HGCA

PROJECT REPORT No. 95

CONTROL OF SEPTORIA AND EYESPOT IN WINTER WHEAT: FUNGICIDE APPLICATIONS IN RESPONSE TO GROWTH STAGE AND FORECASTS OF DISEASE RISK

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CONTROL OF SEPTORIA AND EYESPOT IN WINTER WHEAT: FUNGICIDE APPLICATIONS IN RESPONSE TO GROWTH STAGE AND FORECASTS OF DISEASE RISK

by

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This is the final report of a four year project which commenced in May 1987. The work was led by Dr. D. J. Royle, IACR Long Ashton Research Station in collaboration with Dr. P. Mercer, Department of Agriculture for Northern Ireland, Dr. J. E. Jenkyn, IACR Rothamsted Experimental Station and Dr. M. J. Hims, Central Science Laboratory - Harpenden. The work was funded by a grant of £163,092 from the Home-Grown Cereals Authority (Project No. 0008/4/87).

CONTENTS

SUMMARY

This coordinated HGCA project attempts to provide farmers with options for saving fungicide sprays and improving disease control pre-anthesis by integrating decision-making, particularly on septoria and eyespot control. Under a wider range of conditions than would be possible otherwise, it also seeks to define more precisely critical conditions for disease development and study the effects on yield of disease epidemics which develop at different times during the season.

In 1987 observations were made at Long Ashton, Rothamsted and DANI Belfast, to develop hypotheses and experience for a series of field experiments of a common design to be established in the 1987-88 season. In an experiment at LARS with 4 cultivars of winter wheat (Avalon, Slejpner, Brock and Moulin) grown at 4 sites which differed with respect to aspect, soil type and cropping sequence, *Septoria tritici* differed in severity according to site but not cultivar. Eyespot also varied between sites rather than cultivar, though Slejpner seemed least affected. In a separate experiment, the onset of severe *S. tritici* on the top leaves of cv. Longbow was delayed to a similar extent by different forecast-guided timings of prochloraz; this was unexpected because the first application was before the top leaves had emerged. Observations at RES confirmed earlier evidence that the R-pathotype of eyespot initially progresses more slowly from leaf sheaths to stems than the W-type. Further evidence was also obtained that fungicide sprays at GS 37 can be as effective at controlling eyespot as at GS 31. In N. Ireland yields and 1000-grain weights of cv. Norman increased as the number of sprays of several fungicide combinations were increased in a field experiment. The effects of treatment on disease were not, however, consistent between assessments made at GS 57 and GS 71.

In the harvest seasons between 1988-90 field experiments were done by LARS, RES and DANI to examine the effects of different growth stage based and forecast guided spray programmes on disease progress, control and grain yield. Greatest benefits were from sprays applied to the flag leaf, though differences in disease control and yield response between sprays applied at different times after flag leaf emergence varied and were inconsistent.

In terms of yield none of the spray programmes consistently out-performed the others. However, the Long Ashton *Septoria* forecast, and a programme comprising sprays at GS37 & 59 performed consistently over cultivars, sites and seasons. A 3 spray programme always provided a significant yield increase above that of the untreated, but there was strong evidence that the 3rd spray was not economically justified in a high proportion of cases.

Satisfactory models explaining disease intensity and yield were not obtained for these experiments. In part this was because the experiments were designed for analyses by other techniques. However, recent studies at LARS have shown that the interaction between winter wheat and *S. tritici* is far more complex than previously believed. As a consequence, accurate models that are reliable in the long-term will need to account for these interactions. A model explaining yields in terms of eyespot and the maximum rate of increase of *S. tritici* on the flag and 3rd leaves was fitted to the DANI data. This model explained 84% of yield variation, but it was only appropriate for cv. Brock. None of the models fitted to Long Ashton data were convincing.

Spray programmes starting at GS31 tended to control eyespot better than those starting at GS37. Light rainfall occurring after a spray generally enhanced eyespot control, presumably

because this provided a mechanism for redistribution of the chemical to the base of the crop. In one case there was evidence that heavier rainfall may have reduced fungicide performance by washing-off, because both *S. tritici* and eyespot control were reduced.

Between 1988-89 ADAS conducted a complementary programme of 6 experiments designed to create a series of different disease epidemics. The aim was to investigate the properties of a range of protectant and eradicant fungicides, active against several foliar wheat diseases.

Moderate to severe disease caused by *Septoria tritici* occurred in five of the experiments. These experiments successfully identified some of the periods conducive for *S. tritici* infection and provided an insight into factors affecting the development of mildew and the rusts. The experiments also indicated the effect of fungicide applications, upon disease development and yield, when they were made either side of the infection periods.

Analysis of disease progress and weather records suggested that critical conditions for initial development of *S. tritici* occurred during late April to mid-June at all sites. Heavy rain, giving 5mm on 1 day or a total of 10mm or more on 2 or 3 successive days, occurred at all sites prior to the appearance of symptoms on a particular leaf layer. At two of the sites rainfall during May was considerably lower than at the other sites. This was reflected by a delay in symptom development and disease did not become severe on the top two leaves. At all sites, the length of the incubation period on any of the top three leaves varied between 295 and 448 degree days, although precise identification of the primary splash-event responsible was not always possible.

Mildew developed at only two of the sites. Rapid increase of mildew occurred only once the crop canopy was complete, indicating that crop microclimate may have an influence by governing the rate of inoculum production from within the crop. Disease progress curves supported this possibility because mildew was developing on the lower leaves prior to its appearance on younger leaves. Brown rust and yellow rust occurred at only one site each. Their appearance and progress were associated with temperatures reported to favour to infection, tissue colonisation and sporulation. However, it was impossible to estimate the times of primary or secondary infection because records of leaf wetness were not taken at either site.

Eyespot developed to slight or moderate levels at three of the six sites. A moderate or high degree of control was achieved by one or more elements of the sequential spray programmes. This effect was associated with the occurrence of moderate to substantial amounts of rain within a few days of fungicide application.

Sequential spray programmes commencing later than growth stage (GS) 31 but immediately prior to the critical periods (splash-events) for leaf infection by *S. tritici* provided the best disease control and yield benefit. Similar effects were apparent with mildew and rusts. Regression models incorporating, as independent variables, percentage leaf disease on leaves 1, 2 and/or 3 satisfactorily explained yield loss at the six sites.

1. INTRODUCTION AND AIMS

In England and Wales *Septoria tritici* and *S. nodorum* and eyespot (*Pseudocercosporella herpotrichoides*) are currently the most serious fungal diseases of winter wheat. They cause large-scale losses in yield and quality despite regular routine use of fungicides (ADAS/CSL winter wheat survey). *S. tritici* is the most important disease on wheat in N. Ireland but, although eyespot is widespread there, levels are generally low probably because cultivation is less intensive.

During the last decade, *S. tritici* appears to have replaced *S. nodorum* as the dominant *Septoria* species in the UK, possibly because of changes in fungicide and nitrogen usage and in the wheat varieties grown. Whilst its control by routine fungicide spray programmes can be effective and give economic yield responses, this is not always the case so there is scope for better timing of fungicide applications and for improving judgements of the need for sprays. Since 1982 *S. tritici* on wheat has been studied as a model system within a programme of work at Long Ashton Research Station (LARS) on disease forecasting, funded through the Office of Science & Technology (OST) and the Ministry of Agriculture, Fisheries & Food (MAFF). Inoculum concentrations in crops in spring and upward splash transport of inoculum in heavy rainfall have been identified as important limiting factors in the development of *S. tritici* epidemics. Knowledge about the mechanisms involved has been incorporated into hypotheses designed to test the principle of forecasting the need for control of this disease (Royle et al., 1986; Shaw & Royle, 1986). The basic components of this forecast are shown schematically in Fig. 1.

For some years eyespot was adequately controlled by Benzimidazole (MBC) fungicides, usually applied at the beginning of stem extension (GS 30-31). However, resistance to this group of compounds is now widespread (Griffin & Yarham, 1983; Yarham, 1986) and control with alternative compounds (mainly prochloraz) has been somewhat variable. The development of MBC-resistance has been paralleled by changes in the frequency of different pathotypes which differ in their relative pathogenicity to wheat and rye. Thus, the wheat (W)-pathotype that used to dominate has now largely been replaced by the rye (R)-pathotype (Bateman et al., 1986; Yarham, 1986) which, although more pathogenic than the W-pathotype to rye, is nevertheless damaging to both wheat and barley. Established work at Rothamsted Experimental Station

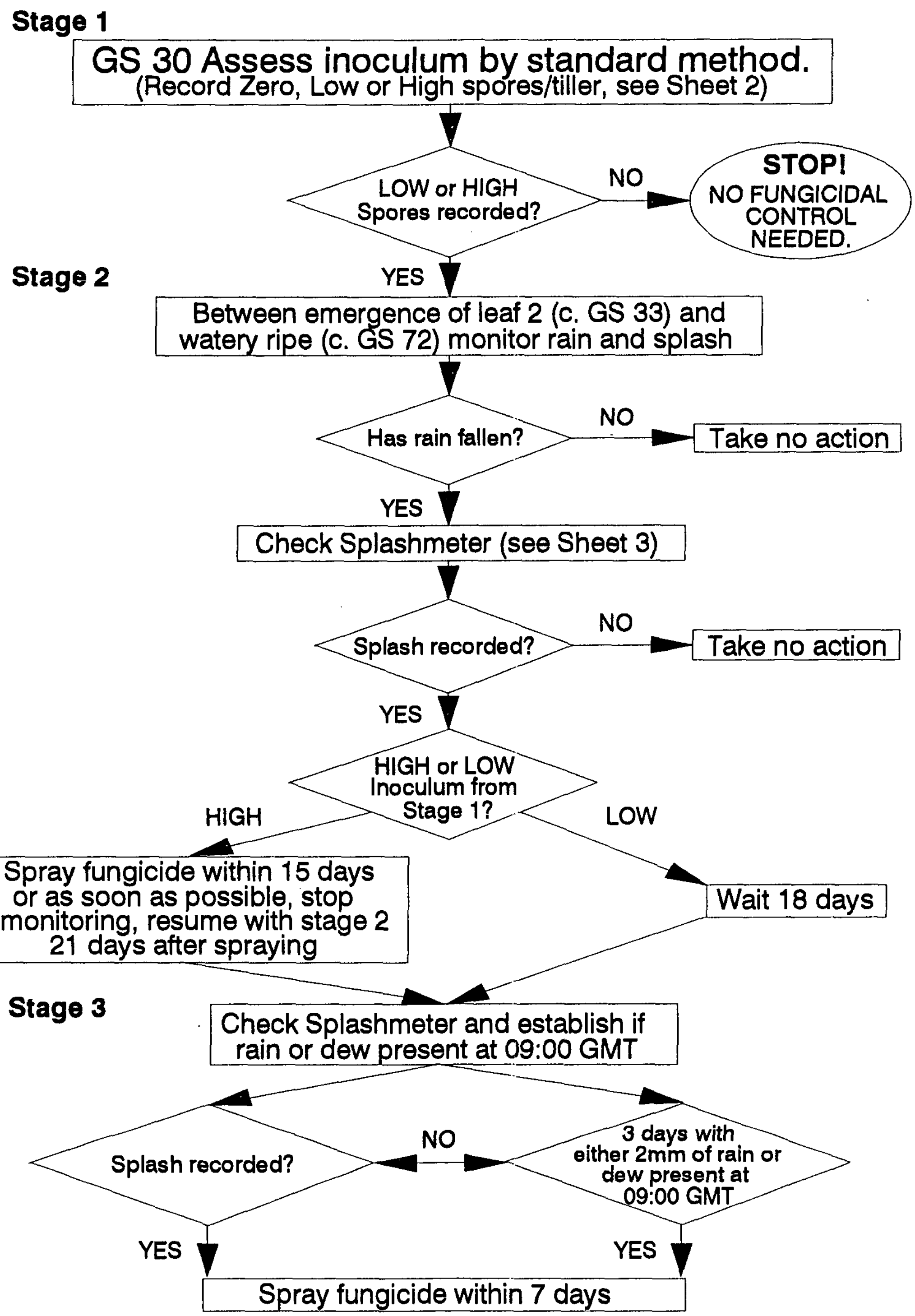


Fig. 1. Flow diagram showing the decision criteria of the LARS *Septoria tritici* forecast (Treatment C). Sheets 2 and 3 (referred to at stages 2 & 3) are shown in Appendix I.

(RES), largely funded by MAFF, is studying the comparative epidemiology of W- and R-type isolates with the longer term aim of improving forecasting and control.

In detailed studies on *Septoria* and eyespot it is often desirable to avoid infection with other pathogens so, in the eyespot experiments for example, crops are usually grown after a break, plots are inoculated with the appropriate pathotypes and fungicides are applied routinely to control other diseases. However, the situation is very different in farmers' crops where several diseases occur and interact and where fungicides applied to control one disease may also be used or have useful side-effects on others (*e.g.*, prochloraz for both eyespot and *Septoria* control). This coordinated HGCA project attempts to provide farmers with options for saving fungicide sprays and improving disease control pre-anthesis by integrating decision-making, particularly on *Septoria* and eyespot control. Under a wider range of conditions than would be possible otherwise, it also seeks to define more precisely critical conditions for disease development and study the effects on yield of disease epidemics which develop at different times during the season.

Studies toward integrating *S. tritici* and eyespot control were undertaken at LARS, RES and DANI. Data collected in this element of the work are reported in Section 2. Conditions for disease development and the effects on crop yield from delays in disease onset were done by CSL and ADAS and are reported in Section 3. Finally, Section 4 provides a summary linking these two pieces of work, with particular reference to the implications for disease management in winter wheat.

2. COMPARISON OF FORECAST AND PROPHYLACTIC SPRAY PROGRAMS

2.1 Background

Currently, around 50% of UK winter wheat crops receive 2 fungicide sprays, 25% receive 3 and a further 5% receive 4 or more (ADAS/CSL - winter wheat survey). The justification for such frequent treatments is claimed from trial evidence that indicates worthwhile yield responses. However, ADAS/CSL national surveys show that some important diseases *e.g.*, leaf and glume blotches caused by *Septoria spp.* are frequently as severe now as during the early 1970s when fungicide inputs were much lower. Moreover, there has been a discernible shift in the cost:benefit equation for cereal production. Public awareness and concern about the environmental burden and perceived health risks from fungicides, have been heightened by campaigners and the media. Also, producers have found that their profit margins have narrowed considerably. Disease management must therefore balance two apparently disparate aims, by both reducing fungicide input and maintaining satisfactory disease control. This can only be achieved by making fungicide applications more effective and efficient.

Rational control of fungal diseases in cereals necessitates that the need for and timing of control measures are determined with precision. This implies that we must be able to predict the risk of disease development and the ensuing yield loss.

2.2 Preliminary Studies: 1986-87

The first year of the HGCA-funded work started in the middle of the 1986-87 growing season so a number of separate preliminary observations were made at Long Ashton Research Station, Rothamsted Experimental Station and Belfast, DANI. These were used to develop hypotheses and experience to provide a foundation for the coordinated series of field experiments undertaken in subsequent years.

2.2.1 Methods: 1986-87 Experiments

(a) *Long Ashton Research Station*

Observations were made on the development patterns of several diseases in winter wheat cultivars with varying resistance patterns and in contrasting situations. Small, unreplicated blocks (12 x 4 m) of Avalon, Slejpner, Brock and Moulin were sown on 2 - 3 October 1986 at

4 locations at LARS differing according to aspect, soil type and cropping sequence (Table 1). Leaf diseases were recorded on five occasions from 15 May - 22 July and eyespot on 10 July (GS 75-79).

Table 1. **Characteristics of the Long Ashton sites, 1986-87**

	Site			
	A	B	C	D
Aspect:	Flat	Slopes east	Slopes south	Slopes south
Soil:	Red/brown, deep fine sandy loam. Imperfectly drained. Low organic matter. Weakly structured.	Red/brown silty clay loam. Poorly drained.	Reddish loam over sandstone. Well drained.	Clay loam with brash. Poorly drained.
Previous cropping:				
1986	Fallow	Potatoes	Grass/fallow	Winter wheat
1985	"		"	"
1984	"		Mixed trees	"
1983	Winter wheat			Winter oilseed rape
1982	Winter barley			Winter wheat

HGCA funding also allowed observations to be made on the response of *S.tritici* development to single applications of prochloraz made in replicated plots (12 x 6 m) of cv. Longbow at: GS 31 (to simulate an eyespot control spray); as soon as possible after *Septoria* infection was first forecast using a splashmeter (Royle *et al.*, 1986); or 2 weeks after *Septoria* infection was first forecast. This was part of a larger 'forecasting' trial designed to study the effects of weather and inoculum amounts on the *S. tritici* populations in wheat, and reported elsewhere by Shaw & Royle (1987).

(b) *Rothamsted Experimental Station*

Eyespot disease is difficult to identify and quantify, particularly prior to stem extension. For this reason little field work was done in the first year. Instead, the opportunity was taken to familiarise the technician responsible for field monitoring, with the principal diseases of wheat and techniques for the isolation and characterisation of the causal pathogens, especially *P. herpotrichoides*. In addition data from related work in 1987 were collated.

(c) *Belfast, DANI*

A field experiment was done to examine the effects of different fungicides, applied singly and in 2- and 3-spray programmes on control of mainly *S. tritici* and on yield. Replicated plots (15 x 2 m) of cv. Norman were sown on 25 September 1986 and harvested on 7 September 1987. Diseases were assessed twice during the season.

2.2.2 Results & Discussion: 1986-87 Experiments

(a) *Long Ashton Research Station*

In response to rainy weather in late May-June, *S. tritici* developed relatively late in the season though severely in some treatments (Table 2). Differences in disease levels were explained not by cultivars but by sites (Table 3); this result was partly attributable to some accidental spraying of fungicide to site D, though sites A and B generally sustained more disease than C or D. Even though there was no significant effect of cultivar, there was a tendency for Brock and Slejpner to sustain more severe disease than Avalon and Moulin at the unsprayed sites.

Eyespot was most severe on sites A and D (Table 4). Site D followed 2 years of winter wheat, whilst site A followed fallow but was obviously very fertile with plants larger and growing well in advance of those at other sites. Low levels of eyespot arose at site C on which there had never been cereal cropping. Any differences in eyespot levels between cultivars were slight and were more marked at low incidence. Slejpner tended to sustain the least disease.

In the 'forecasting' experiment, all three timings of prochloraz delayed the appearance of severe disease on the flag and leaf 2 by about 10 days but did not prevent it altogether. The effect of the timings was indistinguishable, which was surprising since treatment E was applied before either of the 2 top leaves were present. This observation has important implications for use of prochloraz and related fungicides in conjunction with forecasting and was explored further in the coordinated field experiments that followed between 1987-89. Laboratory studies suggest that prochloraz shows little upward movement within the plant and little activity against spores or established pycnidia.

Table 2. *Septoria tritici* **severity on different cultivars and at different sites, Long Ashton 1987**

		Site							
		A		B		C		D	
Date	Cultivar	flag	2nd	flag	2nd	flag	2nd	flag	2nd
15/05	A	0	0	0	0	0	0	0	0
	S	0	0	0	0	0	0	0	0
	B	0	0	0	0	0	0	0	0
	M	0	0	0	0	0	0	0	0
04/06	A	0	0.1	0	0.2	0	0	0	0
	S	0	0	0	0	0	0	0	0
	B	0	0	0	0	0	0	0	0
	M	0	0.1	0	0.1	0	0	0	0
25/06	A	0	3.0	0.1	8.8	0	0.2	0	0.1
	S	0	0.3	0	9.4	0	0	0	0
	B	0.1	3.1	0.1	28.1	0.1	0.1	0	0
	M	0.1	7.1	0.1	12.8	0	0	0	0
09/07	A	0.9	4.7	0.8	44.1	1.2	12.2	0.1	0.2
	S	5.5	19.0	6.2	76.8	1.4	18.5	0.1	0.5
	B	30.3	31.0	3.5	46.0	0.9	17.6	0	0.4
	M	12.3	6.5	1.4	40.4	0.4	5.3	0	5.9
22/07	A	41.0	-	78.0	-	82.0	-	5.2	-
	S	77.0	-	85.0	-	60.0	-	4.9	-
	B	88.0	-	89.0	-	78.0	-	4.8	-
	M	91.0	-	88.0	-	51.0	-	2.1	-

A, Avalon; S, Slejpner; B, Brock; M, Moulin

Table 3. **Analysis of variance of data presented in Table 2.**

	Contrast					
	Site x cultivar		Site[a]		Cultivar[a]	
Date	flag	2nd	flag	2nd	flag	2nd
15/05						
04/06	NS	NS	NS	*	NS	NS
25/06	NS	*	*	**	NS	NS
09/07	***	**	**	**	NS	NS
22/07	**	-	***	-	NS	-

Table 4. **Number of main stems from 10 with eyespot for different cultivars at different sites, Long Ashton 1987.**

	Site				
Cultivar	**A**	**B**	**C**	**D**	**All sites**
Avalon	10(7)[a]	5(1)	3(0	9(6)	**27(14)**
Slejpner	8(2)	4(0)	0(0)	7(2)	**19(4)**
Brock	10(9)	2(0)	1(1)	9(6)	**22(16)**
Moulin	10(6)	5(1)	1(0)	7(4)	**23(11)**
All cultivars	**38(24)**	**15(2)**	**5(1)**	**32(18)**	

[a] numbers in parentheses equal number of stems with severe eyespot

(b) *Rothamsted Experimental Station*

Results obtained in 1987 confirmed earlier evidence for differences in the epidemiology of the different pathotypes of *P. herpotrichoides*. They suggest that the R-pathotype initially progressed less rapidly from the leaf sheaths to the stems than did the W-pathotype although by the end of the season the disease was equally severe with both pathotypes (Table 5). Further evidence was also obtained that relatively late sprays (at about GS 37) of carbendazim and prochloraz can be at least as effective as earlier sprays, which was encouraging for the prospect of integrating control of eyespot and *Septoria* in spring. Samples were taken in July 1987 to characterise the eyespot population in a crop of winter wheat which preceded the field experiment sown in the autumn 1987 as part of the coordinated HGCA series. Of the stems sampled, 48% were affected by eyespot and 29% by sharp eyespot. Tests showed that the proportions of R- and W-pathotypes were 69 and 31% respectively.

Table 5. **Eyespot in plots inoculated with Rye and Wild pathotypes, Rothamsted 1987**

		% stems with leaf sheath lesions	% stems with moderate or severe lesions	
Crop	**Inoculum**	**GS30-31[a]**	**15 June**	**3 July**
Barley	W-type	86	78	92
	R-type	82	32	90
Wheat	W-type	88	37	88
	R-type	89	23	84

[a] Barley sampled on 20 April, wheat on 29 April

(c) *Belfast, DANI*

Table 6 shows that increasing yields and 1000-grain weights resulted from increasing the number of sprays applied. Although there were also significant effects of fungicide sprays on amounts of *S. tritici*, visually these did not appear to be very great. Better understanding of the relationship between *S. tritici* and yield seems to be needed. Amounts of eyespot in this experiment were low with an average index value at harvest of 1.6 and no significant effect of fungicides.

Table 6. Effect of different fungicides and timing on the severity of *Septoria tritici*, yield and 1000-grain weights in cv. Norman, Hillsborough, N. Ireland 1987

Treatment[a]	% severity of *S. tritici*[a] GS57	GS71	Yield th^{-1} (15% moisture)	1000-grain dry weight (g)
MBC[b]	8.4 (16.9)	5.2 (13.2)	8.3	60.5
Prop[c]	10.2 (18.6)	8.4 (16.8)	8.2	64.7
Proch[d]	5.8 (14.0)	7.9 (16.3)	8.4	63.0
Chlor[e]	13.2 (21.3)	11.3 (19.6)	8.6	62.6
MBC, Prop	10.2 (18.6)	8.4 (16.8)	8.6	65.4
Proch, Prop	11.5 (19.8)	3.0 (10.0)	8.6	65.3
MBC, Prop, Chlor	9.2 (17.7)	9.6 (18.1)	8.6	65.9
Proch, Prop, Chlor	5.1 (13.1)	5.3 (13.3)	9.0	65.3
Untreated	12.4 (20.6)	13.9 (21.9)	8.0	59.9
SE (42df)	(2.3)	(1.9)	0.2	0.6
		***	***	***

[a] values in parentheses are arcsin transformed
[b] Listed in order of application: first at GS37, second at GS57 & third at GS71
[c] Benzimidazole [d] Propiconazole [e] Prochloraz [f] Chlorothalonil

2.3 Replicated Field Experiments at 3 Regional Sites: 1988-90

2.3.1 Experimental detail: 1988-90

Five replicated field experiments with an identical design were established, 2 each at LARS and DANI and one at RES. The aim was to compare disease control and yield response at different sites and on different cultivars in response to a range of fungicide treatments, applied either routinely according to crop growth stage or in response to disease forecasts.

The LARS and RES experiments included 3 cultivars, Longbow, Avalon and Rendezvous, chosen for their differing susceptibilities to eyespot and Septoria (Table 7). Those in Belfast varied over the period of the study (Table 7). Ten treatments being examined (Table 8). Prochloraz was used for all sprays up to GS 37, propiconazole from GS 39 onwards.

At intervals, from GS32-80, random destructive samples of 10 main tillers were taken from across the half portion of each plot designated for disease assessment. Untreated plots were sampled weekly. Other treatments were sampled at approximately fortnightly intervals starting from the first application of fungicide. Fully expanded leaves, less than 50% senescent were scored visually for the percentage severity of *S. tritici, S.nodorum,* powdery mildew yellow rust and brown rust.

Table 7. Details of HGCA experimental field sites at Long Ashton Research Station (LARS), Rothamsted Experimental Station (RES) and Department of Agriculture N. Ireland (DANI), between 1988-90

Year	Crop	Sowing date	Cultivar	Site identification
Long Ashton Research Station				
1988	1st wheat	30/10/87	Avalon Longbow Rendezvous	LA1-88
	2nd wheat	01/11/87	as above	LA2-88
1989	1st wheat	18/10/88	as above	LA1-89
	2nd wheat	17/11/88	as above	LA2-89
Rothamsted Experimental Station				
1988	1st wheat		as above	RES1-88
1989	2nd wheat		as above	RES2-88
Belfast, DANI				
1988	1st wheat	17/10/87	Brock	DAN1-88
	2nd wheat	02/10/87	Brock	DAN2-88
	1st wheat	20/09/88	Hornet	DAN1-89
	3rd wheat	30/09/88	Fortress	DAN2-89
	1st wheat	27/09/89	Brock	DAN1-90
	3rd wheat	12/10/89	Mercia	DAN2-90

On several occasions during the season (weekly at RES), 25 main tillers from the designated areas of each plot were destructively sampled. These were carefully rinsed under running water. Sharp eyespot and *Fusarium* were scored as presence/absence and the percentage incidence of each was calculated. Eyespot was recorded as severity using the scale described by Scott &

Hollins (1974).

Table 8. Description of the 10 treatments compared at LARS, RES and DANI between 1988-1990

Treatments	
A	Unsprayed
B	Forecast (ADAS criteria[1]) eyespot spray (prochloraz).
C	*Septoria* forecast priority (see Fig. 1). If no *Septoria* spray called for up to GS37 then prochloraz applied at GS37 only if eyespot threshold (ADAS criteria) is met. Thereafter, propiconazole according to *Septoria* forecasts.
D	Prochloraz at GS31.
E	Prochloraz at GS31, then *Septoria* forecast sprays (propiconazole).
F	Prochloraz at GS31, propiconazole at GS39.
G[2]	Prochloraz at GS31, propiconazole at GS39 & GS59
G_R[3]	Prochloraz at GS31, propiconazole at GS59
H	Prochloraz at GS37
I	Prochloraz at GS37, then *Septoria* forecast sprays (propiconazole).
J	Prochloraz at GS37, propiconazole at GS59

[1] ADAS criteria: >20% of stems with lesions penetrating 2 or more leaf sheaths at GS30. If not, delay spray decision according to further inspections up to GS32.
[2] Not applied at Rothamsted
[3] Not applied at Long Ashton or Belfast, DANI

2.3.2 Foliar Disease

(a) Belfast, DANI

1988 harvest season

Although most of the season had average rainfall, April and May were relatively dry at the 2 sites DAN1-88 and DAN2-88. As a consequence of this dry spell only moderate levels of *S. tritici* developed. Other diseases were absent throughout the monitoring period. The upper leaves had trace levels of *S.tritici* until around anthesis, GS60, after which the rate of disease progress increased. Between treatments, differences in disease on leaves 4-3 were negligible. However, for leaves 2-flag, there were significant differences between treatments from around GS70 (Table 9 & 10). At both sites treatment G, the 3 spray programme, gave the most complete protection. More generally, treatments with an early spray at GS31 gave the best control.

Table 9. Mean severity of *S. tritici* on leaves 2-flag, in the 1st wheat (DAN1-88) at GS74.

Treatment	Mean severity of *Septoria tritici* (%)			
	leaf 2		flag leaf	
	cube root transformed	back-transform	cube root transformed	back-transform
A untreated	1.47	3.20	2.68	19.14
D GS31	1.28	2.08	2.28	11.84
E GS31 + F	0.89	0.71	1.85	6.32
F GS31 + 39	0.62	0.24	1.94	7.27
G GS31 + 39 + 59	0.41	0.07	1.27	2.04
H GS37	1.08	1.25	1.96	7.56
I GS37 + F	1.54	3.68	2.87	23.57
J GS37 + 59	0.75	0.43	2.21	10.72
LSD 5%	0.50		0.74	

Table 10. Mean severity of *S. tritici* on leaves 2-flag, in the 3rd wheat (DAN2-88) at GS74.

Treatment	Mean severity of *Septoria tritici* (%)			
	leaf 2		flag leaf	
	cube root transformed	back-transform	cube root transformed	back-transform
A untreated	2.41	13.95	1.08	1.21
D GS31	2.33	12.71	0.97	0.91
E GS31 + F	2.10	9.20	0.62	0.24
F GS31 + 39	1.86	6.47	0.77	0.46
G G31 + 39 + 59	1.39	2.68	0.08	0.00
H GS37	2.65	18.65	1.16	1.55
I GS37 + F	2.16	10.06	0.81	0.53
J GS37 + 59	1.99	7.90	0.41	0.07
LSD 5%	0.72		0.35	

1989 harvest season

In 1989 rainfall was well below average over much of the season. This led to some drought stress at both sites, and early harvesting. Levels of *S. tritici* were comparatively lower than in 1988. However, mildew was present at moderate levels at both sites and yellow rust was a problem. All treatments tended to reduce levels of *S. tritici*. However, it was not possible to identify one treatment as more effective than the rest.

Yellow rust was much more severe on the 3rd wheat, DAN2-89, than on the 1st wheat DAN1-89. Significant differences in yellow rust severity due to treatment were not detected at either site.

1990 harvest season

Septoria tritici was restricted to leaves 3 and 4 until after GS55/56. For the first wheat, DAN1-90, the flag leaf suffered only trace levels of disease. However, for the 3rd wheat, DAN2-90, high levels of disease were recorded on the flag leaf from GS71 onwards. This can be attributed to particularly favourable weather conditions at the 3rd wheat site.

Mildew was a constant problem at both sites and required treatment with the selective fungicide tridemorph. This has no effect against *Septoria* and was applied at GS32 & 51 at DAN1-90 and at GS37 at DAN2-90.

Yellow rust was recorded at neither site during the monitoring period.

(b) Long Ashton Research Station

1988 harvest season

Generally the patterns of development of *S.tritici* in the untreated plots were consistent with NIAB ratings. Thus, cv. Longbow suffered most disease and cv. Rendezvous least. However, rapid late development of disease on the flag leaf of cv. Rendezvous exceeded the maximum disease severity on cv. Avalon for this leaf layer.

For all 3 cultivars disease development in May (leaves 6-4) was followed by a period during June of little disease progress. Disease began to increase on leaves 3-flag towards the end of June.

The longevity of leaf layers was similar on the 3 cultivars and no clear differences were detectable in the rates of senescence. However, there was some evidence that the senescence on the flag leaf of cv. Rendezvous was slightly delayed. This may be an artefact of sampling and assessment errors, but it does explain the late records of high disease severity on the flag leaf of Rendezvous.

1989 harvest season

Levels of *S. tritici* were comparatively much lower in 1989 than in 1988. This was presumably due to the uncharacteristic dry spring and summer experienced in 1989. At both sites, DAN1-90 & DAN2-90, the flag leaves remained virtually clean of disease. For cvs. Rendezvous and Avalon leaves 3-2 suffered less than 3% disease. On cv. Longbow these leaves were slightly more seriously affected, but only towards the end of leaf life and at levels well below 10%. Differences in *S. tritici* due to treatment were not significant.

2.4.1 Eyespot control

There is limited information about the conditions that lead to damaging attacks of eyespot. As a consequence, control strategies against the disease are based mainly upon comparative yield trials. These indicate that good eyespot control can be achieved by a fungicide spray applied at GS31. Delaying this spray until GS37 reduces the efficacy of the control obtained.

The practical implementation of forecast based control strategies, such as the LARS splashmeter system for *S. tritici*, will be considerably enhanced if other diseases can be controlled effectively at the times triggered by the forecast. A principal aim of this study was therefore to delay application of the eyespot control spray to coincide with a spray targeted specifically against *S. tritici*.

1988 harvest season

(i) Long Ashton Research Station

Site LA1-88: Eyespot severity levels prior to harvest were low (9.1%, cv. Avalon; 9.6%, cv. Longbow; 4.5%, cv. Rendezvous). Little or no benefit was achieved from the various spray programmes for cv. Longbow or cv. Rendezvous. On cv. Avalon, severity was reduced to between 1-7% below the unsprayed level. Treatments including a spray at GS31 appeared to be most successful, but because eyespot levels were low and the differences between treatments small, it is not possible to validate these observations statistically.

Site LA2-88: Eyespot severity was higher at this site and major differences between treatments were discernible. The cultivars Avalon and Longbow were most seriously affected, severity on cv. Rendezvous was below a level that would lead to an economic yield loss. However, the same evidence of control was shown across all 3 cultivars (Table 11). The LARS forecast treatment (C) did not control eyespot at this site. Programmes with sprays at either GS31 or GS37 suppressed eyespot intensity, best control being achieved with treatments that included a GS31 spray. Rainfall occurred soon after sprays applied at GS31 and GS37, but not after the spray triggered by the LARS forecast at GS32/33 (Fig. 2).

(ii) Rothamsted Experimental Station

1988 harvest season

Site RES-88: Eyespot control achieved by GS31 applications was greater than from sprays applied later. This was particularly pronounced for Rendezvous where the difference was statistically significant (Table 12). For cvs. Longbow and Avalon, the same pattern of control was detected but this was not validated by the statistical tests.

Table 11. Eyespot severity prior to harvest at Long Ashton (site LA2-88), 1988

			Eyespot severity	
Treatment		cv. Avalon	cv. Longbow	cv. Rendezvous
A	Untreated	32.1	34.1	1.4
C	LARS forecast[1]	30.7	17.9	2.7
D	GS31	10.3	5.5	0
E	GS31 + forecast[2]	2.2	3.4	1.1
F	GS31 + 39	5.5	2.2	0
G	GS31 + 39 + 59	8.7	3.5	0
H	GS37	15.5	6.3	1.2
I	GS37 + forecast[3]	14.0	10.0	1.1
J	GS37 + 59	17.1	12.7	1.3

[1] Forecast sprays applied at GS33 + 55
[2] Forecast spray applied at GS45
[3] Forecast spray applied at GS65

Table 12. Eyespot severity prior to harvest at Rothamsted (site RES-88), 1988

Treatment		Eyespot severity		
		cv. Avalon	cv. Longbow	cv. Rendezvous
A	Untreated	65.8	66.7	33.3
B	ADAS forecast[1]	43.3	53.3	28.3
C	LARS forecast[2]	45.8	58.3	19.2
D	GS31	41.7	49.2	10.8
E	GS31 + forecast[3]	42.5	46.5	13.3
F	GS31 + 39	37.5	42.5	21.7
G_R	GS31 + 39	43.3	42.1	11.7
H	GS37	50.0	56.7	30.0
I	GS37 + forecast[4]	51.2	55.0	30.8
J	GS37 + 59	48.3	55.8	27.5

[1] Forecast sprays applied at GS31
[2] Forecast spray applied at GS37 + 67
[3] Forecast spray applied at GS37
[4] Forecast spray applied at GS37 + 67

(iii) Belfast, DANI

1988 harvest season

Site DAN1-88: Treatments for which the first spray was delayed until GS37 generally provided some reduction in eyespot severity, but ANOVA indicated that levels were not significantly lower than in untreated plots (Table 13). A single spray at GS31 did not reduce eyespot severity to a level that was statistically distinguishable from the unsprayed, or treatments including a first spray at GS37. However, when the GS31 spray was complemented with a later spray at GS39, control was improved above that of treatments that did not receive a spray at these growth stages (Fig 3).

Unfortunately, meteorological records were not site specific for the Belfast experiments so accurate rainfall records are not available. It is therefore impossible to discover if the GS37 spray was coincident with a dry spell, in contrast to light rainfall after the GS39 spray. Such a scenario would lead to redistribution of the GS39 spray to the base of the crop, but not the GS37 spray. This would explain the comparatively enhanced eyespot control achieved by the GS39 application.

Table 13. Mean eyespot severity prior to harvest at DANI, 1988

Treatment		Eyespot severity DAN1_88 (cv. Brock)	Eyespot severity DAN2_88 (cv. Brock)
A	Untreated	57.7	53.5
C	LARS forecast[1]	36.7	26.2
D	GS31	45.9	43.1
F	GS31 + 39	39.2	33.3
G	GS31 + 39 + 59	28.9	28.3
H	GS37	47.5	54.6
I	GS37 + forecast[2]	65.9	47.6
J	GS37 + 59	45.8	44.2
	lsd (5%)	16.6	15.3

[1] Forecast sprays applied (incorrectly) at GS39 + 72
[2] Forecast spray applied (incorrectly) at GS72

1989 harvest season

(i) Long Ashton Research Station

Sites LA1-89 and LA2-89: The variation in eyespot severity between treatments was high. Several treatments were more severely diseased than untreated plots (Fig. 4). No common pattern, with respect to spray timings was evident for this variability.

(ii) Belfast, DANI

Site DAN1-89: Eyespot levels were high in all treatments (Table 14), and ANOVA detected no significant differences between any treatment and the unsprayed. Rainfall was heavy after the early sprays (Table 15). Therefore, it is possible that these sprays were, to some extent, washed-off. This is supported by observations made of the development of *S. tritici*, particularly on leaf 4 (Table 16).

Table 14. Mean eyespot severity prior to harvest at DANI, 1989

Treatment		Eyespot severity DAN1_89 (cv. Hornet)	Eyespot severity DAN2_89 (cv. Fortress)
A	Untreated	83.8	91.3
C	LARS forecast[1]	76.3	59.4
D	GS31	70.6	71.9
E	GS31 + forecast	69.4	53.1
F	GS31 + 39	70.0	58.1
G	GS31 + 39 + 59	68.8	50.6
H	GS37	76.3	80.6
I	GS37 + forecast[2]	85.0	75.6
J	GS37 + 59	76.9	74.4
	lsd (5%)	17.5	10.8

Table 15. Daily rainfall in relation to application of sprays at GS31 and GS 32 at site DAN1-89

	rainfall (mm)		
	5.5	7.4	
GS31⇉	0.3	0.1	⇇GS32
	4.6	3.4	
	0	12.2	
	12.1	11.6	
	0	2.4	

Table 16. Maximum severity of *Septoria tritici* on leaves 4-2 at Belfast site DAN1-89 in 1989

Treatment	*S. tritici* severity (%) leaf 2	leaf 3	leaf 4
untreated (A)	0.9	5.2	14.9
GS31 (D)	2.0	4.2	19.8
GS31 + 39 (F)	1.3	7.5	14.1
GS31 + 39 + 59 (G)	0.4	3.1	13.6
GS32 + 34.5 + 59 (C)[a]	0.6	2.8	4.5
GS32 + 34.5 + 59 (E)[a]	0.2	2.2	4.6

[a] *S. tritici* forecast sprays timed incorrectly

1990 harvest season

(i) Belfast DANI: Levels of eyespot were low and none of the treatments differed significantly from the untreated at either DAN1-90 or DAN2-90 (Table 17).

Table 17. Mean eyespot severity prior to harvest at DANI, 1990

		Eyespot severity	
Treatment		DAN1_90 (cv. Brock)	DAN2_90 (cv. Brock)
A	Untreated	5.6	6.9
C	LARS forecast[1]	18.7	5.6
D	GS31	5.6	10.0
E	GS31 + forecast	12.5	5.0
F	GS31 + 39	16.9	7.5
G	GS31 + 39 + 59	14.4	11.9
H	GS37	3.1	11.9
I	GS37 + forecast[2]	14.4	10.0
J	GS37 + 59	3.7	4.4
	lsd (5%)	14.5	6.7

2.3.2.1 Yields

(a) Yield comparisons

Yield data in this section are reported in contrast to the unsprayed treatment A. Thus, unless specified otherwise, treatment response/improvement refers directly to this comparison.

(i) *Long Ashton Research Station*

Over the two years of the experiment, no treatment was consistently better than the rest. However, in terms of accumulated yield improvement above the unsprayed plots, treatments C (LARS forecast), J (GS37 + 59) and G (GS31 + 39 + 59) were the most successful.

1988 harvest

First wheat (LA1-88)

Yields were generally good at >9 t ha^{-1} for the best treatment (Table 18). The LARS forecast treatment (C) gave the best yield response for cvs. Avalon and Longbow (Table 18). However, for cv. Longbow, low yielding plots from treatments C, J and G led to a high coefficient of variation between treatments. As a consequence, statistical differences between treatments for this cultivar were not detected. The low yielding plots were confined to one corner of the trial. When these were excluded from the analyses, treatments C (LARS forecast), J (GS37 + 59) and E (GS31 + LARS forecast) were found to have the best yield responses

Treatment E (GS31 + LARS forecast) gave the highest yield for cv. Rendezvous. Several treatments, including G (GS31 + 39 + 59) and C (LARS forecast) were statistically indistinguishable from E (Table 18).

Second wheat (LA2-88)

Yields were marginally lower than achieved in the 1st wheat at >8.5 t ha^{-1} for the best treatments (Table 19). Treatment G provided the greatest yield for cv. Avalon and the second greatest yield for cvs. Longbow and Rendezvous. For all 3 cultivars treatment C (LARS forecast) was indistinguishable from the best treatment.

Table 18. Mean plot yields (@15% moisture) for Long Ashton, 1st wheat, 1988 (LA1-88)

Treatment			Yield (t ha^{-1})	
		Avalon	Longbow[a]	Rendezvous
A	Untreated	8.13	7.78	7.85
B	ADAS forecast	8.55	8.19	8.29
C	LARS forecast	9.08	8.66 (9.77)	8.83
D	GS31	8.60	9.23	8.56
E	GS31 + forecast	8.87	9.66	9.07
F	GS31 + 39	8.30	8.38	8.91
G	GS31 + 39 + 59	9.03	7.47 (8.69)	9.04
H	GS37	8.75	8.52	8.22
I	GS37 + forecast	8.88	8.41	8.83
J	GS37 + 59	8.99	7.98 (9.64)	8.89
	LSD (5%)	0.67	-	0.79

[a]Values in parentheses are mean yields excluding anomalous plots that were located in one corner of the trial

Table 19. Mean plot yields (@15% moisture) for Long Ashton, 2nd wheat, 1988 (LA2-88)

		Yield (t ha^{-1})		
Treatment		**Avalon**	**Longbow**	**Rendezvous**
A	Untreated	7.24	7.31	7.28
B	ADAS forecast	7.76	6.75	7.21
C	LARS forecast	8.45	9.14	8.05
D	GS31	8.07	8.07	7.38
E	GS31 + forecast	8.43	9.07	7.47
F	GS31 + 39	8.58	9.43	7.85
G	GS31 + 39 + 59	8.91	9.35	8.46
H	GS37	8.11	7.83	7.56
I	GS37 + forecast	8.63	8.72	7.48
J	GS37 + 59	8.61	8.80	8.55
	LSD (5%)	0.63	0.70	0.78

1989 harvest

First wheat (LA1-89)

Yields were low on all 3 cultivars at <7.5 t ha^{-1} even for the best treatments (Table 20). Treatments were statistically indistinguishable from the unsprayed plots for all 3 cultivars. However, in terms of yield, the unsprayed was ranked lowest for cvs. Longbow and Rendezvous and 3rd lowest for cv. Avalon (Table 20).

