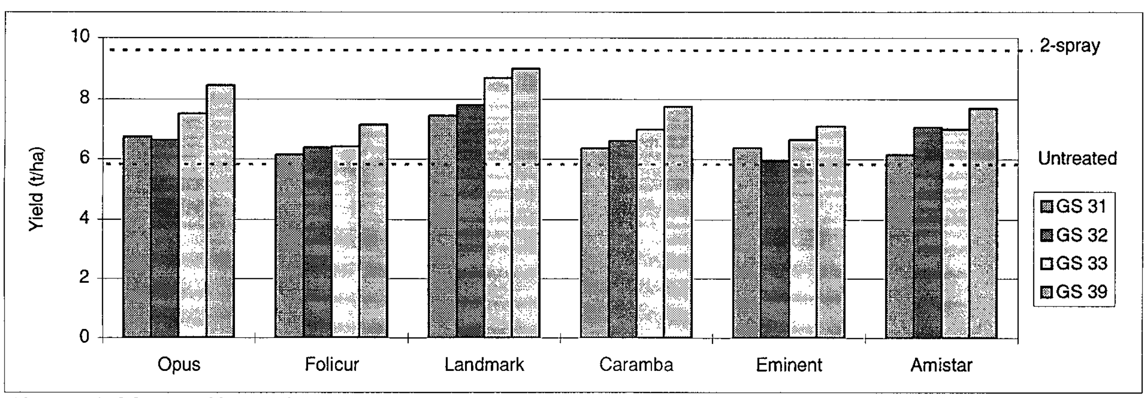


Figure 1.22. Effect of treatments on wheat yield, Morley 1997.

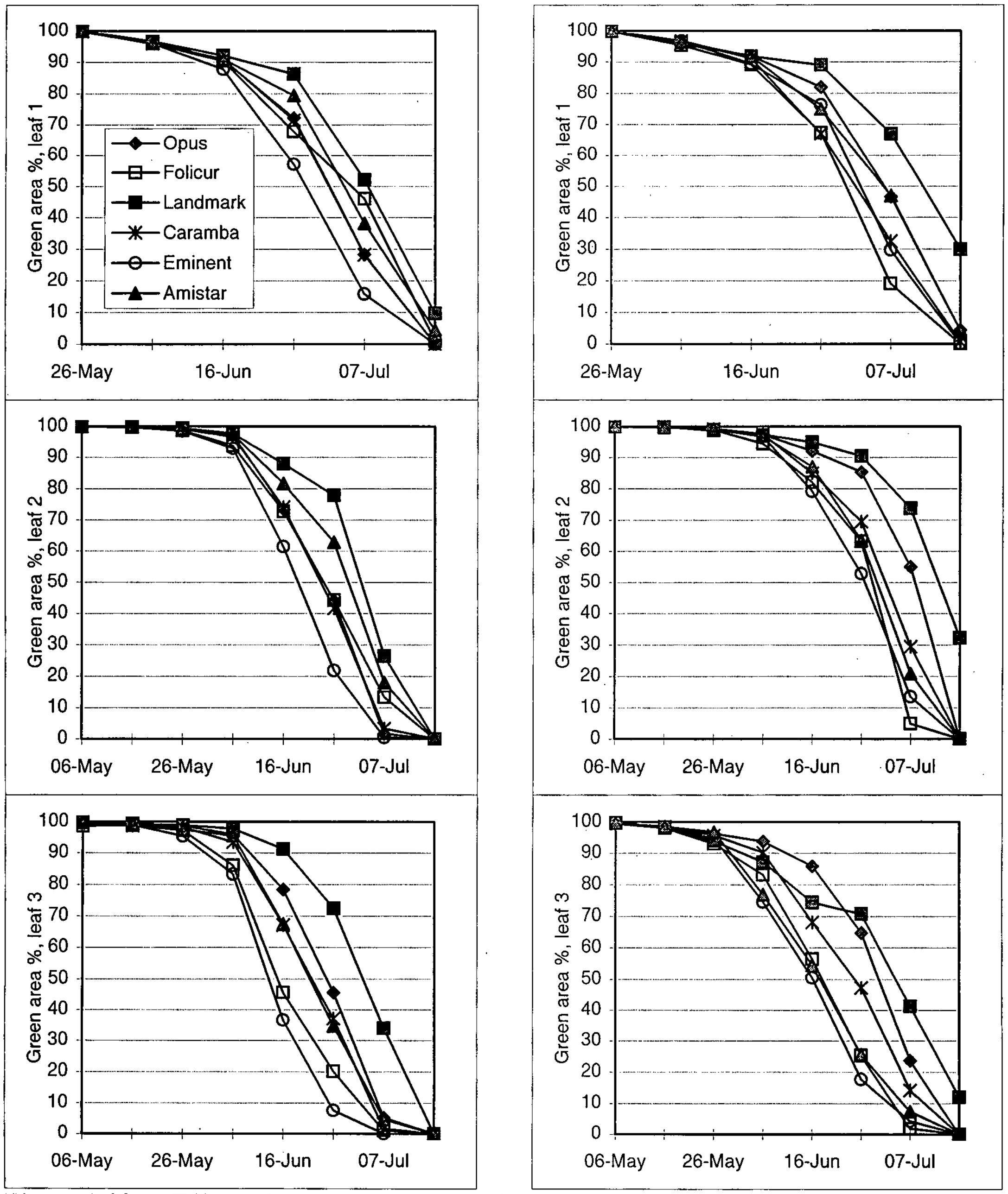


Figure 1.23. Effect of treatments on duration of green canopy on leaves 1, 2 and 3, Morley 1997;
left: following GS 32 application; right: following GS 33 application.

The *S. tritici* epidemic at West Bagborough in 1998 developed more rapidly than in any other experiment in the three years of the project (Figure 1.24). On leaf 3, GS 33 was the optimum timing, with the best treatments at this timing (Opus, Landmark and Amistar plus Opus) achieving almost as good a control as the two-spray programmes of those fungicides (Figure 1.25). Landmark at GS 33 was almost as effective on leaf 2. Two-spray programmes of Opus, Landmark and Amistar plus Opus gave very good control on each of the top two leaves. GS 39 was the most effective single spray timing on the flag leaves for each fungicide except for Ensign and Amistar, for which the optimum was at GS 33.

There were marked differences between treatments in green canopy retention from both GS 33 and GS 39, with a particularly large effect of Landmark at GS 33 on leaves 1 and 2 (Figure 1.27). On leaf 3, Landmark, Opus and Amistar plus Opus all increased green leaf retention on leaf 3.

Two-spray programmes of Opus, Landmark and Amistar plus Opus outyielded the Opus Team two-spray standard, whereas other fungicides did not (Figure 1.26). For all fungicides except Ensign, the two-spray programme gave higher yields than any single timing. For Ensign, which gave lower yields than any other fungicide, a single application at GS 33 was comparable with the GS 32 and GS 39 programme of that fungicide.

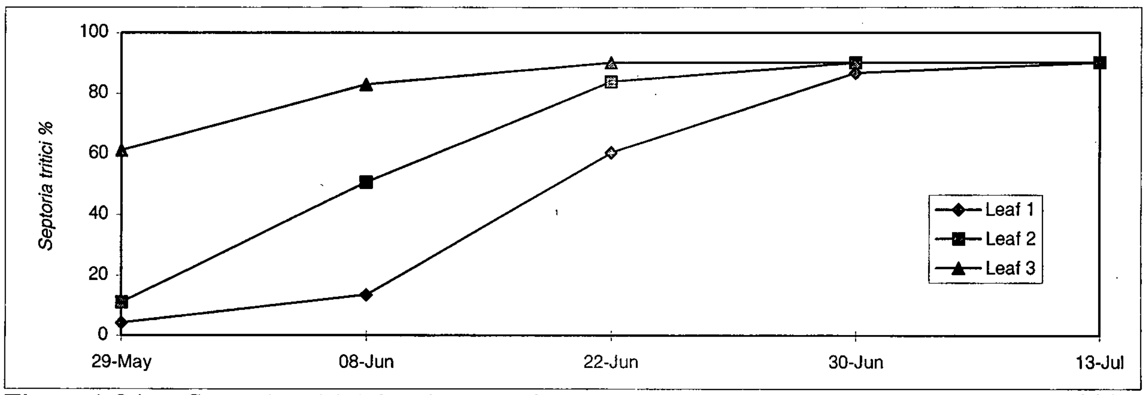


Figure 1.24. *Septoria tritici* development in untreated wheat plots, West Bagborough 1998.

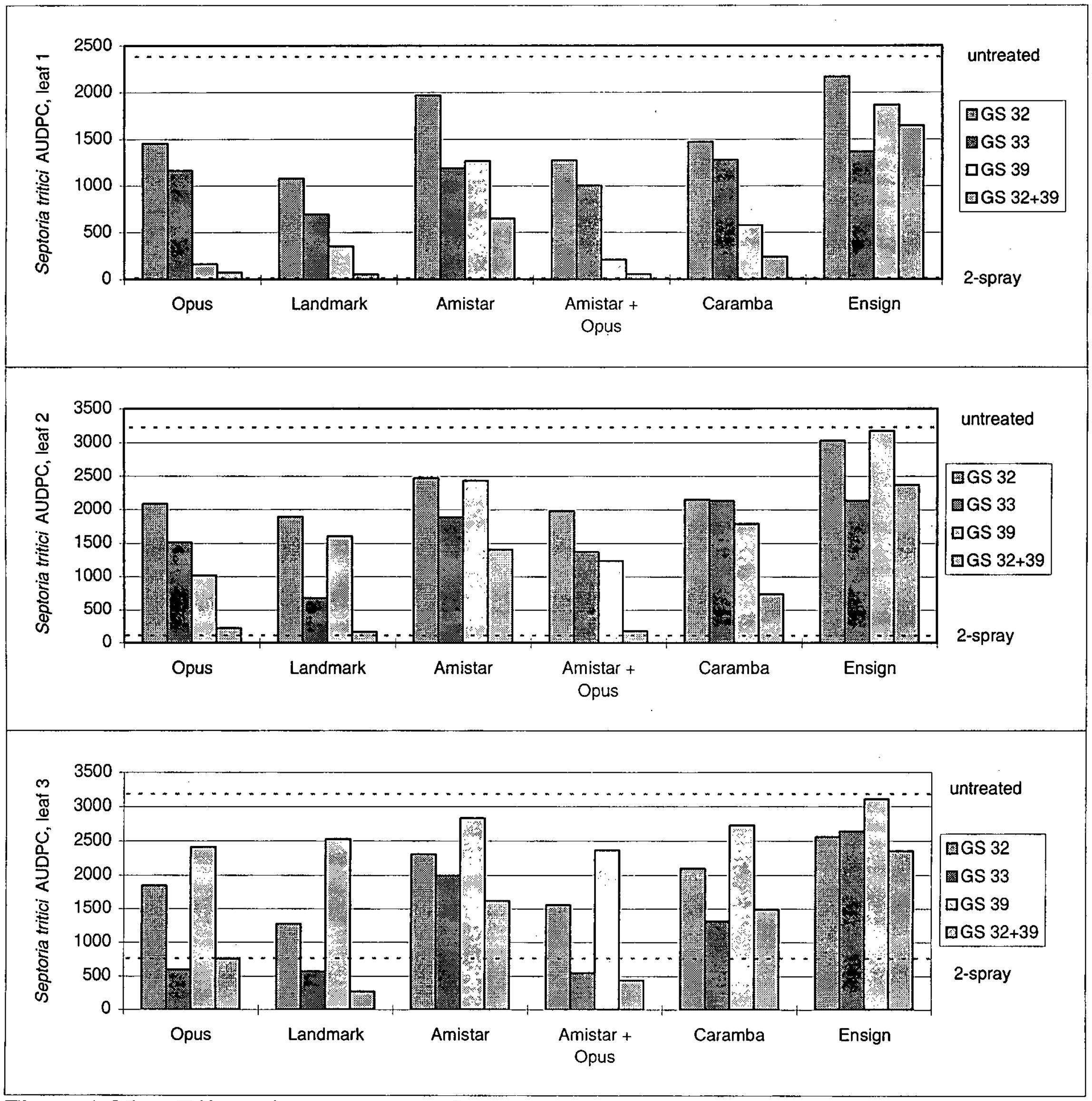


Figure 1.25. Effect of treatments on *Septoria tritici* AUDPC, West Bagborough 1998.

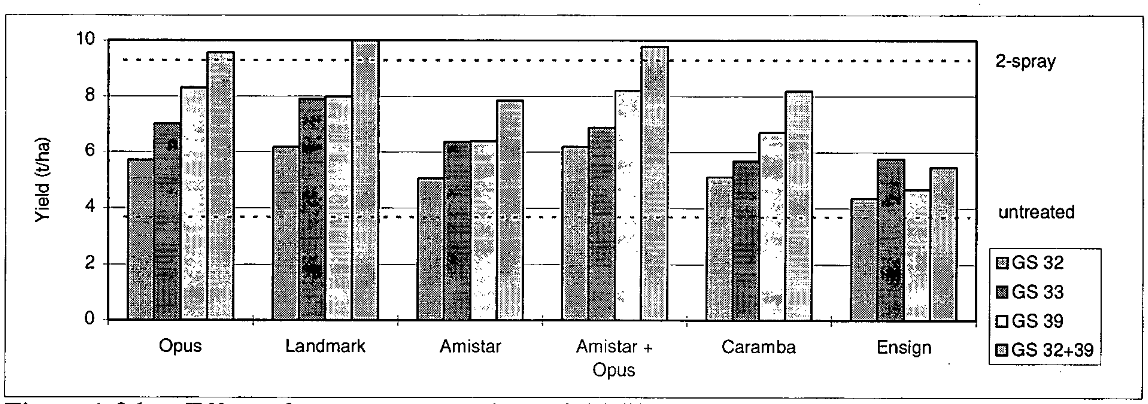


Figure 1.26. Effect of treatments on wheat yield, West Bagborough 1998.

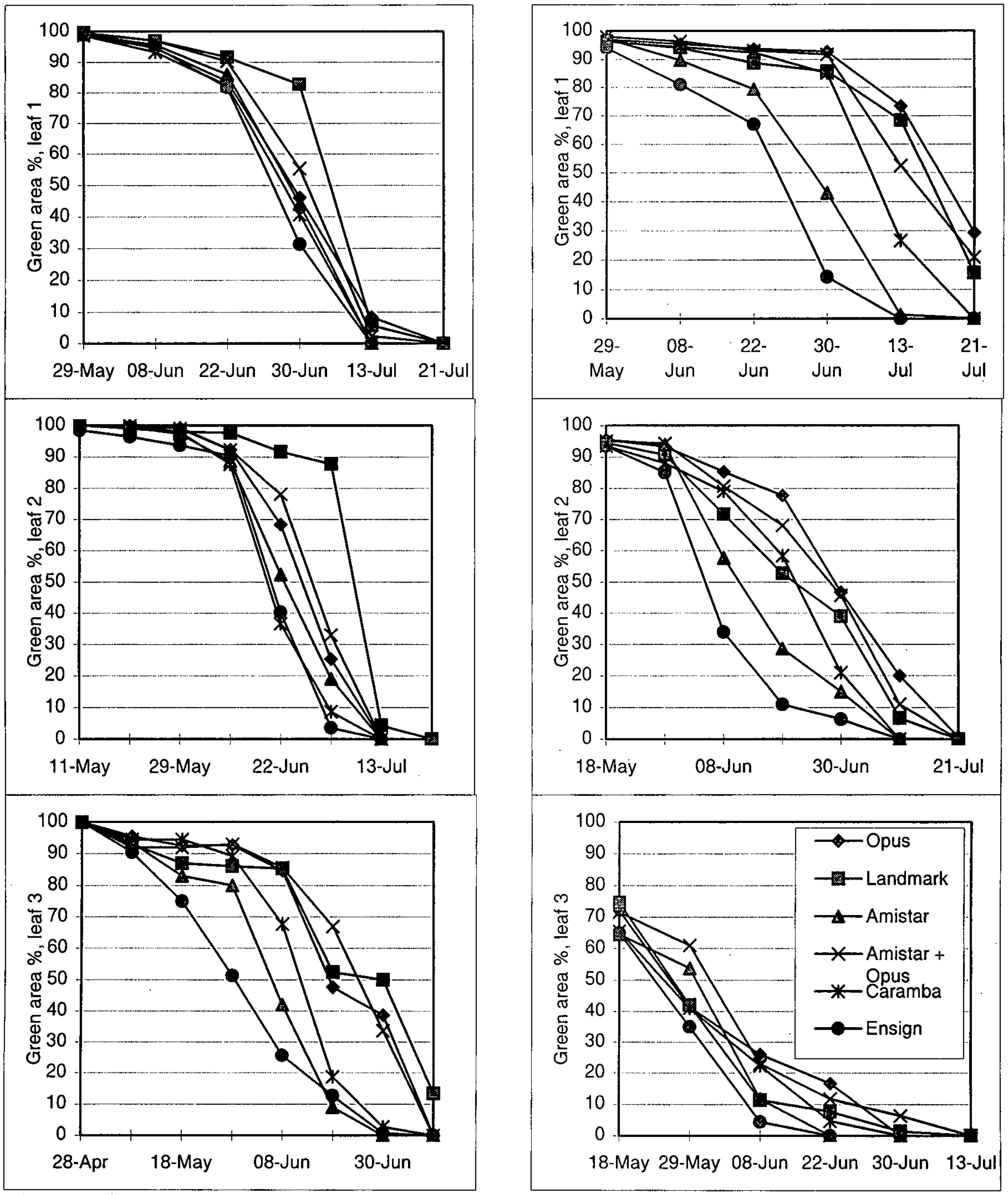


Figure 1.27. Effect of treatments on duration of green canopy on leaves 1, 2 and 3, West Bagborough 1998;
left: following GS 33 application; right: following GS 39 application.

At ADAS Rosemaund in 1998, single sprays of each fungicide at any timing gave poorer control of *S. tritici* on leaf 3 than a GS 32+39 programme (Figure 1.29). GS 33 was the optimum timing on this leaf layer for all fungicides except Amistar plus Opus, for which GS 32 was equally effective. Landmark gave slightly better control than either Opus or Amistar plus Opus. On leaf 2, Landmark, Opus and Amistar plus Opus all gave good control from GS 33 application. These three fungicides applied at GS 39 were also very effective on the flag leaves, as was Landmark from GS 33 application.

Effects of treatments on green leaf duration were noticeable on leaf 3 from GS 33 or GS 39 application (Figure 1.31). Effects on the top two leaves were smaller, although Landmark at GS 39 did show benefit in green area on both of these leaves in early July.

Two sprays of Landmark or Amistar plus Opus outyielded two sprays of Opus or Opus Team (Figure 1.30). Among single applications of Landmark, GS 33 and GS 39 gave similar yield increases, and this level of yield was matched only by Amistar plus Opus at GS 39. Both Amistar and Ensign were more effective at GS 33 than GS 39 and, for Ensign, the yield from the GS 33 timing was comparable with the two-spray programme.

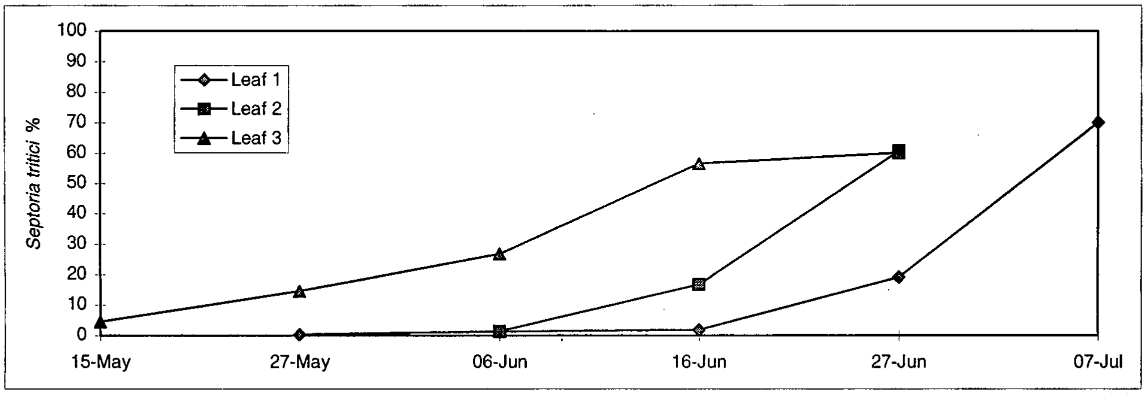


Figure 1.28. *Septoria tritici* development in untreated wheat plots, ADAS Rosemaund 1998.

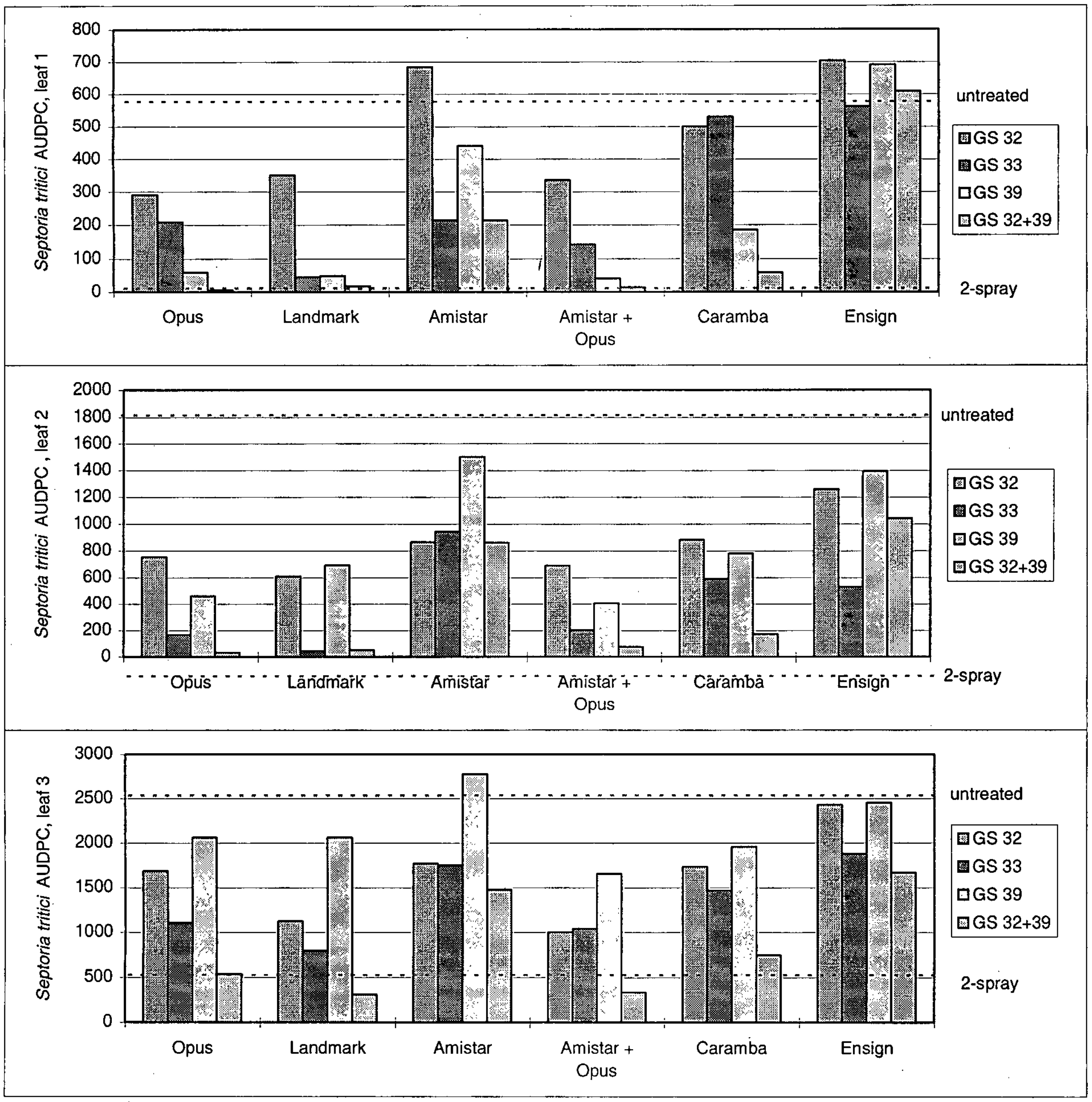


Figure 1.29. Effect of treatments on *Septoria tritici* AUDPC, ADAS Rosemaund 1998.

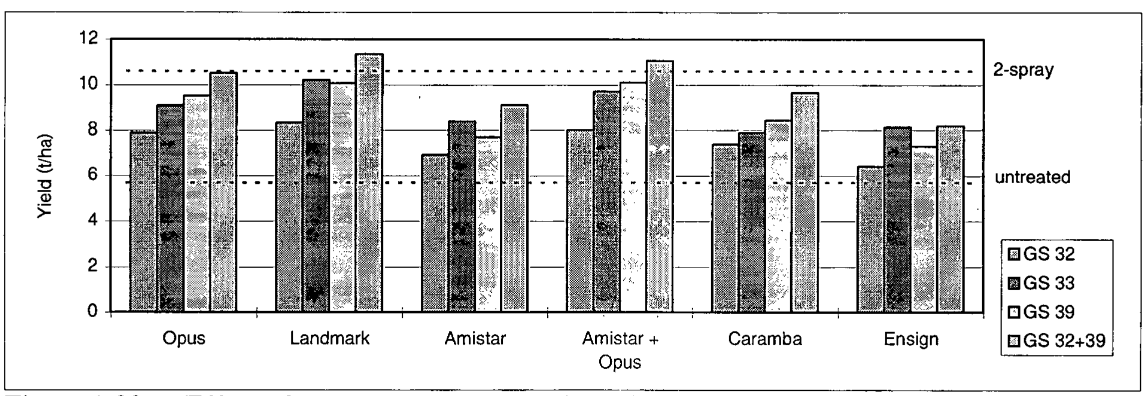


Figure 1.30. Effect of treatments on wheat yield, ADAS Rosemaund 1998.

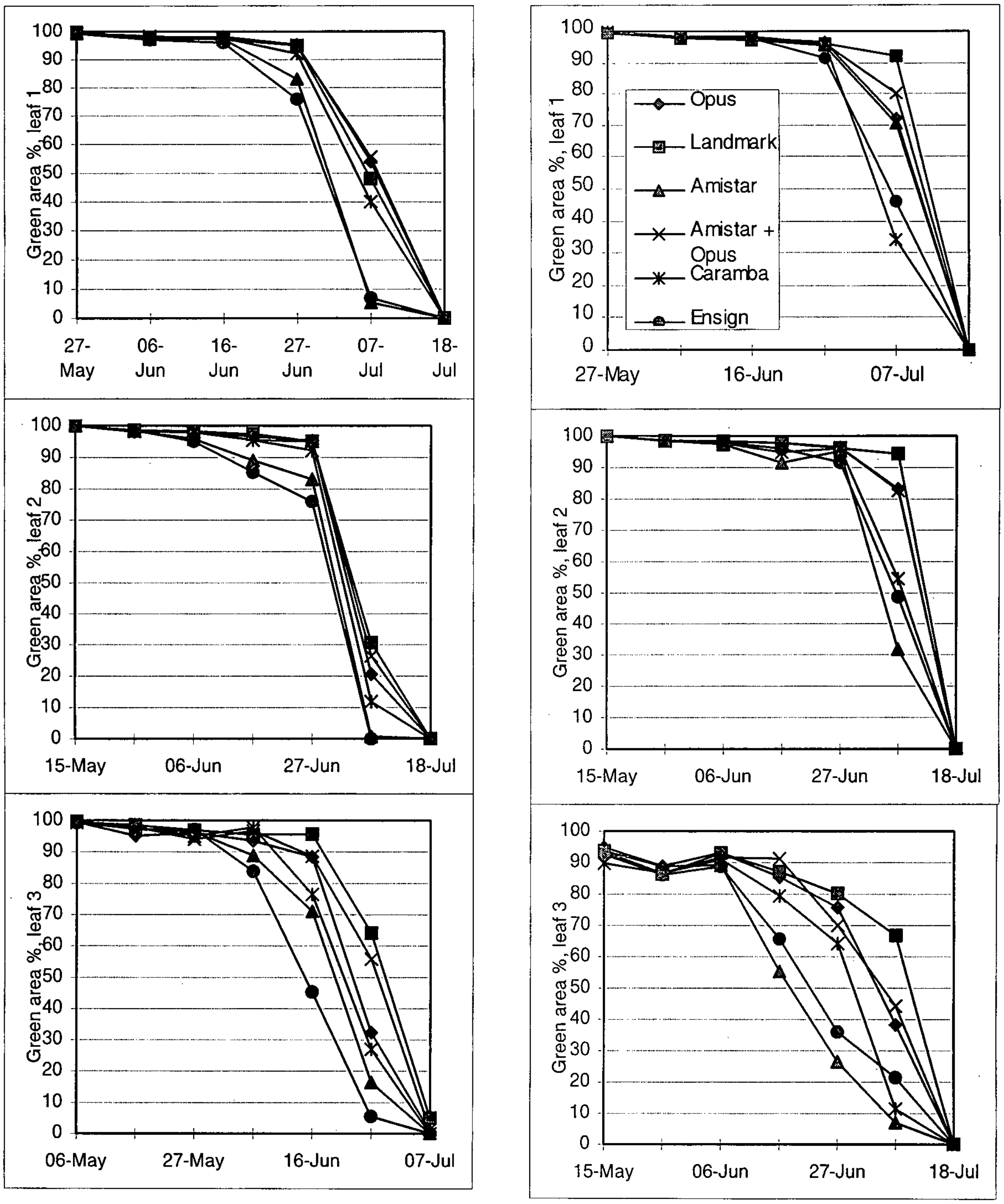


Figure 1.31. Effect of treatments on duration of green canopy on leaves 1, 2 and 3, ADAS Rosemaund 1998;
left: following GS 31-32 application; right: following GS 33 application.

At Morley in 1998, *S. tritici* and brown rust were both of significance (Figures 1.32 and 1.33), but *S. tritici* severity was much lower than at the other two sites. On leaf 3, all GS 33 treatments except Amistar and Ensign gave good control of *S. tritici*, as did Landmark and, to a lesser extent, Amistar plus Opus, at GS 32 (Figure 1.34). Amistar and Ensign were more effective applied at GS 32 than at GS 33. *S. tritici* was controlled well on leaf 2 by all GS 39 fungicides, although Ensign was slightly poorer than the others, and also by Landmark, Opus and Amistar plus Opus at GS 33. GS 39 was clearly the optimum timing for *S. tritici* contrl on the flag leaves, but Caramba and Ensign were weaker than the other fungicides.

Brown rust on leaf 2 was controlled very well by Opus, Landmark and Amistar plus Opus at either GS 33 or GS 39, and other fungicides gave good, though slightly poorer, control (Figure 1.35). GS 39 was the optimum timing for brown rust control on flag leaves, with Caramba and Ensign clearly weaker than the other fungicides.

Effects of treatments on green canopy were relatively small, and are not shown.

Although disease severity was lower than at the other sites, there were still large yield increases, with 4.06 t/ha over the untreated yield of 6.25 t/ha from the two-spray Opus Team standard (Figure 1.36). For all fungicides except Opus, the two-spray programme gave a higher yield than any single application, and the best single timing was GS 39.

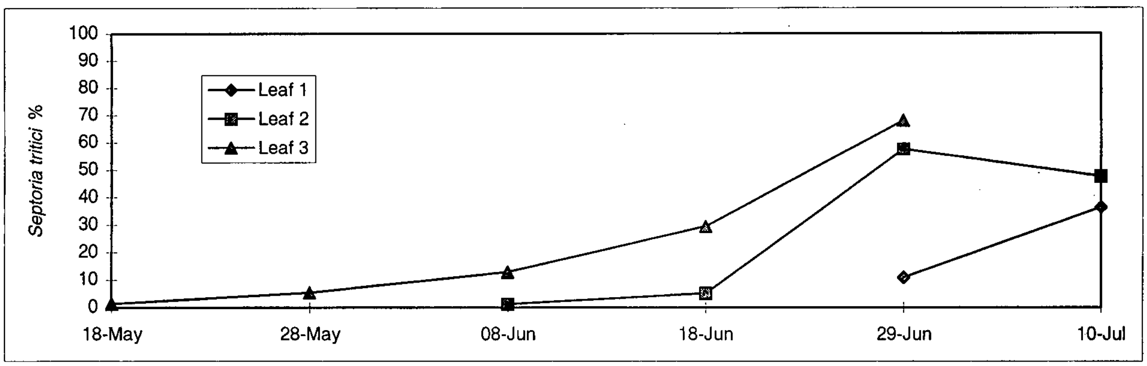


Figure 1.32. *Septoria tritici* development in untreated wheat plots, Morley 1998.

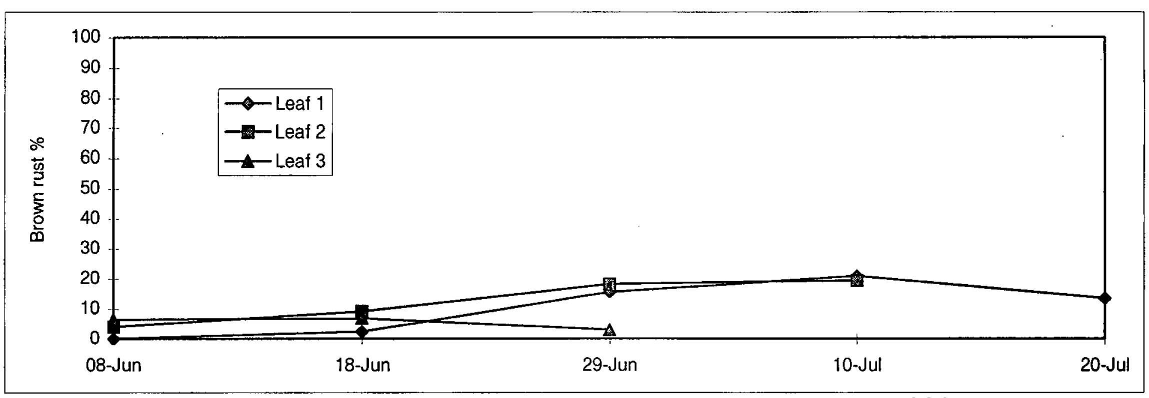


Figure 1.33. Brown rust development in untreated wheat plots, Morley 1998.

