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Improved pea production for sustainable arable farming: development of ascochyta blight epidemics, year 3 results

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1 Executive summary

This report outlines the project “Epidemic development of ascochyta blight”, which completes the third and last year of work in the MAF Sustainable Farming Fund (SFF) project “Improved pea production for sustainable arable farming”.

1.1 Project objectives

- Together with the other parts of the SFF project, to generate information on the development of ascochyta blight in order to provide management tools that growers can use to control the disease.
- To obtain fundamental information about the timing and progress of ascochyta blight epidemics and the effect of these epidemics on pea crop yield. This more theoretical information forms the basis for year 4 and 5 evaluations of the system for forecasting ascochyta disease incidence.

1.2 Trial details

The work was carried out during the 2006• 07 growing season at the property of Rob McIlraith at St Andrews, South Canterbury. Peas were sown at 3 different times, plots were inoculated at 2 different times, and fungicides were applied at different times and for different durations to control the start, intensity and length of ascochyta epidemics. Weather conditions were conducive to the development of the pathogen that causes ascochyta blight but trial areas were also irrigated after inoculations to ensure adequate moisture levels for infection.

In addition, 4 field trials were carried out in Canterbury during the 2006–07 growing season to measure the effects of a commonly used fungicide seed treatment on the establishment of seedlings of 2 pea cultivars (Falloon et al. 2007).

1.3 Key findings

1. What effect does sowing date have on yield if ascochyta blight is present?

The main conclusion from this trial was that the sowing date had a major influence on final yield; early-sown crops (August) had greater yields than later-sown crops (sown in September and October). There were 6 different crop growth stages when plants were inoculated: emergence, 4 nodes, 5 nodes, 8 nodes, enclosed bud and first open flower. In the untreated Nil treatments, the yields were: 1.5, 3.3, 1.8, 5.6, 3.8 and 6.0 t/ha respectively. This indicates that timing of sowing was a more important factor in determining the final yield than the crop growth stage – the earlier the sowing the greater the yield. However, there was a small increase in yield as the crop matured (comparing the second inoculation with the first inoculation) within a sowing date, this yield increase was 0.4 t/ha for the August sowing, 0.5 t/ha for the September sowing and 0.3 t/ha for the October sowing. This was most likely because the plants that were inoculated first were exposed to the inoculum for longer and hence had greater disease levels, as determined by measurements made of all the individual disease indicators.

2. What are the most important growth stages to protect with fungicide applications if ascochyta blight is present?

Results from last year indicated that growth stages from node 7 to early flower were the most critical stages to protect with fungicides. The crop stages that were most important to protect with fungicide applications (i.e. had least disease and highest yields) in this trial varied depending on the time of sowing. In the August sowing, treatments that started from first open flower were the highest yielding (6.2–6.9 t/ha), but did not necessarily have the least ascochyta blight. Early treatment at 8 nodes resulted in low levels of disease but lower yield than the other treatments, probably due to early senescence. In the September and October sowings the highest yielding treatments were those that started from early flower and flat pod (September) or 7th node and visible bud (October) stage, but these did not have the least disease. Treatments applied earlier resulted in greater amounts of ascochyta towards the end of the growing season and lower yields. The results indicated that the later growth stages were more important to protect with fungicides than the earlier ones.

3. What is the effect of different levels of disease severity on final crop yield?

To determine how different levels of disease severity influenced final crop yield, correlations between yield and disease measurements were calculated. The correlations between yield and disease measurements were strongly affected by the differing relationships between yield and disease variables for each of the different sowing dates. There was a reasonable correlation between yield and area under the disease progress curve (AUDPC) for the September data and a moderate correlation for the October data with yield decreasing with increasing AUDPC. There were moderate to strong correlations between yield and pod and stem scores where yield decreased with increased ascochyta on stems and pods. The Full treatment that received weekly fungicide applications, always had the highest yield, and the Nil treatment had the lowest yields in most cases. However, for the other treatments, there was not a clearly identifiable level of ascochyta that corresponded with a decrease in yield, especially in the August sowing. In the September and October sowings, increasing ascochyta severity at the last assessment date corresponded with decreased final yield. These results will require further analysis.

4. What effect does fungicide seed treatment have on yield?

No benefit to seedling establishment from seed treatment was demonstrated in these 4 trials. However, previous research has shown that considerable improvement in establishment and crop yield can result from seed treatments as a result of control of *Pythium* spp., *Fusarium oxysporum* and prevention of downy mildew epidemics. We recommend that fungicide seed treatments should continue to be routinely used for peas because they provide worthwhile insurance against soilborne seedling diseases that can harm seedling establishment, and against epidemics of downy mildew in young crops.

5. What further analyses are underway?

Further analysis of the results presented in this report will be carried out as a part of an extension to this project on "Making peas pay – extension of outcomes to farmers" with a particular focus on evaluating the accuracy and robustness of the system for forecasting ascochyta disease incidence by monitoring disease incidence in growers' pea fields in locations with good weather data. In year two, the ascochyta disease forecast based on the weather will be delivered to growers using the FAR Crop Action and emails from HortNZ's Process Vegetable Product Group.

2 Introduction

This report outlines the project "Epidemic development of ascochyta blight", which completes the third and last year of work in the MAF Sustainable Farming Fund project "Improved pea production for sustainable arable farming". The objectives of the project were to:

- together with the other parts of the SFF project, generate information on the development of ascochyta blight in order to provide management tools that growers could use to control the disease;
- obtain fundamental information about timing of ascochyta (and other disease) epidemics and about the effect of these epidemics on yield by using sowing dates, fungicide sprays, and artificial inoculation to manipulate the epidemics.

The work was carried out during the 2006• 07 growing season at the property of Rob McIlraith at St Andrews, South Canterbury. Peas were sown at 3 different times, plots were inoculated at 2 different times and fungicides were applied at different times and for different lengths to control the start, intensity and length of ascochyta epidemics. Ascochyta blight of peas is caused by a combination of three pathogenic fungi. These are:

- *Mycosphaerella pinodes* (Berk. & Blox.) Vestergr., the perfect stage of *Ascochyta pinodes*, which causes ascochyta blight;

- *Phoma medicaginis* var *pinodella* (L.K. Jones) Boerema, also known as *Ascochyta pinodella*, which causes ascochyta foot rot; and
- *Ascochyta pisi* Lib., which causes leaf and pod spot.

The main focus of this trial was on ascochyta blight caused by *M. pinodes.* However, symptoms of ascochyta foot rot as well as other diseases were also scored at the detailed assessment.

The research approach involved using:

- 3 different sowing dates (August, September, October),
- 2 different inoculating timings: at emergence of the last (October) sowing date and 3 weeks later so that plants at the different sowing dates were at different growth stages,
- 6 different fungicide treatments (Nil, Full and 4 different 3 (or 4) week fungicide treatments).

The aims of the project were to:

- relate disease onset at different crop growth stages to final yield,
- compare final disease severities with yield,
- relate timing of fungicide sprays to final disease levels and to yield,
- obtain various disease progress curves,
- collate weather data (rainfall, leaf wetness and temperature) that can be compared with disease progress over time,
- obtain information on crop growth stages that are most important to protect with fungicide if ascochyta is observed.

This report describes the materials and methods used in the field trial, presents results and then assesses them in terms of the relevant research questions outlined above.

3 Materials and methods

3.1 Trial site, design and treatments

The trial was carried out on the property of Rob McIlraith at St Andrews, South Canterbury. The processing pea cultivar Durango was used (germination 99%, abnormal 0%, hollow heart 0%, conductivity 24 uS/cm per g, expected field germination 91% and seed count 4905 seeds per kg).

The first sowing (August) was on 23 August 2006 and emerged on approx. 13 September 2006. The second sowing (September) was on 22 September 2006 and emerged on approx. 13 October 2006. The third and final sowing date (October) was 18 October 2006 and seedlings emerged on 5 November.

Six fungicide application treatments were chosen to include a range of timings and number of applications (Figure 1). Fungicides were applied at

7–10-day intervals (weather dependent) by NZ Arable. The first fungicide treatments were applied on 7 October 2006 to the August Full treatment plots (Table 1). The second fungicide treatment was applied on 21 October 2006 to August and September Full plots. All Full treatment plots were sprayed for the first time on 4 November 2006. Thereafter, plots were sprayed weekly (Saturdays depending on weather). The last fungicide treatment was applied on 27 January 2007. Each time, the fungicides Melody Duo (iprovalicarb and propineb) at a rate of 2.5 kg/h, Proline (prothioconazole, DMI) at 0.8 L/ha and Protek (carbendazim) at 0.5 L/ha were applied.

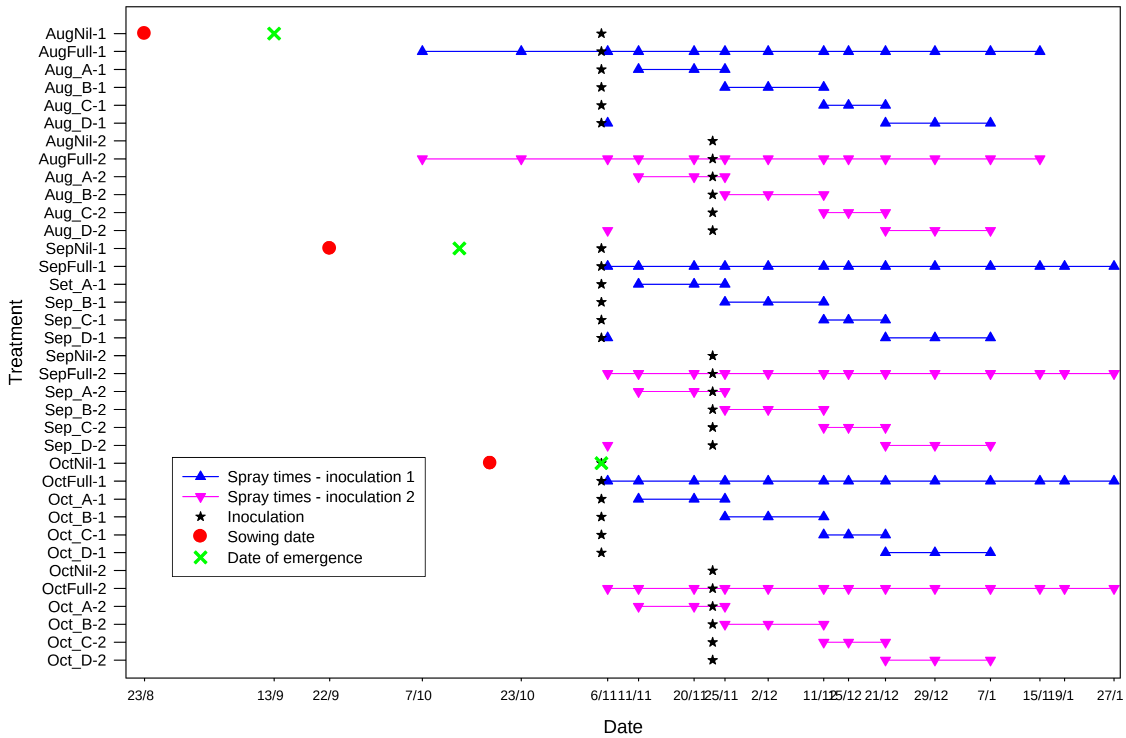

Figure 1: Treatment plan.

Table 1: Fungicide application schedule at the St Andrews trial site.

Date	
7/10/2006	August Full plots (6 plots)
23/10/2006	August Full plots (6 plots)
6/11/2006	Full plots, August and September D plots (24 plots)
11/11/2006	Full and A plots (36 plots)
20/11/2006	Full and A plots (36 plots)
25/11/2006	Full, A and B plots (54 plots)
2/12/2006	Full and B plots (36 plots)
11/12/2006	Full, B and C plots (54 plots)
15/12/2006	Full and C plots (36 plots)
21/12/2006	Full, C and D plots (54 plots)
29/12/2006	Full and D plots (36 plots)
7/1/2007	Full and D plots (36 plots)
15/1/2007	August, September and October Full plots (18)
19/1/2007	September and October Full plots (12)
27/1/2007	September and October Full plots (12)

The trial (Figure 2) was a partially balanced split-plot design with sowing dates as main plots (columns of 4 plots). The treatments were laid out in a design derived from a Latinised resolvable row and column design so that there were 9 replicates of a 2 x 6 factorial (inoculation by fungicide treatment). There were 3 replicates for each sowing and columns were randomised in replicates (9 columns per replicate). Plots were 1.6 m wide and 10 m long and there was a buffer plot of bare ground between each trial plot at the edge of the trial area.

Trial plots were inoculated on one of 2 occasions: 5 (first inoculation) or 23 (second inoculation) November 2006. The trial plots were inoculated using inoculum produced on barley grain infected with *Mycosphaerella pinoides* in the laboratory using the same methodology as that used in previous trials (Viljanen-Rollinson et al. 2005).

