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Improved pea production for sustainable arable farming: MAF SFF project - first annual report

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A report prepared for
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1 Executive summary

1.1 Project aims

This project, which aims to highlight practical methods for improving productivity of pea crops, proceeded during the 2004-05 growing season (year 1 of 3). Information relevant to the project was first reviewed and then two field trials were established, monitored and harvested. This report outlines the results obtained in the project to 30 June 2005.

1.2 Trial #1 (field peas)

Trial #1 (field peas) was at the property of Mr Rob McIlraith, St Andrews, South Canterbury. Seed of cv. Midichi was sown into trial plots, and treatments of irrigation (without or with), cultivation (without or with deep ripping), and fungicide applications (without or with; see below) were applied in the trial. Disease and crop growth were monitored throughout the season. Seed was harvested at crop maturity.

The fungicide treatment reduced disease in the plots. Mean Ascochyta blight scores for plants in the fungicide-treated plots were 68% less on plant stems and 55% less on pods than in plants in the untreated plots. The irrigation and the deep ripping treatments only had a slight effect on Ascochyta scores and at times interacted with the fungicide treatments. Mean grain yield from fungicide-treated plots (4.55 tonne/ha) was 76% greater than that from the untreated plots (2.58 tonne/ha), an effect due to increases in numbers of pods/plant, numbers of peas/pod and seed weight. Seed harvested from plots had an approx. 5% incidence of fungi likely to cause Ascochyta blight on average. Trial treatments had little effect on levels of infection on the seed.

1.3 Trial #2 (processing peas)

Trial #2 (processing peas) was at the property of Mr Bruce Garrett, Ladbrooks, Canterbury. Seed of cv. Durango was sown into trial plots, and treatments of sowing date (October or November), inoculation (without or with the main fungus causing Ascochyta blight), and fungicide applications (without or with; see below) were applied in the trial. Disease and crop growth parameters were monitored throughout the season. Vining yields and dry seed yields were assessed.

Vining yield from the October sowing was 12 tonne/ha, 33% more than from the November sowing (9 tonne/ha). Plants from the November sowing had more severe Ascochyta blight on stems (+42%) and pods (+260%), than plants from the October sowing. Inoculation of plots increased Ascochyta

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blight scores on plant stems (+46%) and pods (+230%) relative to the uninoculated plots. Mean Ascochyta blight scores for plants in the fungicide-treated plots were 46% lower on plant stems and 78% lower on pods than for plants from untreated plots. Mean grain yield from fungicide-treated plots (5.77 tonne/ha) was 21% more than that from the untreated plots (4.75 tonne/ha), an effect due to increases in numbers of pods/plant and seed weight.

1.4 Trial features

The 'fungicide' treatment applied in both trials was designed to test the potential to control all potential foliar diseases, rather than to provide a basis for formulating a disease management regime for Ascochyta blight in processing and field pea crops. The treatment consisted of a total of six applications at approx. 2-week intervals from the 3 node stage of crop growth. At each application, three to five active ingredients were sprayed on the treated plots. The total cost of this 'treatment' in each trial was equivalent to over $1100/ha.

At both field trial sites, December rainfall was more than twice that of a long term average. Similarly, both mean minimum and maximum and mean average temperatures for December at both sites were lower than long-term averages.

1.5 Conclusions

These trials were carried out during an unusually damp and cool growing season, where rainfall was high and the crops were never under water stress. The environmental conditions throughout most of the season were very conducive to disease development, particularly for Ascochyta blight and downy mildew. Nevertheless, the trials have demonstrated that where disease is severe, considerable improvements in pea grain yields can be achieved where diseases are controlled using fungicides.

Future research in this project will assess appropriate strategies for managing soil moisture to optimise pea production. As well, the feasibility of developing disease prediction systems for peas will be examined, and the efficacy of fungicide applications for managing pea diseases will be tested.

1.6 Key summary points from the first year

- During the 2004/05 growing season, rainfall in December was more than twice the long-term average at both trial sites used in this study. Similarly, minimum and maximum temperatures were lower than long-term means. Incidence and severity of downy mildew and Ascochyta blight were high during this growing season. It is possible that the high rainfall and low temperatures during the first half of the growing season were conducive to the development of these diseases.
- Treatment with fungicide had by far the greatest effect on the severity of Ascochyta blight and downy mildew, the two predominant diseases found in the two field trials. The fungicide regime used was an experimental tool aiming to reduce foliar diseases of peas, but not designed as a

practical or economic pea crop management method. Nevertheless, the treatments resulted in a 76% grain yield increase for field peas, and a 21% seed yield increase for vining peas. This strongly suggests that adequate control of foliar diseases can benefit pea crop productivity.

- Irrigation and ripping only had a slight effect on Ascochyta scores, and at times, these factors interacted with fungicide treatments. Ascochyta blight was sometimes more severe when either ripping or irrigation were used than when neither or both were used.
- Future research in this project should aim to confirm and quantify relationships between weather and disease, develop practical disease control strategies and continue to examine effects of water availability. In growing seasons where rainfall is closer to average and pea crops are probably under moisture stress, methods of improving root development and water uptake are more likely to affect pea yields.

2 Introduction

Pea crops are important in arable production systems because they can provide useful cash returns as processing or grain/seed crops. Furthermore, peas can be effective break crops in cereal rotations, helping to improve soil fertility (nutrients and structure) and disease control in cereal-based cropping systems. However, total yields from pea crops have been decreasing in recent years despite small increases in areas being sown by arable farmers.

After extensive consultation with growers, processing and seed companies, and research providers involved in the pea industry over the many factors that may affect pea yields, a consensus developed suggesting that combinations of biotic and abiotic stresses are likely to be responsible for depressed yields in pea crops. Foliar diseases, particularly Ascochyta blight, and water availability were considered the factors most likely to be involved. A project was therefore developed to measure the effects of these factors on the productivity of pea crops, and to develop improved methods for managing disease and water stress.

The overall aim of the present project was to measure the individual impacts of abiotic and biotic stresses on pea crop productivity, and synergies amongst them. The project has a desired outcome of providing a tool for arable farmers that will allow them to predict the onset of biotic and abiotic stresses, forecast their likely effects and make management decisions that will optimise pea crop performance. The present report outlines progress in the first year of this 3-year project.

The report begins with a literature review of Ascochyta blight on peas. Two field trials, carried out on commercial farms during the 2004-05 growing season, are then described, and the extensive data sets from these are presented and discussed.

3 Ascochyta blight of peas – review of published information relevant to this project

3.1 Ascochyta blight – the disease

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 three fungi often occur together and can be difficult to distinguish due to isolate variation. The main species that occurs in New Zealand is *M. pinoides*. This fungus causes symptoms of dark irregular spots on leaves and stems. The spots may grow together to form larger lesions. In severe infections the leaves may dry up, but remain attached to affected plants. Most lesions are found on the lower leaves and stems, which are closer to the stubble-borne inoculum on the soil surface. Stem lesions usually are first found at the points of leaf attachment and are brown to purple. In severe cases whole stems may be covered with lesions. The lesions may also be found on the flower stalks before flowering ceases, and their occurrence is followed by blossom drop. Lesions form on pods and the fungus can also infect the seeds. Seeds in older pods are most susceptible to damage. Infected seed may appear normal, or may be shrunken and discoloured. Lesions caused by Ascochyta foot rot are commonly more concentrated at the base of affected stems, and near the point where the cotyledons are attached. With Ascochyta foot rot, a blackening of plant taproots and stem bases may occur. Early season infection leads to weathering of stem bases and collapse of plants as the first pods fill, resulting in premature lodging and further yield and quality reductions.

Ascochyta blight has been shown to affect yield by decreasing the numbers of seeds and individual seed weight (Tivoli et al. 1996; Xue et al. 1997, 1998; Garry et al. 1998). It has also been shown to affect leaf and plant photosynthetic activity (Garry et al. 1998) and radiation use efficiency (Lucas et al. 1998; Beasse et al. 2000). According to studies in Canada (Hnatowich 2000), for every 10% of infected stem area about 5-6% yield loss can be expected. If 10-15% of the pod area is covered with lesions, then 5-10% of the seeds are likely to become infected.

3.2 Epidemiology

Mycosphaerella pinoides reproduces sexually by pseudothecia, which release wind-dispersed ascospores, and asexually (*Ascochyta pinodes*) by pycnidia, which contain conidia that are splash-dispersed. Under field

conditions, the main source of primary inoculum is usually ascospores, which are also important in the secondary spread of the disease. Ascochyta blight is also a seedborne disease, but infected plant debris is the primary source of infection in established pea-growing areas. High numbers of spores are released early in the growing season from crop residues, and ascospores are released in high numbers from senescent parts of infected plants later in the season. The spores land on plant surfaces, germinate, produce germ tubes, form appressorium-like structures, and then enter the plant through the epidermal walls. Once the fungus penetrates the epidermis, it forms a structure similar to an infection vesicle. From this structure, penetration hyphae are formed that initiate the development of intra- and intercellular hyphae. Following infection, a rapid breakdown of plant tissue occurs. After colonisation of plant tissue, the fungus survives as mycelia, chladymospores and pycnidia on straw fragments and in soil. When temperatures are above freezing and sufficient moisture is available, old pycnidia mature, new pycnidia and pseudothecia develop and their spores are released to infect new pea crops. Seedlings contract infection as they emerge through infected residue, and additional transmission may occur with rain splash of soil onto leaves and stems. *Phoma medicaginis* var. *pinodella* also persists in fields by producing chladymospores and pycnidia. This pathogen can survive in the soil for 10 years or more. *Ascochyta pisi* is a weak saprophyte and over-wintering in the field is not important, but seedborne carry over is extremely important. Internal seed infection is rare and most inoculum is carried externally in dust or small straw particles.