Table 20. **Mean plot yields (@15% moisture) for Long Ashton, 1st wheat, 1989 (LA1-89)**

Treatment			Yield (t ha^{-1})	
		Avalon	**Longbow**	**Rendezvous**
A	Untreated	6.52	7.50	6.20
B	ADAS forecast	7.00	8.06	6.64
C	LARS forecast	7.08	8.03	7.10
D	GS31	7.10	7.44	6.67
E	GS31 + forecast	6.97	8.06	6.92
F	GS31 + 39	7.34	7.69	6.59
G	GS31 + 39 + 59	7.04	8.24	6.50
H	GS37	6.63	7.96	6.14
I	GS37 + forecast	6.65	8.43	6.82
J	GS37 + 59	6.51	7.99	6.62
	LSD (5%)	0.71	1.80	0.88

Second wheat (LA2-89)

Yields were also low at LA2-89, although in excess of 8 t ha^{-1} was achieved by the best of the treatments for cv. Longbow (Table 21). None of the treatments gave a yield significantly different from the unsprayed treatment (which, in terms of yield, had the second lowest rank for all 3 cultivars).

Table 21. Mean plot yields (@15% moisture) for Long Ashton, 2nd wheat, 1989 (LA2-89)

Treatment			Yield (t ha^{-1})	
		Avalon	Longbow	Rendezvous
A	Untreated	6.87	6.74	6.79
B	ADAS forecast	7.23	7.04	6.89
C	LARS forecast	7.02	7.13	6.95
D	GS31	6.95	7.29	6.95
E	GS31 + forecast	6.75	7.31	7.19
F	GS31 + 39	6.85	7.05	7.00
G	GS31 + 39 + 59	7.24	7.15	6.93
H	GS37	7.12	6.89	7.41
I	GS37 + forecast	7.12	6.89	7.18
J	GS37 + 59	7.04	7.38	7.35
	LSD (5%)	0.47	1.12	0.57

(ii) *Rothamsted Experimental Research Station*

1988 harvest

The LARS forecast treatment performed consistently and was statistically indistinguishable from the highest yielding treatment across all 3 cultivars (Table 22). Treatments with an early spray around GS31/33 and a later spray to the flag leaf were most successful

Table 22. Mean plot yields (@15% moisture) for Rothamsted, 1988 (RES-88)

Treatment			Yield (t ha^{-1})	
		Avalon	Longbow	Rendezvous
A	Untreated	7.32	7.79	7.88
B	ADAS forecast	8.05	8.61	8.82
C	LARS forecast	8.78	9.14	9.58
D	GS31	8.28	8.92	8.34
E	GS31 + forecast	8.08	8.66	8.58
F	GS31 + 39	8.99	9.44	8.91
G_R	GS31 + 59	8.54	9.58	9.10
H	GS37	7.95	8.25	8.71
I	GS37 + forecast	7.99	8.15	8.92
J	GS37 + 59	8.35	9.34	9.03
	LSD (5%)	0.60	0.79	0.67

1989 harvest

As at Long Ashton, yields were comparatively lower in 1989 than in 1988 (Table 23). Some treatments timed by forecast were identical to growth stage based treatments and these were combined for the purposes of analysis. None of the treatments performed consistently better than the rest.

Table 23. Mean plot yields (@15% moisture) for Rothamsted, 1989 (RES-89)

		Yield (t ha^{-1})		
Treatment (replicates)		Avalon	Longbow	Rendezvous
A	Untreated (4)	5.88	7.02	6.59
B	ADAS forecast (8)	6.81	7.82	6.90
C	LARS forecast (12)	6.57	7.68	6.48
E	GS31 + forecast (4)	6.34	7.87	6.79
F	GS31 + 39 (4)	5.87	7.69	6.68
G_R	GS31 + 59 (4)	6.80	7.64	6.57
I	GS37 + forecast (4)	6.46	7.64	6.95
	LSD (5%): min-rep	0.81	0.75	0.35
	max-min	0.66	0.62	0.28
	med-max	0.52	0.49	0.23
	med-min	0.71	0.65	0.30

(iii) *Belfast, DANI*

The LARS forecast regime (treatment C) was only applied correctly at the N. Ireland sites in 1990, prior to this there was some confusion about the correct analysis of the splashmeter information.

<u>1988 harvest</u>

The 3-spray program (treatment G) gave the best yield response in both the 1st (DAN1-88) and 2nd (DAN2 88) wheats. However, particularly for the 2nd wheat, the improvement was not significantly better than achieved by most of the other treatments including some single spray programmes (Table 24).

Table 24. Mean plot yields (@15% moisture) for DANI 1st wheat (DAN1-88) and 2nd wheat (DAN2-88), 1988

Treatment		Yield (t ha^{-1}) DAN1-88 (cv. Brock)	DAN2-88 (cv. Brock)
A	Untreated	6.36	6.43
D	GS31	7.04	7.47
E	GS31 + forecast	7.51	8.00
F	GS31 + 39	6.64	8.17
G	GS31 + 39 + 59	7.20	8.40
H	GS37	6.84	8.05
I	GS37 + forecast	6.66	7.10
J	GS37 + 59	7.11	7.93
	LSD (5%)	1.71	2.05

<u>1989 harvest</u>

Treatment J (GS37 + 39) was the highest ranked programme for the first wheat (DAN1-89; Table 25). The ranked order suggests that a late spray was important (Table 25). However, disease records provide no obvious reason for this. Eyespot levels were high in all the plots at this experiment (69-85% severity). In control plots *S. tritici* was absent on the flag leaf, and severity was below 2% on leaf 2 and 6% on leaf 3. The response to the late spray might therefore have been due to a tonic effect or some other disease factor.

For the continuous wheat (DAN2-89) *S. tritici* in the control plots was absent on the flag and 2nd leaves, and present at only low severity on the 3rd and 4th leaves (<0.5% and <3% respectively). Eyespot control was best in the plots receiving sprays in the period GS35-39. However, this was not reflected in yield improvements (Table 25).

Table 25. **Mean plot yields (@15% moisture) for DANI 1st wheat (DAN1-89) and 3rd wheat (DAN2-89), 1989**

Treatment		Yield (t ha^{-1}) DAN1-89 (cv. Hornet)	Yield (t ha^{-1}) DAN2-89 (cv. Fortress)
A	Untreated	5.17	5.53
C	LARS forecast	5.62	6.15
D	GS31	5.23	6.03
E	GS31 + forecast	5.90	5.65
F	GS31 + 39	5.16	5.18
G	GS31 + 39 + 59	6.05	5.99
H	GS37	4.68	5.28
I	GS37 + forecast	5.79	5.98
J	GS37 + 59	6.43	5.98
	LSD (5%)	0.97	1.41

<u>1990 harvest</u>

The 2nd wheat (DAN2-90) was badly and unevenly effected by take-all (*Gaeumannomyces graminis*). This probably explains the poor yield response to the 3-spray (G) and LARS forecast (C) treatments (Table 26).

In the 1st wheat (DAN1-90) the yield of the LARS forecast treatment (C) was comparable with that of the 3 spray treatment (G), 10.4 & 10.6 t ha^{-1} respectively (Table 26).

Table 26. **Mean plot yields (@15% moisture) for DANI 1st wheat (DAN1-90) and 3rd wheat (DAN2-90), 1990**

Treatment		Yield (t ha^{-1}) DAN1-90 (cv. Brock)	Yield (t ha^{-1}) DAN2-90 (cv. Brock)
A	Untreated	8.16	5.35
C	LARS forecast	10.39	4.93
D	GS31	9.07	5.78
E	GS31 + forecast	9.91	6.23
F	GS31 + 39	9.22	6.39
G	GS31 + 39 + 59	10.60	5.71
H	GS37	9.59	7.18
I	GS37 + forecast	10.31	7.12
J	GS37 + 59	10.45	7.12
	LSD (5%)	1.48	2.80

(b) Reliability of yield response

The accumulated yield improvement (t ha^{-1}) above the control was calculated for each treatment x cultivar combination for each of the regional sites. This was used to provide an indication of the reliability of the treatments across seasons, sites and cultivars. Table 27 shows the 4 most successful treatments with respect to the accumulated yield response at Long Ashton and at Rothamsted. At Belfast, DANI, the incorrect application of the LARS forecast treatment prevents a complete comparison. Even in 1990 when the LARS was used successfully, the data from DAN2-88 were of limited value because of the uneven effects of take-all.

Treatments C (LARS forecast), J (GS37 + 59), G (GS31 + 39 + 59) and G_R (GS31 + 39) were most reliable, and generally were statistically indistinguishable (see Tables 18-23)

Table 27. The four highest ranked treatments with respect to accumulated yield above the untreated

Ranked order of treatments	Long Ashton Research Station			Rothamstead Experimental Station		
	cv. Avalon	cv. Longbow	cv. Rendezvous	cv. Avalon	cv. Longbow	cv. Rendezvous
1	C	G	J	G_r	J	C
2	G	C	C	D	G_r	J
3	J	I	G	J	D	G_r
4	F	J	E	C	C	H

(c) Economic implications of a 3-spray programme

The 3 spray programme (treatment G) generally provided a significant yield response above that of the unsprayed. However, at Long Ashton a 3 spray programme was found to give a negative economic return on some occasions. This conclusion was reached from rather crude calculations where the cost of a spray is equivalent to 0.2 t ha^{-1} grain weight. However, with continued constraint of profit margins on wheat, this is probably an under-estimate of the true cost of a fungicide application.

A direct comparison of the additional yield delivered by the GS59 spray was possible by comparing treatments F (GS31 + 39) and G (GS31 + 39 + 59). Table 28 shows this comparison for Long Ashton. On Avalon, a spray at GS59 was generally beneficial. However, half the applications of a 3rd spray to cv. Longbow and 3/4 to cv. Rendezvous led to an economic loss.

Table 28. **Comparison of the yield difference between treatments F (GS31 + 39) and G (GS31 + 39 + 59) at Long Ashton Research Station. The economic evaluation of this difference is based upon a cost of 0.2 t ha^{-1} for a fungicide application**

Site	Treatment Yield F GS31 + 39	Treatment Yield G GS31 + 39 + 59	Yield Difference G-F	Economic profit (+) loss (-)
1. cv. Avalon				
LA1-88	8.30	9.03	0.73	+
LA2-88	8.58	8.91	0.33	+
LA1-89	7.34	7.04	-0.30	-
LA2-89	6.58	7.24	0.39	+
2. cv. Longbow				
LA1-88	8.38	8.69	0.31	+
LA2-88	9.43	9.35	-0.08	-
LA1-89	7.69	8.24	0.55	+
LA2-89	7.05	7.15	0.10	-
3. cv. Rendezvous				
LA1-88	8.91	9.04	0.13	-
LA2-88	7.85	8.46	0.61	+
LA1-89	6.59	6.50	-0.09	-
LA2-89	7.00	6.93	-0.07	-

In contrast, at Belfast, DANI, the 3rd spray was economically justified in 5 of 6 experiments; although for one experiment the gain was negligible (Table 29). At site DAN2-90 the experiment was unevenly effected by take-all and the poor performance of the 3-spray programme can probably be attributed to this factor.

Table 29. **Comparison of the yield difference between treatments F (GS31 + 39) and G (GS31 + 39 + 59) at Belfast, DANI. The economic evaluation of this difference is based upon a cost of 0.2 t ha^{-1} for a fungicide application**

Site	Treatment Yield F GS31 + 39	Treatment Yield G GS31 + 39 + 59	Yield Difference G-F	Economic profit (+) loss (-)
DAN1-88 (cv. Brock)	6.64	7.20	0.56	+
DAN2-88 (cv. Brock)	8.17	8.40	0.23	+/break-even
DAN1-89 (cv. Hornet)	5.16	6.05	0.89	+
DAN2-89 (cv. Fortress)	5.18	5.99	0.72	+
DAN1-90 (cv. Brock)	9.22	10.60	1.38	+
DAN2-90 (cv. Brock)	6.39	5.71	-0.68	-

(d) Models explaining yield

Multiple regression models were fitted to explain the relationship between yield (t ha^{-1}) or yield fraction which was calculated as the treatment yield divided by the unsprayed yield.

The design of the experiments imposed limitations on the use of the data for this purpose:

(a) At Long Ashton, excepting the unsprayed, disease assessments were not done on a regular basis. Hence, the data contained a large number of missing and/or extrapolated values. This compromises the accuracy of the fitted models.

(b) At Belfast, DANI, the data were collected regularly, but the same cultivars were not used in each experiment. Therefore the degrees of freedom were considerably reduced when accounting for cultivar as a factor in the analyses.

(c) In general aliased terms were a problem with all data sets where analyses incorporated cultivar as a factor.

The time of disease onset for a particular leaf layer was determined as the number of days from sowing to the mid-point between the last day when the disease was absent and the first day when disease was recorded. Where disease was recorded at trace levels on the first assessment date, disease onset was recorded as 3.5 days prior to that assessment. Plots without disease were excluded from the analyses.

Good models (high R^2, significant partial regression coefficients) must be meaningful in terms of the host/pathogen relationship. Thus, terms measuring the date of disease onset, rate of disease increase, maximum severity reached on a particular leaf layer, and the Area under the disease progress curve (AUDPC) were calculated and included in the regression analyses.

For Long Ashton data the regression of disease onset against yield or yield fraction did not provide a satisfactory model (Table 30). Similar models fitted for Belfast, DANI were also poor (Table 30). Inclusion of cv. as a factor in the analyses provided regression models that were significant, but had very low R^2 values for Long Ashton data (Table 30). Significant models were fitted for Belfast for disease onset against yield. However, aliased terms due to the inclusion of cv. as a factor caused some confounding (Table 30).

Table 30. Parameters included in multiple regression models to explain yield in terms of the first appearance of disease symptoms caused by *S. tritici*

Data set	Response variable	Fitted terms	F probability for relationship	R^2
Long Ashton Research Station	yield	*S. tritici* onset on flag (x cv)	ns ($p>0.01$)	2.2% (13.0%)
	yield	*S. tritici* onset on flag & 2nd leaf (x cv)	ns ($p>0.05$)	2.1% (11.4%)
	yield fraction	*S. tritici* onset on flag (x cv)	$p>0.05$ ($p>0.01$)	2.2% (9.5%)
	yield fraction	*S. tritici* onset on flag & 2nd leaf (x cv)	ns ($p>0.05$)	1.9% (9.7%)
Belfast, DANI	yield	*S. tritici* onset on flag (x cv)	ns ($p>0.01$)	0.5% (39.0%)
	yield	*S. tritici* onset on flag & 2nd leaf (x cv)	ns ($p>0.05$)	4.8% (42.5%)
	yield fraction	*S. tritici* onset on flag (x cv)	ns (ns)	0 (0)
	yield fraction	*S. tritici* onset on flag & 2nd leaf (x cv)	ns (ns)	0 (0)

Critical point models fitted for *S. tritici* for GS39 (flag leaf emerged) and GS59 (ear emerged) were not significant at either Long Ashton or Belfast ($R^2 < 10\%$). Similarly, maximum severity of *S. tritici* summed over the top 4 leaves did not provide an adequate model.

In the case of Belfast the best model for yield was explained by eyespot and the rate of increase of *S. tritici* on the flag and 3rd leaves. This model has the form:

$$\text{Yield} = 9.39 - 4.9X_1 + 11.4X_2 - 0.05X_3$$

where: X_1 = Maximum rate of increase of *S. tritici* on flag leaf

X_2 = Maximum rate of increase of *S. tritici* on 3rd leaf

X_3 = Severity of eyespot at end of season

Intuitively, it appears strange that X_3 should be positively correlated with yield. This suggests rapid disease progress on this leaf layer promotes yield. However, it is more likely that correlation reflects late build-up of disease from a low level at the end of leaf life. This occurred at 4 of the 6 experiments sited in N. Ireland. Rapid disease development for the 3rd leaf was thus positively correlated with low disease.

The relationship was not as clear cut for Long Ashton where the best model achieved for stem base pathogens included eyespot and *Fusarium* ($p>0.01$, $R^2=43\%$), with Fusarium explaining the major proportion of the variation. This model must be treated with some scepticism because quantitative assessments of *Fusarium* are notoriously difficult and the symptoms can often be confused with eyespot and sharp eyespot.

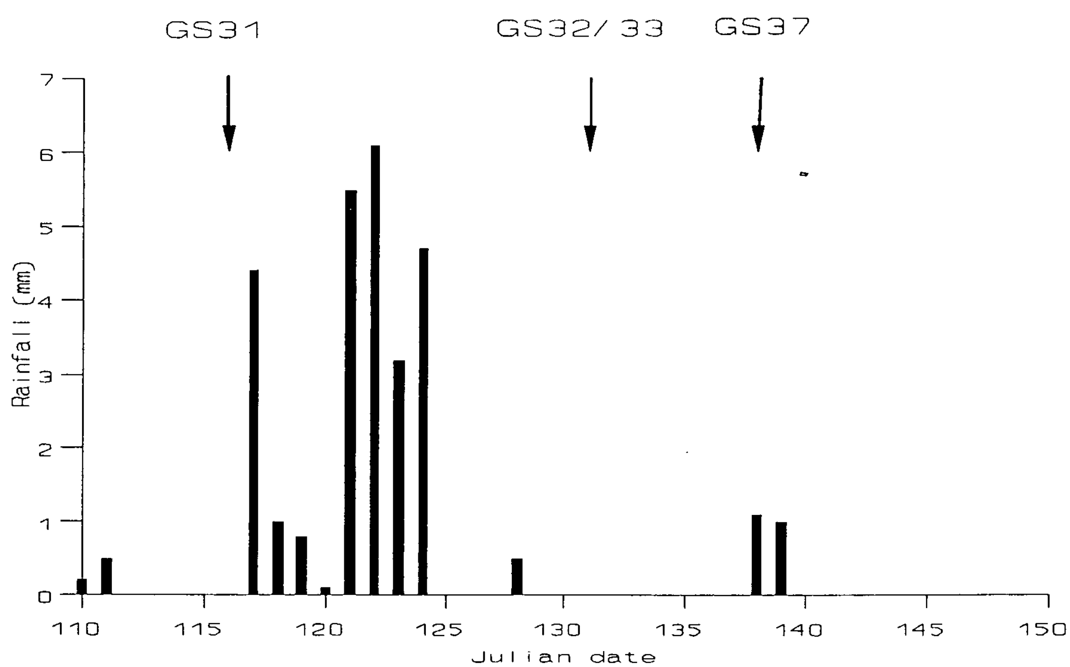
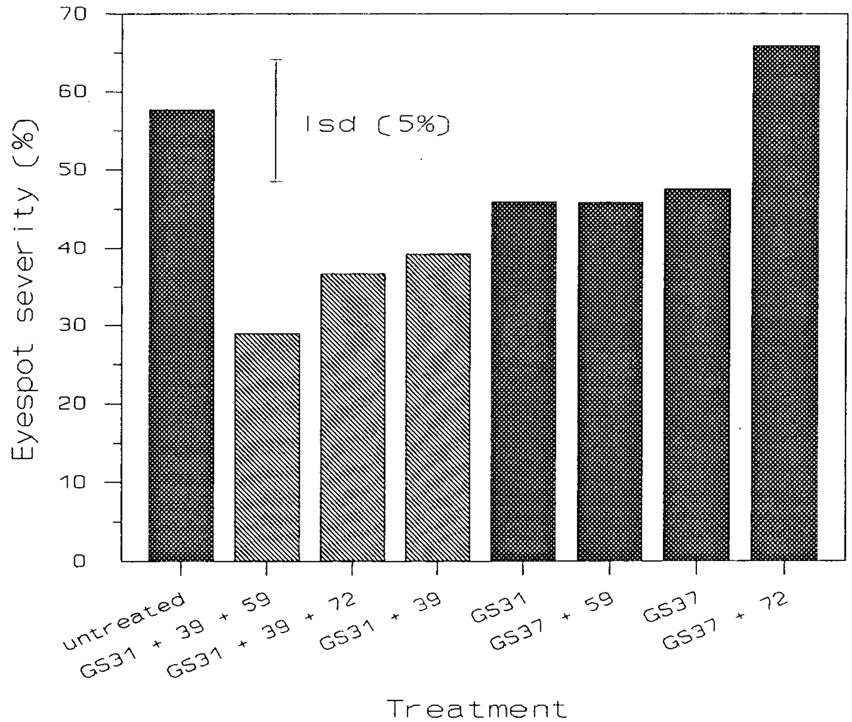


Fig. 2. Daily rainfall against date at site LA2-88 from April 19 (day 110) to May 20 (day 141) in 1988. Arrows represent the application dates of fungicides applied in response to growth stage (GS31 & GS37) and in response to the LARS *Septoria* forecast (GS32/33).

(a)



(b)

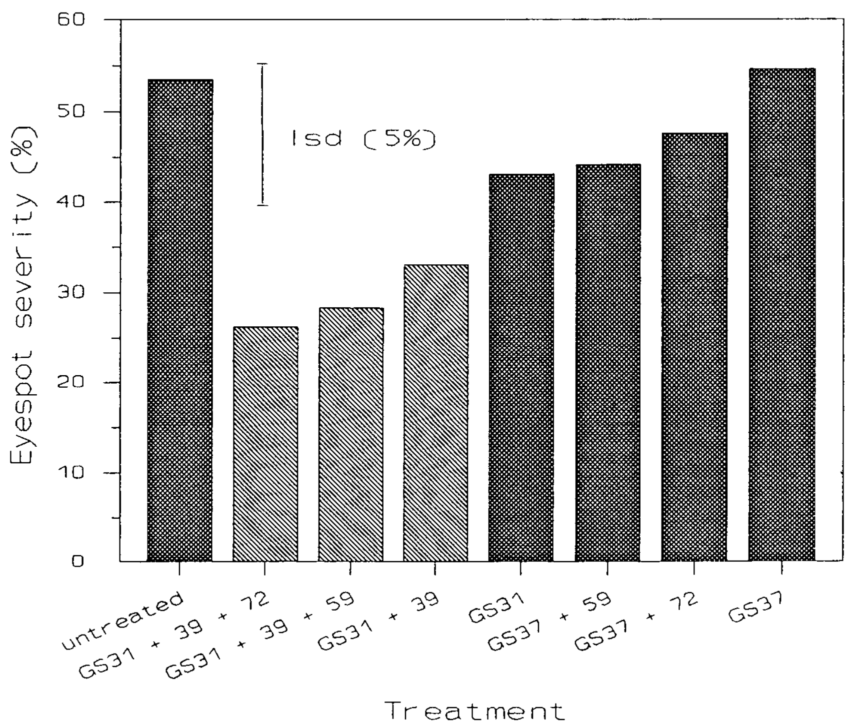
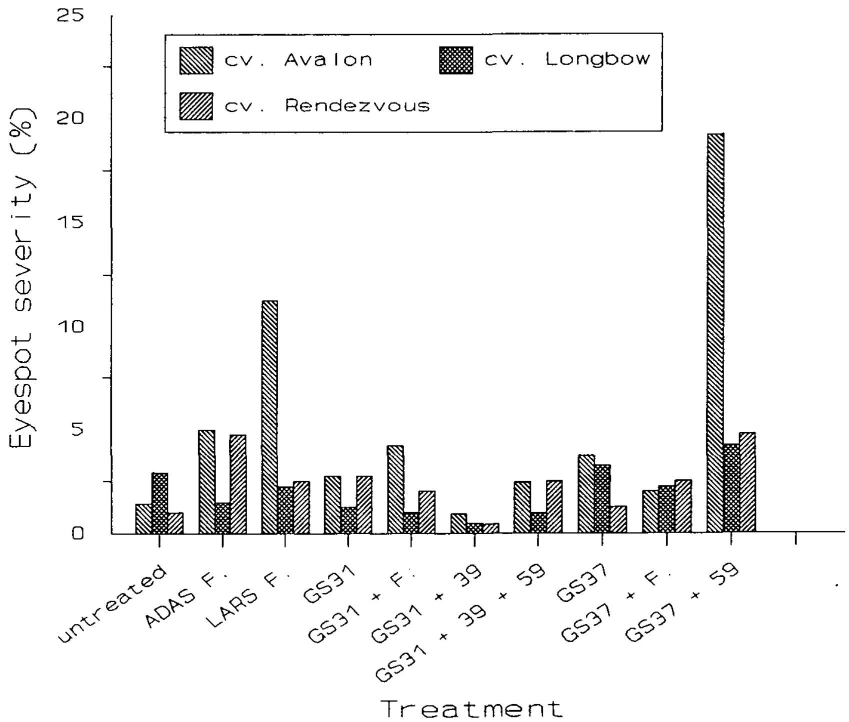


Fig 3. Eyespot severity at (a) DAN1-88 and (b) DAN2-88

(a)



(b)

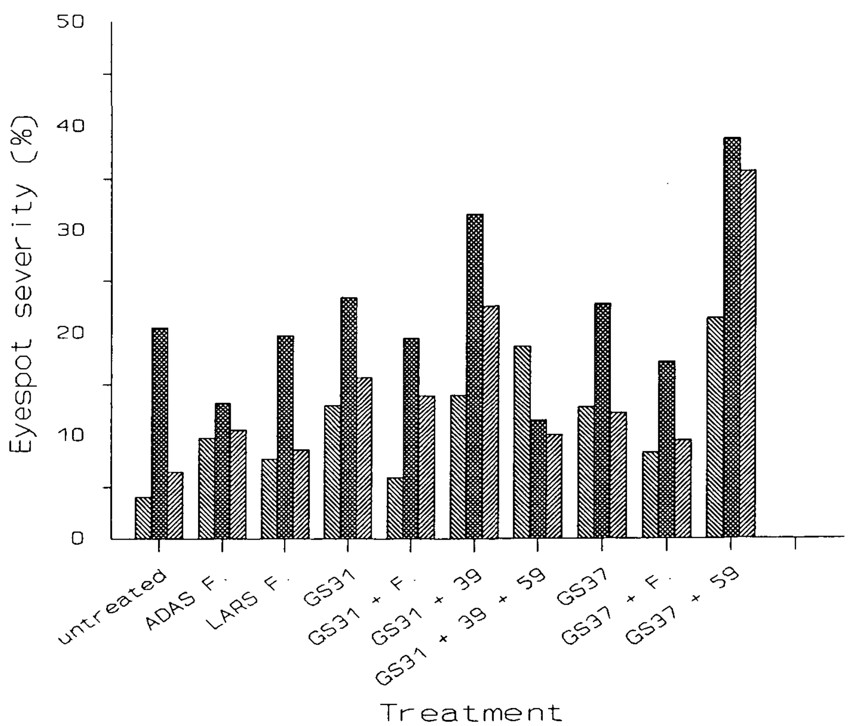


Fig.4. Eyespot severity prior to harvest at (a) site LA1-89 and (b) site LA2-89.

3. DEFINITION OF FAVOURABLE CONDITIONS FOR DAMAGING DISEASE ATTACKS

3.1 Background

There is need to know at what crop growth stage individual diseases cause most severe damage and conversely at what stages disease can be tolerated without significant yield penalty. The ability to control the onset of epidemics throughout the growing season would assist in the provision of such information, allowing a greater understanding of the relationship between disease incidence, crop growth stage and yield loss. Monitoring of crop growth stage and meteorological variables plus repeated and careful estimates of disease throughout the growth of the crop would assist this process but also would provide data upon which it may be possible to base simple schemes to forecast disease risk or development.

Different spray treatments beginning successively later in the season, thus delaying the start of disease, have been used to control potato early blight epidemics (Teng & Bissonnette, 1985). Such a profile provides a relationship between the onset of disease, its development and yield loss. A systematic rather than randomised design can be used to promote a disease gradient across the experiment. Additionally, observations from many unreplicated plots facilitate regression analysis. The present experiments, based on this approach, were adopted jointly by ADAS and Long Ashton Research Station in 1984. An experiment using these methods on barley has already been described (Shaw & Royle, 1987). Six experiments were conducted by CSL and ADAS on winter wheat, in an attempt to define more precisely, critical conditions for the onset of epidemics of leaf diseases and eyespot. The aim was to improve spray timing, increase awareness of the importance of the biological properties of fungicides and study the effects on yield loss of epidemics which develop at varying times during the season. Results from similar experiments executed in 1985 and 1986 have been published (Thomas *et al.*, 1989). The work reported here was based on this previous work although the approach was modified to gain extra information.

3.2 Experimental Detail

Experiments were executed at six sites, two in each of the 1987, 1988 and 1989 harvest years. The six sites were as follows: 1987 - Englefield, Berks cv. Avalon; Stawell, Somerset cv. Mission; 1988 Dorchester, Dorset cv. Avalon; Rosemaund EHF, Hereford cv. Hornet;

1989 - Rosemaund EHF cv. Apollo; Terrington EHF, Norfolk cv. Hornet. Sequential applications were made of two broad-spectrum mixtures of fungicides selected to achieve as close as possible to complete disease control of either stem base and leaf disease or leaf diseases only. An unreplicated design was chosen in preference to a replicated block design to maximize the number of treatments for regression analysis. The objective was to induce a series of epidemics by sequential application of fungicide sprays in plots arranged in a systematic design.

3.2.1 Treatments 1987

(a) *Full disease control*: prochloraz (400g ai/ha) + fenpropimorph (750g ai/ha) at four week intervals using full rates of both fungicides for the first spray in each sequence, and 3/4 rate fenpropimorph (563g ai/ha) and full rate prochloraz thereafter.

(b) *Leaf disease control*: fenpropimorph (750g ai/ha) + chlorothalonil (lOOOg ai/ha) at 3 week intervals. Treatments at recommended rates, but using fenpropimorph at 3/4 rate (563g ai/ha) for each spray except the first.

(c) *Layout*: Single, unreplicated block; plots split for full or leaf disease control. Plots were arranged in treatment order with successive treatments commencing at weekly intervals from Wednesday 1 April until 8 July (Fig. 5).

(d) *Site*: first or second wheat crop.

3.2.2 Treatments 1988 & 1989

Sequential applications of a broad spectrum mixture of fungicides selected to achieve as close as possible to complete disease control in addition to single applications of four fungicides applied at weekly intervals from early May to mid-June.

(a) *Full control*: prochloraz + fenpropimorph at four week intervals using full rates of both fungicides for the first spray in each sequence, and 3/4 rate fenpropimorph and full rate prochloraz thereafter (Fig. 6).

(b) *Selective control with timed sprays*: single sprays of propiconazole 125g ai/ha(Tilt,

Treatment		Plot number																															
Date		G	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	G
April	1	–	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	8	–	–	–	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	15	–	–	–	–	–	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	22	–	–	+	–	–	–	–	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	29	–	+	–	–	+	–	–	–	–	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
May	6	–	–	–	+	–	–	+	–	–	–	–	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	13	–	–	+	–	–	+	–	–	+	–	–	–	–	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	20	–	–	–	–	+	–	–	+	–	–	+	–	–	–	–	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	27	–	+	–	–	–	–	+	–	–	+	–	–	+	–	–	–	–	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–
June	3	–	–	+	+	–	–	–	–	+	–	–	+	–	–	+	–	–	–	–	+	+	–	–	–	–	–	–	–	–	–	–	–	–
	10	–	–	–	–	+	+	–	–	–	–	+	–	–	+	–	–	+	–	–	–	–	+	+	–	–	–	–	–	–	–	–	–	–
	17	–	–	–	–	–	–	+	+	–	–	–	–	+	–	–	+	–	–	+	–	–	–	–	+	+	–	–	–	–	–	–	–	–
	24	–	+	+	–	–	–	–	–	+	+	–	–	–	–	+	–	–	+	–	–	+	–	–	–	–	+	+	–	–	–	–	–	–
July	1	–	–	–	+	+	–	–	–	–	–	+	+	–	–	–	–	+	–	–	+	–	–	+	–	–	–	–	+	+	–	–	–	–
	8	–	–	–	–	–	+	+	–	–	–	–	–	+	+	–	–	–	–	+	–	–	+	–	–	+	–	–	–	–	+	+	–	–

Odd numbers – Full programme – fenpropimorph + prochloraz

Even numbers – Leaf diseases – fenpropimorph + chlorothalonil

Plot 31 is untreated

G – untreated guard plot at each end – take to harvest.

Fig. 5. Plot layout at Englefield & Stawell, 1987

Treatment — Plot number

Date	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
05/04	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12/04	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
19/04	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
26/04	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
03/05	-	*	*	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10/05	-	-	-	*	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17/05	-	-	-	-	*	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
24/05	-	-	-	-	-	*	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
31/05	-	*	*	-	-	-	*	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
07/06	-	-	-	*	-	-	-	*	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-
14/06	-	-	-	-	*	-	-	-	*	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-
21/06	-	-	-	-	-	*	-	-	-	*	-	-	-	+	-	-	-	-	-	-	-	B	F	T	P
28/06	-	*	*	-	-	-	*	-	-	-	*	-	-	-	+	-	-	-	-	-	-	-	-	-	-

Date	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
05/04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12/04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
19/04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
26/04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
03/05	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	F	B	P	T	-	-	-	-	-
10/05	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	P	T	F	B	-
17/05	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	P	B	T	F	-	-	-	-	-
24/05	-	-	-	-	-	-	-	-	-	-	-	-	B	P	T	F	-	-	-	-	-	-	-	-	-
31/05	-	-	-	-	-	-	-	-	F	T	B	P	-	-	-	-	-	-	-	-	-	-	-	-	-
07/06	-	-	-	-	T	P	F	B	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
14/06	B	T	P	F	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21/06	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
28/06	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-				

+ = fenpropimorph (750g ai/ha) + prochloraz (full rate) (400g ai/ha)

* = fenpropimorph (3/4 rate) (563g ai/ha) + prochloraz (full rate) (400g ai/ha)

T = propiconazole (Tilt or Radar) (125g ai/ha, 0.5 litres product/ha)

B = chlorothalonil (Bravo) (1000g ai/ha, 2 litres product/ha)

F = fenpropimorph (Corbel or Mistral) (750g ai/ha, 1 litre product/ha)

P = prochloraz (Sportak) (400g ai/ha, 1 litre product/ha)1988; cyproconazole (Alto) (80g ai/ha, 0.8 litres/ha) 1989

Plots 1, 16, 17, and 47 are untreated

Plot 2 is a discard plot to balance to overall design and remove edge effects, but it should be taken to yield for comparison

Fig. 6. Layout adopted in 1988 & 1989 at sites with high eyespot risk

Ciba-Geigy: 0.5 litre product/ha), prochloraz 400g ai/ha (Sportak, Schering Agriculture: 1.0 litre product/ha), fenpropimorph 750g ai/ha (Corbel, BASF: 1 litre product/ha) and chlorothalonil 1OOOg ai/ha (Bravo, ISK Europe: 2 litres product/ha) at recommended rates, applied at weekly intervals from early May (Fig. 6). In 1989 cyproconazole 80g ai/ha (Alto, Sandoz: 0.8 litre product/ha) replaced prochloraz.

(c) *Layout*: Single, unreplicated block arranged with full control treatments at one end, in treatment order, with successive treatments commencing at weekly intervals from the week commencing 4 April at sites where eyespot is anticipated (Fig. 6), or 18 April elsewhere, with a final spray in the week commencing 27 June (Fig. 7). Single sprays were placed within the same linear pattern; in both cases treatments starting successively later were towards the centre and on either side of the untreated control, with additional untreated plots at both ends; treatment 1 was replicated as a discard to avoid edge effects from a fully sprayed plot adjacent to a control plot.

3.2.3 Records and assessments

The following data were collected:

(a) Crop development

Date, growth stage and plant height (average distance from soil surface to top-most ligule) at each treatment date. Row spacing and tiller number at GS31.

(b) Disease development

In plots to be sprayed for the first time (i.e. weekly intervals on untreated area) disease severity was estimated on all fully expanded leaves where the average senescence within a leaf layer is < 50% in the best treatment and stem base diseases on at least 10 plants.

For treated plots, leaf diseases at 14 day intervals (1987) and 7 day intervals (1988 & 1989) from commencement of treatment (i.e. first assessment 15 April). Stem base diseases at GS75 and, in addition, all plots at GS59-65 if more than 20% stems are affected in the untreated.

Green leaf area, ear disease and growth stage on 22 July or thereabouts according to crop

Treatment — Plot number

Date	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44
19/04	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
26/04	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
03/05	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10/05	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	P	T	F	B	-
17/05	-	*	*	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	P	B	T	F	-	-	-	-	-
24/05	-	-	-	*	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	B	P	T	F	-	-	-	-	-	-	-	-	-
31/05	-	-	-	-	*	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	F	T	B	P	-	-	-	-	-	-	-	-	-	-	-	-	-
07/06	-	-	-	-	-	*	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	T	P	F	B	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
14/06	-	*	*	-	-	-	*	-	-	-	+	-	-	-	-	-	-	-	-	B	T	P	F	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21/06	-	-	-	*	-	-	-	*	-	-	-	+	-	-	-	B	F	T	P	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
28/06	-	-	-	-	*	-	-	-	*	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

+ = fenpropimorph (750g ai/ha) + prochloraz (full rate) (400g ai/ha)

* = fenpropimorph (3/4 rate) (563g ai/ha) + prochloraz (full rate) (400g ai/ha)

T = propiconazole (Tilt or Radar) (125g ai/ha, 0.5 litres product/ha)

B = chlorothalonil (Bravo) (1000g ai/ha, 2 litres product/ha)

F = fenpropimorph (Corbel or Mistral) (750g ai/ha, 1 litre product/ha)

P = prochloraz (Sportak) (400g ai/ha, 1 litre product/ha)1988; cyproconazole (Alto) (80g ai/ha, 0.8 litres/ha) 1989

Plots 1, 14, 15, and 45 are untreated

Plot 2 is a discard plot to balance to overall design and remove edge effects, but it should be taken to yield for comparison

Fig. 7. Layout adopted in 1988 & 1989 at sites with low eyespot risk

growth stage and at 14 day or 7 day intervals until the flag leaf reaches less than 50% green leaf area on the best treatment. Ear diseases on 8 July and 22 July or thereabouts.

Each assessment was performed using standardized procedures issued by the former Disease Assessment Branch, CSL Harpenden.

(c) Host phenology and leaf development

In order to relate leaf 1 etc. at early assessment dates to the flag leaf later, 20 leaf 1's were tagged at around GS30-31 and related to leaf development in all subsequent assessments up to completion of ear emergence.

(d) Harvest records

Yield at 85% dry matter, 1000 grain weight, specific weight, Hagberg falling number at appropriate sites.

(e) Meteorological records

On site weather stations were used to monitor daily maximum and minimum temperature, and daily rainfall.

(f) Septoria tritici inoculum and the use of the LARS splashmeter

Inoculum potential was recorded using the spore count procedure developed by Long Ashton Research Station. In addition rain splash was recorded using the "splashmeter". Protocols for the assessment of inoculum potential for *S. tritici*, splashmeters and protocols for their use were provided by LARS. Data for inoculum potential, splash occurrence and septoria development were analyzed by LARS.

3.2.4 Analysis of disease progress

Unhindered disease progress (untreated plots) on each leaf present at GS30-31 and each subsequent leaf produced up to the completion of flag leaf expansion was plotted for the period GS30-31 up to GS75. This was matched against rainfall and accumulated temperature an attempt to identify imputed infection events for *S. tritici.* To aid presentation and further analysis, for both untreated and treated plots disease progress in the form of the area under the disease progress curve (AUDPC) was calculated using interpolated daily increments in disease on each of the top three leaves. Each daily value for disease was multiplied by the mean daily temperature (in an effort to reduce differences between sites and aid cross-site analysis) and all values accumulated as the AUDPC in disease degree days. Simple regression models were calculated to relate yield loss to disease severity. The more complex non-linear critical point regression analyses to relate eradicant and protectant fungicide activity to the degree of disease control (i.e. reduction in the AUDPC) and fit time-response curves have yet to be completed for the sequential spray programmes and the single active ingredients. This will be performed on a much greater volume of data obtained from a total of 21 experiments (including the six reported here) of a similar design.

3.3 Results

3.3.1 Englefield 1987

(a) Rainfall and development of Septoria tritici

Rainfall incidence and the progression of *Septoria tritici* development on leaves 1-7 are presented in Figure 8. From GS32 onwards it appears that there were at least 10 rain-splash events with the potential to disperse pycnidiospores upwards through the canopy. This potential was reflected in the development of *S. tritici* to moderately high levels (c.27-41%) on leaves 1-3 before GS75. Because of their frequency it is not possible, at least with absolute certainty, to identify the major splash event(s) responsible for the upward transport of inoculum. However, the shape of the unhindered disease progress curves indicates that there may have been at least two splash events responsible for inoculum transport and subsequent infection. Table 31 below provides an estimate of the timing of these splash events based on a latent period of c. 400 days -°C for *S. tritici,* the maximum expression of symptoms from the imputed primary and secondary infection events and the incidence of rainfall.

Table 31. **Imputed rain-splash events and length of imputed latent period, Englefield 1987**

Event	Day degrees °C (date) or date (day degrees °C) leaf number		
	3	2	1
ME* 1° symptoms	27 May	10 June	24 June
Degree days (from 1 April)	598	784	964
- 400 degree days (date)	198 (21-22 April)	384 (7 May)	564 (24-25 May)
Imputed splash event (day degrees)	29 April (303)	13 May (448)	30 May (641)
Actual difference (day degrees)	295	336	323
ME 2° symptoms	16 June	30 June	15 July
Degree days (from 1 April)	853	1072	1337
- 400 degree days (date)	453 (13-14 May)	672 (1-2 June)	937 (22-23 June)
Imputed splash event (day degrees)	13 May (448)	2-3 June (690)	24-26 June (978)
Actual difference (day degrees)	405	382	359

*Maximum expression of symptoms from primary (1°) or secondary (2°) infection events

(b) Septoria tritici: AUDPC and fungicide activity

The AUDPC of *S. tritici* for each sprayed plot is plotted in Figure 9. As might be expected on a site with multiple splash events the AUDPC for each successive leaf was somewhat smaller than the previous one. This is particularly evident with leaves 1 and 2 though much less evident with leaves 2 and 3, a reflection of their exposure to at least one more infection event compared to leaf 1. The shape of AUDPCs clearly indicate, despite some fairly large fluctuations, that sequential spray programmes commencing before the end of April - GS32 (leaf 3), before GS39 (leaf 2) and before GS45 (leaf 1) gave at least a 50-70% reduction in the AUDPC. Prochloraz and fenpropimorph were almost consistently superior to chlorothalonil and fenpropimorph in their apparent ability to reduce the AUDPC particularly when used in spray programmes that commenced before GS45. In programmes that commenced later than this date differences were far less marked.

(c) Eyespot development

Eyespot development is depicted in Figure 10. Prochloraz and fenpropimorph generally gave better control of eyespot than chlorothalonil and fenpropimorph; programmes of both fungicide combinations that started early gave better control than those that started later.

(d) Yield and grain quality effects

Figures 11-14 depict the effects of the spray programmes on yield and grain quality. All of the latter, with the exception of Hagberg Falling Number showed a tendency to decline as the start of the sequential spray programmes was delayed. This was particularly marked with yield (which had to be estimated due to combining problems and therefore cannot be regarded as reliable) and thousand grain weight. Specific weight was considerably more erratic than estimated yield or thousand grain weight and declined to any degree only when the start date of the fungicide spray programme was delayed until after GS39. Hagberg Falling Number showed completely the opposite trend, increasing markedly with delay in the start of the fungicide spray programmes. There was little difference in the effects of the two fungicide combinations on yield and on grain quality.