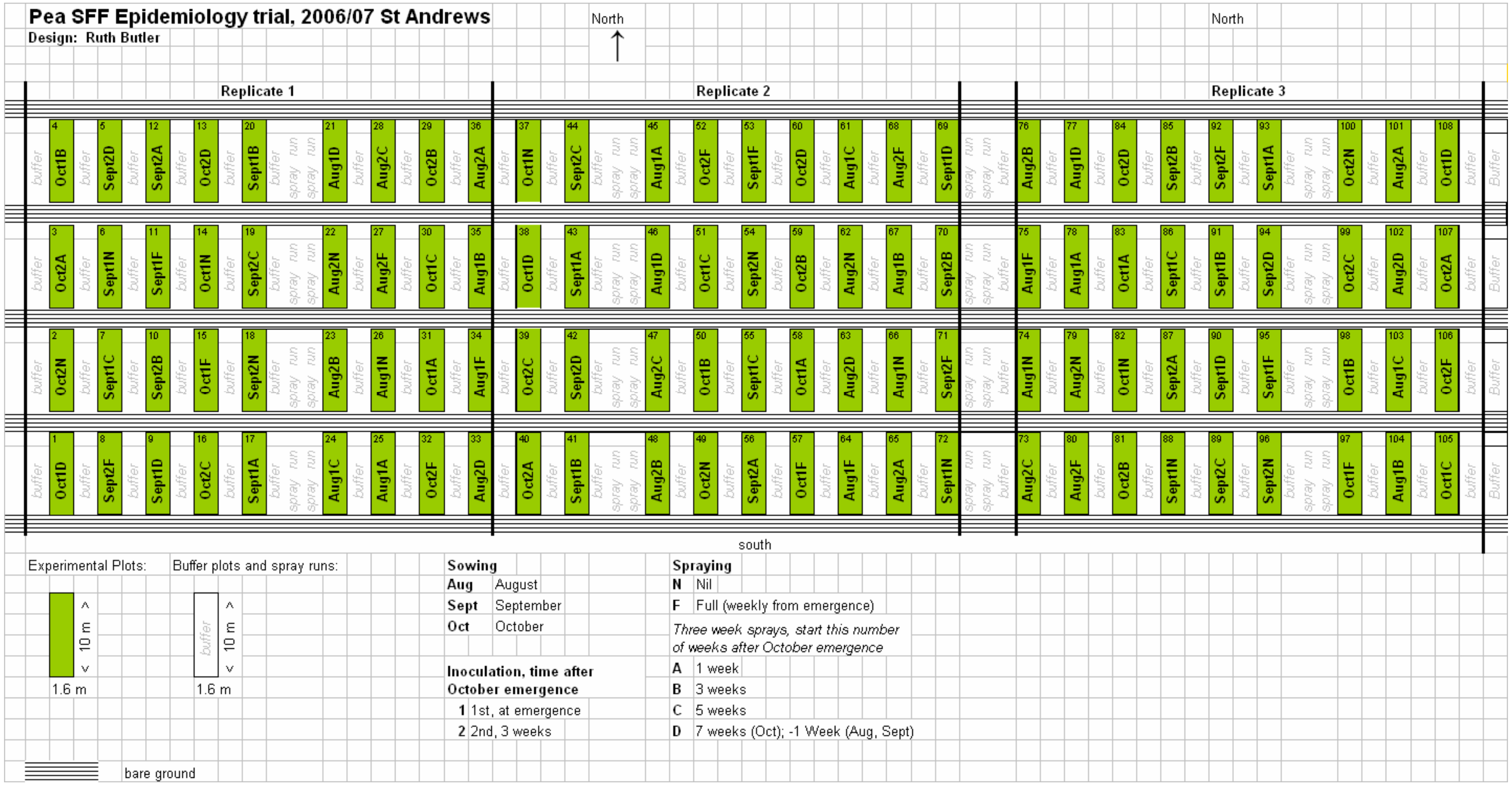

Figure 2: Trial plan.

3.2 Crop management

The herbicide Bladex 90 WG (active ingredient cyanazine, 1.5 kg/ha) and Sencor (metribuzin 0.25 g/ha), together with the insecticide Karate (lambdacyhalothrin, 30 ml/ha) were applied to the trial area on 5 November 2006. The herbicide Gallant NF (haloxyfob, 0.65 L/ha) mixed with the adjuvant Uptake (paraffinic oils and surfactants, 0.5%) was applied on 28 December 2006 by the grower. A second application of Karate at a rate of 20 ml/ha was sprayed on 25 November 2006.

Irrigation was carried out by the grower on:

- 23 October 2006: 34 mm
- 6 November 2006: 6.6 mm
- 7 November 2006: 34 mm
- 24 November 2006: 26 mm.

3.3 Measurements

3.3.1 Plant emergence

Plant emergence was measured on 27 October 2006 for the August and September sowing dates and on 13 November 2006 for the October sowing date when the plants were at the 7, 4 and 5 node growth stage respectively. Total number of plants on both sides of the 1 m length measuring tape were counted and two 1 m lengths were counted in each plot.

3.3.2 Disease severity and growth stage

Plots were assessed every 7–10 days from 3 November to determine the severity of ascochyta blight (Table 2). Severity was measured by randomly selecting 20 plants in each plot and recording the percent infected area. At the final assessment, 4 groups of 5 plants were assessed in detail, with separate scores for percentage leaf area infected with ascochyta on the pods and stems. The presence of other diseases was also recorded. This detailed assessment was carried out on 18 January 2007 (August and September sowing dates) or 7 February (October sowing date). Growth stage was assessed for each sowing date at each disease assessment by calculating the mean of 10 plants.

Table 2: Disease assessment dates (whole-plant disease scores), days after inoculation 1, days after inoculation 2, days after emergence (DAE) and crop growth stages (GS, Knott 1987) for August, September and October sowing dates.

	Days after		August		September		October	
Date	Inoculation 1	Inoculation 2	DAE	GS[1]	DAE	GS	DAE	GS
03/11/06	-	-	51	108	21	104	-	-
13/11/06	8	-	61	202	31	108	7	104
23/11/06	18	-	71	203	41	201	17	105
04/12/06	29	11	82	205	52	202	28	106
14/12/06	39	21	92	206	62	204	38	109
21/12/06	46	28	99	207	69	205	45	202
28/12/06	53	35	106	207	76	206	52	203
9/01/07	65	47	118	208	88	207	64	205
18/01/07	74	56	128	208/209	98	207	74	206
25/01/07	81	63	135	209	105	208	81	206/207
07/02/07	94	76	141	210	118	209/210	94	207

[1]Growth stage descriptions: 104 – 4th node; 108 – 8th node; 201 – enclosed bud; 202 – visible bud; 203 – 1st open flower; 204 – pod set; 205 – flat pod; 206 – pod swell; 207 – pod fill; 208 – green wrinkled pod; 209 – yellow wrinkled pod; 210 – dry seed.

3.3.3 *Yield*

Plots were harvested on 8 February 2007 (August sowing) or 19 March (September and October sowings). Seed yields (kg/plot) were recorded.

3.3.4 *Weather station*

A weather station was located approximately 500 m north of the trial site and recorded hourly rainfall, air temperature, soil temperature, leaf wetness, relative humidity and solar radiation.

3.4 *Methods of analyses*

Approaches to data analysis followed those used last year. However, the initial analyses for the ascochyta data summaries and yield were carried out using REML (restricted maximum likelihood) because the design was an unbalanced split-plot design, with sowing dates applied to columns of 4 plots. Confidence limits shown on the graphs for disease at individual dates were from these REML analyses. For the summaries of the ascochyta scores and the detailed assessments of pods and stems, the spatial structure (i.e. column structure) was found not to be important, so the analysis was simplified and analysis of variance used instead; the result are presented for these analyses of variance. All analyses were carried out using Genstat (GenStat Committee 2006).

3.4.1 *Disease assessments*

The dates when disease was first recorded to be more than 0 and 5% were calculated. These dates were then converted into days from crop emergence using the separate emergence dates for each sowing date. Maximum disease was the maximum disease observed for a plot. Assessment 8 (on 9 January 2007) was the last occasion when all plots still had live plants. After this assessment date some plots senesced. AUDPC was calculated as before using 1 November 2006 as the start date. No disease was observed before this date so there were no contributions to the AUDPC for the August and September crops from before this date. Once the plants in the plot were dead, no further contributions were made to the AUDPC.

The percentage of live plants that had ascochyta foot rot or downy mildew was calculated for each sowing date and fungicide treatment combination. These were analysed approximately using a binomial generalised linear model (McCullagh & Nelder 1989).

3.4.2 *Yield*

After the initial analyses for the yield were carried out using REML, the spatial structure (i.e. column structure) was found to be important, but adjustment of column differences had little effect on the results so the results of a simplified analysis (ignoring columns) using analysis of variance are presented. As before, all analyses were carried out using Genstat (GenStat Committee 2006).

3.4.3 *Plant emergence*

Plant emergence was calculated from the mean of the 2 counts per plot, with the mean converted into plants per m^2. Analyses were the same as those for yield.

4 *Results and discussion*

Several components of crop growth and disease development at the St Andrews field trial are presented in this section. Plant emergence (Section 4.1) is described first. A summary of ascochyta development is presented in Section 4.2 that draws together the main conclusions from this trial. Yield and the correlations between yield and disease measurements are described in Sections 4.3 and 4.4. The next section (4.5) describes the individual aspects of ascochyta blight in more detail, starting with the mean maximum ascochyta severity (Section 4.5.1), which is a measurement of the maximum disease severity for the treatment across all replicates and assessment dates. Area under the disease progress curve (Section 4.5.2), the amount of disease integrated between the start of the epidemic until the last disease assessment, is described next. This is followed by a description of ascochyta severity at the 8th assessment (Section 4.5.3), number of days from emergence to the time when ascochyta severity reached either 0 (Section 4.5.4) or 5% (Section 4.5.5), and descriptions of the detailed measurements carried out on 18 January (August and September sowing) or 7 February (October sowing) on pods and stems (Section 4.5.6). Finally, ascochyta foot rot and downy mildew and the presence of other diseases (Section 4.6) are described.

4.1 Plant emergence

There was a significant interaction between inoculation time and sowing date ($P = 0.04$), but fungicide treatment had little effect on plant emergence ($P > 0.5$ for the main effect of treatment and all interactions involving treatment). Plant numbers were similar for the 3 sowing dates for first inoculation (means of 116, 120 and 121 plants for August, September and October sowing respectively), but plant numbers increased with sowing date for the second inoculation (means of 110, 124 and 142 for August, September and October). This is in line with the usual situation where plant emergence increases with sowing date as soil temperature increases. Plant emergence in this trial was greater than in the 2005–06 trial when plant emergence varied from 33 to 93 plants/m^2 with a mean of 63.3 plants/m^2.

Table 3: Plant emergence (plants/m^2) for each sowing date, inoculation and fungicide treatment.

Sowing date	Inoculation	Nil	Full	A	B	C	D
August	1	110.0	107.8	101.1	140.0	123.3	115.6
	2	116.7	108.9	120.0	105.6	105.6	102.2
September	1	118.9	135.6	106.7	122.2	117.8	118.9
	2	123.3	116.7	117.8	134.4	133.3	120.0
October	1	122.2	118.9	124.4	130.0	108.9	121.1
	2	141.1	146.7	160.0	127.8	131.1	144.4
LSD 5% (df = 70)		36.1					

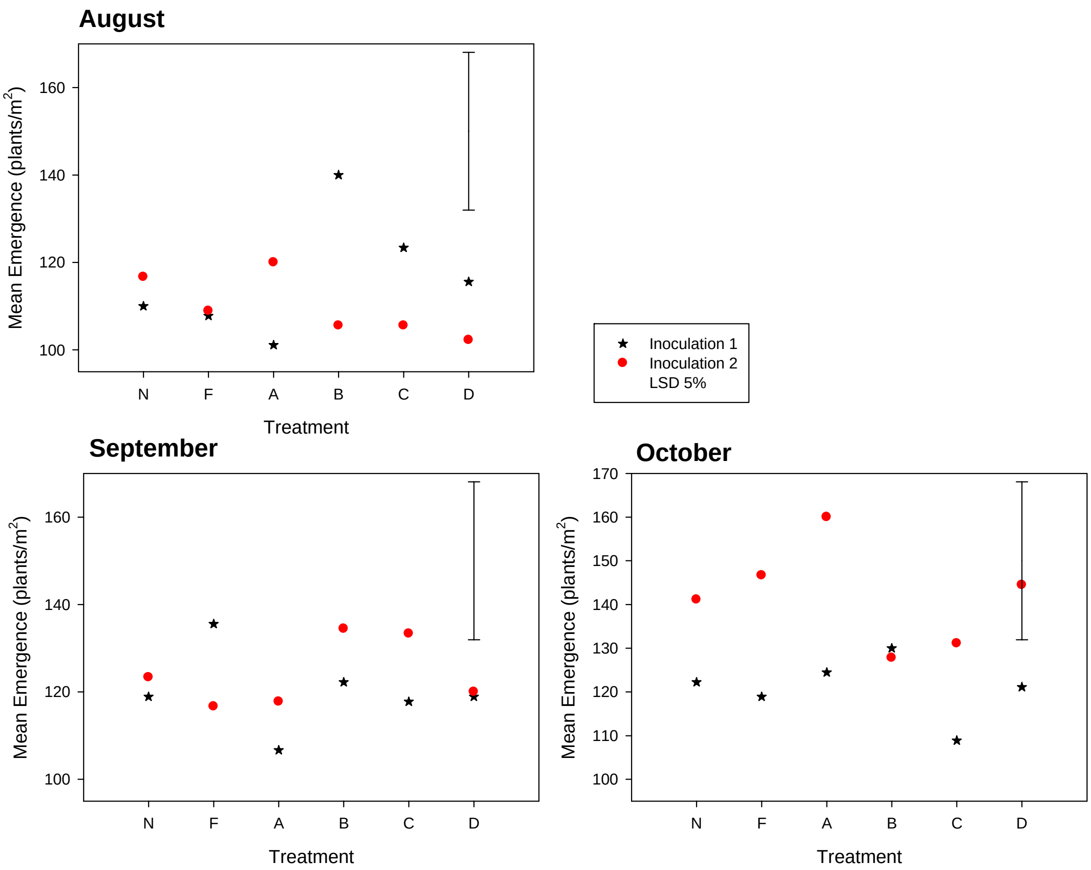

Figure 3: Mean emergence (plants/m^2) for each sowing date, inoculation and fungicide treatment.

4.2 Summary of ascochyta development

Ascochyta disease development was measured regularly during the growing season and analysed in various ways. The relevant research questions that we aimed to answer by completing the experiment were:

- How does timing of disease onset at different stages of crop growth influence crop yield?
- What crop stages are most important to protect with fungicide applications if ascochyta blight is present? Is there a critical threshold level of ascochyta severity when we need to commence fungicide applications in order to avoid yield losses?
- How do different levels of disease severity influence final crop yield?

Disease progress curves together with the individual disease and yield parameters were examined to answer these questions. Figures 4 and 5 show ascochyta development (percent disease severity) for each sowing date, inoculation and fungicide treatment over time. Figures 6 to 8 link ascochyta development with the mean daily temperature, total daily rainfall (irrigation), number of hours of leaf wetness for each day, fungicide application schedules, inoculation dates, growth stage and yields. In this report only the main trends are explored, much more detailed analysis of results from all trials over the 3-year project will be carried out as part of the extension to this project (Making peas pay – extension of outcomes to farmers) in 2007–08.

How does timing of disease onset at different stages of crop growth influence crop yield?