Spores of *M. pinoides* germinate over a wide range of temperatures (5-35°C), provided there is adequate moisture. Infection occurs over a similar temperature range. At lower temperatures, longer periods of leaf wetness are required, although lesions are often larger and more numerous in these conditions. Spores can survive interrupted wet periods and retain their ability to infect when favourable moisture conditions resume. Roger et al. (1999) found that spore dispersal was related to rainfall and maturity of fruiting bodies. Conidia were dispersed by rain-splash to a maximum of 30 cm above the soil surface, but greatest numbers were collected at the soil surface. Conidium dispersal occurred shortly after the formation of pycnidia on pea stipules. Maximum numbers of ascospores were trapped from 1 m above the soil surface early in the season, but canopy closure provided a barrier to ascospore dispersal, probably because air circulation was reduced. The severity of Ascochyta blight can vary according to temperature, the concentration of inoculum and the duration of leaf wetness. The most important factor determining whether or not infection occurs is the period of leaf wetness following inoculation, whereas temperature and inoculum concentration are the main factors determining the severity of the disease. Plant injury may also play a minor role in disease infection and spread (Banniza & Vanderberg 2003).

Disease control should aim to reduce or prevent the pathogens from reproducing and the disease from spreading. Crop susceptibility increases with the maturity of plants so crop husbandry practices should aim to reduce premature senescence, for example by using a low sowing density. Crop rotation with a 4-year break between pea crops and removal or burial of infected plant material reduces the amount of inoculum (Hnatowich 2000). In

Canada, seed testing and sowing disease-free seed are recommended because they decrease the risk of spreading *M. pinoides* into new pea-growing areas (Hnatowich 2000). No cultivars are resistant to Ascochyta blight, but some cultivars exhibit higher tolerance than others to the disease.

3.3 Inoculation techniques and establishment of epidemics

Tivoli et al. (1996) produced inoculum by culturing *M. pinoides* on barley grain previously placed in plastic bags, moistened and autoclaved twice at 120°C for 1 h at 24 h intervals. After 3 weeks' incubation at 20^0C, infected barley grains (10 g/m^2) were spread in the field when plants had 5-6 nodes to simulate a natural homogenous infection. In the uninfested plots, a mixture of flutriafol and chlorothalonil was sprayed on a 14-day schedule, starting at flowering.

Xue & Warkentin (2001) screened 335 pea lines from different countries. They established epidemics by inoculating field plots with 10 g per plot of infected pea straw that was naturally infected with *M. pinodes* in the previous season, air-dried, and cut into 2 cm pieces. Sprinkler irrigation was used on dry days during the growing season to encourage infection.

Wroth & Khan (1999), in Western Australia, inoculated field plots by spreading mechanically mulched diseased pea straw across trial areas planted in April (stubble was applied once only in April to simulate the natural weathering of inoculum as occurs in nature). They used a Burkard spore sampler to monitor the number of spores trapped per hour.

3.4 Disease assessment

Tivoli et al. (1996), in France, assessed disease intensity at the end of June on the reproductive nodes of 10 plants per plot. Disease intensity was assessed on each stipule, internode and pod of each plant using a 0-5 scale (0, no lesion; 1, a few scattered flecks; 2, numerous flecks; 3, 25-50% plant parts covered by small coalesced lesions; 4, 50-75% plant parts covered; 5, 75-100% plant parts covered by extensive coalesced lesions). One week before harvest the height of the stems on 10 plants per plot and the length of stem encircled by lesions were assessed.

Xue & Warkentin (2001) assessed blight severity using a 0-9 scale (Xue et al. 1996). Plants were assessed five times at 10-day intervals starting at inoculation date. Area under the disease progress curve (AUDPC) was calculated for each plot. A total of seven cultivars were assessed for components of partial resistance, including leaf area with symptoms, stem area with symptoms, pod area with symptoms, and percent seed infection.

Wroth & Khan (1999) assessed plants in each plot for disease development on the main stems, and on the leaves attached to the main stems, every second week. They recorded plant height, number of nodes, and phenological development. Disease incidence and severity were measured. Disease incidence on the main stems (% stem infected) was determined as the length of each stem with disease lesions relative to the total length of the stem, measured from the base of the plant. Number of nodes with stem

lesions was noted. Disease severity was measured as the proportion of stem completely blackened by lesions and was referred to as stem girdling. In leaves, disease incidence was determined as the proportion of leaves with lesions, whereas disease severity was the proportion of senescent leaves. The proportion (%) of diseased leaf area was assessed using a standards key (Key 32; NIAB 1985).

3.5 Effects of Ascochyta blight on yield components

Tivoli et al. (1996) assessed pea yield components by taking 10 plants per plot at random and determining the number of stems per plant, their height, the number of reproductive nodes, the number of pods, and the number of seeds per pod and per stem. The harvest index (dry weight of seeds/total dry weight) and the biomass of plants were measured after drying samples at 70°C for 24 h. Blight was severe on leaves and on internodes of the basal part of the plants, and pods had few lesions. The disease did not have an effect on the number and length of stems per plant.

3.6 Modelling of disease epidemics

Literature has been searched to identify models or decision support systems that can be used to evaluate the risk of Ascochyta blight development in crops. One such system has been published in the Pulse Production Manual published by the Saskatchewan Pulse Growers, Saskatoon, Canada (Hnatowich 2000).

This system is being developed at Agriculture and Agri-Food Canada (AAFC), Saskatoon Research Centre by Dr Lone Buchwaldt and Dr Bruce Gossen. The system is based on a set of guidelines for identifying situations where foliar fungicide application is most cost-effective. It identifies risk factors that best describe:

A. plant stand,

B. number of days with rain in the last 14 days,

C. 5-day weather forecast, and

D. amount of disease.

The relative risks associated with each factor that control disease development are shown below. The risk value is then calculated as A+B+C+D. When the risk value is 50 or above, a fungicide application is recommended. If the risk value is less than 50, a fungicide application is not recommended, but a new assessment should be made at 3-5-day intervals until the crop is no longer flowering. If the crop remains almost disease-free until after flowering, fungicide application is generally not cost-effective.

This assessment summarises the relative risk associated with factors that control disease development. However, the decision to apply fungicide is the producer's responsibility and AAFC does not assume any liability regarding its use.

Inspect at least 10 locations in the pea crop at 10% flowering	
A. Plant stand	Risk factor
1. Thin (resulting in high weed pressure and low yield expectation)	0
2. Moderate (resulting in some weeds and a potential low yield)	5
3. Normal (approximately: 88 plants/m^2)	10
4. Dense (more plants than normal or variety with lush growth habit)	15
B. Number of days with rain in the past 14 days	
0 days	0
1-2 days	5
3-4 days	10
5-6 days	15
7 or more days	20
C. The 5-day weather forecast	
1. Dry	0
2. Unpredictable	10
3. Light showers	15
4. Amount of rain	20
D. Amount of Ascochyta blight on pea foliage at first bloom stage	
1. No visible symptoms	0
2. Up to 10% of the leaf area infected on the bottom 1/3 of the plants	5
3. 10 to 20% of the leaf area infected on the bottom 1/3 of the plants	10
4. 20 to 50% of the leaf area infected on the bottom 1/3 of the plants	15
5. 20 to 50% of the leaf area infected on the bottom 1/3 of the plants, and up to 20% of the leaf area infected on middle 1/3	30

To our knowledge, this is the only published decision support system for Ascochyta blight. However, Tivoli and co-workers at INRA, Le Rhey, France, have carried out intensive experiments on the epidemiology of *M. pinoides*. For example, they have quantified the effects of the pathogen on yield and on photosynthesis, the role of seed infection in seedling emergence and disease development as well as more fundamental studies on the effects of the environment on the development of the disease. Their group (Beasse et al. 2000) published a pea growth model that was based on the combination of Ascochyta blight progression in the canopy (number of nodes affected by the disease) and the structure of the canopy (leaf area index (LAI) profile).

The calculations for the model included:

- estimation of the contribution of each node to radiation absorption,
- calculation of the reduction in the contribution of each node due to disease,
- using the relationship between the relative decrease in photosynthetic activity of a diseased leaf and its disease score, and
- summing these individual contributions to provide an estimation of the total crop growth.