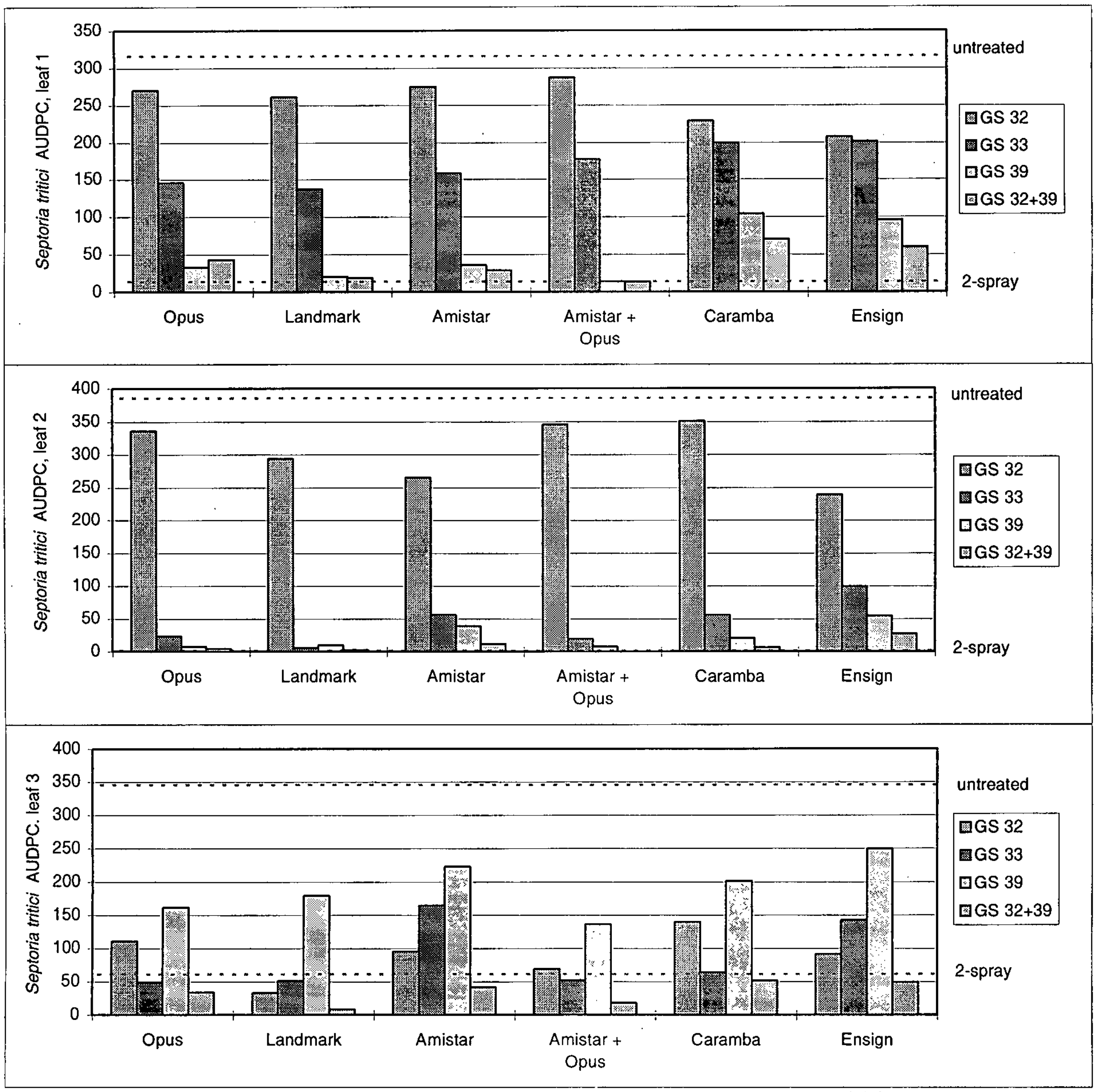


Figure 1.34. Effect of treatments on *Septoria tritici* AUDPC, Morley 1998.

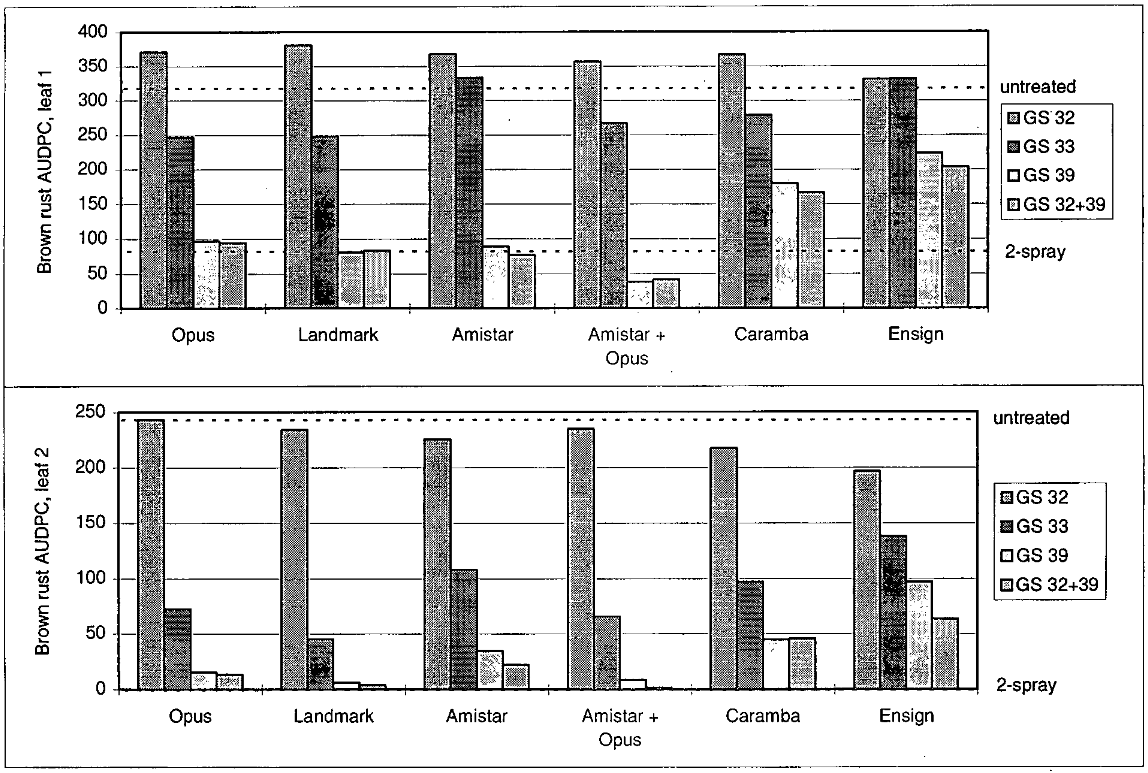


Figure 1.35. Effect of treatments on brown rust AUDPC, Morley 1998.

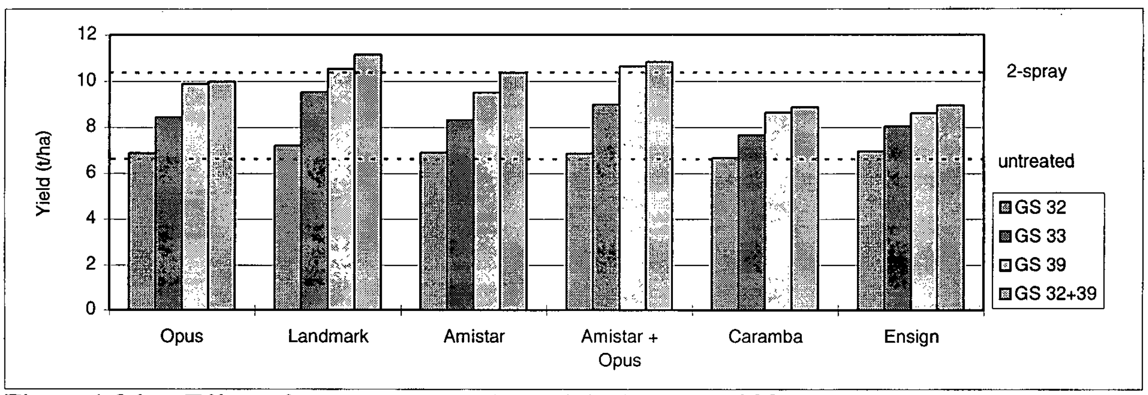


Figure 1.36. Effect of treatments on wheat yield, Morley 1998.

2. WINTER WHEAT YELLOW RUST

In 1996, yellow rust was first recorded in early June, and developed rapidly during June in untreated plots to affect 60% of leaf 2 by 1 July and 50% of leaf 1 by 11 July (Figure 2.1).

The epidemic was still in its early stages when leaf 4 became senescent, so there was little yellow rust development on this leaf. On leaf 3, each fungicide applied at GS 32 and Opus, Folicur and Landmark at GS 33 gave complete control, and there was little disease following GS 33 application of Caramba or Eminent (Figure 2.2). GS 39 sprays were less effective; Folicur had the lowest AUDPC, but this was not significantly different from any other except Landmark. All GS 59 sprays gave statistically significant reductions in yellow rust, with Landmark the most effective, but sprays applied at this stage were markedly less effective than at the earlier timings. On leaf 2, there were no statistically significant differences between fungicides at any one application timing, but GS 59 applications were less effective than those made earlier. There was an indication that the GS 39 timing was less effective than earlier timings, though this difference was not statistically significant. All fungicides applied at GS 39, and Opus, Folicur and Landmark at GS 33 gave complete disease control on the flag leaves. Other GS 33 treatments and all GS 59 treatments also gave good control.

Effects of the GS 32 and GS 33 treatments on green leaf retention are shown in Figure 2.4. Following GS 32 treatment, Landmark, Opus and Folicur had the greatest green leaf area on leaves 1, 2 and 4 at the final assessment of those leaf layers. Among those three fungicides, Landmark showed an advantage over the others on leaves 2 and 4. There was little difference between treatments on leaf 3 (not shown), although Landmark had slightly greater green leaf than the others. After treatment at GS 33, Landmark gave the greatest green leaf area on leaves 1 and 2, followed by Eminent. There was little difference between treatments on leaf 3, but Opus and Landmark had the greatest green leaf area at the final assessment on leaf 4.

The standard two-spray Opus Team programme gave a yield increase over the untreated control of 2.80 t/ha (Figure 2.3). The single applications of Landmark at GS 32, GS 33 or GS 39 gave a yield increase almost as large as that from the two-spray standard, as did Opus and Caramba at GS 39 and Folicur and Eminent at GS 33. GS 59 applications gave smaller yield increases than any other timing for each fungicide except Eminent, for which GS 32 gave the lowest yield.

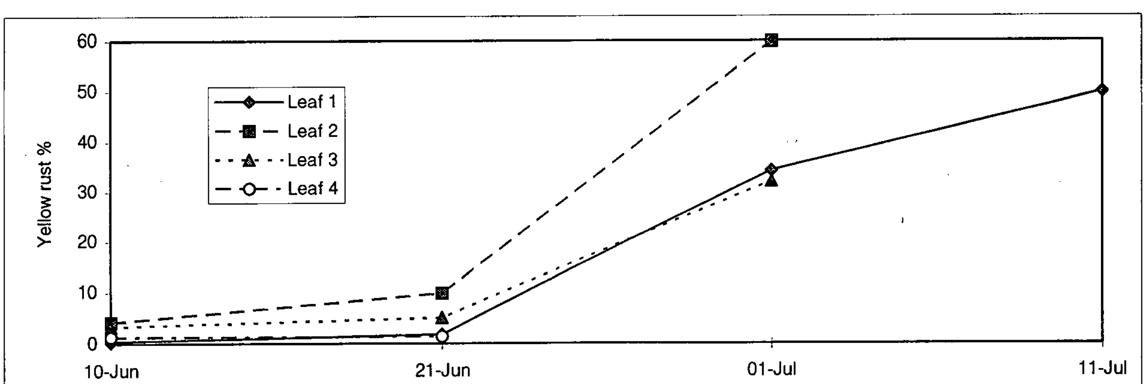


Figure 2.1. Yellow rust development in untreated wheat plots, ADAS Terrington 1996.

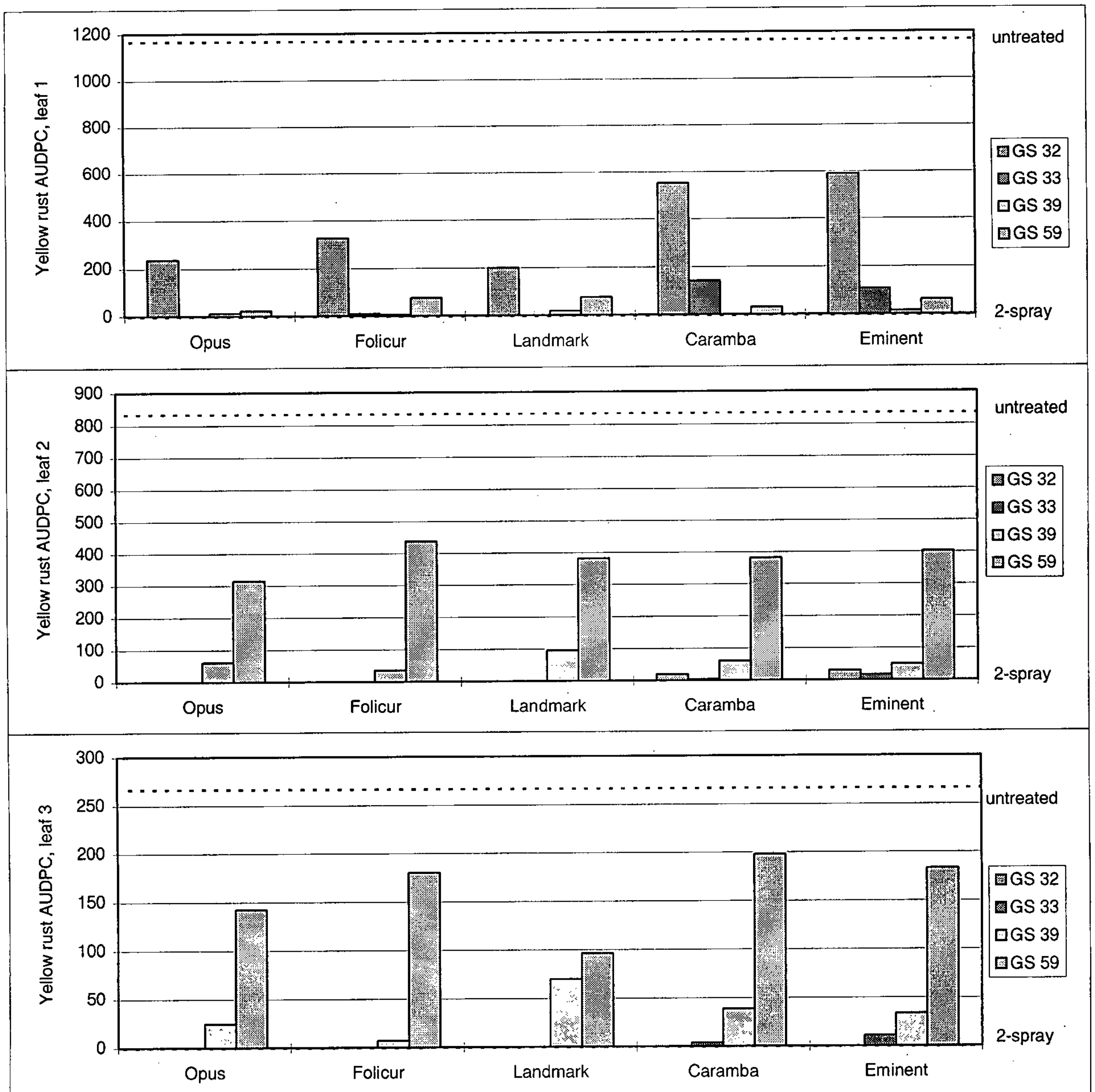


Figure 2.2. Effect of treatments on wheat yellow rust AUDPC, ADAS Terrington 1996.

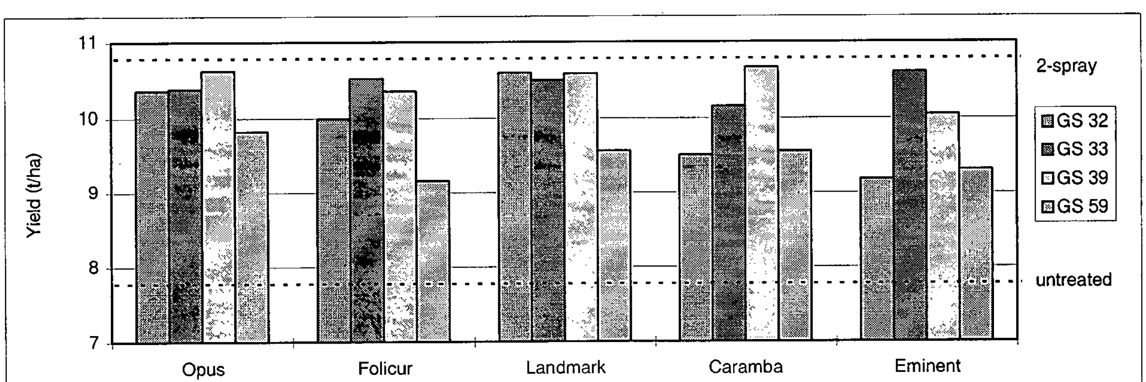


Figure 2.3. Effect of treatments on wheat yield, ADAS Terrington 1996.

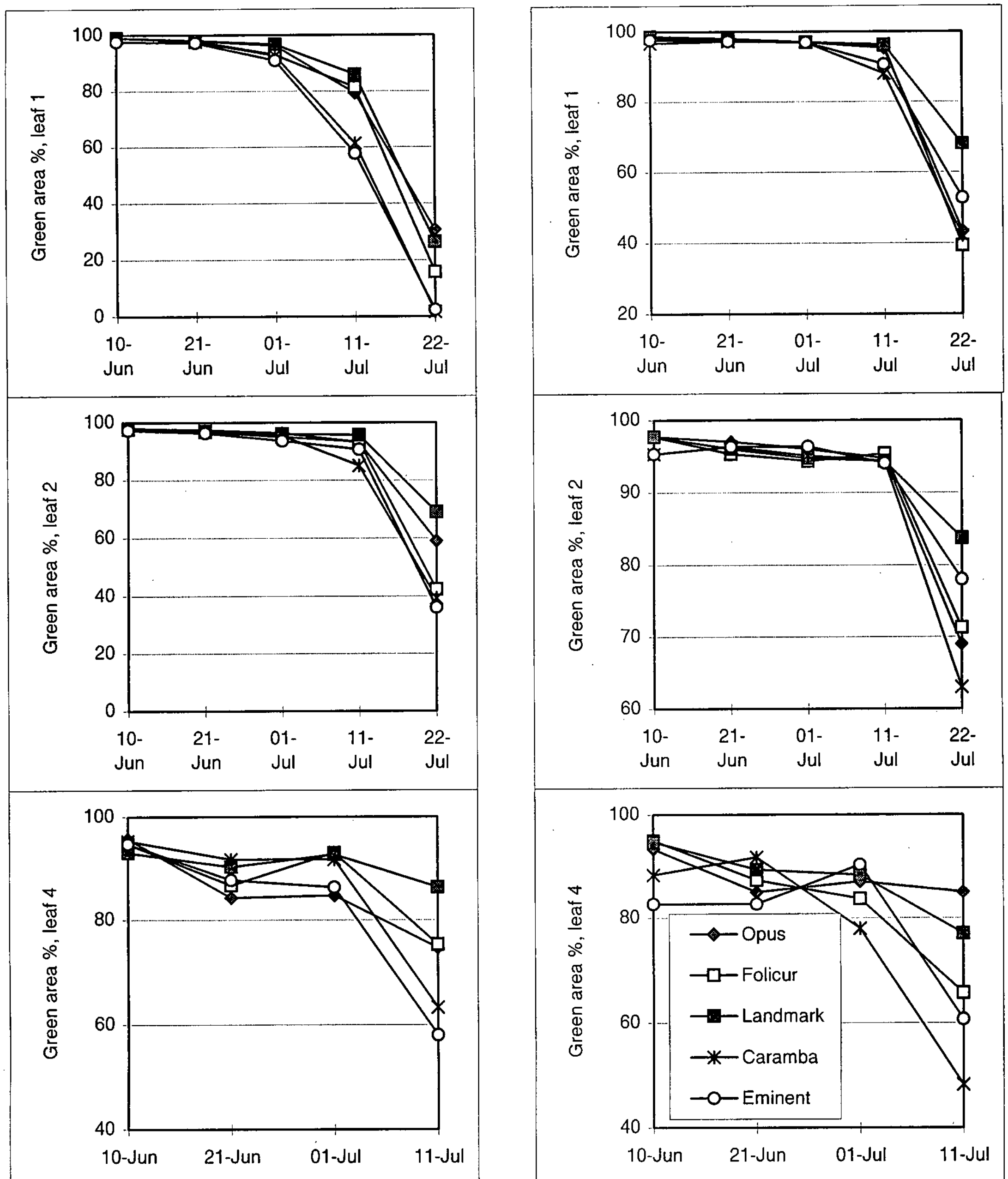


Figure 2.4. Effect of treatments on duration of green canopy on leaves 1, 2 and 4, ADAS Terrington 1996;
left: following GS 32 application; right: following GS 33 application

In 1997 at ADAS Terrington, yellow rust was first recorded in the trial in mid May, but rust severity never exceeded 7% on any leaf layer all season (Figure 2.5). *Septoria tritici* was the predominant disease in the trial (Figure 2.6).

The standard two-spray programme of Opus Team gave almost complete control of yellow rust on leaves 1 and 2. On leaf 2 there were no significant differences in yellow rust between fungicides at any one timing, although GS 39 applications were less effective than those made earlier in the season (Figure 2.7). There was also an indication that GS 31 applications were less effective particularly for Caramba and Eminent, though again this was not significant. All application timings on the flag leaf provided good control of the low levels of yellow rust.

On leaf 3, there was least *Septoria tritici* following the GS 32 applications of the fungicides whereas, on leaf 2, GS 33 was the optimum timing (Figure 2.8). Opus and Landmark, when applied at GS 32 or GS 33, were as effective as the two-spray programme of Opus Team on leaves 3 and 2 respectively. All fungicides gave statistically significant reductions in *S.tritici* compared to the untreated crop on leaf 3, Landmark having the lowest AUDPC on this leaf layer. The flag leaf had lower levels of *S.tritici* than leaves 2 and 3. All fungicides, gave reductions in disease compared with the untreated; GS 33 and GS 39 applications were generally the most effective, but Eminent gave better control at GS 32.

Effects of the GS 32 and GS 33 treatments on green leaf retention are shown in Figure 2.10. At the final assessment of 18 July, the greatest green area on leaves 1 and 2 was given by Opus and Landmark and, on leaf 1 only, Amistar. After treatment at GS 33, Landmark gave the greatest green leaf area on leaves 1 and 2, followed by Amistar. There was little difference between treatments on leaves 3 and 4 from either of these treatment timings (not shown).

The crop lodged severely in early July. The standard two-spray programme of Opus Team gave a yield of 5.53 t/ha, just 1.1 t/ha above the untreated control (Figure 2.9). The highest yield from any of the treatments was 6.07 t/ha from Amistar at GS 33, with Landmark at the same timing at 5.99 t/ha. Landmark and Amistar at GS 33 or GS 39, and also Landmark at GS 32, outyielded the two-spray Opus Team standard, whereas none of the single applications of Opus or any other fungicide did. All fungicides significantly increased yield compared with the untreated.

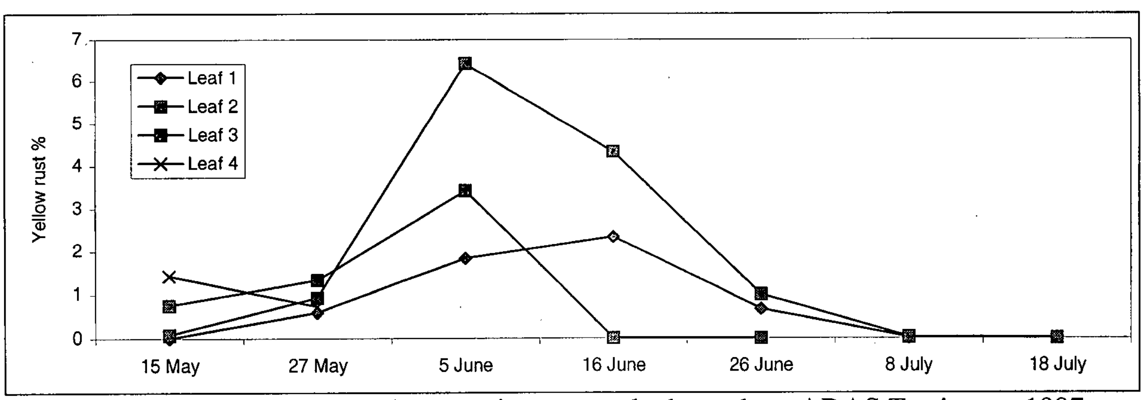


Figure 2.5. Yellow rust development in untreated wheat plots, ADAS Terrington 1997.

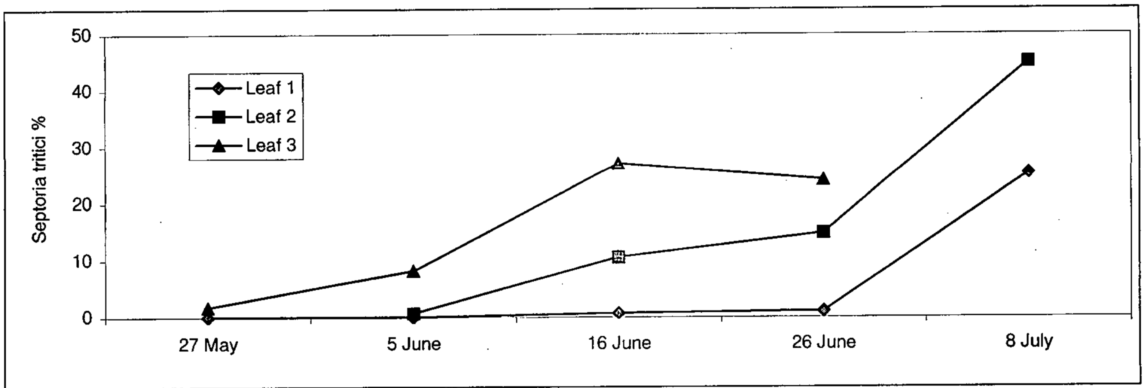


Figure 2.6. *Septoria tritici* development in untreated wheat plots, ADAS Terrington 1997.

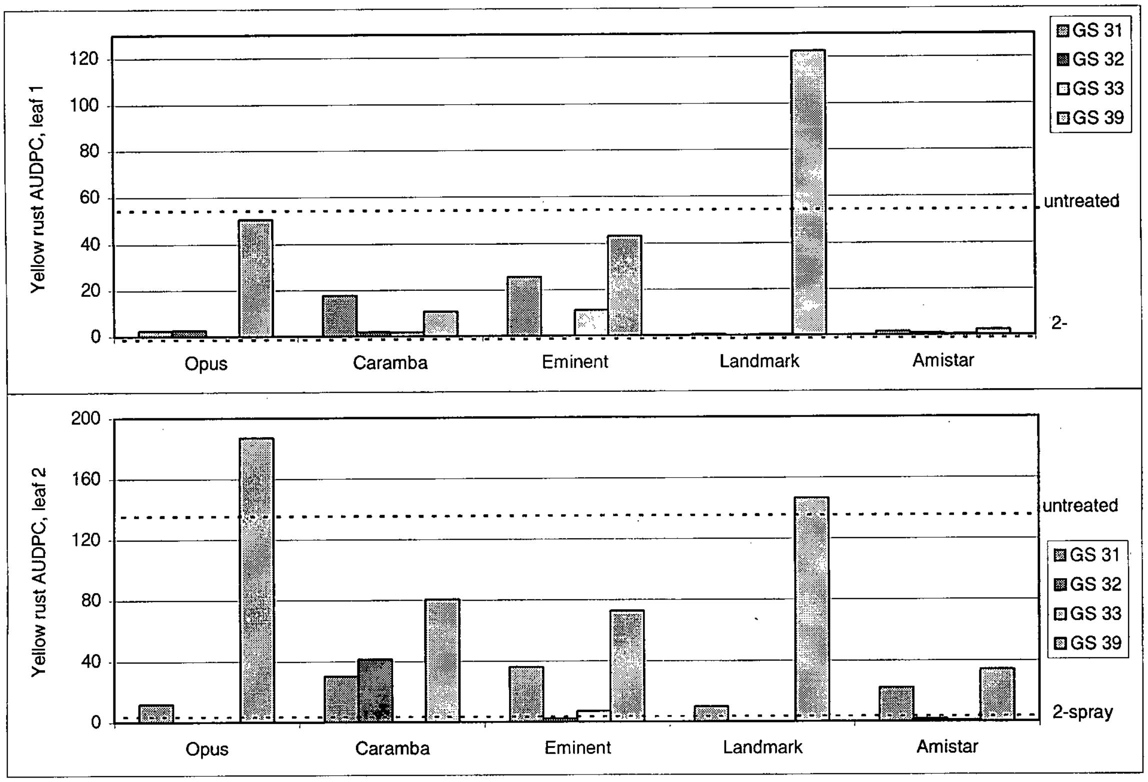


Figure 2.7. Effect of treatments on yellow rust AUDPC, ADAS Terrington 1997.

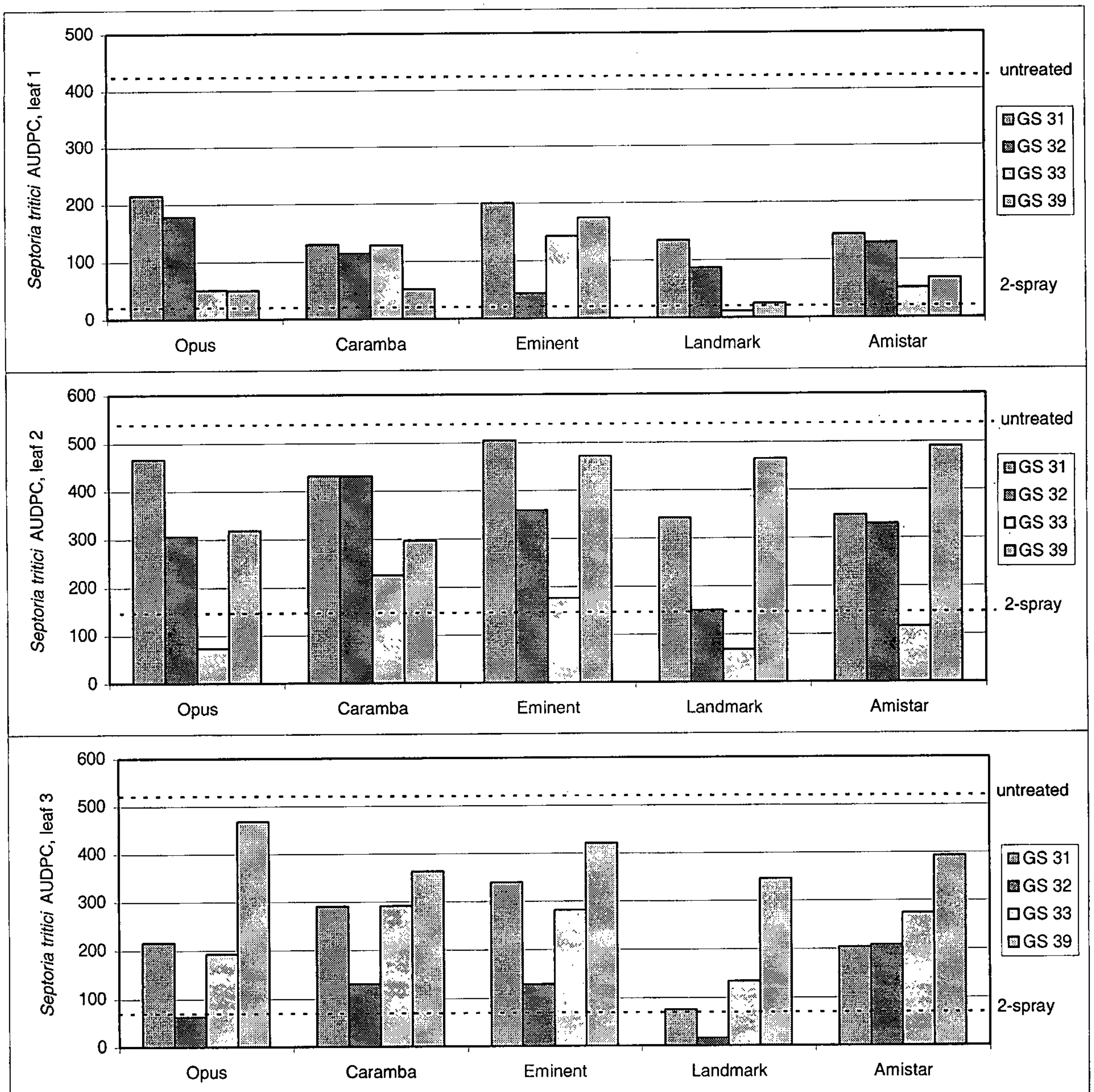


Figure 2.8. Effect of treatments on *Septoria tritici* AUDPC, ADAS Terrington 1997.

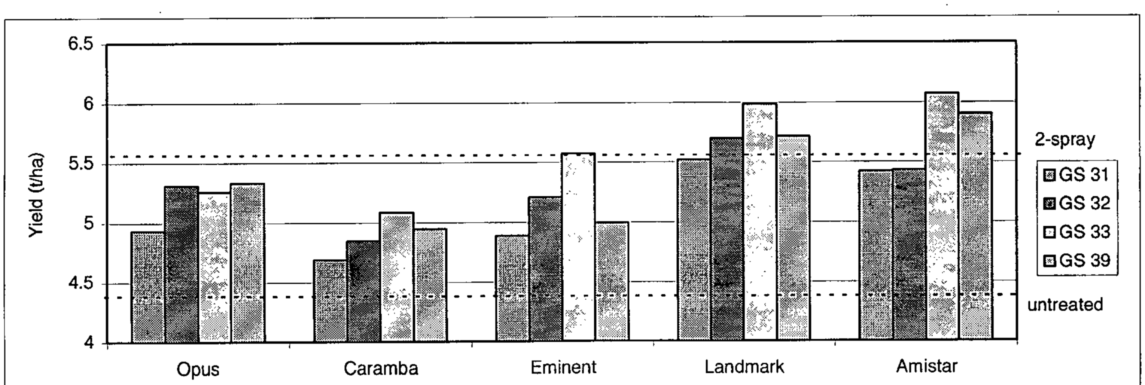


Figure 2.9. Effect of treatments on wheat yield, ADAS Terrington 1997.