There were 6 different crop growth stages at which plants were inoculated: emergence, 4 nodes, 5 nodes, 8 nodes, enclosed bud and first open flower. In the untreated Nil treatments, the yields were 1.5, 3.3, 1.8, 5.6, 3.8 and 6.0 t/ha respectively. This indicates that timing of sowing was a more important factor in determining the final yield than the crop growth stage – the earlier the sowing the greater the yield. However, there was a small increase in yield as the crop matured (comparing the second inoculation with the first inoculation) within a sowing date, this increase was 0.4 t/ha in August sowing, 0.5 t/ha in September sowing and 0.3 t/ha in October sowing. This was most likely because plants that were inoculated first were exposed to the inoculum for longer and hence had greater disease levels, as determined by measurements of all of the individual disease indicators: mean maximum disease severity, AUDPC, disease severity at assessment 8, mean number of days from emergence to disease severity of more than 5%, ascochyta severity on pods and stems and level of foot rot.

What crop growth stages are the most important to protect with fungicide applications if ascochyta blight is present?

Results from last year indicated that growth stages from node 7 to early flower were the most critical stages to protect with fungicides, but it was possible that disease severity was a more important indicator than growth stage. The crop stages that were most important to protect with fungicide applications (i.e. had least disease and highest yields) in this trial varied, depending on the time of sowing. In the August sowing, treatments B, C and D were the highest yielding treatments (6.2–6.9 t/ha), but not the ones with least ascochyta blight. The corresponding growth stages when fungicide sprays were applied were from first open flower onwards. Treatment A, which started at an earlier growth stage of 8 nodes, had low levels of disease but lower yield than the other treatments, probably due to early senescence. In the September and October sowings the highest yielding treatments were C and D, but apart from inoculation 2 in the October sowing these were not the ones with lowest disease. These treatments were applied from early flower and flat pod (September sowing) or from 7th node and visible bud (October sowing). Treatments A and B resulted in greater amounts of ascochyta towards the end of the growing seasons and lower yields.

The results indicated that it was more important to protect the later growth stages with fungicides than the earlier ones.

Since crop growth stage did not appear to be a critical factor, was there a critical threshold level of ascochyta severity when we needed to commence fungicide applications in order to avoid high disease levels and yield losses? It appeared that the critical threshold levels were not consistent between treatments. In the August sowing, the first inoculation treatment B started before disease severity reached 5% and this treatment had low disease levels (AUDPC was 433) and one of the highest yields of 6.7 t/ha. In contrast, treatment C started when disease severity had reached nearly 10%, so disease levels were higher (AUDPC was 1067) but it did not seem to adversely affect the yield (6.9 t/ha). An early fungicide application (treatment A) started when there was just a trace of ascochyta, and had very low disease levels (AUDPC was 107) but yielded less than treatments B or C (6.1 t/ha), probably because of early senescence.

The epidemics that developed after the August second inoculation occurred later and had lower AUDPC values than those that developed after the first inoculation. On 4 December all treatments had less than 5% disease and all fungicide treatments, apart from treatment D, started prior to disease levels reaching 5%. Again treatment A yielded least but treatment B had low disease levels and yielded the second highest (6.8 t/ha) after the full treatment. Disease levels and yields of treatments C and D were similar although treatment D started later than treatment C, after disease severity had reached 8%.

The results of the September and October sowings also indicated that it was more important to protect the later growth stages with fungicides than the earlier ones.

How do different levels of disease severity influence final crop yield?

To determine how different levels of disease severity influenced final crop yield, correlations between yield and disease measurements were calculated. The main effect on yield was from the sowing date: the earlier the sowing date, the greater the yields. August sowing had the greatest yields (5.8–7.5 t/ha), followed by the September sowing (3.5–6.6 t/ha) and then the October sowing (1.6–4.8 t/ha). Yields varied with inoculation and treatment. The correlations between yield and disease measurements were strongly affected by the differing relationships between yield and disease variables for each of the different sowing dates. There was a reasonable correlation between yield and AUDPC for the September data and a moderate correlation for the October data with yield decreasing with increasing AUDPC. There were moderate to strong correlations between yield and pod and stem scores where yield decreased with increased ascochyta on stems and pods. The Full treatment always had the highest yield, and the Nil treatment had the lowest yields in most cases. However, for the other treatments, there was not a clearly identifiable level of ascochyta that corresponded with a decrease in yield, especially in the August sowing. In the September and October sowings, increasing ascochyta severity at the last assessment date corresponded with decreased final yield. These results will require further analysis.

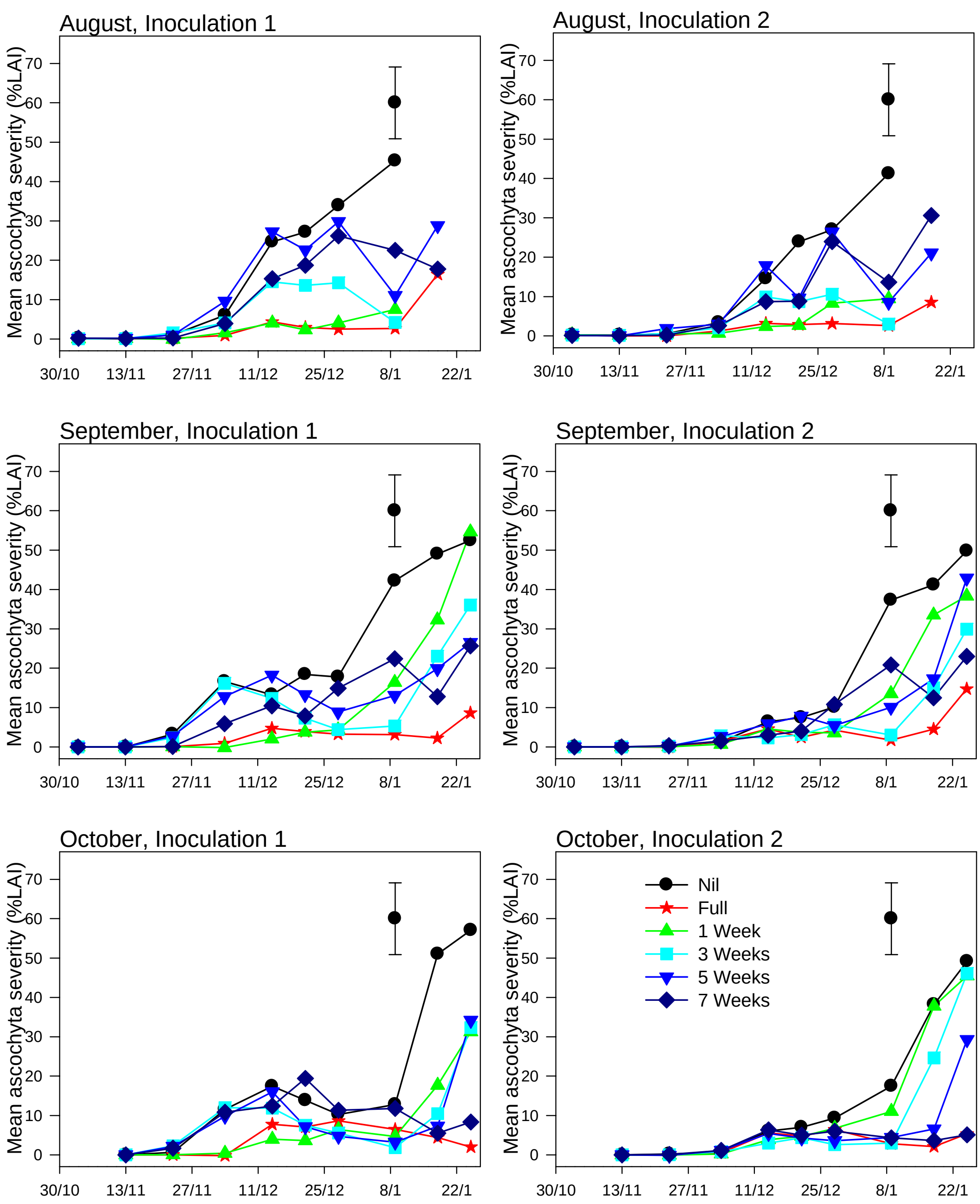

Figure 4: Ascochyta disease progress curves for each sowing date, inoculation and fungicide treatment

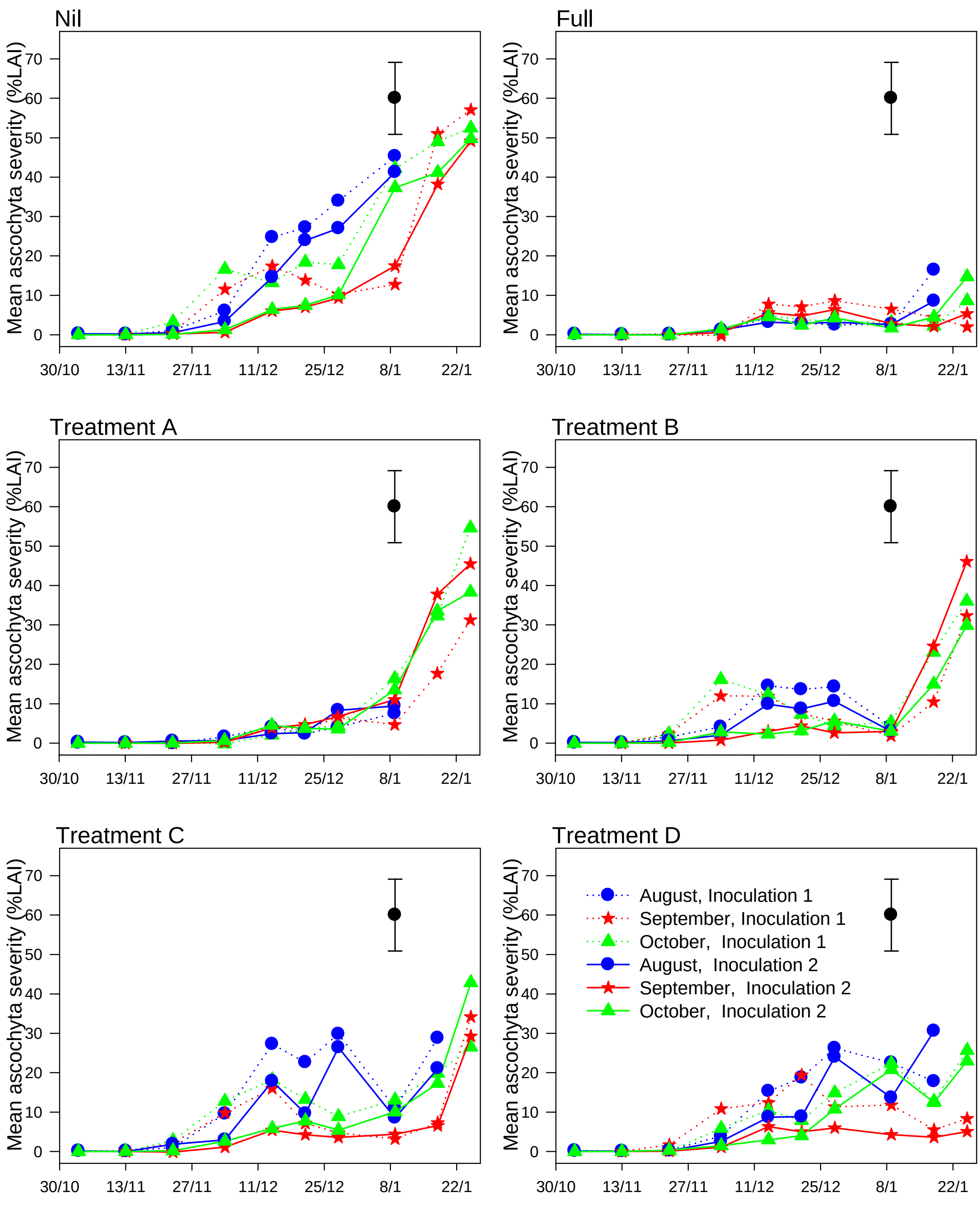

Figure 5: Ascochyta disease progress curves for each fungicide treatment, sowing date and inoculation.

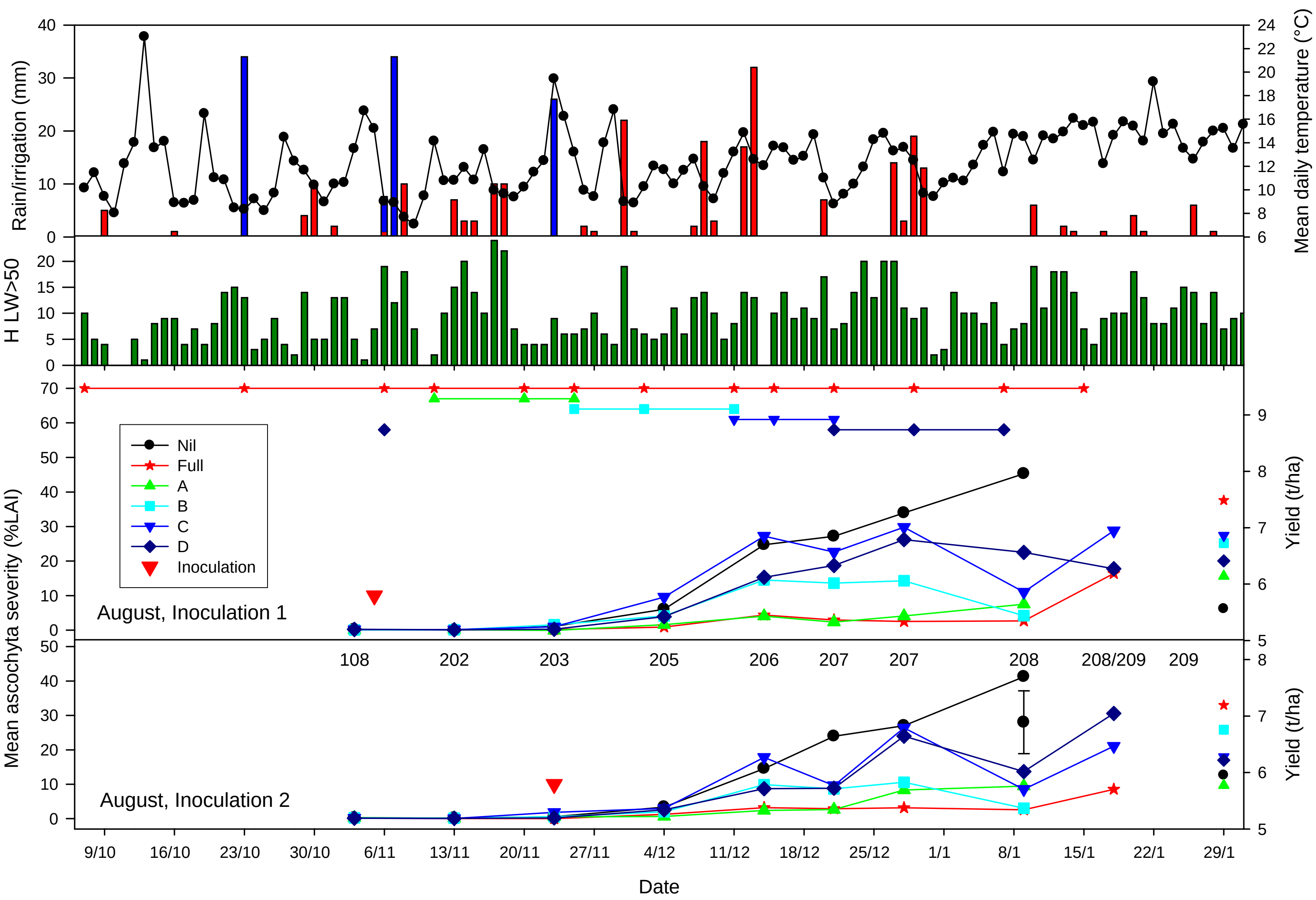

Figure 6: Ascochyta disease progress curves for August sowing for each fungicide treatment, related to total daily rainfall (red), irrigation (blue), mean temperature (black), number of hours when leaf wetness was more than 50%, fungicide schedule, inoculation, growth stage and final yield. 95% confidence limit is shown for all treatments for date 9/1/07, the confidence limits for the other dates were similar.