The model included estimations of decreases in radiation interception efficiency (RIE) and radiation use efficiency (RUE) in the field due to *M. pinodes*. The disease affected crop growth mainly by decreasing RUE, with a slight decrease in RIE. The model comprised the decrease in photosynthesis

rate in the leaves, the vertical gradient of disease intensity and the differences in photosynthetic function of the various layers of the canopy. The decrease in RUE resulted solely from losses in the photosynthetic efficiency in diseased leaves. They recommended that the model could be used for disease management, defining damage thresholds for chemical application and criteria for the selection of tolerant varieties. The model has been further tested and validated in France (Le May et al. 2005) using six commercially grown pea cultivars with different plant architectural features such as stem height, branching ability and standing ability. This model may be useful in further studies of Ascochyta blight in this project.

4 Field trial 1 (property of Mr Rob McIlraith, St Andrews, South Canterbury)

4.1 Trial design

This trial was with the marrowfat pea cultivar Midichi. The trial had eight treatments, consisting of all combinations of two levels of three factors. These factors (and levels) were:

- irrigation (full irrigation and no irrigation): to produce crops with lower and higher yield potential;
- cultivation (with and without deep ripping before planting): To produce crops with lower and higher susceptibility to infection by Ascochyta resulting from contrasting restrictions on the root systems, and different root aeration and drainage;
- fungicide (with and without fungicide applications to control foliar diseases): to produce contrasting levels of disease. A best practice pesticide regime was applied to the treated plots at approx. 2 week intervals, commencing at the three node stage of crop growth. Six fungicide applications (Table 1) were made to the treated plots during crop growth, with the spray application procedures carried out by New Zealand Arable;
- the trial was in 32 plots – four replicates of the eight treatments;
- a split-plot design was used with the irrigation treatments as main plots and the other treatments as split-plot treatments;
- each plot consisted of two drill-strips, each 10 m long and 1.2 m (eight rows) wide;
- there was a buffer strip between plots to provide some isolation between treatments with different levels of disease.

4.2 Crop management

- The trial area was marked out on 16 September after preliminary cultivation following grazing of a previous rape crop. The soil was a Templeton silt loam.
- The appropriate plots were ripped to about 350 mm depth. Each plot was ripped with two runs of the ripper, which was 2 m wide.
- After ripping, the whole area received a final surface cultivation before planting.
- The 104 drill-strips were sown on 2 October with Plant Research (NZ) Ltd's seeder.
- Treated seed of the marrowfat pea cultivar Midichi was sown at the equivalent of 456 kg/ha (547 g/strip; mean seed weight = 390 mg; germination = 95%; effective field emergence assumed to be 90%) with the aim of achieving a plant population of 100 per m^2.
- No fertiliser was applied and, apart from the treatments, the trial was managed as for the surrounding crop.
- Regular fungicide applications at 2-week intervals from the three node crop growth stage began on 1 November (Table 1) to fungicide treated plots.
- The irrigated treatment was watered once, with 12 mm on 17 November.
- Harvest date (dry seed stage) was 25 February 2005.

4.3 Measurements

- Soil moisture content profiles were measured each week by Hydro Services Ltd in all plots. The access tubes were placed at a depth of 1.0 m and as close to the same position in each plot as possible. Readings were taken every week at six different depths, 0-200, 200-300, 300-400, 400-500, 500-600, and 600-800 mm using a CPN 503DR neutron probe. Results were used to schedule irrigations and to determine the effects of the treatments on (a) crop water use during crop growth, (b) patterns of water extraction from the root zone, and (c) timing and severity of water deficit.
- Disease incidence and severity were assessed during vegetative growth (22 November), at first flower (10 December), early in pod-fill (23 December), at pod-fill (18 January) and TR105 (31 January). For each assessment, 10 plants per plot were removed to the laboratory. Ascochyta blight and any other diseases present on the plants were scored using standard disease assessment keys (see Appendices I to V). Individual leaves, stipules, stems and pods were scored at each node for Ascochyta, and each node was scored overall for downy mildew. For Ascochyta, an overall stem score was also given for each plant. Ascochyta was not present at the first two assessment dates and at the third assessment (22 December) there were not yet any pods to score. Downy mildew was present at all assessment dates. Downy mildew was

assessed on 22 November and 7 December 2004 by measuring the severity of the disease on each node on a scale from 0 to 10 using standard disease severity keys (Falloon et al. 1995; Appendix V). On 22 December, downy mildew was assessed as presence or absence on each plant, and on 19 and 31 January, it was assessed as presence or absence on each node of each plant. In some cases, no data were obtained from some plants in a plot due to plant breakage during transport, with a maximum of two plants missing in a plot for the first four assessments and up to seven in the final assessment (these were dead plants).

- Crop growth was measured twice, at first flower and at mid pod-fill growth stages (approx. TR = 105). The first measurement was done on 7 December 2004 and the second on 17 January 2005. Each time, all plants in a 0.5 m^2 quadrate were removed from each plot and the following parameters were determined: plant populations, biomass, leaf area index, numbers of nodes, first flowering node, numbers of branches, numbers of pods, numbers of peas/pod, pod and pea weights, leaf and stem fresh and dry weights.
- Seed yield was measured at maturity on 23 February 2005, both from 1 m^2 quadrate samples and on combine harvest samples harvested from the second drill-strip of each plot by Plant Research (NZ) Ltd.
- Ascochyta infection in harvested seed was measured after harvest. Samples from each plot were tested for the presence of *Ascochyta* spp. and related fungi. The methodology used was as recommended by ISTA (International Rules for Seed Testing Effective from 1 January 2002-05 (2002): Detection of *Ascochyta pisi* on *Pisum sativum* (Pea). Fifty seeds were randomly taken from each of the samples and surface sterilised (1% available chlorine as sodium hypochlorite) for 10 min, followed by draining. Ten seeds were placed on each Petri dish containing potato dextrose agar (PDA). Plates were incubated at 20^{0}C and examined for colony growth after 7 days. Treatment means are presented; no statistical analyses of the results was carried out because of the very low incidence of fungi on seeds, and because no trends in the means were detected.
- Weather data were collected from Campbell Scientific CR10X weather station that measured hourly temperature and relative humidity at 1.4 m height, soil temperature (10 cm below soil surface), leaf wetness, rainfall and solar radiation. The weather station was placed in the field site on 24 November and weather data from midnight 25 November was used in this project. Ten-year (1992-2001) monthly averages for Timaru were provided by Robert Zyskowski of Crop & Food Research, Lincoln, to allow comparisons of this season's weather variables with long-term means.

Table 1: Fungicide spray application schedule for Trial 1 (McIlraith property, St Andrews). Products and rates applied, and weather conditions at application are indicated.

Spray	Date	Product	Rate	Water rate	Weather conditions
1	1 Nov 2004	Sereno	1.5 kg/ha	250 L/ha	Air temp: 16°C
		Carbendazim	0.5 kg/ha		RH: 70%
		Karate Zeon	40 ml/ha		Cloud cover: 100%
					Wind: 5-10 km/h N
					Drying cond.: OK
2	15 Nov 2004	Sereno	1.5 kg/ha	250 L/ha	Air temp: 13°C
		Carbendazim	0.5 kg/ha		RH: 70%
		Karate Zeon	40 ml/ha		Cloud cover: 50%
					Wind: 5-10 km/h SE
					Drying cond.: OK
3	29 Nov 2004	Sereno	1.5 kg/ha	250 L/ha	Air temp: 14°C
		Carbendazim	0.5 kg/ha		RH: 70%
		Karate Zeon	40 ml/ha		Cloud cover: 100%
					Wind: 0-5 km/h SE
					Drying cond.: OK
4	13 Dec 2004	Sereno	1.5 kg/ha	250 L/ha	Air temp: 14°C
		Amistar	0.75 L/ha		RH: 75%
		Folicur	0.44 L/ha		Cloud cover: 100%
		Karate Zeon	40 ml/ha		Wind: 0-5 km/h SW
					Drying cond.: slow
5	23 Dec 2004	Sereno	1.5 kg/ha	250 L/ha	Air temp: 18°C
		Amistar	0.75 L/ha		RH: 65%
		Folicur	0.44 L/ha		Cloud cover: 50%
		Karate Zeon	40 ml/ha		Wind: 5-10 km/h N
					Drying cond.: good

4.4 Statistical analyses

4.4.1 Soil moisture

Soil moisture measurements were taken regularly on all plots from 4 November until 17 February. Only soil moisture deficits are explored here. The mean, maximum, and total deficits over dates were calculated for each plot. The plot summaries were analysed with analysis of variance.

4.4.2 *Ascochyta*

Data from the final three assessments were analysed. There were no pods until the fourth assessment. Average scores were calculated for each assessed plant (averaging over nodes for pods, stipules, leaves and stem scores), and then the average of these per plot was calculated. Average plot scores were also calculated for pod 1 (first pod), pod 2 and stem. Scores for leaves 1 and 2 and stipules 1 and 2 were zero in the majority of cases, so these were not included in the analyses. The plot averages were analysed with analysis of variance separately for each assessment.

4.4.3 *Downy mildew*

For the first two assessment dates, average scores of downy mildew were calculated for each assessed plant (averaging over nodes), and then the average of these per plot was calculated. These were then analysed with analysis of variance, separately for each assessment. The percentage of plants with disease (incidence of disease) was calculated for each plot. For each of the five assessments, these were analysed with a binomial generalised linear model (McCullagh & Nelder 1989). The effects of fungicide, irrigation and ripping were assessed in the analysis of deviance done as part of this analysis, similarly to analysis of variance. In the table of results, 95% confidence limits are presented with the percent infected plants. These were calculated as part of the analysis.