3.3.2 Stawell 1987

(a) Rainfall and development of Septoria tritici

Rainfall incidence and the progression of *Septoria tritici* development on leaves 1-5 are presented in Figure 15. From GS32 onwards there appears to have been only three recognisable splash events with the apparent potential to transport inoculum from the base of the crop onto the upper leaves. The shape of the disease progress curves for *S. tritici* on the top three leaves indicates that there may have been two major infection events associated with rain splash. Table 32 below provides an estimate of the occurrence and timing of infection using 400 degree days as the length of the latent period for *S. tritici* to relate maximum symptom expression and imputed primary and secondary infection events due to rain-splash.

(b) Septoria tritici: AUDPC and fungicide activity

The AUDPC of *S. tritici* for each sprayed plot is presented in Figure 16. The level of disease remained low on leaf 3 in plots that received their first fungicide spray before GS33 but began to increase on plots that received their first spray after this growth stage. On the basis of a change in the rate of increase in the AUDPC for leaves 2 and 3 a second infection event appears to have occurred between 3 and 10 June; this infection event also appears to have been responsible for the change in the rate of increase of the AUDPC from leaf 1. Prochloraz and fenpropimorph generally gave slightly greater reductions in the AUDPC for *S. tritici* compared to chlorothalonil and fenpropimorph presumably because of the greater eradicant activity of prochloraz. This was particularly marked on leaf 2 from GS57 to GS73.

Table 32. **Imputed rain-splash events and length of imputed latent period, Stawell 1987**

Event	Day degrees °C (date) or date (day degrees °C) leaf number		
	3	2	1
ME* 1° symptoms	1 July	1 July	15 July
Degree days (from 1 April)	1080	1080	1322
- 400 degree days (date)	680 (2 June)	680 (2 June)	922 (21-22 June)
Imputed splash event (day degrees)	5 June (721)	5 June (721)	25-26 June (983)
Actual difference (day degrees)	359	359	339
ME 2° symptoms	15 July	15 July	-
Degree days (from 1 April)	1322	1322	-
- 400 degree days (date)	922 (21-22 June)	922 (21-22 June)	-
Imputed splash event (day degrees)	25-26 June	25-26 June	-
Actual difference (day degrees)	339	339	-

(c) Brown rust: disease progress. AUDPC and fungicide activity

Brown rust was first noted on 25 June and developed to c. 20% on leaves 2 and 3 by 15 July; on leaf 1 it developed to only c. 2% (Fig. 15). Fungicide programmes that started after GS57-61 failed to control brown rust as effectively as those that started before this growth stage. The prochloraz/fenpropimorph mixture was consistently superior to the chlorothalonil/fenpropimorph mixture in reducing the AUDPC (Fig. 17).

(d) Eyespot development and control

Eyespot development and control exhibited a good relationship with the use of the prochloraz/fenpropimorph mixture (Fig. 18). Fungicide programmes that started after GS31 -32 gave increasingly poorer control with each subsequent delay in starting the spray programme. No such trend was apparent with the chlorothalonil/fenpropimorph mixture.

(e) Yield and grain quality effects

Yield and, to a lesser extent, thousand grain weight and specific weight exhibited a good relationship with the length of the delay in starting fungicide spray programmes (Fig. 19) Programmes commencing before or at GS39 showed no significant reduction in yield compared to programmes that started at GS30. Programmes that started at or after GS41 were associated with a steady decline in yield with each increase in the length of the time interval between GS39 and the start of the spray programme. Although this trend was not so readily apparent thousand grain weight and specific weight behaved in a similar manner with respect to growth stage and the start of spraying. (Figs. 20-21). There were no apparent differences between the two fungicide mixtures for their effects on yield and grain quality. Hagberg Falling Number was not recorded at this site.

3.3.3 Dorchester 1988

(a) Rainfall and development of Septoria tritici

Rainfall incidence and the progression of *Septoria tritici* development on leaves 1-5 are presented in Figure 22. This site was unusually early so that GS32 occurred on April 19 and it was apparent from the monitoring of leaf phenology that leaf 3 was present at least from 1 April if not earlier. On the basis of the 400 day degree latent period for *S. tritici* primary infection of leaf 3 may have occurred before 1 April but there was no record taken for on-site rainfall before this date. From 1 April there were readily identifiable and discrete rain-splash events which were clearly associated with the changes in the apparent rate of increase in the level of disease on leaves 1-3 (Table 33).

Table 33. Imputed rain-splash events and length of imputed latent period, Dorchester 1987

Event	Day degrees °C (date) or date (day degrees °C) leaf number		
	3	2	1
ME* 1° symptoms	28 April	2 June	20 June
Degree days (from 1 April)	227	649	899
- 400 degree days (date)	not recorded	249 (30 April-1 May)	499 (20 May)
Imputed splash event (day degrees)	not recorded	30 April-3 May (264)	24-26 June (554)
Actual difference (day degrees)	not recorded	385	345
ME 2° symptoms	24 May	20 June	28 June
Degree days (from 1 April)	542	899	1027
- 400 degree days (date)	142 (18-19 April)	499 (20 May)	627 (31 May-1 June)
Imputed splash event (day degrees)	18 April (141)	24-26 May (554)	28-30 May (599)
Actual difference (day degrees)	401	345	428

(b) Septoria tritici: AUDPC and fungicide activity

The AUDPC plotted for each of leaves 3, 2 and 1 is shown in Figures 23-25. For the sequential sprays only those programmes commencing before GS32 gave an acceptable reduction in the AUDPC for leaf 3. Of the individual active ingredients only propiconazole applied at GS37 gave an acceptable degree of control - c.70% reduction in AUDPC; prochloraz gave only a 50% reduction; fenpropimorph only c. a 30% reduction; chlorothalonil gave no reduction (Fig. 23). On leaf 2 sequential sprays that started at GS32 gave virtually complete control of *S. tritici,* whilst those that started at or after GS37 gave only c. a 50% reduction in the AUDPC. Propiconazole and prochloraz applied as single sprays at GS37 reduced the AUDPC by c. 80% and C. 70% respectively, whilst fenpropimorph and chlorothalonil gave reductions of only 25-30% (Fig. 24). On leaf 1 sequential sprays that started at or before GS65 gave virtually complete control of *S. tritici.* Single applications of active ingredients that produced the greatest reductions in the AUDPC were: chlorothalonil @ GS45-c. 94%; propiconazole @ GS57-c. 97%; prochloraz @ GS59-c.87%; fenpropimorph @ GS59-c.66% (Fig. 25).

(c) Eyespot development

Only the sequential programme that commenced at GS32 gave a marked reduction in the eyespot index (Fig. 26).

(d) Yield and grain quality

Sequential spray programmes that commenced at GS32 gave the highest yields attained but the latter declined markedly with each week's delay in commencing subsequent spray programmes (Fig. 27). Chlorothalonil, prochloraz and propiconazole applied at GS57 gave very similar and the highest yields attained by any of the timings of the single sprays. Fenpropimorph behaved similarly but the yield attained was less than that of the untreated. Thousand grain weight showed a similar trend to that of yield (Fig. 28); specific weight was extremely erratic although there was a trend towards lower specific weights with later applications of sequential spray and single active ingredients (Fig. 29). Hagberg Falling Number was not measured for this site.

3.3.4 Rosemaund 1988

(a) Rainfall and development of Septoria tritici

Rainfall incidence and the progression of *S. tritici* development on leaves 1-4 are presented in Figure 30. From GS32 onwards there appears to have been at least five rain-splash events with the potential to transport inoculum onto the upper leaves. This potential was reflected in the development of *S. tritici* to high levels (c. 37-65%) on the top three leaves before GS81. The shape of the disease progress curves indicates that there may have been two major events responsible for inoculum transport and subsequent leaf infection. Table 34 below provides an estimate of the timing of these splash events.

Table 34. Imputed rain-splash events and length of imputed latent period, Rosemaund 1987

Event	Day degrees °C (date) or date (day degrees °C) leaf number		
	3	2	1
ME* 1° symptoms	28 May	6 June	30 June
Degree days (from 1 April)	556	661	1019
- 400 degree days (date)	146 (18-19 April)	261 (2 May)	619 (2-3 June)
Imputed splash event (day degrees)	26 April (208)	29 April-3 May (252)	7-9 June (688)
Actual difference (day degrees)	348	409	331
ME 2° symptoms	30 June	30 June	24 July
Degree days (from 1 April)	1019	1019	1366
- 400 degree days (date)	619 (2-3 June)	619 (2-3 June)	966 (26-27 June)
Imputed splash event (day degrees)	7-9 June (688)	7-9 June (688)	25 June (941)
Actual difference (day degrees)	331	331	425

(b) Septoria tritici: AUDPC and fungicide activity

All sequential spray programmes that commenced after GS31-32 (for leaf 3, Fig. 31), GS32-37 (for leaf 2, Fig. 32) and GS43 (for leaf 1, Fig. 33) gave successively smaller reductions in the AUDPC calculated for these three leaves. Of the single active ingredient propiconazole applied at GS37 gave the greatest reduction (70%) in the AUDPC on leaf 3; the other three active ingredients performed similarly but achieved only c. a 46% reduction. On leaf 2 propiconazole achieved c. a 90% reduction in the AUDPC when applied as GS37 as did chlorothalonil when applied at GS39; prochloraz and fenpropimorph achieved reductions of c. 80% when applied at GS39 and GS37 respectively. On leaf 1 chlorothalonil, propiconazole and prochloraz achieved maximum reductions in the AUDPC of c. 93%,84% and 74% respectively when applied at GS39. Fenpropimorph achieved a maximum reduction of only c. 67% when applied at GS37.

(c) Mildew: disease progress

Mildew progress on leaves 1-5 is presented in Figure 34. The disease reached high levels on leaves 4 and 5 prior to GS37. Mildew started to develop on leaves 3 and 2 from GS31 onwards and on leaf 1 from GS39 onwards to reach levels of 22-25% at GS75-79. Rapid development of mildew only started once the canopy was complete from GS39 onwards for leaves 2 and 3 and from GS63 onwards for leaf 1.

(d) Mildew: AUDPC and fungicide activity

All sequential spray programmes that commenced after GS39 (leaf 3, Fig. 35), GS59 (leaf 2, Fig. 36) and GS59 (leaf 1, Fig. 37) gave successively smaller reductions in the AUDPC calculated for mildew development on the top three leaves. Of the single active ingredients fenpropimorph showed a similar trend and achieved a maximum reduction of 84% in the AUDPC when applied at GS37 (11 May). Propiconazole, prochloraz and chlorothalonil achieved a not dissimilar result on leaf 2 although the profile of the AUDPC was far more erratic. On leaf 1 all four active ingredients achieved a high degree of control, approaching 70-95% depending on growth stage and the timing of each active ingredient.

(e) Yield and grain quality effects

Sequential spray programmes that started after GS43 gave successively smaller yield increases over the untreated control (Fig. 38). Individual active ingredient showed a similar trend but the growth stage for the maximum yield response achieved by each varied as follows: chlorothalonil and prochloraz - both GS39, fenpropimorph - GS37 and propiconazole GS43. Thousand grain weight and specific weight showed not dissimilar trends to that of yield (Figs. 39-40). Hagberg Falling Number showed the opposite trend, increasing with each subsequent delay in the first application of sequential spray programmes and active ingredients alike (Fig. 41).

3.3.5 Rosemaund 1989

(a) Rainfall and development of Septoria tritici

Septoria tritici developed to only low levels (<5%) on the top three leaves prior to GS85. Wet periods were limited to three discrete potential rain splash events on 22 May, 2 and 9

June. The date (12 July) of maximum expression of leaf symptoms (5% disease) on leaf 2 occurred at 1192 day degrees °C from the 1 April. The date (20 June) of the first appearance of symptoms on leaf 2 occurred at 849 day degree from 1 April almost exactly 400 day degrees after 22 May when more than 10 mm of rain occurred (Fig. 42). No AUDPC was calculated for *S. tritici* on this site due to its late development.

(b) Mildew progress

Moderate levels (c. 20%) were present on leaves 5 and 4 up to GS32 and GS37 respectively. Mildew was apparent on one or more of the top three leaves from GS32 onwards but began to develop rapidly only from GS69 onwards to reach levels greater than 30% by GS85 (Fig. 42).

(c) Mildew: AUDPC and fungicide activity

Sequential spray programmes that commenced at GS45 (for leaf 3), GS51 (for leaf 2) and GS69 (for leaf 1) or later than any of these growth stages gave successively smaller reductions in the AUDPC for mildew on the top three leaves. Chlorothalonil gave maximum reductions of up to 35% in the AUDPC for any of the top three leaves. Of the other three single active ingredients cyproconazole and fenpropimorph appeared to be more active than propiconazole achieving reductions in the AUDPC of c. 75% and 67% on leaf 3 when applied at GS37,c.75% and 60% on leaf 2 when applied at GS37-45 and both c. 85% on leaf 1 when applied at GS45 (Figs. 43-45).

(d) Yield and grain quality

Yield declined successively with each week's delay in commencing the sequential sprays but marked reductions occurred only after GS33. The highest yields obtained by application of chlorothalonil, cyproconazole and fenpropimorph were at GS37, the two latter fungicides considerably out performing the first (Fig. 46). Thousand grain and specific weights were greater when sequential sprays were started during the period GS37-63 and GS37-55. The highest thousand grain and specific weights due to application of single active ingredient were associated with GS45-55 and GS45-63 timings respectively (Figs. 47-48). Results for Hagberg Falling Number were very erratic but there was a trend for later fungicide applications to favour higher HFN's (Fig. 49).

3.3.6 Terrington 1989

(a) Rainfall and development of Septoria tritici

Rainfall incidence and the progression of *S. tritici* development on the top five leaves is shown in Figure 50. The disease reached only low levels on leaves 4 and 5 and became moderately severe only on leaf 3 (c. 32% @ GS61) with c. 5-6% on leaf 2 at GS59-65. The shape of the disease progress curve indicates that there may have been two infection events. Table 35 below provides an estimate of the timing of their occurrence.

Table 35. Imputed rain-splash events and length of imputed latent period, Terrington 1989

Event	Day degrees °C (date) or date (day degrees °C) leaf number		
	3	2	1
ME* 1° symptoms	31 May	15 June	30 June
Degree days (from 1 April)	599	790	1019
- 400 degree days (date)	199 (28-29 April)	390 (16-17 May)	619 (2-3 June)
Imputed splash event (day degrees)	24 April (169)	10-12 May (332)	7-9 June (688)
Actual difference (day degrees)	430	458	-
ME 2° symptoms	15 June	-	-
Degree days (from 1 April)	790	-	-
- 400 degree days (date)	390 (16-17 May)	-	-
Imputed splash event (day degrees)	10-12 May (332)	-	-
Actual difference (day degrees)	458	-	-

(b) Septoria tritici: AUDPC and fungicide activity

Figures 51 and 52 indicate that sequential sprays commencing after GS51 failed to reduce at all the AUDPC for *S. tritici* on leaves 3 and 2. All four of the single active ingredients applied before or at GS51 gave reduction in the AUDPC in the range of 80-100%. Applications after GS51, still gave reductions that ranged from c. 10% to c. 90%.

(c) Yellow rust: Disease progress

Yellow rust first appeared on the top three leaves at GS55-57 on June 7 and progressed rapidly to reach levels of 35% and 32% on leaves 1 and 2 respectively at GS75 (30 June). On leaf 3 however, the disease reached a level of only 5% at GS75 (Fig. 50).

(d) *Yellow rust: AUDPC and fungicide activity*

Figures 53 and 54 indicate that sequential spray programmes commencing after GS51 achieved successively smaller reductions in the AUDPC for yellow rust on leaves 1 and 2. In addition those that started at GS31(19 April), GS37(12 May) and GS39(19 May) failed to achieve the degree of reduction in the AUDPC achieved by other sequential spray programmes. All of the individual active ingredients achieved a 95-100% reduction in the AUDPC when applied at GS41(26 May). Applications before or after this date gave smaller reductions in the AUDPC which varied with the length of the time interval between 26 May and the date of application.

(e) *Yield and grain quality*

Yield declined markedly when sequential spray programmes began at GS33 or later although those that started between GS41-59 gave some improvement (Fig. 55). Thereafter yield continued to decline markedly. Individual active ingredients gave yields from a single application at GS37-39 equivalent to the best of the sequential spray programmes. Cyproconazole, propiconazole and fenpropimorph maintained this or a similar level of yield maintenance from two or more timings of fungicide application.

Thousand grain and specific weight exhibited a steady decline with the progression in the delay of the start of the sequential spray programmes (Figs. 56-57). Despite the apparent erratic effects of the individual active ingredients on thousand grain and specific weights, cyproconazole, fenpropimorph and propiconazole achieved results equivalent to the best of the sequential spray programmes despite the different growth stages at which this occurred. Chlorothalonil achieved results considerably lower than those of the other three fungicides. Hagberg Falling Number was markedly reduced when sequential sprays started at GS35 and GS41-59 and also when active ingredients were applied at GS41-51 (Fig. 58).

3.4 Discussion

3.4.1 Development of *Septoria tritici* and temporal incidence of rainfall

S. tritici developed to a greater or lesser degree on all six sites. High levels of disease on the top 3 leaves at the sites used in 1987 and 1988 were associated with the occurrence of several rain splash events with the apparent potential to transport inoculum from the bottom of the crop canopy to the upper leaves. By contrast in 1989 *S. tritici* developed to high levels only on leaf 3 at the Terrington site. At both of the sites used in 1989 there were three or less rain splash events apparently capable of transporting inoculum. However, on the basis of current criteria Rosemaund in particular in 1989 would have been considered a site of high risk for septoria development. Identification of the actual rain splash event responsible for major infection of any one of the top three leaves may be possible using the date of symptom development and the length of the latent period for *S. tritici* -c. 400 day degrees. However, as Tables 31 to 35 indicate, this is not entirely reliable since the calculated difference in day degrees from the imputed splash event and initial on maximum symptom development varied quite markedly around the 400 day degree period. Clearly the fairly crude rainfall criteria (of 5 mm on any one day or 10 mm during any three day period with rain on each of these days) used as a basis for estimating infection risk, need to be refined, *e.g.* by the use of the LARS splash meter or by relating rainfall intensity (however this is measured) to rain splash, infection and subsequent disease development.

3.4.2 Septoria tritici: AUDPC and fungicide activity

The application of sequential spray programmes and individual active ingredients constrained the development of the AUDPC for *S. tritici* up to a critical growth stage, the latter being associated with the occurrence of a rain splash event c. 400 degree days + the residual activity of the fungicides (measured in degree days) prior to the appearance of the first symptoms. Thus without knowledge of the residual activity of the fungicides AUDPC cannot be easily used to identify or confirm the occurrence of rain splash events; only unhindered disease progress curves may be used reliably for this purpose.

The two sites employed in 1987 were originally designed to establish yield loss relationships and as such had no individual active ingredients applied as single treatments. However, the sequential nature and temporal delay in starting the multiple spray programmes allowed disease to develop on the top three leaves only when the first or subsequent application of the multiple spray programme failed to eradicate previous successful infections or prevent future infections. The steady and/or large stepwise increases in the AUDPC on the top three leaves testifies to the occurrence of several rain splash and infection events. Differences in protectant and eradicant activity between prochloraz/fenpropimorph and chlorothalonil/fenpropimorph were readily apparent only on leaf 2. At Stawell prochloraz/fenpropimorph maintained a greater degree of control of *S. tritici* compared to chlorothalonil/fenpropimorph. At Englefield the latter maintained the greater degree of control. This may have been due to the greater incidence of rainfall during May and June at Englefield compared to Stawell and hence the reliance on protectant fungicide activity.

S. tritici developed to high levels on the top three leaves at Dorchester and Rosemaund in 1988. At Dorchester disease appeared to begin its development almost as soon as each leaf emerged. Leaf 3 had 40% *S. tritici* by mid-May. Consequently the degree of control of *S. tritici* on both leaf 3 and 2 was poor once spraying commenced after May 3 (GS33-37). Of the individual fungicides only those with reasonably good eradicant activity, propiconazole and prochloraz, reduced the AUDPC to any marked degree. Conversely the delay in the timing of infection of leaf 1 provided an excellent test of both the eradicant and protectant properties of the individual active ingredients since the disease, even on the sequentially sprayed plots did not increase markedly until after GS65. A similar situation occurred at Rosemaund although the early development of the disease was not so dramatic.

S. tritici developed to a marked degree at only the Terrington site in 1989 and then only on leaf 3 and to a much reduced extent on leaf 2. The profile of the AUDPC indicates that protectant and eradicant activity was sufficient to control *S. tritici* until spray application was delayed until 26 May-1 June. Thereafter eradicant activity of all treatments, with the exception of cyproconazole, was insufficient to maintain control.

On the basis of non-linear critical point regression analysis and curve fitting to these and other results from similar MAFF-funded experiments, it should be possible to provide a fairly precise estimate of the degree of protectant and eradicant activity of the fungicides used in these experiments against *S. tritici.*

3.4.3 Mildew development and fungicide activity

Mildew developed to moderately high levels (20-40%) at Rosemaund in both 1988 and 1989. Although the epidemic started considerably earlier in 1988 it was less severe than that of 1989, the latter accelerating only from GS69 onwards. Despite this fact profiles of the AUDPCs were similar in the two years, with both protectant and eradicant activity being apparent with the individual active ingredients. All of the fungicides appeared capable of major reduction in the AUDPC for mildew, depending on the timing of application relative to initial disease development and inherent activity. On the basis of non-linear regression analysis and curve fitting to these and other results from similar MAFF-funded experiments, it should be possible to provide a fairly precise estimate of the degree of protectant and eradicant activity of the fungicides used in these experiments against mildew. However, there is, as yet, no readily available model on which to base the prediction of mildew development.

3.4.4 Brown rust development and fungicide activity

Brown rust developed only at Stawell in 1987. The disease was not apparent until GS65 but developed rapidly to colonise c. 20% of leaves 2 and 3 at GS77. The AUDPC for brown rust on the top three leaves indicates that if spraying did not commence until the disease was apparent then the degree of control was much reduced, particularly on leaf 2. Moreover, even with some of the sequential spray programmes that started considerably earlier than GS61 the time interval between two consecutive spray applications allowed the brown rust pathogen to infect one or more leaves (mostly leaf 2) and develop to a certain degree. Not surprisingly prochloraz/ fenpropimorph exhibited greater eradicant activity compared to chlorothalonil/fenpropimorph although the latter possessed protectant activity at least equivalent if not slightly superior to that of the former. Brown rust development is governed principally by temperature and the occurrence of moisture on the leaves. Figure 59 shows maximum, mean and minimum temperatures for the Stawell site. It is apparent from Figure 59 that brown rust began its epidemic development only when the daily mean temperature was almost consistently within the range of the cardinal temperatures for brown rust as defined by Clifford & Harris (1981).

3.4.5 Yellow rust development and fungicide activity

Yellow rust developed only at Terrington in 1989. The disease was not apparent until GS55-57 on 7 June but thereafter developed rapidly on leaves 1 and 2 to colonise > 30% leaf area at GS75. The profiles of the AUDPCs for yellow rust indicate clearly that if spraying did not commence until after symptom appearance then the degree of disease control was much reduced. Moreover some of the sequential spray programmes that started considerably earlier than GS55-57 allowed the disease to develop presumably because the time interval between consecutive spray applications was too long to allow effective control. All single active ingredients exhibited both protectant and eradicant control and on the basis of non-linear regression analysis and curve fitting to these and other results from similar MAFF-funded experiments, it should be possible to provide a fairly precise estimate of the degree of protectant and eradicant activity of the fungicides used in these experiments against yellow rust. Known fungicide activity coupled with knowledge of yellow rust development should improve the prospects for efficient control of this potentially aggressive disease. It is worth noting that the maximum, mean and minimum daily temperatures at Terrington in 1989 (Fig. 60) were well within the cardinal temperature bands as estimated by Park (1990).

3.4.6 Eyespot development and fungicide activity

Eyespot developed at slight to moderate levels at Stawell and at moderate to severe levels at Englefield and Dorchester. At each site there was a tendency for eyespot control to decline with each week's delay in the start of the sequential spray programmes. This was particularly obvious at the Stawell site with the use of prochloraz/fenpropimorph and also, although far more erratically, with chlorothalonil/fenpropimorph. The marked variation in the activity of the latter was at least in part associated with the lack of rainfall in the period 11-26 April and 2-10 May. A similar explanation could be applied to the erratic control of eyespot at the Englefield site where dry periods occurred between 11-27 April and 2-10 May. At Dorchester the only sequential spray programme to reduce markedly the level of eyespot started on 26 April at GS32 just before very heavy rain on 28 April-3 May. A subsequent dry period was associated with a lack of control from fungicide application on 3 and 10 May. It is understood that eyespot control by prochloraz is considerably improved in some instances when periods of rainfall occur soon after fungicide application (Jordan, unpublished). All of the individual active ingredients were associated with a degree of eyespot control when applied at particular growth stages. However the profile of eyespot control could not be readily explained on the basis of known fungicide activity.

3.4.7 Yield and grain quality effects

Disease development and severity exhibited good correlation with yield and to a lesser extent with specific weight and thousand grain weight. Variation in yield was well explained by changes in thousand grain weight and to a lesser extent by specific weight so that diseases may be considered to affect yield principally through reduced grain size and density. The relationship between yield and disease severity at the six sites is given Table 36.

At the sites where Hagberg falling number (HFN) was recorded, significant relationships were found with green area on the flag leaf (GLA) during milk or dough development. At Englefield, the correlation was with GLA at GS85 and was -0.87. The regression was also highly significant, accounting for 73% of the variance. Hagberg falling number is clearly influenced by the retention of green leaf area during the ripening period and is at odds with the requirements for maximising yields. Whilst a maximum amount of green leaf on the flag and second leaf is required during grain filling, programmes which maintain a healthy flag leaf much beyond GS75 would appear to be deleterious to optimal Hagberg numbers, so that in milling wheats fungicide regimes will need to be tailored to this requirement.

Table 36. Disease severity/yield loss relationships

Site	Relationship	R^2	Significance of regression
Dorchester	Y = 7.71 - 0.0157 St1 - 0.0232 St2 - 0.0149 St3	45.0%	P<0.001
Englefield	Y = 11.1 - 0.107 St1 - 0.0546 St2	75.7%	P<0.001
Rosemaund 1988	Y = 8.07 0.065 Mi2 - 0.0379 St2	75.3%	P<0.001
Rosemaund 1989	Y = 12.2 - 0.0576 Mi1 - 0.0513 Mi2 - 0.0962 Mi3	74.6%	P<0.001
Stawell	Y = 10.0 - 0.0182 St2 - 0.0154 St3 - 0.193 Br1	94.6%	P<0.001
Terrington	Y = 8.26 - 0.0239 Yr1 - 0.0448 Yr2	65.6%	P<0.001

Br1 = % Brown rust on leaf 1 at GS71-75
Mi1-3 = % Mildew on leaves 1-3 at GS71-75
St1-3 = % *Septoria tritici* on leaves 1-3 at GS71-75
Yr1-3 = % Yellow rust on leaves 1-2 at GS71-75

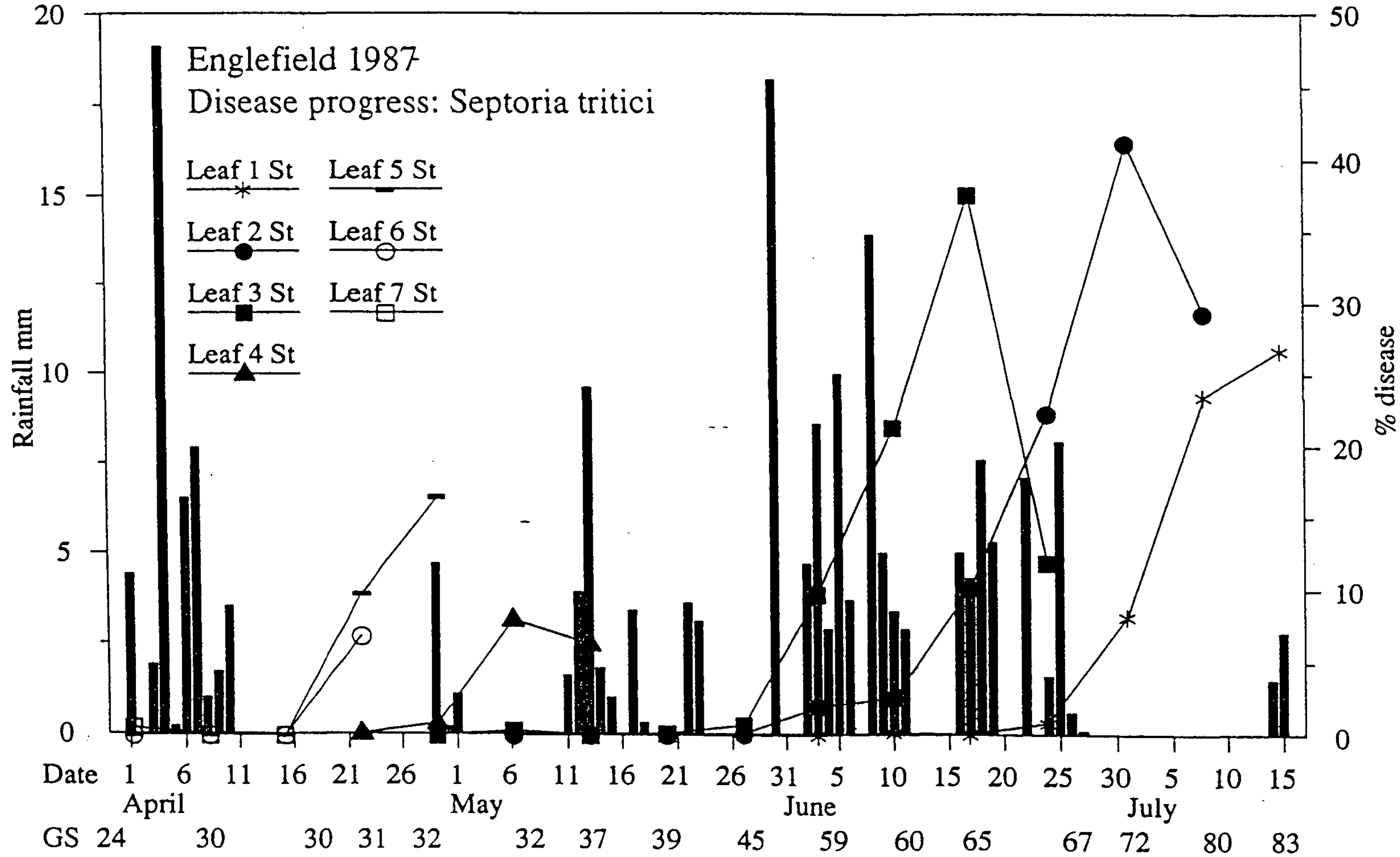

Englefield 1987
Disease progress: Septoria tritici
Leaf 1 St
Leaf 2 St
Leaf 3 St
Leaf 4 St
Leaf 5 St
Leaf 6 St
Leaf 7 St
Rainfall mm
% disease
Date 1 6 11 16 21 26 1 6 11 16 21 26 31 5 10 15 20 25 30 5 10 15
April
May
June
July
GS 24 30 30 31 32 32 37 39 45 59 60 65 67 72 80 83

Fig. 8

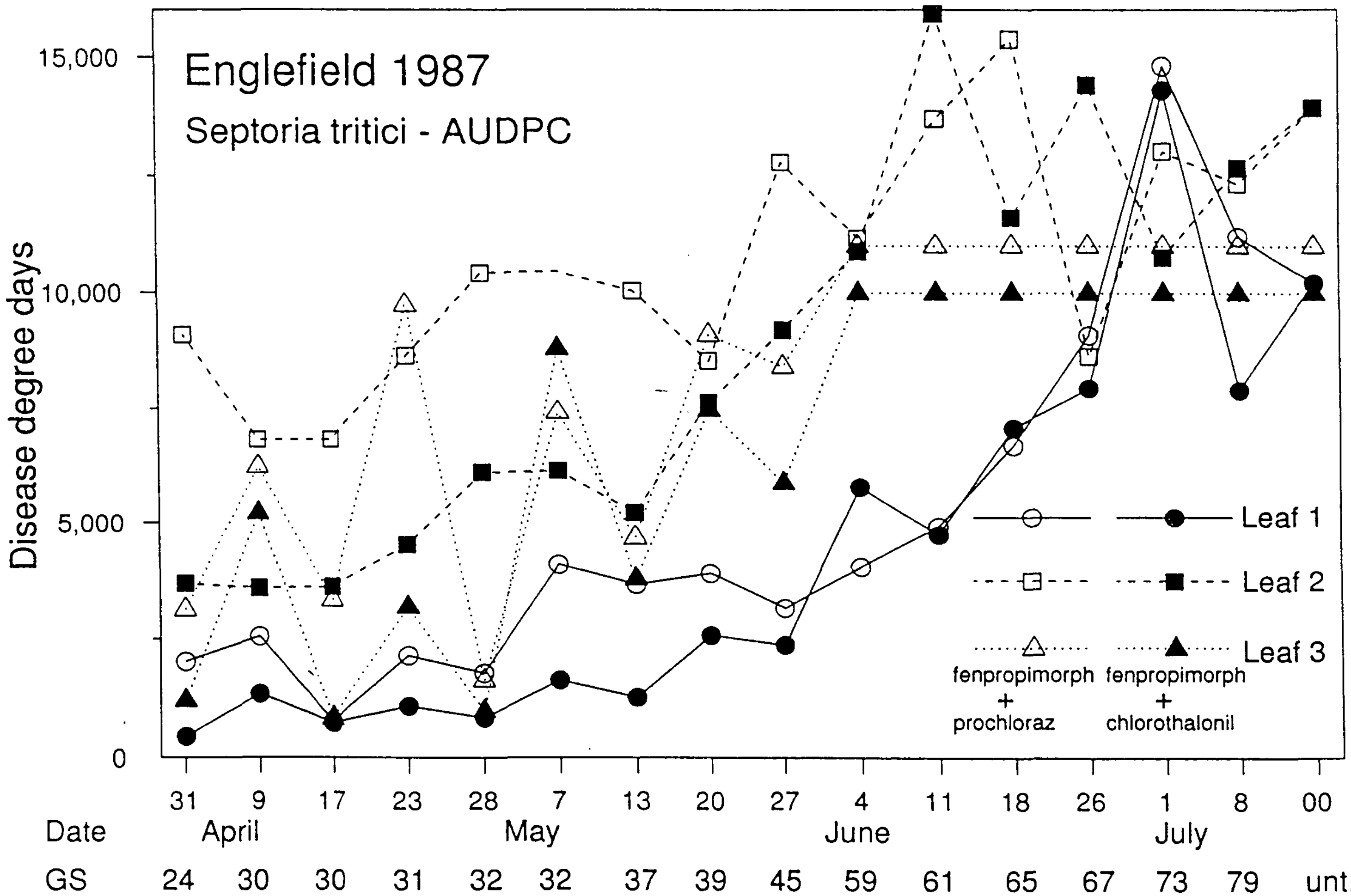

Englefield 1987
Septoria tritici - AUDPC
Disease degree days
15,000
10,000
5,000
0
Leaf 1
Leaf 2
Leaf 3
fenpropimorph + prochloraz
fenpropimorph + chlorothalonil
Date
31 9 17 23 28 7 13 20 27 4 11 18 26 1 8 00
April
May
June
July
GS
24 30 30 31 32 32 37 39 45 59 61 65 67 73 79 unt.

Fig. 9

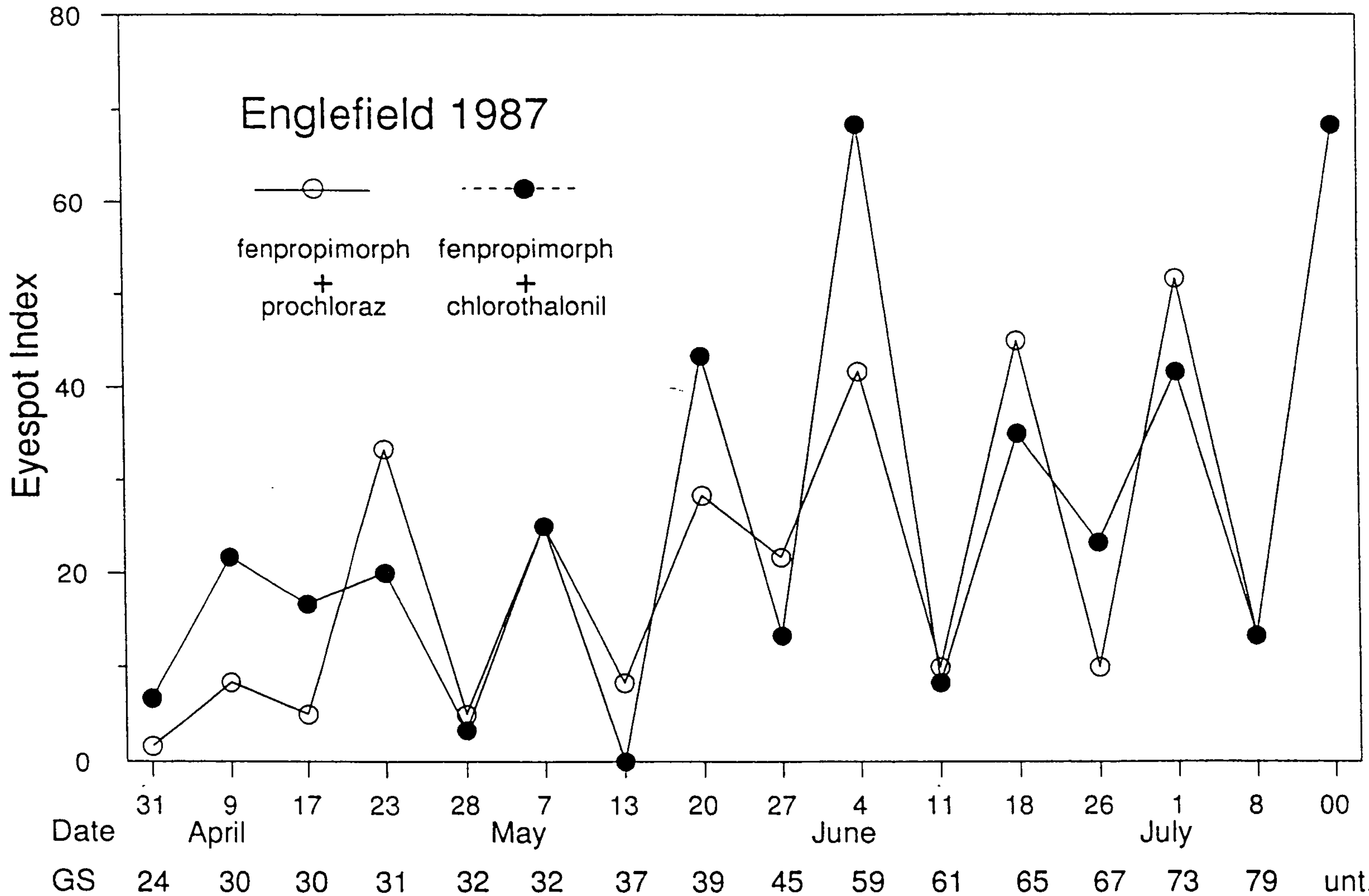

Englefield 1987
fenpropimorph + prochloraz
fenpropimorph + chlorothalonil
Eyespot Index
0
20
40
60
80
Date
31 9 17 23 28 7 13 20 27 4 11 18 26 1 8 00
April
May
June
July
GS
24 30 30 31 32 32 37 39 45 59 61 65 67 73 79 unt.

Fig. 10

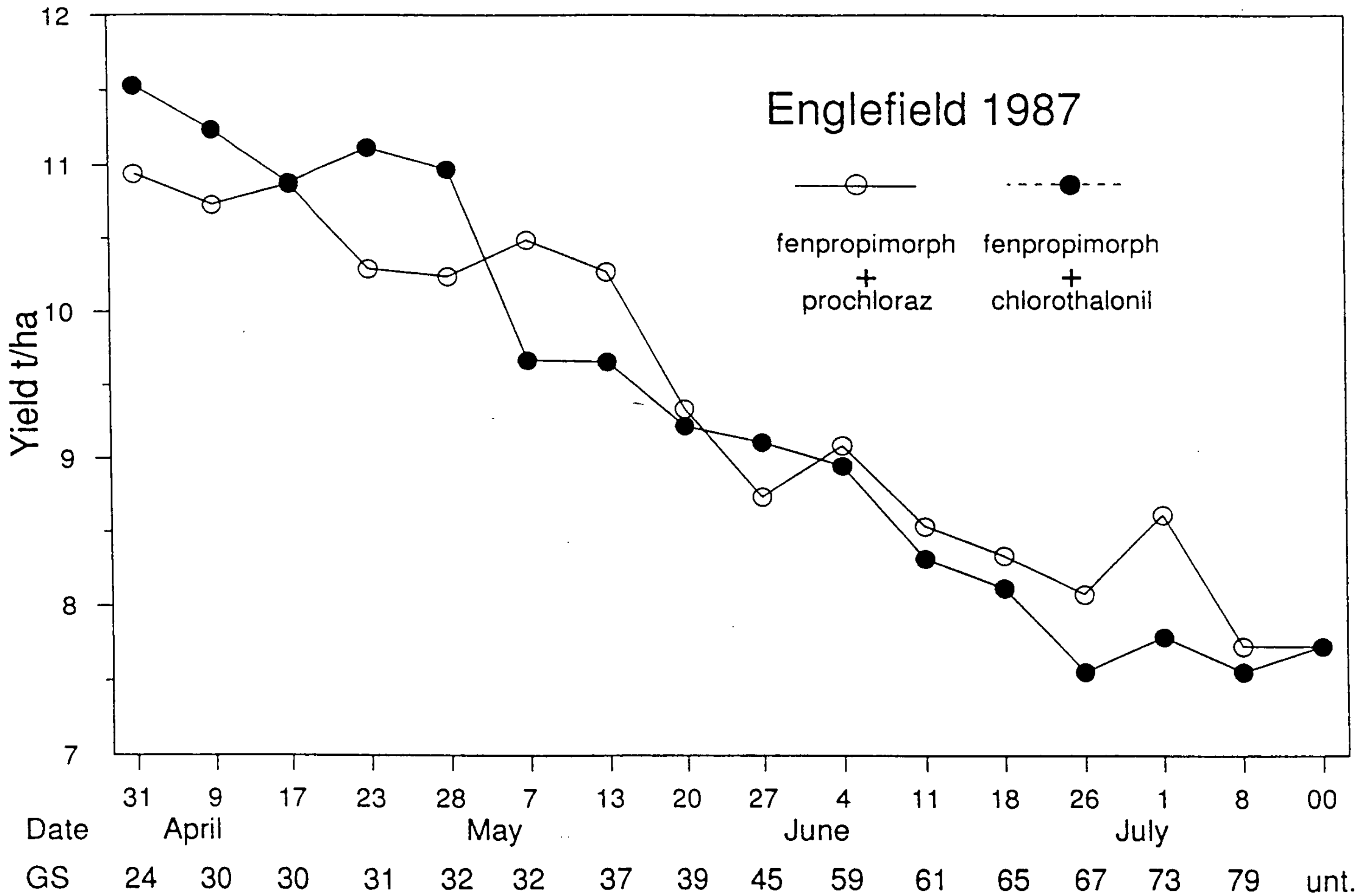

Englefield 1987
fenpropimorph + prochloraz
fenpropimorph + chlorothalonil
Yield t/ha
12
11
10
9
8
7
Date
31 9 17 23 28 7 13 20 27 4 11 18 26 1 8 00
April
May
June
July
GS
24 30 30 31 32 32 37 39 45 59 61 65 67 73 79 unt.