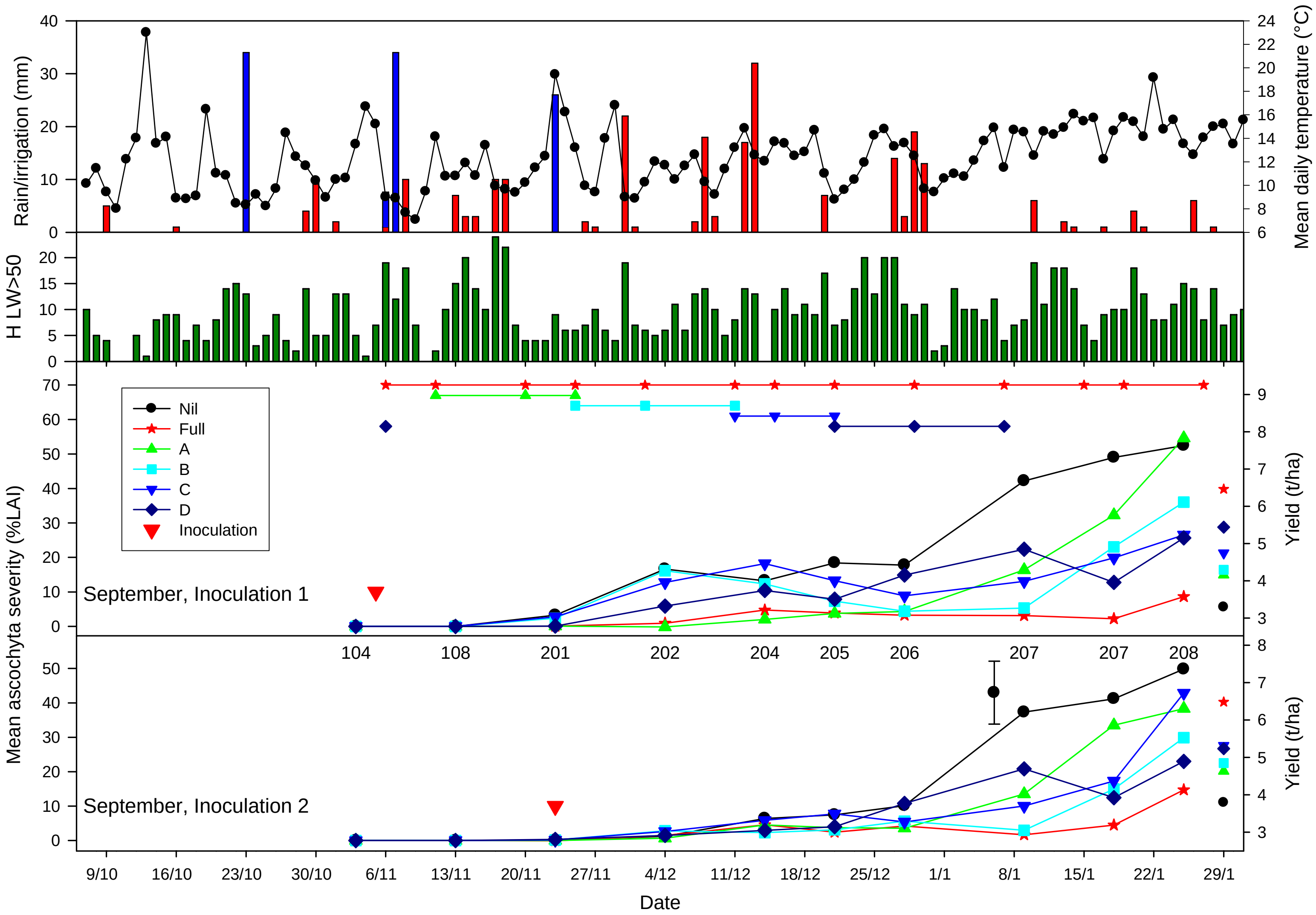

Figure 7: Ascochyta disease progress curves for September sowing for each fungicide treatment, related to total daily rainfall (red), irrigation (blue), mean temperature (black), number of hours when leaf wetness was more than 50%, fungicide schedule, inoculation, growth stage and final yield. 95% confidence limit is shown for all treatments for date 9/1/07, the confidence limits for the other dates were similar.

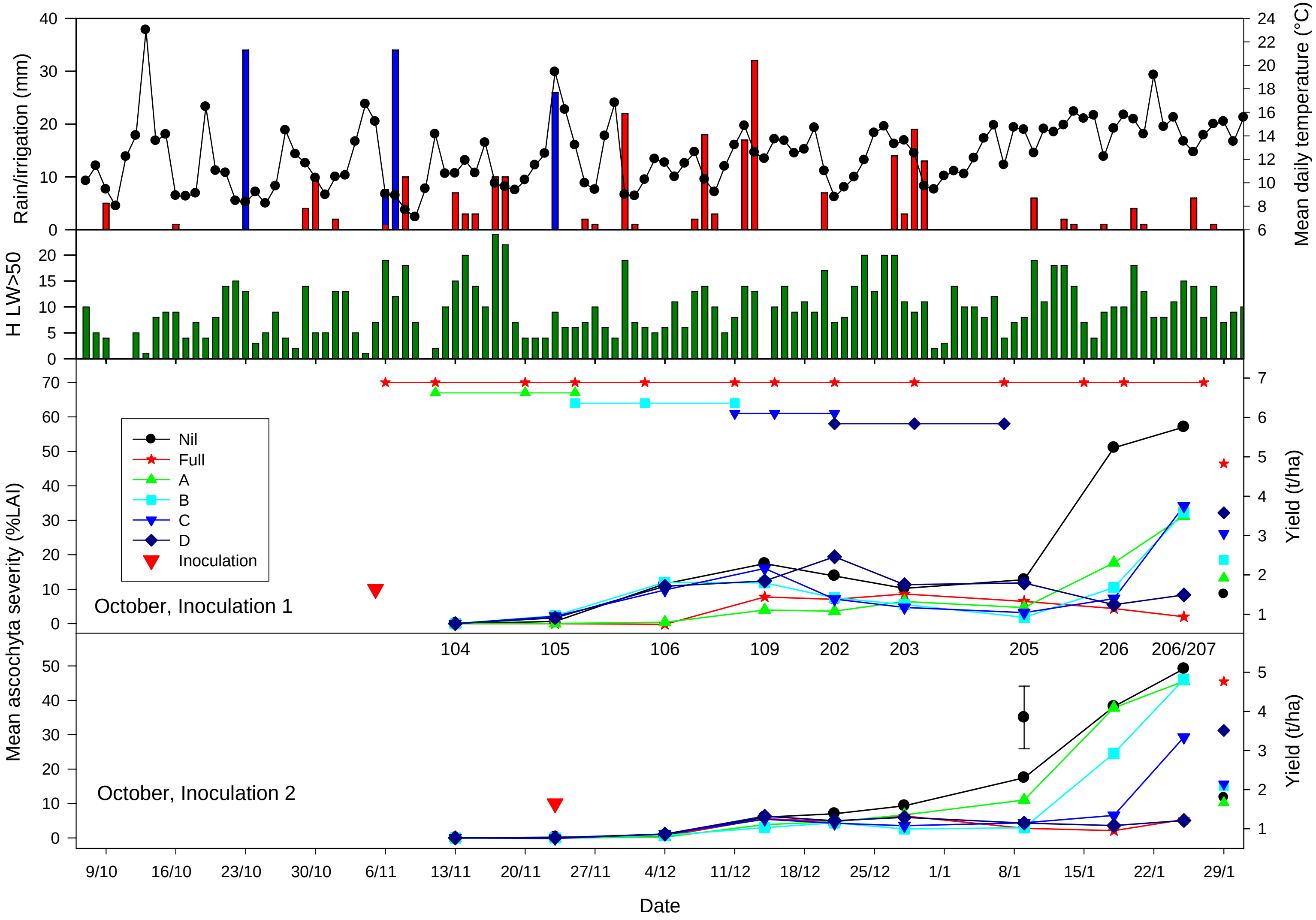

Figure 8: Ascochyta disease progress curves for October sowing for each fungicide treatment, related to total daily rainfall (red), irrigation (blue), mean temperature (black), number of hours when leaf wetness was more than 50%, fungicide schedule, inoculation, growth stage and final yield. 95% confidence limit is shown for all treatments for date 9/1/07, the confidence limits for the other dates were similar.

Table 4: Actual St Andrews weather station and long-term Timaru (1992–2002) means (LTM) for minimum and maximum temperature (°C) and total monthly rainfall (mm).

	Mean min. temp.		Mean max temp.		Total monthly rainfall	
	Actual	LTM	Actual	LTM	Actual	LTM
September	3.5	2.7	16.5	14.0	4	45.3
October	4.0	4.9	17.3	16.3	28	49.7
November	6.1	5.9	17.6	17.4	71	54.4
December	7.3	8.6	16.7	19.7	129	54.9
January	10.3	10	19.0	20.7	22	47.4

Figure 9: Plot 68 (August, second inoculation, Full treatment) surrounded by untreated buffer plots that appear brown due to severe ascochyta infection. Photo taken 18 January 2007.

4.3 *Yield*

Plot yields in this trial varied from 1.6 to 7.5 t/ha. There was a significant interaction between inoculation time, sowing date and treatment ($P < 0.001$) for yield (Figure 10). For any given treatment and inoculation time, yield was greatest for the August sowing date, followed by the September sowing, with yield least for the October sowing (Table 5). However, these differences in yield varied with both inoculation ($P = 0.029$ for the sowing date by inoculation interaction) and treatment ($P < 0.001$ for the sowing date x treatment interaction). Yields for the August and October sowing tended to be slightly lower with the second inoculation than with the first inoculation (by around 0.2 t/ha), whereas for the September sowing, yields tended to be greater with the second inoculation than with the first (by around 0.3 t/ha). There was slightly less difference in yields between sowing dates for the Full treatment and treatment D than for the other treatments. For the September and October sowing, yields tended to increase with spray timing (i.e. increased from treatment A to treatment D), with the greatest yield for the Full treatment and the least for the Nil. However, for the August sowing, only the Full treatment showed a substantial yield increase over the Nil treatment, with yields increasing only slightly for the other treatments: other than Full, yields were greatest for treatment B followed by treatment C.

Table 5: Yield (t/ha) for each sowing date, inoculation and fungicide treatment.

		Treatment					
Sowing date	Inoculation	Nil	Full	A	B	C	D
August	1	5.67	7.54	6.14	6.75	6.71	6.38
	2	5.89	7.26	5.80	6.76	6.31	6.14
September	1	3.45	6.45	4.07	4.15	4.87	5.41
	2	3.71	6.55	4.66	4.91	5.17	5.31
October	1	1.64	4.78	1.74	2.56	2.87	3.67
	2	1.98	4.58	1.76	1.92	2.32	3.42
Lsd 5% (df = 70)		0.75					

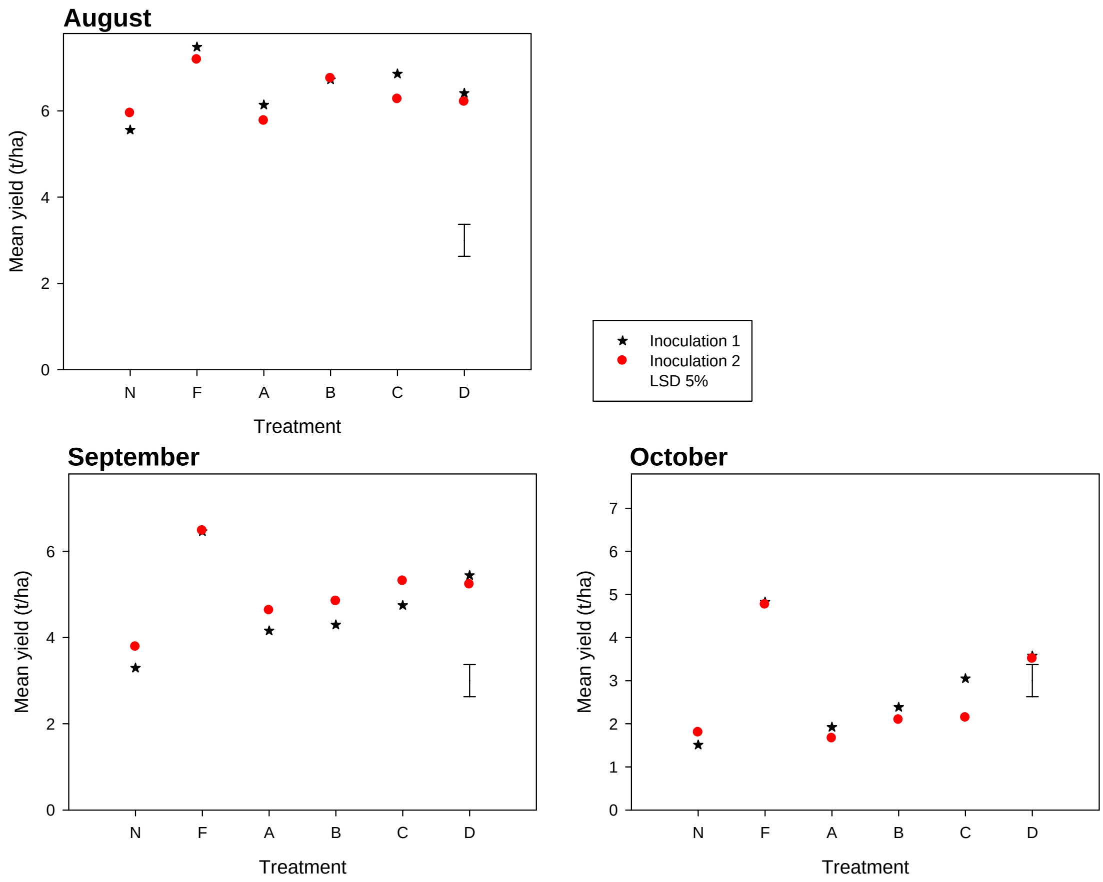

Figure 10: Mean yield (t/ha) for each sowing date, inoculation and fungicide treatment.