4.4.4 *Numbers of nodes and dead nodes*

The number of nodes and the number of dead nodes were calculated using the downy mildew data, for each plant. The mean number of nodes per plant in a plot was then calculated. The percentage of dead nodes per plot was calculated as 100 * (total dead nodes per plot) / (total number of nodes per plot). This gave a plot average weighted by the total number of nodes per plant (which differed little in practice from the mean % dead for each plant for each plot). Mean numbers of nodes were analysed with analysis of variance. The percentage of dead nodes was analysed similarly to the percentage of diseased plants using a binomial generalised linear model. Individual nodes were not assessed at the third assessment.

4.4.5 *Grain yields*

Plot yields, 100 seed weight, number of plants per m^2, number of peas per pod and mean pea weight were analysed with analysis of variance. Further analysis of the yield components was carried out (results only partly presented here). The data were analysed initially utilising the split-plot design. However, the variability between the main plots was less that that within the main plots. This may have been due to the irrigation method. A feature of the irrigation treatment was that adjacent plots were not irrigated independently, so the main plots of blocks 1 and 2 were irrigated together, and the main plots of blocks 3 and 4 were irrigated together. This may have affected the variability between and within blocks and plots. For this reason, the trial was treated as a randomised block design and analysed using simple ANOVA. The data had one outlying plot for almost all the variates measured.

Plot 6 was unusual for all parameters, and had a large influence on the analysis. This plot also led the data to appear non-normal and heteroscedastic for several variates. The data from this plot were therefore excluded from the final analysis.

All analyses were carried out with GenStat (GenStat Committee 2005).

4.5 Results and discussion

4.5.1 Soil moisture deficit

Changes in soil moisture deficit over time followed similar patterns for all plots (Fig. 1). Neither ripping nor irrigation affected (P>0.05) the soil moisture deficit (Table 2). However, the maximum deficit was increased when fungicide was applied (from around 59 to 65, P=0.013). The fungicide treatment did not affect the mean or total deficit (P>0.05). Yields were not strongly related to moisture deficit (Fig. 2), with correlations of 0.2, -0.10 and -0.09 between yield and maximum, mean and total moisture deficit respectively. The plots did not reach any significant moisture stress. Although there are no figures for the exact point at which soil moisture deficit causes plant stress, previous research on similar soil has shown that the critical deficit below which there was no further yield increase was 88 mm. The maximum soil moisture deficit for individual plots reached at the St Andrews site was 83 mm with a mean maximum deficit of 69 mm.

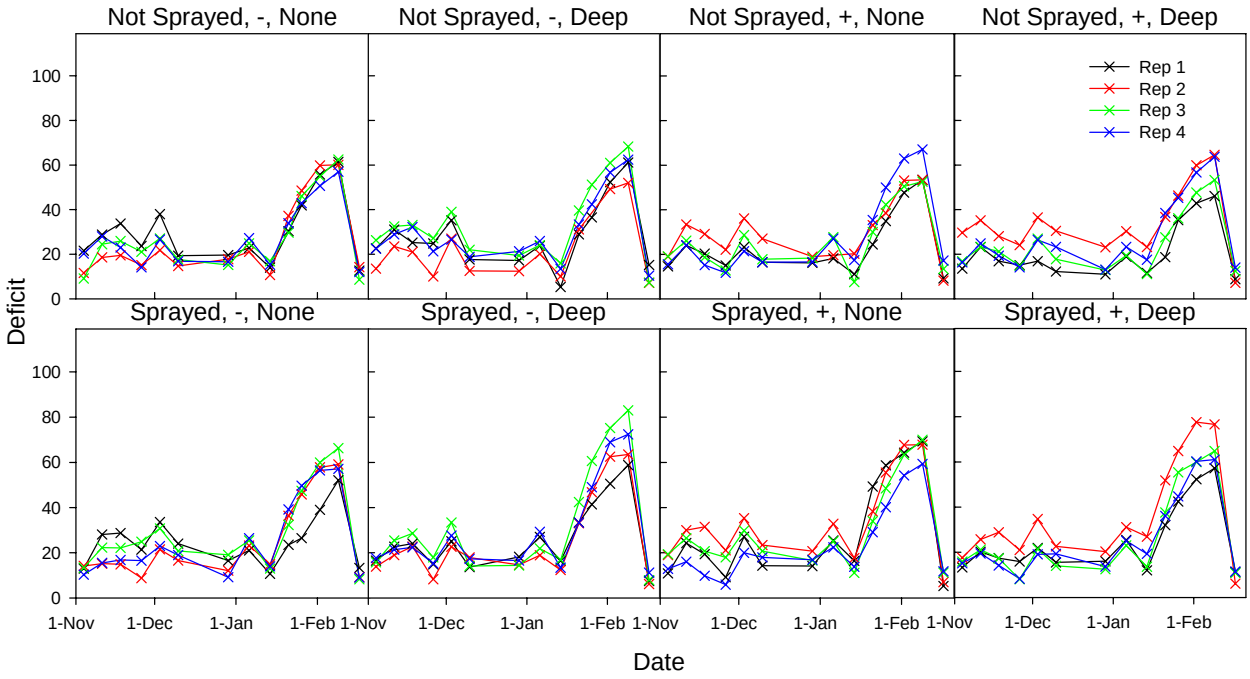

Figure 1: Probe moisture measurements over time for each measured plot (-,+ irrigation) at St Andrews.

Table 2: St Andrews trial, Mean summaries of soil moisture deficit.

Fungicide	Irrigation	Ripping	Max	Mean	Total
Nil	Nil	Nil	60.25	27.91	390.67
		With	60.95	28.42	392.25
	With	Nil	56.63	26.86	376.05
		With	56.92	26.86	376.10
With	Nil	Nil	58.65	26.24	367.40
		with	69.43	28.69	401.60
	With	Nil	66.60	28.95	405.32
		With	65.15	28.59	400.27
LSD (*P*=0.05), for irrigation					
Same	df=18		11.50	8.24	119.38
Different			9.91	4.68	68.43
	(df)		(12)	(5)	(5)

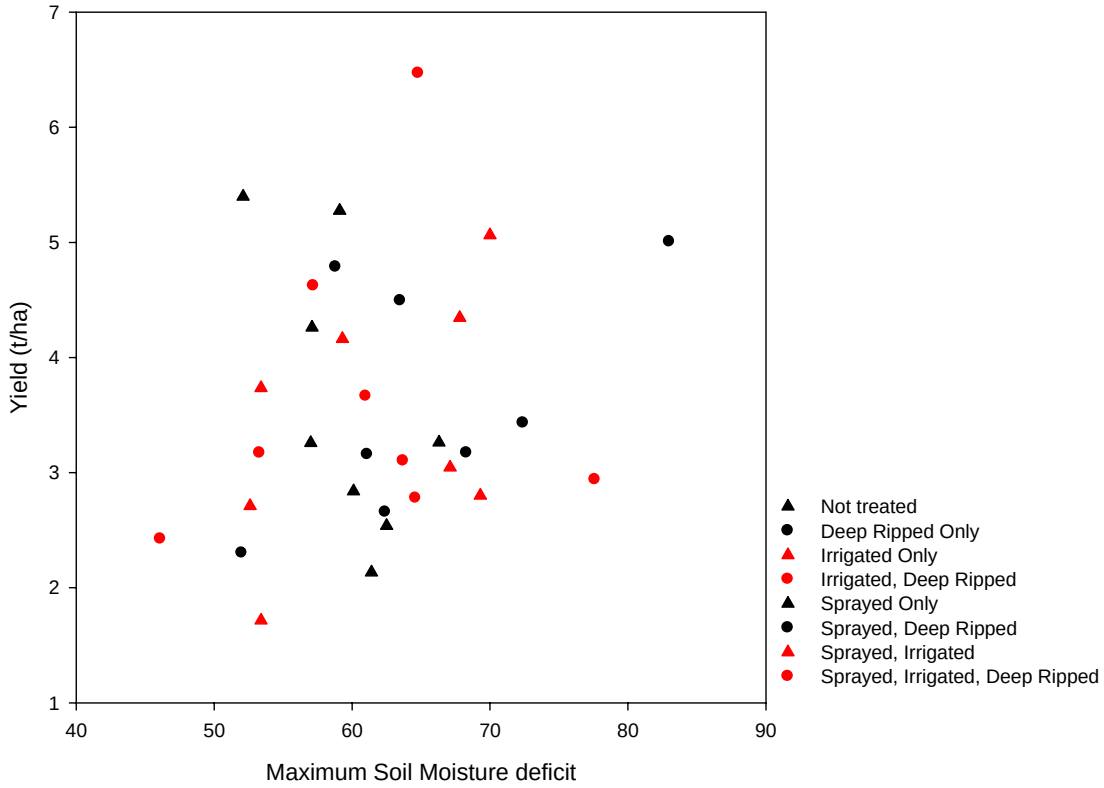

Figure 2: Relationship between yield and maximum soil moisture deficit for St Andrews trial.