Fig. 11

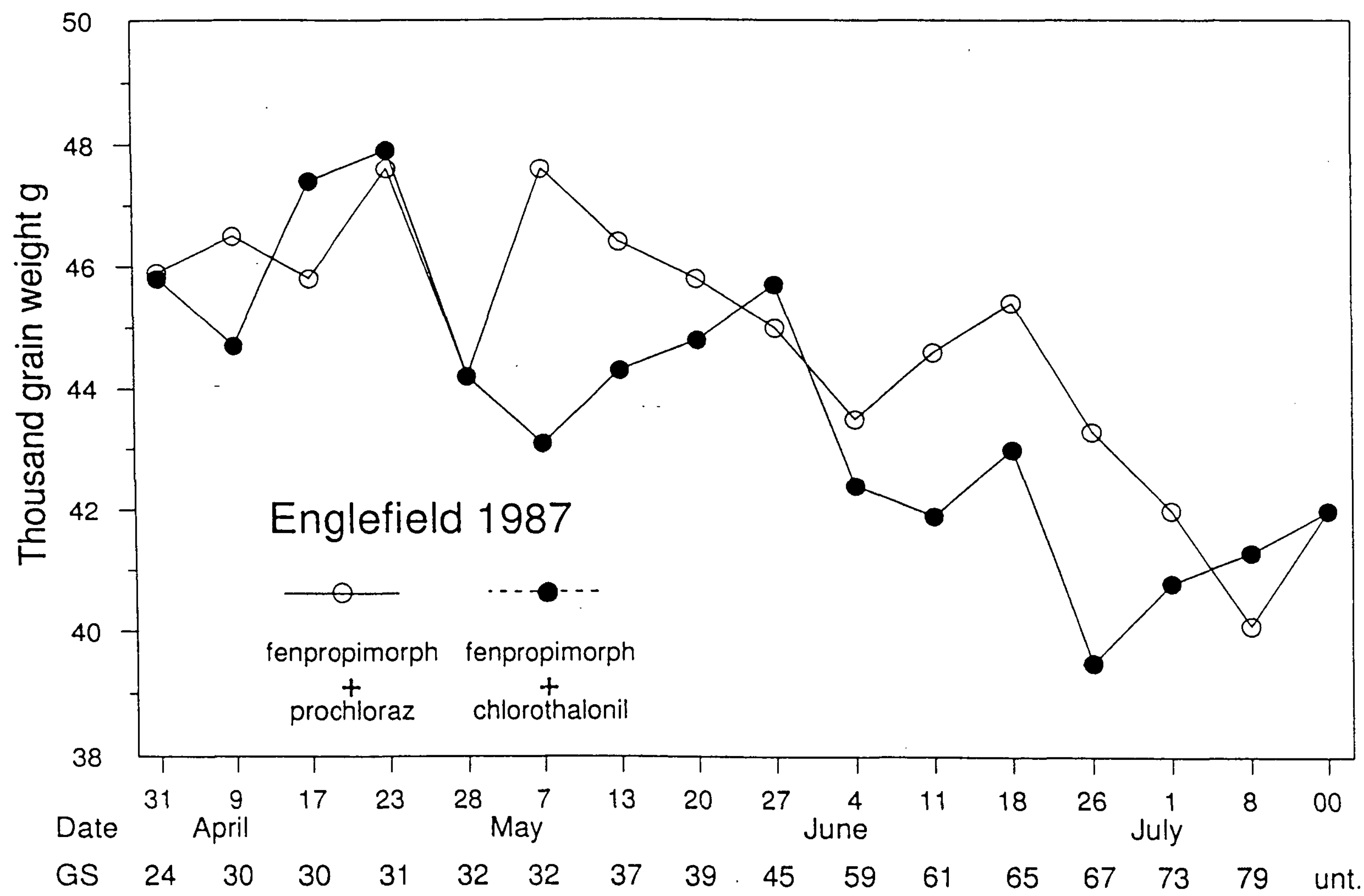

Thousand grain weight g
50
48
46
44
42
40
38
Englefield 1987
fenpropimorph + prochloraz
fenpropimorph + chlorothalonil
Date
31 9 17 23 28 7 13 20 27 4 11 18 26 1 8 00
April
May
June
July
GS
24 30 30 31 32 32 37 39 45 59 61 65 67 73 79 unt.

Fig. 12

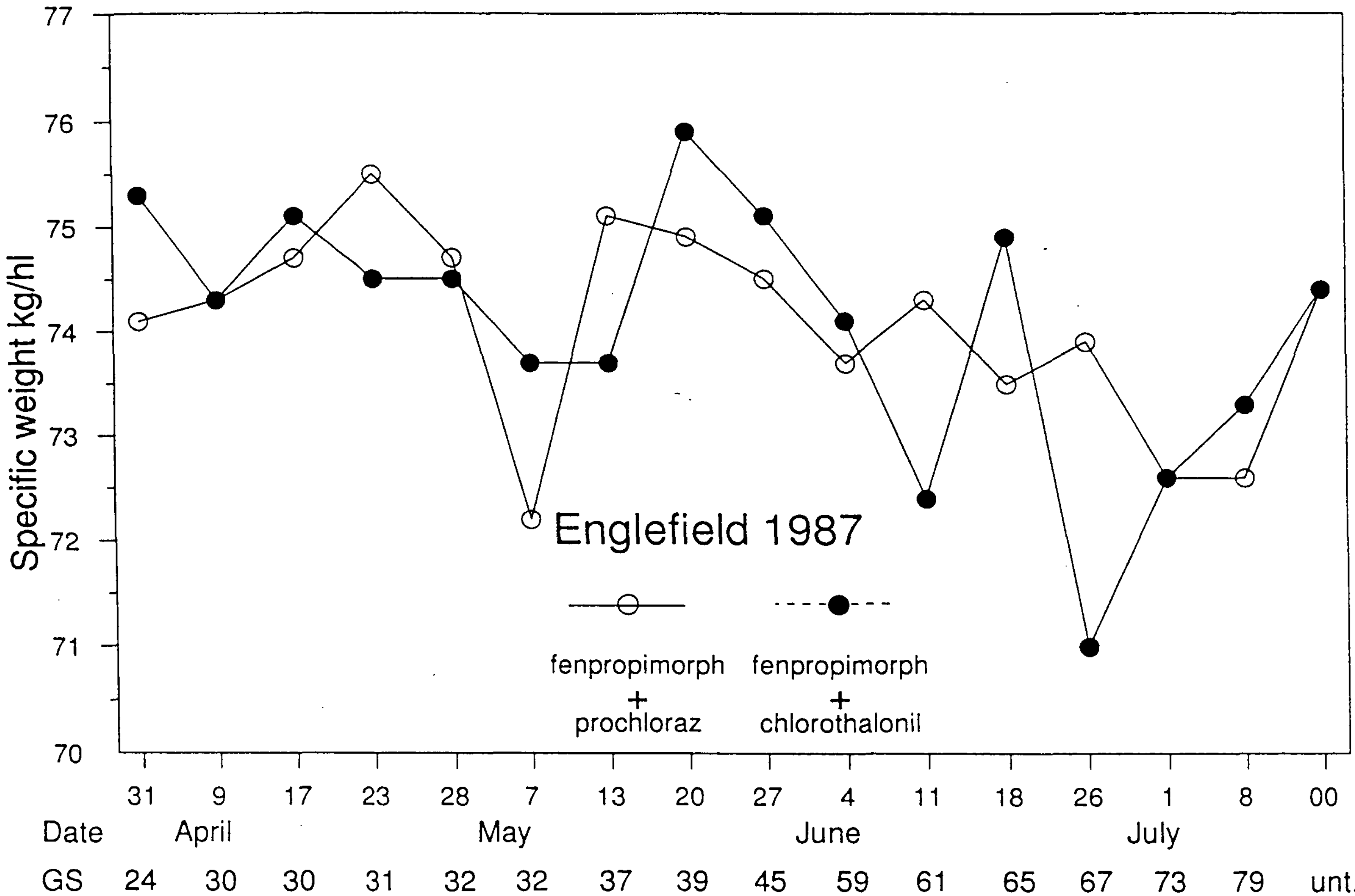

Specific weight kg/hl
77
76
75
74
73
72
71
70
Englefield 1987
fenpropimorph + prochloraz
fenpropimorph + chlorothalonil
31 9 17 23 28 7 13 20 27 4 11 18 26 1 8 00
Date April May June July
GS 24 30 30 31 32 32 37 39 45 59 61 65 67 73 79 unt.

Fig. 13

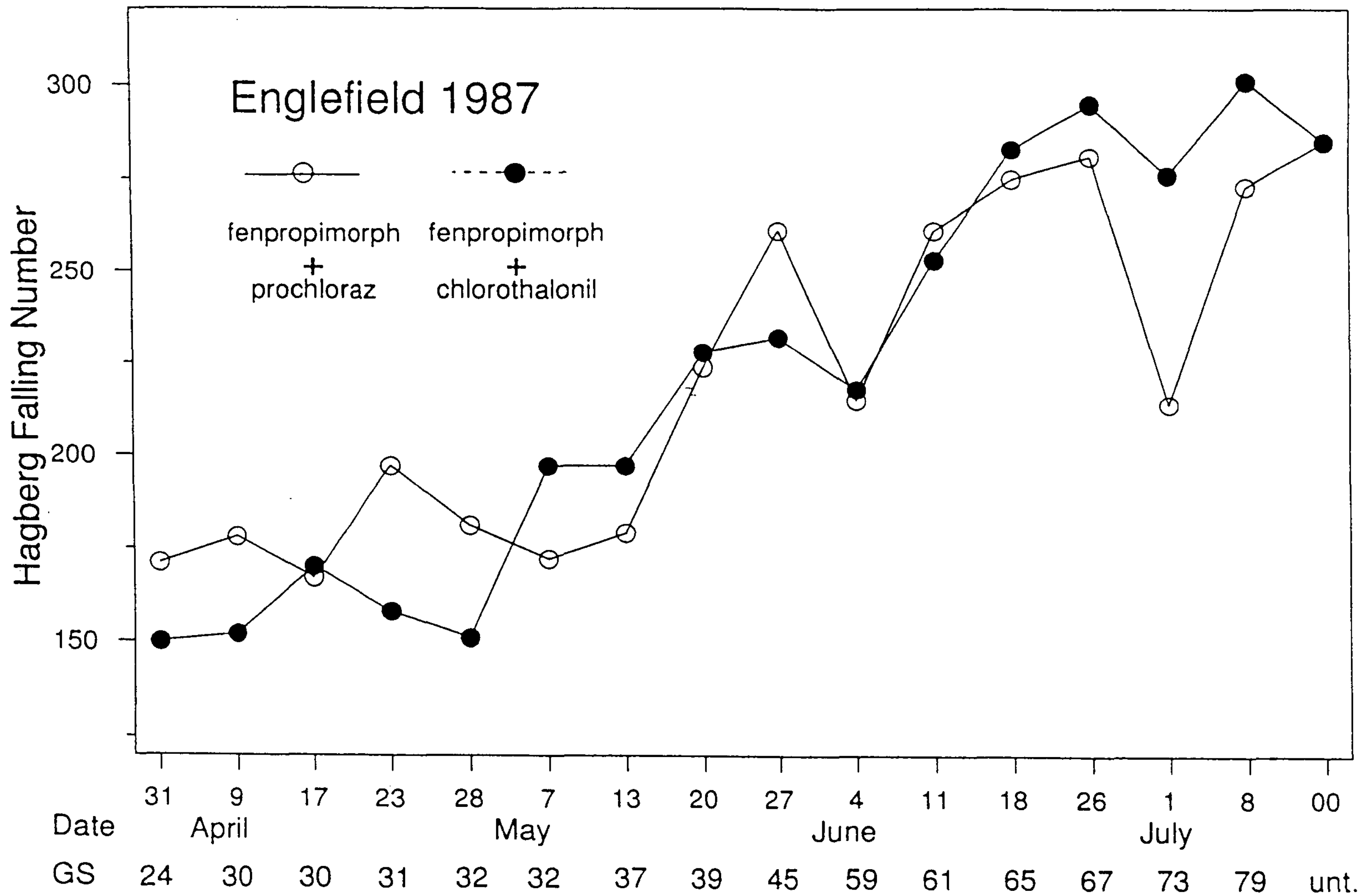

Englefield 1987
fenpropimorph + prochloraz
fenpropimorph + chlorothalonil
Hagberg Falling Number
300
250
200
150
Date
31
9
April
17
23
28
7
May
13
20
27
4
June
11
18
26
1
July
8
00
GS
24
30
30
31
32
32
37
39
45
59
61
65
67
73
79
unt.

Fig. 14

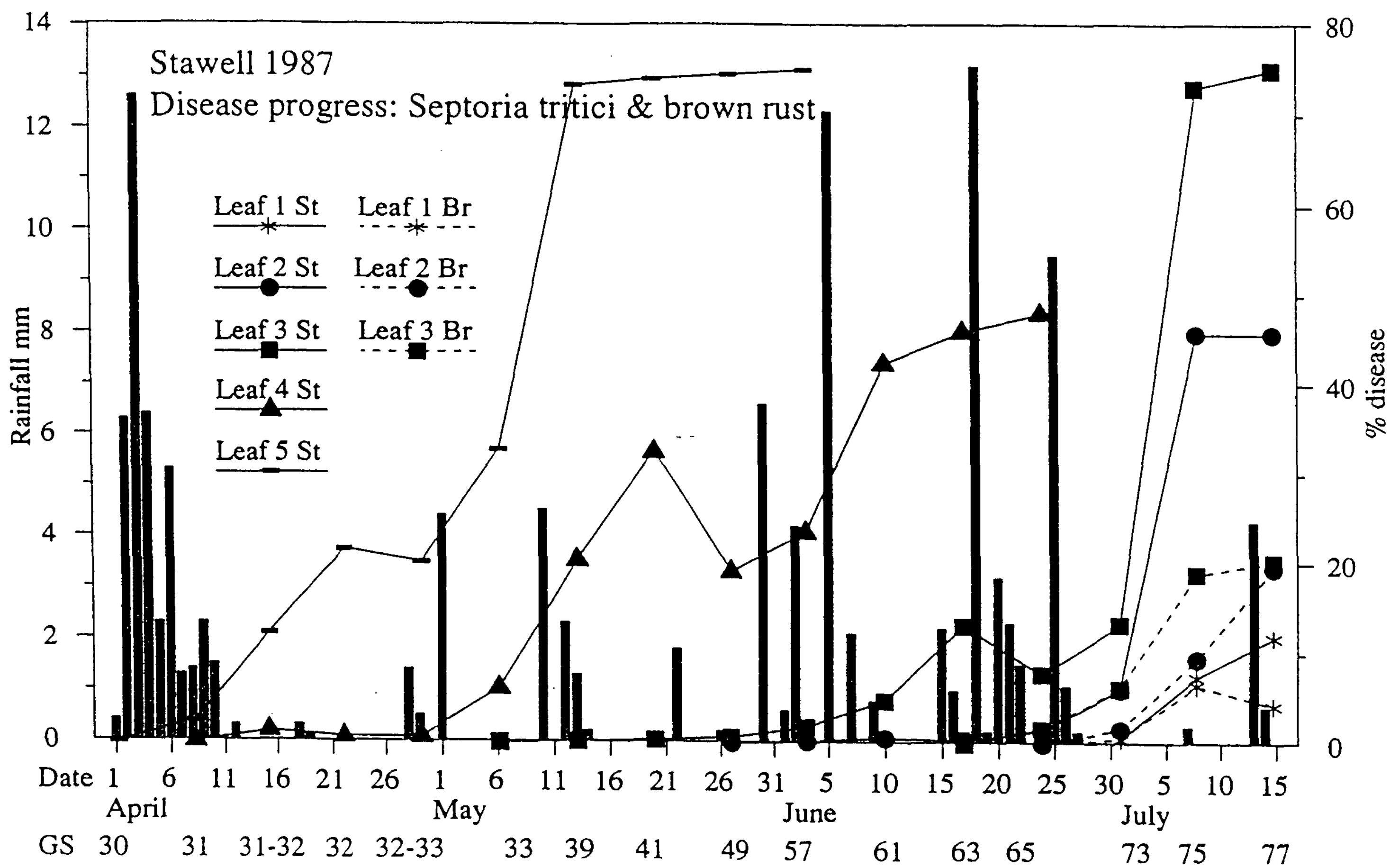

Stawell 1987
Disease progress: Septoria tritici & brown rust
Leaf 1 St
Leaf 1 Br
Leaf 2 St
Leaf 2 Br
Leaf 3 St
Leaf 3 Br
Leaf 4 St
Leaf 5 St
Rainfall mm
% disease
Date 1 6 11 16 21 26 1 6 11 16 21 26 31 5 10 15 20 25 30 5 10 15
April May June July
GS 30 31 31-32 32 32-33 33 39 41 49 57 61 63 65 73 75 77
0 2 4 6 8 10 12 14
0 20 40 60 80

Fig. 15

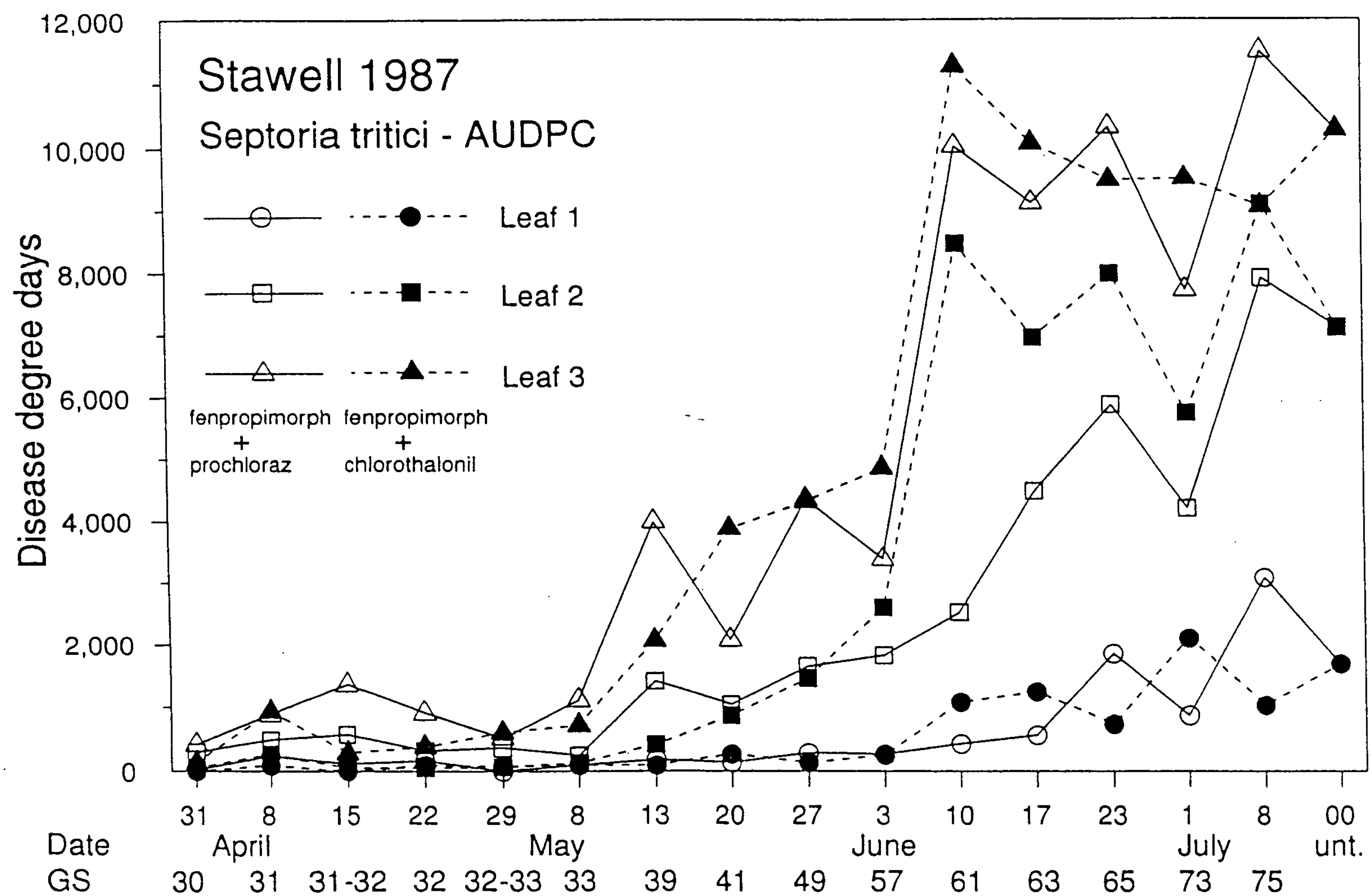

Stawell 1987
Septoria tritici - AUDPC
Leaf 1
Leaf 2
Leaf 3
fenpropimorph + prochloraz
fenpropimorph + chlorothalonil
Disease degree days
12,000
10,000
8,000
6,000
4,000
2,000
0
31 8 15 22 29 8 13 20 27 3 10 17 23 1 8 00
Date April May June July unt.
GS 30 31 31-32 32 32-33 33 39 41 49 57 61 63 65 73 75

Fig. 16

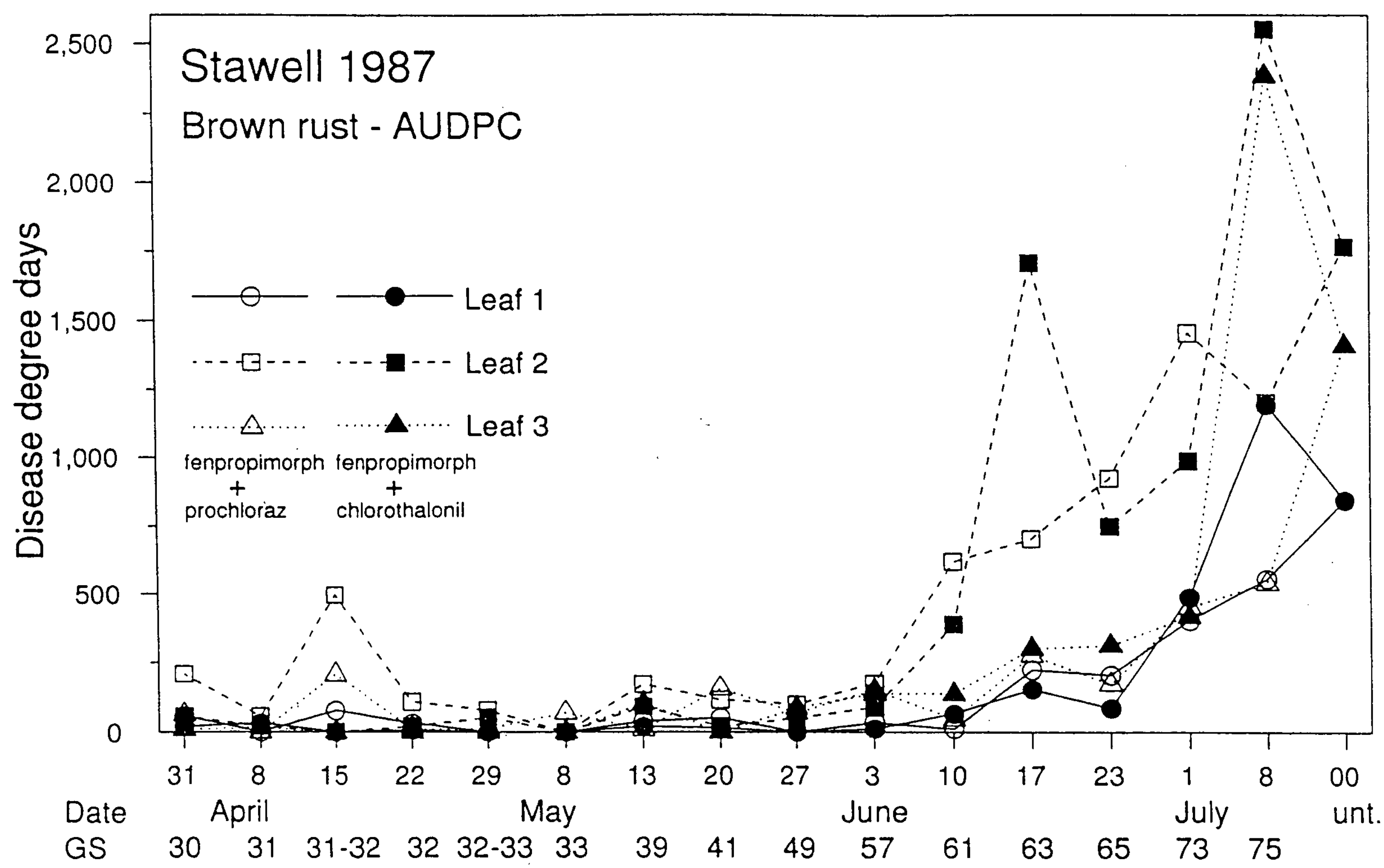

Stawell 1987
Brown rust - AUDPC
Disease degree days
2,500
2,000
1,500
1,000
500
0
Leaf 1
Leaf 2
Leaf 3
fenpropimorph + prochloraz
fenpropimorph + chlorothalonil
31 8 15 22 29 8 13 20 27 3 10 17 23 1 8 00
Date April May June July unt.
GS 30 31 31-32 32 32-33 33 39 41 49 57 61 63 65 73 75

Fig. 17

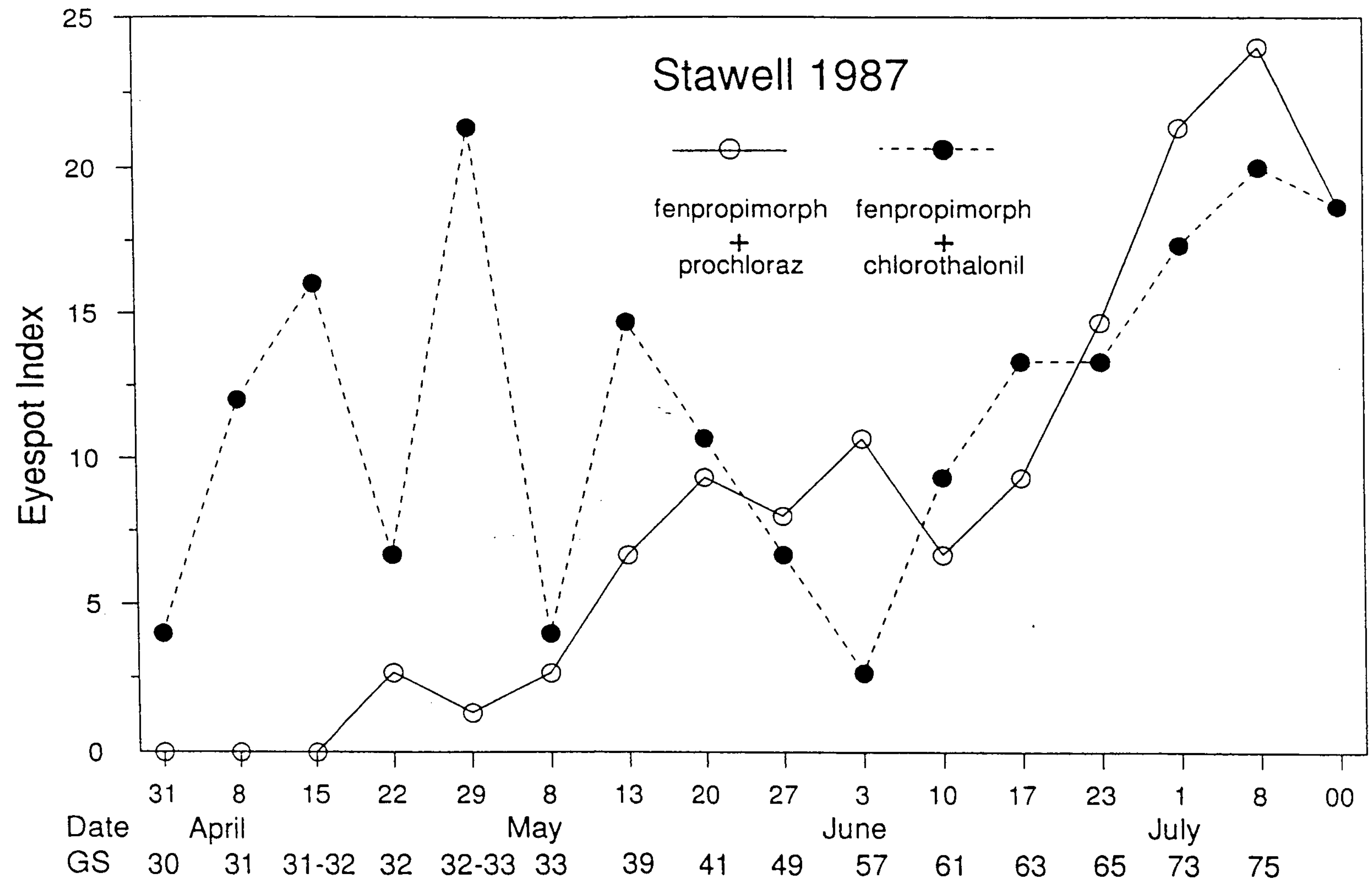

Stawell 1987
fenpropimorph + prochloraz
fenpropimorph + chlorothalonil
Eyespot Index
0
5
10
15
20
25
31
8
15
22
29
8
13
20
27
3
10
17
23
1
8
00
Date
April
May
June
July
GS
30
31
31-32
32
32-33
33
39
41
49
57
61
63
65
73
75

Fig. 18

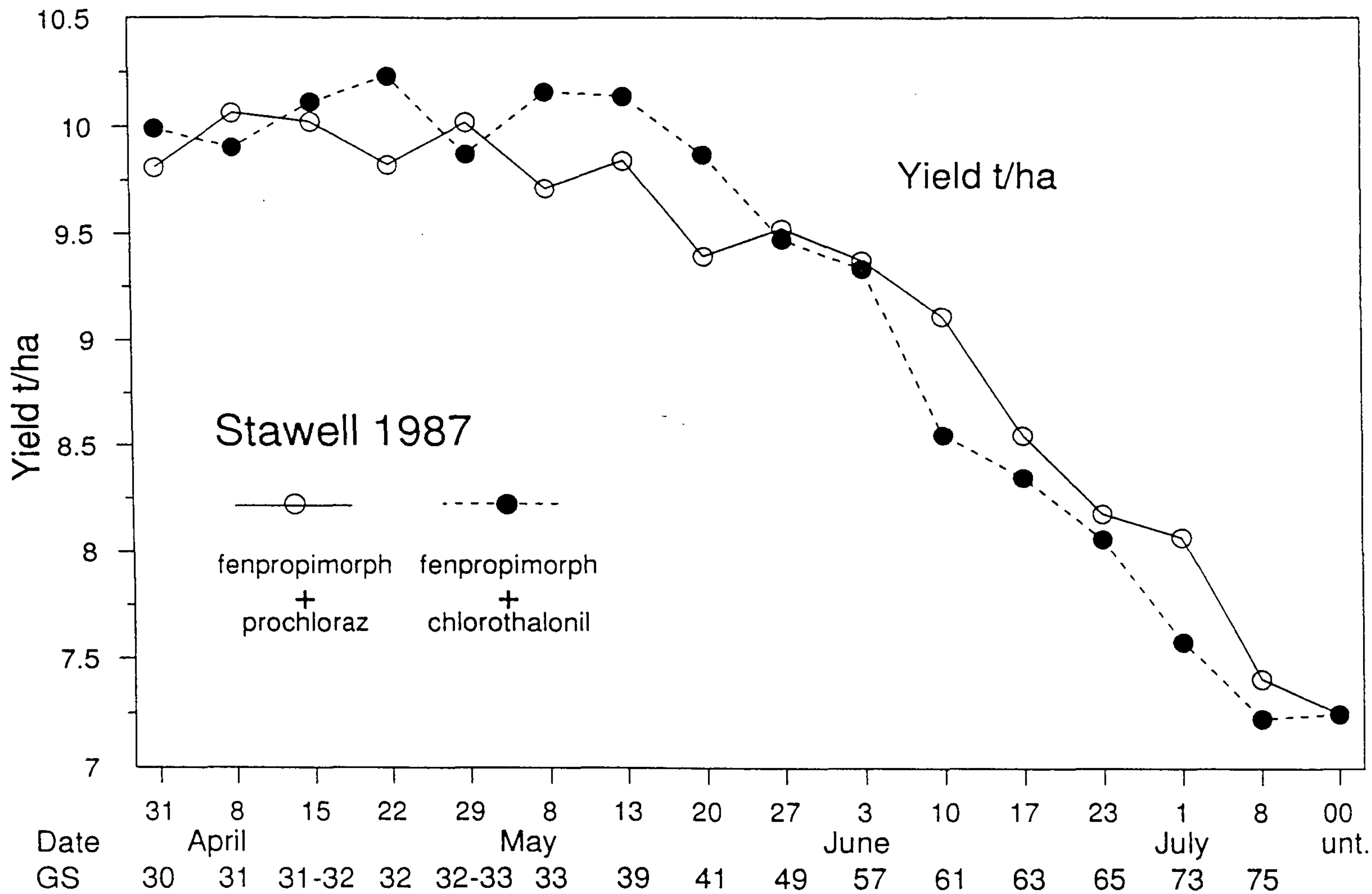

10.5
10
9.5
9
8.5
8
7.5
7
Yield t/ha
Yield t/ha
Stawell 1987
fenpropimorph
+
prochloraz
fenpropimorph
+
chlorothalonil
31
8
15
22
29
8
13
20
27
3
10
17
23
1
8
00
Date
April
May
June
July
unt.
GS
30
31
31-32
32
32-33
33
39
41
49
57
61
63
65
73
75

Fig. 19

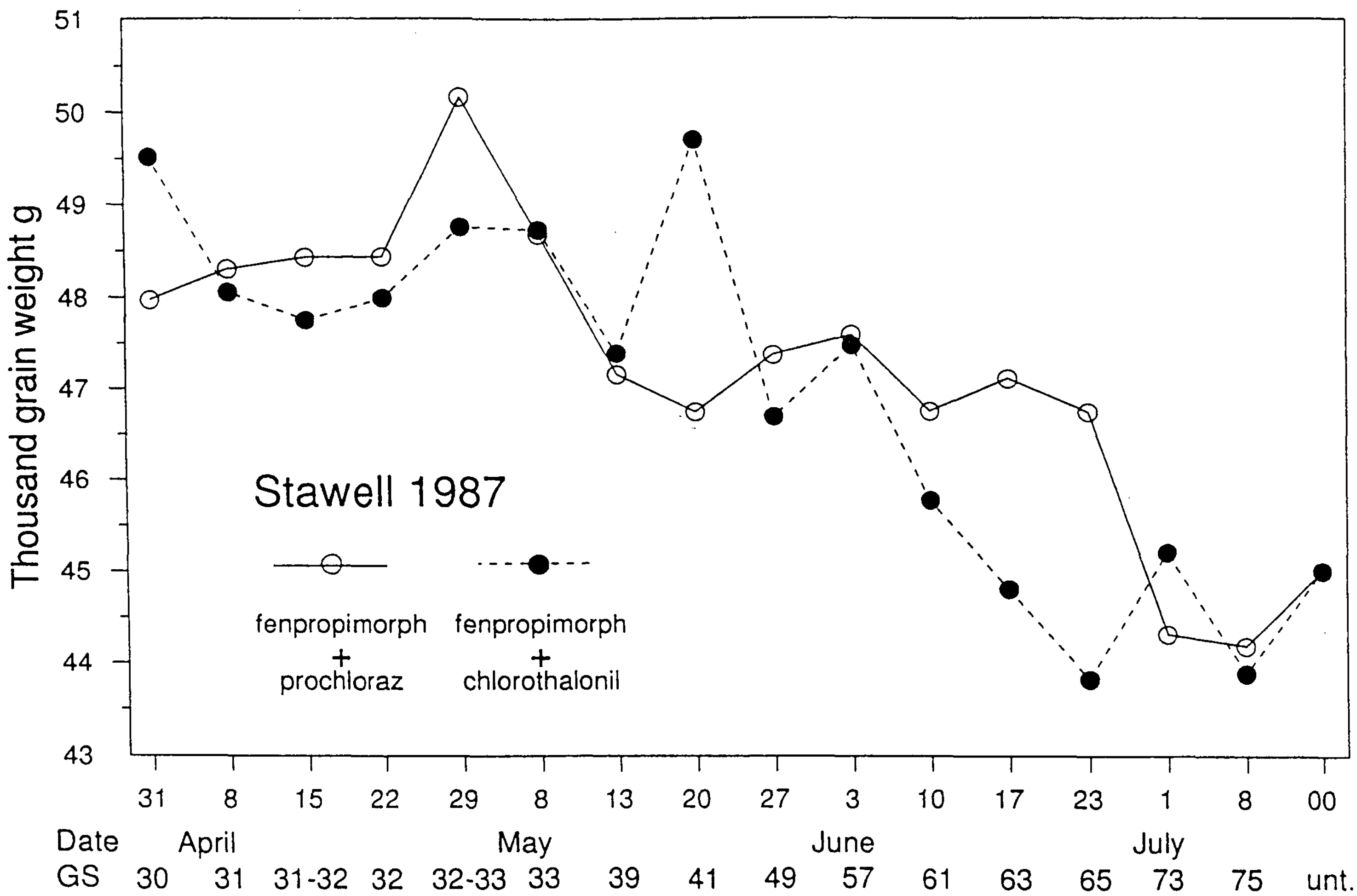
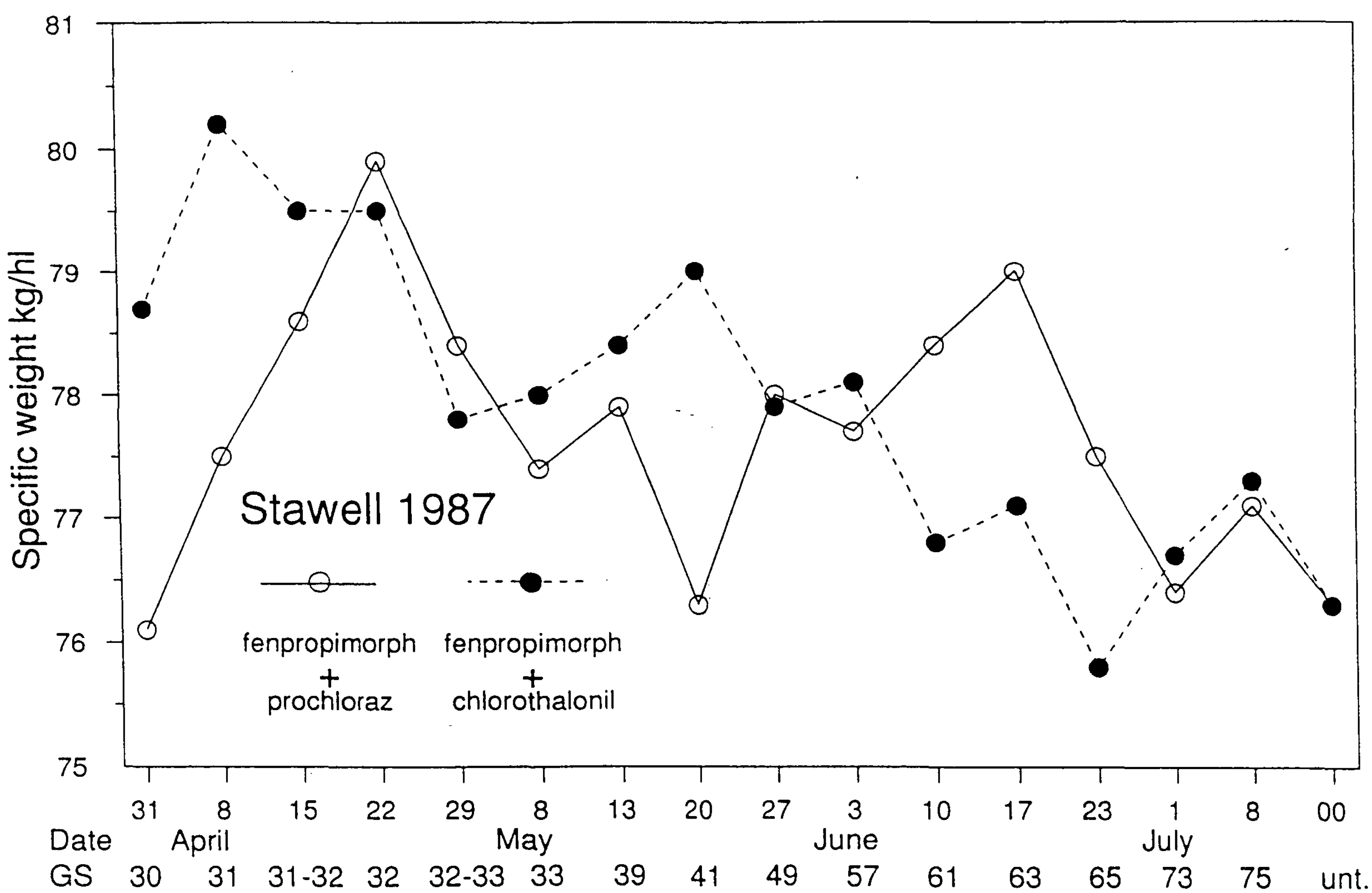

Thousand grain weight g
51
50
49
48
47
46
45
44
43
Stawell 1987
fenpropimorph + prochloraz
fenpropimorph + chlorothalonil
31 8 15 22 29 8 13 20 27 3 10 17 23 1 8 00
Date April May June July
GS 30 31 31-32 32 32-33 33 39 41 49 57 61 63 65 73 75 unt.

Fig. 20



Specific weight kg/hl
81
80
79
78
77
76
75
Stawell 1987
fenpropimorph + prochloraz
fenpropimorph + chlorothalonil
31
8
15
22
29
8
13
20
27
3
10
17
23
1
8
00
Date
April
May
June
July
GS
30
31
31-32
32
32-33
33
39
41
49
57
61
63
65
73
75
unt.