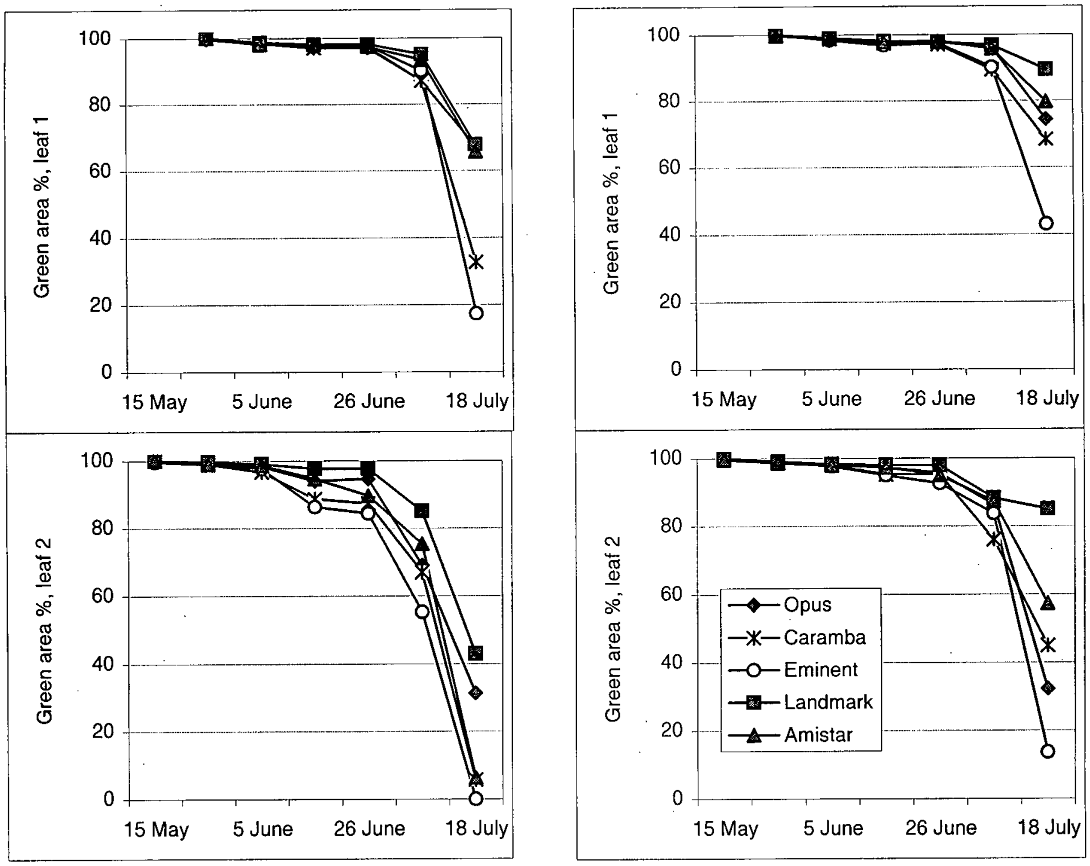


Figure 2.10. Effect of treatments on duration of green canopy on leaves 1 and 2, ADAS Terrington 1997;
left: following GS 32 application; right: following GS 33 application

In 1998, there was a severe yellow rust epidemic, but other diseases were relatively unimportant (Figure 2.11).

On leaf 3, the two-spray Opus Team standard gave only approximately 30% control of yellow rust (Figure 2.12). Single GS 31 or GS 39 applications of Opus, Landmark, Amistar and Neon all gave similar control to the standard Opus Team two-spray programme, as did programmes of these fungicides with a spray at each of these timings. Amistar + Opus gave best control at GS 31, but had no effect at GS 39, and Ensign was effective at GS 39 only. On leaf 2, Opus, Landmark, Amistar and Amistar + Opus at GS 31 were as effective as both the two-spray Opus Team standard and the two-spray (GS 31 + 39) programmes of those fungicides. Ensign gave poorer control, and Neon had no effect. None of the single sprays at GS 33 or GS 39 reduced disease. On the flag leaves, two-spray programmes of Opus, Landmark and Amistar + Opus gave virtually complete control, as did the Opus Team two-spray programme. Two sprays of Amistar gave over 80% reduction of yellow rust whereas, in comparable programmes, Ensign gave approximately 67% control and Neon 25% control. None of the single applications gave more than 50% control; all Opus, Landmark and Amistar + Opus treatments gave a statistically significant reduction whereas, among the other three fungicides, significant reductions were given only by Amistar at GS 33 and Neon at GS 39.

The two-spray Opus Team standard gave a yield increase of 4.48 t/ha over the untreated yield of 4.02 t/ha (Figure 2.13). Two-spray programmes of Amistar + Opus and Landmark gave yields significantly higher than that from Opus Team, whereas Opus and Amistar alone did not differ significantly from Opus Team. Two applications of Ensign gave an increase of over 3.1 t/ha, whereas two sprays of Neon gave only 0.8 t/ha. All single applications gave lower yields than the two-spray standard. Among the single applications, Amistar + Opus at GS 39 gave the highest yield, followed by all timings of Landmark. GS 39 applications of each fungicide gave higher yields than GS 31 or GS 33, except for Landmark which gave the highest yield from GS 33.

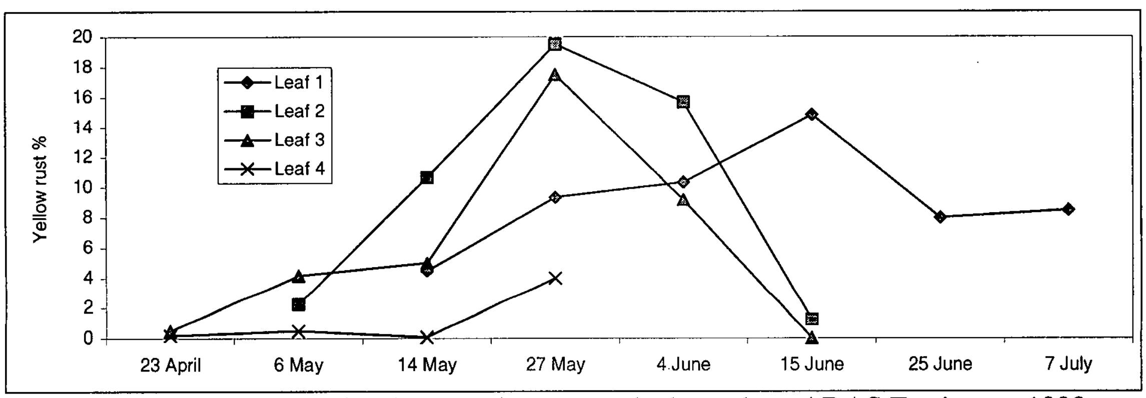


Figure 2.11. Yellow rust development in untreated wheat plots, ADAS Terrington 1998.

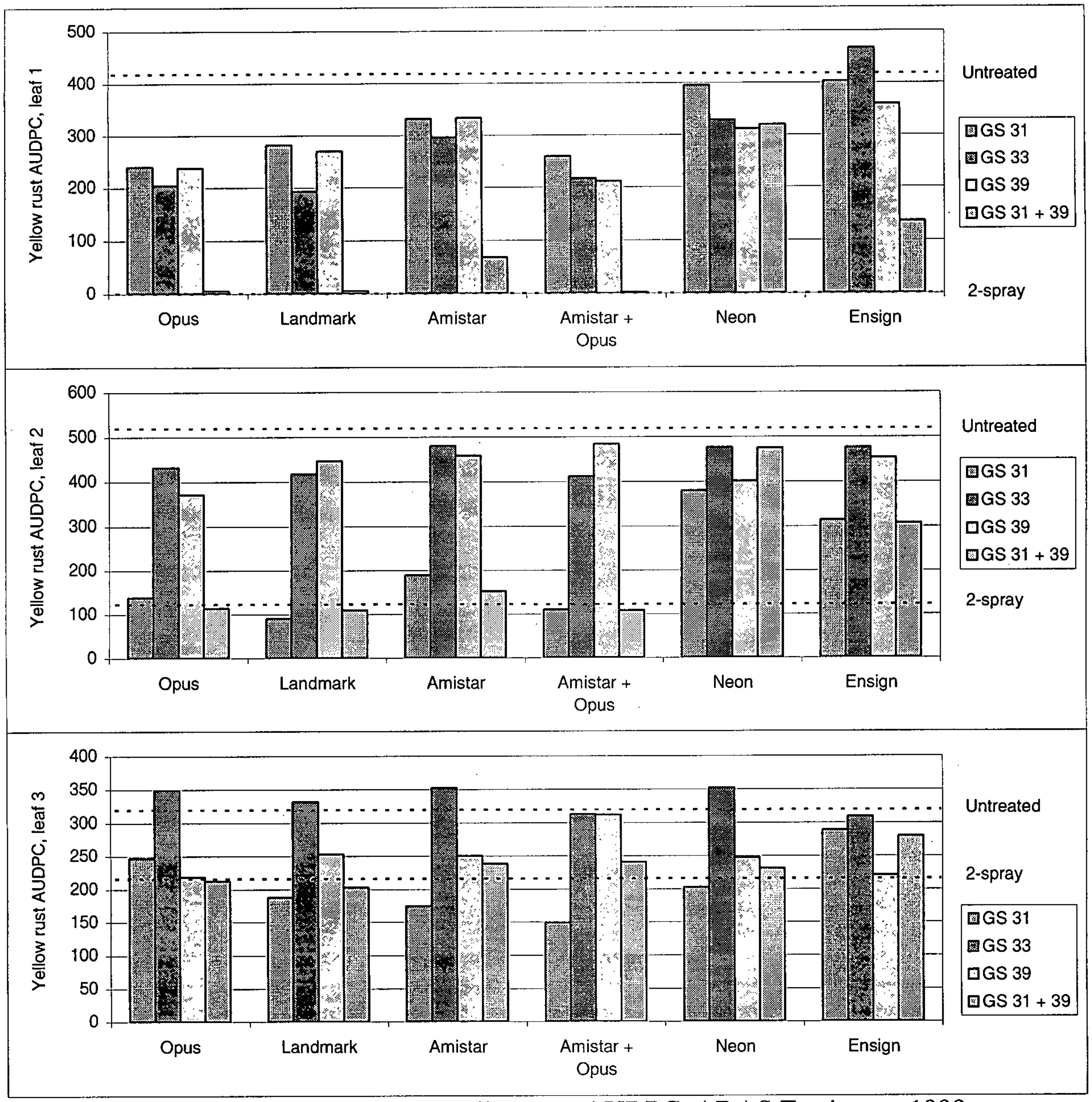


Figure 2.12. Effect of treatments on yellow rust AUDPC, ADAS Terrington 1998.

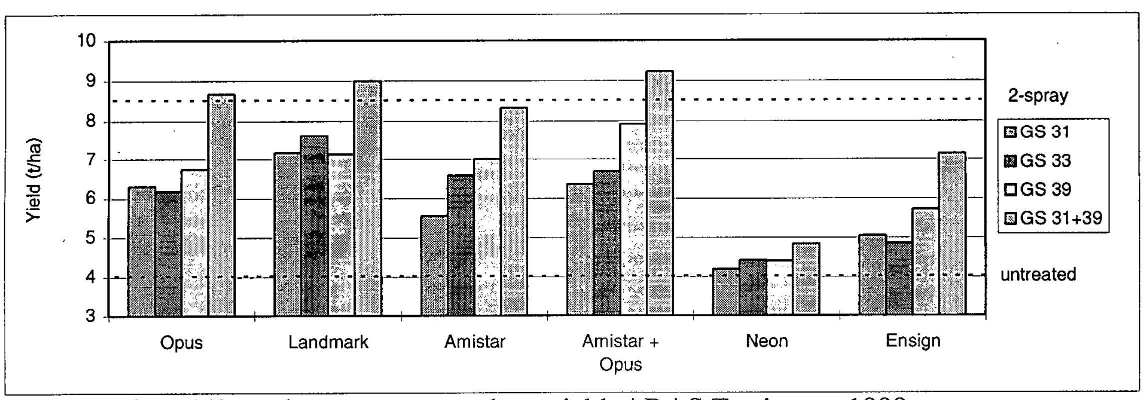


Figure 2.13. Effect of treatments on wheat yield, ADAS Terrington 1998.

3. WINTER WHEAT MILDEW

In 1996, the mildew epidemic at Arthur Rickwood did not develop to any extent until early June, but then increased steadily in untreated plots such that there was between 15 and 20% infection of each of leaves 2 and 3 by the time they senesced (Figure 3.1). The standard two-spray programme of Opus Team gave good but not complete mildew control on each of leaves 2-4 (Figure 3.2).

On leaf 4, there was a clear decline in fungicide performance from successively later sprays, but few of the differences between fungicides at each spray timing were statistically significant (Figure 3.2). Ensign at GS 33 was significantly more effective than any other fungicide at that timing except for Tern. There were also indications that Ensign was the most effective fungicide at each of the other timings, particularly GS 32, at which it gave virtually complete control. Unix also gave good control at GS 32 but was less effective later; the mixture of Unix and Tern did not show such a sharp decline in performance from later sprays. On leaf 3, GS 32 or GS 33 application of Ensign or Tern gave good control, with complete control from Ensign at GS 32. Unix was also effective at GS 32, but not at GS 33, whereas Opus gave good control at GS 33 only. On leaf 2, all GS 33 treatments gave good control, particularly Tern, Opus and Ensign. Most GS 39 treatments were almost as effective as GS 33 treatments, with the exception of Unix. GS 32 applications of Ensign and Unix also showed a strong effect on leaf 2. Disease levels on the flag leaves were low.

In a dry summer, the crop ripened rapidly and unevenly, and there were no significant differences between treatments in yield (Figure 3.3).

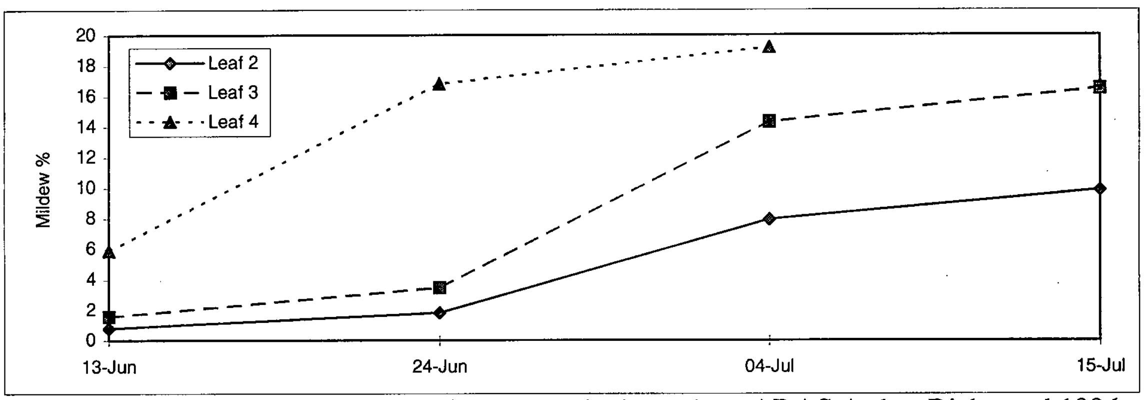


Figure 3.1. Mildew development in untreated wheat plots, ADAS Arthur Rickwood 1996.

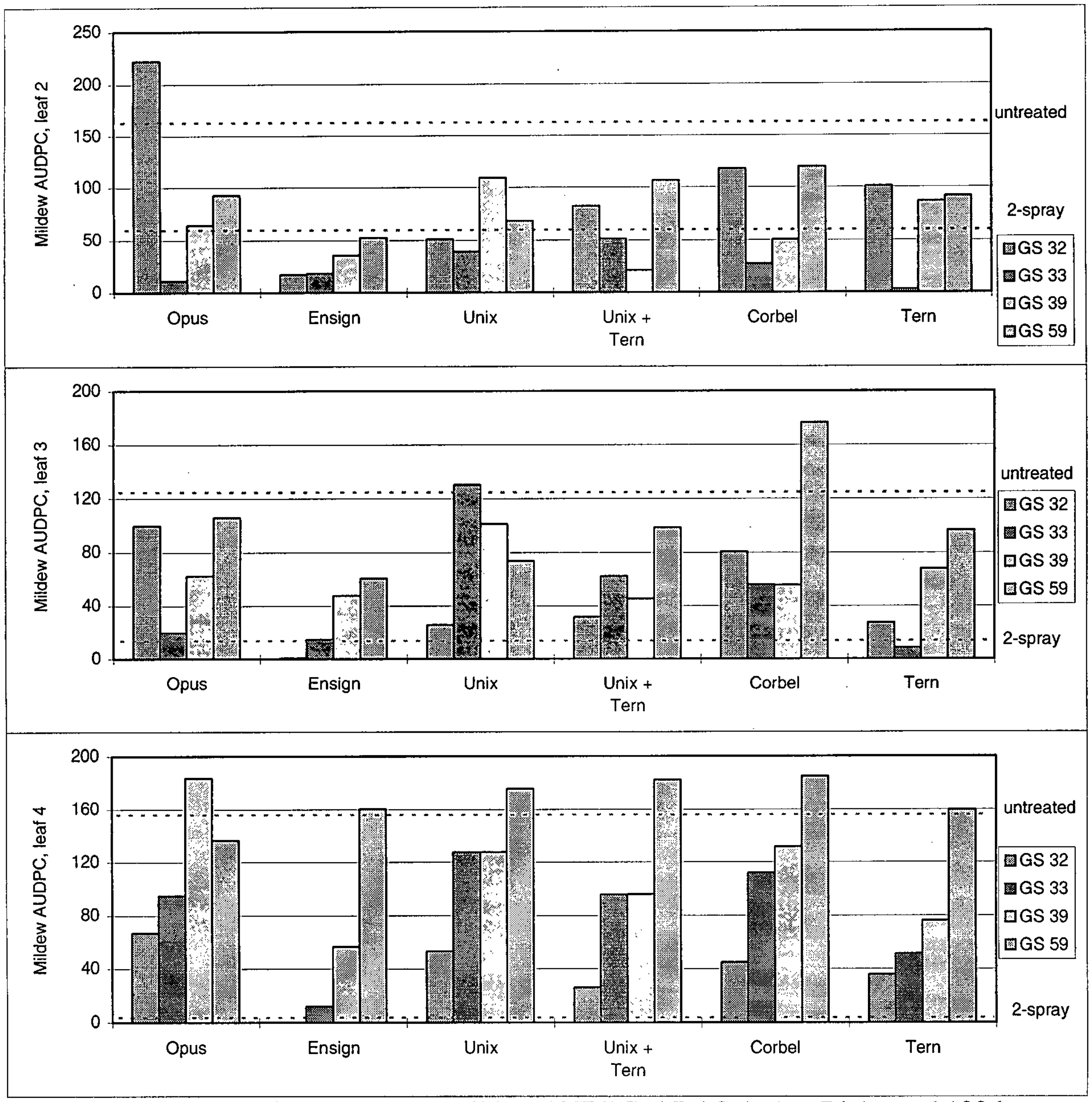


Figure 3.2. Effect of treatments on mildew AUDPC, ADAS Arthur Rickwood 1996.

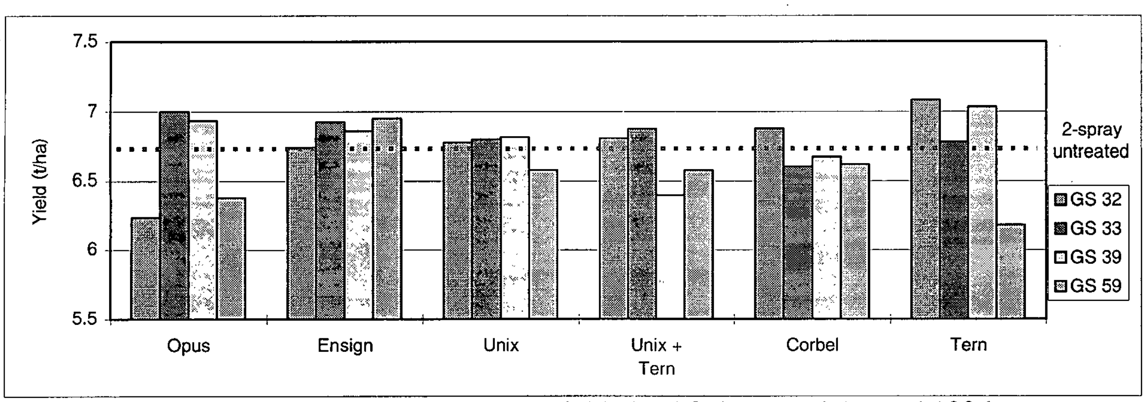


Figure 3.3. Effect of treatments on wheat yield, ADAS Arthur Rickwood 1996.

Mildew levels at Aberdeen in 1996 were very low until the end of June, but increased a little during July (Figure 3.4). In consequence, there were few significant differences between treatments. On leaf 3, Ensign at GS 32 or GS 33, Unix at GS 33 or GS 39, and Unix + Tern and Opus at GS 39 gave the greatest reductions in mildew (Figure 3.5). On leaf 2, GS 39 sprays gave the greatest reductions in mildew for all fungicides except Unix, which was most effective at GS 33.

There was a yield response of 0.30 t/ha to the standard two-spray programme, but no significant differences between fungicides or timings (Figure 3.6).

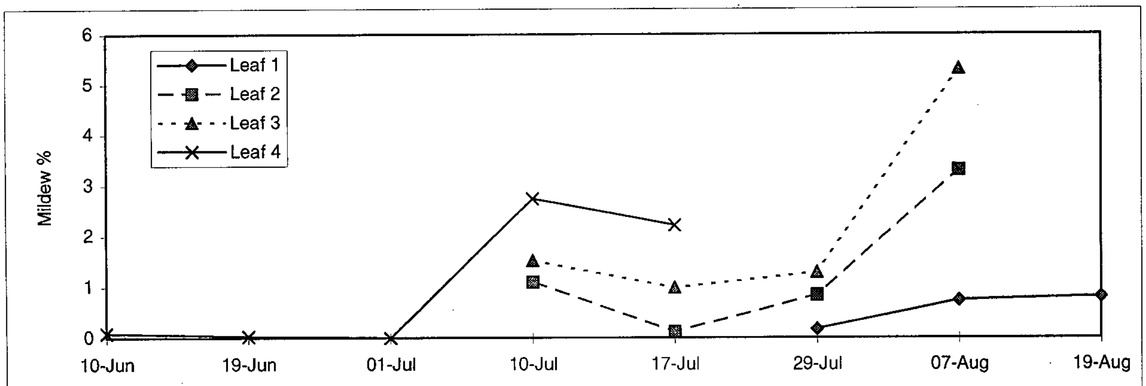


Figure 3.4. Mildew development in untreated wheat plots, SAC Aberdeen 1996.

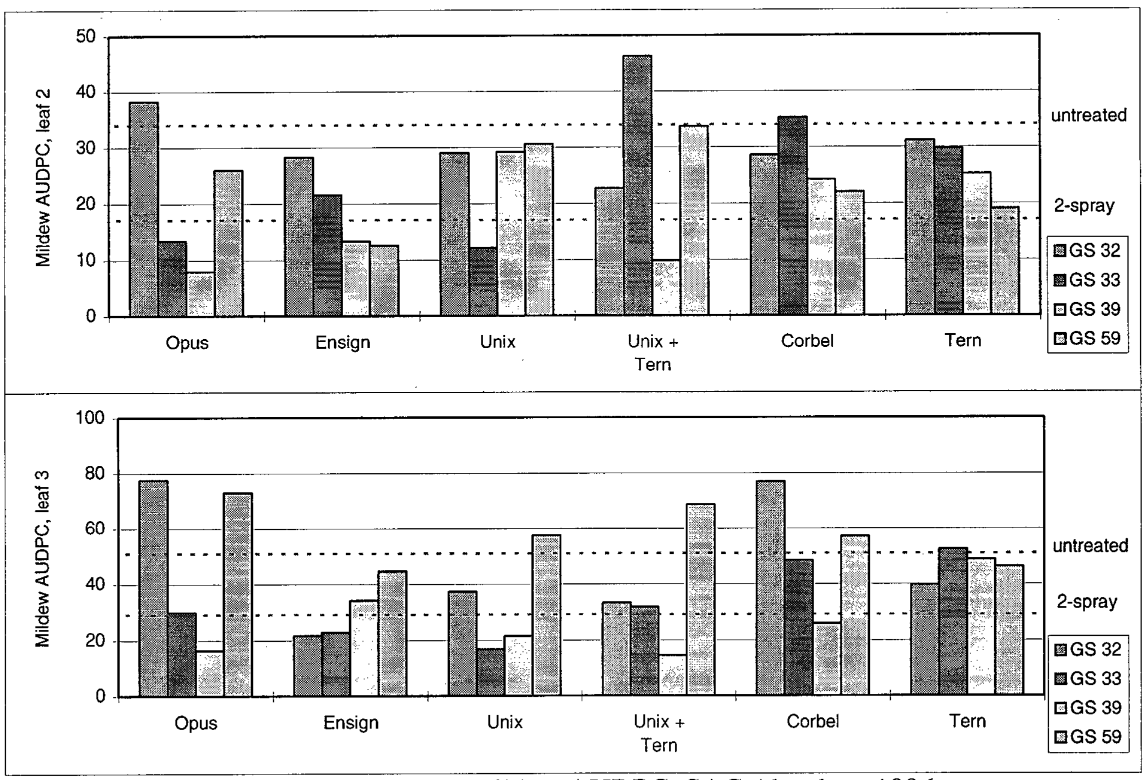


Figure 3.5. Effect of treatments on mildew AUDPC, SAC Aberdeen 1996.

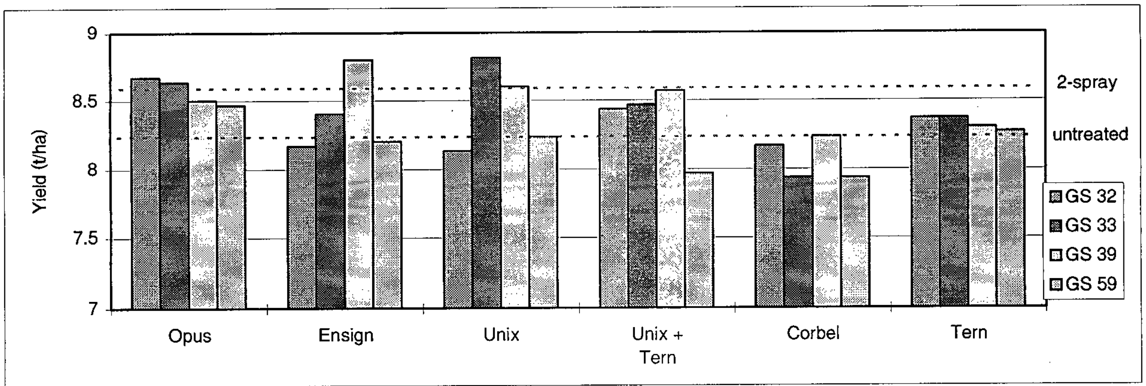


Figure 3.6. Effect of treatments on wheat yield, SAC Aberdeen 1996.

Mildew was more severe at ADAS Arthur Rickwood in 1997 than in 1996, having become established in untreated plots in early May. The disease developed rapidly in June, when it began to infect the flag leaf, reaching about 15% on leaves 3 and 4 by mid July (Figure 3.8). The standard two-spray control of Opus Team gave good control on leaves 1-3 but was not as effective on leaf 4 (Figure 3.9).

On leaf 4, the earliest applications (at GS 31) gave better disease control with Ensign and Fortress giving the best results, though these were not significantly different from Tern. (Figure 3.9). Application at GS 32 or later had little effect on mildew on leaf 4. On leaf 3, all products at all timings, except Unix + Tern at GS 31, reduced mildew. The optimum timing on this leaf layer for Opus, Ensign and Tern was GS 32, but Fortress was more effective at GS 31 application timing. The optimum timing for Fortress, Unix and Tern on leaf 2, was GS 33, whereas Ensign gave good control at both GS 32 and GS 33. Ensign was the only fungicide for which a single application could match the two-spray Opus Team standard treatment. On the flag leaves, Ensign and Fortress were effective at GS 32, GS 33 or GS 39, whereas all other fungicides were markedly more effective applied at GS 39 than at the earlier timings.

Stagonospora (Septoria) nodorum was also present in the crop from June onwards and developed rapidly. There was over 35% infection of flag leaves by 21 July. The two-spray programme of Opus Team gave good control on each of the top three leaves (Figure 3.7). On leaf 3, Opus and Unix gave the greatest reduction in the disease, although Tern at GS 33 and Ensign at GS 32 also gave good control. Opus at GS 33 or GS 39, Ensign at GS 39 and Unix + Tern at GS 31 gave best control on leaf 2, and on the flag leaves Opus at GS 39 was clearly superior to all other treatments, and was almost as effective as the two-spray programme of Opus Team.

The two-spray standard treatment of Opus Team gave a yield increase of 1.28 t/ha over the untreated yield of 6.09 t/ha (Figure 3.10). The greatest yield increases from single applications were from Ensign at GS 32 and GS 33, which gave increases of 1.06 and 1.05 t/ha respectively. Fortress at GS 31 and Unix at GS 39 also gave increases in the order of 1.0 t/ha.

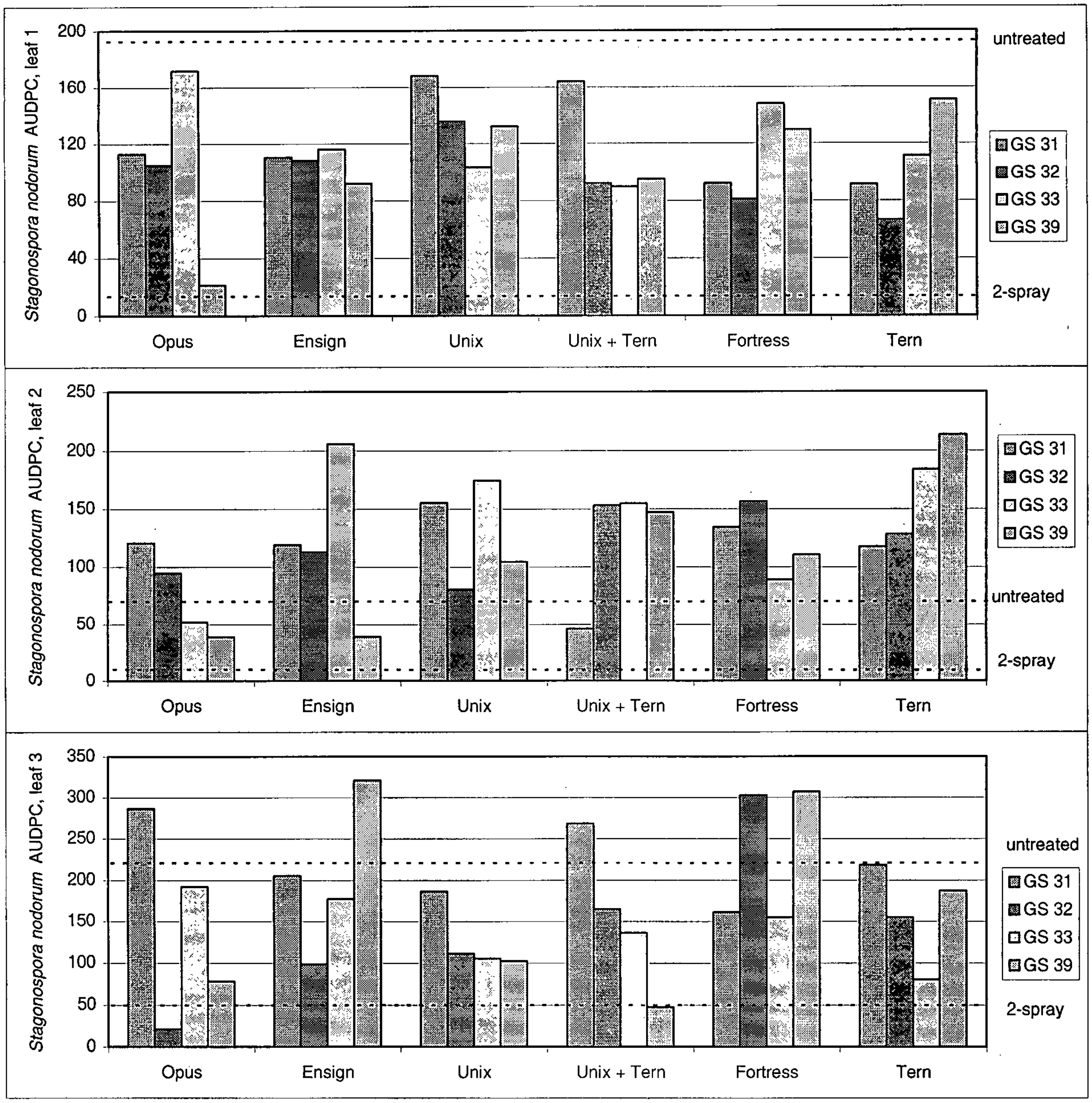


Figure 3.7. Effect of treatments on *Stagonospora nodorum* AUDPC, ADAS Arthur Rickwood 1997.

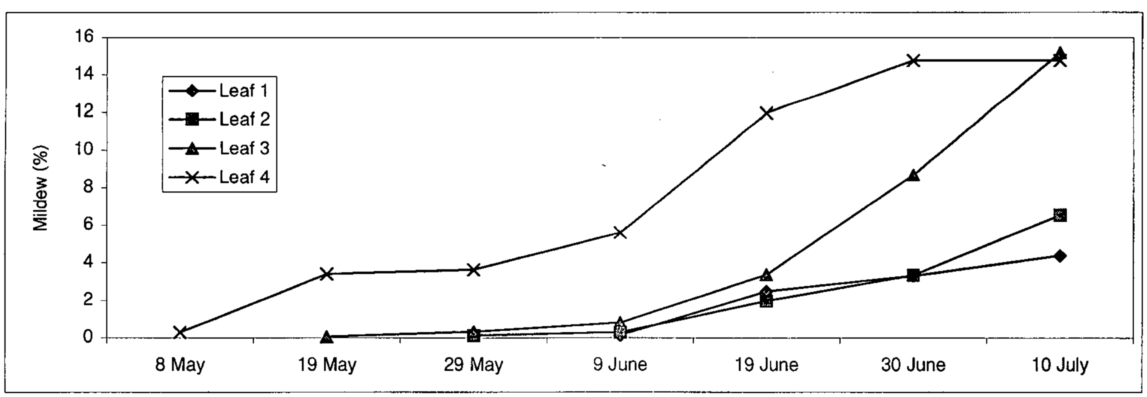


Figure 3.8. Mildew development in untreated wheat plots, ADAS Arthur Rickwood 1997.