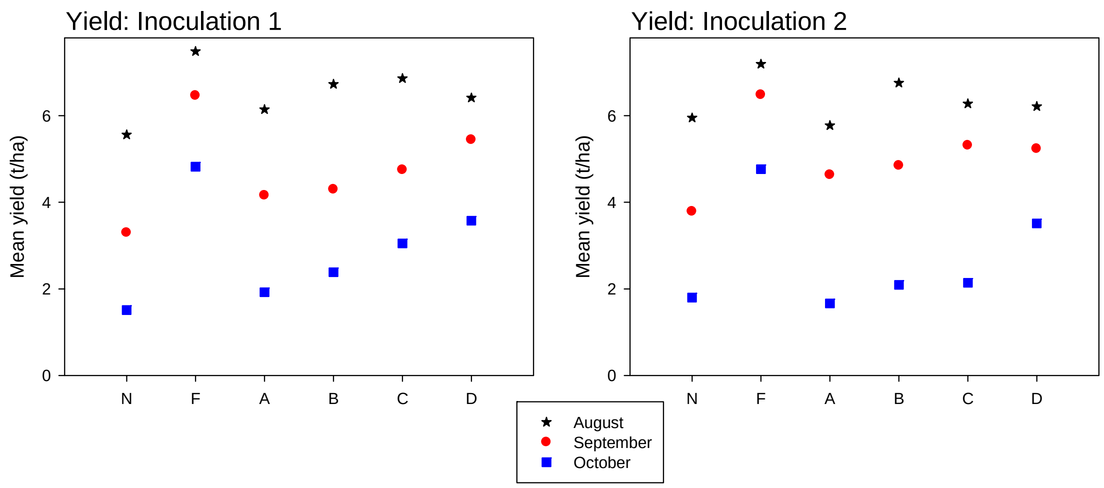

Figure 11: Mean yield (t/ha) for each inoculation, sowing date and fungicide treatment.

4.4 Comparison between yield and disease measurements

Tables 6–10 show the correlation between the plot yields and the mean plot value for several of the disease measurements, both for all data and for data from each sowing date separately. The overall correlations were strongly affected by the differing relationships between yield and the disease variables for each of the different sowing dates (Figure 12), and were thus not particularly useful. The high correlation with date0 was mostly due to the overall difference in yields between the sowing dates and a similar difference for the date0: the relationship vanished for individual sowing dates. Conversely, the apparent lack of relationship between yield and AUDPC for the whole dataset masked reasonable relationships found for the September data, and a moderate correlation for the October data where yield tended to decrease with increasing AUDPC. There were moderate to strong relationships between yield and the final pod and stem scores, with yields tending to decrease with increasing disease. Correlations between yield and maximum disease were also quite strong for the September and October sowing dates, but the correlation for August was quite weak.

Table 6: Correlations between yield and ascochyta mean severity plot values, for all data and for data from each sowing date separately.

	All data	August	September	October
Pod score	-0.77	-0.49	-0.58	-0.85
Stem score	-0.70	-0.54	-0.69	-0.88
Max disease	-0.51	-0.34	-0.72	-0.80
AUDPC	-0.19	-0.36	-0.68	-0.50
Penultimate disease	0.03	-0.49	-0.45	-0.24
Date0	-0.80	*	-0.10	-0.06
Date5	0.07	0.25	0.50	-0.07

*All date0 were the same for the August sowing.

Table 7: Correlations between mean plot values: all sowing dates

Weight t/ha	1.00							
Pod score	-0.77	1.00						
Stem score	-0.70	0.92	1.00					
Max disease	-0.51	0.53	0.61	1.00				
AUDPC	-0.19	0.26	0.42	0.74	1.00			
Penultimate disease	0.03	0.06	0.24	0.53	0.80	1.00		
Date0	-0.80	0.51	0.39	0.22	-0.09	-0.23	1.00	
Date5	0.07	-0.11	-0.22	-0.32	-0.67	-0.39	0.06	1.00
	Weight t/ha	Pod score	Stem score	Max. disease	AUDPC	Penult. dis	Date0	Date5

Table 8: Correlations between mean plot values: August sowing.

Weight t/ha	1.00							
Pod score	-0.49	1.00						
Stem score	-0.54	0.79	1.00					
Max disease	-0.34	0.38	0.66	1.00				
AUDPC	-0.36	0.39	0.66	0.94	1.00			
Penultimate disease	-0.49	0.64	0.84	0.81	0.80	1.00		
Date0	*	*	*	*	*	*	1.00	
Date5	0.25	-0.25	-0.52	-0.69	-0.77	-0.43	*	1.00
	Weight t/ha	Pod score	Stem score	Max. disease	AUDPC	Penult. dis	Date0	Date5

*All date0 were the same for the August sowing.

Table 9: Correlations between mean plot values: September sowing.

Weight t/ha	1.00							
Pod score	-0.58	1.00						
Stem score	-0.69	0.92	1.00					
Max disease	-0.72	0.46	0.55	1.00				
AUDPC	-0.68	0.61	0.65	0.70	1.00			
Penultimate disease	-0.45	0.56	0.57	0.62	0.86	1.00		
Date0	-0.10	-0.11	-0.02	0.07	-0.04	-0.12	1.00	
Date5	0.50	-0.33	-0.41	-0.37	-0.76	-0.52	-0.14	1.00
	Weight t/ha	Pod score	Stem score	Max. disease	AUDPC	Penult. dis	Date0	Date5

Table 10: Correlations between mean plot values: October sowing.

Weight t/ha	1.00							
Pod score	-0.85	1.00						
Stem score	-0.88	0.94	1.00					
Max disease	-0.80	0.88	0.87	1.00				
AUDPC	-0.50	0.62	0.66	0.77	1.00			
Penultimate disease	-0.24	0.29	0.32	0.44	0.72	1.00		
Date0	-0.06	0.15	0.16	0.02	-0.12	0.01	1.00	
Date5	-0.07	-0.04	-0.01	-0.16	-0.57	-0.32	0.15	1.00
	Weight t/ha	Pod score	Stem score	Max. disease	AUDPC	Penult. dis	Date0	Date5

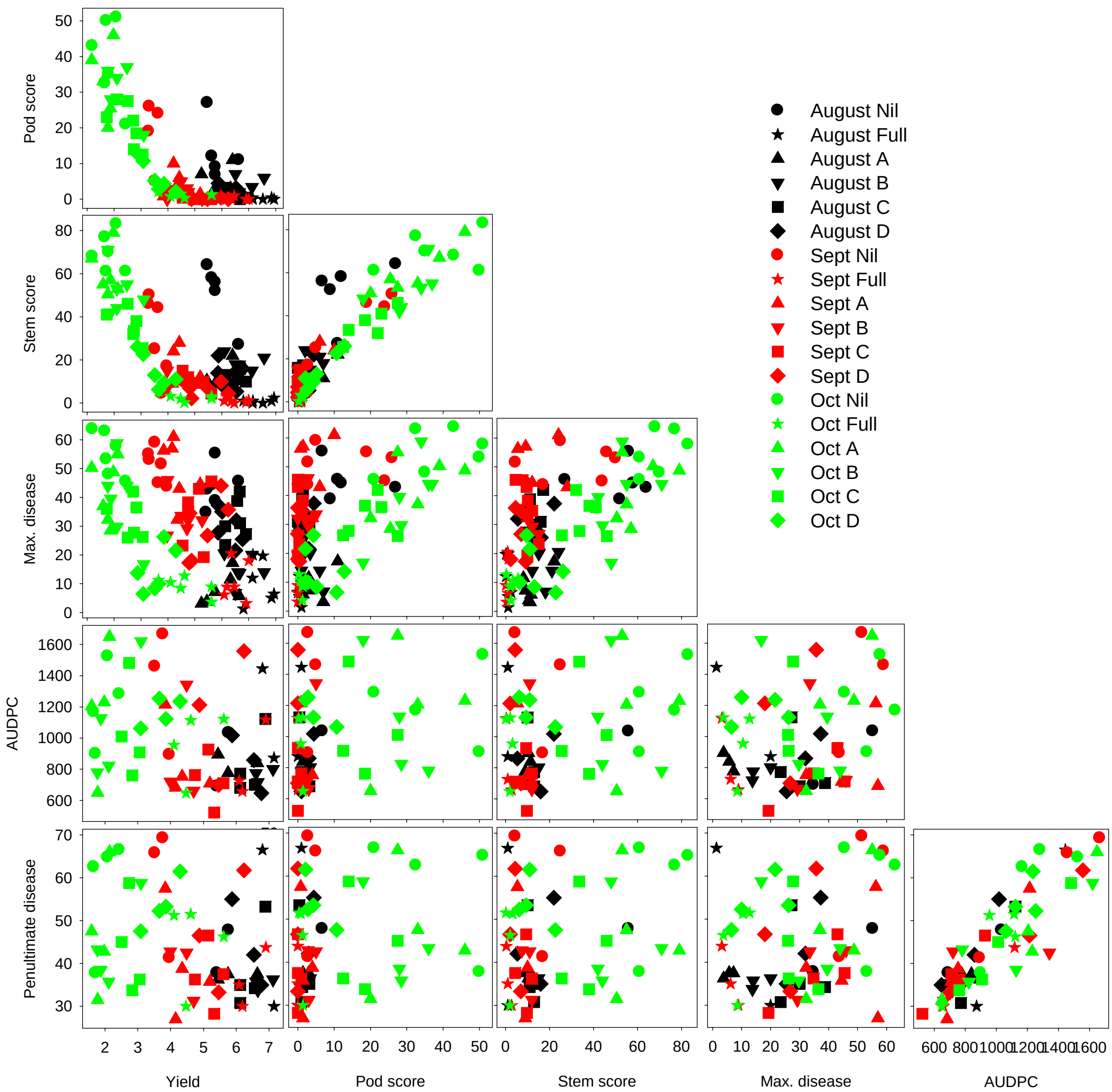

Figure 12: Correlations between yield and ascochyta mean severity plot values for each sowing date and fungicide treatment.

4.5 Ascochyta blight measurements

4.5.1 Maximum ascochyta severity

The greatest mean maximum ascochyta (i.e. maximum disease severity for the plot over all disease assessment dates) was found on the Nil plots (from 42 to 62%), although maximum disease levels in treatment A were similar in the Nil plots for the September sowing first inoculation, and for the October sowing second inoculation (Table 11, Figure 13). For the August sowing, maximum disease levels tended to decrease with the time of spraying from A to D (Figure 13). Differences between the sowing dates varied substantially for treatment A, both inoculations, and for treatment B, second inoculation. Maximum disease was much less for treatment A for the August sowing than for either the September or October sowing. With the first inoculation, maximum disease was greater for the September sowing with treatment A than for the October sowing, whilst the reverse was true for the second inoculation (Figure 14). There was a similar pattern for treatment B, except that the differences were not as great. Differences between sowing dates were not significant for treatments C and D for the first inoculation, but there were some differences for the second inoculation.

Table 11: Mean maximum ascochyta blight severity (% leaf area infected) for each sowing date, inoculation and fungicide treatment.

		Treatment					
Sowing date	Inoculation	Nil	Full	A	B	C	D
August	1	45.6	15.4	7.0	16.2	36.0	28.1
	2	41.5	6.1	9.2	13.5	28.2	31.6
September	1	53.2	10.0	58.1	35.4	25.7	29.3
	2	49.2	12.0	39.9	31.1	42.2	29.4
October	1	61.5	10.8	32.6	30.2	34.9	20.5
	2	48.9	7.8	51.3	47.4	29.9	8.3
Lsd 5% (df = 70)		11.2					

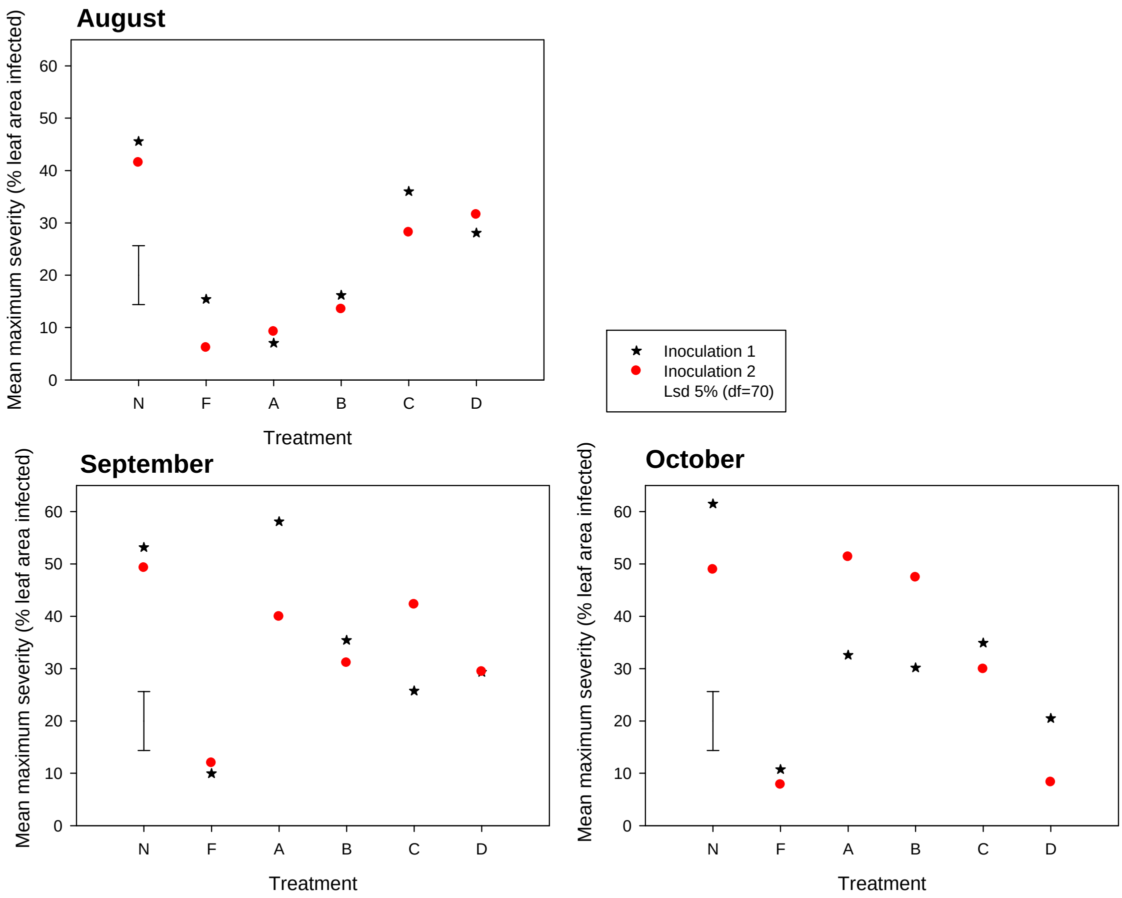

Figure 13: Mean maximum ascochyta blight severity (% leaf area infected) for each sowing date, inoculation and fungicide treatment.