Fig. 21

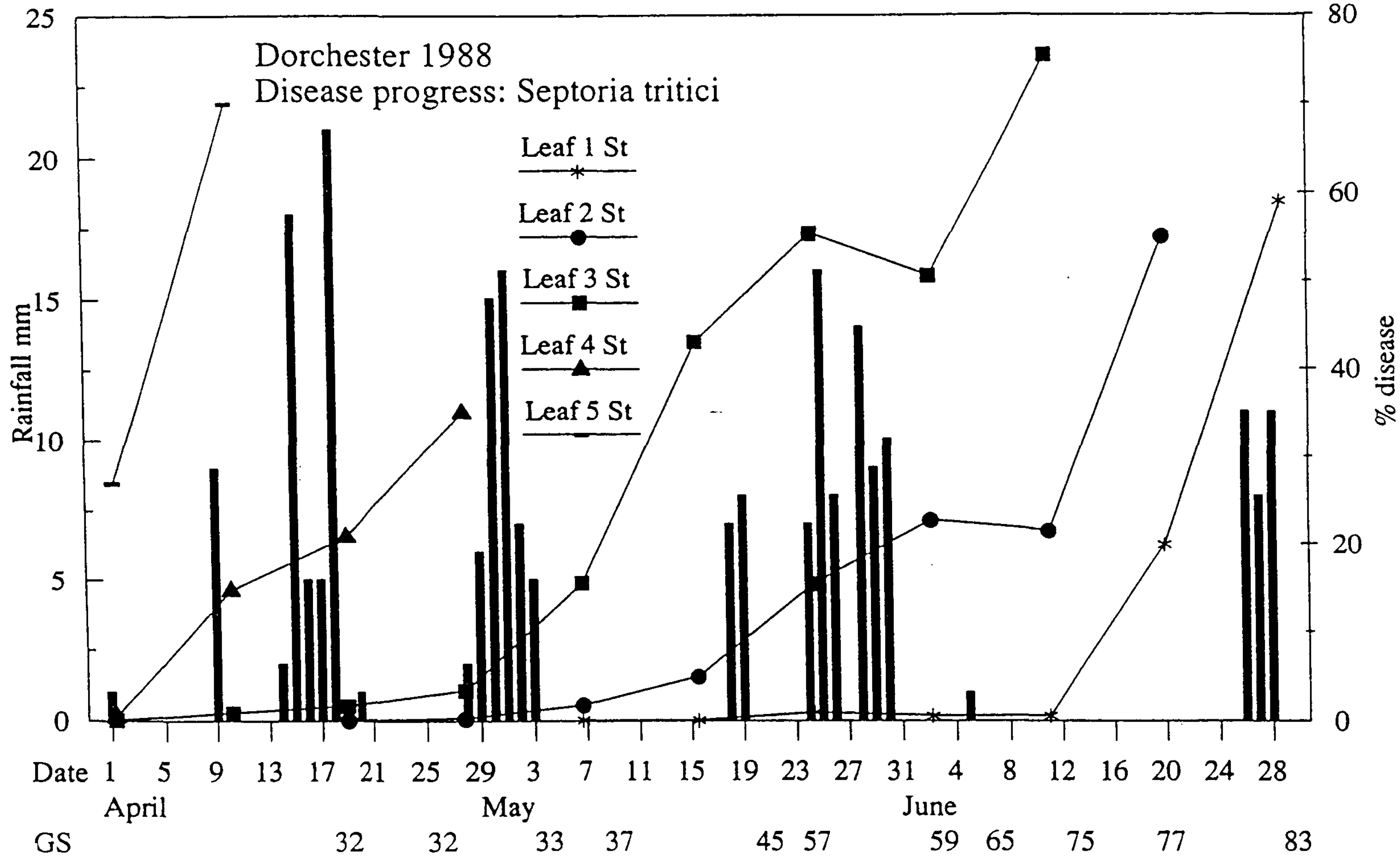

Dorchester 1988
Disease progress: Septoria tritici
Leaf 1 St
Leaf 2 St
Leaf 3 St
Leaf 4 St
Leaf 5 St
Rainfall mm
% disease
0
5
10
15
20
25
0
20
40
60
80
Date 1 5 9 13 17 21 25 29 3 7 11 15 19 23 27 31 4 8 12 16 20 24 28
April
May
June
GS 32 32 33 37 45 57 59 65 75 77 83

Fig. 22

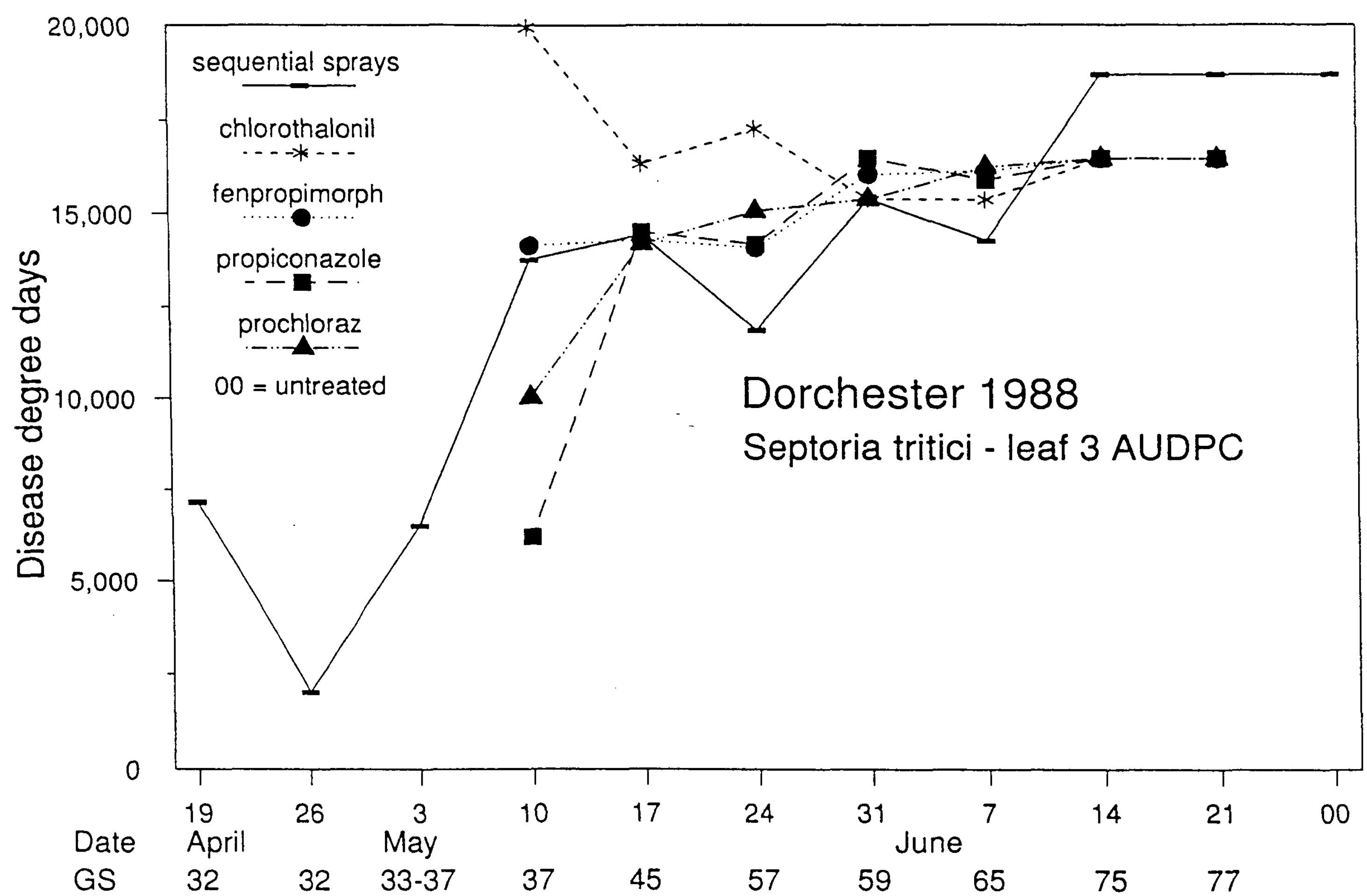

Dorchester 1988
Septoria tritici - leaf 3 AUDPC
Disease degree days
20,000
15,000
10,000
5,000
0
sequential sprays
chlorothalonil
fenpropimorph
propiconazole
prochloraz
00 = untreated
19
26
3
10
17
24
31
7
14
21
00
Date
April
May
June
GS
32
32
33-37
37
45
57
59
65
75
77

Fig. 23

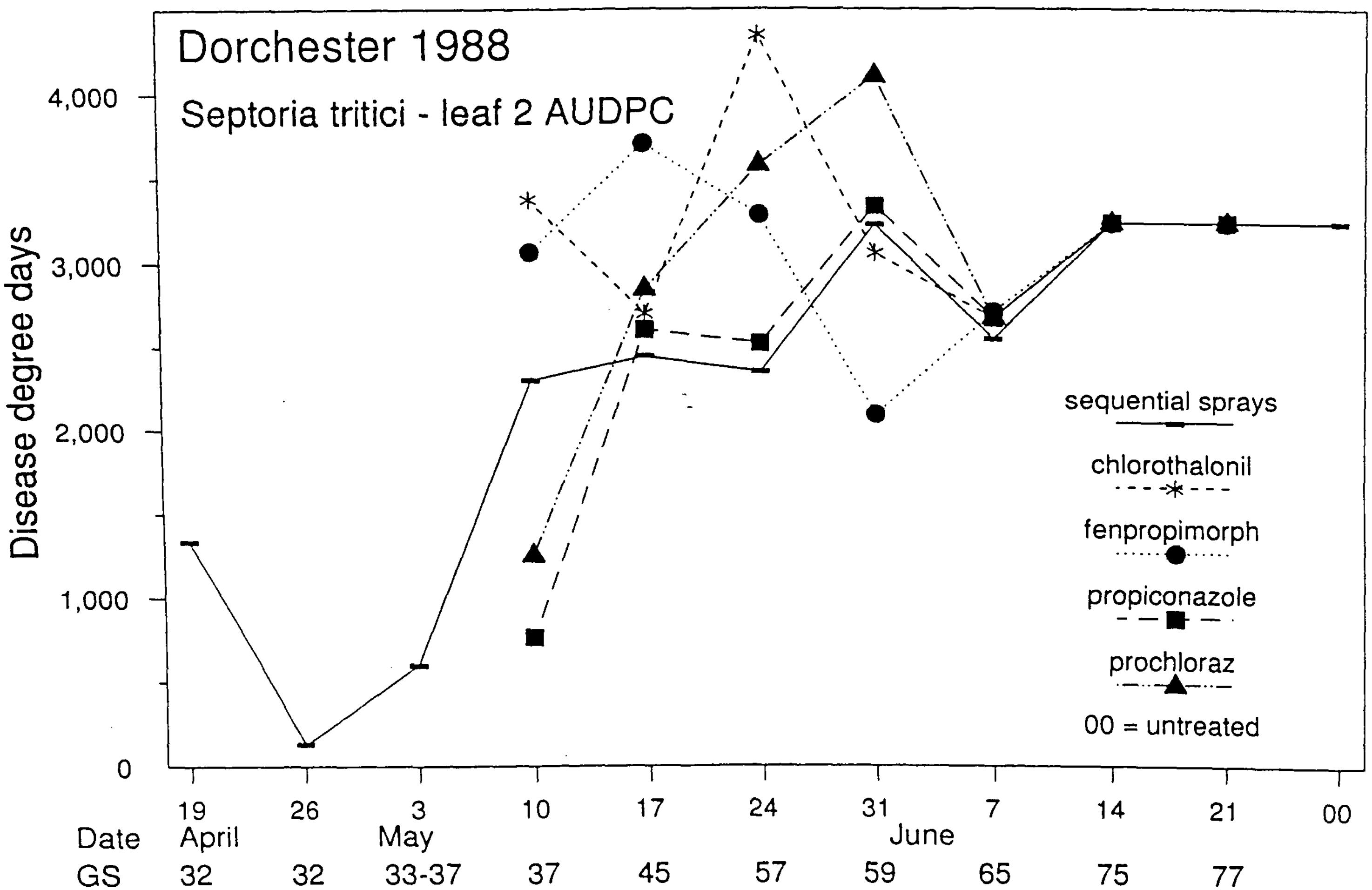

Dorchester 1988
Septoria tritici - leaf 2 AUDPC
Disease degree days
0
1,000
2,000
3,000
4,000
Date
19 April
26
3 May
10
17
24
31
June
7
14
21
00
GS
32
32
33-37
37
45
57
59
65
75
77
sequential sprays
chlorothalonil
fenpropimorph
propiconazole
prochloraz
00 = untreated

Fig. 24

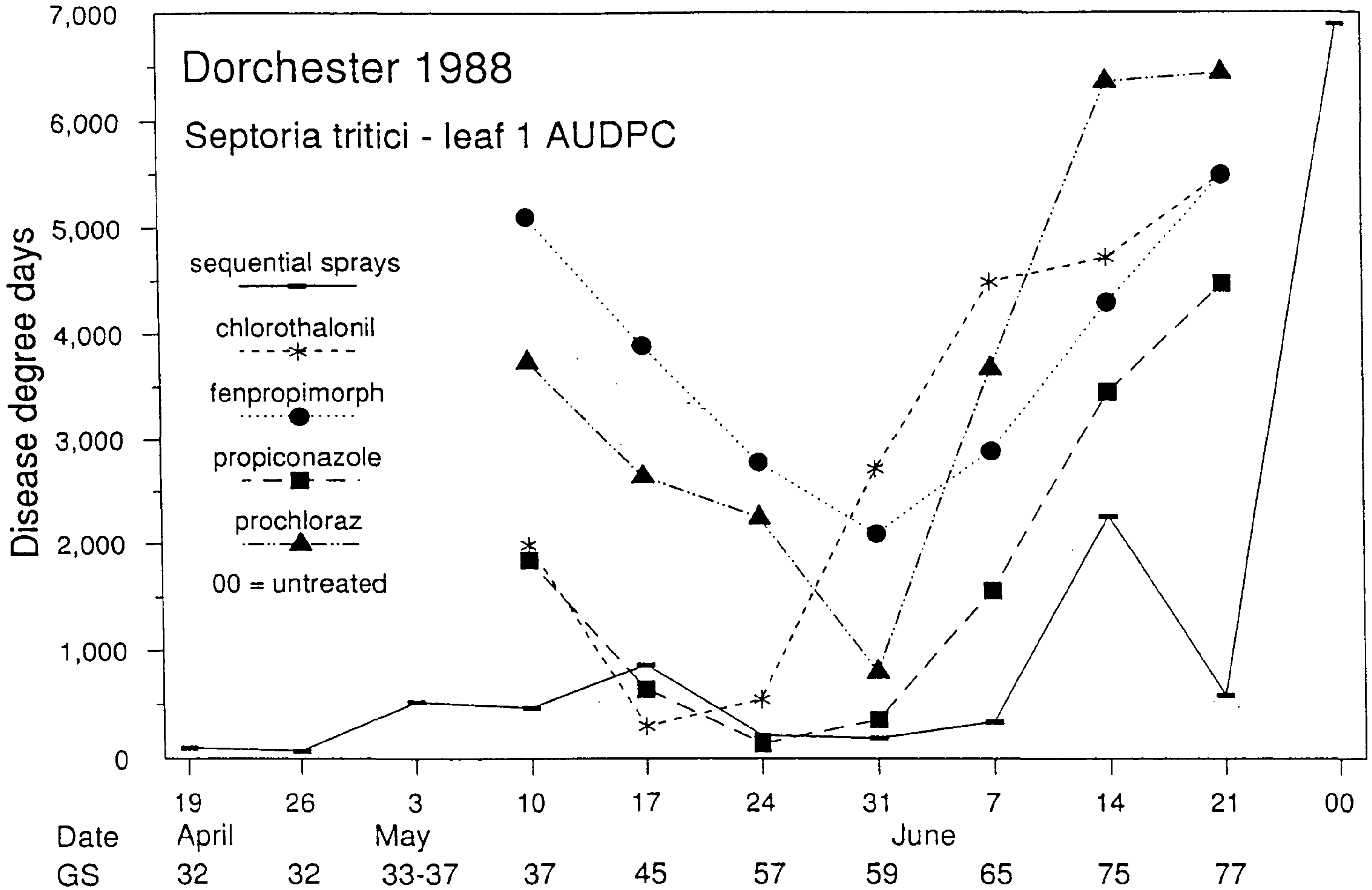

Dorchester 1988
Septoria tritici - leaf 1 AUDPC
Disease degree days
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
sequential sprays
chlorothalonil
fenpropimorph
propiconazole
prochloraz
00 = untreated
19
26
3
10
17
24
31
7
14
21
00
Date
April
May
June
GS
32
32
33-37
37
45
57
59
65
75
77

Fig. 25

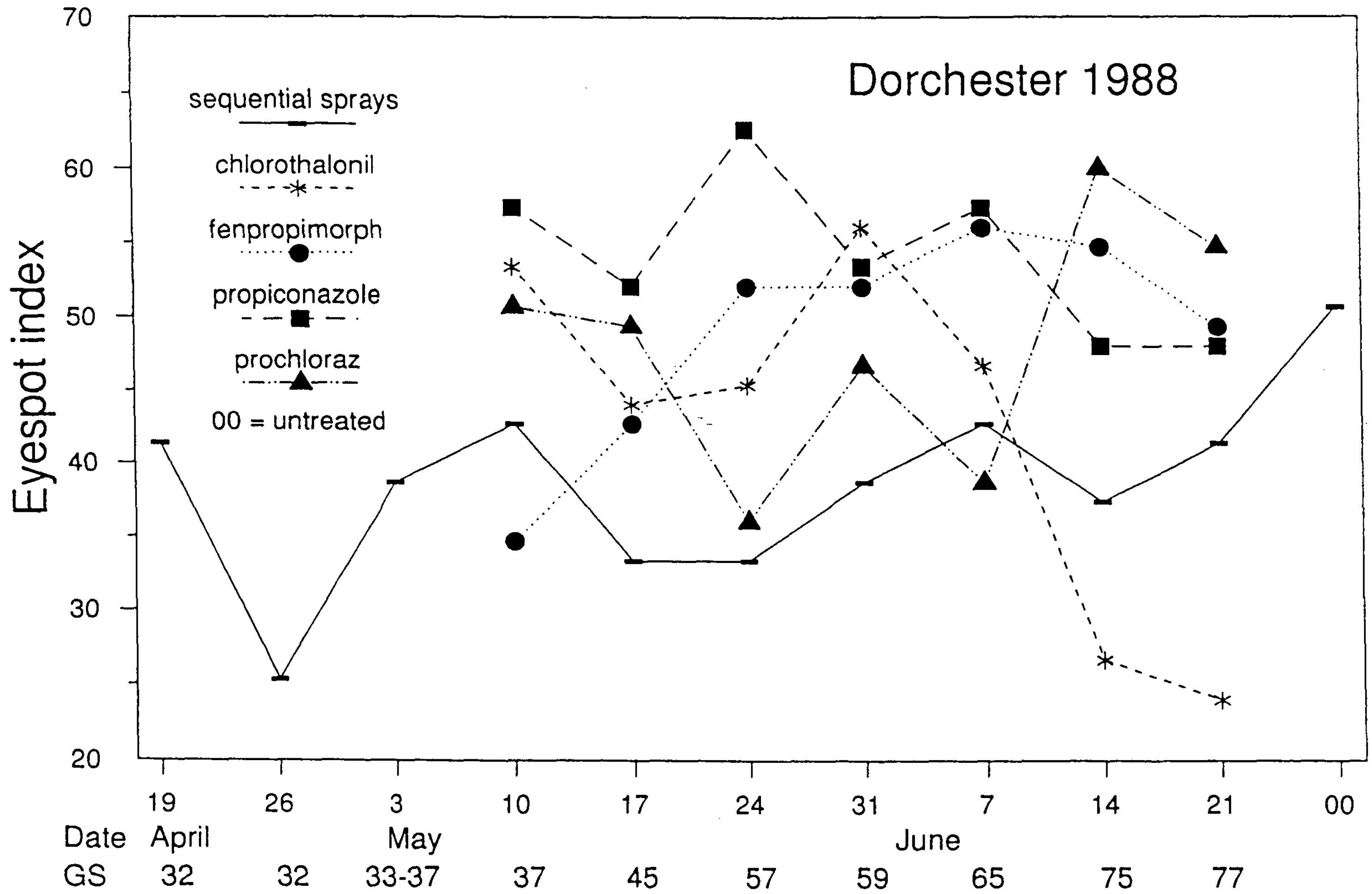

Dorchester 1988
Eyespot index
70
60
50
40
30
20
sequential sprays
chlorothalonil
fenpropimorph
propiconazole
prochloraz
00 = untreated
19 26 3 10 17 24 31 7 14 21 00
Date April May June
GS 32 32 33-37 37 45 57 59 65 75 77

Fig. 26

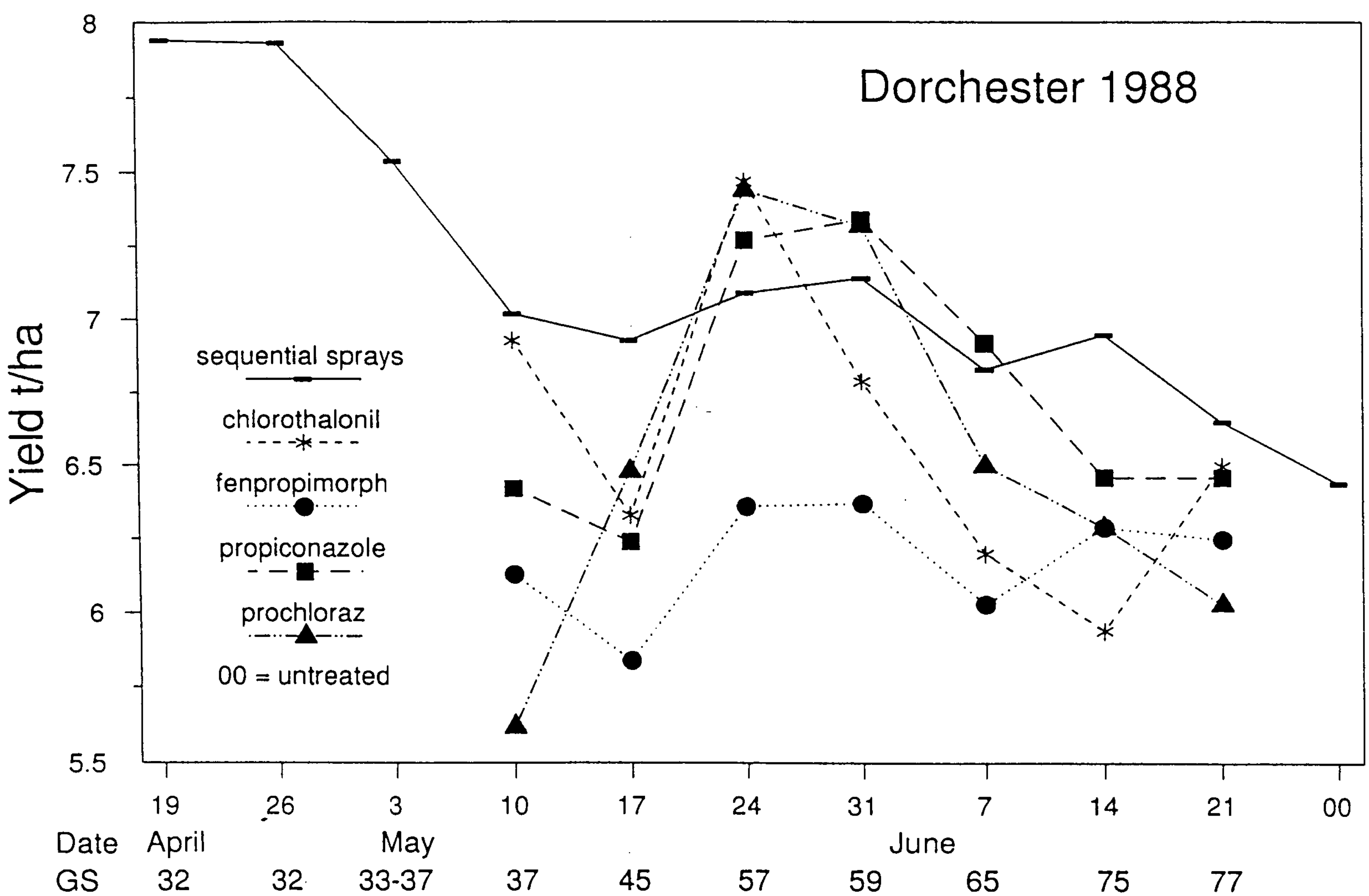

Dorchester 1988
Yield t/ha
8
7.5
7
6.5
6
5.5
sequential sprays
chlorothalonil
fenpropimorph
propiconazole
prochloraz
00 = untreated
19
26
3
10
17
24
31
7
14
21
00
Date
April
May
June
GS
32
32
33-37
37
45
57
59
65
75
77

Fig. 27

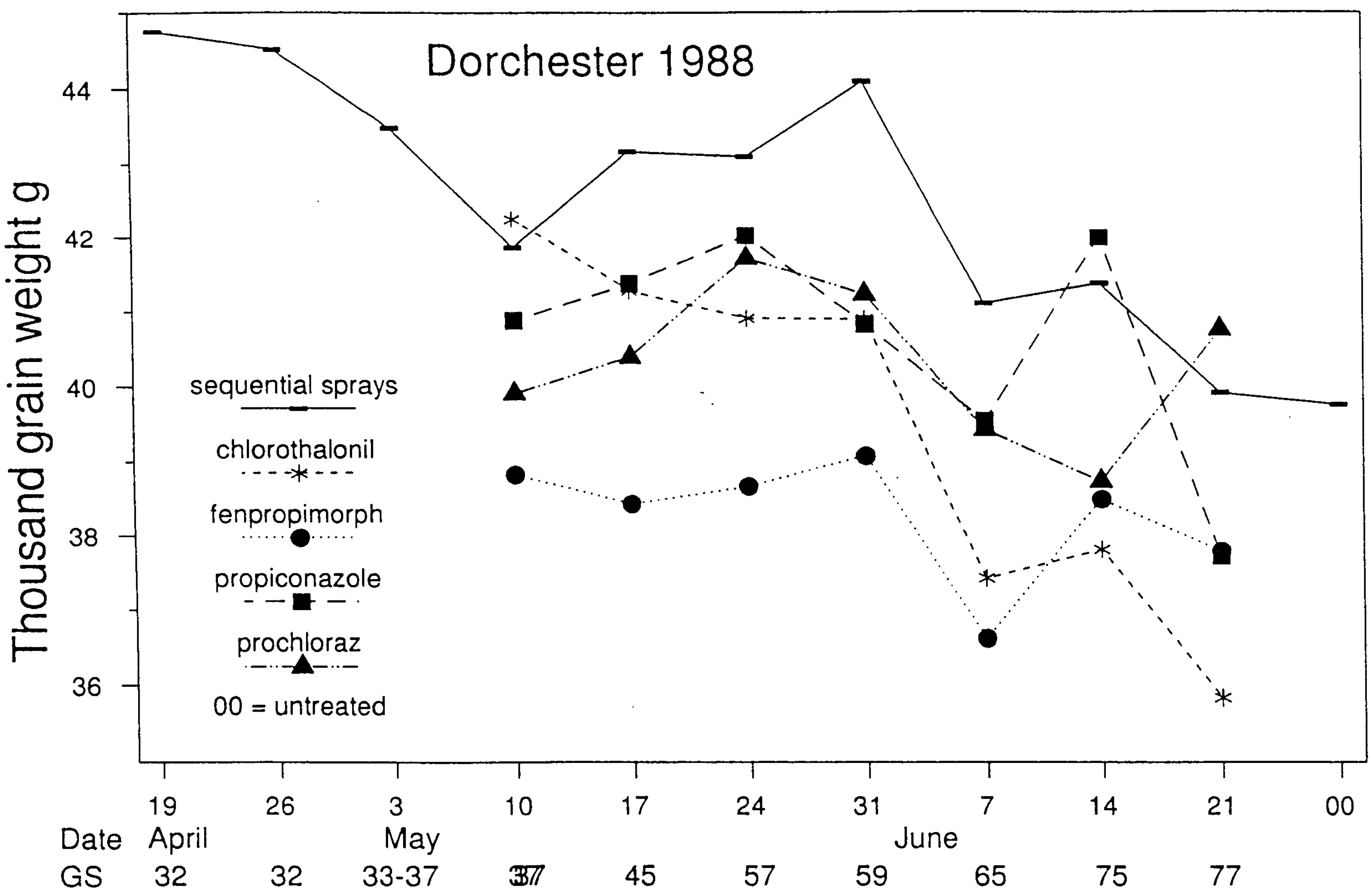

Dorchester 1988
Thousand grain weight g
44
42
40
38
36
sequential sprays
chlorothalonil
fenpropimorph
propiconazole
prochloraz
00 = untreated
19
26
3
10
17
24
31
7
14
21
00
Date
April
May
June
GS
32
32
33-37
37
45
57
59
65
75
77

Fig. 28

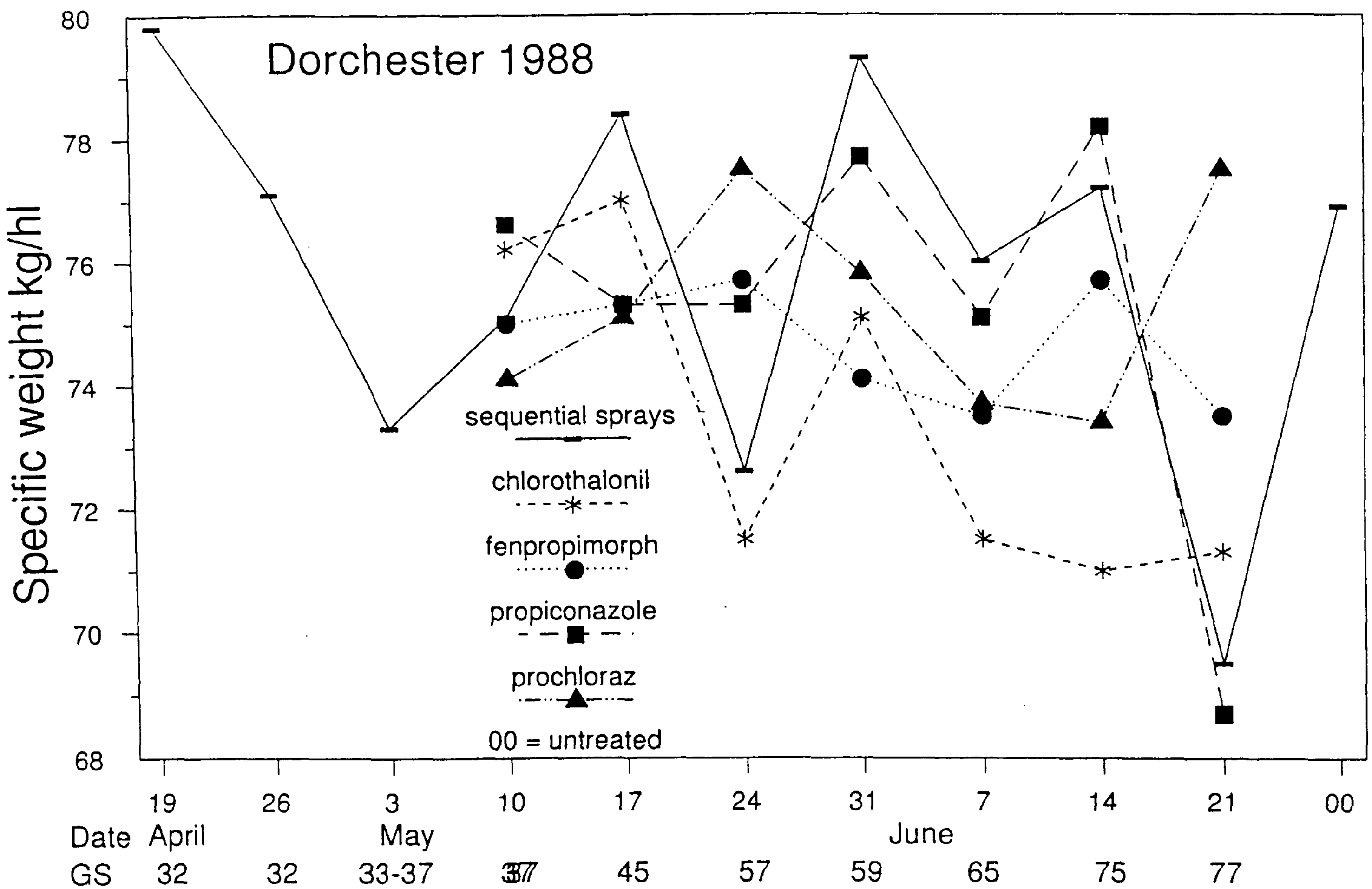

Dorchester 1988
Specific weight kg/hl
80
78
76
74
72
70
68
sequential sprays
chlorothalonil
fenpropimorph
propiconazole
prochloraz
00 = untreated
19
26
3
10
17
24
31
7
14
21
00
Date April
May
June
GS 32
32
33-37
37
45
57
59
65
75
77

Fig. 29

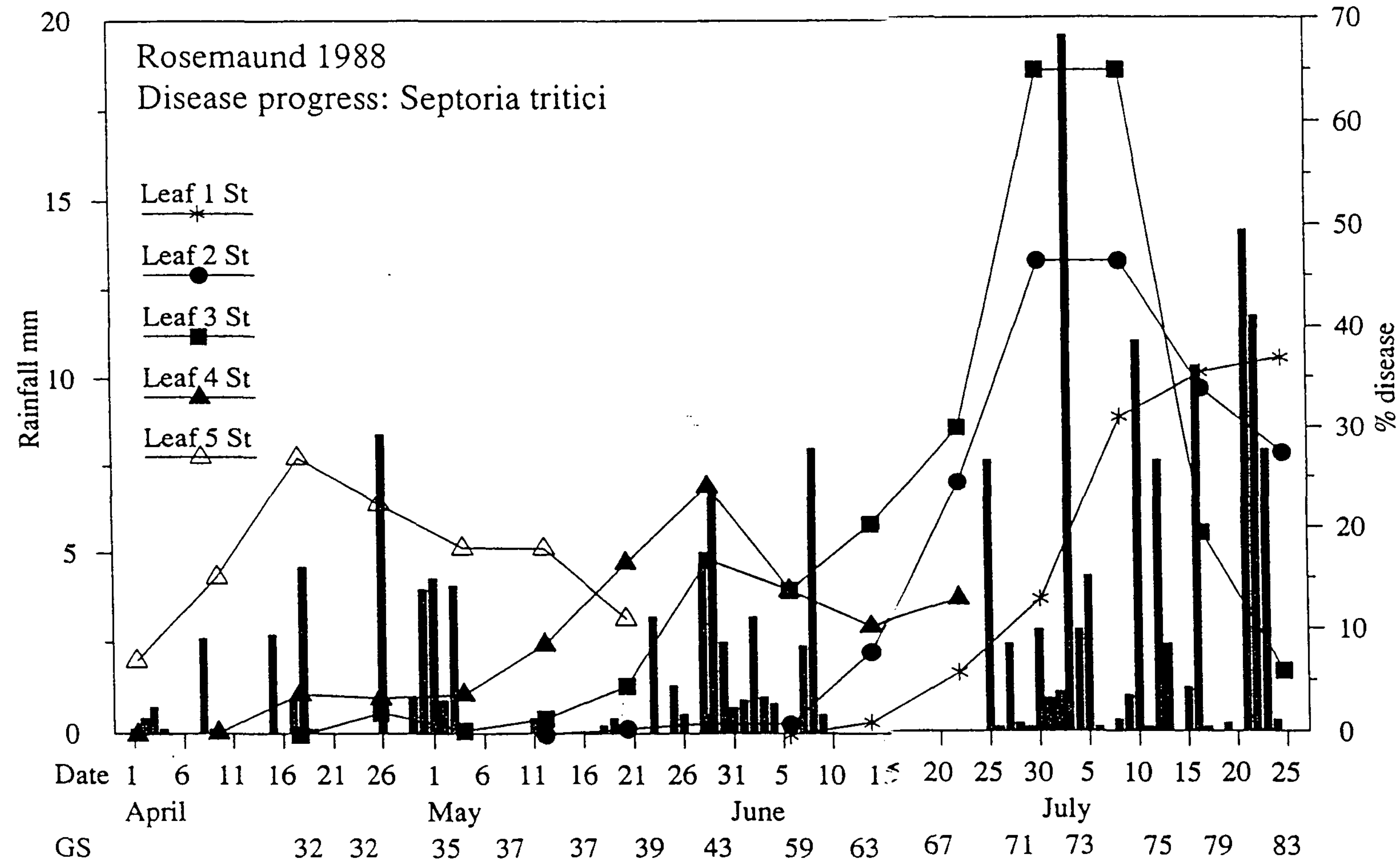

Rosemaund 1988
Disease progress: Septoria tritici
Leaf 1 St
Leaf 2 St
Leaf 3 St
Leaf 4 St
Leaf 5 St
Rainfall mm
% disease
Date 1 6 11 16 21 26 1 6 11 16 21 26 31 5 10 15 20 25 30 5 10 15 20 25
April
May
June
July
GS 32 32 35 37 37 39 43 59 63 67 71 73 75 79 83

Fig. 30

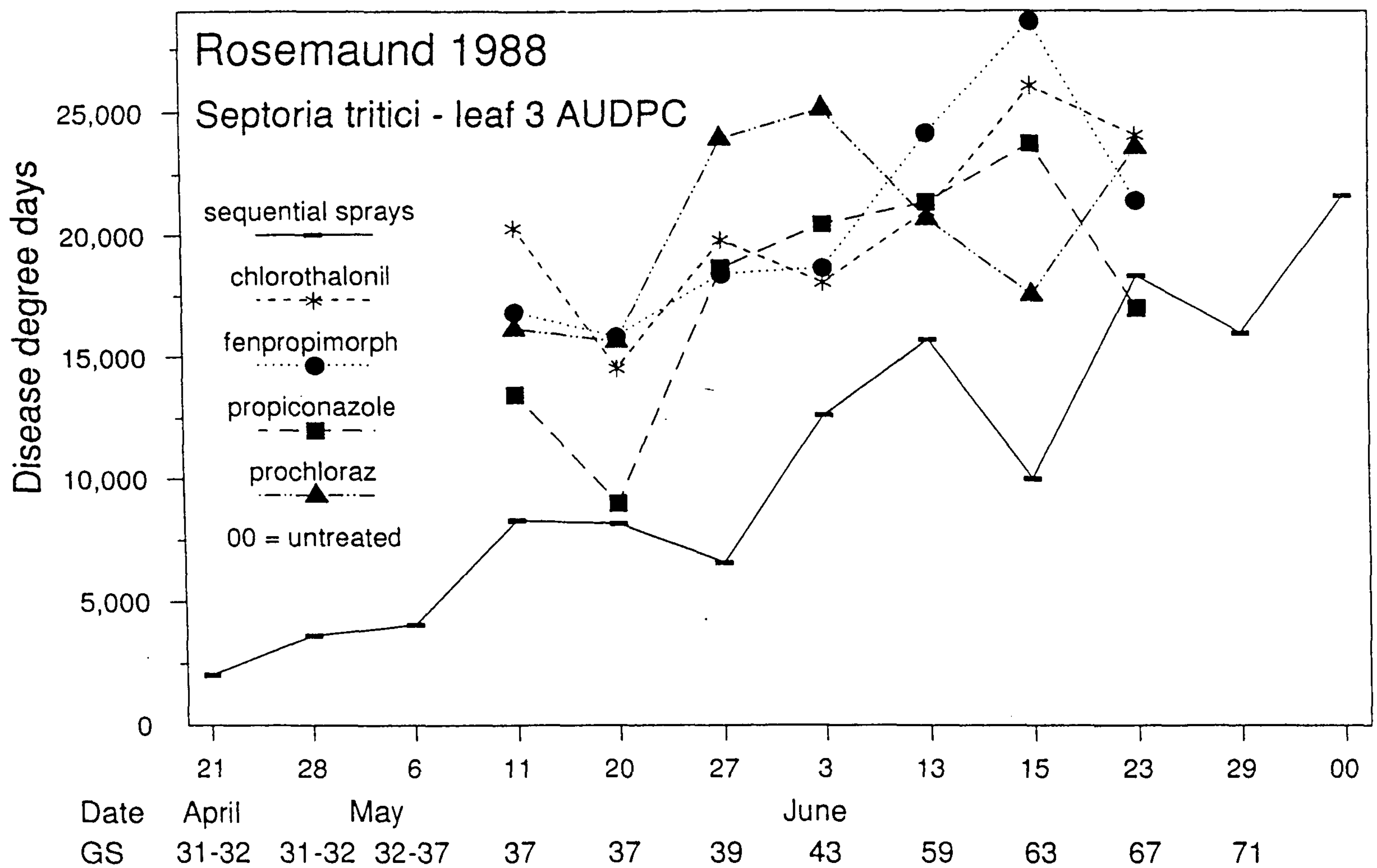

Rosemaund 1988
Septoria tritici - leaf 3 AUDPC
Disease degree days
25,000
20,000
15,000
10,000
5,000
0
sequential sprays
chlorothalonil
fenpropimorph
propiconazole
prochloraz
00 = untreated
21
28
6
11
20
27
3
13
15
23
29
00
Date
April
May
June
GS
31-32
31-32
32-37
37
37
39
43
59
63
67
71

Fig. 31

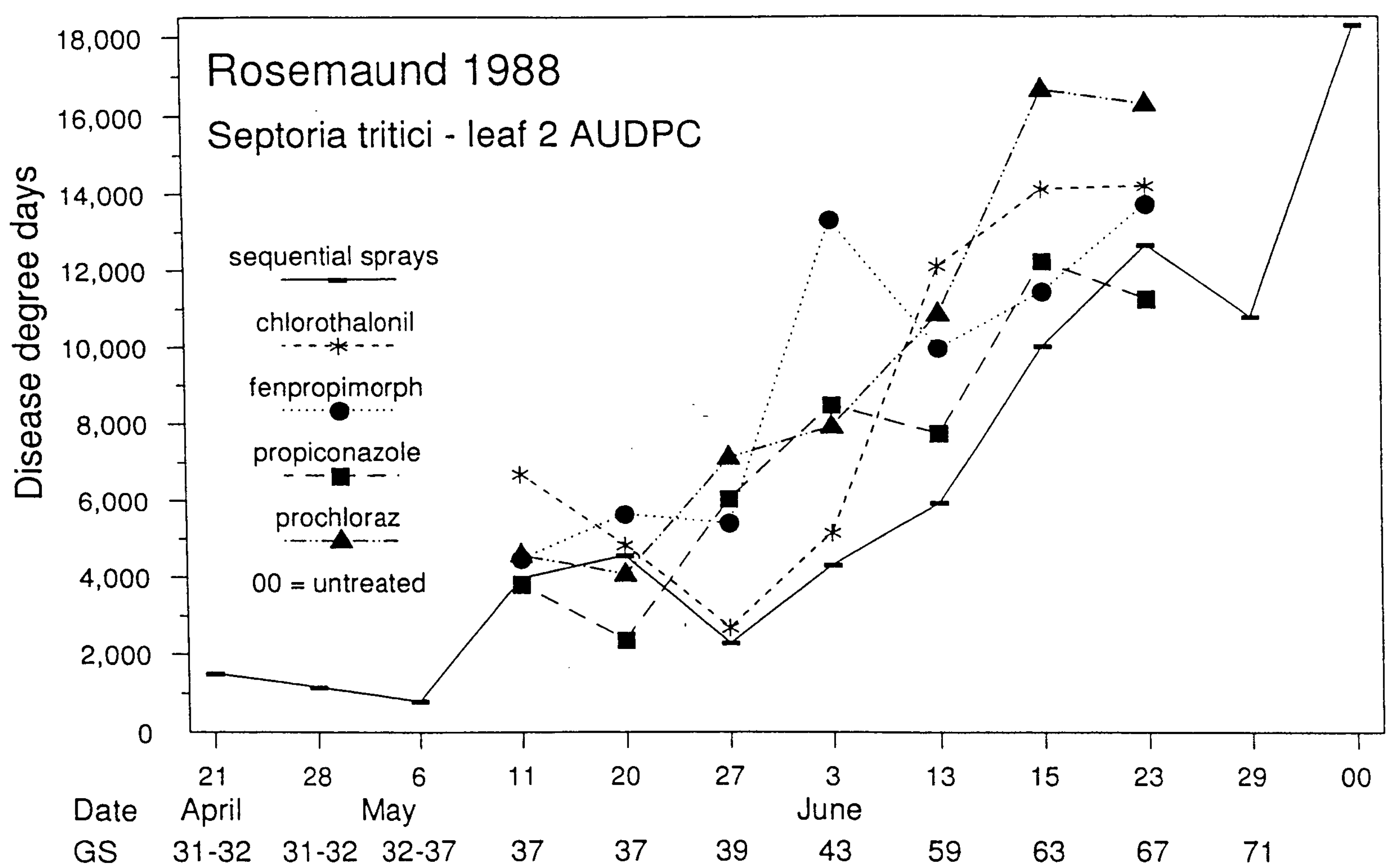

Rosemaund 1988
Septoria tritici - leaf 2 AUDPC
Disease degree days
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
sequential sprays
chlorothalonil
fenpropimorph
propiconazole
prochloraz
00 = untreated
21
28
6
11
20
27
3
13
15
23
29
00
Date
April
May
June
GS
31-32
31-32
32-37
37
37
39
43
59
63
67
71