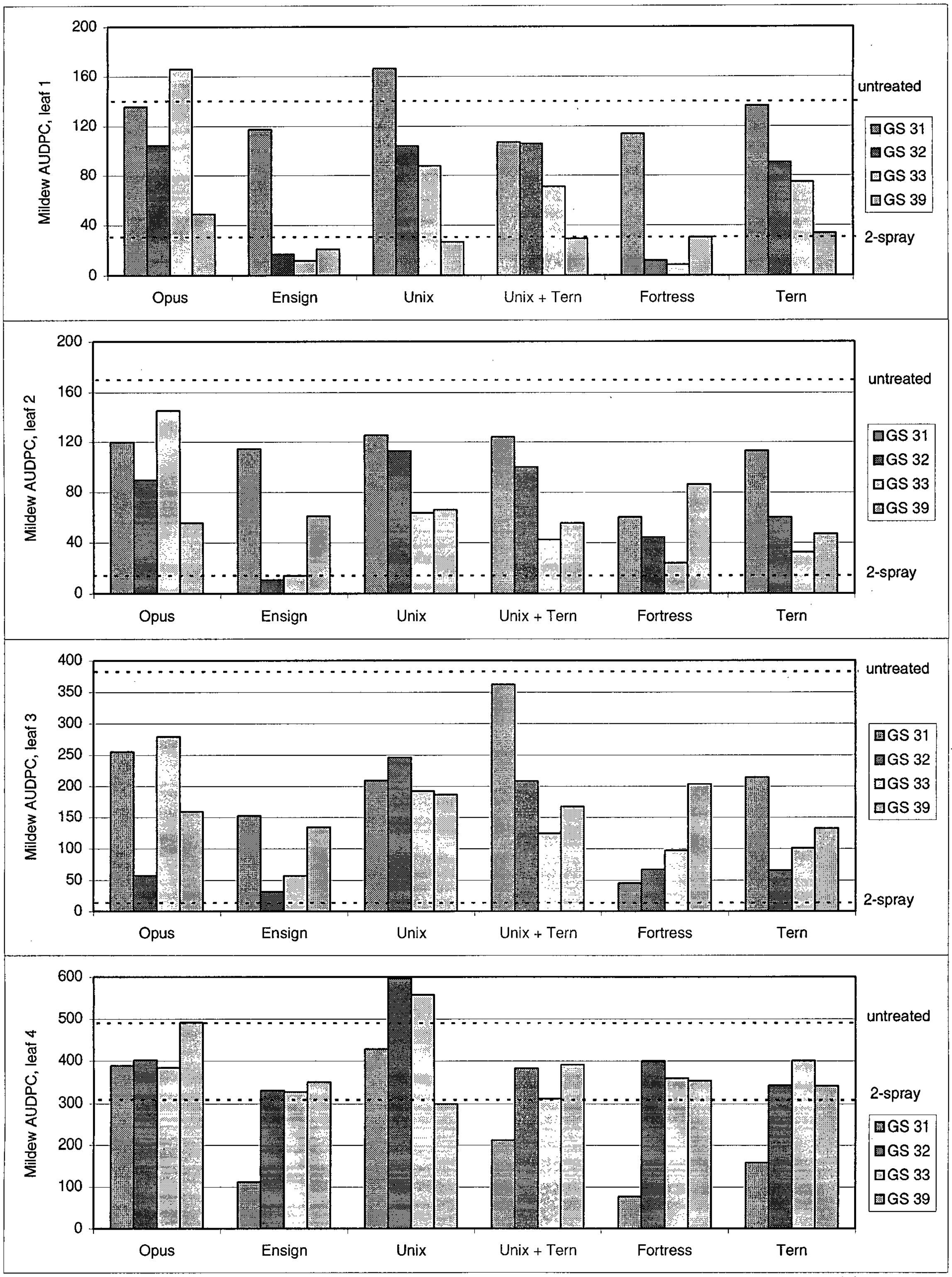


Figure 3.9. Effect of treatments on mildew AUDPC, ADAS Arthur Rickwood 1997.

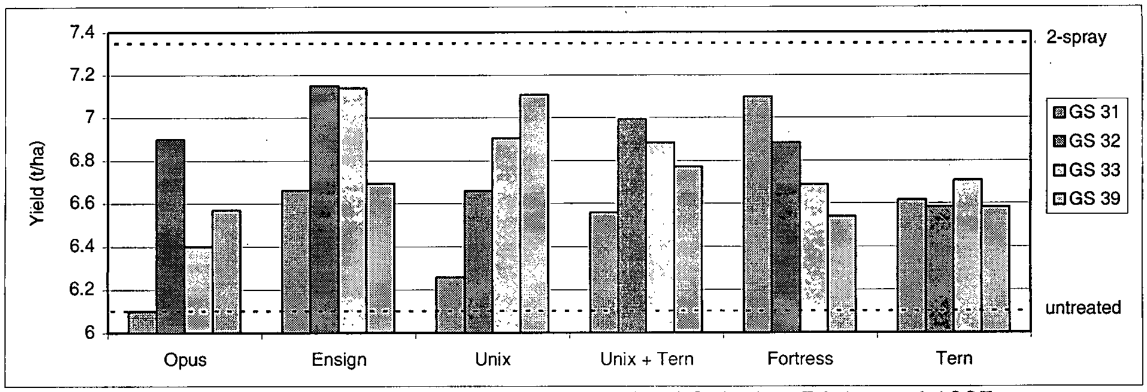


Figure 3.10. Effect of treatments on wheat yield, ADAS Arthur Rickwood 1997.

At SAC Aberdeen in 1997, mildew levels remained low, with a maximum of 9% on leaf 2 on 14 July (Figure 3.11). Mildew levels on leaf 3 reached 7% by early July. The optimum timing for control on this leaf layer was GS 33 which was the most effective timing for all products except Ensign, which controlled mildew best when applied at GS 32, and Unix, which gave very poor control at any timing (Figure 3.12). On leaf 2, the fungicides applied at GS 33 gave best disease control, except for Fortress, which was the most effective fungicide and gave best results following GS 32 application. Ensign also performed well at GS 32 . On the flag leaves, all fungicides reduced mildew, but the most effective treatments were Ensign and Fortress at GS 32 or GS 33. Opus and Unix gave better control when applied at GS 39 than at GS 33.

Septoria tritici was also present in the crop. On leaf 3 Opus was the most effective fungicide at all timings except GS 39, and was significantly better than all products except Unix + Tern (Figure 3.13). There was a similar trend on leaf 2, with best control from Opus at GS 32 or GS 33. Ensign at GS 33 was the most effective treatment on the flag leaves, followed by Opus at GS 33. Among the other fungicides, Fortress and Unix showed little activity, but Tern did give a consistent reduction in *S. tritici* on the flag leaves and, from GS 32 or GS 33 application, on leaf 2.

All treatments significantly improved yield over the untreated of 4.48 t/ha (Figure 3.14). The best response was from Unix applied at GS 39, which gave a yield of 6.07 t/ha, in excess of the Opus Team two-spray programme, which gave 5.72 t/ha. Opus applied at GS 33 or GS 39 also performed well, as did Ensign at GS 32.

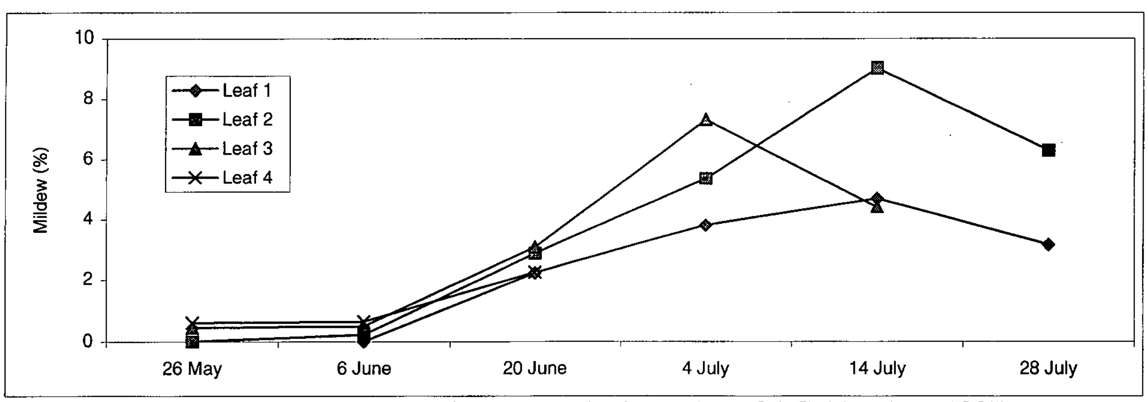


Figure 3.11. Mildew development in untreated wheat plots, SAC Aberdeen 1997.

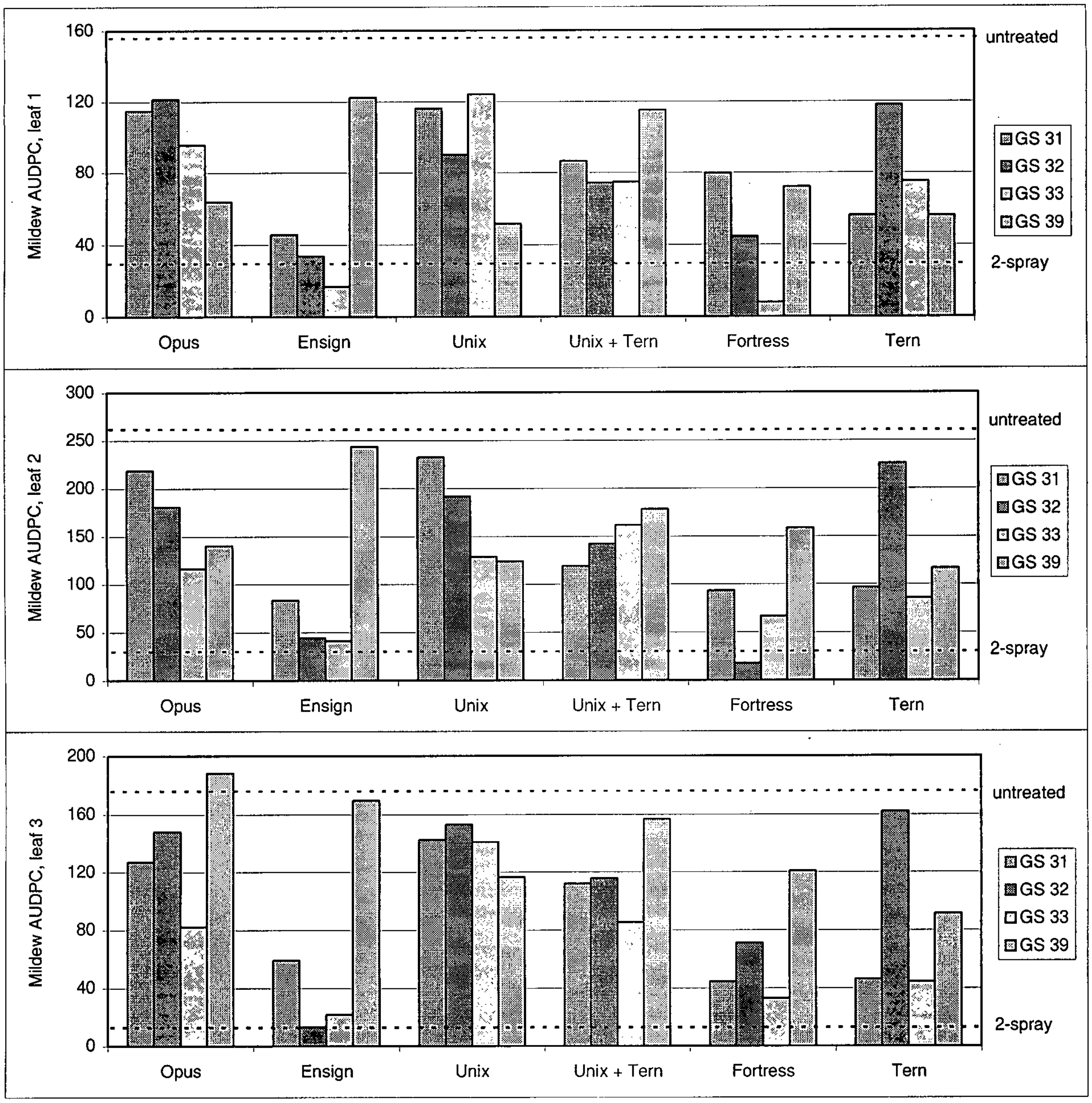


Figure 3.12. Effect of treatments on mildew AUDPC, SAC Aberdeen 1997.

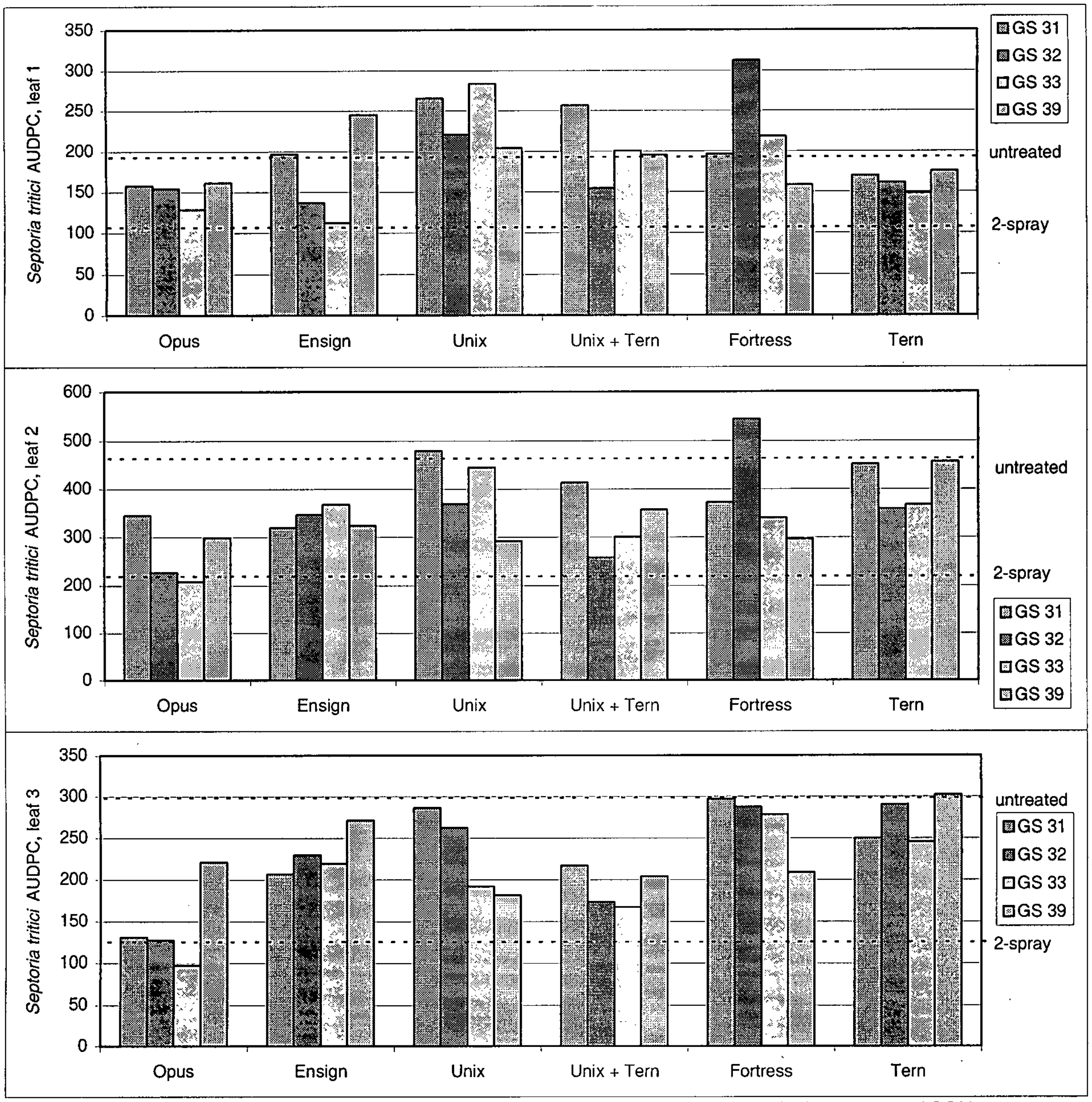


Figure 3.13. Effect of treatments on *Septoria tritici* AUDPC, SAC Aberdeen 1997.

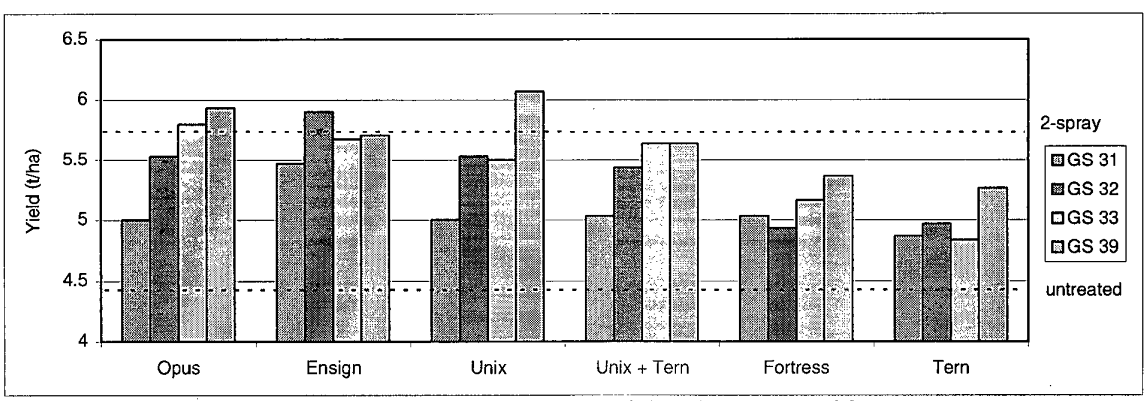


Figure 3.14. Effect of treatments on wheat yield, SAC Aberdeen 1997.

In 1998, mildew developed rapidly in untreated plots at ADAS Arthur Rickwood, reaching almost 30% on leaves 3 and 4 by the beginning of June (Figure 3.15). Leaves 1 and 2 were also affected, with a peak of 8% and 14% respectively on these leaves.

On leaf 4, Landmark, Ensign and Fortress, when applied at GS 31, gave over 90% control of mildew (Figure 3.16). In contrast, the two-spray Opus Team standard gave only 55% control. Single sprays of Landmark, Ensign, Neon or Tern at GS 33 or GS 39 were comparable with the two-spray Opus Team treatment, as was nix at any timing. However, Fortress at GS 33 or GS 39 was less effective than the Opus Team treatment. Control of mildew on leaf 3 was less poorer than on leaf 4. All products reduced disease levels when compared to the untreated crop. Fortress at GS 31 gave the greatest reduction in mildew, followed by two-spray programmes of Landmark or Tern. On leaf 2, a single application applied at GS 33 gave best control for all fungicides except Fortress which performed best when applied twice, at GS 31 + GS 39. All applications of Landmark were more effective than the two-spray Opus Team control. The best mildew control on the flag leaf was given by Landmark and Ensign, but all single applications at GS 33 or GS 39 were more effective than the two-spray Opus Team standard, with the exceptions of Neon and Tern at GS 33.

Septoria tritici and *S. nodorum* were also present in the trial at ADAS Arthur Rickwood, although levels of the latter only reached 5% on the flag leaf. Brown rust was also seen to rapidly increase in severity late in the season, and reached 15% and 19% on leaves 1 and 2 respectively.

Brown rust on each of the top two leaves was controlled very well by Landmark at GS 33 or GS 39, and with good control also from Ensign and Neon and, to a lesser extent, Tern (Figure 3.17). Unix and Fortress had very little effect.

Landmark gave the greatest green area retention on leaves 1–4 at Arthur Rickwood following GS 33 and GS 31 + GS 39 applications. These effects were most pronounced on leaves 2 and 3 (Figure 3.18). Ensign was also effective at these timings, but Fortress and Unix were not as effective as the other products at retaining green area towards the end of the season.

The untreated yield at ADAS Arthur Rickwood was 5.44 t/ha (Figure 3.19). All treatments increased yield, with the two applications of Landmark giving the highest yield at 8.41 t/ha. The two-spray Opus Team standard yielded 7.49 t/ha, and the only other treatments to give yields above this were the GS 33 and GS 39 timings of Landmark and the two-spray programme of Ensign. For each of the other four fungicides, a single application at GS 33 gave a yield increase which was comparable with the two-spray programme of that fungicide.

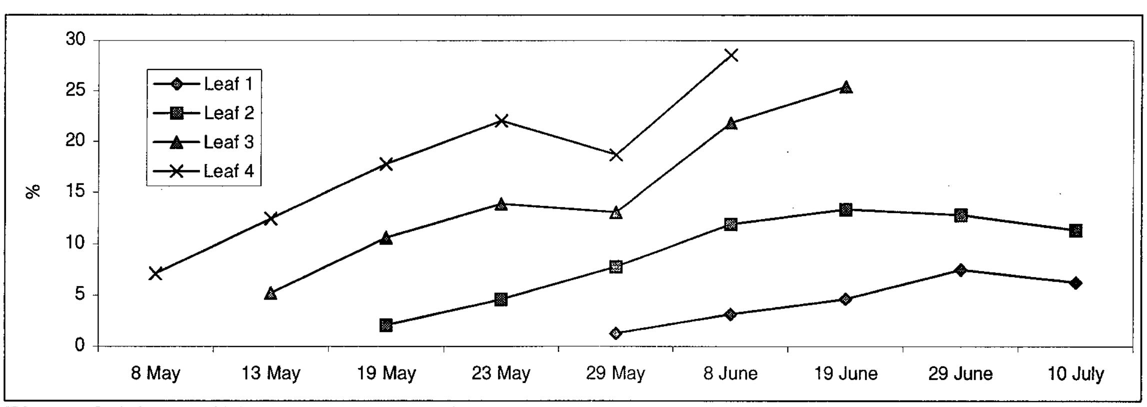


Figure 3.15. Mildew development in untreated wheat plots, ADAS Arthur Rickwood 1998.

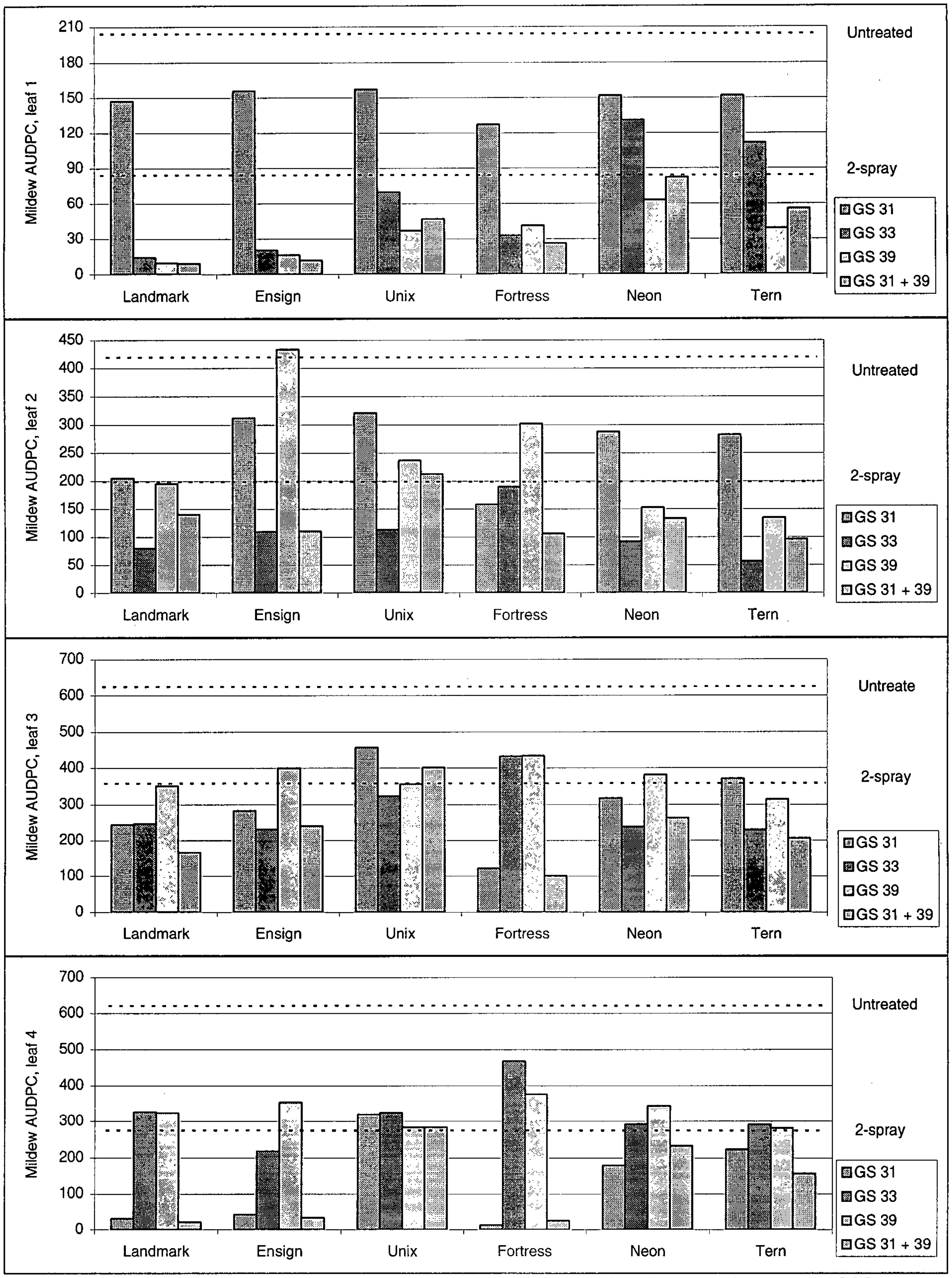


Figure 3.16. Effect of treatments on mildew AUDPC, ADAS Arthur Rickwood 1998.

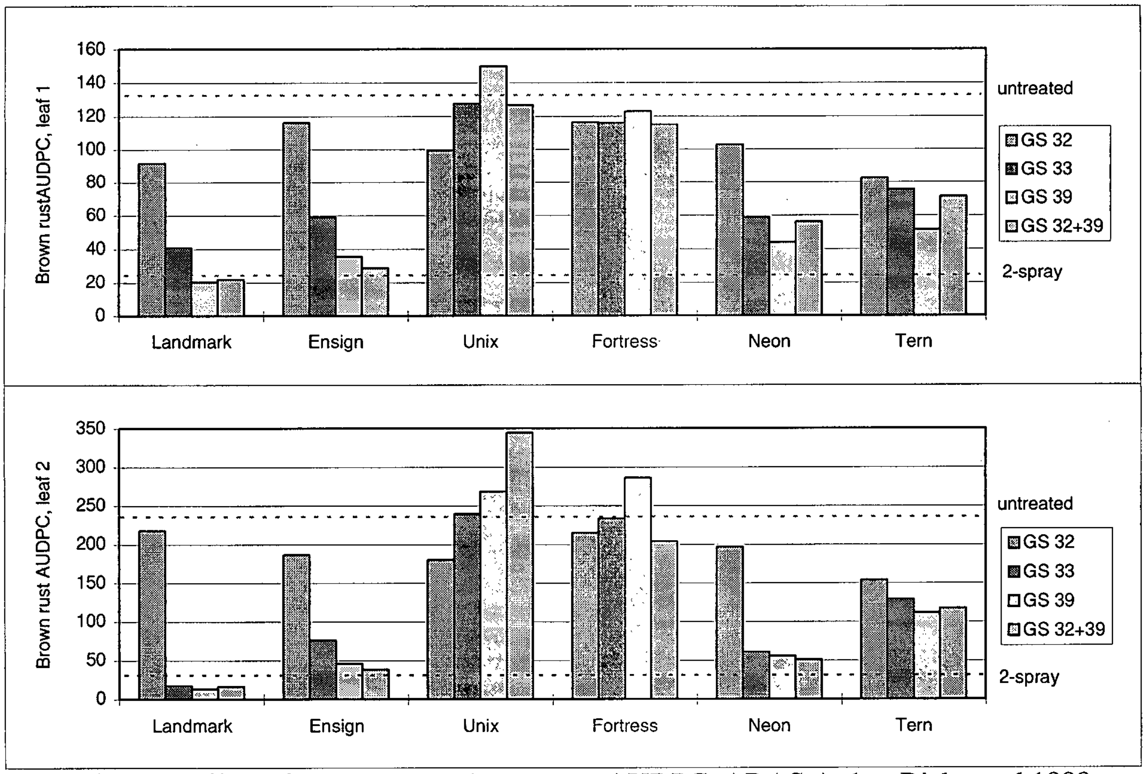


Figure 3.17. Effect of treatments on brown rust AUDPC, ADAS Arthur Rickwood 1998.

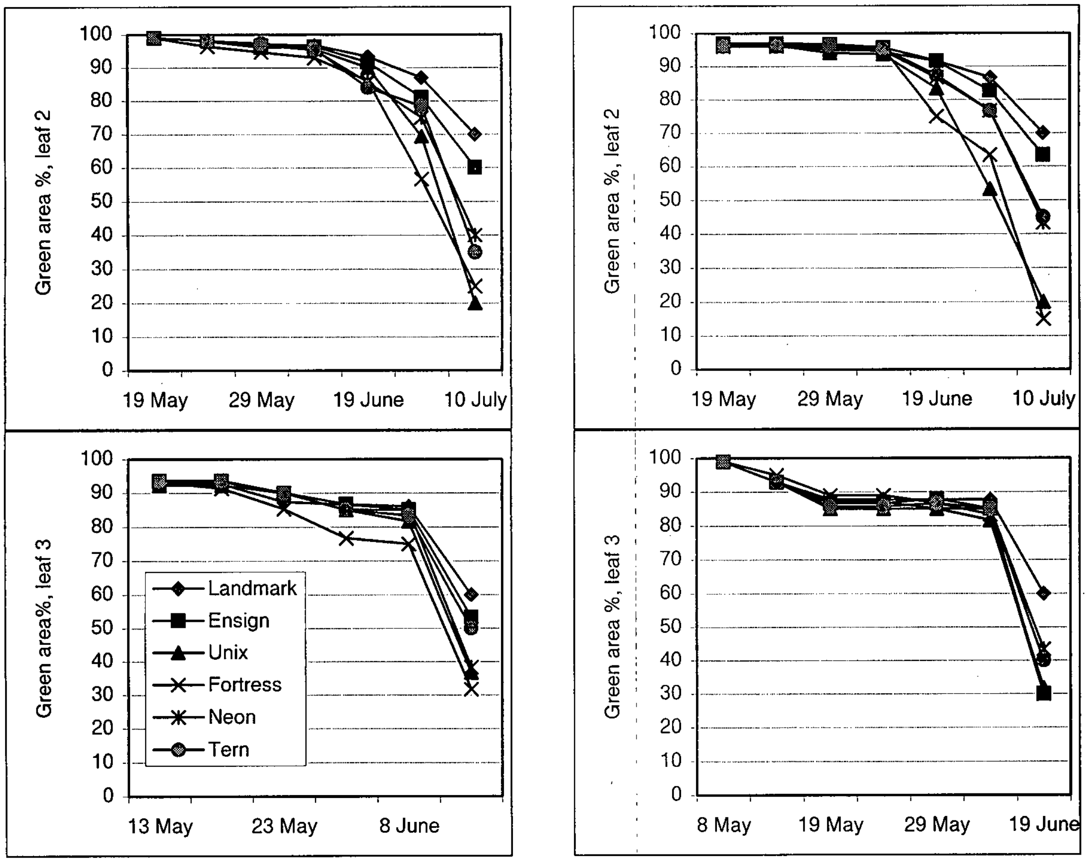


Figure 3.18 Effect of GS 33 treatments (left) and GS 31+39 programmes (right) on green leaf area, ADAS Arthur Rickwood 1998.

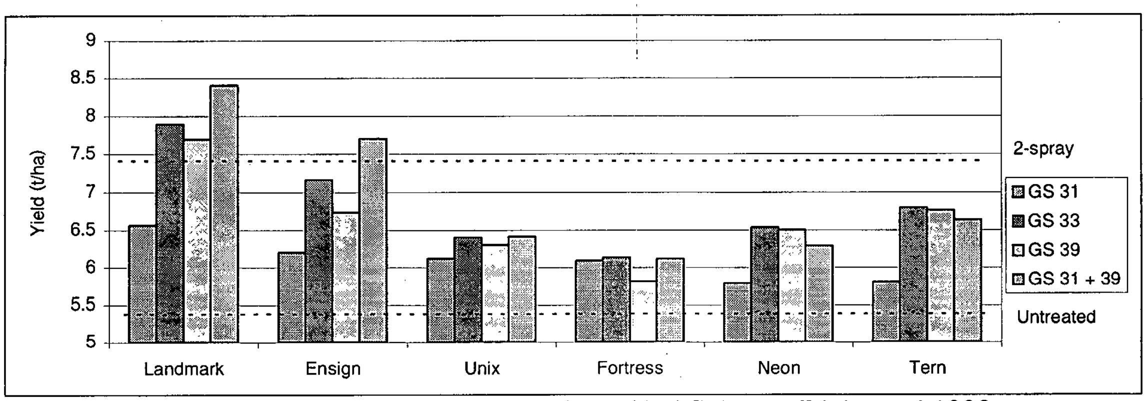


Figure 3.19. Effect of treatments on wheat yield, ADAS Arthur Rickwood 1998.

At SAC Aberdeen in 1998, mildew and *Septoria tritici* were present in the trial crop from late May (Figures 3.20 and 3.21). The wet weather in June and July checked the progress of mildew development and it never reached above 7% on any leaf layer all season. The predominant disease was *S. tritici* which reached levels of almost 25% on leaf 3 by late July.

Mildew levels on leaf 4 and on the flag leaves were particularly low, with no clear effects of treatments. On leaf 3, there was a clear effect of fungicide timing, with GS 31 applications being more effective than other single applications (Figure 3.22). For Landmark, Ensign and

Unix and, to a lesser extent, Unix, the GS 31 application gave good control, comparable with the two-spray programme of that fungicide. Neon and Tern gave good control when applied as a two-spray programme, but single applications of these fungicides were less effective. On leaf 2, the pattern was similar, with best control from Landmark, Ensign and Fortress at GS 31. GS 33 applications of the same fungicides were much less effective.