4.5.2 *Ascochyta scores*

Ascochyta blight was not present in the first and second disease assessment but was first noted in plots at the third assessment date (23 December). For average plant score, fungicide had the greatest effect at all three assessment dates (P<0.001), with average scores generally lower with fungicide than without (Fig. 3, Table 3). However, the effect of fungicide varied with irrigation (P=0.043), and to a lesser extent with ripping (P=0.087 for the three-way interaction). These interactions were principally because Ascochyta score was not reduced by fungicide neither when irrigation or ripping was applied. At the second assessment, Ascochyta score tended to be greater when either irrigation or ripping was used, but when both were used Ascochyta score was similar to when neither was used (P=0.005 for the irrigation X ripping interaction). At the third assessment, irrigation had no significant effect, but ripping tended to increase Ascochyta score (P=0.021). Over time, Ascochyta score tended to increase on all parts of the plants assessed and analysed, with the odd exception (e.g. for average plant score, 'no irrigation, no ripping with fungicide').

Stem Ascochyta scores (Fig. 3, Table 3) were also most strongly affected by fungicide, with lower scores when fungicide was applied, at all three assessments (P<0.001). At the first assessment, ripping also had an effect on stem Ascochyta score (P=0.016), with scores slightly lower with ripping

(average reduction of 0.8). At the second assessment, the effect of fungicide was modified both by ripping and irrigation (P=0.01 for the three-way interaction). When fungicide was not applied ripping and irrigation had little effect, but when it was applied, Ascochyta scores on the stems were higher if either ripping or irrigation were used. If both were used, however, scores were similar to when neither was used. At the final assessment, neither ripping nor irrigation had statistically significant effects (P>0.2).

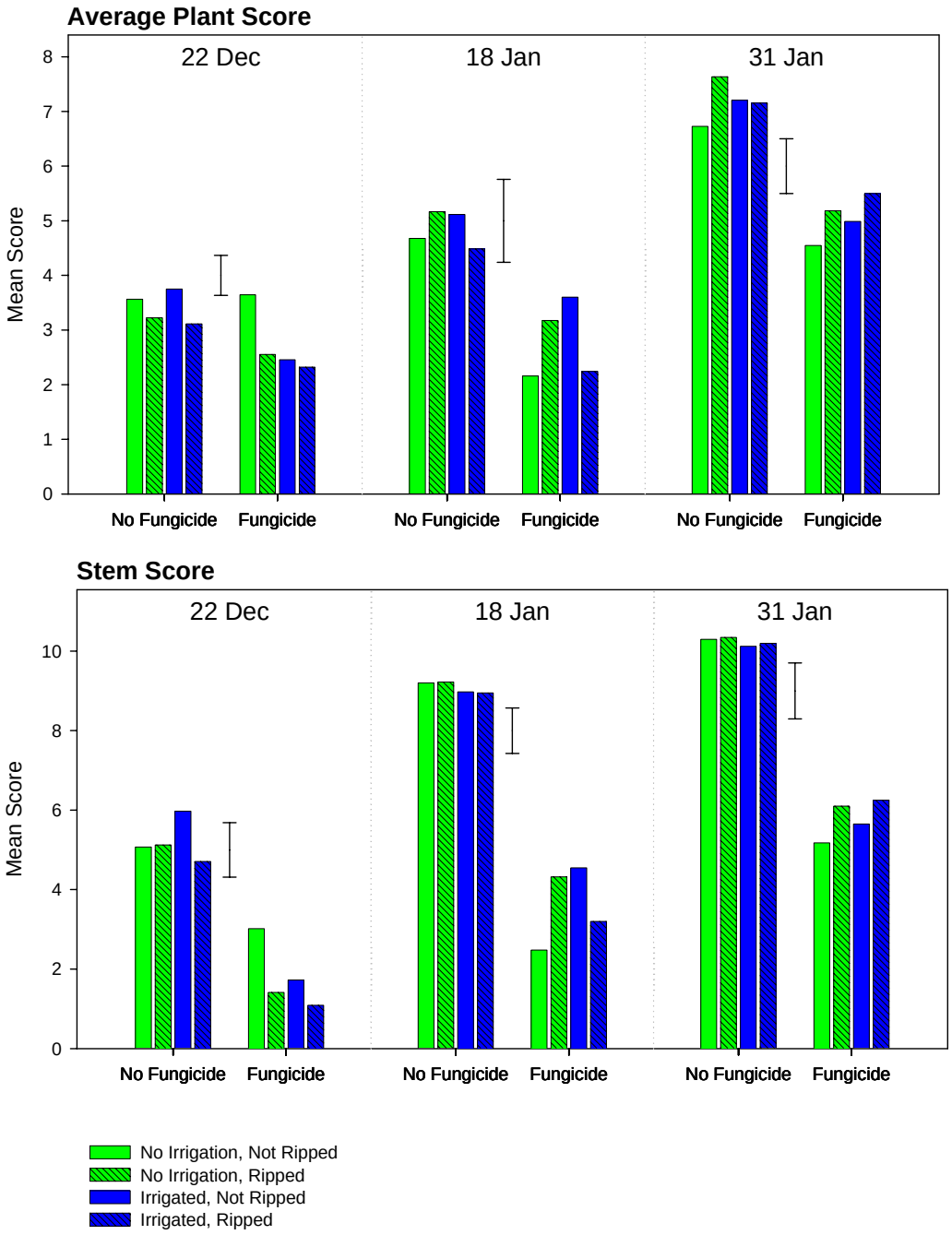

Figure 3: Mean plant or stem Ascochyta scores on a scale from 0 to 11 at the St Andrews trial site. Error bars are LSDs (maximum of the two in the table).

Table 3: Mean Ascochyta scores for each treatment, for plants and stems.

			Average plant score			Average stem score		
Irrigation	Ripping	Fungicide	22/12	18/01	31/01	22/12	18/01	31/01
Nil	Nil	Nil	3.6	4.7	6.7	5.1	9.2	10.3
		With	3.6	2.2	4.5	3.0	2.5	5.2
	With	Nil	3.2	5.2	7.6	5.1	9.2	10.4
		With	2.6	3.2	5.2	1.4	4.3	6.1
With	Nil	Nil	3.7	5.1	7.2	6.0	9.0	10.1
		With	2.5	3.6	5.0	1.7	4.6	5.6
	With	Nil	3.1	4.5	7.2	4.7	9.0	10.2
		With	2.3	2.2	5.5	1.1	3.2	6.2
LSD 5%, for means with irrigation								
Same	(df=18)		0.7	1.2	0.8	1.4	1.1	1.3
Different			0.7	1.5	1.0	1.3	1.1	1.4
	(df)		(19)	(8)	(11)	(20)	(21)	(17)

For Ascochyta score on pods, fungicide again had the greatest effect (*P*<0 001), reducing the disease on pods at both assessments (Fig. 4, Table 4). At the second assessment, disease score on Pods 1 and 2 were also affected by irrigation and ripping (*P*=0.017 and *P*=0.002 for the ripping X irrigation interaction for Pods 1 and 2). When either ripping or irrigation were used, Ascochyta tended to be more severe than when neither or both were used. For pod 1, there was some evidence that irrigation and ripping modified the effect of the fungicide treatment (*P*=0.064 for the 3-way interaction), with negligible effects of ripping and irrigation when fungicide was not used. At the third assessment, Ascochyta score on Pod 1 was increased with ripping, on average by 0.8. There was some evidence that the fungicide effect was modified by ripping (*P*=0.057 for the fungicide X ripping interaction), with a slightly greater fungicide effect in the absence of ripping. There was evidence (*P*=0.055) of a similar effect on Pod 2.

Overall, fungicide had the greatest effect on Ascochyta blight severity in this trial. There was less disease on whole plants, stems and pods in fungicide-treated plots than in treated plots. Irrigation and ripping only had a slight effect on Ascochyta scores and, at times, interacted with the fungicide treatments. Ascochyta severity was sometimes more severe when either ripping or irrigation were used than when neither or both were used.

Table 4: Mean Ascochyta scores for each treatment, for pods.