Fig. 32

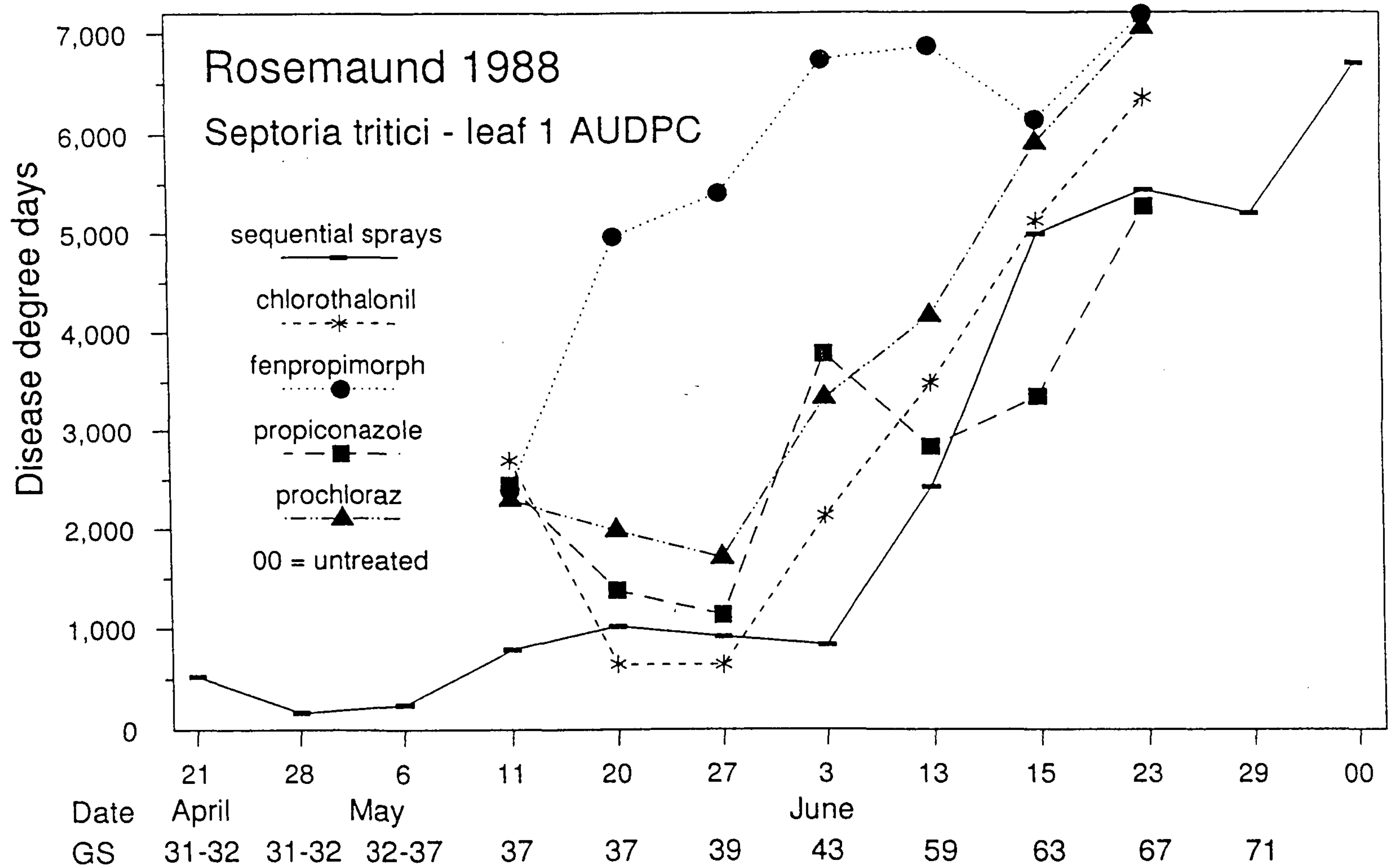

Rosemaund 1988
Septoria tritici - leaf 1 AUDPC
Disease degree days
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
sequential sprays
chlorothalonil
fenpropimorph
propiconazole
prochloraz
00 = untreated
21 28 6 11 20 27 3 13 15 23 29 00
Date April May June
GS 31-32 31-32 32-37 37 37 39 43 59 63 67 71

Fig. 33

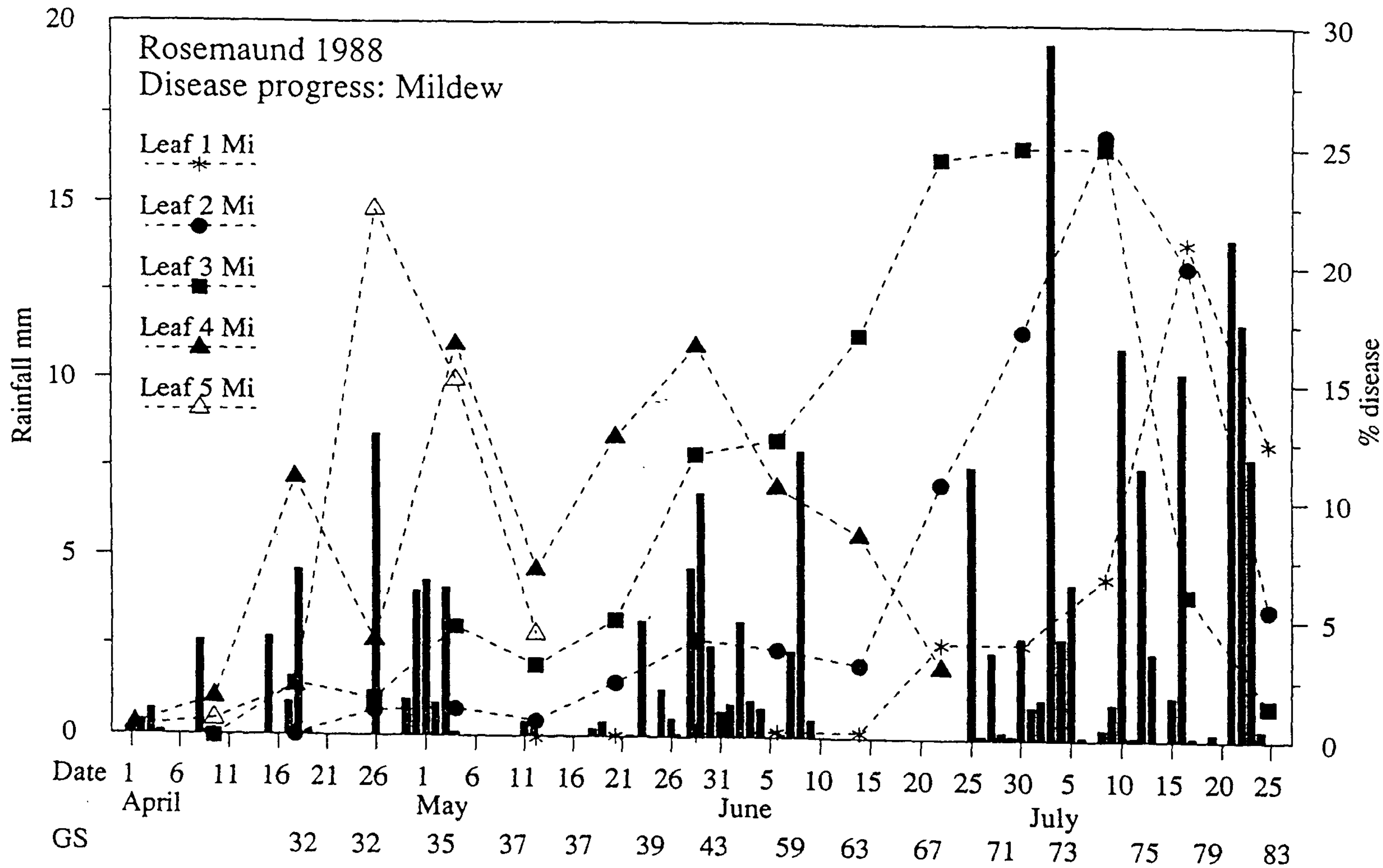

Rosemaund 1988
Disease progress: Mildew
Leaf 1 Mi
Leaf 2 Mi
Leaf 3 Mi
Leaf 4 Mi
Leaf 5 Mi
Rainfall mm
% disease
0
5
10
15
20
25
30
Date 1 6 11 16 21 26 1 6 11 16 21 26 31 5 10 15 20 25 30 5 10 15 20 25
April
May
June
July
GS 32 32 35 37 37 39 43 59 63 67 71 73 75 79 83

Fig. 34

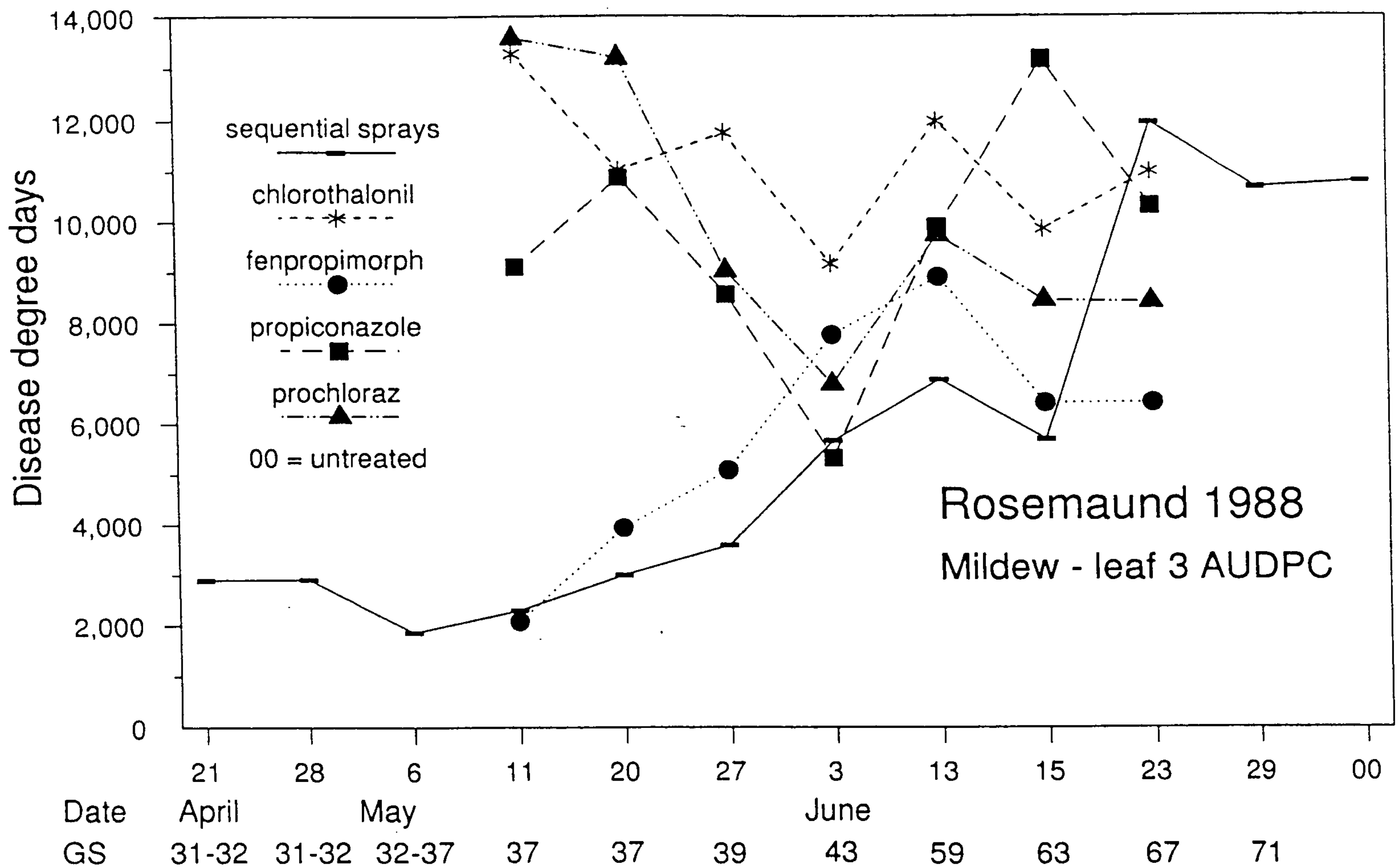

Disease degree days
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
sequential sprays
chlorothalonil
fenpropimorph
propiconazole
prochloraz
00 = untreated
Rosemaund 1988
Mildew - leaf 3 AUDPC
21 28 6 11 20 27 3 13 15 23 29 00
Date April May June
GS 31-32 31-32 32-37 37 37 39 43 59 63 67 71

Fig. 35

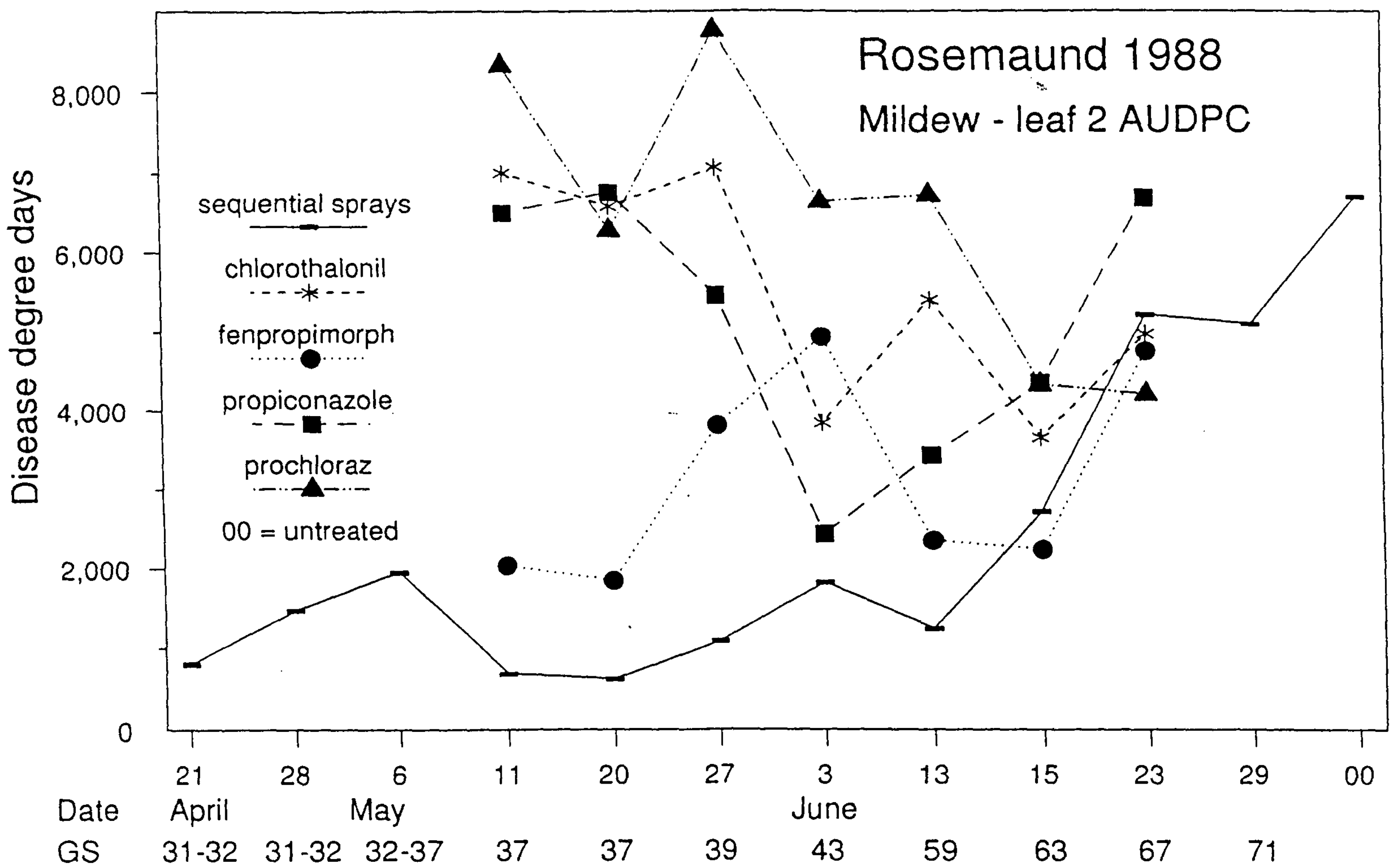

Rosemaund 1988
Mildew - leaf 2 AUDPC
Disease degree days
0
2,000
4,000
6,000
8,000
sequential sprays
chlorothalonil
fenpropimorph
propiconazole
prochloraz
00 = untreated
21
28
6
11
20
27
3
13
15
23
29
00
Date
April
May
June
GS
31-32
31-32
32-37
37
37
39
43
59
63
67
71

Fig. 36

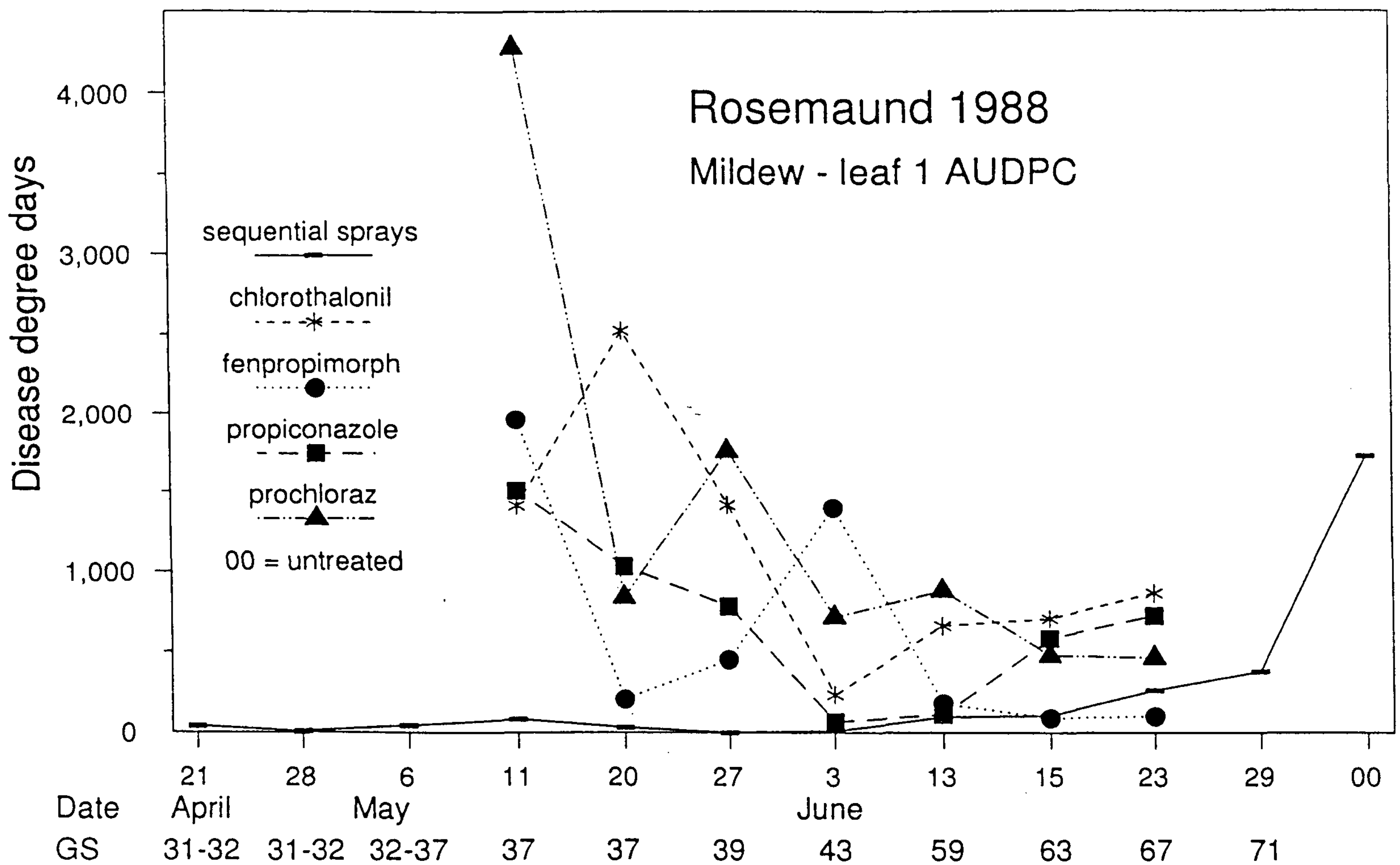

Rosemaund 1988
Mildew - leaf 1 AUDPC
Disease degree days
4,000
3,000
2,000
1,000
0
sequential sprays
chlorothalonil
fenpropimorph
propiconazole
prochloraz
00 = untreated
21
28
6
11
20
27
3
13
15
23
29
00
Date
April
May
June
GS
31-32
31-32
32-37
37
37
39
43
59
63
67
71

Fig. 37

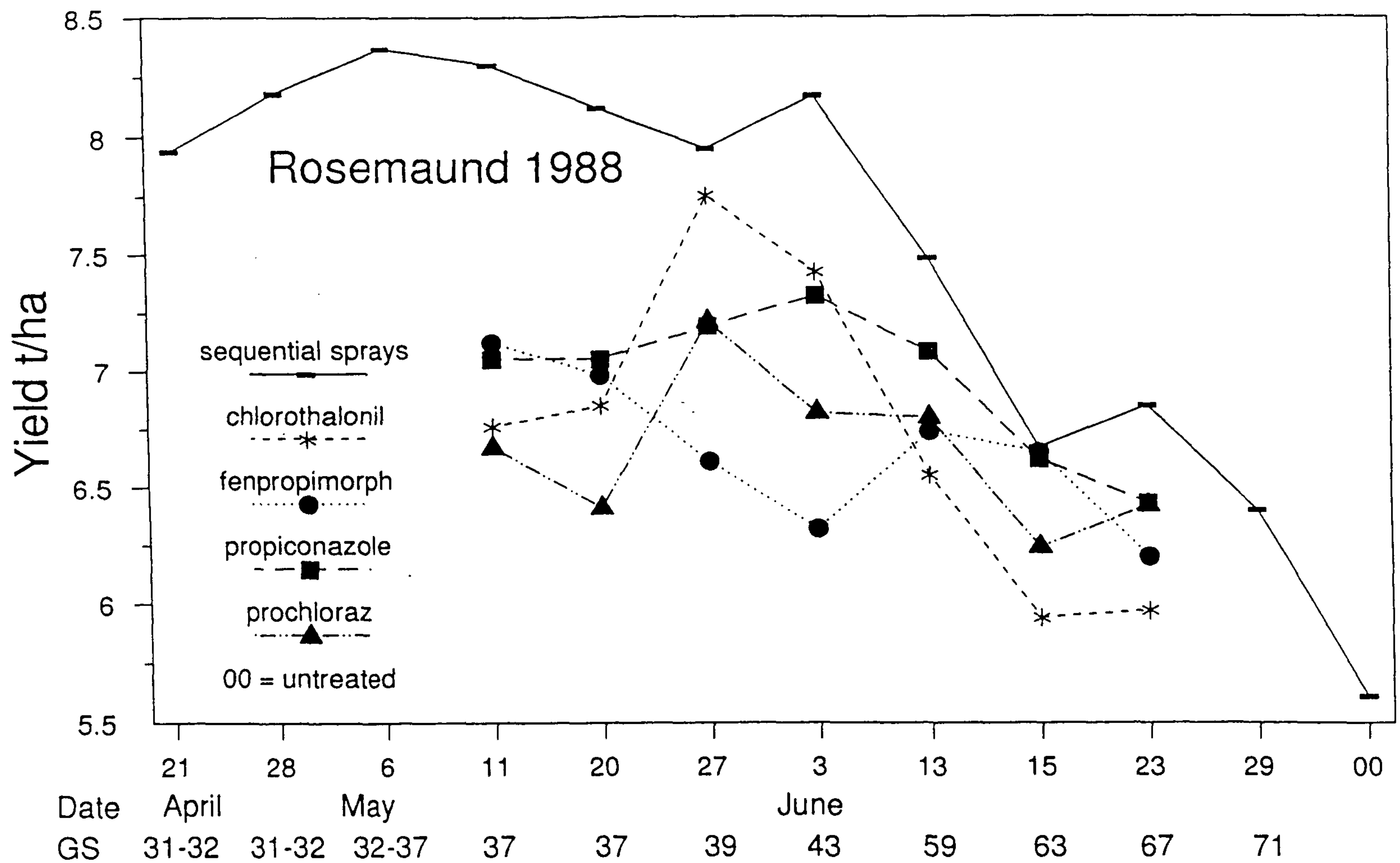

Rosemaund 1988
Yield t/ha
8.5
8
7.5
7
6.5
6
5.5
sequential sprays
chlorothalonil
fenpropimorph
propiconazole
prochloraz
00 = untreated
21
28
6
11
20
27
3
13
15
23
29
00
Date
April
May
June
GS
31-32
31-32
32-37
37
37
39
43
59
63
67
71

Fig. 38

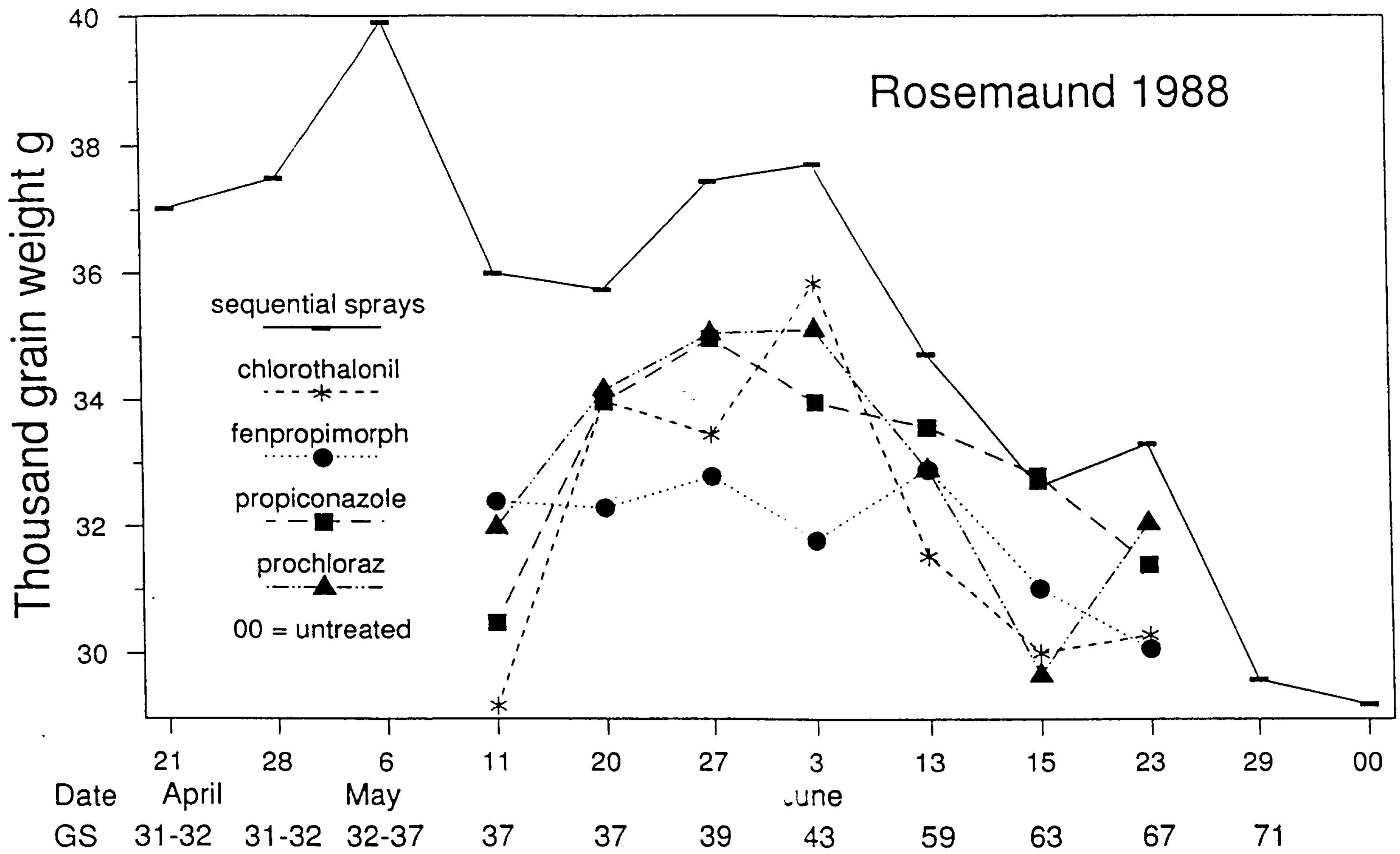

Rosemaund 1988
Thousand grain weight g
40
38
36
34
32
30
sequential sprays
chlorothalonil
fenpropimorph
propiconazole
prochloraz
00 = untreated
Date
21
April
28
6
May
11
20
27
3
June
13
15
23
29
00
GS
31-32
31-32
32-37
37
37
39
43
59
63
67
71

Fig. 39

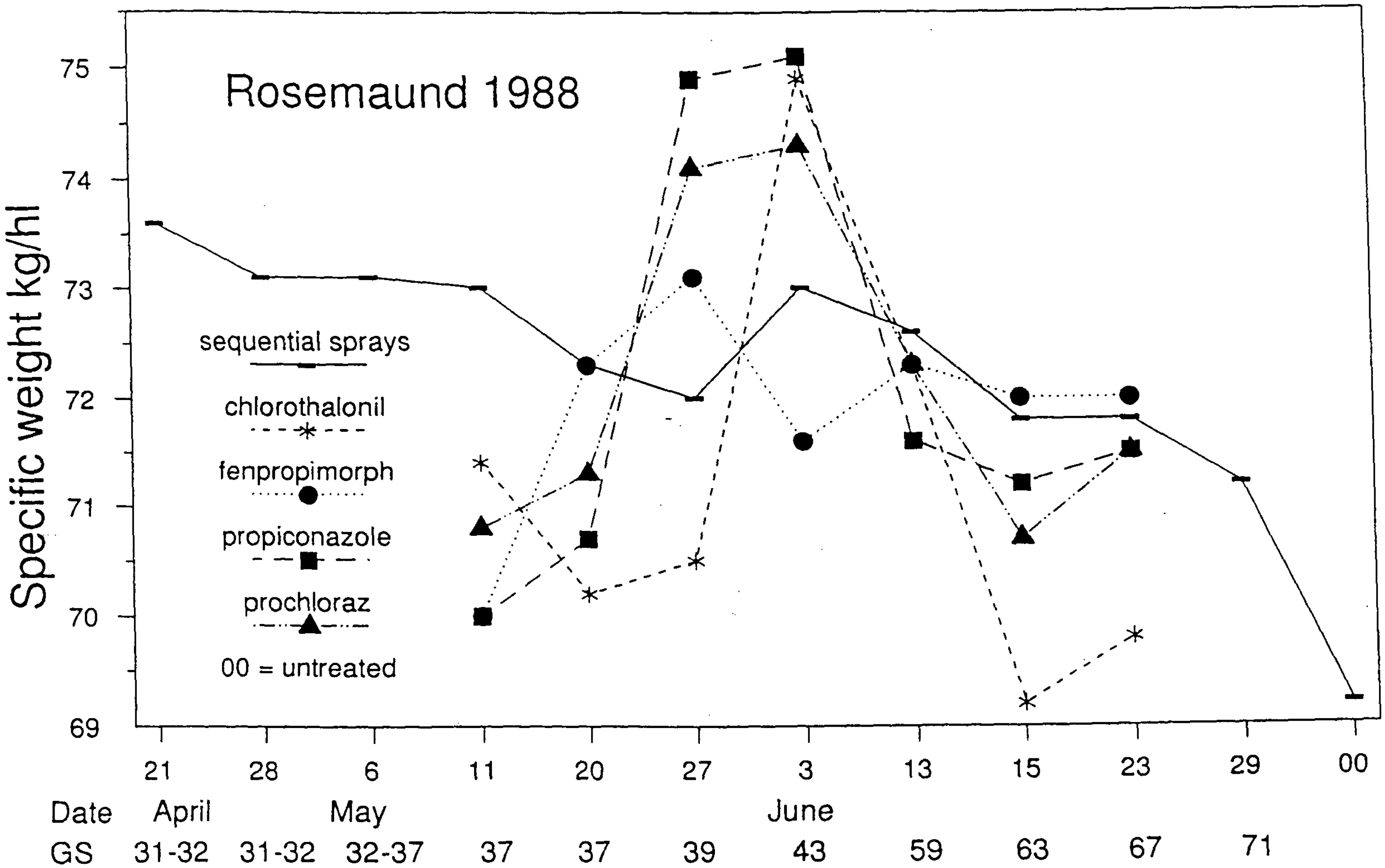
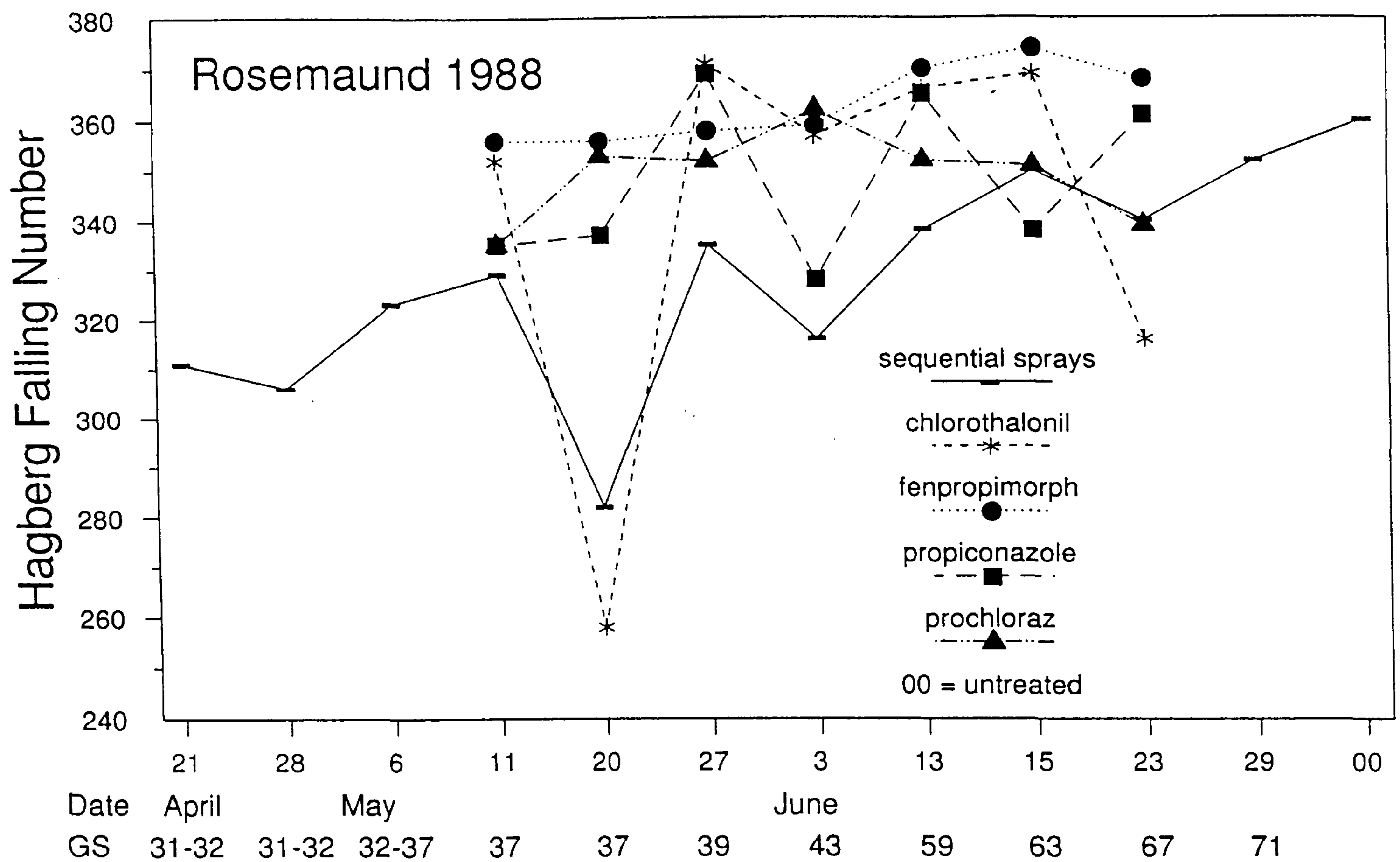

Rosemaund 1988
Specific weight kg/hl
75
74
73
72
71
70
69
sequential sprays
chlorothalonil
fenpropimorph
propiconazole
prochloraz
00 = untreated
Date
21
28
6
11
20
27
3
13
15
23
29
00
April
May
June
GS
31-32
31-32
32-37
37
37
39
43
59
63
67
71

Fig. 40



Hagberg Falling Number
380
360
340
320
300
280
260
240
Rosemaund 1988
sequential sprays
chlorothalonil
fenpropimorph
propiconazole
prochloraz
00 = untreated
21
28
6
11
20
27
3
13
15
23
29
00
Date April May June
GS 31-32 31-32 32-37 37 37 39 43 59 63 67 71

Fig. 41

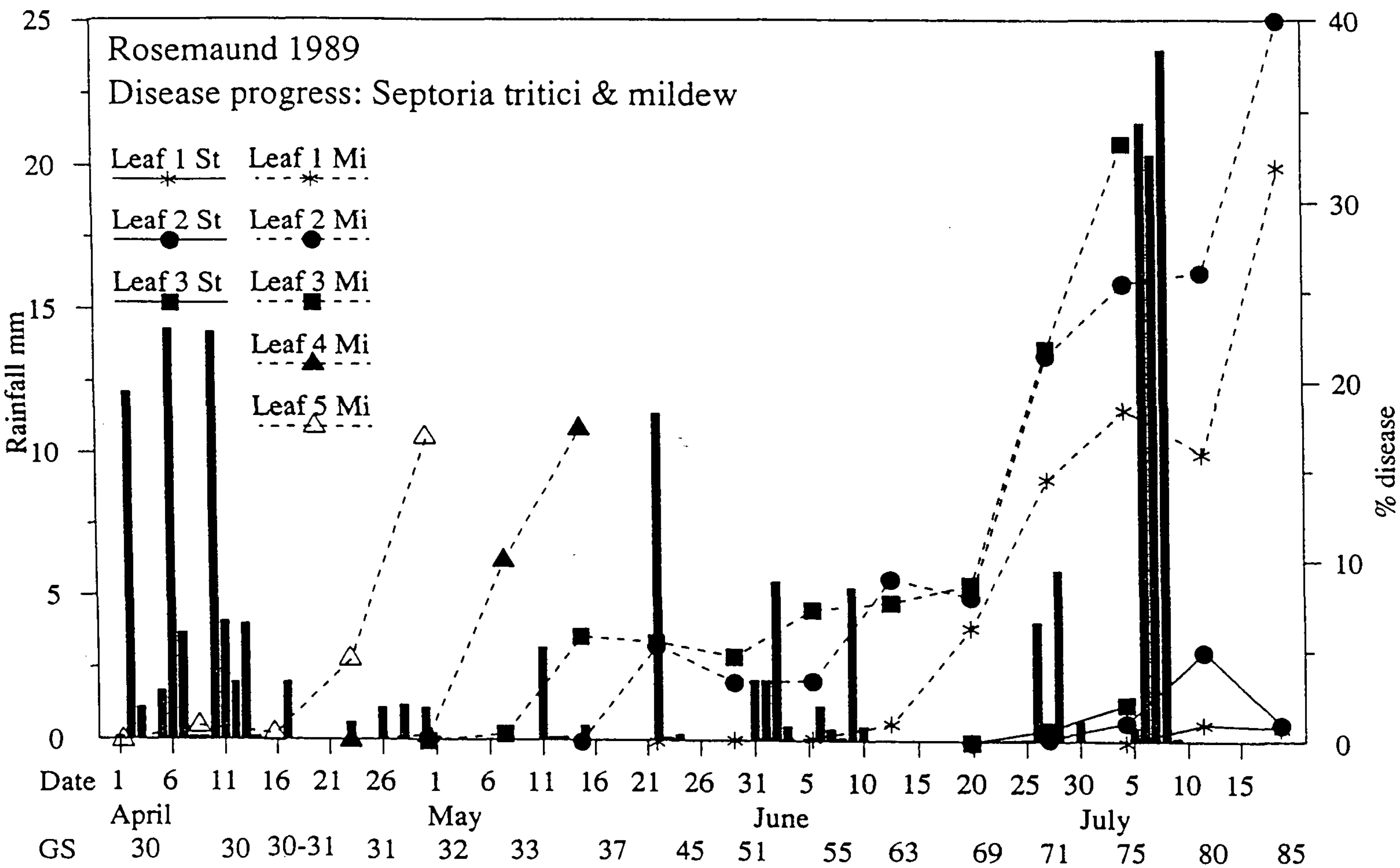

Rosemaund 1989
Disease progress: Septoria tritici & mildew
Leaf 1 St
Leaf 1 Mi
Leaf 2 St
Leaf 2 Mi
Leaf 3 St
Leaf 3 Mi
Leaf 4 Mi
Leaf 5 Mi
Rainfall mm
% disease
Date
April
May
June
July
GS

Fig. 42

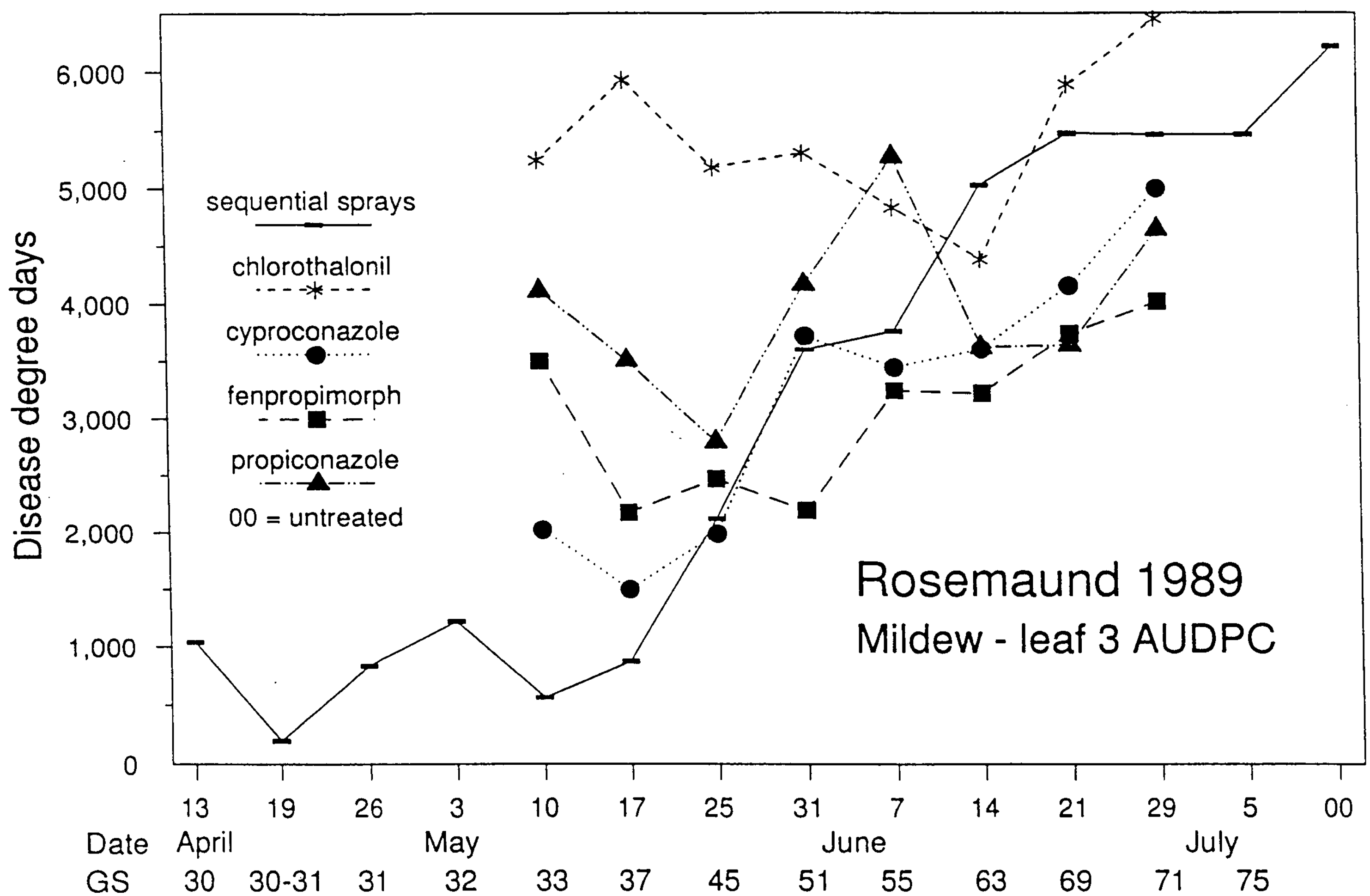

Rosemaund 1989
Mildew - leaf 3 AUDPC
Disease degree days
6,000
5,000
4,000
3,000
2,000
1,000
0
sequential sprays
chlorothalonil
cyproconazole
fenpropimorph
propiconazole
00 = untreated
13 19 26 3 10 17 25 31 7 14 21 29 5 00
Date April May June July
GS 30 30-31 31 32 33 37 45 51 55 63 69 71 75