Landmark at GS 33 or GS 39 gave good control of *Septoria tritici* on the top two leaves, and Ensign gave partial control, but other fungicides had little effect.

Effects on green canopy retention were most evident on leaf 2, with Landmark and Ensign showing greatest retention of green area into August (Figure 3.23).

The highest yield of 6.18 t/ha was given by Landmark at GS 33, compared with an untreated yield of 4.70 t/ha (Figure 3.24). This was higher than the two-spray Opus Team standard (5.99 t/ha). Landmark, Ensign and Unix all gave yield increases from application at GS 33 or GS 39, whereas there was little effect on yield from Fortress, Neon or Tern.

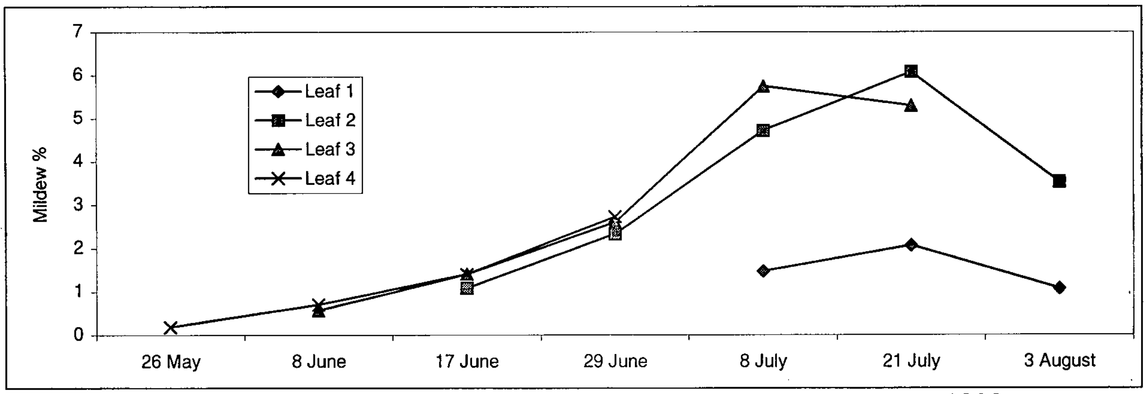


Figure 3.20. Mildew development in untreated wheat plots, SAC Aberdeen 1998.

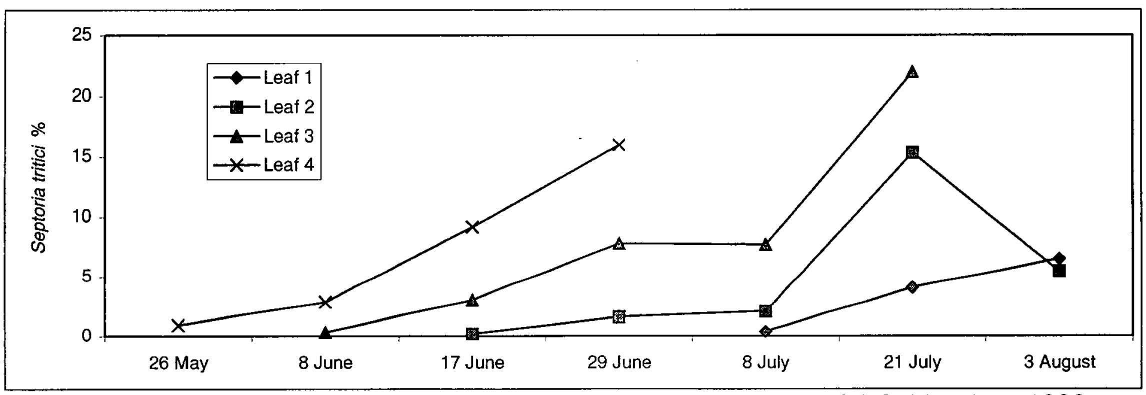


Figure 3.21. *Septoria tritici* development in untreated wheat plots, SAC Aberdeen 1998.

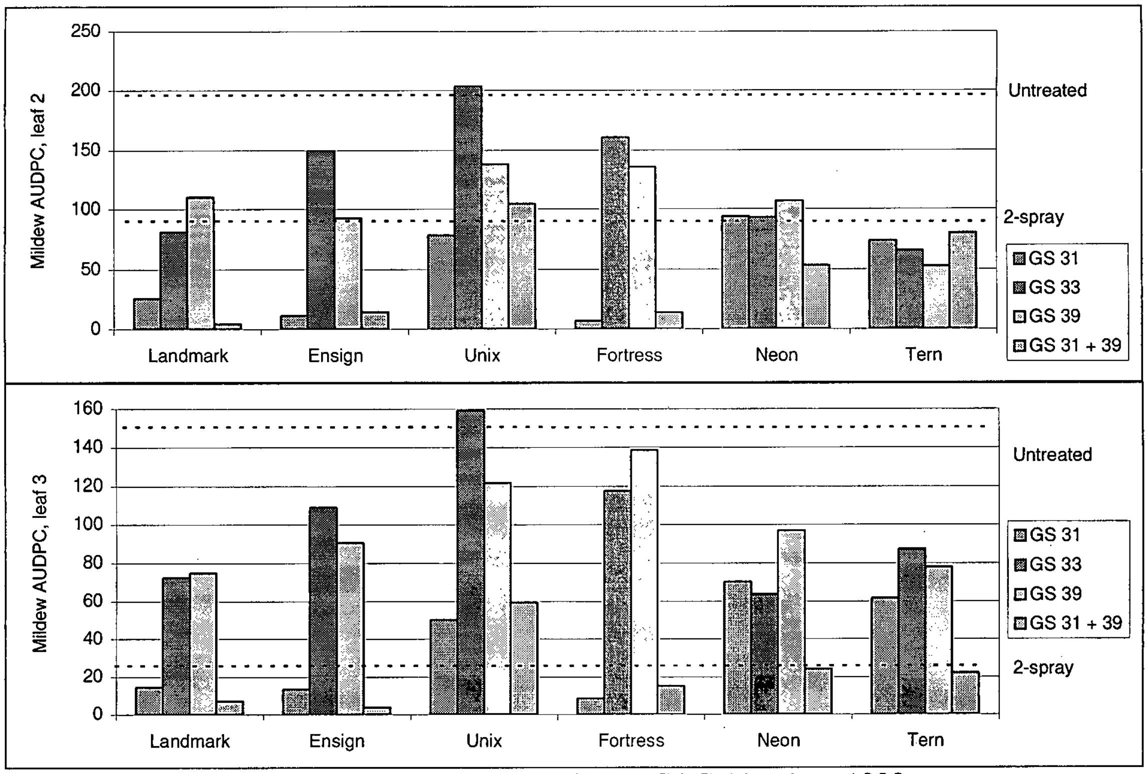


Figure 3.22. Effect of treatments on wheat mildew, SAC Aberdeen 1998.

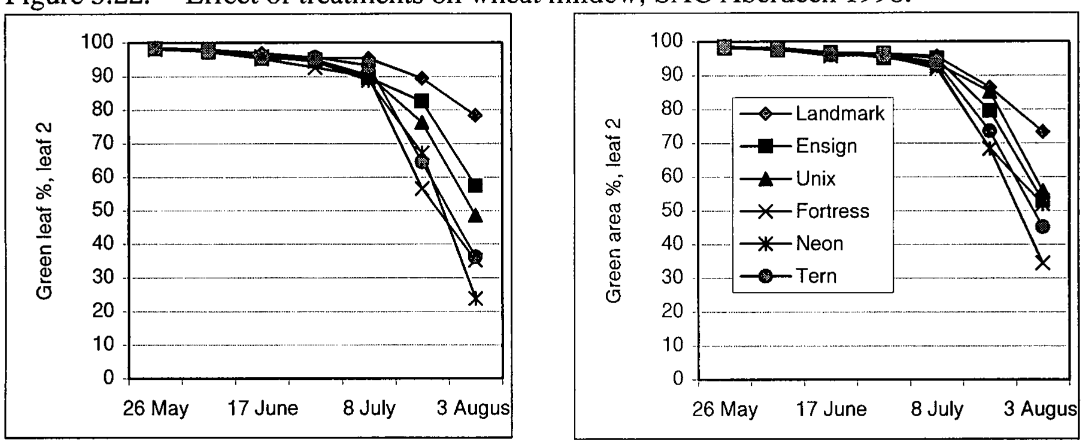


Figure 3.23 Effect of treatments on green leaf retention, SAC Aberdeen 1998: left: GS33; right: GS31 + 39

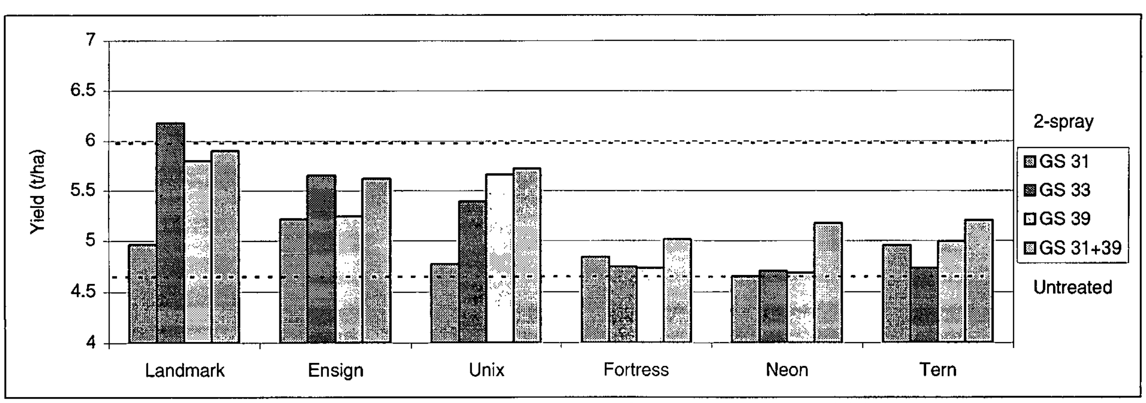


Figure 3.24. Effect of treatments on wheat yield, SAC Aberdeen 1998.

Sensitivity of pathogen isolates to morpholine fungicides

Significant differences in sensitivity to fenpropimorph were detected between the two sites (Table 3.1). The analysis of EC_{50} data revealed that isolates collected at the Aberdeen site were significantly less sensitive to fenpropimorph than isolates collected at Arthur Rickwood in both 1996 and 1997. The 1998 data for Arthur Rickwood suggests a decline in sensitivity from 1997 to 1998. Isolates were not significantly different in their sensitivity to fenpropidin, although isolates from Arthur Rickwood in 1996 and 1997 were marginally more sensitive than either those from Aberdeen in those years, or from Arthur Rickwood in 1998.

Table 3.1. Sensitivity of survey isolates to fenpropimorph based on mean EC_{50} values in g l^{-1} from the two trial sites 1996 - 1998

Isolate source	1996 f/morph	1996 f/din	1997 f/morph	1997 f/din	1998 f/morph	1998 f/din
Aberdeen	0.334	0.118	0.348	0.123	-	-
Arthur Rickwood	0.184	0.100	0.187	0.112	0.205	0.118
P	0.004	0.471	0.003	0.634		
SED	0.0341	0.0174	0.0350	0.0171		

To put the data in context, survey data gathered between 1993 and 1996, as part of an HGCA funded study (Project Report Number 143E) are presented in Table 3.2. There was a decline in the mean sensitivity to fenpropimorph from season to season, with a significant decrease ($P \leq 0.001$) in sensitivity between 1994 and 1995. This shift in the mean sensitivity of isolates was continued into the first year of the trials reported here (1996), so that the isolates from the trial are within the range of sensitivity detected in the preceding season as part of a more general survey. Sensitivity to fenpropidin, on the other hand, remained steady, with no significant shifts between seasons, and the sensitivity in the current experiments lies within the range detected in previous years.

Table 3.2. Sensitivity to fenpropimorph and fenpropidin of isolates of powdery mildew collected from 1993 to 1996

	Sensitivity: mean EC_{50} (g l^{-1})	
Year	Fenpropidin	Fenpropimorph
1993	0.113	0.167
1994	0.105	0.185
1995	missing	0.327
1996	0.110	0.334*
	$P = 0.628$	$P \leq 0.001$

* this mean is for Scottish isolates only since the preceding years are also Scottish data. Mean including English data = 0.266

4. WINTER BARLEY

Mildew and brown rust (ADAS Rosemaund)

In 1996, mildew levels were relatively low, although there was some late development, mainly on leaves 2 and 3 (Figure 4.1). There were large variations in mildew development on leaf 2 following fungicide application (Figure 4.2). Opus and Unix applied on 2 May provided comparable control to the two-spray standard. Sanction applied on 2 May was rather less effective than Opus applied on 2 May but more effective than Opus applied on 22 April. Sanction applied on either 11 or 22 April had little effect on mildew on leaf 2.

On leaf 4, single early timings showed smaller AUDPC values for mildew than the two-spray standard with 11 April timing giving lowest disease severity (Figure 4.4). There were no significant differences between fungicides or interactions with timings. Treatments applied at GS 33 or GS 39 had limited effect on mildew on leaf 4. Mildew on leaf 3 was controlled most effectively by the 2 May timings (GS 33). Treatment timings and fungicide product differences were significant and interactions were also detected. Sanction was less effective than other treatments when averaged over all timings. HGCA6 gave good control on leaf 3 from a GS 31 timing. Both treatment timings and product differences were also apparent for mildew control on leaf 2, but there were no interactions. The two late timings (GS 33 and GS 39) were most effective for all fungicides. On the flag leaf, the late spray (GS 39) was most effective timing, but useful control was still provided by the GS 33 treatments.

There were significant differences in yield between the different dates of spray application and between fungicides but no interaction between these factors (Figure 4.3). There was a progressive increase in yield with later spray timings from 1 April (8.27 t/ha) to 14 May (8.94 t/ha). The last single spray gave a yield comparable to the two-spray standard (8.98 t/ha), a response of 1.1 t/ha. All the new fungicides gave slightly higher yields than Sanction, but these differences were not all significant.

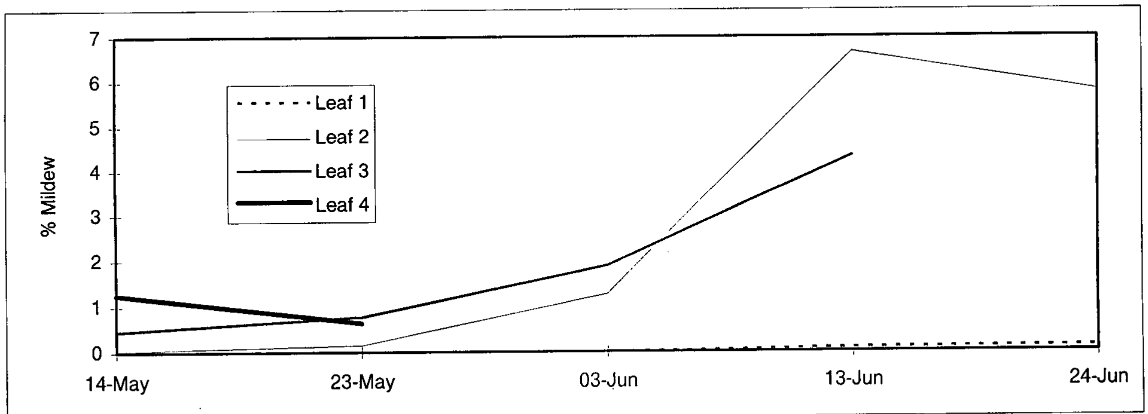


Figure 4.1. Mildew development in untreated barley plots, ADAS Rosemaund 1996.

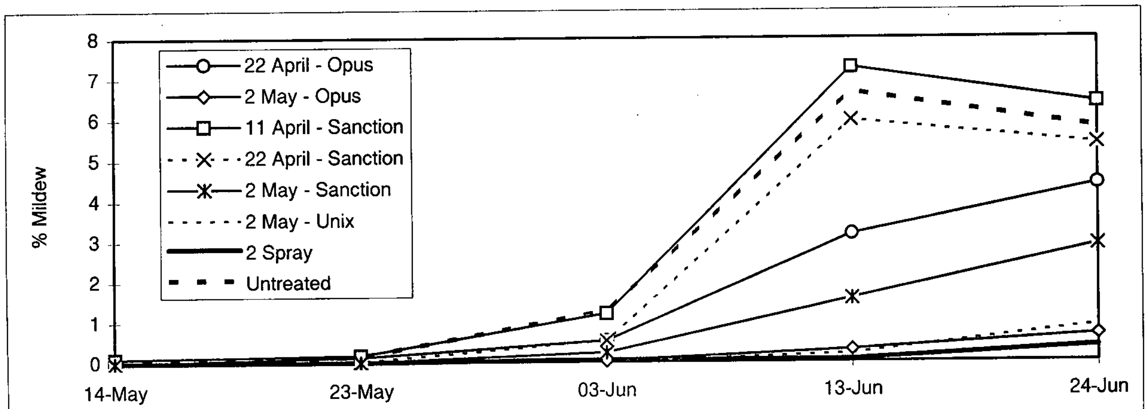


Figure 4.2. Barley mildew control by selected treatments, ADAS Rosemaund 1996.

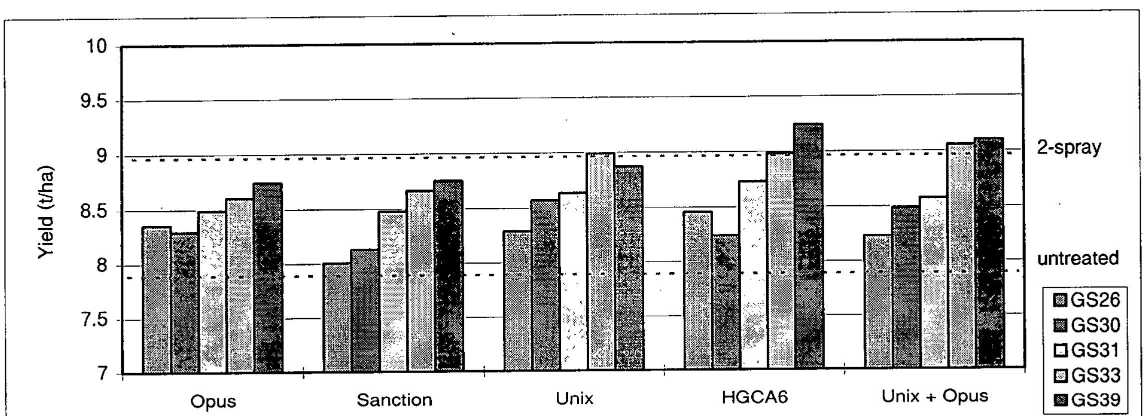


Figure 4.3. Effect of treatments on barley yield, ADAS Rosemaund 1996.

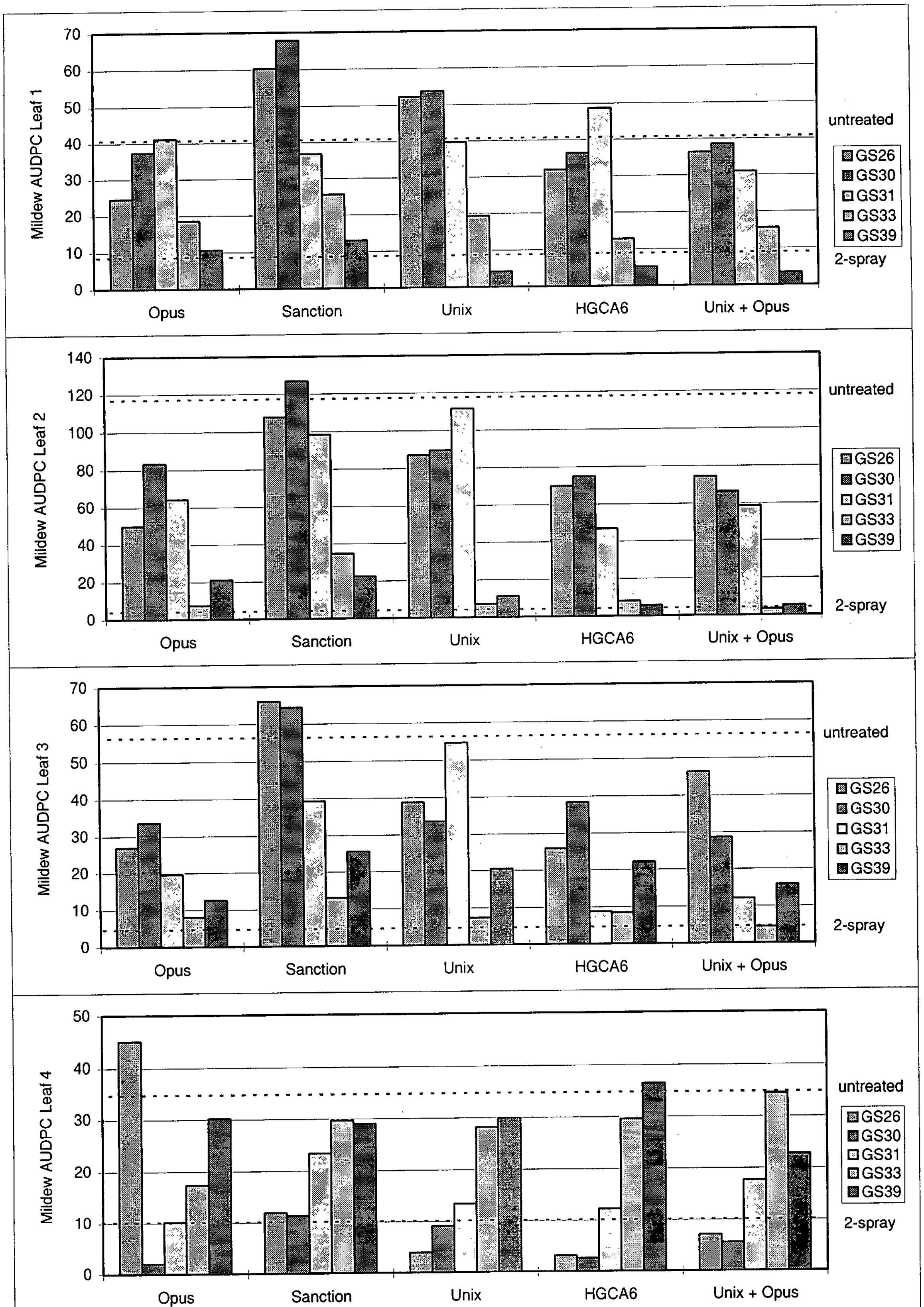


Figure 4.4. Effect of treatments on barley mildew AUDPC, ADAS Rosemaund 1996.

In 1997, mildew was the most important disease and it developed strongly on eventual leaves 2, 3 and 4 (peak severities 16.3%, 19.3% and 21.2% respectively) with some infection of the flag leaf (3.9% in untreated) (Figure 4.5). Traces of brown rust appeared on the upper three leaves.

Mildew developed most rapidly between April 22 and May 13 on leaves 3 and 4, and between May 13 and June 3 on leaf 2. On leaf 2, mildew was controlled by sprays applied on 13 May particularly Opus, Landmark and the two-spray standard. (Figure 4.6). Landmark provided excellent mildew control on leaf 2 from all 4 dates of application. Other fungicides showed larger differences between dates of application. For other leaf layers more obvious timing effects were apparent and there were clear trends favouring the earlier timings for leaf 4 and leaf 3 and favouring the latest timings on the flag leaf. The most effective single sprays gave comparable results to the two-spray standard.

Treatments substantially reduced mildew infection on the flag leaf (Figure 4.8). Highly significant effects of timing and fungicide were apparent and there was an interaction between these factors. Mildew control improved at later timings with AUDPC values ranging from 41.6 on 1 April to 10.7 on 13 May. The two-spray standard gave almost complete control. The outstanding fungicides were Landmark and Unix + Opus which were superior to Opus, Sanction and Amistar. Closer examination of mildew control by individual fungicides showed that Opus was very effective when applied on 2 or 13 May, compared with sprays on 1 or 22 April. Landmark was effective throughout. Unix was less effective on 2 May than either 22 April or 13 May, but was very effective in mixture with Opus at all three dates. Amistar appeared to be rather more effective on 22 April and 2 May than on 13 May.

On leaf 2, mildew control was very effective, and treatments reduced AUDPC values from 436 in the untreated to 98.5. Timing, fungicide and interactions between these two factors all showed highly significant effects. The two-spray standard was superior to single timings. The outstanding fungicide was Landmark, followed by Unix + Opus and Opus alone. Although all treatments and timing gave mildew control, the optimum timing varied between fungicides. The 2 May treatment was most effective for Opus and Sanction, 22 April for Unix and Amistar whilst Unix + Opus and Landmark were highly effective throughout from 22 April to 13 May, and comparable to the two-spray standard.

Mildew control on leaf 3 was slightly less effective than that recorded on leaf 2. The 13 May sprays were much less effective than other single applications and the two-spray standard. The fungicide rankings were similar to that seen on the top two leaves though the degree of control was rather poorer.

Timing effects were significant on leaf 4, but no fungicide differences were detected. The earliest timing on 1 April was most effective and mildew was progressively less well controlled by later sprays. The two-spray standard performed well under sustained mildew activity.

Treated yields averaged 0.70 t/ha more than the untreated control of 7.48 t/ha (Figure 4.7). There were significant responses to all the single spray timings compared with the untreated and the 2 May timing gave 0.34 t/ha lower yield than the two-spray standard. There were no significant differences between the mean yields at the individual spray dates. All fungicides increased yield, with highest yield from Landmark (8.37 t/ha) which was superior to Opus (8.08 t/ha) and Sanction (8.01 t/ha). There were no interactions between fungicide and timing elements.

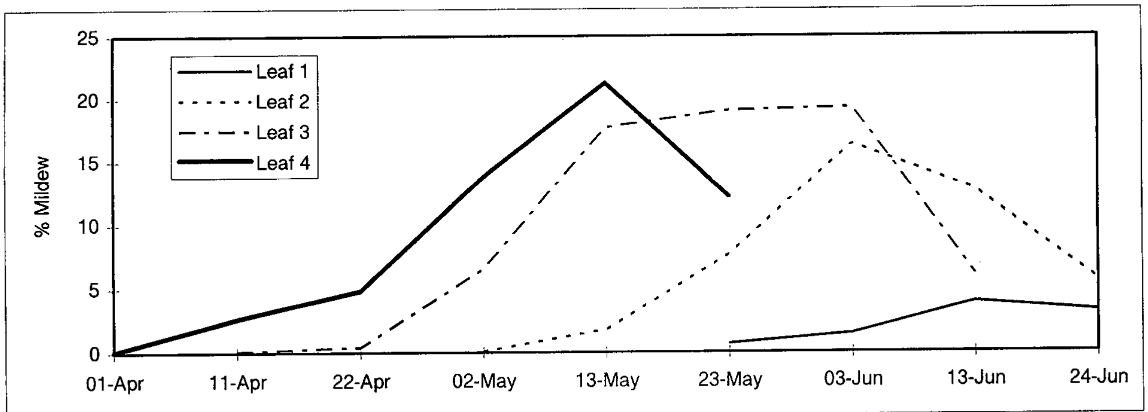


Figure 4.5. Mildew development in untreated barley plots, ADAS Rosemaund 1997.

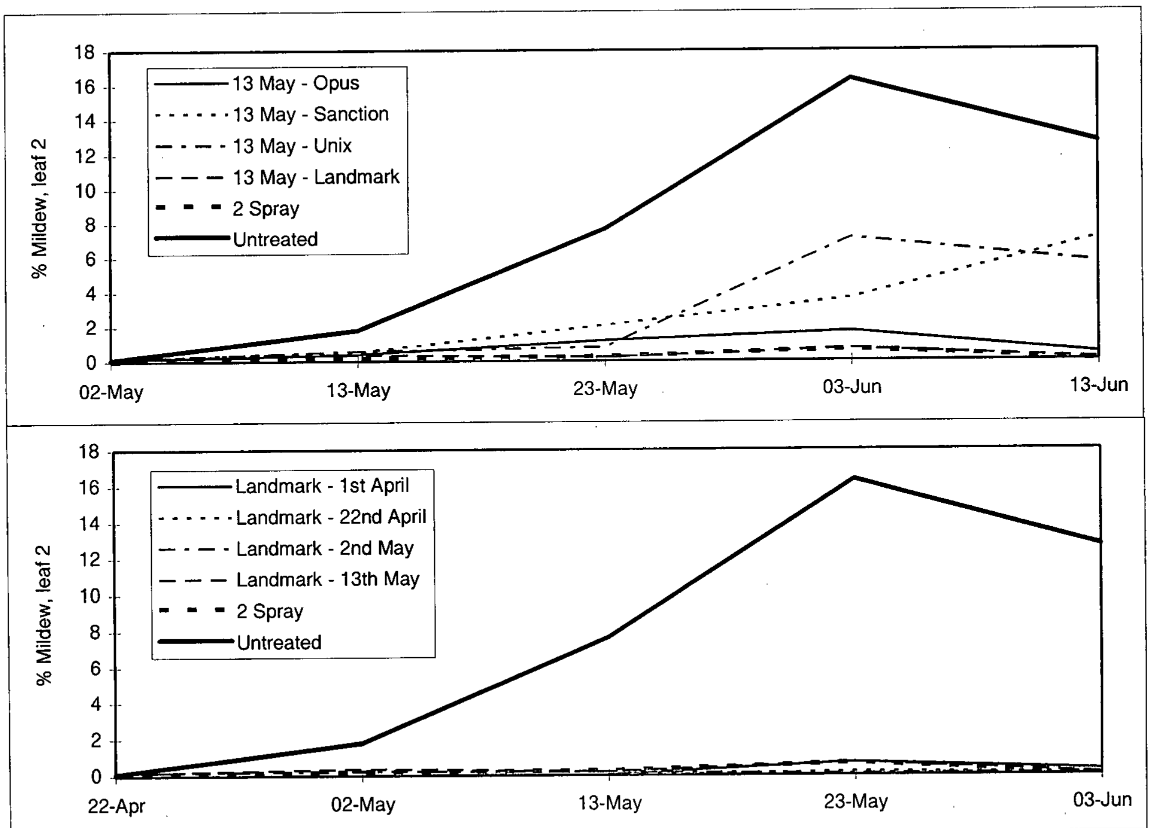


Figure 4.6. Effect of selected treatments on barley mildew, ADAS Rosemaund 1997.

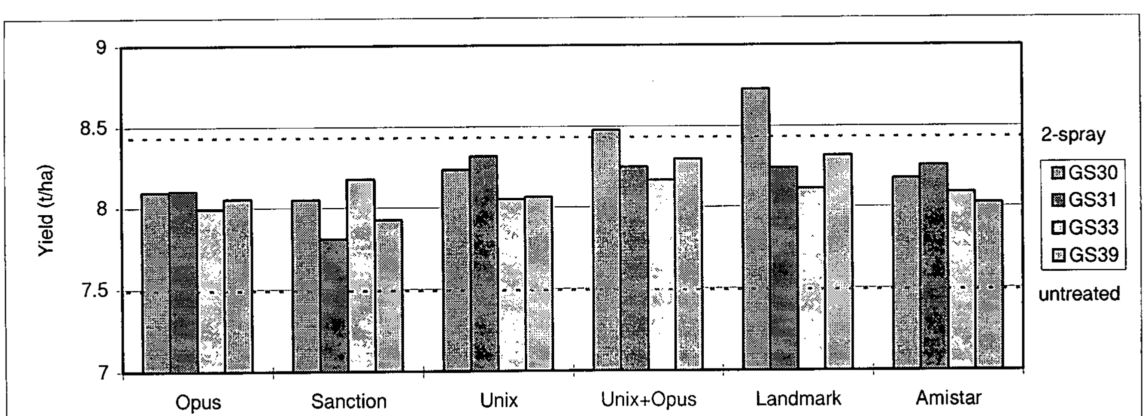


Figure 4.7. Effect of treatments on barley yield, ADAS Rosemaund 1997.

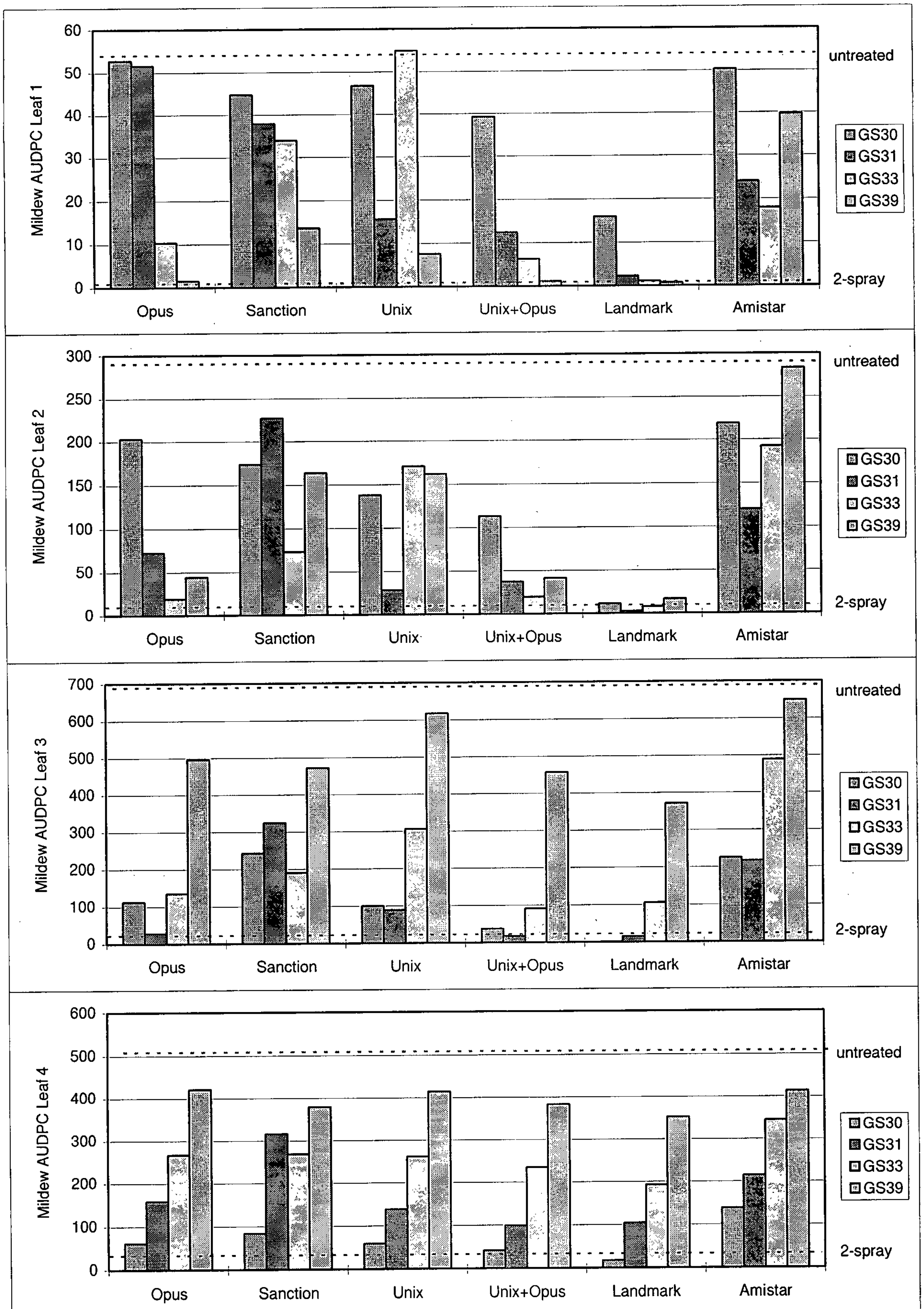


Figure 4.8. Effect of treatments on barley mildew AUDPC, ADAS Rosemaund 1997.