			Pod 1		Pod 2	
Irrigation	Ripping	Fungicide	18/01	31/01	18/01	31/01
Nil	Nil	Nil	6.6	8.5	5.6	8.2
		With	2.0	3.9	1.6	3.9
	With	Nil	6.6	8.7	5.7	8.2
		With	3.0	4.9	2.8	4.5
With	Nil	Nil	6.6	8.5	5.6	8.1
		With	3.0	4.2	2.8	4.1
	With	Nil	6.4	8.7	4.8	7.8
		With	2.2	6.0	1.7	5.5
LSD 5%, for means with irrigation						
Same	(df=18)		0.8	1.2	0.9	1.2
Different			1.0	1.2	1.2	1.3
	(df)		(8)	(20)	(9)	(15)

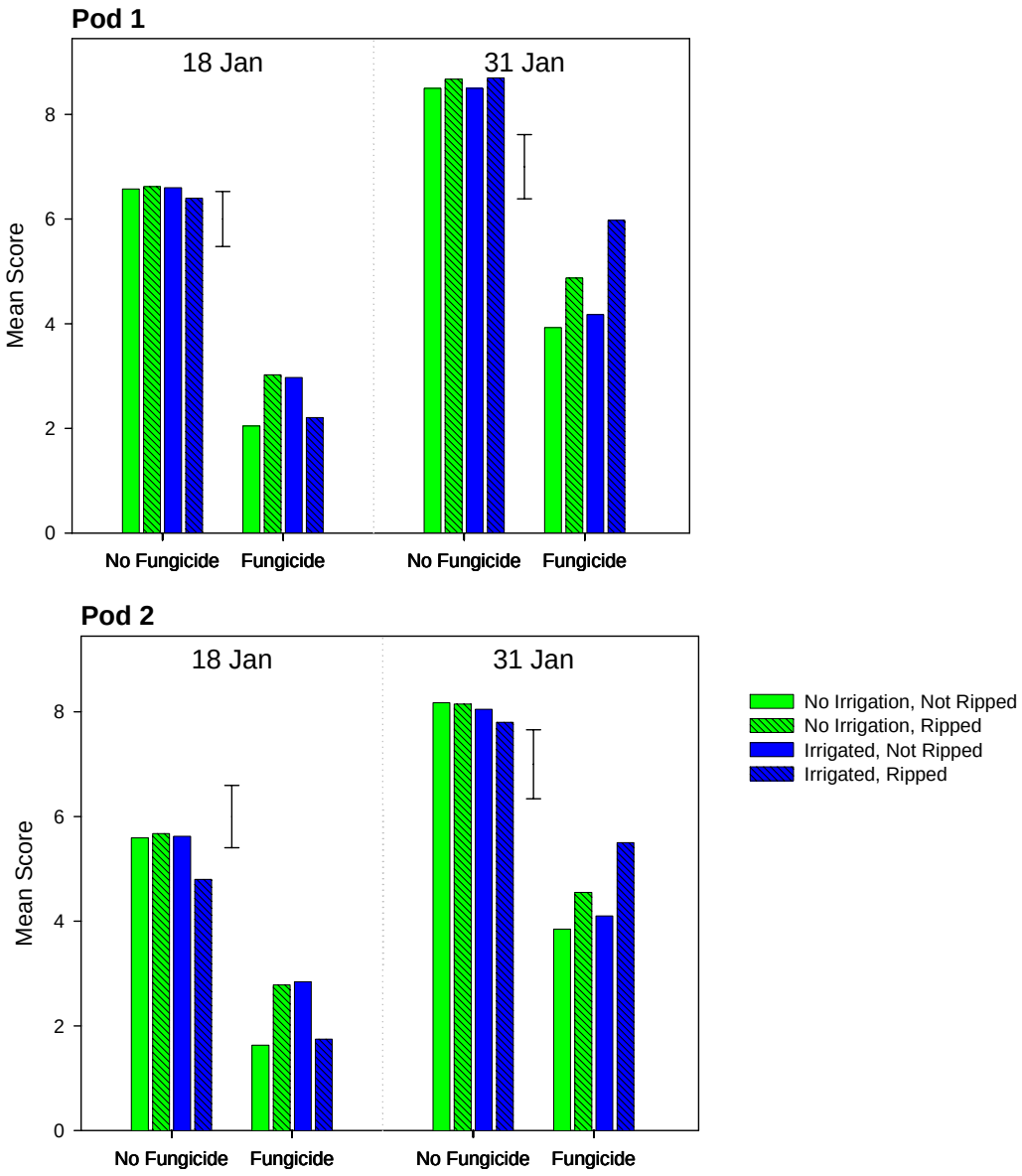

Figure 4: Mean Ascochyta scores on Pods 1 and 2. Error bars are LSDs (maximum of the two in the table).

4.5.3 *Downy mildew*

Downy mildew severity was analysed for the first two assessment dates. Average plant downy mildew severity scores for these dates were not affected by ripping (P>0.05; Table 5, Fig. 5). At the first assessment, downy mildew severity was reduced by the fungicide (P<0.001), from an average score of 1.2 with no fungicide to 0.75 with fungicide applied. Irrigation had no significant effect (P>0.05) on downy mildew severity. At the second assessment, neither fungicide nor irrigation had a strong effect, but there was some indication that downy mildew severity score was reduced with fungicide applied when irrigation was used (P=0.056 for the irrigation X fungicide interaction).

Table 5: Mean downy mildew scores for each treatment.

			Assessment	
Fungicide	Irrigation	Ripping	22/11/04	07/12/04
Nil	Nil	Nil	1.08	1.93
		With	1.34	2.06
	With	Nil	1.13	2.23
		With	1.22	1.93
With	Nil	Nil	0.73	1.98
		With	0.79	2.26
	With	Nil	0.75	1.64
		With	0.71	1.79
LSD 5%, for means with irrigation				
Same	(df=18)		0.23	0.50
Different			0.26	0.57
	(df)		(12)	(13)

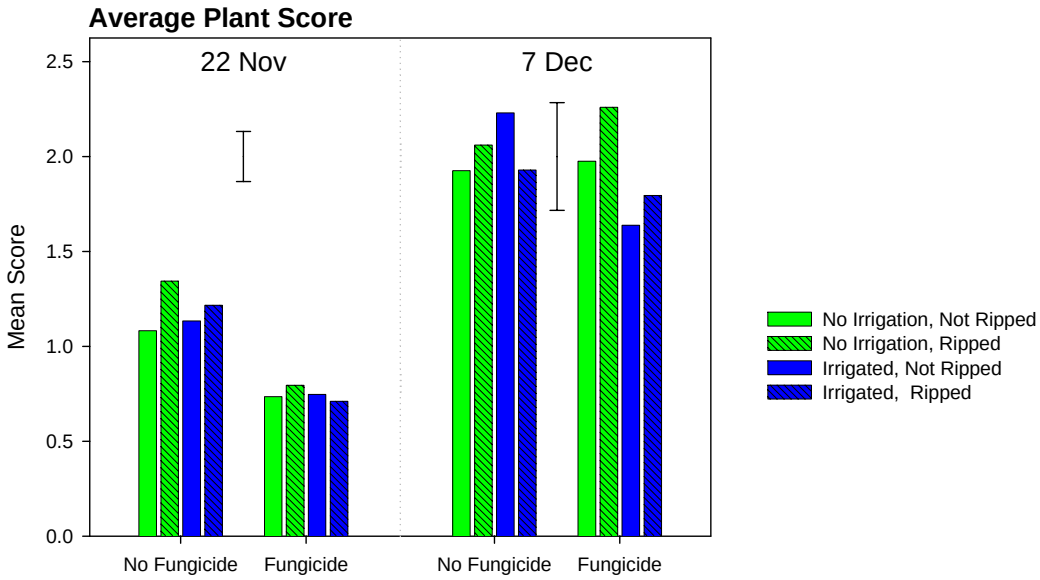

Figure 5: Mean downy mildew scores per plant. Error bars are LSDs (maximum of the two in the table).

4.5.4 *Presence/absence of downy mildew*

At the first assessment, downy mildew incidence was not significantly affected by either ripping or irrigation ($P>0.05$), but was reduced to 93% of plants infected in the fungicide-treated plots, compared with 99% incidence in unsprayed plots (Table 6, Fig. 6). At the second assessment, all plants had some downy mildew infection. At the third assessment, irrigation, ripping and fungicide all had effects, with statistically significant three way interactions ($P=0.002$ and 0.022 respectively). The percentage of affected plants was generally lower when fungicide was applied. Where no fungicide was applied, fewer plants were affected when both ripping and irrigation were also applied. With fungicide, fewer plants were affected when irrigation was also applied, and the percentage of affected plants was greatest without either ripping or irrigation. By the final assessment, the fungicide effect had largely disappeared ($P>0.1$) largely due to death of nodes (Fig. 6), but infection levels were still affected by ripping and irrigation ($P=0.038$ for the irrigation and ripping interaction), with a slightly higher proportion of plants affected when either ripping or irrigation (but not both) were used.

Overall, downy mildew was more severe early in the growing season, with almost every plant having symptoms. Some systemic infection was also noted (data not presented). Plots treated with fungicide had less downy mildew than untreated plots at the first and third assessments, with complex interactions between all treatments at the third assessment.

Table 6: Percentage of plants affected by downy mildew (95% confidence limits).