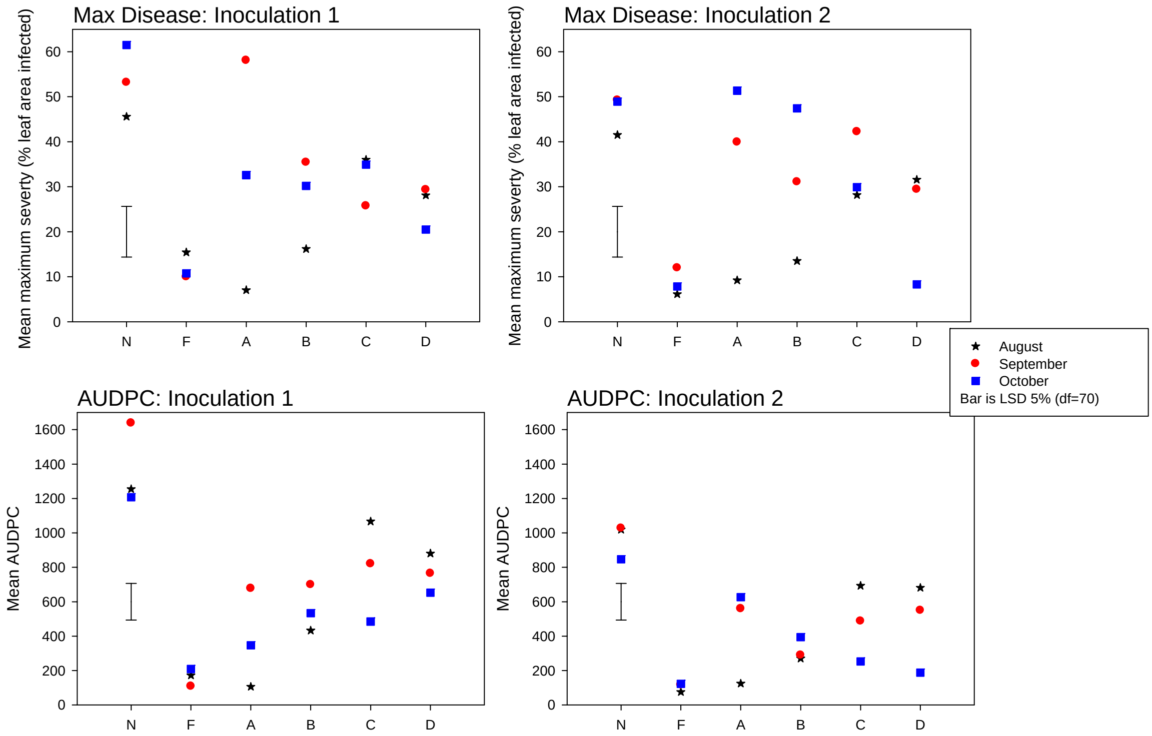

Figure 14: Mean maximum ascochyta blight severity (% leaf area infected) and area under the disease progress curve (AUDPC) for each inoculation, sowing date and fungicide treatment.

4.5.2 Area under the disease progress curve

Area under the disease progress curve is the amount of disease integrated between the start of the epidemic until the last disease assessment. It is a summary variable often used to represent the profile of disease observations in each plot. In this trial, AUDPC was greater for the Nil treatment (it varied from 847 to 1638) than for all other treatments (Table 12, Figure 15). AUDPC was lowest for the Full treatment, although AUDPC for treatment A for the August sowing was similar to the Full treatment for both inoculation times.

Table 12: Mean area under the disease progress curve for each sowing date, inoculation and fungicide treatment.

		Treatment					
Sowing date	Inoculation	Nil	Full	A	B	C	D
August	1	1254.7	172.0	106.5	432.6	1066.9	880.8
	2	1019.3	75.6	124.8	270.6	693.0	681.3
September	1	1638.4	108.6	677.2	699.7	820.9	764.5
	2	1027.5	116.8	559.9	289.4	487.5	550.1
October	1	1206.9	208.8	346.7	533.4	484.6	652.5
	2	846.6	123.3	627.0	394.3	252.9	187.5
Lsd 5% (df = 70)		212.8					

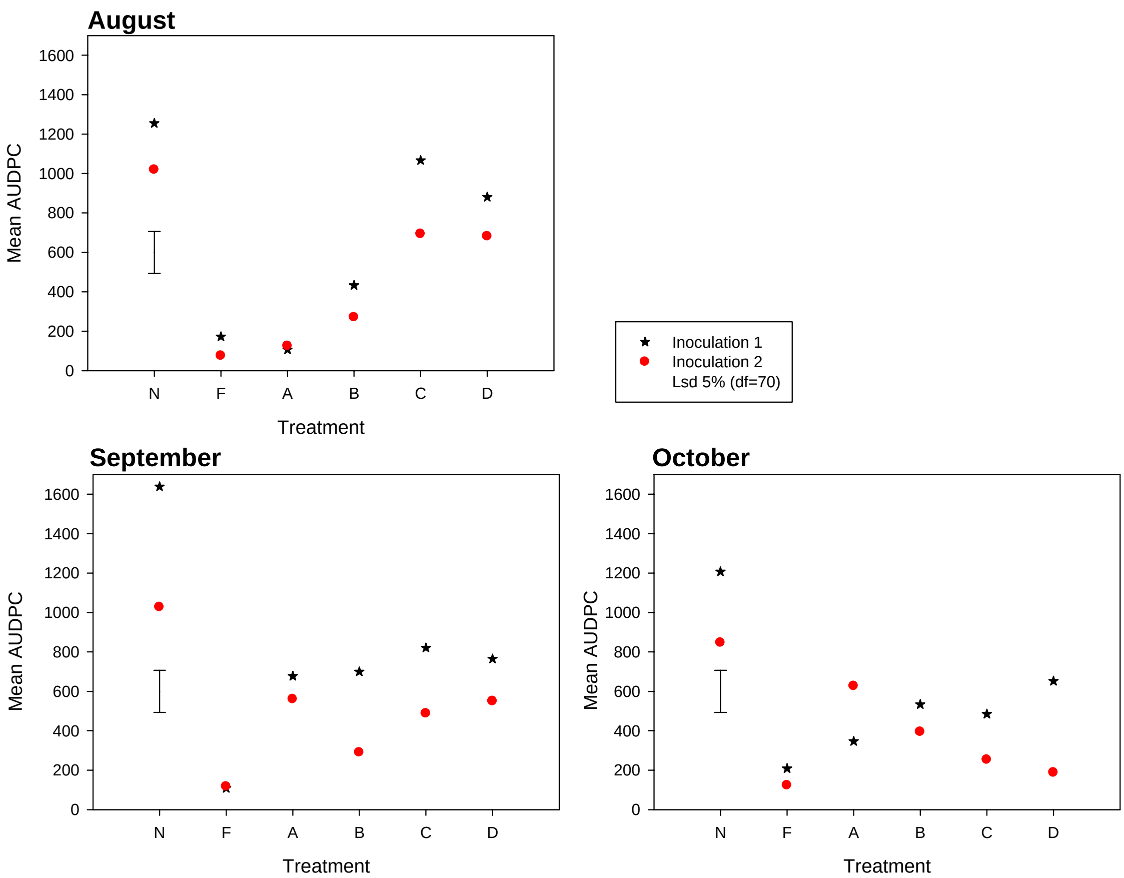

Figure 15: Mean area under the disease progress curve (AUDPC) for each sowing date, inoculation, and fungicide treatment.

4.5.3 *Ascochyta severity at assessment 8 on 9 January 2007*

At assessment 8, the August-sown plots were at green wrinkled pod stage, September-sown plots at pod fill and October-sown plots at flat pod stage. This was the last assessment when all the plots still had live plants. At this assessment for a given inoculation time and sowing dates, mean ascochyta severity levels were highest for the Nil treatment, although not significantly so in all cases (Table 13, Figure 16). The difference in severity between Nil and other treatments was greatest in the August-sown plots, where Nil plots had severities of above 42% and the other treatments had severities between 0.9 and 22.4%. Mean disease levels for the Full treatment were all below 4% (Table 13). Treatment B had mean disease levels that were similarly low (Figure 16) for all sowing dates. On the other plots, mean disease tended to be less for the October sowing than for the other sowings, and disease tended to be highest for the September sowing.

Table 13: Mean ascochyta severity (% leaf area infected) at assessment 8 for each sowing date, inoculation and fungicide treatment.

		Treatment					
Sowing date	Inoculation	Nil	Full	A	B	C	D
August	1	45.6	1.0	7.0	2.9	11.1	22.4
	2	41.5	0.9	8.1	1.4	8.3	13.5
September	1	43.1	1.6	16.2	3.2	12.3	22.8
	2	37.2	0.6	12.7	1.2	8.5	21.4
October	1	12.2	3.2	4.0	1.3	1.3	10.8
	2	18.0	0.5	9.8	0.3	2.8	3.4
Lsd 5% (df=70)		10.8					

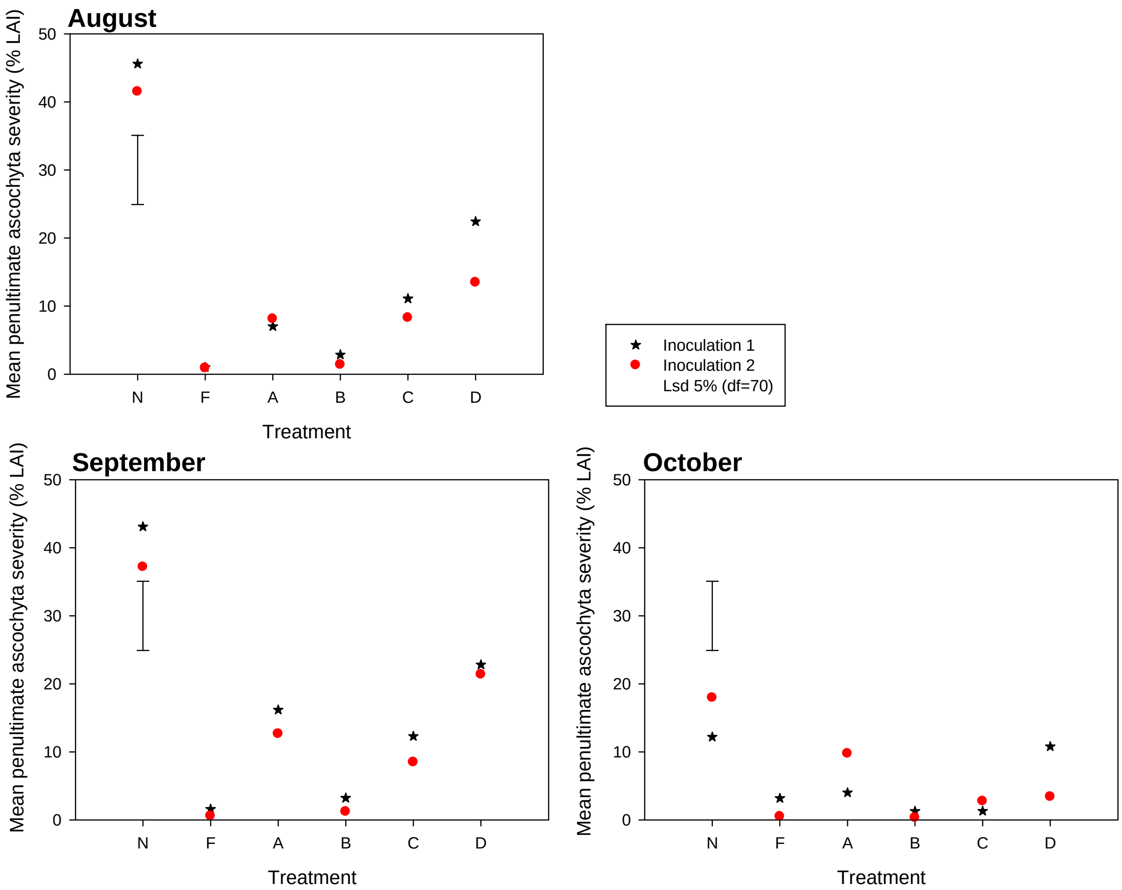

Figure 16: Mean ascochyta severity (% leaf area infected) at assessment 8 for each sowing date, inoculation and fungicide treatment.