Fig. 43

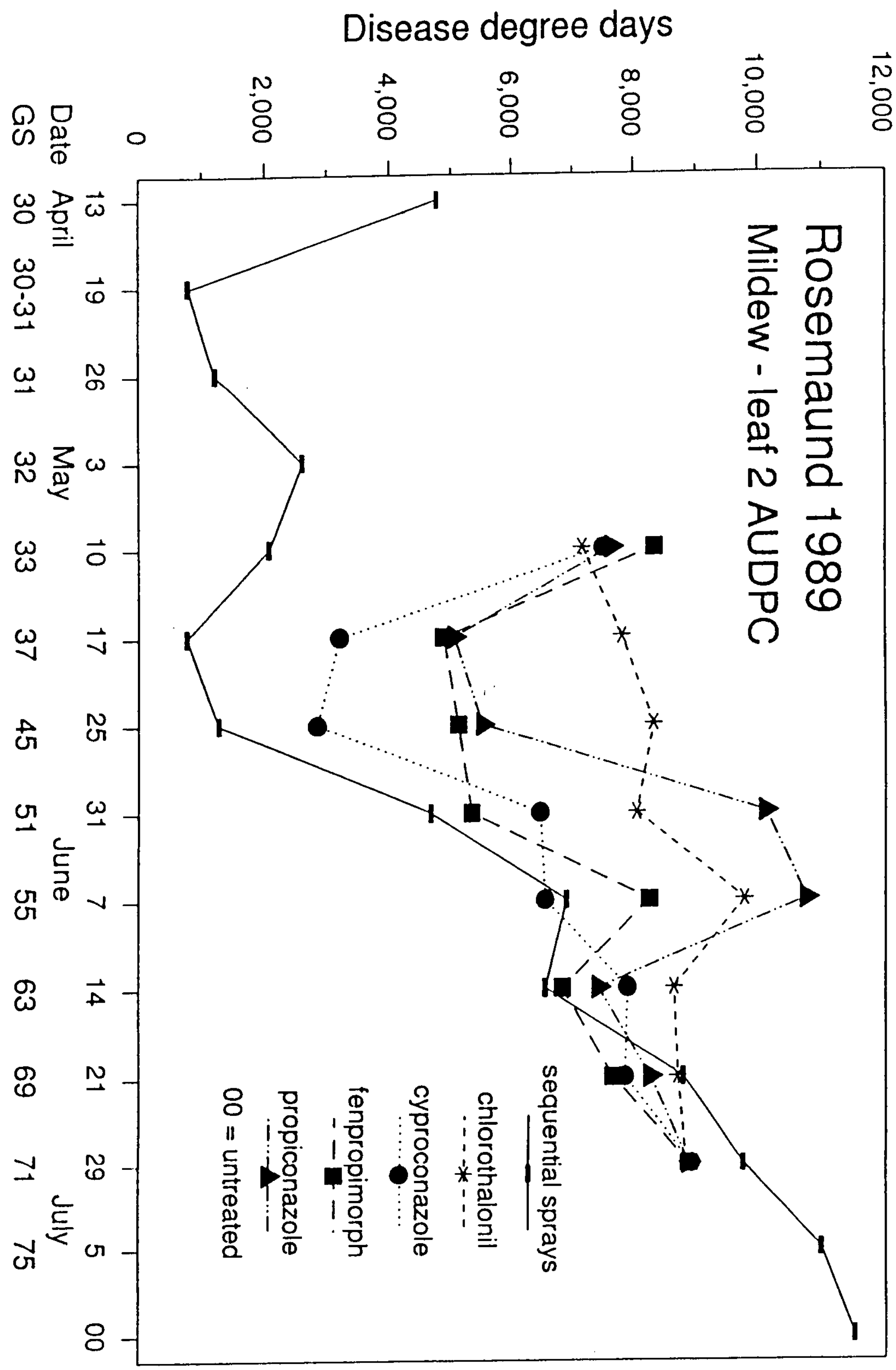

Rosemaund 1989
Mildew - leaf 2 AUDPC
Disease degree days
0
2,000
4,000
6,000
8,000
10,000
12,000
Date
GS
13 19 26 3 10 17 25 31 7 14 21 29 5 00
April May June July
30 30-31 31 32 33 37 45 51 55 63 69 71 75
sequential sprays
chlorothalonil
cyproconazole
fenpropimorph
propiconazole
00 = untreated

Fig. 44

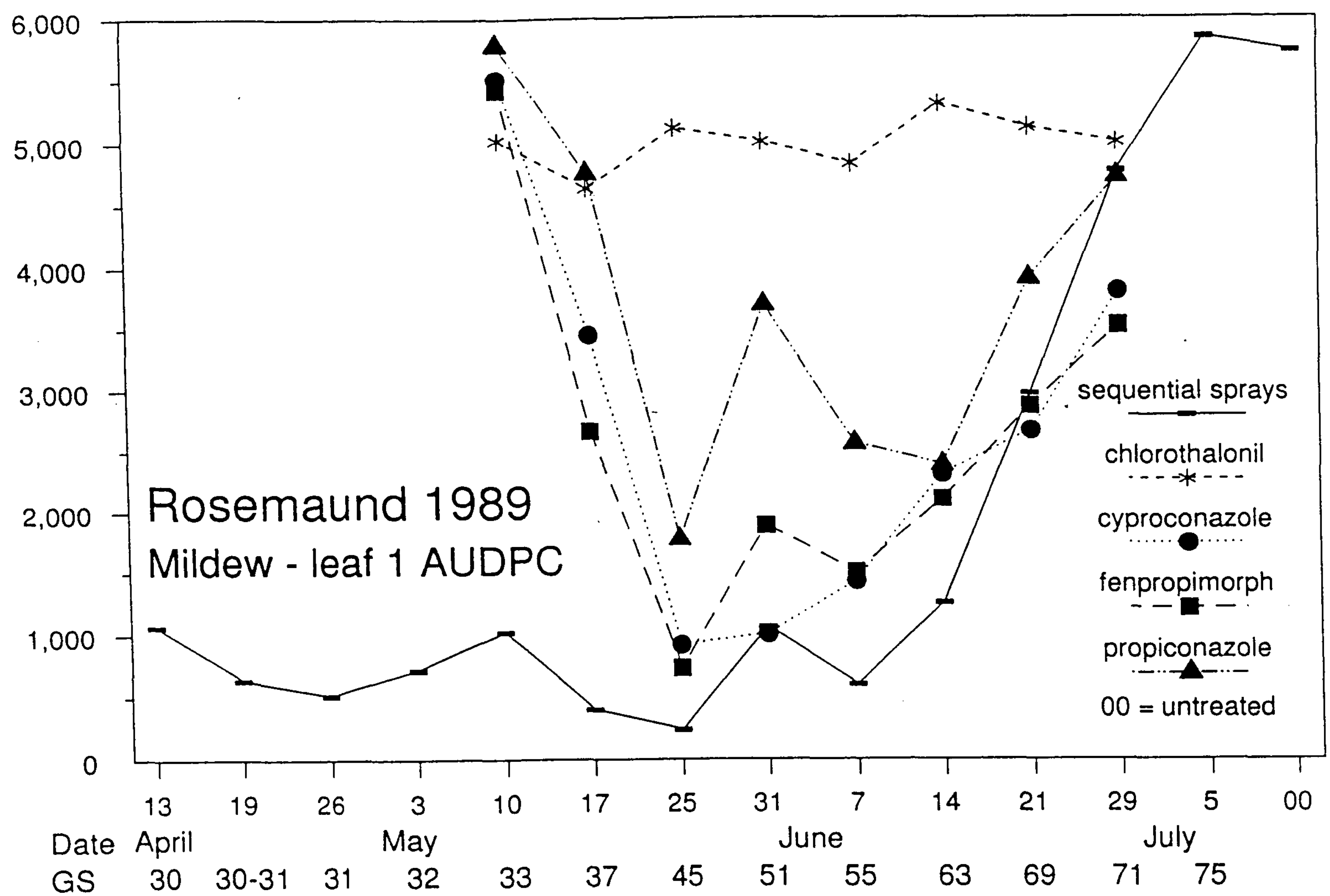

Rosemaund 1989
Mildew - leaf 1 AUDPC
6,000
5,000
4,000
3,000
2,000
1,000
0
sequential sprays
chlorothalonil
cyproconazole
fenpropimorph
propiconazole
00 = untreated
13
19
26
3
10
17
25
31
7
14
21
29
5
00
Date April
May
June
July
GS 30 30-31 31 32 33 37 45 51 55 63 69 71 75

Fig. 45

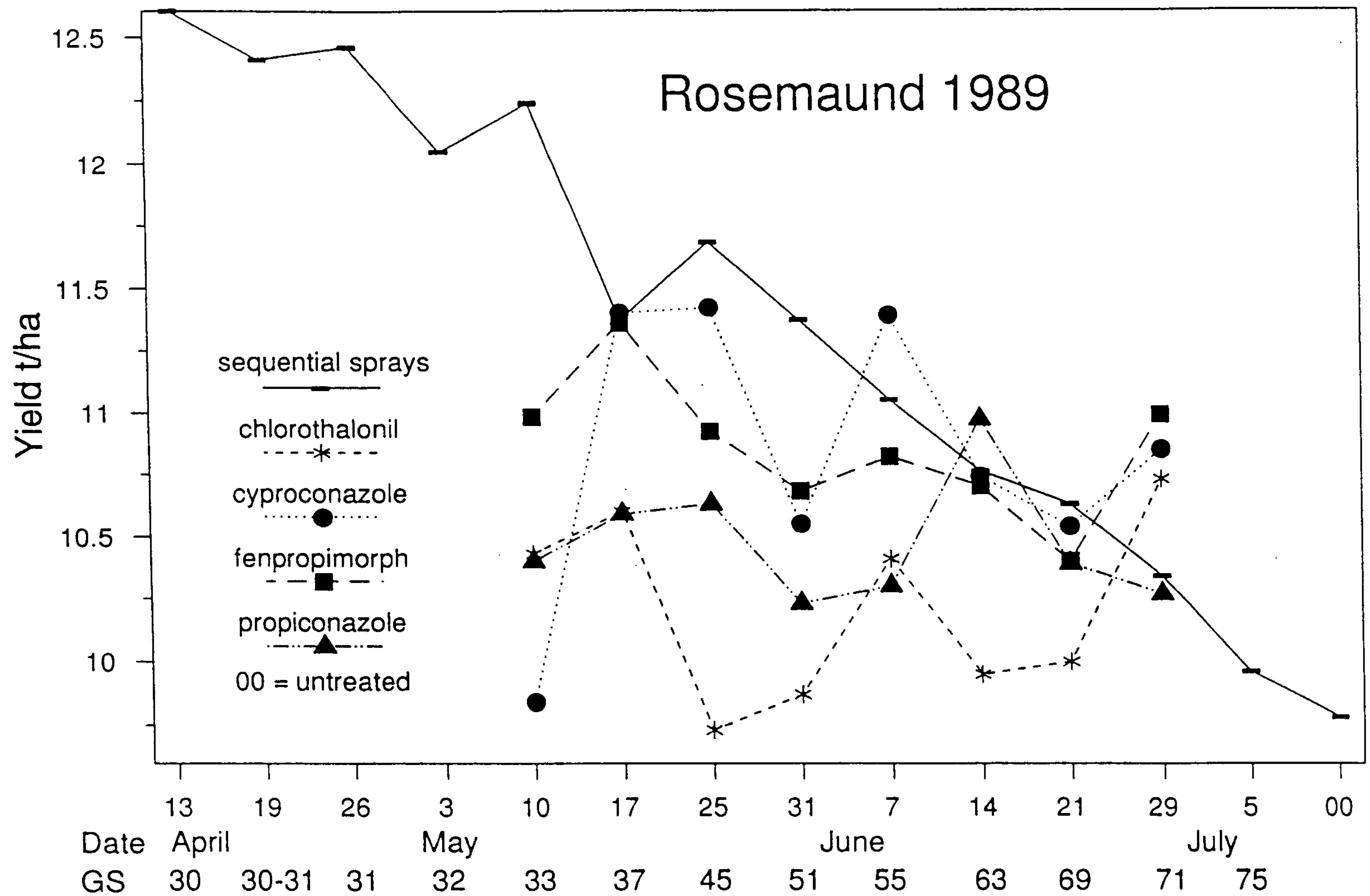
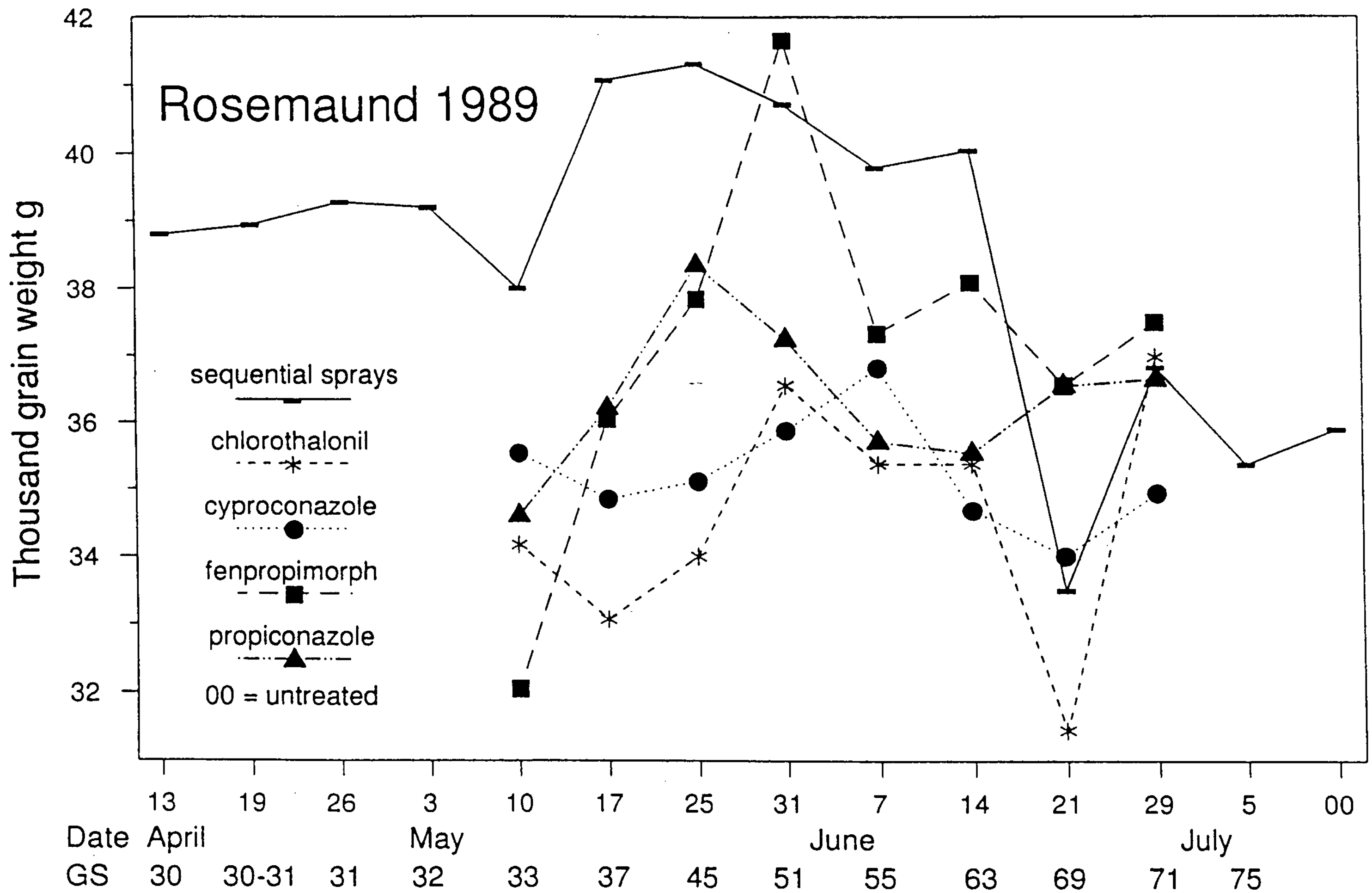
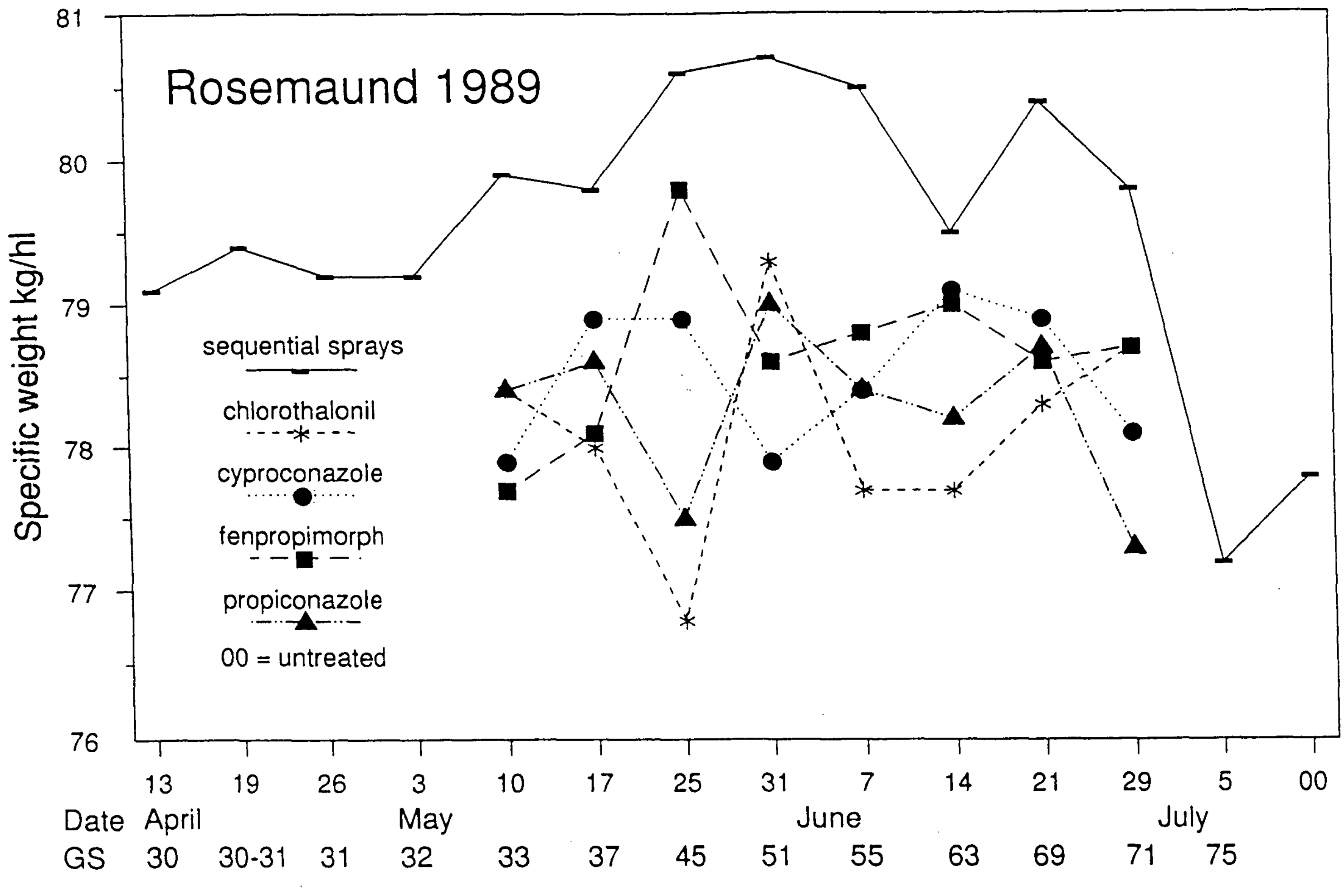

Rosemaund 1989
Yield t/ha
12.5
12
11.5
11
10.5
10
sequential sprays
chlorothalonil
cyproconazole
fenpropimorph
propiconazole
00 = untreated
13
19
26
3
10
17
25
31
7
14
21
29
5
00
Date April
May
June
July
GS 30 30-31 31 32 33 37 45 51 55 63 69 71 75

Fig. 46



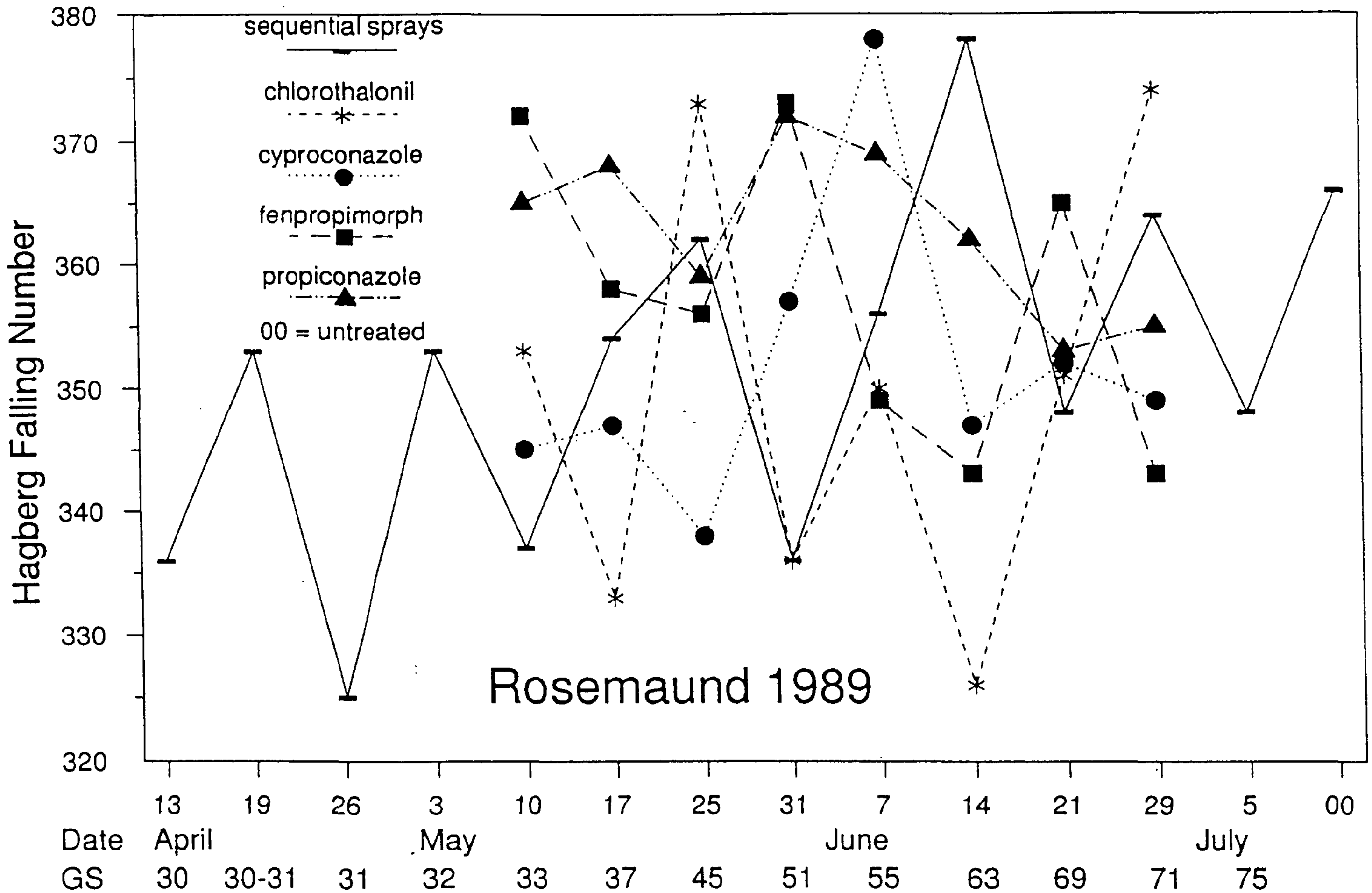
Rosemaund 1989
Thousand grain weight g
42
40
38
36
34
32
sequential sprays
chlorothalonil
cyproconazole
fenpropimorph
propiconazole
00 = untreated
13 19 26 3 10 17 25 31 7 14 21 29 5 00
Date April May June July
GS 30 30-31 31 32 33 37 45 51 55 63 69 71 75

Fig. 47



Rosemaund 1989
Specific weight kg/hl
81
80
79
78
77
76
sequential sprays
chlorothalonil
cyproconazole
fenpropimorph
propiconazole
00 = untreated
13 19 26 3 10 17 25 31 7 14 21 29 5 00
Date April May June July
GS 30 30-31 31 32 33 37 45 51 55 63 69 71 75

Fig. 48



Hagberg Falling Number
380
370
360
350
340
330
320
sequential sprays
chlorothalonil
cyproconazole
fenpropimorph
propiconazole
00 = untreated
Rosemaund 1989
13 19 26 3 10 17 25 31 7 14 21 29 5 00
Date April May June July
GS 30 30-31 31 32 33 37 45 51 55 63 69 71 75

Fig. 49

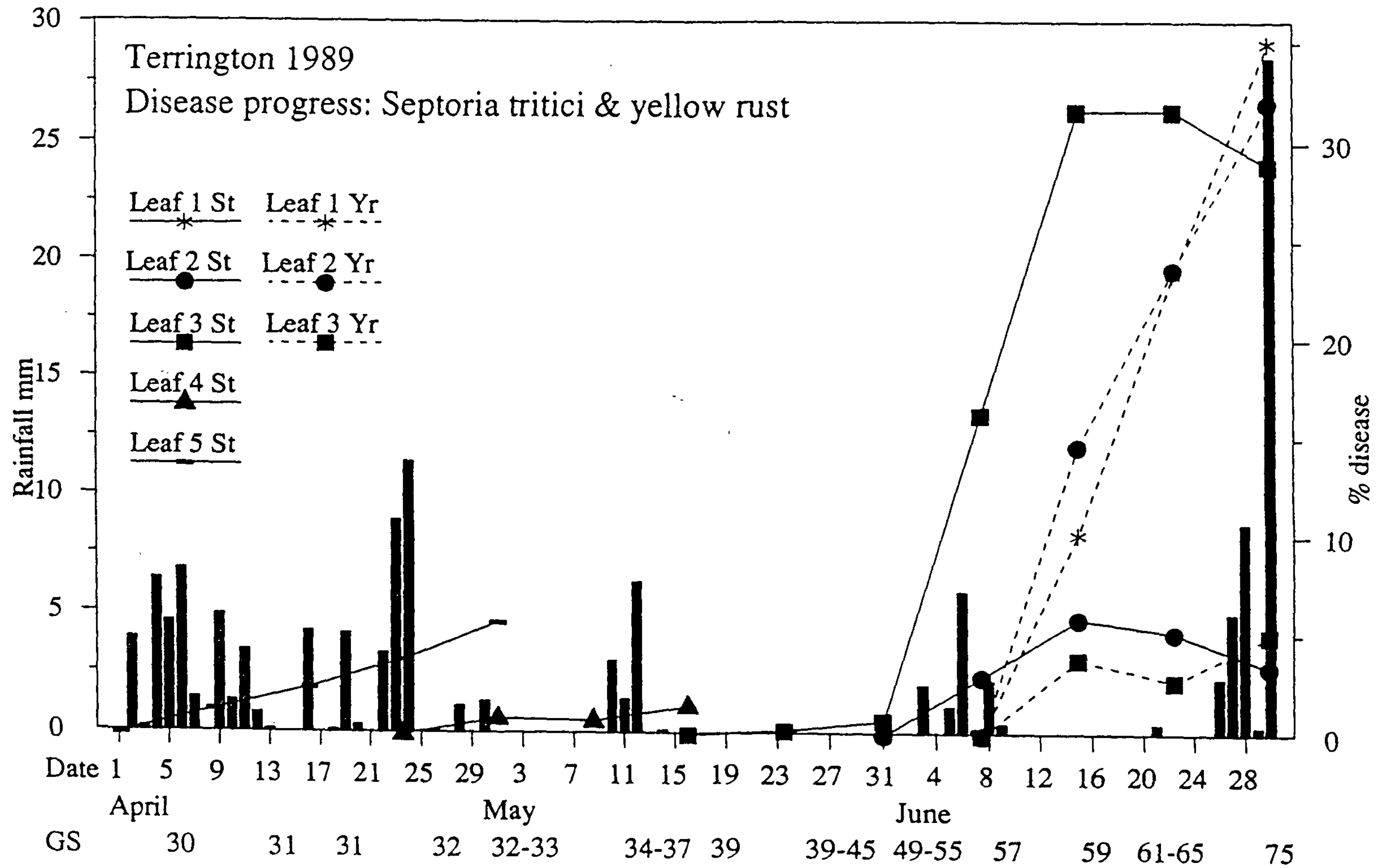

Terrington 1989
Disease progress: Septoria tritici & yellow rust
Leaf 1 St
Leaf 1 Yr
Leaf 2 St
Leaf 2 Yr
Leaf 3 St
Leaf 3 Yr
Leaf 4 St
Leaf 5 St
Rainfall mm
% disease
0
5
10
15
20
25
30
Date 1 5 9 13 17 21 25 29 3 7 11 15 19 23 27 31 4 8 12 16 20 24 28
April
May
June
GS 30 31 31 32 32-33 34-37 39 39-45 49-55 57 59 61-65 75

Fig. 50

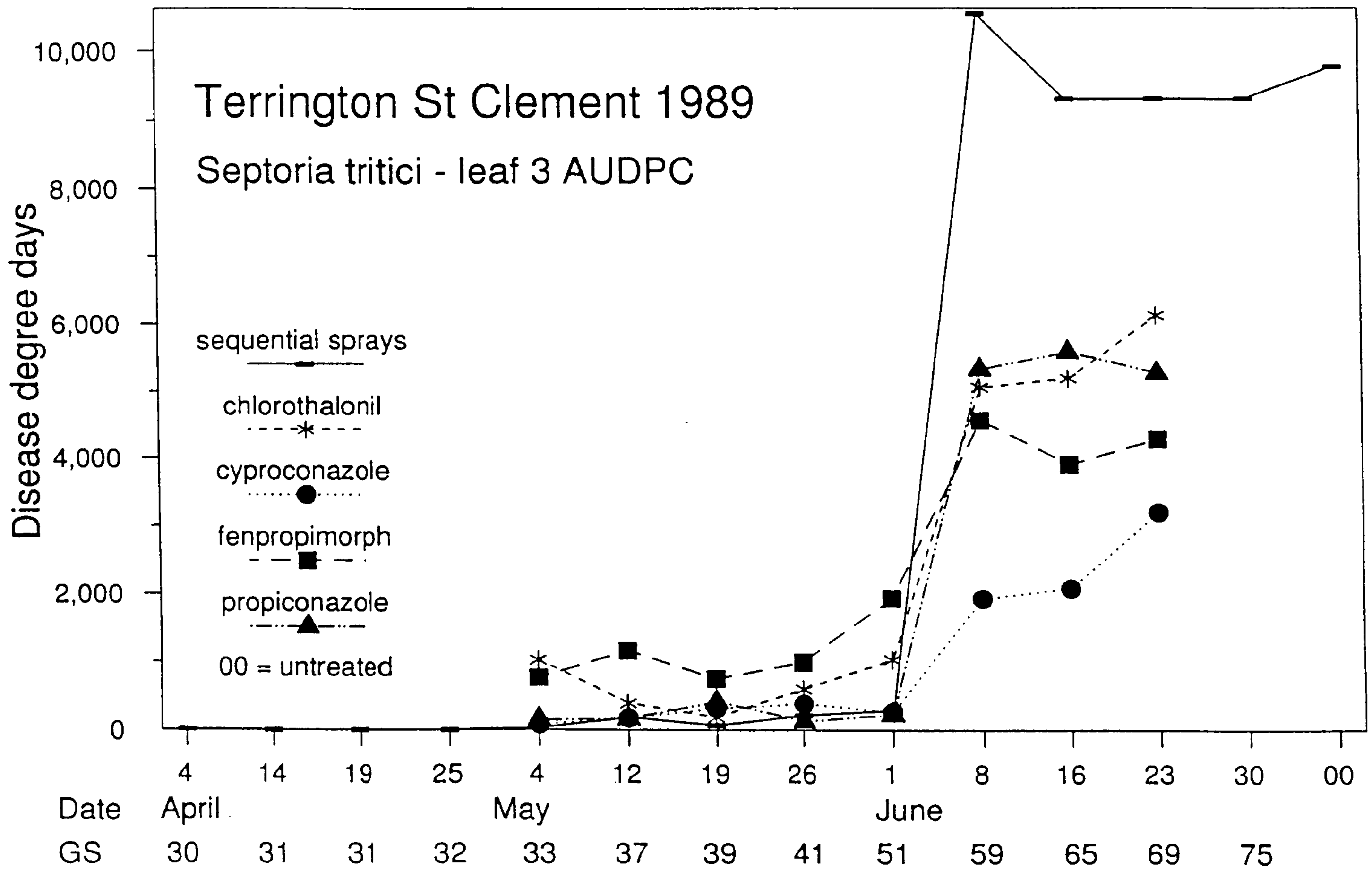

Terrington St Clement 1989
Septoria tritici - leaf 3 AUDPC
Disease degree days
10,000
8,000
6,000
4,000
2,000
0
sequential sprays
chlorothalonil
cyproconazole
fenpropimorph
propiconazole
00 = untreated
4
14
19
25
4
12
19
26
1
8
16
23
30
00
Date
April
May
June
GS
30
31
31
32
33
37
39
41
51
59
65
69
75

Fig. 51

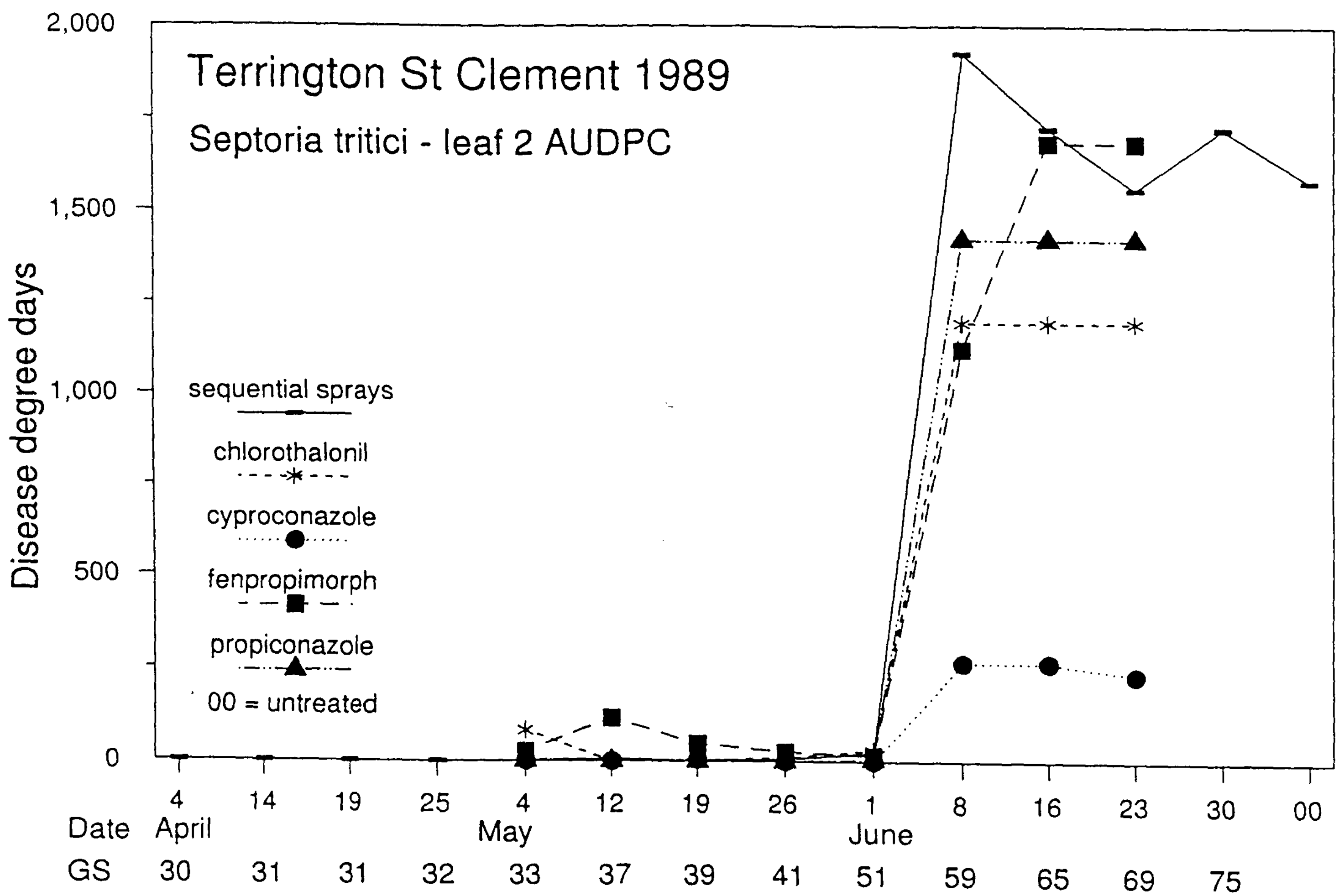

Terrington St Clement 1989
Septoria tritici - leaf 2 AUDPC
Disease degree days
2,000
1,500
1,000
500
0
sequential sprays
chlorothalonil
cyproconazole
fenpropimorph
propiconazole
00 = untreated
Date
4 April
14
19
25
4 May
12
19
26
1 June
8
16
23
30
00
GS
30
31
31
32
33
37
39
41
51
59
65
69
75

Fig. 52

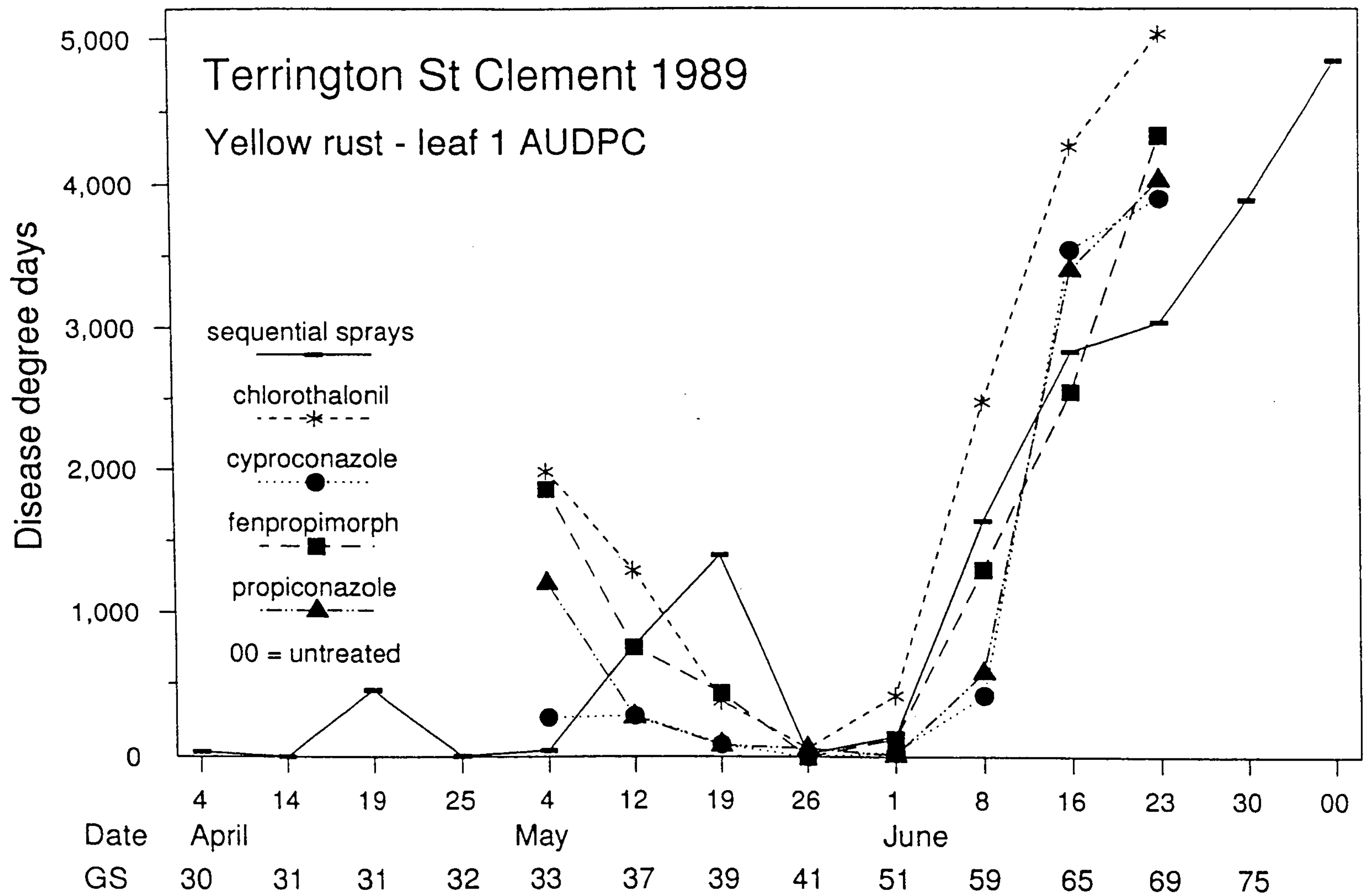

Terrington St Clement 1989
Yellow rust - leaf 1 AUDPC
Disease degree days
5,000
4,000
3,000
2,000
1,000
0
sequential sprays
chlorothalonil
cyproconazole
fenpropimorph
propiconazole
00 = untreated
4 14 19 25 4 12 19 26 1 8 16 23 30 00
Date April May June
GS 30 31 31 32 33 37 39 41 51 59 65 69 75

Fig. 53

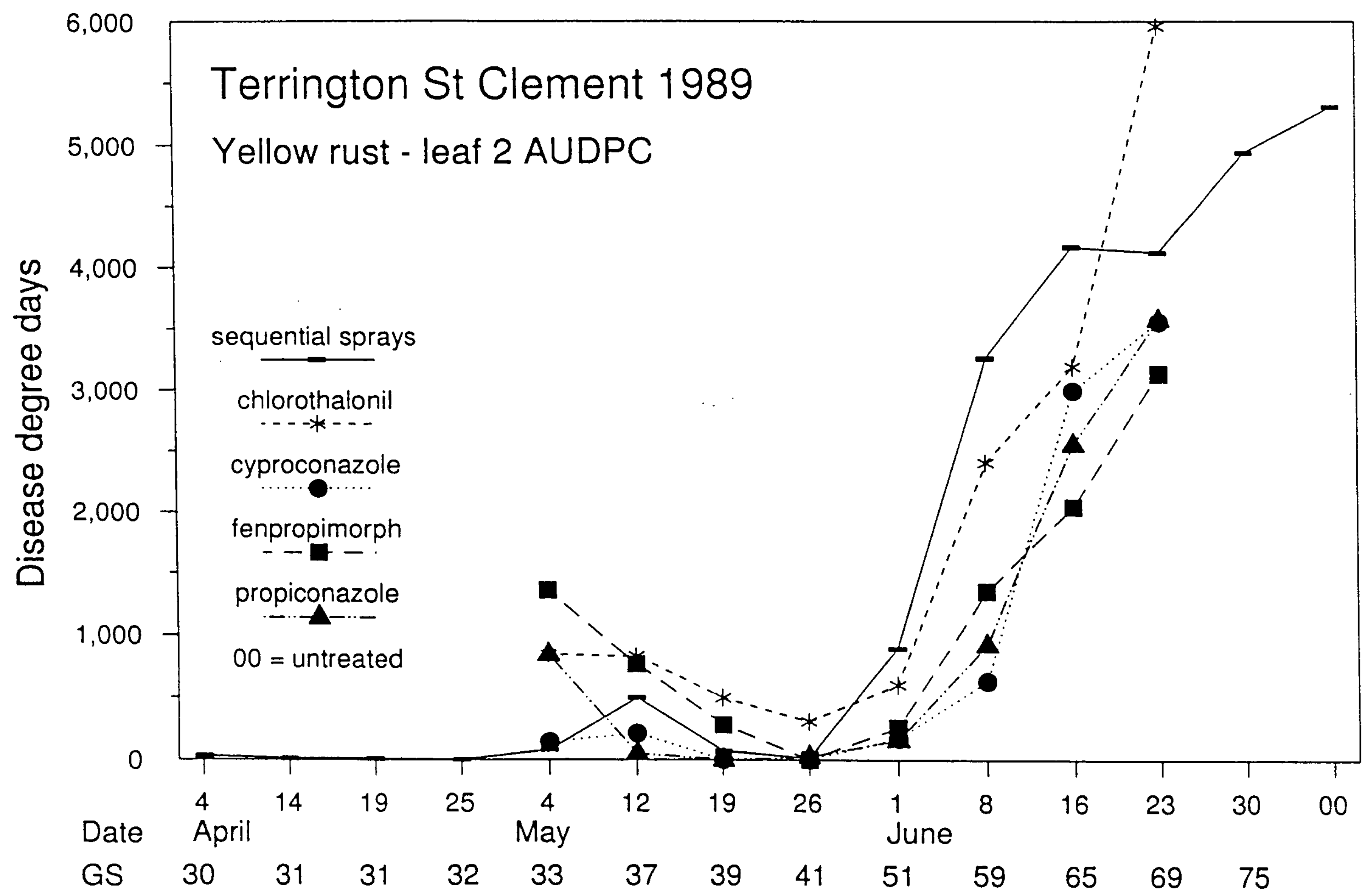

Terrington St Clement 1989
Yellow rust - leaf 2 AUDPC
Disease degree days
6,000
5,000
4,000
3,000
2,000
1,000
0
sequential sprays
chlorothalonil
cyproconazole
fenpropimorph
propiconazole
00 = untreated
Date
4 14 19 25 4 12 19 26 1 8 16 23 30 00
April
May
June
GS
30 31 31 32 33 37 39 41 51 59 65 69 75