			Assessment				
Fung.	Irrig	Rip	22/11/04	07/12/04	22/12/04	18/01/05	31/01/05
Nil	Nil	Nil	100.0 (91.2,100)	100 (91.0,100)	70.0 (54.3,82.1)	66.7 (50.7,79.6)	10.0 (3.3,26.8)
		With	100.0 (91.2,100)	100 (91.2,100)	87.5 (73.3,94.7)	70.0 (54.3,82.1)	15.4 (5.9,34.5)
	With	With	97.5 (84.3,99.6)	100 (91.2,100)	80.0 (64.8,89.7)	85.0 (70.4,93.1)	12.5 (4.1,32.4)
		With	100.0 (91.2,100)	100 (91.2,100)	53.8 (38.3,68.6)	62.5 (46.8,76.0)	0.0 (0.0,12.8)
With	Nil	Nil	90.0 (76.2,96.2)	100 (91.2,100)	39.5 (25.4,55.6)	74.4 (58.6,85.6)	2.9 (0.4,17.7)
		With	97.5 (84.3,99.6)	100 (91.2,100)	24.3 (13.2,40.5)	65.0 (49.2,78.1)	8.1 (2.6,22.3)
	With	Nil	92.5 (79.2,97.6)	100 (91.2,100)	7.5 (2.4,20.8)	65.0 (49.2,78.1)	5.4 (1.4,19.2)
		With	95.0 (82.1,98.7)	100 (91.2,100)	12.8 (5.4,27.3)	75.0 (59.5,86.0)	2.9 (0.4,18.1)

4.5.5 *Number of nodes per plant*

Numbers of nodes per plant were not significantly affected by irrigation or ripping ($P>0.05$) at any of the four dates where nodes were counted (Table 7). However, node numbers were reduced by fungicide at the second and final assessments ($P=0.026$ and $P<0.001$ respectively), by around 0.3 and 1 nodes respectively.

Table 7: Mean number of nodes per plant. (Not recorded on 22/12/04).

			Assessment			
Fungicide	Irrig.	Rip	22/11/04	07/12/04	18/01/05	31/01/05
Nil	Nil	Nil	7.1	11.3	22.1	22.5
		With	7.4	11.1	20.3	21.8
	With	Nil	7.1	11.2	20.8	22.7
		With	7.1	11.0	21.4	22.1
With	Nil	Nil	7.3	10.9	20.7	21.6
		With	7.2	10.9	21.2	21.3
	With	Nil	7.2	10.9	20.9	20.9
		With	7.0	10.9	22.0	21.4
LSD 5% for means with irrigation						
Same	(df=18)		0.4	0.5	1.7	1.1
Different			0.5	0.5	1.5	1.1
	(df)		(9)	(17)	(20)	(18)

4.5.6 *Percentage of nodes with dead leaves*

The percentage of nodes with dead leaves generally increased over time (Table 8, Fig. 6). At the first assessment, there were only a few dead nodes on the plants. Without ripping, there were no dead nodes, but a small percentage (around 1%) of nodes had dead leaves when ripping was used ($P=0.01$). Similarly, dead nodes were more likely when the fungicide was not applied ($P=0.05$). At the second assessment, the picture was more complex, with a significant 3-way interaction ($P=0.032$) between fungicide, ripping and irrigation. There was a generally lower percentage of nodes with dead leaves where fungicide was applied, but the fungicide effect was greater when neither ripping nor irrigation were applied. By the fourth assessment, the major factor affecting nodes with dead leaves was fungicide ($P<0.001$), with fewer dead nodes (48%) when fungicide was applied than when it was not (64%). Fungicide was still the major factor at the final assessment ($P<0.001$) with around 78% of nodes with dead leaves with no fungicide compared to 69% where fungicide was applied. However, numbers of nodes with dead leaves were also affected by irrigation and ripping ($P=0.031$ for the interaction), with fewer dead nodes when neither were applied (around 69%), than when either or both were used (around 74%).

Table 8: Percentage of nodes that were dead (95% confidence limits). (Not recorded on 22/12/04).

			Assessment			
Fung.	Irrig.	Rip	22/11/04	07/12/04	18/01/05	31/01/05
Nil	Nil	Nil	0.7 (0.1,3.4)	16.8 (12.5,22.2)	63.3 (59.6,66.9)	77.3 (72.1,81.8)
		With	0.0 (0.0,1.2)	16.3 (12.0,21.6)	63.3 (59.5,67.0)	78.4 (72.8,83.1)
	With	Nil	2.1 (0.8,5.3)	14.7 (10.7,19.9)	64.7 (61.0,68.3)	78.1 (72.4,83.0)
		With	0.4 (0.0,3.4)	17.0 (12.6,22.4)	63.7 (60.0,67.3)	76.9 (71.3,81.6)
With	Nil	Nil	0.3 (0.0,3.3)	5.7 (3.4,9.7)	46.0 (42.1,49.9)	61.8 (56.4,66.9)
		With	0.0 (0.0,1.3)	12.1 (8.5,17.1)	46.8 (43.0,50.6)	71.4 (66.4,76.0)
	With	Nil	0.3 (0.0,3.3)	12.2 (8.5,17.2)	52.3 (48.4,56.1)	73.0 (68.0,77.5)
		With	0.0 (0.0,1.3)	10.1 (6.8,14.8)	45.4 (41.7,49.2)	70.3 (65.0,75.1)

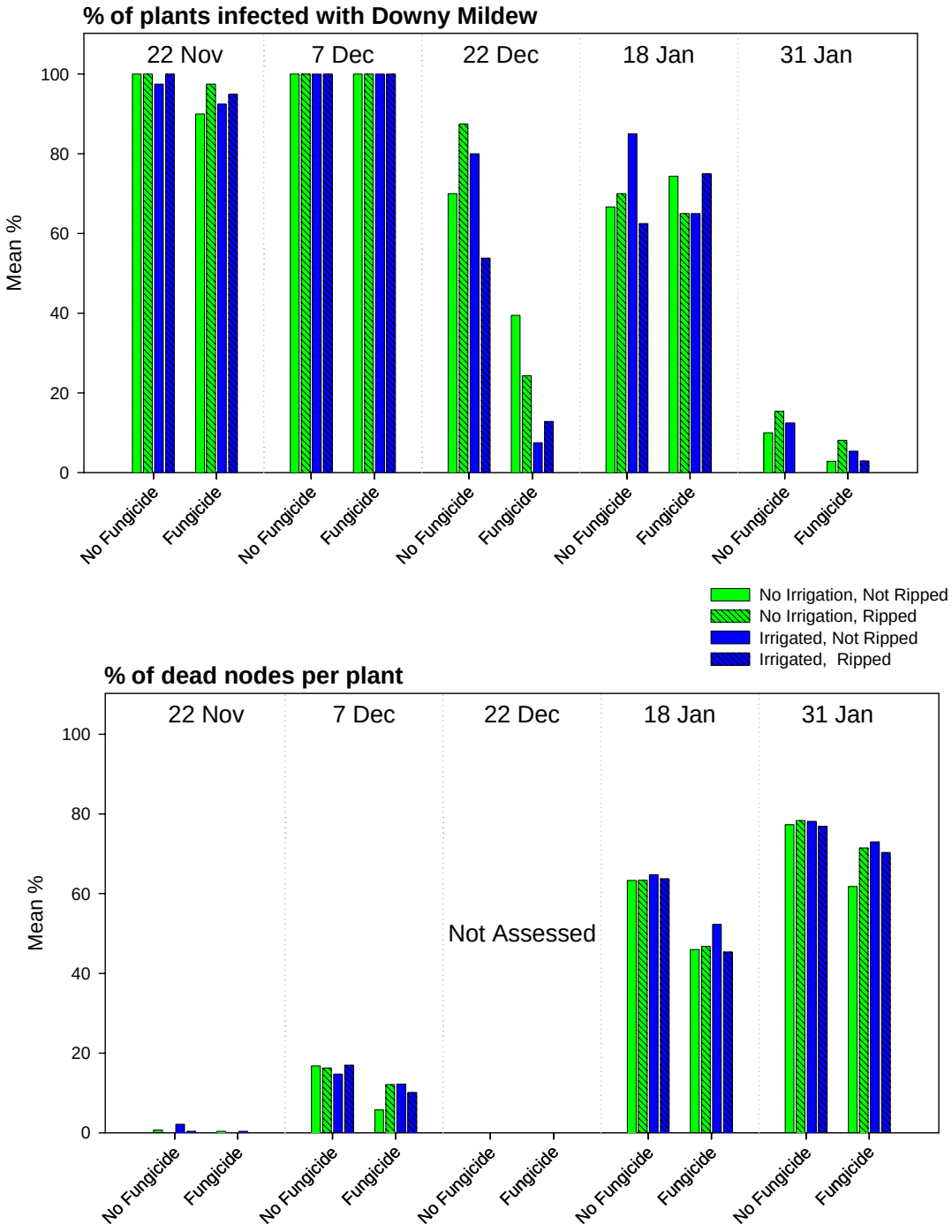

Figure 6: Percentage of infected plants, and percentage of nodes per plant with dead leaves (see table for confidence limits).

4.5.7 *Grain yields*

Yield of harvested grain (Table 9) was not significantly affected (P>0.05) by either the irrigation or the deep ripping cultivation treatments. The fungicide applications resulted in a 76% increase in grain yield, through increased 100 seed weight, mean numbers of pods/plant and peas/pod.

Table 9: Mean plot harvested seed yields and yield components for different treatments applied to plots of Midichi peas in Trial 1.