4.5.4 Number of days from emergence to ascochyta severity above 0%

The mean number of days from emergence to when ascochyta blight severity was more than 0% mainly varied with sowing date ($P < 0.001$), partly reflecting the different emergence and inoculation times, but also because the disease appeared earlier in the earlier sown crops (3 November 2006 for August, 13–18 November for September and 23–30 November for October sowing date; Table 14, Figure 17). August-sown plots had low levels of ascochyta already before the first inoculation on 5 November, confirming that low levels of background inoculum were around. When disease first reached above 0%, the August sowing was at the 8th node stage, while September sowing was only at a 4 node stage and October sowing had not emerged. For the October sowing, the disease was observed in treatment A last (30 November 2006); in the Full plots and Nil, second inoculation slightly earlier (26 November 2006); and in all other treatments on 23 November (Table 15).

Table 14: Mean number of days from emergence to ascochyta blight severity (% leaf area infected) of more than 0% for each sowing date, inoculation and fungicide treatment.

		Treatment					
Sowing date	Inoculation	Nil	Full	A	B	C	D
August	1	51.0	51.0	51.0	51.0	51.0	51.0
	2	51.0	51.0	51.0	51.0	51.0	51.0
September	1	31.0	34.3	37.7	34.3	37.7	31.0
	2	31.0	31.0	31.0	31.0	31.0	34.3
October	1	19.0	22.7	26.3	19.0	19.0	19.0
	2	22.7	22.7	26.3	19.0	19.0	19.0
Lsd 5% (df=70)		4.9					

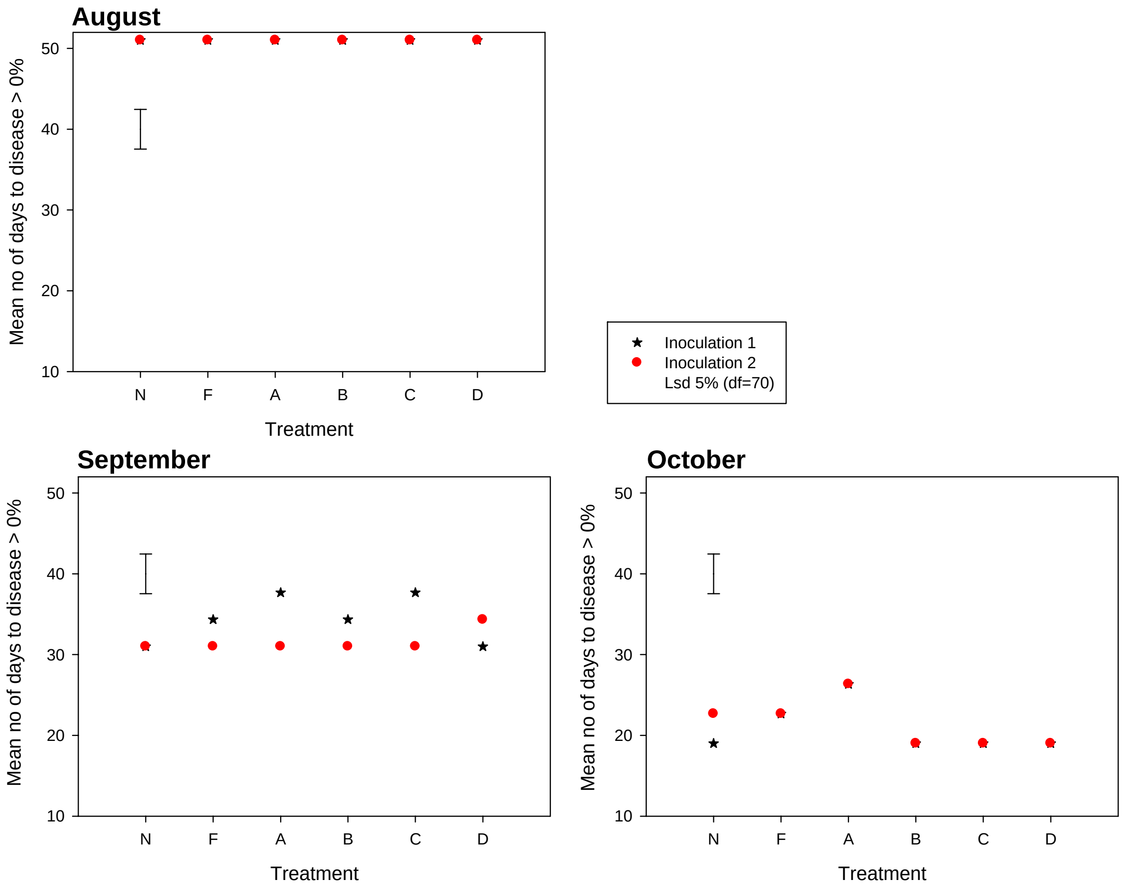

Figure 17: Mean number of days from emergence to ascochyta blight severity (% leaf area infected) of more than 0% for each sowing date, inoculation and fungicide treatment.

Table 15: Mean date when ascochyta blight was more than 0% for each sowing date, inoculation and fungicide treatment.

		Treatment					
Sowing date	Inoculation	Nil	Full	A	B	C	D
August	1	03/11/06	03/11/06	03/11/06	03/11/06	03/11/06	03/11/06
	2	03/11/06	03/11/06	03/11/06	03/11/06	03/11/06	03/11/06
September	1	13/11/06	16/11/06	19/11/06	16/11/06	19/11/06	13/11/06
	2	13/11/06	13/11/06	13/11/06	13/11/06	13/11/06	16/11/06
October	1	23/11/06	26/11/06	30/11/06	23/11/06	23/11/06	23/11/06
	2	26/11/06	26/11/06	30/11/06	23/11/06	23/11/06	23/11/06

4.5.5 Number of days from emergence to ascochyta severity above 5%

There was more variation in the number of days until ascochyta severity reached more than 5% than for the time until the disease first appeared (Table 16, Figure 18). Ascochyta levels reached 5% last for the Full treatment for the August and September sowings, but for the October sowing disease above 5% appeared last for treatment A for the first inoculation and last for treatments C and D for the second inoculation. Disease levels above 5% were observed first for the October sowing in the Nil plots and (first inoculation) treatment D (Table 17).

Table 16: Mean number of days from emergence to disease severity (% leaf area infected) of more than 5% for each sowing date, inoculation and fungicide treatment.

		Treatment					
Sowing date	Inoculation	Nil	Full	A	B	C	D
August	1	85.3	127.0	123.3	88.7	82.0	92.0
	2	92.0	129.3	119.3	92.0	88.7	94.3
September	1	52.0	104.0	84.0	55.3	52.0	57.7
	2	75.3	101.7	88.0	99.3	79.3	76.0
October	1	30.0	44.7	72.0	33.3	33.3	30.0
	2	47.0	68.0	53.3	75.0	74.3	58.7
Lsd 5% (df = 70)		13.4					

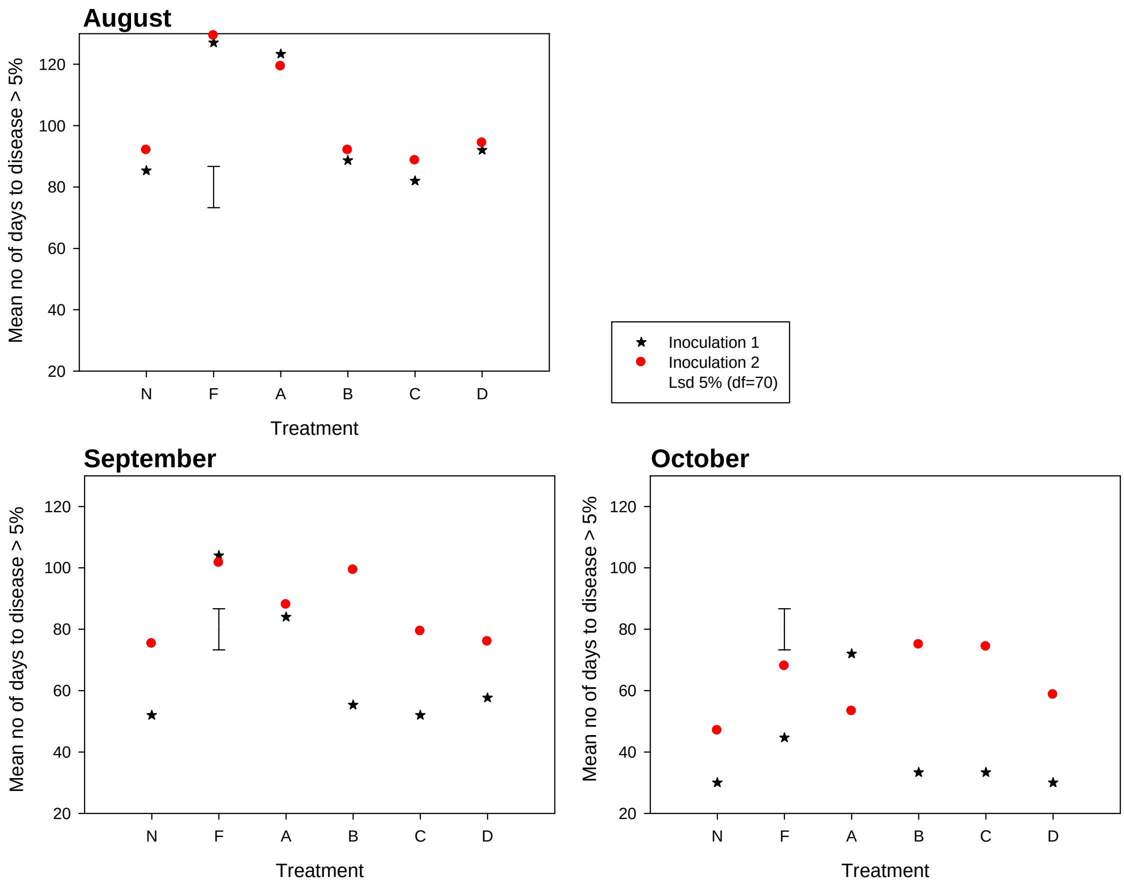

Figure 18: Mean number of days from emergence to ascochyta blight severity (% leaf area infected) of more than 5% for each sowing date, inoculation and fungicide treatment.

Table 17: Mean date when ascochyta severity (% leaf area infected) reached more than 5% for each sowing date, inoculation and fungicide treatment.

		Treatment					
Sowing date	Inoculation	Nil	Full	A	B	C	D
August	1	07/12/06	17/01/07	14/01/07	10/12/06	04/12/06	13/12/06
	2	14/12/06	20/01/07	10/01/07	14/12/06	10/12/06	16/12/06
September	1	04/12/06	25/01/07	05/01/07	07/12/06	04/12/06	09/12/06
	2	27/12/06	22/01/07	09/01/07	20/01/07	31/12/06	28/12/06
October	1	04/12/06	18/12/06	15/01/07	07/12/06	07/12/06	04/12/06
	2	26/11/06	26/11/06	30/11/06	23/11/06	23/11/06	23/11/06

4.5.6 *Ascochyta blight severity on pods and stems*

Detailed ascochyta severity assessments on pods and stems were carried out on 18 January (August and September sowing) or 7 February 2007 (October sowing). Plants were then at growth stage green/yellow wrinkled pod (August), or pod fill (September and October sowings). Patterns of ascochyta severities were similar in stems and pods (Tables 18–19, Figures 19–20). Inoculation time only had a significant effect for treatments A (greater severity in second than first inoculation) and Nil (greater severity in first than second inoculation). For the other treatments, the time of inoculation made on average less than 3% difference in disease.

For treatment D, which varied between the October and August/September sowings, there was little difference between the August and September sowings. For the remaining 5 treatments, there was a significant interaction (P < 0.001) between sowing date and treatment, indicating that the differences between the treatments varied between sowing dates. The Full fungicide treatment controlled disease very well on pods and stems (means all below 2%), with no difference between sowing dates. For the other 4 treatments, ascochyta was noticeably greater for the October sowing than for the August and September sowings. This suggests that younger plants (October sowing) were more susceptible to ascochyta than plants that were older (August and September sowing).

Table 18: Final ascochyta blight severity (% area infected) on pods for each sowing date, inoculation and fungicide treatment.

		Treatment					
Sowing date	Inoculation	Nil	Full	A	B	C	D
August	1	14.3	0.0	0.8	3.0	1.0	2.8
	2	10.1	0.6	7.0	3.8	1.4	1.7
September	1	15.9	0.0	4.1	2.6	0.5	0.3
	2	10.6	0.3	3.8	1.7	0.5	0.3
October	1	42.2	0.8	26.2	27.8	17.7	6.4
	2	35.3	1.6	37.5	32.7	21.5	6.2
Lsd 5% (df = 67)							
August or September		10.9					
October		7.7					
October vs August or September		9.4					

Table 19: Final ascochyta blight severity (% area infected) on stems for each sowing date, inoculation and fungicide treatment.