In 1998, mildew emerged as the prominent disease in early spring together with low levels of brown rust, net blotch and *Rhynchosporium* (Figure 4.9). As the season progressed, brown rust increased significantly and became the predominant disease from May onwards reaching 21.3% on the flag leaf and 10.8% on leaf 2 (Figure 4.10). Mildew affected up to 4.8% of the flag leaf and 3.0% of leaf 2 (Figure 4.9). Other diseases recorded were net blotch at up to 1.3% on leaf 3 and *Rhynchosporium* at 2.9% also on leaf 3.

Mildew on the flag leaf was well controlled by the final spray applied at GS 39 (9 May), particularly by Opus and Landmark and the two-spray standard of Sanction + Corbel. Averaged over all timings, Landmark was the most effective fungicide whereas Amistar was the least effective. There were highly significant differences between both timings and fungicides (but no interaction) for mildew control on the flag leaf. The untreated AUDPC value was 67.5 and this was reduced to 1.9 by the two-spray standard, 6.5 by the GS 39 timing and 4.0 by GS 31 + 39 sprays (Figure 4.12). Amistar gave partial control but was inferior to all other treatments.

Under low mildew pressure on leaf 2, the second spray at GS 32 was the most effective timing, and treatment with Landmark, Unix + Opus, Amistar + Opus and Neon + Opus all gave over 90% control. The poor control of mildew from Amistar was clearly apparent on leaf 2, though its control of brown rust was excellent and superior to Opus alone.

Brown rust on the flag leaves was reduced from 21.3% in untreated plots to 0.3% by two sprays of Amistar + Opus, 0.7% by Neon + Opus and 1.1% by Amistar alone. The two-spray standard of Sanction + Corbel also performed well (2.2% rust). There were large differences between spray timings with brown rust averaging 2.9% from GS 39 sprays, 8.4% from GS 32 sprays and 11.4% from GS 31 sprays. All products gave good control, as shown by AUDPC data, when applied as two-spray programmes, but differences were apparent between single applications at GS 39, with Unix + Opus being less effective than other sprays (Figure 4.14). Landmark, Amistar and Amistar + Opus were still effective from the GS 32 timing and even GS 31 sprays had some effect. Single applications of Amistar at GS 31 or GS 32 were more effective than comparable treatments with Opus, but this difference was not seen for GS 39 sprays or the two-spray programmes (Figure 4.13).

Amistar showed superior control of brown rust to Opus on leaf 2 (0.35% and 1.47% respectively) and was similar to Amistar + Opus (0.5%) and Neon + Opus (0.51%), when untreated infection was 10.8%. There was a clear advantage from all two-spray treatments compared with single applications at GS 32 or GS 39, the latter being too late for this leaf layer. The Sanction + Corbel standard performed well. Unix + Opus was inferior to other fungicides for brown rust control on leaf 2.

All fungicide treatments gave statistically significant yield increases over the untreated yield of 4.65 t/ha (Figure 4.11). Effects of both fungicide and timing were statistically significant, but the interaction was not. Two-spray programmes of all test fungicides gave yields greater than that of the Sanction + Corbel standard, by 0.89-1.50 t/ha. Among two-spray programmes, the highest yields were from Opus, Landmark, Amistar + Opus and Unix + Opus, within the range 7.75-7.89 t/ha. The highest yields from single sprays were from Landmark and Neon + Opus at GS 32, closely followed by all timings of Amistar + Opus and Amistar alone at GS 31.

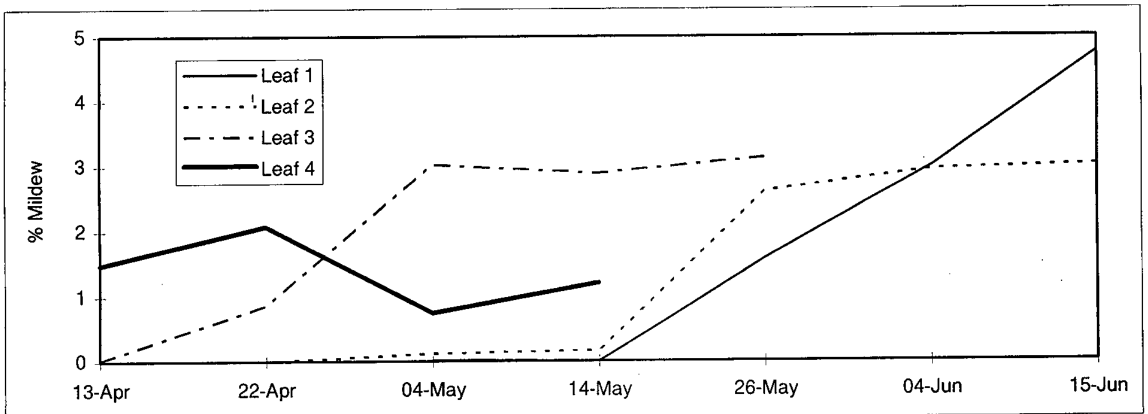


Figure 4.9. Mildew development in untreated barley plots, ADAS Rosemaund 1998.

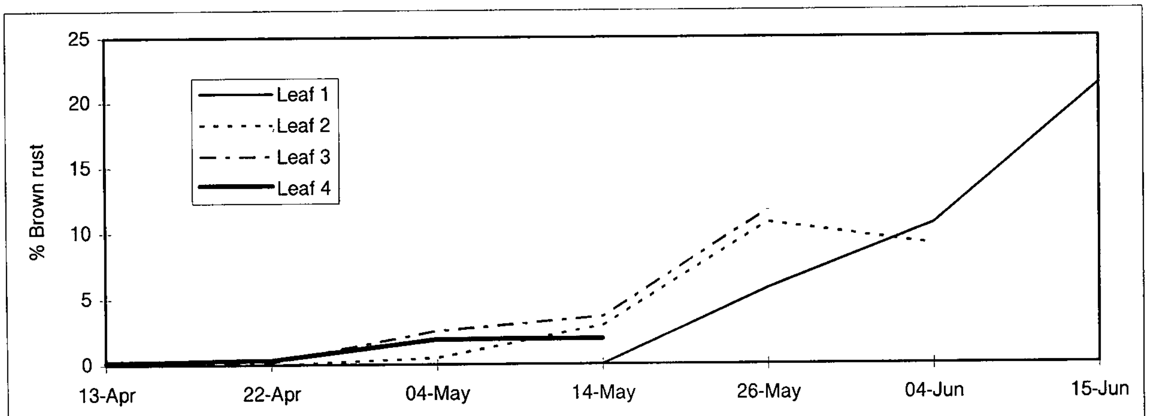


Figure 4.10. Brown rust development in untreated barley plots, ADAS Rosemaund 1998.

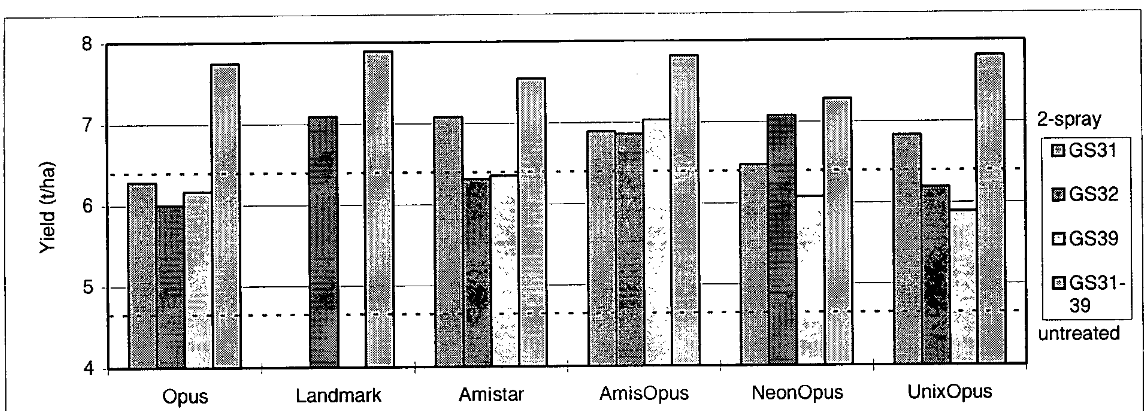


Figure 4.11. Effects of treatments on barley yield, ADAS Rosemaund 1998.
N.B. Single applications of Landmark at GS 31 and GS 39 were omitted

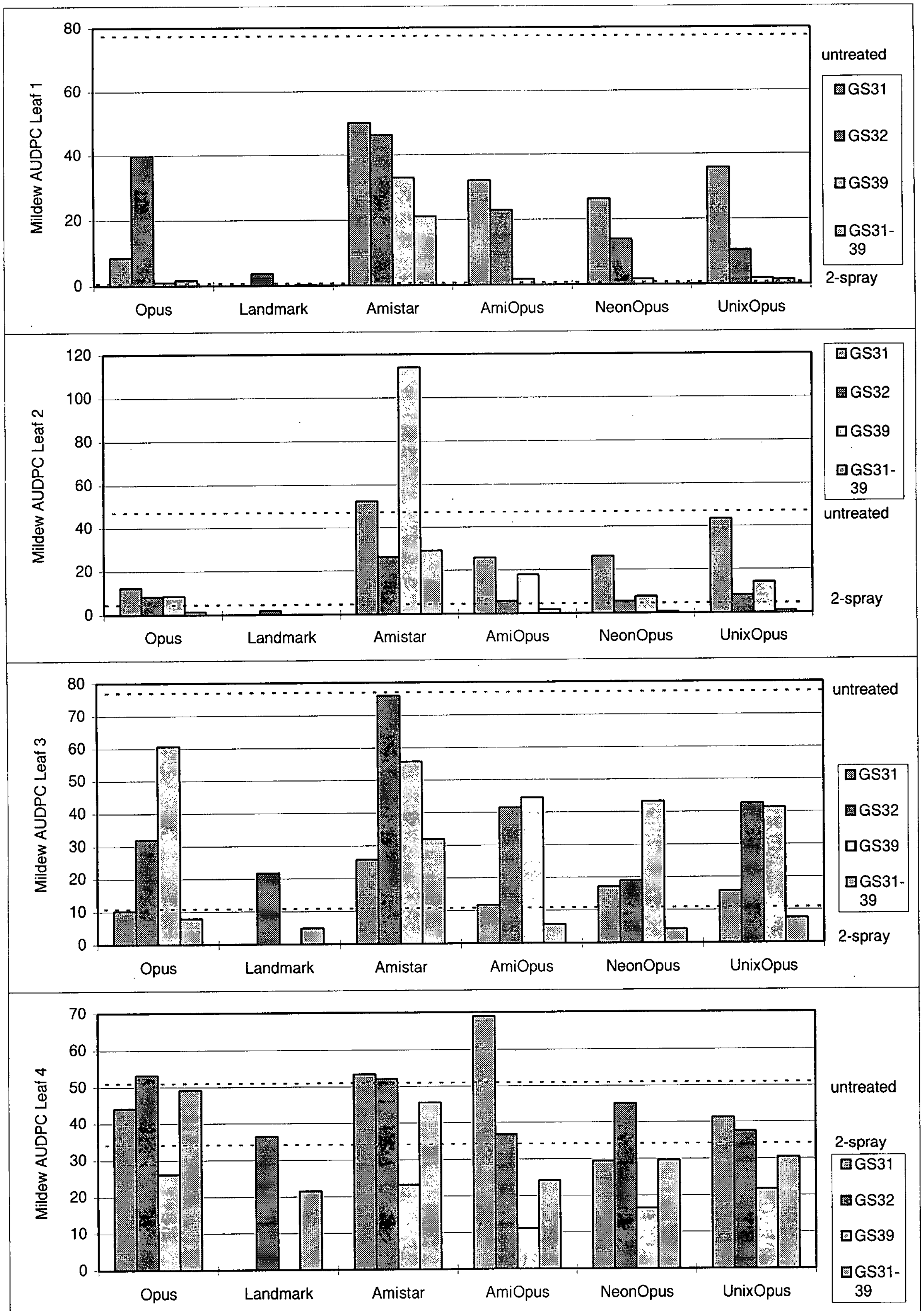


Figure 4.12. Effect of treatments on barley mildew AUDPC, ADAS Rosemaund 1998.
N.B. Single applications of Landmark at GS 31 and GS 39 were omitted

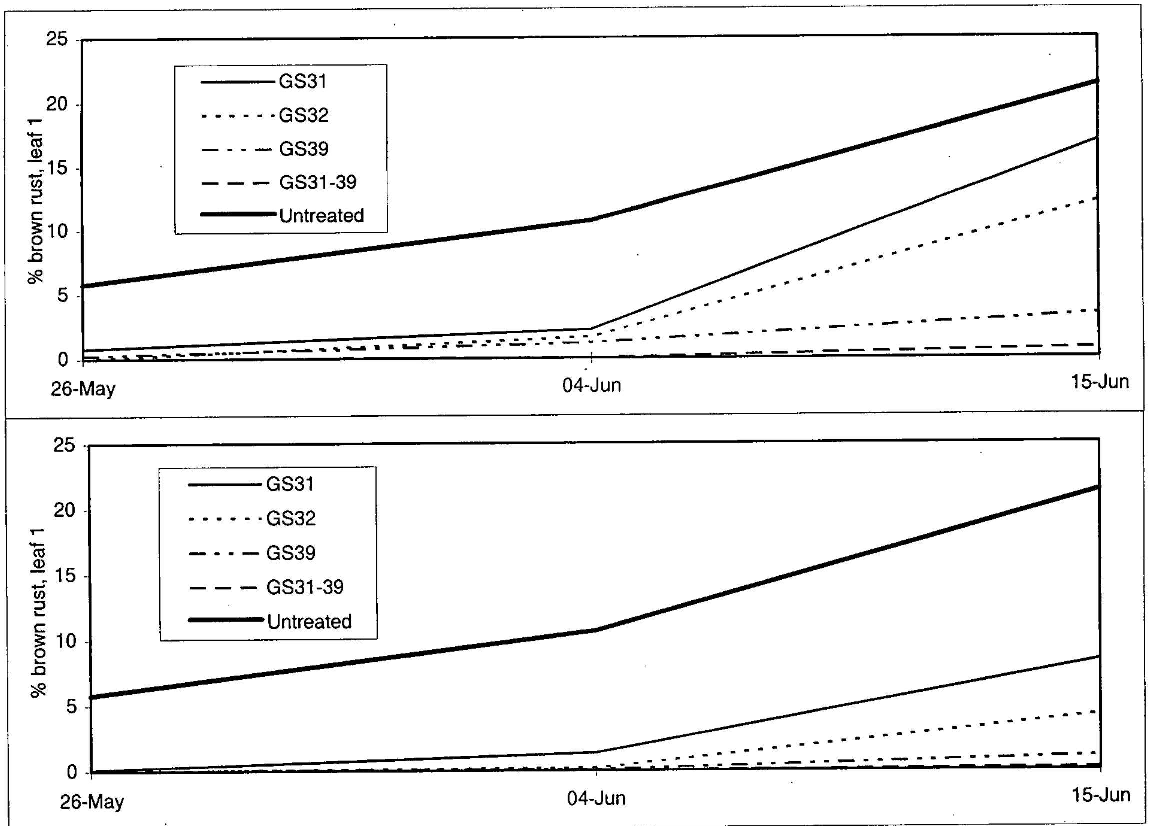


Figure 4.13. Brown rust development following application of Opus (above) or Amistar (below) at various growth stages, ADAS Rosemaund 1998.

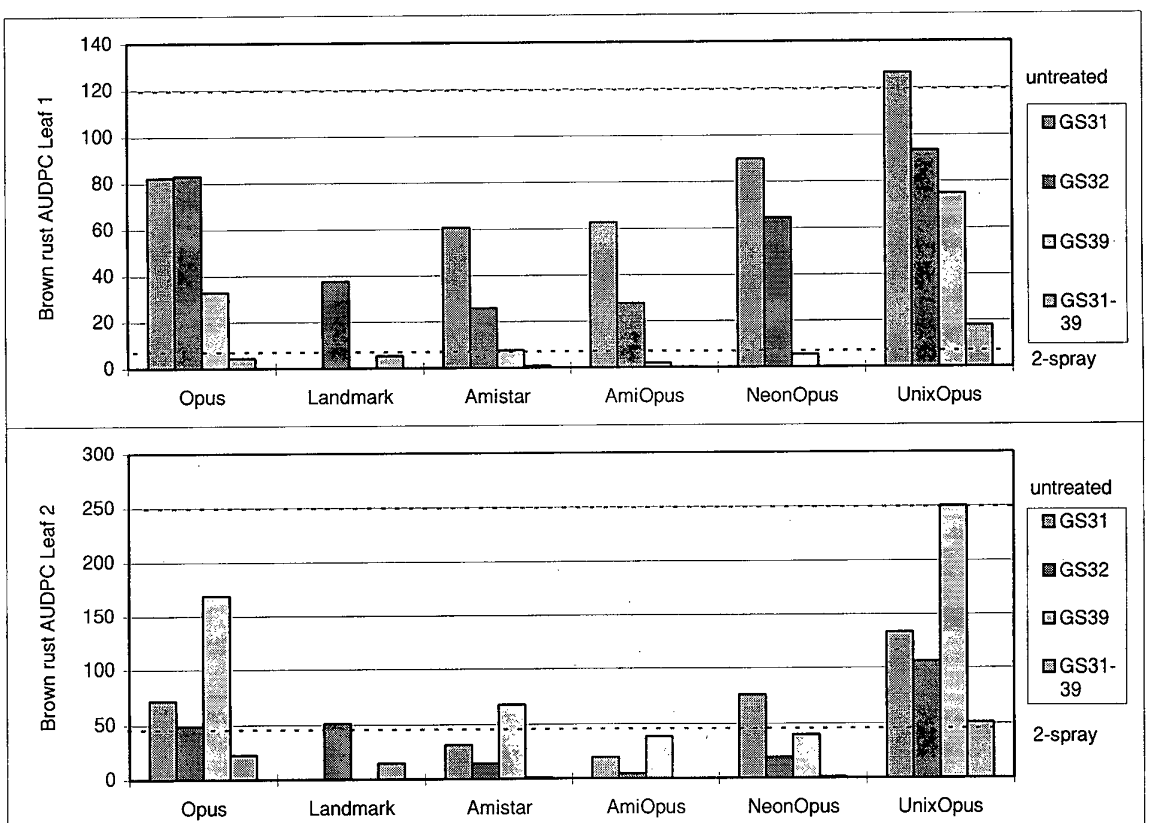


Figure 4.14. Effect of treatments on barley brown rust AUDPC, ADAS Rosemaund 1998. N.B. Single applications of Landmark at GS 31 and GS 39 were omitted.

Net blotch (Morley Research Centre)

In 1996, net blotch was well controlled on leaf 2 by 13 May sprays of Opus, and Unix + Opus offered a marginal improvement over the two-spray standard, Sanction and Unix. The advantage of the Unix + Opus mixture over Unix alone was also apparent on leaf 4 (Figure 4.16).

There were no significant differences between timings and fungicides for net blotch control on leaf 4 although most new fungicide treatments had lower AUDPC values than the two-spray standard (Figure 4.18). On leaf 3, there were strong effects of timings with later timings (April 22 and May 13) proving most effective. Several of the new fungicides looked promising in relation to the Sanction standard. Timing and treatment differences were apparent on leaf 2 where May sprays (GS 33 and GS 39) were most effective. Overall, new products gave rather better disease control than Sanction. Very little net blotch appeared on the flag leaf and treatment timing differences were not significant.

There were no significant effects of treatments on yield, and treated yields varied by only 0.1 t/ha from the untreated control of 6.58 t/ha (Figure 4.17).

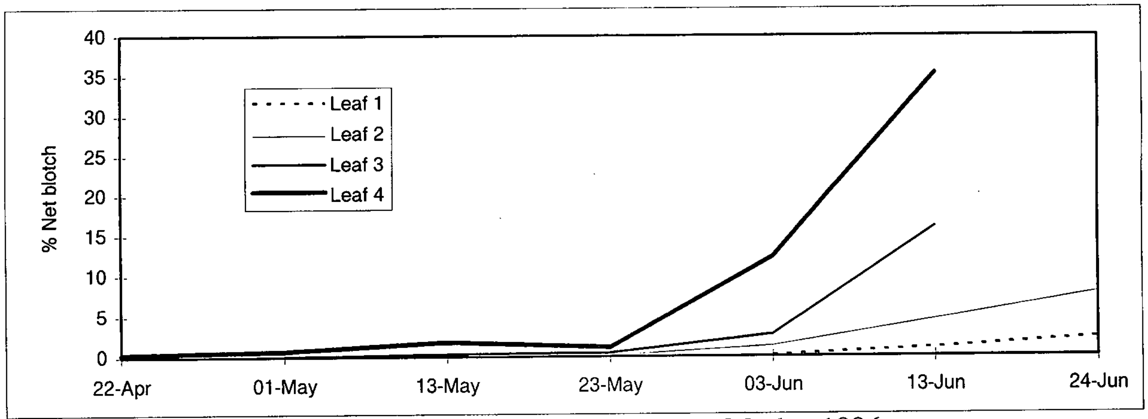


Figure 4.15. Net blotch development in untreated barley, Morley 1996.

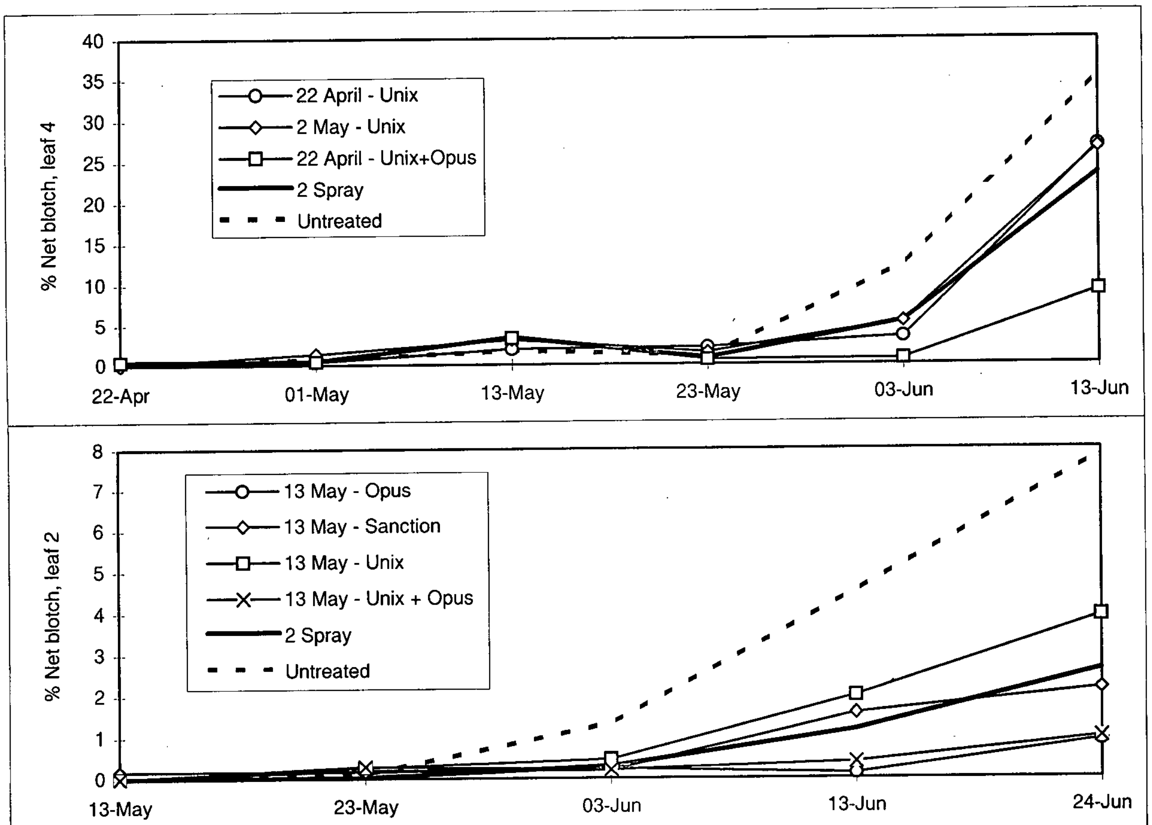


Figure 4.16. Effects of selected treatments on net blotch, Morley 1996.

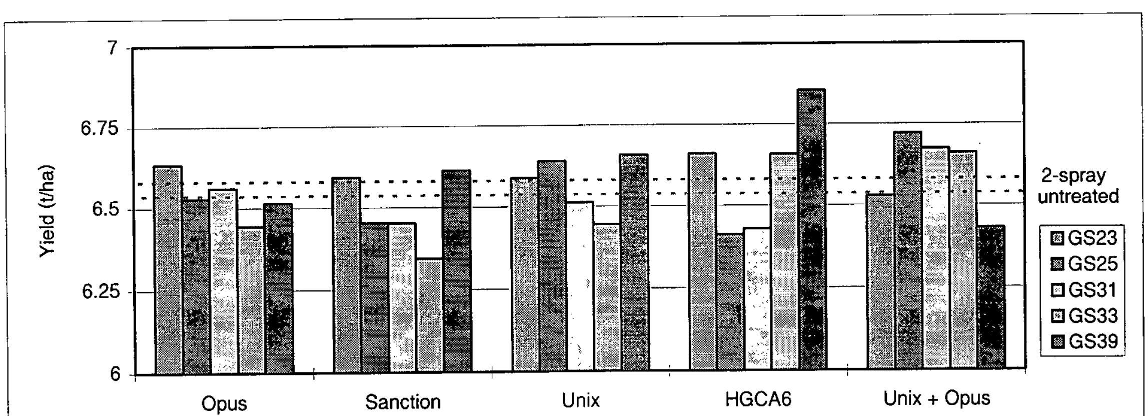


Figure 4.17. Effect of treatments on barley yield, Morley 1996.

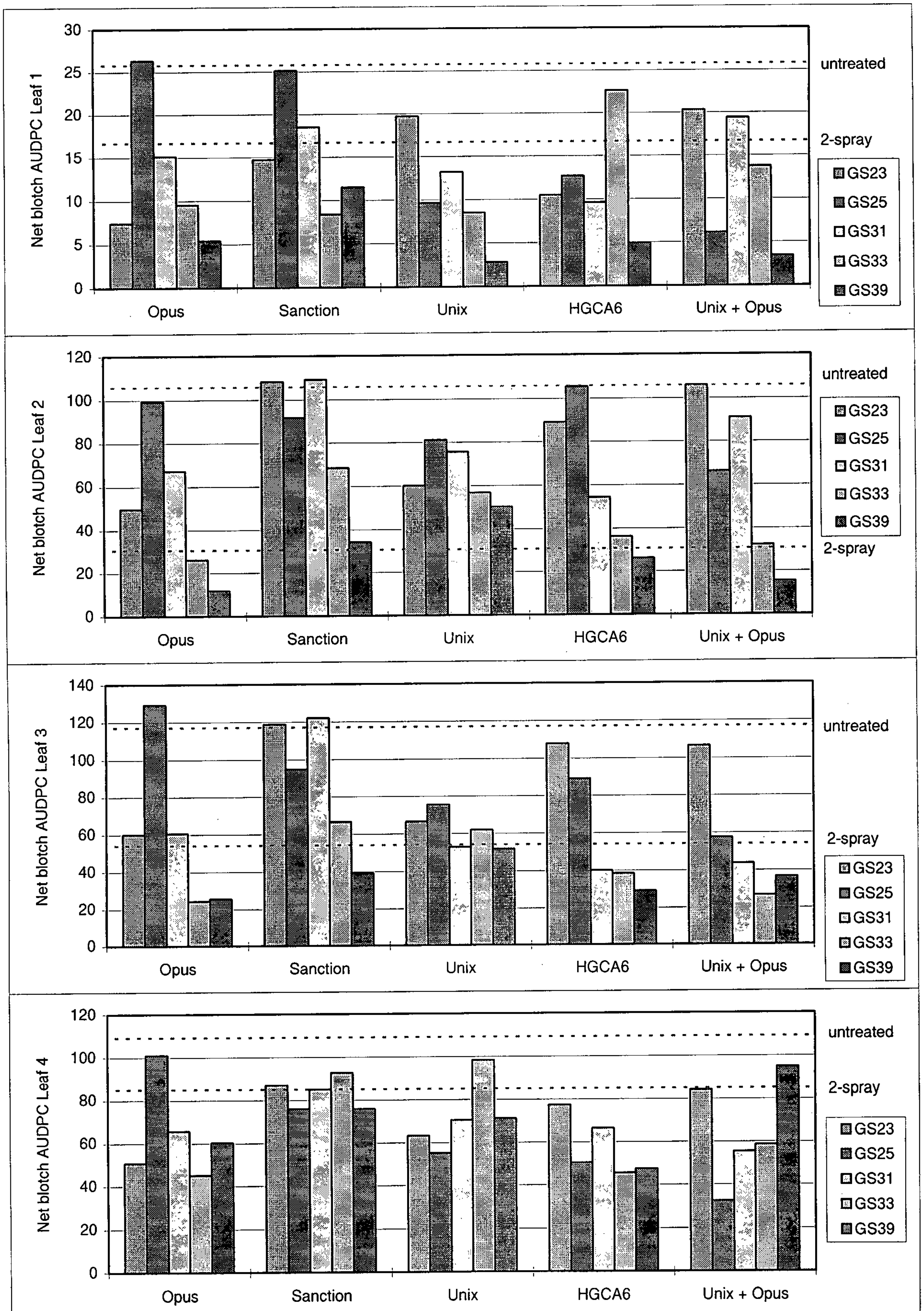


Figure 4.18. Effect of treatments on barley net blotch AUDPC, Morley 1996.

In 1997, net blotch developed most rapidly on the top 3 leaves from 14 May onwards (Figure 4.19). Amistar and Opus provided the more effective control of net blotch on the flag leaf from 13 May applications, rather better than two-spray standards (Figure 4.20). Improved control of net blotch with late timings was apparent for Amistar (Figure 4.20), although April sprays gave long lasting effects. The latest timing generally gave the best control of net blotch on the upper leaves, though early sprays (GS30-31) of Unix + Opus appeared to have long lasting effects (Figure 4.20).

Low levels of net blotch on the flag leaf were rather poorly controlled, but timing, fungicide and timing x fungicide interactions were apparent. Treatments gave an average AUDPC value of 38.5 compared with untreated value of 86.1. The 13 May and two-spray timings were more effective than earlier treatments. The 13 May timing was most effective for all fungicides though Amistar performed as well on 2 May as on 13 May.

Moderately severe net blotch on leaf 2 was most effectively controlled by 13 May timing. Amistar gave best control, followed by Landmark. Overall control was only moderate and even Amistar failed to give 50% control. The latest timing on 13 May was most effective, though Amistar proved as effective on 2 May.

Differences between fungicides but not between timings were apparent on leaf 3. Amistar, Landmark and Opus, alone or in mixture with Unix, were the most effective treatments, reducing net blotch by about 70%.

Timing rather than fungicide effects were detected on leaf 4 and there was an interaction between fungicide and timing. The 13 May applications resulted in less net blotch than earlier timings and the two-spray standard under low disease pressure. The latest timing gave the lowest mildew for all treatments except Unix + Opus which showed least net blotch from 1 April spray.

Treatments gave a significant mean yield increase of 0.68 t/ha over untreated control of 6.15 t/ha. There were no differences between spray timings but large effects of fungicide. Amistar (7.24 t/ha) and Landmark (7.03 t/ha) were higher yielding than Sanction (6.43 t/ha) and Opus (6.69 t/ha) (Figure 4.21). Whilst there were no interactions between fungicide and timing, Amistar gave the highest yield at each spray date, in the range 0.38-0.64 t/ha above the two-spray standard, and all single sprays of Landmark and Amistar gave higher yields than the two-spray standard.

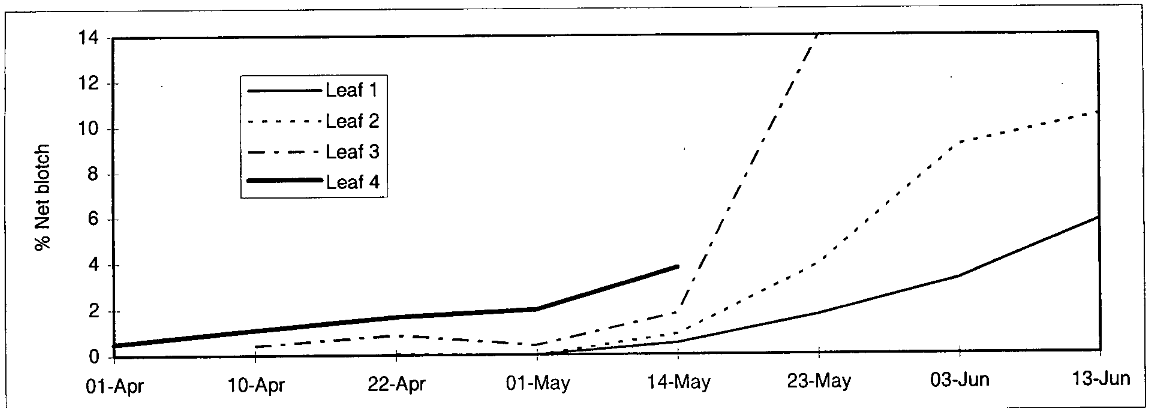


Figure 4.19. Net blotch development in untreated barley plots, Morley 1997.