Fig. 54

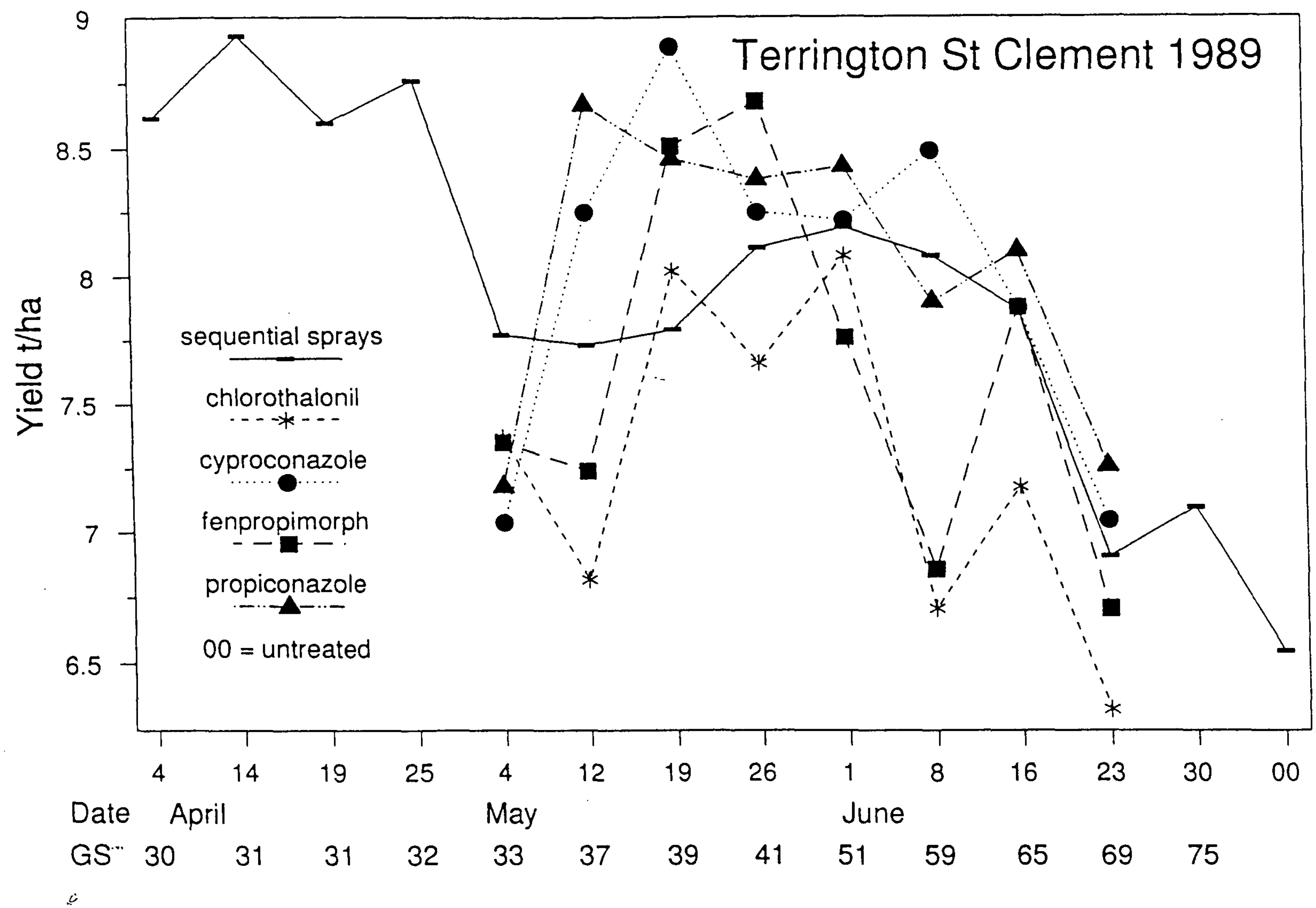

Terrington St Clement 1989
Yield t/ha
9
8.5
8
7.5
7
6.5
sequential sprays
chlorothalonil
cyproconazole
fenpropimorph
propiconazole
00 = untreated
4
14
19
25
4
12
19
26
1
8
16
23
30
00
Date
April
May
June
GS
30
31
31
32
33
37
39
41
51
59
65
69
75

Fig. 55

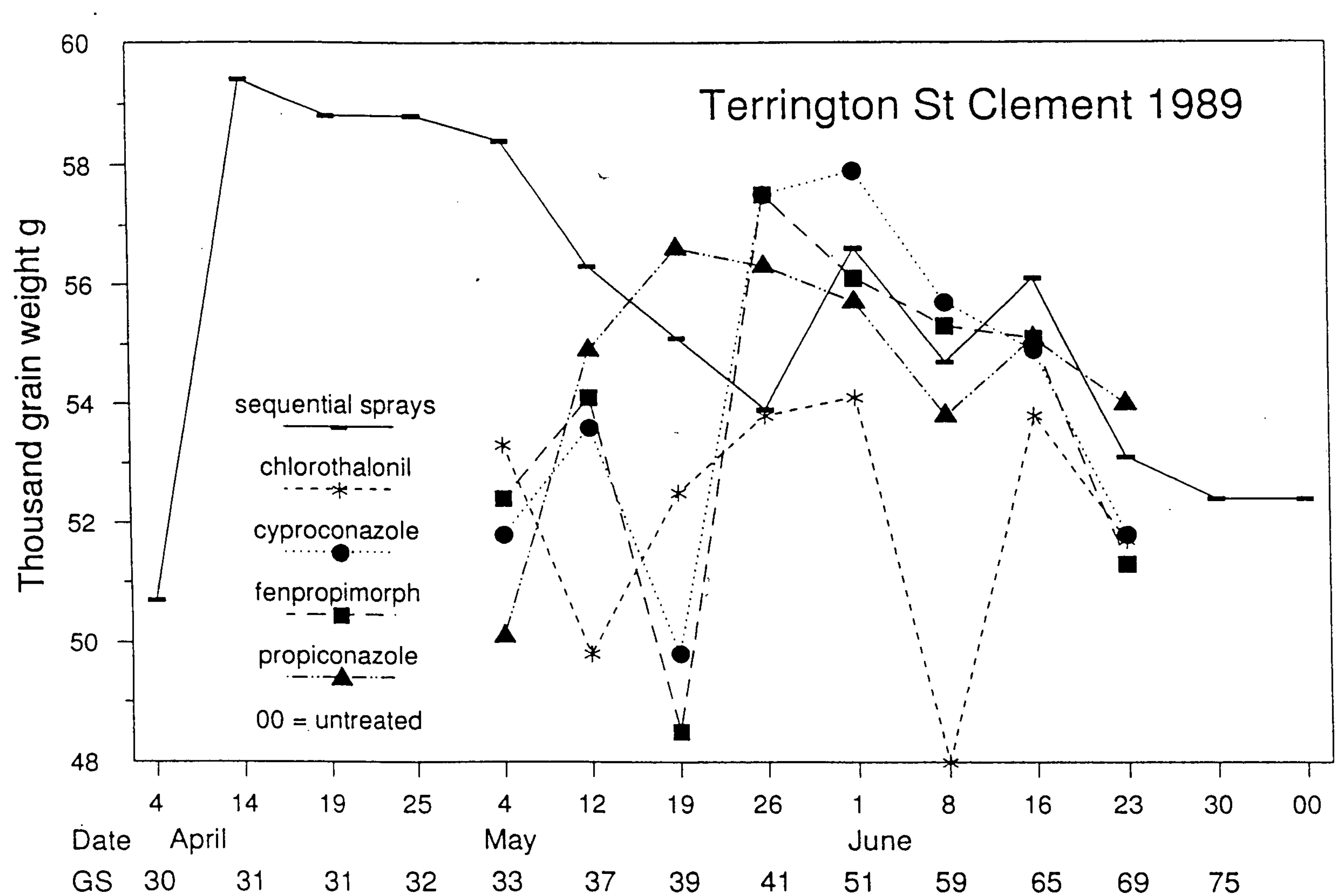

Terrington St Clement 1989
Thousand grain weight g
60
58
56
54
52
50
48
sequential sprays
chlorothalonil
cyproconazole
fenpropimorph
propiconazole
00 = untreated
4 14 19 25 4 12 19 26 1 8 16 23 30 00
Date April May June
GS 30 31 31 32 33 37 39 41 51 59 65 69 75

Fig. 56

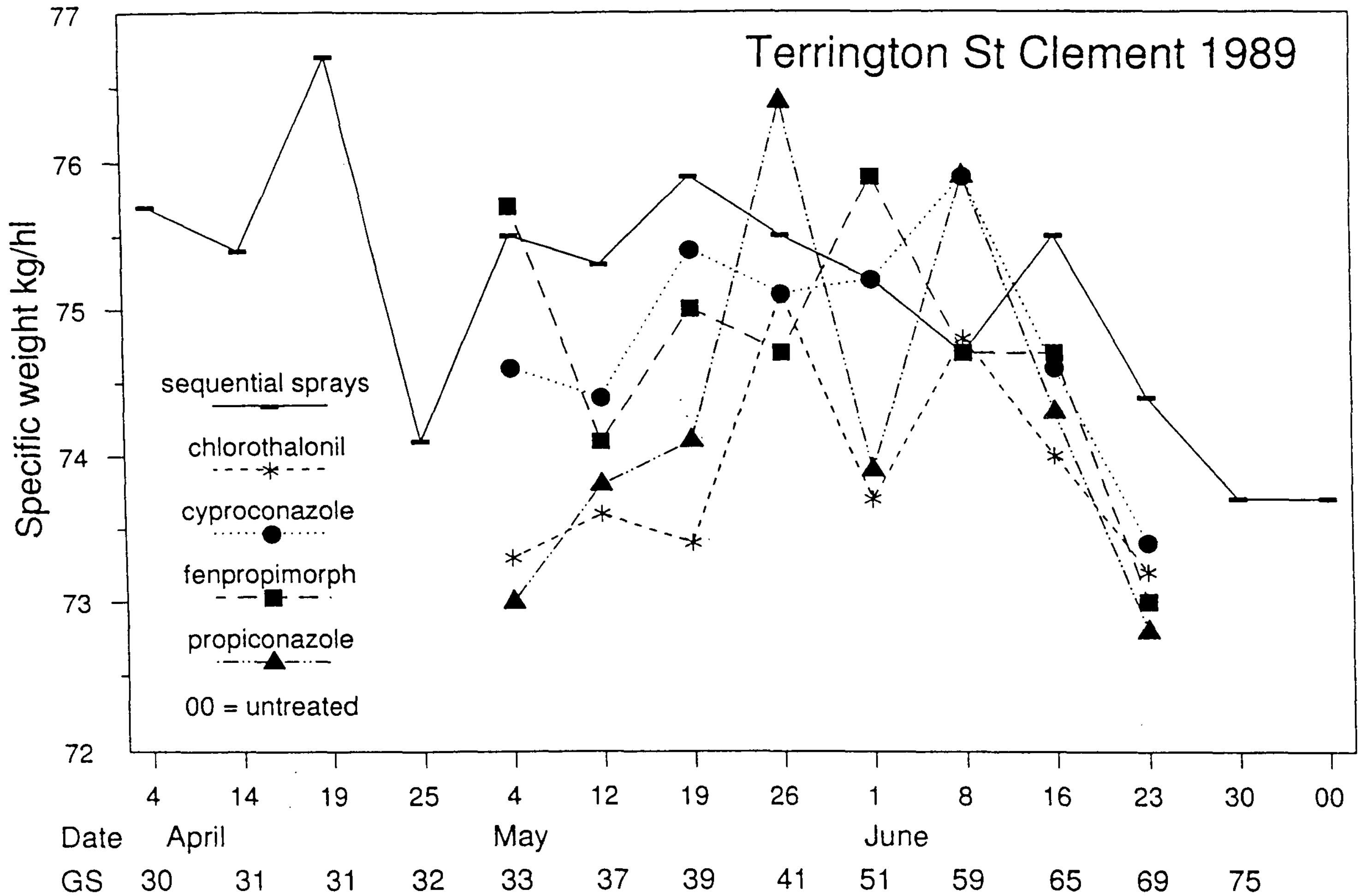

Terrington St Clement 1989
Specific weight kg/hl
77
76
75
74
73
72
sequential sprays
chlorothalonil
cyproconazole
fenpropimorph
propiconazole
00 = untreated
4
14
19
25
4
12
19
26
1
8
16
23
30
00
Date April
May
June
GS 30 31 31 32 33 37 39 41 51 59 65 69 75

Fig. 57

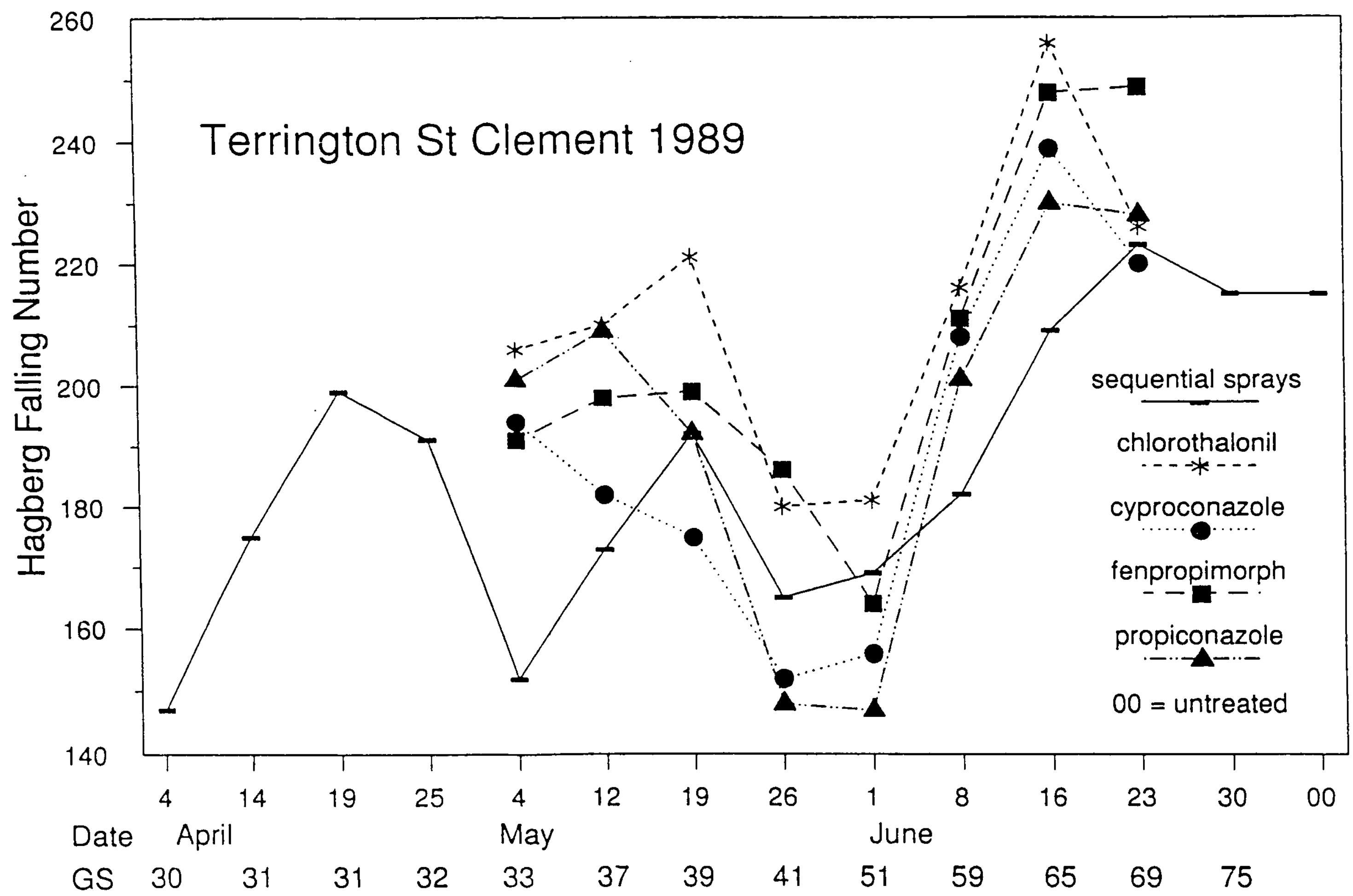

Terrington St Clement 1989
Hagberg Falling Number
260
240
220
200
180
160
140
4
14
19
25
4
12
19
26
1
8
16
23
30
00
Date
April
May
June
GS
30
31
31
32
33
37
39
41
51
59
65
69
75
sequential sprays
chlorothalonil
cyproconazole
fenpropimorph
propiconazole
00 = untreated

Fig. 58

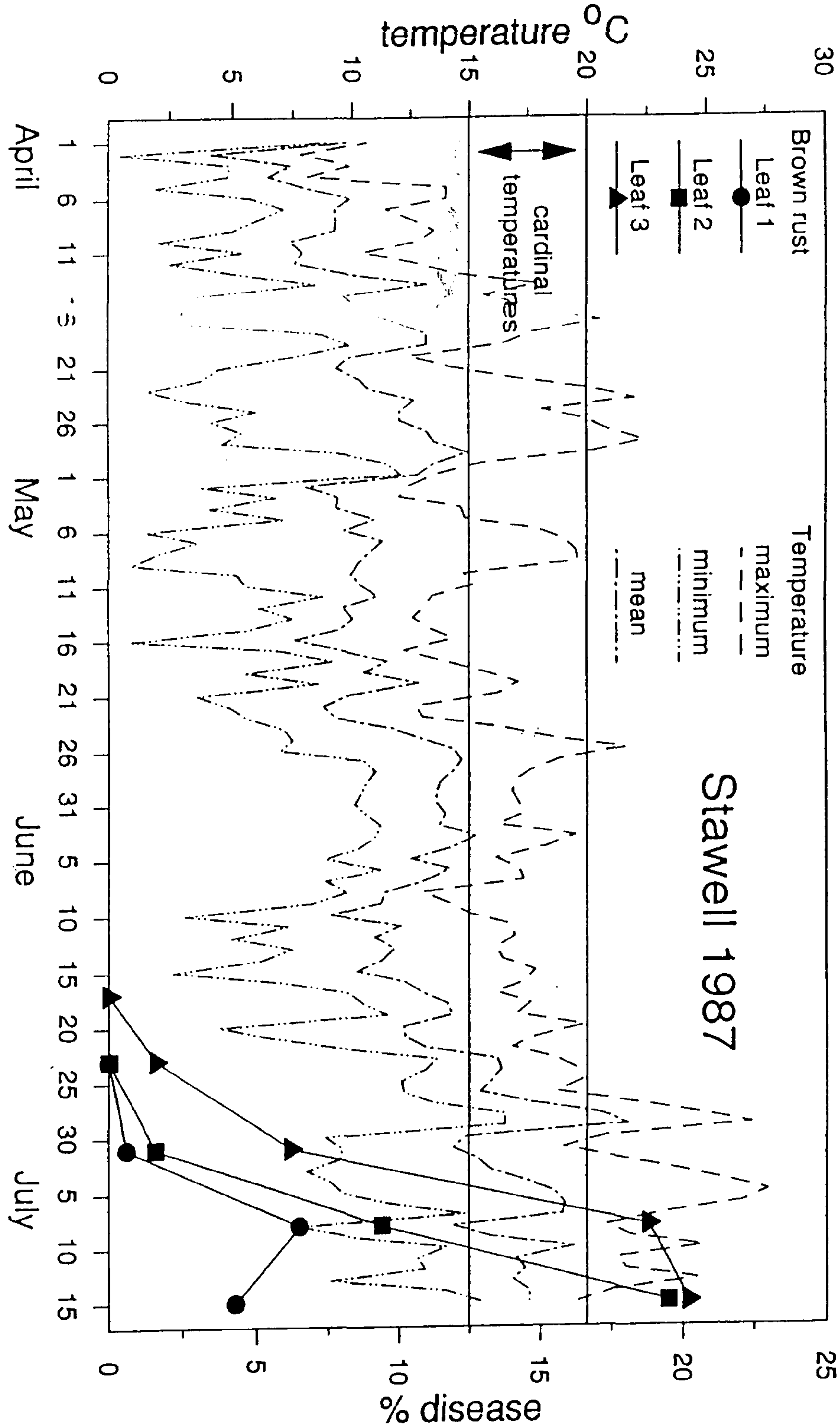

Stawell 1987
Brown rust
Leaf 1
Leaf 2
Leaf 3
Temperature
maximum
minimum
mean
cardinal temperatures
temperature °C
% disease
April
May
June
July

Fig. 59

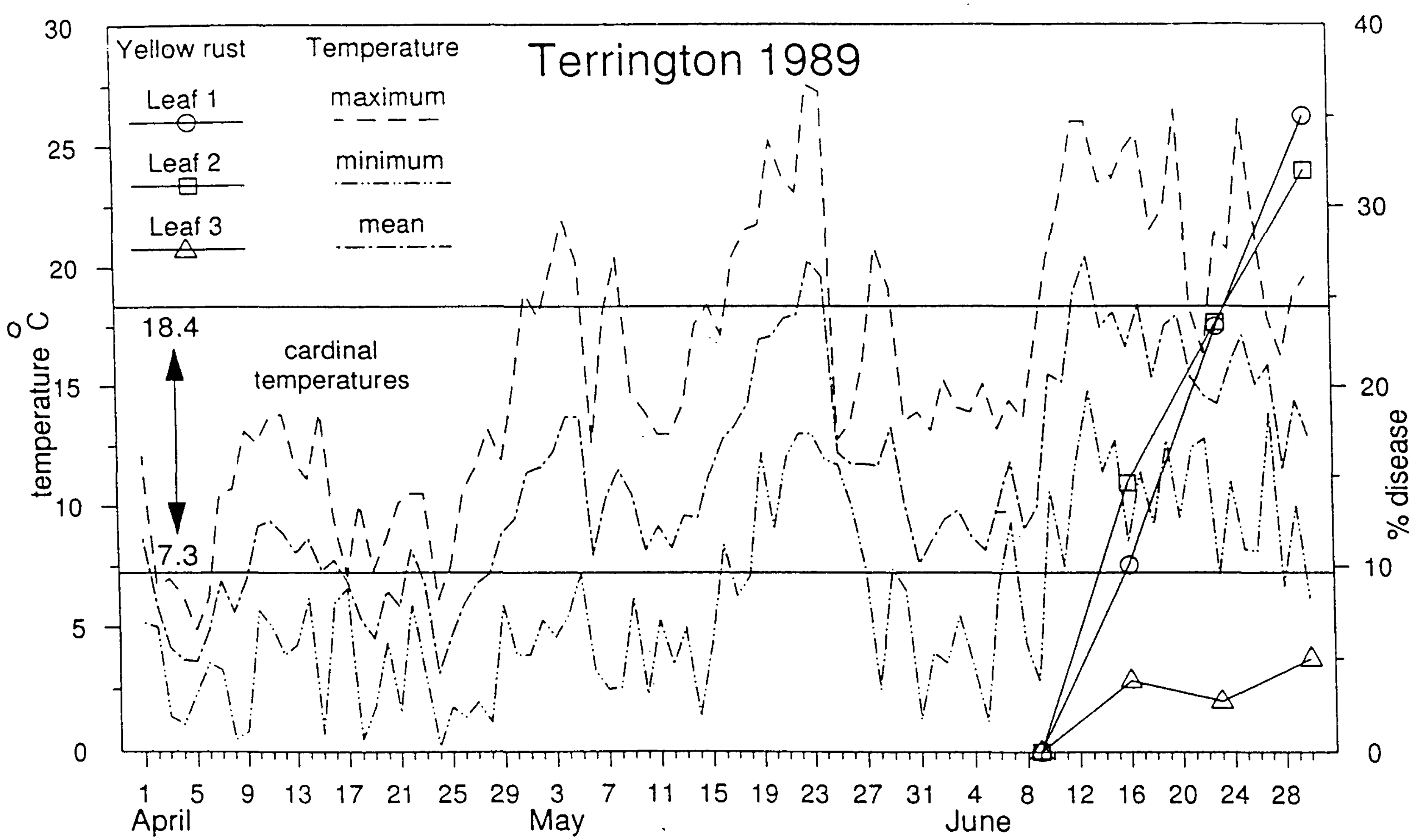

Terrington 1989
Yellow rust
Leaf 1
Leaf 2
Leaf 3
Temperature
maximum
minimum
mean
18.4
7.3
cardinal
temperatures
temperature °C
0
5
10
15
20
25
30
% disease
0
10
20
30
40
1
5
9
13
17
21
25
29
3
7
11
15
19
23
27
31
4
8
12
16
20
24
28
April
May
June

Fig. 60

4. PROSPECTS FOR INTEGRATED CONTROL

The experiments done at IACR and DANI, Belfast, demonstrated that growth stage based spray programmes often provide good disease control and yield improvements. However, it is clear that an element of luck is required with such an approach. In some years, protection from sprays, applied according to growth stage criteria, fails to coincide with periods when the crop is vulnerable to disease. When this occurs control is reduced and yield penalties may be incurred.

One answer to this might be sought by providing blanket protection through the season in the form of a 3 spray programme such as treatment G (GS31 + 39 + 59). Whilst this gives virtually complete control of *S. tritici* the 3rd spray may often be applied at an economic penalty rather than gain.

For several common diseases of winter wheat, ADAS experiments showed that the most effective sequential spray programmes commenced after GS31 but prior to conditions reported to favour the specific disease. This indicates that forecast guided disease control has the potential to improve the efficiency of fungicide use. Unfortunately, the resolution of reliable forecasting criteria from these experiments is not possible without further experimentation and more detailed analyses.

The ADAS experiments also showed that crude rainfall criteria are inappropriate for predicting risk of *S. tritici* development. This supports previous work at LARS that led to the development of the LARS splashmeter. This device has the advantage of measuring the property of rain that is responsible for inoculum dispersal within the crop.

The LARS *S. tritici* forecast system (treatment C) performed consistently in terms of *S. tritici* control and yield improvement above the untreated. Application of this system removes the element of luck that is adopted when using growth stage based programmes. As a consequence it never requires more than 2 fungicide applications and in dry seasons may even dispense with a second spray. Its success is based upon a good understanding of the pathogen.

Employment of the LARS forecast system does however pose some problems. First, decision support criteria must be applied with reference to regular crop monitoring. Although the system is relatively simple, some experience is required to ensure that the information obtained triggers the correct management action. For example, several mistakes were made in timing sprays at DANI using this system. The second problem relates to the integration of other diseases into the system. Because *S. tritici* and eyespot can be controlled by the same chemical it is sensible to attempt to control them together. Unfortunately, eyespot biology is poorly understood so accurate targeting of fungicide is difficult. Moreover, if good control is to be achieved once stem extension has occurred, there is strong evidence that light rainfall is needed for redistribution of the chemical to the base of the crop. This imposes additional difficulties on attempts to control eyespot because accurate local weather predictions are needed.

This coordinated project has highlighted the need for better understanding of key areas of the crop management system. The first of these areas is the basic biology of the pathogens causing disease. The second is in our understanding of the field performance of commonly used fungicides. Without such basic information it remains difficult to design a rational management system that integrates the control of diseases of winter wheat.

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APPENDIX

FORECASTING *Septoria* IN WINTER WHEAT

A method developed at
Long Ashton Research Station, UK

April 1994

INTRODUCTION

This approach to forecast the need for fungicide applications to control ***Septoria tritici*** in winter wheat has been developed from research* by D.J. Royle, M.W. Shaw, T. Hunter, D.J. Lovell and R.R. Coker (1986-1994) on the factors affecting disease development in susceptible wheat cultivars. The method has been widely tested at Long Ashton and, in collaboration with ADAS and ITCF at other sites in the UK and France. It is also currently (1992-94) being evaluated against other decision models in a LINK project funded by Bayer/H-GCA/MAFF.

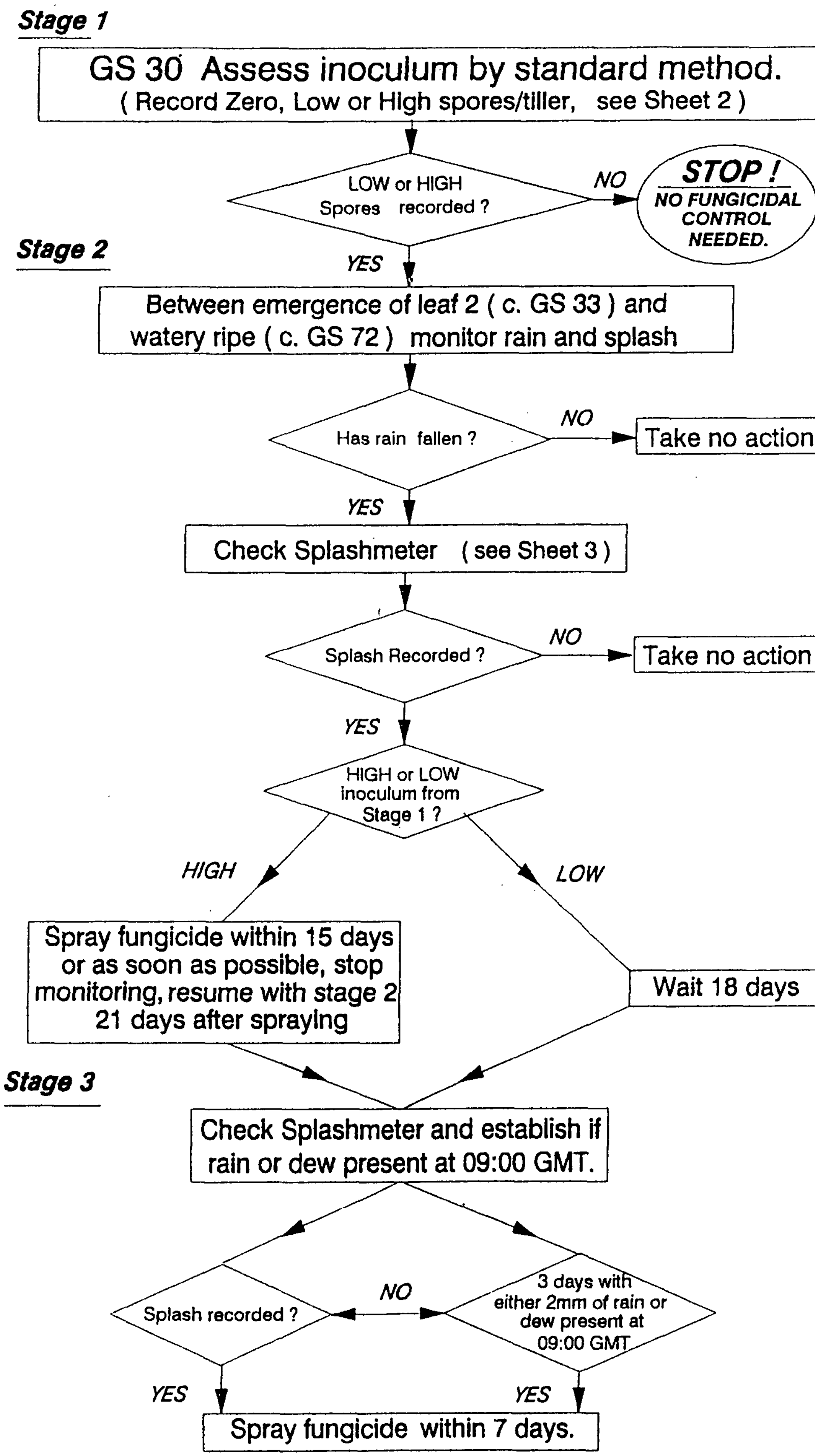
The method shows advantages in control over routine fungicide programmes of 2 or 3 fungicide sprays. Further research is in progress at Long Ashton to improve the approach and to make it more widely applicable for a range of wheat cultivars, for use with specific fungicides and for integration with the management of other wheat diseases which require fungicides.

This protocol is in three "sheets". Sheet 1 depicts the forecast scheme to guide control decisions (which is constantly being up-dated). It is supported by instructions in Sheet 2 for assessing *Septoria* inoculum early in spring and, in Sheet 3, for setting up and operating the Long Ashton "Splashmeter". The Splashmeter is the only simple device available for estimating the extent of vertical rainsplash. The scheme allows for a **maximum** of **2 fungicide sprays per season** with HIGH inoculum, and **1 spray per season** with LOW inoculum.

* *Funded by MAFF, OST and H-GCA*

LONG ASHTON Septoria FORECASTING

Sheet 1: SCHEME OF FORECAST-GUIDED CONTROL OF *Septoria*



LONG ASHTON *Septoria* FORECASTING

Sheet 2: ASSESSMENT OF Septoria IN WHEAT CROPS - A PROCEDURE USING TILLER WASHINGS

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The total amounts of *Septoria tritici* and *Septoria nodorum* in wheat crops cannot usually be determined directly, because their recognition is impeded by their persistence in senescent leaves. This procedure assesses the presence and quantity of pycniospores in individual crops early in spring as a first stage in forecasting (***see Sheet 1***). It should be done late in GS 30, before the first node becomes detectable, i.e. late March-early April in most areas and years.

Stage 1: Sampling

We know that *Septoria* diseases are spatially uniformly distributed in wheat crops; therefore sampling is simple.

1.1 Select an area of the field at least 20m from the edge (or if in an experimental plot, an area considered to be representative and at least 1m from the edge).

1.2 Using a trowel, carefully remove all plants with attached dead leaves and roots (including soil as necessary). **At least 20 plants should be collected from 4 random locations** across the area or plot. These are placed together in a polyethylene bag, and returned to the laboratory. Carry out Stage 2 **on the same day**.

Stage 2: Plant handling

2.1 Carefully, but thoroughly wash all soil from the plants under running tap water. Retain leaf fragments by passing the washings through a sieve (c 2mm mesh).

2.2 Separate the plants and **record the number of tillers** (i.e. all shoots with one expanded leaf) **on each plant**.

2.3 Remove roots with scissors in order to reduce bulk and shake excess water from the plants.

2.4 Place the trimmed plants in 1 or 2-litre flasks depending on the size of the sample. Plants should be loose in the flask, not tightly packed. Add any non-green leaf fragments salvaged from the sieve.

2.5 Cover the neck of the flask loosely to prevent drying out (the plants should be wet but with no obvious surplus water in the bottom of the flask).

2.6 Leave overnight (*c* 18h) indoors (*c* 15-22°C) away from direct light, in a cupboard or beneath a bench.

Stage 3: Preparing a spore suspension

3.1 Add a measured volume of water (containing 10 drops Tween 20/litre). The minimum quantity used should 150ml, though 200ml should be used with larger samples. Immediately shake vigorously by hand for about 15 seconds. Shake again four to five times over the next **20 minutes.**

3.2 Pour off the washings into a beaker, remove 9.0ml and add to 1.0ml of lactophenol-trypan blue (0.025%) in a capped bottle.

Stage 4: Counting

4.1 After mixing, count the number of pycniospores of each *Septoria* sp. separately with the aid of a haemocytometer, either immediately or within a few days.

4.2 The preferred method is to record the volumes of the haemocytometer cell (number of squares under the microscope) which at least 30 spores occupy. If 30 cannot be found, then count the number in the entire cell - this is necessary to keep the detection threshold as low s possible.

Stage 5: Results

Correct for the 9:1 dilution and calculate the **number of spores per tiller**. Relate to "**high**", "**low**" or "**no**" inoculum in the *Septoria* forecast flowchart (***Sheet 1***):

"**Low**" = $<5 \times 10^4$ for *S. tritici*, $<5 \times 10^3$ for *S. nodorum*
"**High**" = $>5 \times 10^4$ for *S. tritici*, $>5 \times 10^3$ for *S. nodorum*

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LONG ASHTON *Septoria* FORECASTING

Sheet 3: USE OF THE SPLASHMETER FOR SPRAY GUIDANCE

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The Long Ashton **"Splashmeter"** indicates occasions when the degree of rainsplash is sufficient for *Septoria* inoculum to be splashed on to the upper leaves of a wheat crop. It has been developed as part of an approach to forecast the need for fungicide applications to control *Septoria tritici* ***(see Sheet 1).*** It may also apply to *Septoria nodorum* but the different biology of the two species means that the forecast approach (and the splashmeter) cannot be expected to be as reliable for *S. nodorum* as for *S. tritici*. **The following instructions should be used in conjunction with the experimental forecast approach(*Sheet 1*)** developed from the Long Ashton research.

Placement:

The splashmeter ***(see attached diagram)*** should be operated in a reasonably open site, more than 10m from buildings or trees, over short grass or mown vegetation near - **but not within** - the crops of interest. Locate the bottom of the receptor paper support 10cm above the dye reservoirs.

Dye:

The dye is a mixture of 5% Cibacron Blue and 10% Uvitex CF, made by Ciba Geigy. It is supplied in diluted form, ready for use. Fill the reservoirs initially to 3mm deep.

Paper marking:

Label each receptor paper at the top with the time and date when the paper was put out and brought in. Use a pencil to write with, as it does not fade in sunshine. Draw two lines horizontally across the paper, one **20cm** and the other **30cm** from the bottom.

Operation:

Start using the splashmeter at the emergence of leaf 2; this is about GS 33 in most cultivars of winter wheat. Stop using the splashmeter at watery ripe (GS 72) or when two sprays have been applied. A spray may be required if traces of dye can be seen above one of the pencil lines on the paper (***See Sheet 1: Flowchart for Septoria forecast-guided sprays***).

Before GS 51 (start of ear emergence) use the lower (20cm) pencil line; after GS 51 use the upper (30cm) line. If, on inspection of the splash paper after rain, more than 7 drops of size ● appear and no spray has been applied for 3 weeks, spray as soon as possible, or within 15 days (depending on the chosen strategy) with an appropriate fungicide (e.g. prochloraz (if eyespot has also to be controlled) before GS 37, flutriafol, propiconazole or other appropriate fungicide afterwards).

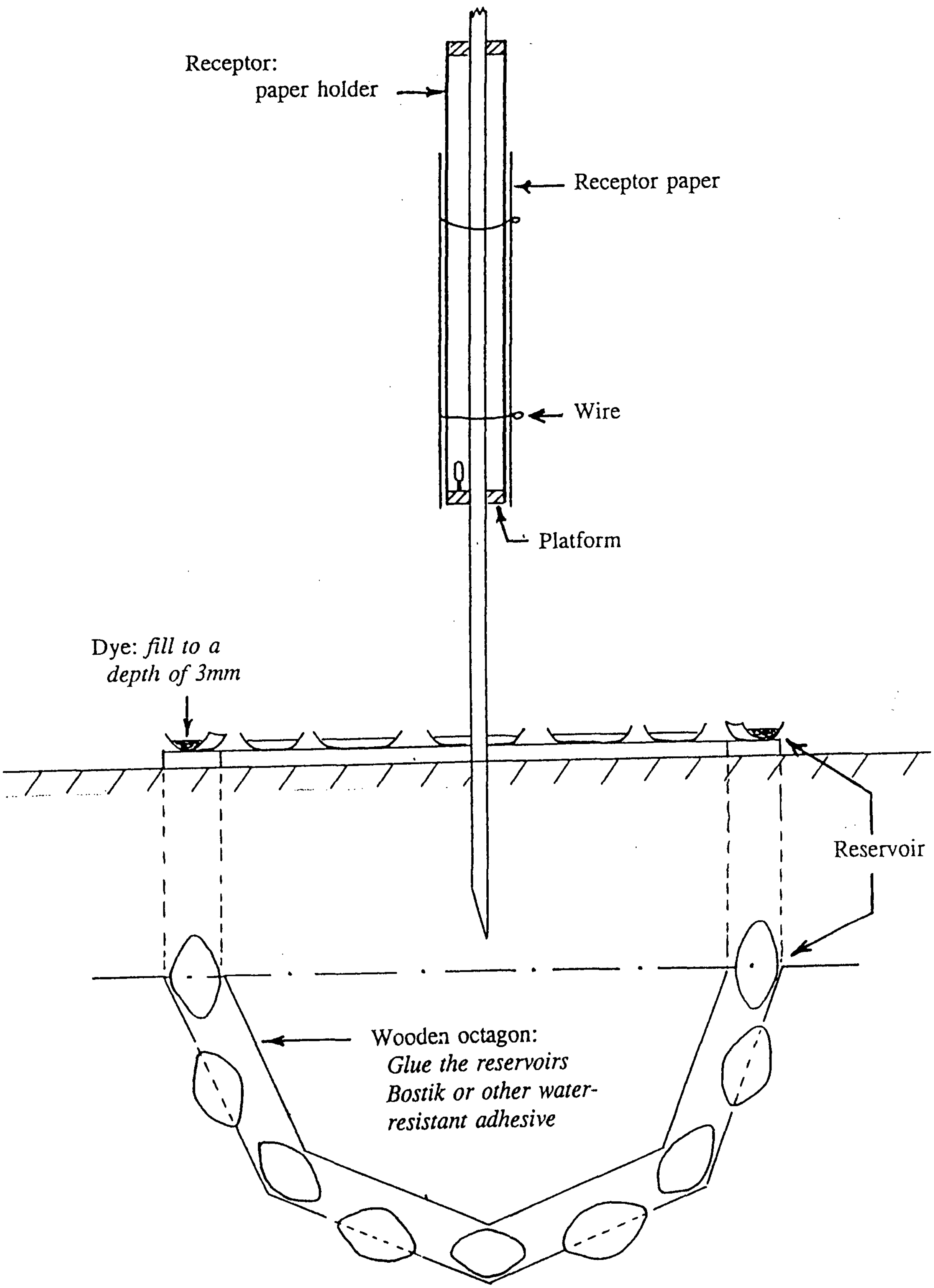
After rain and weekly:

Check the splashmeter. If there are any traces of dye on the receptor paper then change the paper. Check that there is adequate dye in the dishes (it does not matter if the dye has dried, so long as plenty of it is present).

Further notes:

It is important that the dye does not become too dilute; in heavy rain (e.g. more than 7-8mm) it may be desirable to add more dye during the rain. More dye will certainly need adding after each heavy rain storm.

In heavy rain the traces of dye may be quite faint so examine the paper carefully. (This is because the dye binds best under alkaline conditions; prolonged rain will wash out the alkali with which the paper is impregnated).



Long Ashton, April 1994

THE LONG ASHTON SPLASHMETER