		Treatment					
Sowing date	Inoculation	Nil	Full	A	B	C	D
August	1	57.3	1.1	9.9	19.0	12.7	17.5
	2	41.6	0.7	14.0	15.6	13.9	9.3
September	1	33.5	0.7	12.8	11.1	12.3	8.7
	2	28.7	1.3	16.7	10.7	7.9	4.5
October	1	76.0	2.1	54.2	49.0	31.8	15.5
	2	64.0	3.2	66.3	55.3	40.2	14.0
Lsd 5% (df = 68)							
August or September		14.5					
October		10.3					
October vs August or September		12.6					

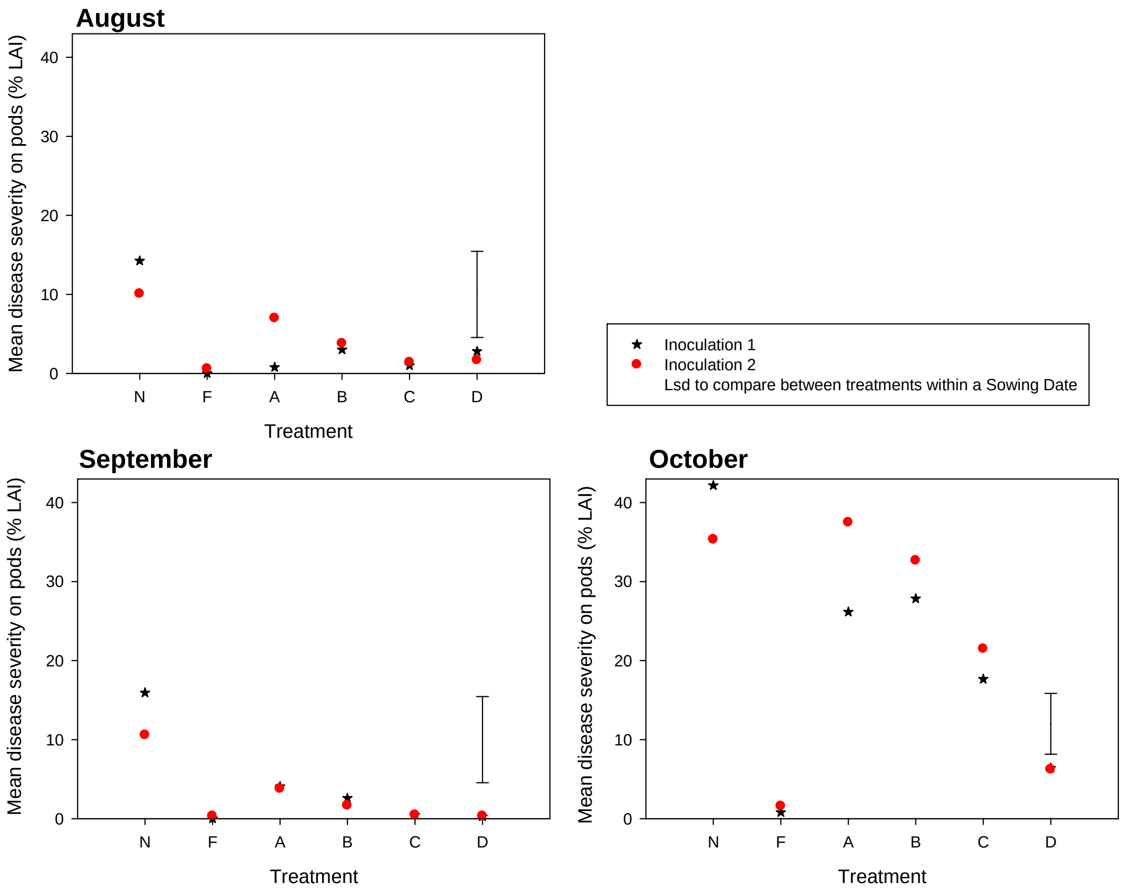

Figure 19: Mean final ascochyta blight severity (% leaf area infected) on pods for each sowing date, inoculation and fungicide treatment.

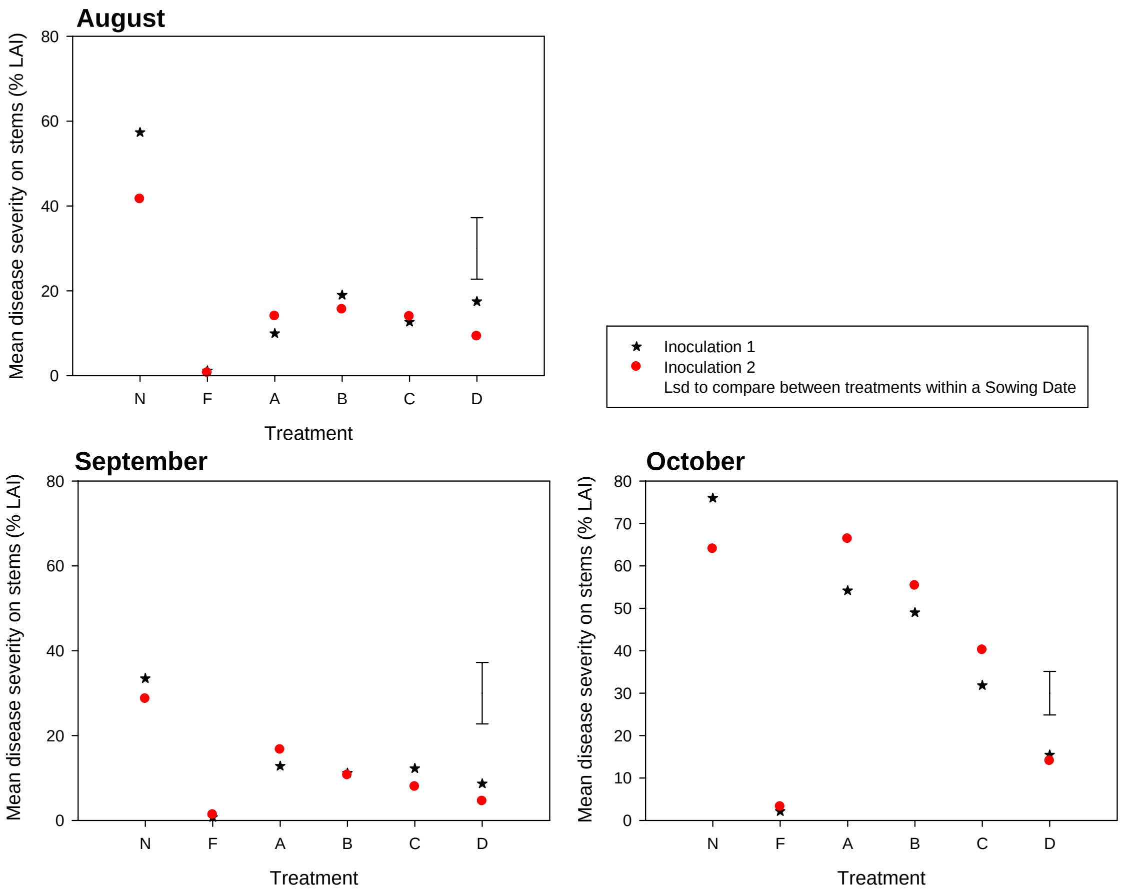

Figure 20: Mean final ascochyta blight severity (% leaf area infected) on stems for each sowing date, inoculation and fungicide treatment.

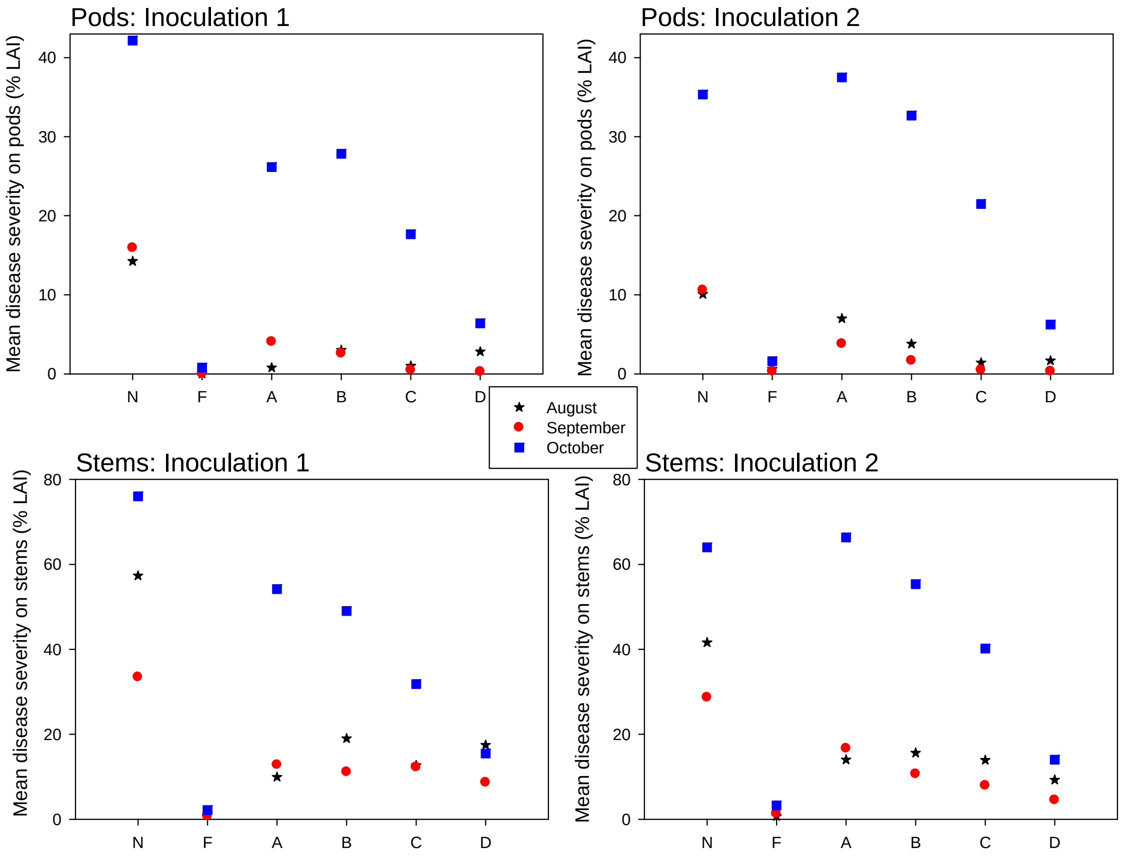

Figure 21: Mean final disease severity on pods and stems for each inoculation, sowing date and fungicide treatment.

4.6 *Ascochyta foot rot and other diseases*

Downy mildew (Figure 22) and ascochyta foot rot severity were also assessed when the detailed assessments were carried out on 18 January 2007 (August and September sowings) or 7 February 2007 (October sowing). There were significant interactions between sowing date, inoculation and the fungicide treatments ($P < 0.05$) for ascochyta foot rot, with no clear patterns (Table 20, Figure 23). Plots with the Full treatment had the least foot rot infection, with little difference between the sowing dates or inoculation times. Nil plots had the most infection for first inoculation, but this was not the case for the second inoculation (Table 21, Figure 24).

Figure 22: Pea plant affected by systemic downy mildew infection caused by Peronospora viciaei.

Table 20: Percentage of live plants with ascochyta foot rot for each sowing date, inoculation and fungicide treatment.

		Treatment					
Sowing date	Inoculation	Nil	Full	A	B	C	D
August	1	100.0	13.3	73.3	93.3	93.3	100.0
	2	60.0	6.7	80.0	66.7	100.0	93.3
September	1	93.3	0.0	40.0	53.3	73.3	86.7
	2	86.7	6.7	53.3	73.3	60.0	86.7
October	1	96.7	3.3	86.7	96.7	80.0	90.0
	2	90.0	16.7	100.0	96.7	93.3	76.7

As for ascochyta foot rot, there were significant interactions between sowing date, inoculation and the fungicide treatments ($P < 0.05$) for percentage of plants infected with downy mildew, with no clear patterns (Table 21, Figure 24). There was slightly less downy mildew in the August sowing than in the other two sowing dates.

Table 21: Percentage of live plants infected with downy mildew for each sowing date, inoculation and fungicide treatment.

		Treatment					
Sowing date	Inoculation	Nil	Full	A	B	C	D
August	1	80.0	46.7	46.7	46.7	53.3	60.0
	2	66.7	40.0	73.3	33.3	73.3	100.0
September	1	100.0	66.7	93.3	93.3	86.7	93.3
	2	93.3	66.7	100.0	86.7	80.0	93.3
October	1	93.3	80.0	100.0	90.0	100.0	93.3
	2	90.0	96.7	96.7	90.0	100.0	100.0

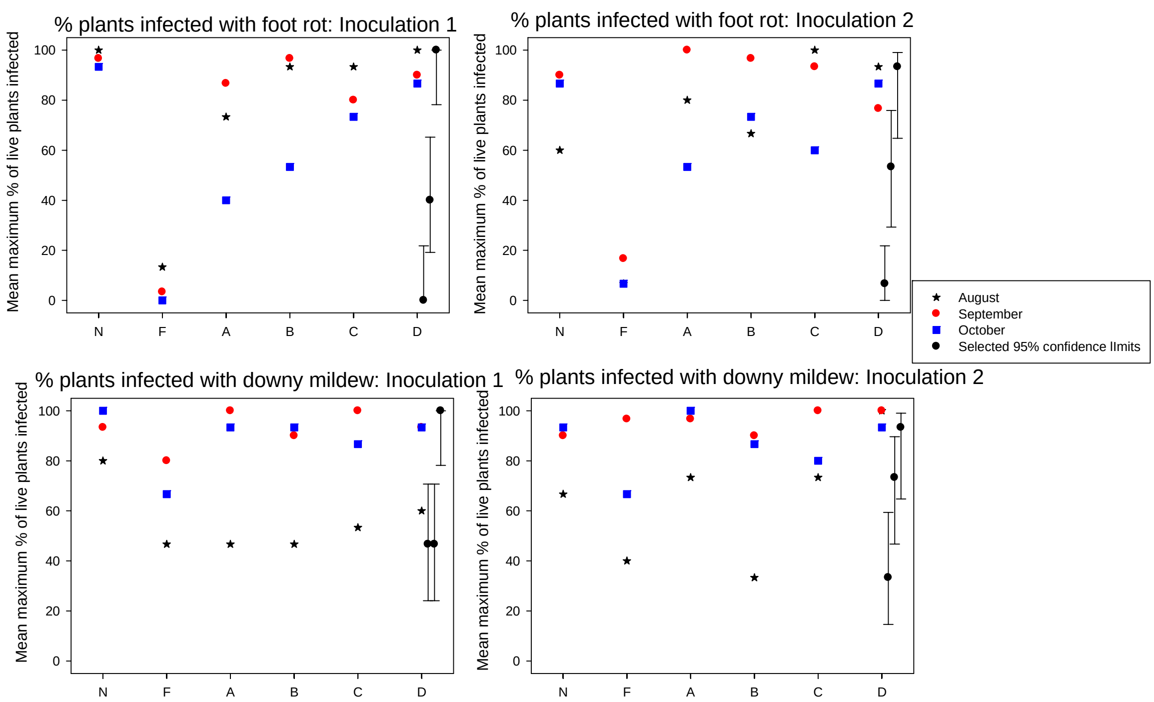

Figure 24: Mean maximum percent of live plants infected with ascochyta foot rot or downy mildew for each inoculation, sowing date and fungicide treatment.

Several other diseases were observed in the plots this season in addition to ascochyta blight and downy mildew. Towards the end of January 2007 several plots were badly infected with *Botrytis cinerea,* especially where flowers had failed to dislodge and caused botrytis on the ends of pods and where plants had fallen over and created conducive conditions for growth of the fungus (Figure 25). Other disease symptoms observed on the plots were caused by *Stemphylium* sp. (Figure 26) and *Sclerotinia sclerotiorum* (Figure 27).

Figure 25: Rotting at the of a pea pod caused by Botrytis cinerea*, and infected pods.*

Figure 26: Lesions on pods caused by Stemphylium *sp.*

Figure 27: Lesions on pods caused by Sclerotinia sclerotiorum*.*

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