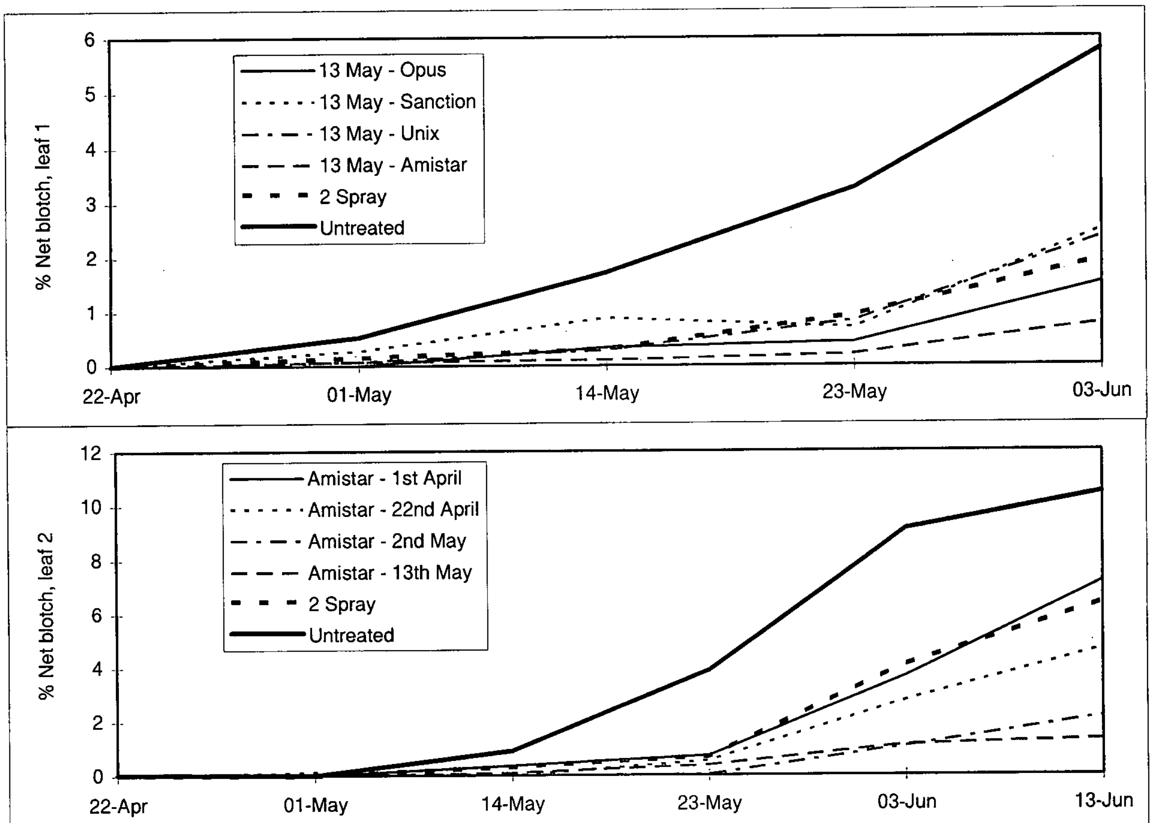


Figure 4.20. Effect of selected treatments on barley net blotch, Morley 1997.

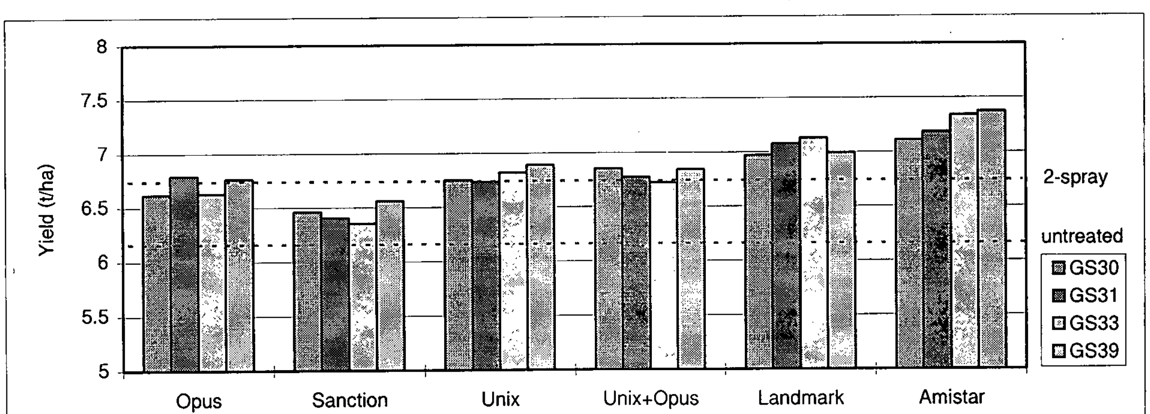


Figure 4.21. Effect of treatments on barley yield, Morley 1997.

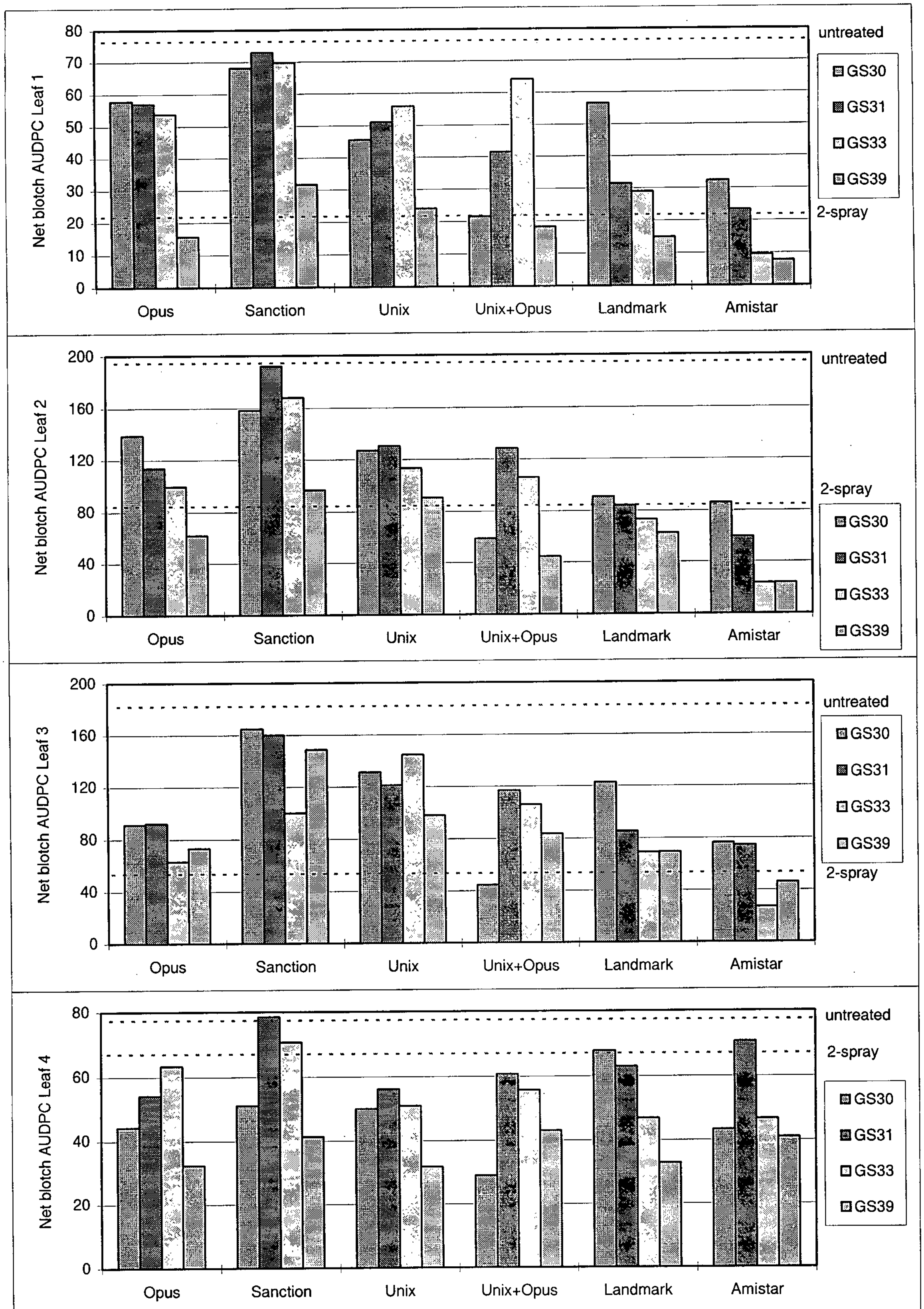


Figure 4.22. Effect of treatments on barley net blotch AUDPC, Morley 1997.

In 1998, net blotch was the most important disease in the crop from early spring and affected the upper leaves severely by mid May, reaching 13.7% on leaf 1, 25% leaf 2 and 18.1% leaf 3 (Figure 4.23).

Control of net blotch on the flag leaf required 2 sprays (mean level 4.0% area affected) rather than a single spray at GS 39 (7.4% area) when untreated leaves had 13.7% area affected. Amistar + Opus (4.5%) and Amistar alone (5.9%) were the most effective products averaged over all timings. They reduced net blotch to only 0.2% area when used as GS 31 + GS 39 programmes, compared with 1.9% for Landmark and 5.1% for Opus alone. The superior control of net blotch given by the two-spray and single GS 39 spray of Amistar is shown in Figure 4.24. The AUDPC data show a progressive improvement in control with the later sprays particularly on leaves 1 and 2 (Figure 4.26). There were significant differences between products with strobilurin chemistry being more effective than the standard and epoxiconazole. Two-spray programmes of Amistar and Amistar + Opus reduced AUDPC values to 4.9 and 2.2 respectively, compared with 232.1 for the control value on the flag leaf.

On leaf 2, which developed 25% net blotch, control was slightly poorer with the Amistar treatment showing 2.2% net blotch, Amistar + Opus 1.0% and Landmark 8.0%. As on the flag leaf, the last spray on 4 May was the most effective for net blotch control. A two-spray programme of Amistar + Opus reduced the AUDPC value from 435.7 to only 8.1, whilst a single spray at GS 39 of this mixture was considerably more effective than the second best treatment which was Amistar alone.

The benefits of single timings were less clear on the lower leaves. Amistar + Opus gave the lowest AUDPC values at each timing on leaf 3, but Opus had the lowest values on leaf 4.

Untreated Puffin yielded 5.40 t/ha and treatments produced yields of up to 8.26 t/ha. Differences between treatment timings and products were significant and interactions were also detected. There were no differences between single sprays (range 6.68 to 6.76 t/ha), but a clear advantage from the two-spray programme (GS 31 + GS 39) which yielded 7.47 t/ha. Amistar + Opus gave the highest yield (7.62 t/ha), just ahead of Amistar (7.42 t/ha) and substantially above Landmark (6.93 t/ha), Opus (6.46 t/ha) and other treatments including the two-spray standard Sanction + Corbel (6.04 t/ha).

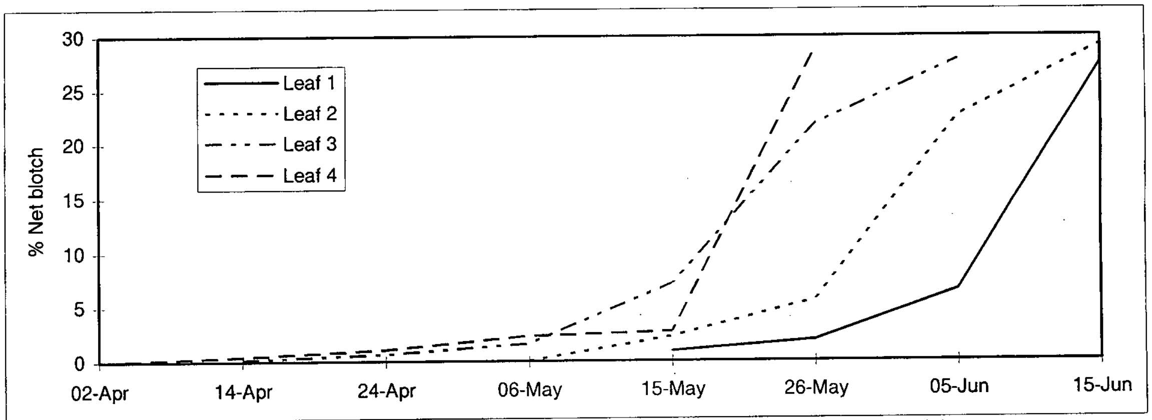


Figure 4.23. Net blotch development in untreated barley plots, Morley 1998.

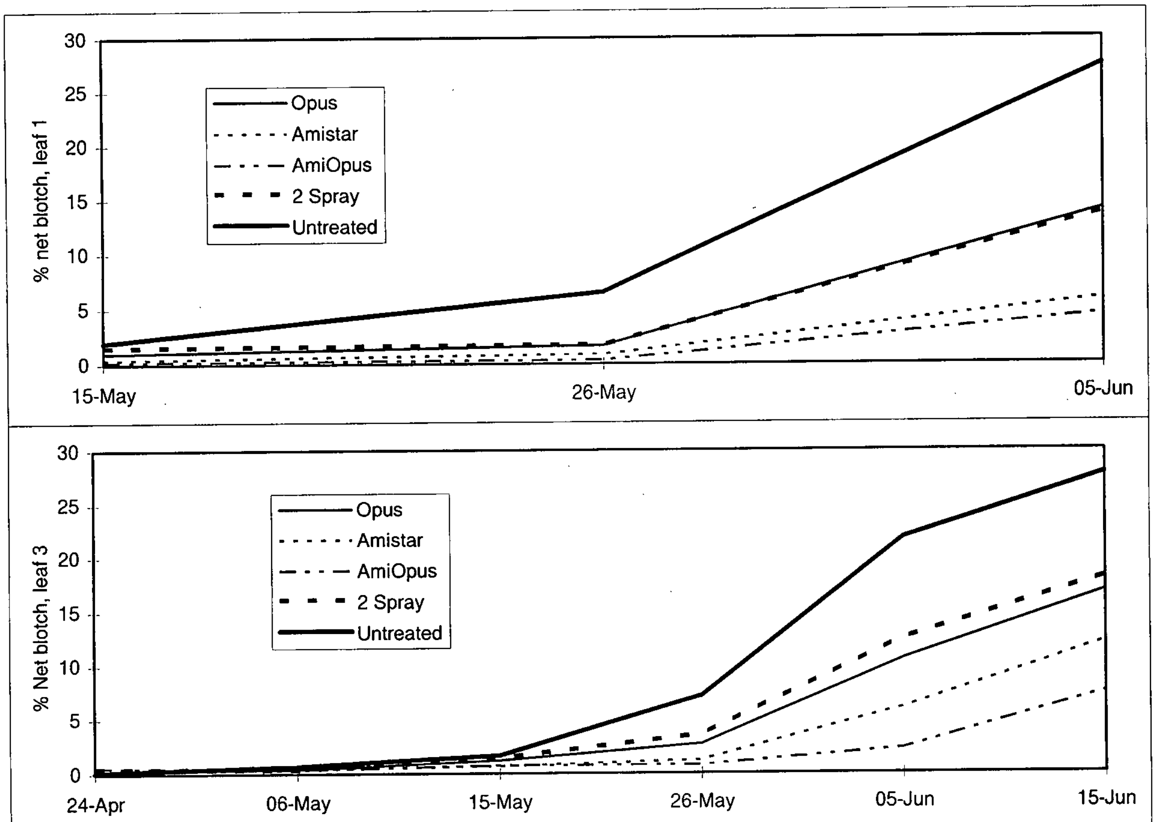


Figure 4.24. Effect of selected treatments on barley net blotch on leaves 1 and 3, Morley 1998.

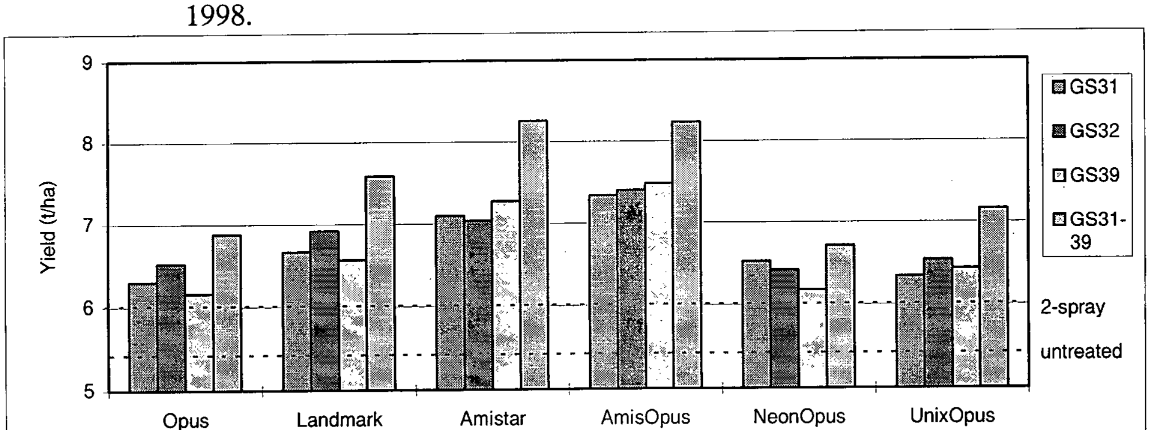


Figure 4.25. Effect of treatments on barley yield, Morley 1998.

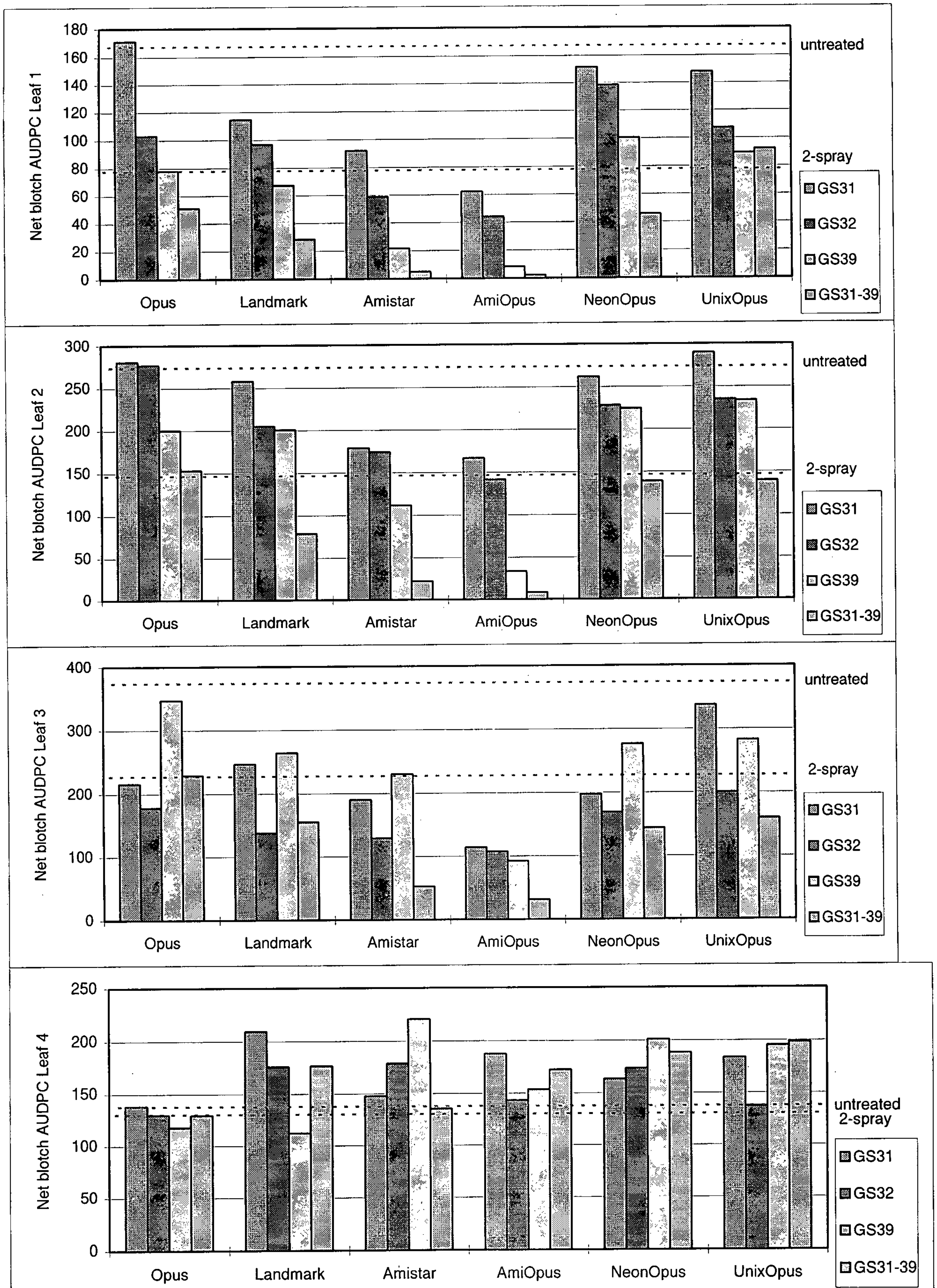


Figure 4.26. Effect of treatments on barley net blotch, Morley 1998.

Rhynchosporium **(Westward Arable Centres)**

In 1996, severe *Rhynchosporium* developed on the upper leaves from 1 April when there was already almost 1% infection on the youngest expanded leaf. There was a late surge of infection on the flag leaf in June (Figure 4.27). By mid May, only three green leaves remained even in treated plots.

Rapid early development on leaf 3 contrasted with more sustained disease progress on leaf 2. Unix, Unix + Opus, and Opus gave marginally better control than the two-spray standard at on 14 May and control appeared to be just starting to fade at that stage (23 days after treatment) (Figure 4.28). On leaf 2, disease control waned between 4 and 12 June with a large surge of infection. It appeared than Sanction applied on 1 April had remained effective up to 4 June (54 days after treatment), whereas Sanction applied on 11 April was already weakening by that date. Unix applied on 22 April was one of the most effective treatments.

Treatment timing, but not fungicide product, had major effect on *Rhynchosporium* control on leaf 4, but only the 1 April (GS 29) spray had useful activity (Figure 4.30). Spray timing was more critical than product choice for *Rhynchosporium* control on leaf 3. The second spray timing (11 April) was noticeably less effective than early or late timings (1 April or 22 April respectively). Sprays in May had no effect on disease on leaf 3. Differences between fungicides were not significant in leaf 3 but were apparent on leaf 2 where Unix showed the lowest AUDPC value when averaged over all timings. However, all treatments including the two-spray standard provided only moderate control (50-70%) at best. The two-spray standard was effective in controlling *Rhynchosporium* on the flag leaf and good results were obtained with the 13 May timing. The spray at GS 33 (2 May) also provided useful control on the flag leaf. Opus was marginally the most effective treatment and superior to Unix.

Fungicide treatments gave significant yield increases, on a low-yielding crop of cv. Willow, of up to 0.78 t/ha over the untreated control yield of 4.51 t/ha (Figure 4.29). There was a general trend for yields to increase as timings became late but the stem extension spray (GS 29) appeared to be slightly higher yielding than the GS 31 timing. All the new fungicides performed similarly and some were marginally higher yielding than the two-spray standard when averaged over all timings. They were also higher yielding than the corresponding single sprays of the standard Sanction, particularly at the late timing.

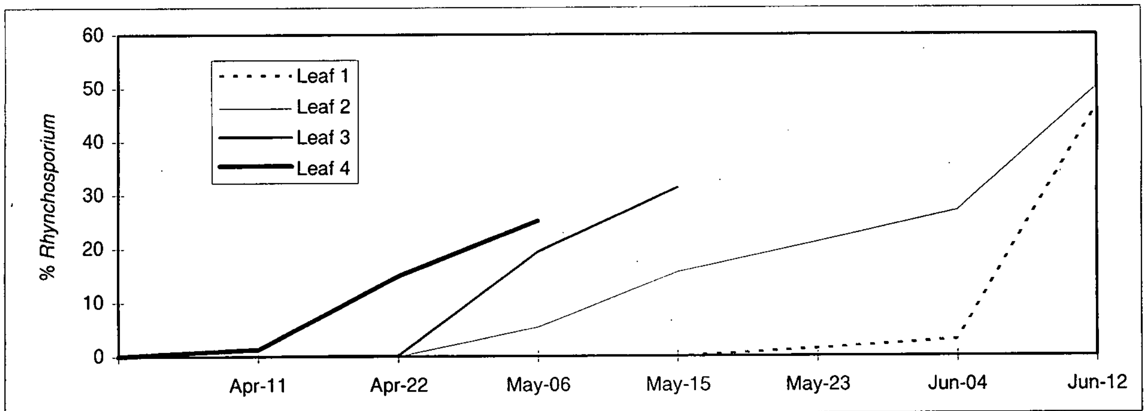


Figure 4.27. *Rhynchosporium* development in untreated barley plots, WAC 1996.

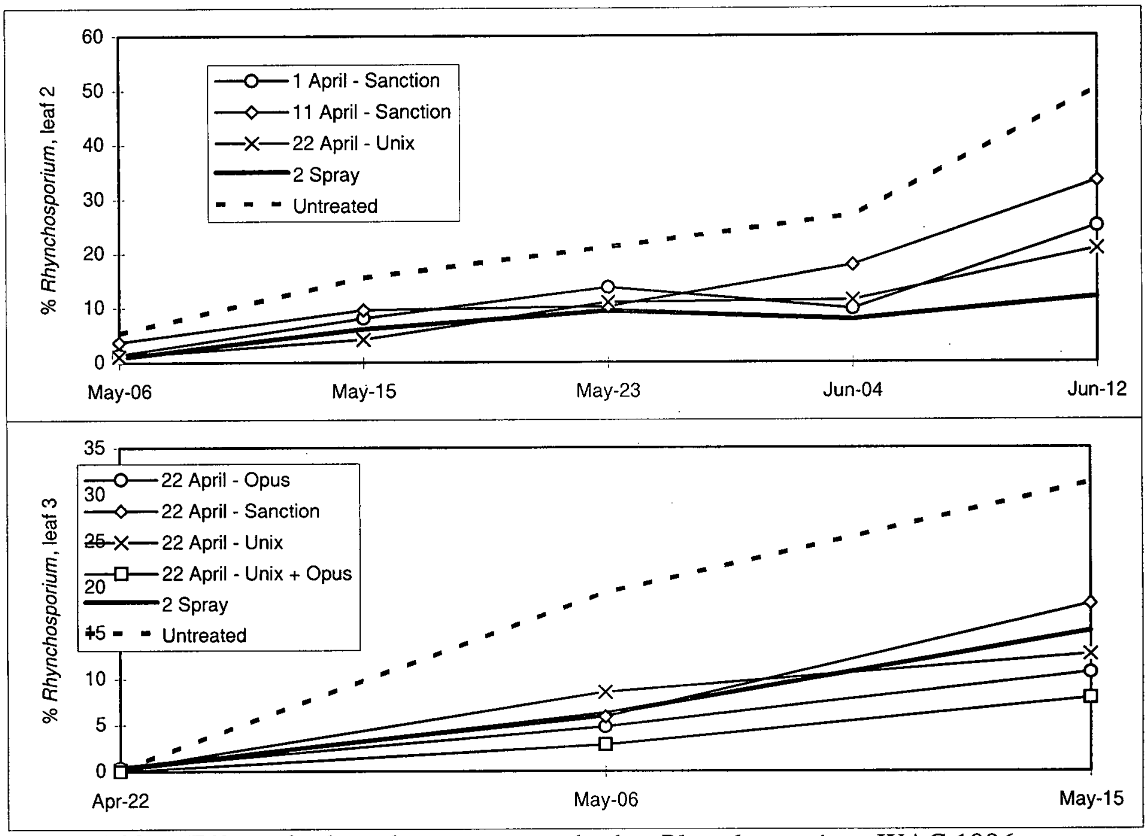


Figure 4.28. Effect of selected treatments on barley *Rhynchosporium*, WAC 1996.

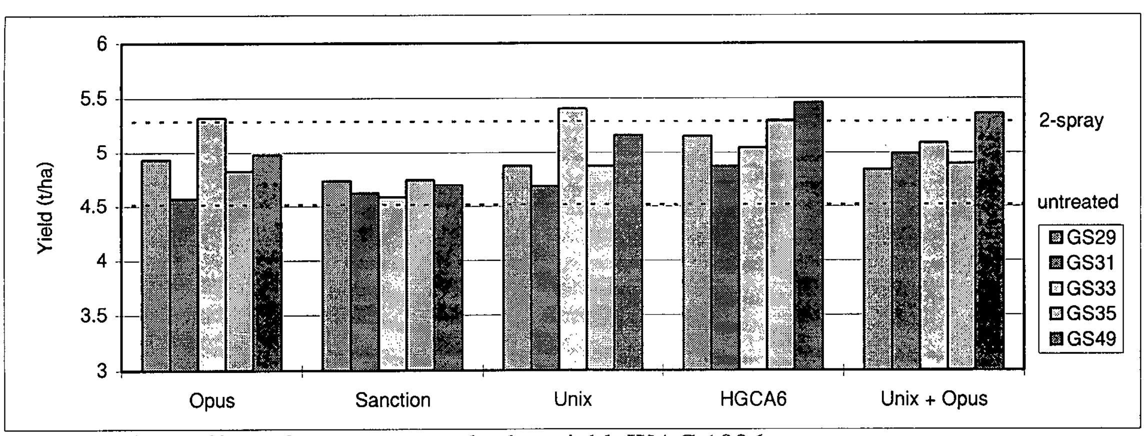


Figure 4.29. Effect of treatments on barley yield, WAC 1996.

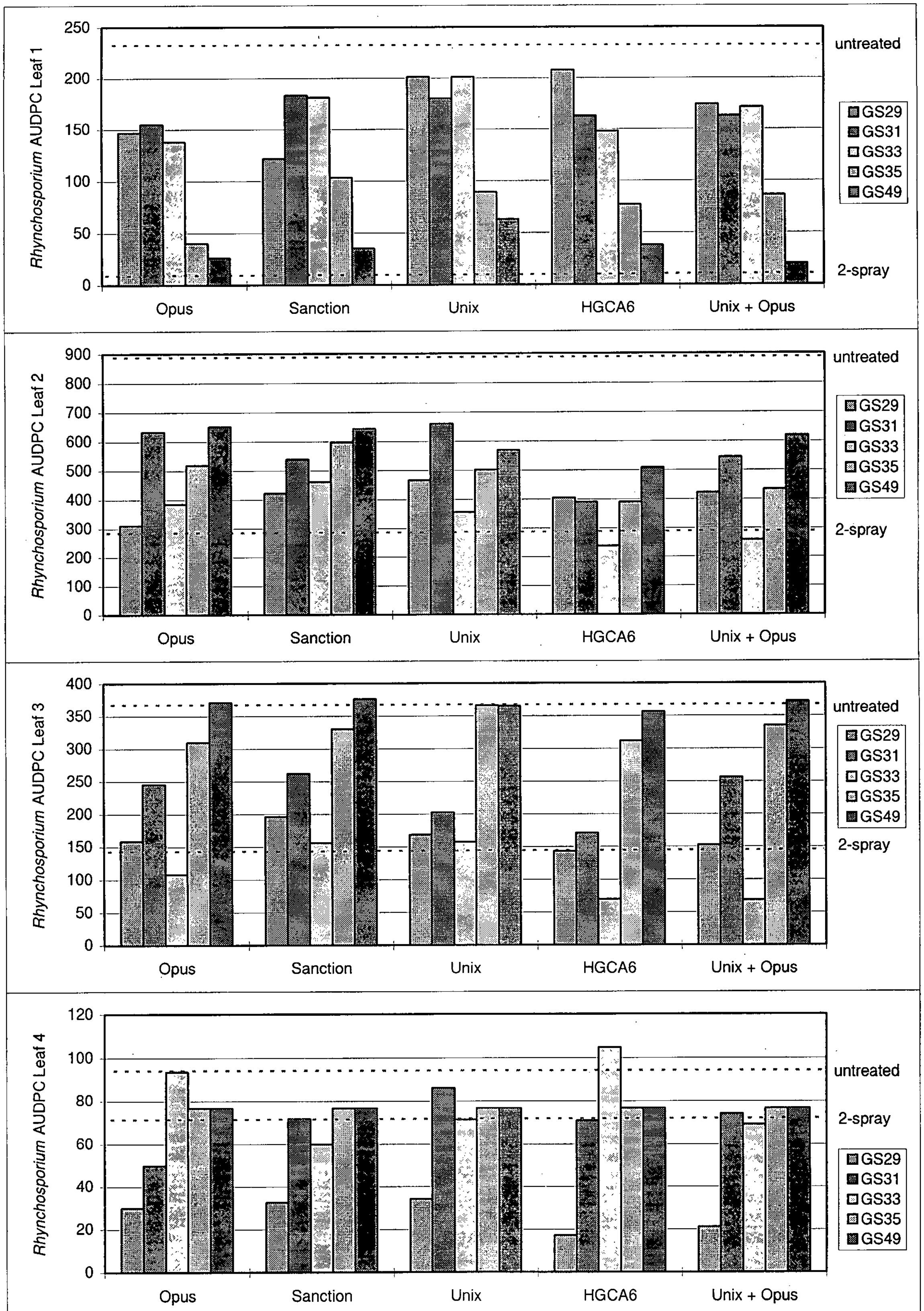


Figure 4.30. Effect of treatments on barley *Rhynchosporium* AUDPC, WAC 1996.

In 1997, *Rhynchosporium* was the most important disease and it affected the lowest leaves most severely : 4.0% leaf 6, 16.7% leaf 5, 6.6% leaf 4, 4.8% leaf 3, 3.6% leaf 2, 1.0% leaf 1 (Fig. 4.31). Periods of active disease development occurred between April 21 and May 12 on leaf 5, May 1 to 23 on leaf 4, and from May 23 to June 2 on the upper leaves (Figure 4.31). Only traces of mildew, net blotch and brown rust were recorded.

On leaf 2, Amistar and Opus applied on 2 May were marginally more effective than the two-spray standard (Fig 4.33). There were clear indications that the latest timing (13 May) was too late for effective control on leaf 2 with Amistar. (Fig. 4.32).

Whereas most treatments were inferior to the two-spray standard, there was apparently a strong yield response to the two earliest timings of Unix. This effect could not be related to disease control as judged from AUDPC values (Fig. 5). In addition, the mixture of Unix + Opus, albeit at lower dose than the single spray of Unix alone, did not show such obvious yield enhancement.

On leaf 4, These effects from different timings and overall benefits from treatments which averaged 17.8 compared with 67.9 for controls. The two-spray standard was more effective than the May treatments but just failed to show significant improvement over April sprays. There were no differences between fungicides or interactions between fungicides and timings.

On leaf 5 treatments reduced AUDPC values by about half (81.7 treated, 161.0 untreated) for leaf blotch on leaf 5. The two-spray standards was that effective timing (49.0) followed by 22 April (71.1). There was little to choose between fungicides, Unix had the lowest AUDPC (73.9) then Opus (77.9).

Treatments gave an average yield response of 0.79 t/ha over untreated of 6.15 t/ha (Figure 4.32). There were no differences between spray timings. The highest yield was given by Unix (7.44 t/ha) which was just significantly higher than Opus (6.64 t/ha) and Sanction (6.67 t/ha).

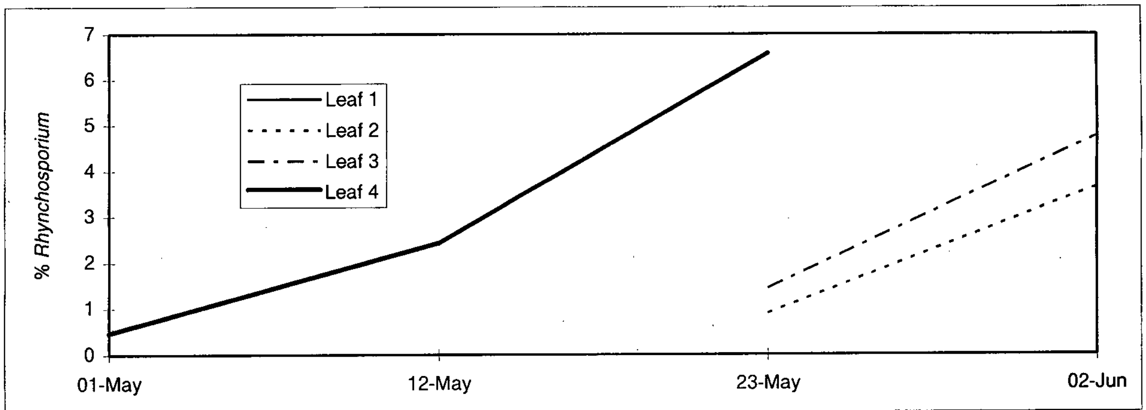


Figure 4.31. *Rhynchosporium* development in untreated barley plots, WAC 1997.

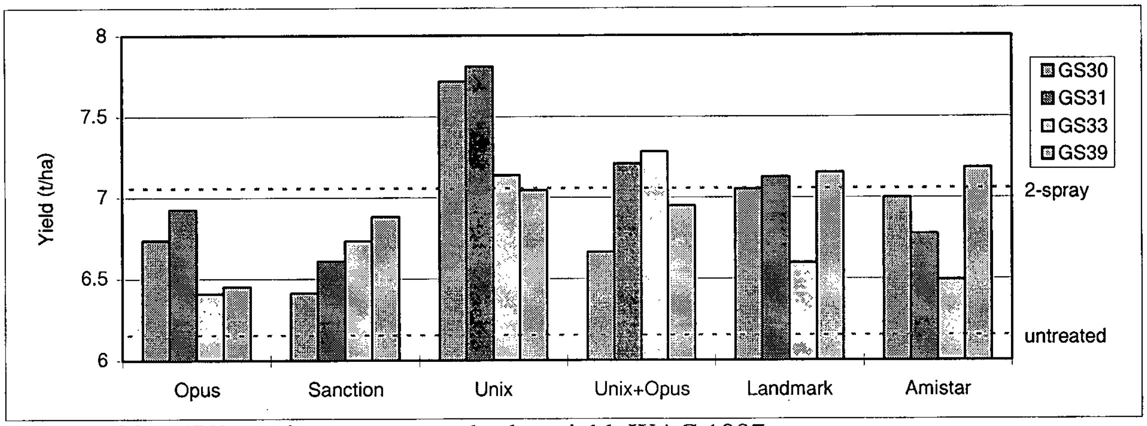


Figure 4.32. Effect of treatments on barley yield, WAC 1997.

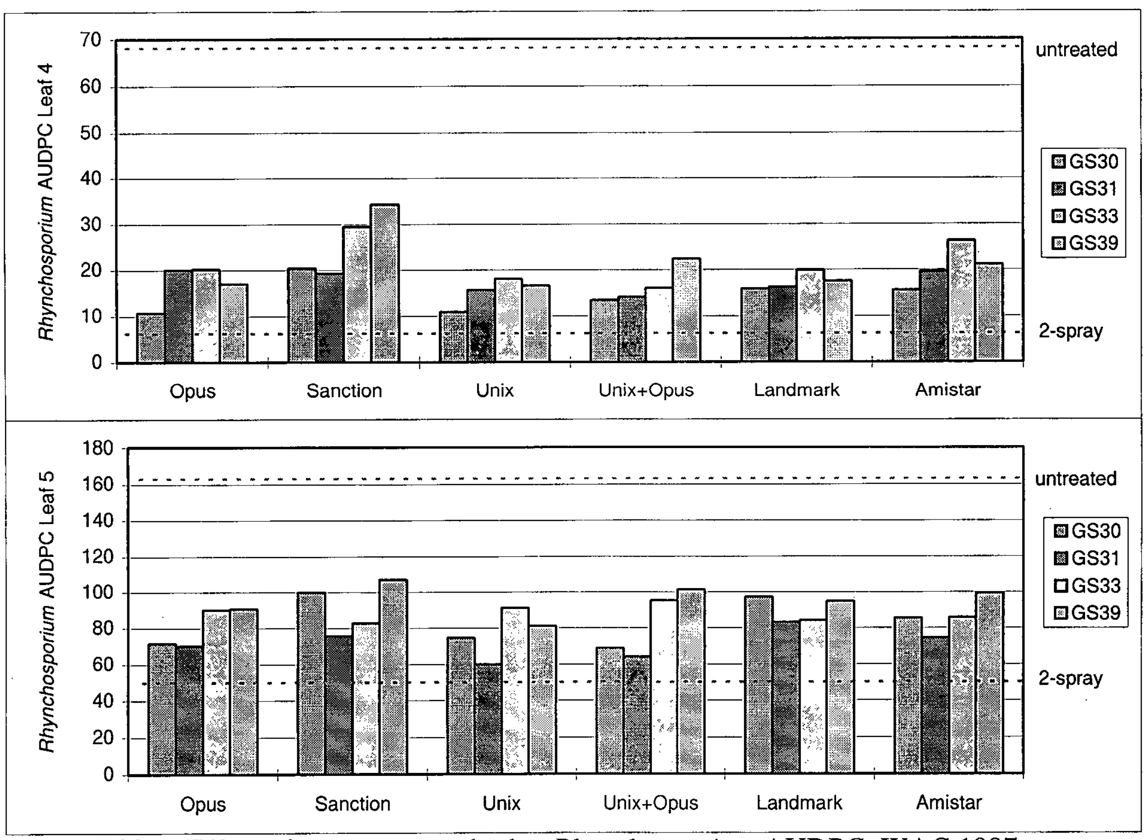


Figure 4.33. Effect of treatments on barley *Rhynchosporium* AUDPC, WAC 1997.

In 1998, *Rhynchosporium* was present by the start of the year, and increased steadily to affect 6.6% of untreated leaf 5 and 0.2% on leaf 4 on 2 April when the first sprays were applied (Figure 4.34). The second sprays were delayed by wet weather until 1 May when *Rhynchosporium* affected 28.4% of leaf 4. Leaf 3 showed 6.7% infected by 1 May, increasing to 21.0% only 10 days later. On the upper leaves, severe infection by *Rhynchosporium* was also evident with 28.0% on leaf 2 at GS 71-73 on 2 June.

Rhynchosporium did not develop to any extent on the flag leaves, and was well controlled by all fungicides (Figure 4.37). However, single applications were generally more effective at GS 32 than at other timings, except for Amistar Pro which gave best control at GS 31.

On leaf 2, as on the flag leaves, GS 32 was generally the most effective single timing, with disease control only slightly inferior to that from the GS 31 + 39 programme. All GS 31 and GS 32 treatments except Opus alone at GS 31 gave reductions in disease of over 70%,, and Unix + Opus gave the greatest reduction in disease at each of GS 31 and GS 32.

On leaf 3, disease control was poorer than on the top two leaves. GS 31 sprays of all fungicides except Amistar gave over 50% control, whereas GS 32 and GS 39 sprays had little effect. Landmark and Amistar Pro at GS 31 gave the best control.

On leaf 4, Landmark and Amistar Pro were the most effective products with 4.2% disease compared with 10.0% for Opus alone and 10.1% for the Sanction + Corbel standard. Only GS 31 applications had any effect on leaf 4.

There were significant effects of timing and fungicides on yield, but no interaction between these factors. Untreated yield was 5.41 t/ha and responses of up to 1.26 t/ha (23%) were obtained (Figure 4.36). There was only a small difference between yields from single sprays which averaged 6.05 t/ha from GS 31 timings, 5.94 t/ha at GS 32 and 5.90 t/ha at GS 39. The highest yield came from the two-spray programme (GS 31 + GS 39 timings) which averaged 6.45 t/ha, indicating almost additive effects from the single spray timing components. This was a substantial improvement over the Sanction + Corbel standard which yielded 5.98 t/ha. Landmark gave the highest yield overall (6.23 t/ha) which was 0.31 t/ha higher than Opus alone and 0.22 t/ha higher than Unix + Opus. The mixtures Amistar + Unix, Amistar Pro and Amistar + Opus gave very similar yields of 6.16, 6.13 and 6.05 t/ha respectively.

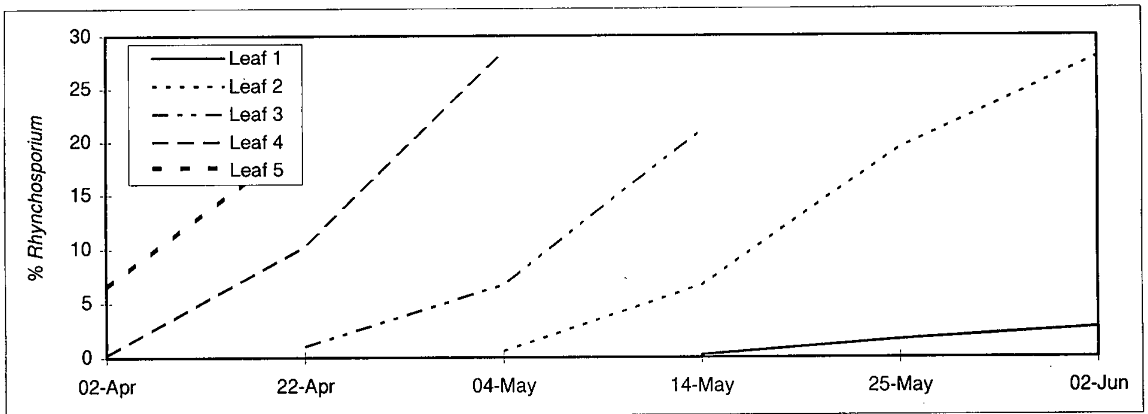


Figure 4.34. *Rhynchosporium* development in untreated barley plots, WAC 1998.

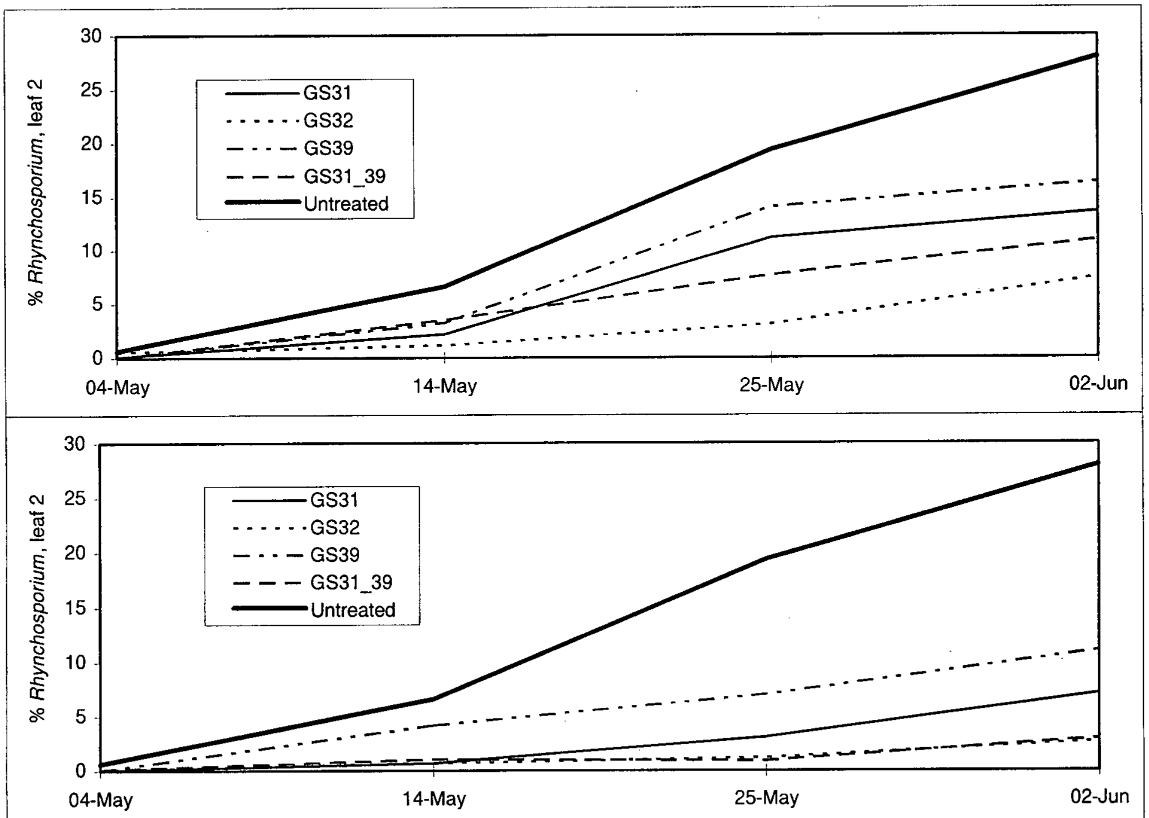


Figure 4.35. Comparison on Opus (above) and Opus plus Unix (below) for control on barley *Rhynchosporium*, WAC 1998.

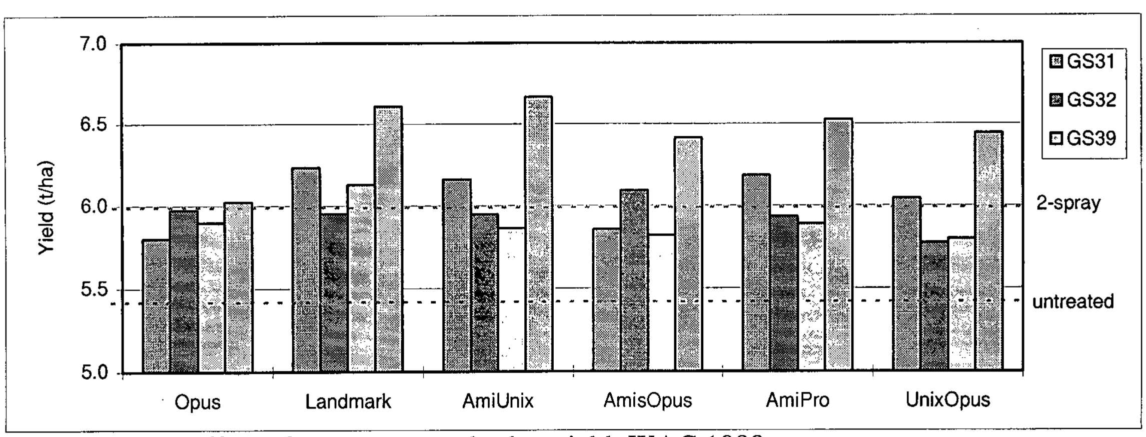


Figure 4.36. Effect of treatments on barley yield, WAC 1998.

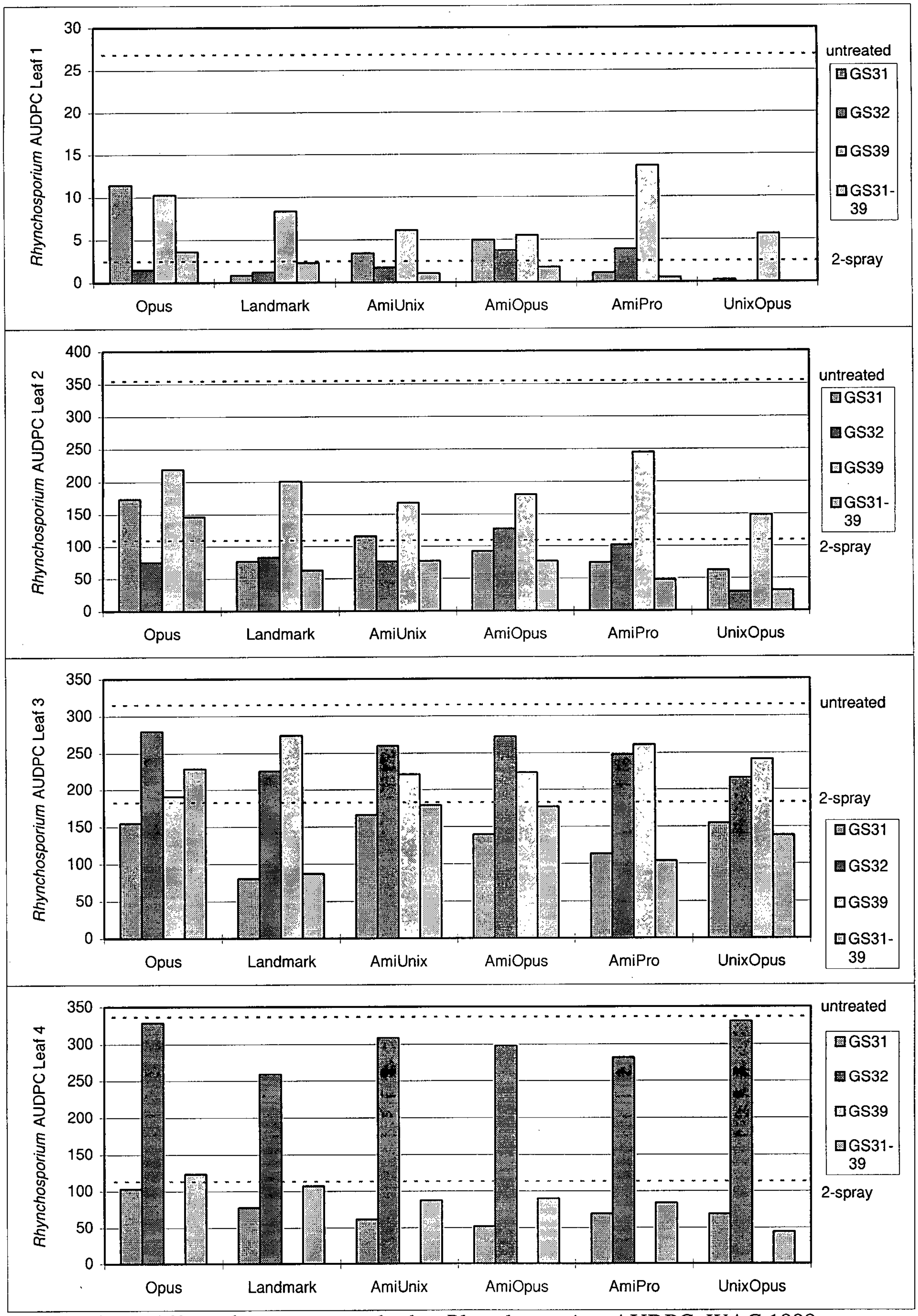


Figure 4.37. Effect of treatments on barley *Rhynchosporium* AUDPC, WAC 1998.

DISCUSSION

Wheat - disease control

All fungicides included in the *Septoria tritici* experiments showed good eradication of latent disease, with the exception of Amistar (strobilurin) and Ensign (strobilurin + fenpropimorph). Fenpropimorph is known to provide a few days eradicant activity, but this was insufficient to confer useful eradicant activity to Ensign under the severe disease conditions in these experiments. The eradicant activity of azoles is well documented. The strongest effects were seen from Opus and Landmark, followed by Folicur, Eminent and Caramba. In general, Caramba showed greater eradication than Folicur, whereas Eminent was similar to Folicur or slightly weaker. There was generally little difference between Opus and Landmark, which is not unexpected since both contain the same rate of epoxiconazole. There are, however, marked differences in formulation of the two products, which has led to comment that epoxiconazole in Landmark may be less effective than in Opus. In these experiments, differences were small, but there were some indications that there was greater disease on leaves 2 and 3 following GS 39 application of Landmark than of Opus, at West Bagborough in 1996, also Morley in 1996 and 1997, and also (on leaf 2 only) at West Bagborough and ADAS Rosemaund in 1998.

The main difference in protectant activity against *S. tritici* was the greater effect of Landmark than other fungicides on leaf 3 following GS 32 application or on leaf 2 following GS 33 application. This long-term protection from Landmark allows greater flexibility in fungicide timing, permitting application slightly earlier than scheduled without loss of efficacy. Amistar, used alone, gave poorer disease control than other fungicides, largely on account of its lack of eradicant activity. There were some indications of its protectant activity, e.g. the effect on leaf 1 from GS 32 and GS 33 applications at ADAS Rosemaund and Morley in 1997. The protectant activity could be conferred by movement of the strobilurin to new growth, or the disease control in the lower canopy may be so effective that there is a barrier to stepwise movement of inoculum up the canopy to the top leaves. Used in mixture with Opus it was comparable with Landmark. Comparing other fungicides, Opus had greatest protectant activity, with little difference between Folicur, Eminent and Caramba, although there were some indications of greater activity from Caramba than either Folicur or Eminent.

Although *Stagonospora (Septoria) nodorum* was not a prime target in this project, some information was gained from ADAS Arthur Rickwood in 1997. Opus, which was the only azole in the experiment, showed the strongest effect, but Unix and Ensign also gave some control.

For yellow rust control, fungicide timing was more important than product choice in the two years when severe rust developed (1996 and 1998). In 1996, best control on the upper leaves was given by GS 33 and GS 39 applications whereas, in 1998, the optimum timings for yellow rust control on leaves 2 and 3 was GS 31 and single applications at GS 33 or GS 39 had relatively little effect. This illustrates the importance of timing for yellow rust control. The epidemic in 1998 started earlier, and the new fungicides have the same limitation of older products in that yellow rust, once established, is very difficult to control. Morpholines are still the most effective fungicides for eradication of yellow rust. In 1996, Landmark was the most effective fungicide on leaves 3 and 4, but this advantage was not evident on the top two leaves. There was little difference in activity between Opus and Folicur, but Caramba and Eminent were slightly less effective. The best protection from application at GS 31, which was before the optimum timing, was from Opus and Landmark. In 1998, Opus, Landmark, Amistar and Amistar plus Opus gave similar results, though Amistar was slightly weaker than the others. Ensign gave over 50% control on flag leaves only when applied as a two-spray programme, but single applications of Ensign and Neon had little effect except for a modest reduction on flag leaves from a GS 31 spray.

Brown rust at Morley in 1998 was controlled better by GS 39 applications than those made earlier, as would be expected for a disease which generally does not become severe before mid June. Landmark and Amistar plus Opus were best, followed by Opus, then Amistar and Caramba and Ensign. There were indications of greater persistence of activity from GS 32 application of Landmark or Amistar plus Opus than from Opus or Amistar applied alone.

Some information on brown rust was also obtained from the mildew experiment at ADAS Arthur Rickwood in 1998, which had a different set of fungicides. Landmark was very effective from GS 33 or GS 39 application, but not at GS 32. Ensign also gave good control, and Neon showed a strong effect on leaf 2, though not leaf 1. Tern also gave some reduction in brown rust, unlike Unix and Fortress which had very little effect.

In the mildew experiments in 1996, Corbel and Tern were both included as standards. Apart from better control given by Tern from GS 33 application, there was little difference between these two fungicides, so Corbel was omitted in the second and third years. Ensign was generally superior to Tern, particularly from GS 32 or GS 33 application. Fortress, introduced to the project in 1997, was comparable with Ensign, but gave greater control from GS 31 application, which indicates longer persistence of control. Unix, applied at GS 32, gave good control in 1996, but was generally less effective than Tern. Neon, which was included only in 1998, was poorer than Ensign and Fortress.

The data on sensitivity of the mildew fungicide to morpholine fungicides show that geographical location was very influential on the sensitivity of isolates tested. Isolates from ADAS Arthur Rickwood were significantly more sensitive than those from SAC Aberdeen in both 1996 and 1997. There was also a marked difference between years, with isolates collected in 1997 being more sensitive than those in 1996 and 1998. The reduction in sensitivity to fenpropimorph, first noted in the HGCA-funded survey in 1995, was continued into 1996, but appeared to have stabilised, with no further decline being noted in this data. The sensitivity of the isolates from both trials lies within limits detected in other work and, although significantly different to each other for fenpropimorph sensitivity, are probably typical of the general mildew population.

Wheat - effects on green canopy

Striking effects of some treatments on canopy duration were observed at many of the *S. tritici* and yellow rust sites, though not so clearly at mildew sites. This green leaf prolongation was greater than could be attributed directly to reduction in disease. This effect was most marked with Landmark, and particularly on leaves 2 and 3, but there was a similar, though smaller, effect from Opus at some sites. This greater persistence of green canopy occurred even where there were indications that disease control from Landmark was slightly poorer than that from Opus. In most cases, the effect was to delay the initial rate of leaf senescence rather than to delay the date at which the canopy became completely senescent, although there were some instances (e.g. West Bagborough 1997) where overall canopy senescence was delayed. This effect on green leaf area generated considerable interest in 1996, resulting in further HGCA-funded projects (0043/01/96 and 0026/01/97) to investigate physiological effects of new fungicides.

Wheat - yield

At each of the *S. tritici* sites, the highest yield from a single application was given by Landmark. The optimum timing for a single application was GS 39 at West Bagborough, but there were instances at other sites (at Morley in 1996 and ADAS Rosemaund in each year) where a single application of Landmark at GS 33 gave a yield comparable with that from GS 39 application. The greater flexibility in timing of Landmark probably relates to differences in disease severity between sites, with the highest levels of disease consistently experienced at the south-western site West Bagborough. This flexibility of timing was not seen with any azole, and shows the flexibility in timing that is conferred by using the strong protectant strobilurin in mixture with a good azole for eradication. Amistar, used alone in 1997, did not match the best treatments for yield, In 1998, the Amistar plus Opus mixture was comparable with Landmark. Under lower disease pressure at Morley, the yield from Amistar alone was almost as high as that from the mixture, but this effect was not seen at West Bagborough or Rosemaund, where disease was more severe. This difference in disease severity between sites may also account for the fact that, at Morley, the best single timing of Opus or Amistar plus Opus (GS 39) gave similar yields to the two-spray programmes of those fungicides, whereas there was a clear advantage from the two-spray programmes at the other two sites.

Among the other fungicides, Opus showed a clearer GS 39 optimum than Landmark, and the best Opus timing matched Landmark for yield in a few instances (ADAS Rosemaund 1997, West Bagborough 1998), but was generally inferior. Folicur, Eminent and Caramba gave similar yields to each other, lower than Opus, but showing the same effect of fungicide timing on yield.

At the yellow rust site in 1996, Landmark and Opus both showed greater flexibility in timing than other fungicides, which showed a GS 33 or GS 39 optimum. GS 33 was clearly the optimum timing for yield in 1997, under lower disease severity, but GS 39 was the optimum for all except Landmark in 1998. Landmark gave similar yields from each single application, with each timing of Landmark outyieding all other single applications except Amistar plus Opus at GS 39. This shows the flexibility in timing with Landmark compared with the other fungicides. There was a yield benefit from the two-spray programme of each fungicide compare with the best single application.

At the mildew sites, effects of treatments on yield were generally smaller and less clear than at the other wheat sites. The largest effect of mildew on yield was at ADAS Arthur Rickwood in 1997. Fortress at GS 31, Ensign at GS 32 or GS 33 and Unix at GS 39 gave the highest yields, showing the protectant activity of Fortress and the need to apply it early for best effect. Ensign showed greater eradicant activity, hence the benefit from slightly later application. Unix is largely a protectant fungicide which was more effective against mildew from timings earlier than GS 39, so the yield benefit from GS 39 application of Unix was probably related to control of *Stagonospora nodorum* rather than mildew. The effect on yield of Landmark at SAC Aberdeen in 1998 was probably related to *S. tritici* control, since Fortress, which was as effective as Landmark against mildew, had no effect on yield.

Barley - disease control

For control of severe mildew, at ADAS Rosemaund in 1997, fungicides applied around the time of emergence of each leaf layer gave best control on that layer. The only fungicide which offered more flexibility was Landmark, for which all timings from GS 30-39 gave good control on leaf 2 and all except GS 30 were effective on the flag leaves. At each timing, Landmark gave better control than any other fungicide, but Unix, Opus and the mixture of Unix plus Opus all gave good control from one timing, but with optimum timing differing between leaf layers. Amistar had little effect on mildew, and comparison of the two azoles in the experiment showed better control from Opus than Sanction, although Sanction did give well over 50% reduction in mildew on each leaf layer from the best timings. Mildew levels in the other two years were lower. In 1996, Unix and HGCA6 were more effective than Opus or Sanction. The only data on Neon are from the 1998 experiment, in which Neon plus Opus (at half rate) was no better than Opus alone, and inferior to Landmark.

Brown rust at ADAS Rosemaund in 1998 was controlled very well by all two-spray programmes, with virtually 100% control from Amistar plus Opus, Amistar alone and Neon plus Opus. Among single applications, Amistar and Amistar plus Opus at GS 33 gave the greatest reduction in disease on leaf 2. On the flag leaves, GS 39 application of Amistar, Amistar plus Opus and Neon plus Opus gave the best control.

The most effective fungicide against net blotch was Amistar. Used alone in 1997, it was markedly more effective at GS 33 or GS 39 than any other fungicide at any timing. In 1998, a mixture of Amistar with Opus gave best control, followed by Amistar alone. For each fungicide apart from Amistar plus Opus, GS 33 application gave best control on leaf 3, but GS 39 gave better control on the top two leaves for all fungicides. However, for each fungicide, two sprays gave better control than any single application. Opus gave better control than Unix in both 1996 and 1997, but Sanction was poorer than Unix.

Good control of *Rhynchosporium* was given in 1996 by all fungicides, but timing was critical, with best control on each leaf layer being given by the applications nearest to the time the leaf layer was emerging. In 1998, timing was also more important than fungicide selection. Landmark gave best control on leaf 3, followed by Amistar Pro, whereas Unix plus Opus was best on the top two leaves. Overall, *Rhynchosporium* appeared to be the most difficult barley disease to control, and the one where new fungicide chemistry has made less impact than for other major foliar diseases.

Barley - green leaf retention and yield

Retention of green canopy was not such a feature of the barley experiments as it was on wheat, and appeared to be related more directly to treatments which gave improved disease control.

Yield responses to fungicide application were generally smaller in barley than in wheat, but there were large responses in the wet summer of 1998 at sites with severe disease, with increases up to 3.24 t/ha ADAS Rosemaund and 2.86 t/ha at Morley. Smaller yield benefits were given by control of *Rhynchosporium* or mildew than by controlling brown rust or net blotch, although, in the case of *Rhynchosporium*, this may be because the experiments in years with severe disease were on sites and on a cultivar with lower yield potential than ADAS Rosemaund and Morley where the brown rust and net blotch experiments were sited. Where disease was less severe, responses were relatively small.

CONCLUSIONS

The two strobilurins introduced to the UK market during the lifetime of this project both showed considerable benefits for wheat and barley growers. Each of the other non-azole fungicides evaluated also showed promise, although use in mixture with an azole or morpholine was often required.

Kresoxim-methyl was available only in formulated mixtures with epoxiconazole (Landmark) and fenpropimorph (Ensign). The main advantage in disease control from Landmark compared with epoxiconazole (Opus) alone was in greater protectant activity on each leaf layer against *S. tritici* from sprays applied before emergence of that leaf layer, allowing greater flexibility overall in fungicide timing. There was also longer retention of green canopy, particularly on leaves 2 and 3, which resulted in consistently higher yields than those from Opus. Azoxystrobin, used alone as Amistar, showed good protectant activity against *Septoria tritici* and yellow rust on wheat, but its lack of eradicant activity resulted in disease control poorer than that of the best azoles, particularly against *S. tritici* which resulted in lower yields. When Amistar was used in mixture with Opus, its performance was similar to that from Landmark.

Although kresoxim-methyl, in mixture with fenpropimprph, gave good control of wheat mildew, this is likely to have limited commercial value for mildew control because of the occurrence of resistance to strobilurins, which has now been confirmed in the UK, albeit at low frequency. The best wheat mildew control was given by Fortress, particularly when applied early. Unix and Neon both showed useful mildew activity, but should be used in mixture for best results.

The superiority of Opus over other azoles for *S. tritici* control was confirmed, but it showed little improvement over Folicur against yellow rust. Among the new azoles, tetraconazole (Eminent) did not show any improvement over Folicur in activity against *S. tritici*, and was weaker against yellow rust. Metconazole (Caramba) showed many similar properties to Folicur; it showed slightly greater activity against *S. tritici* but was poorer against yellow rust.

On barley, there were clear benefits from Amistar for control of net blotch and brown rust. The performance of Amistar against net blotch, a disease which has proved particularly difficult to control with older fungicides, was superior to that of any other fungicide, and brown rust control was comparable with that from the best azole, Opus. Although Ensign gave good control of barley mildew, resistance to strobilurins in barley mildew was found in Germany in 1999, and it is probable that this resistance will also develop in the UK , so it would be unwise to use Ensign where mildew is a prime concern. For *Rhynchosporium*, the currently available strobilurins are beneficial in azole or morpholine mixture but do not offer the advance in disease control that Amistar does for net blotch. Among other new fungicides, Unix has useful activity against net blotch, mildew and *Rhynchosporium*, but needs to be used in mixture for best effect.

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