Treatment	Plot yield (tonne/ha)	100 seed weight (g)	Number of plants/m^2	Number of pods/plant	Number of peas/pod	Mean pea wgt (mg)
Irrigation						
Nil	3.78	33.0	56.1	8.7	5.4	266
With	3.35	32.6	62.4	9.3	5.5	266
LSD(P=0.05)	0.63	2.1	7.1	1.7	0.5	28
Cultivation						
Nil	3.57	32.6	58.0	8.9	5.6	268
Deep ripped	3.57	33.0	60.5	9.2	5.4	264
LSD(P=0.05)	0.38	1.2	7.6	1.1	0.4	11
Fungicide	(+76%)	(+7%)		(+14%)	(+12%)	
Nil	2.58	31.7	58.5	8.4	5.2	262
With	4.55	33.9	60.0	9.6	5.8	270
LSD(P=0.05)	0.38	1.2	7.62	1.1	0.4	11

Further analysis of yield components showed that, in general, only spraying with fungicide had an effect on yield component parameters (Table 10). Treatment with fungicide increased yield. The difference between spraying and not spraying for each parameter is shown in Table 11. In some cases ripping also had an effect, resulting in an increase in yield. The effect of fungicide was always greater than the effect of ripping. For the parameter total peas per m^2, in addition to the main effects of ripping and fungicide, there was an interaction between the two factors (Fig. 7). There was also an interaction, but no main effects, between ripping and fungicide for mean aborted peas per pod (Fig. 8).

Table 10: Important treatment effects on yield component parameters.

Not significant	Fungicide	Fungicide + irrigation	Fungicide + irrigation + interaction	Deep ripping * Spray
Pod number	Total plant fresh weight	Bulk pea fresh weight	Total peas per m^2	Mean number of aborted peas per pod
Remainder fresh weight	Sub-sample fresh weight	Pea number_1		
Remainder dry weight	Pod fresh weight	Total pods per m^2		
Total grain weight	Aborted pea number	Live pod number per m^2		
Total grain weight_1	Pea number			
Total pods per plant	Pea fresh weight			
Pea dry matter %	Dead pod number			
	Dead pod fresh weight			
	Pea dry weight			
	Dead pod dry weight			
	Bulk fresh weight			
	Split pea number			
	Split pea fresh weight			
	Dead pod number per m^2			
	Total live peas per m^2			
	Mean no of peas per pod			
	Mean no live peas per pod			
	Pea yield per pod			
	Pea dry weight per pod			
	Pea yield fresh			
	Pea yield dry			
	Fresh weight per pea			
	Dry weight per pea			
	Pea fresh weight per ha			
	Pea dry weight per ha			

Table 11: Fungicide main effect means.

Spray	Total plant fresh weight	Subsample fresh weight	Pod number	Pod fresh weight	Aborted pea number	Pea number
With	478.60	175.07	104.56	107.10	205.05	295.09
Nil	353.49	135.42	92.94	68.78	142.44	197.69
Spray	Pea fresh weight	Dead pod number	Dead pod fresh weight	Remainder fresh weight	Pea dry weight	Remainder dry weight
With	86.53	18.05	2.66	85.13	79.37	79.42
Nil	53.74	25.94	4.20	76.27	49.13	71.30
Spray	Dead pod dry weight	Bulk fresh weight	Bulk pea fresh weight	Pea number_1	Total grain weight	Split pea number
With	2.47	303.53	136.52	499.66	271.54	26.08
Nil	3.89	218.07	86.08	328.13	261.76	16.81
Spray	Split pea fresh weight	Total pods per m^2	Live pod number per m^2	Dead pod number per m^2	Total peas per m^2	Total live peas per m^2
With	3.17	572.43	472.98	99.45	2723.53	1614.14
Nil	2.10	487.03	351.39	135.65	1777.62	1031.56
Spray	Mean number of peas per pod	Mean live peas per pod	Mean no aborted peas per pod	Total grain weight_1	Total no pods per plant	Pea yield per pod
With	5.75	3.40	2.34	271.54	9.81	0.82
Nil	5.18	3.01	2.17	261.76	8.82	0.58
Spray	Pea dry weight per pod	Pea fresh yield	Pea dry yield	Pea dry matter %	Fresh weight per pea	Dry weight per pea
With	0.75	446.10	408.87	91.68	0.29	0.27
Nil	0.53	279.64	255.76	91.44	0.27	0.25
Spray	Pea fresh weight per ha	Pea dry weight per ha				
With	4.46	4.09				
Nil	2.80	2.56				

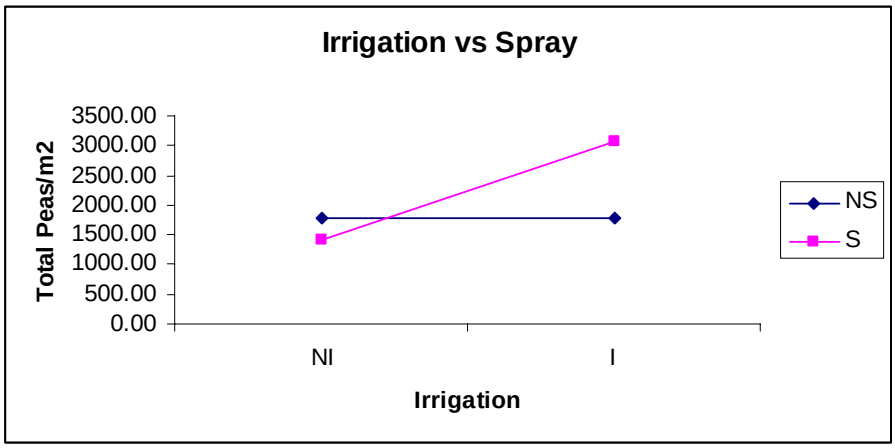

Figure 7: Irrigation X fungicide interaction.

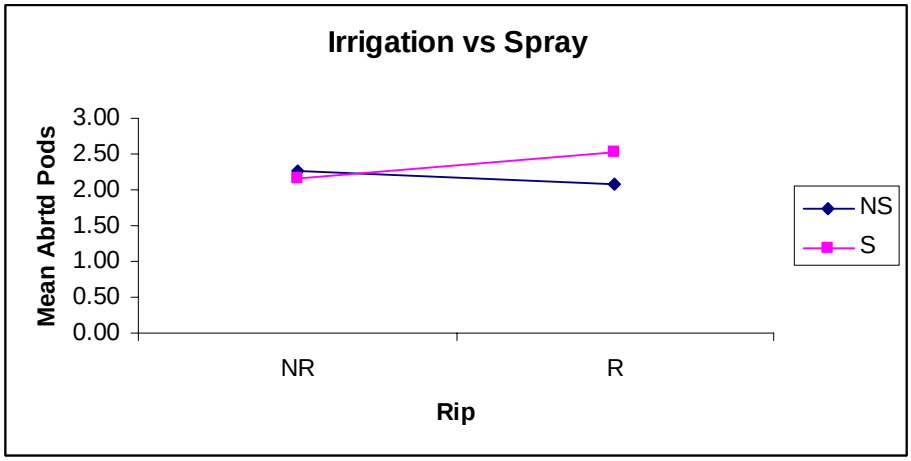

Figure 8: Cultivation X fungicide interaction.

4.5.8 *Infection of seed with* Ascochyta

The overall mean percentage of seed infected with fungi likely to cause Ascochyta blight was 5.2%. There were no obvious treatment effects on the incidence of these fungi, but statistical analysis on these data has not yet been completed.

4.5.9 *St Andrews weather data*

Weather data were received from the weather station located near the trial site from 25 November onwards (this is the day after the weather station was placed in the field). The total rainfall for the month of December at the trial site was 124 mm, more than twice the long-term average for Timaru (Table 12). Rainfall for January was slightly less at the trial site than the long-term average, but February rainfall was considerable more than the long-term average. This was mainly due to a large amount of rainfall during 11-14 February, with 124 mm falling on 14 February (Fig. 9). Both mean minimum and maximum temperatures for the month of December were less than the long-term averages, but January and February means were similar to long-term averages (Fig. 9). Mean daily leaf wetness and the number of hours per day when leaf wetness was more than 50% (leaf wetness more than 50% is considered 'wet' are also graphed (Fig. 9). Rainfall and leaf wetness are the key variables in the epidemiology of *M. pinoides* as they facilitate dispersal, germination, infection and subsequent disease spread during the growing season. It appears that rainfall early in the growing season is very important as it spreads the conidia within the crop. It is therefore important to collect weather data from emergence so that weather conditions in relation to disease spread can be quantified. Canopy closure later in the season provides a barrier for ascospore spread in the canopy (Roger et al. 1999). This season, from 25 November until 17 January, there were 22 rainy days out of 56 days. This, together with high frequency of leaf wetness, provided good conditions for disease spread. However, more data on weather and Ascochyta blight severity over several locations and years are required before accurate disease predictions can be determined.

Table 12: Ten-year (1992-2001) monthly averages for Timaru (data provided by Robert Zyskowski) and actual data for the trial site (in parenthesis).

Month	Mean min temp. (°C)	Mean max temp. (°C)	Total monthly rainfall (mm)
October	4.9	16.3	49.7
November	5.9	17.4	54.4
December	8.6 (7.5)	19.7 (15.9)	54.9 (124)
January	10.0 (10.9)	20.7 (19.6)	47.4 (39)
February	10.1 (12.7)	21.0 (21.0)	38.5 (170)

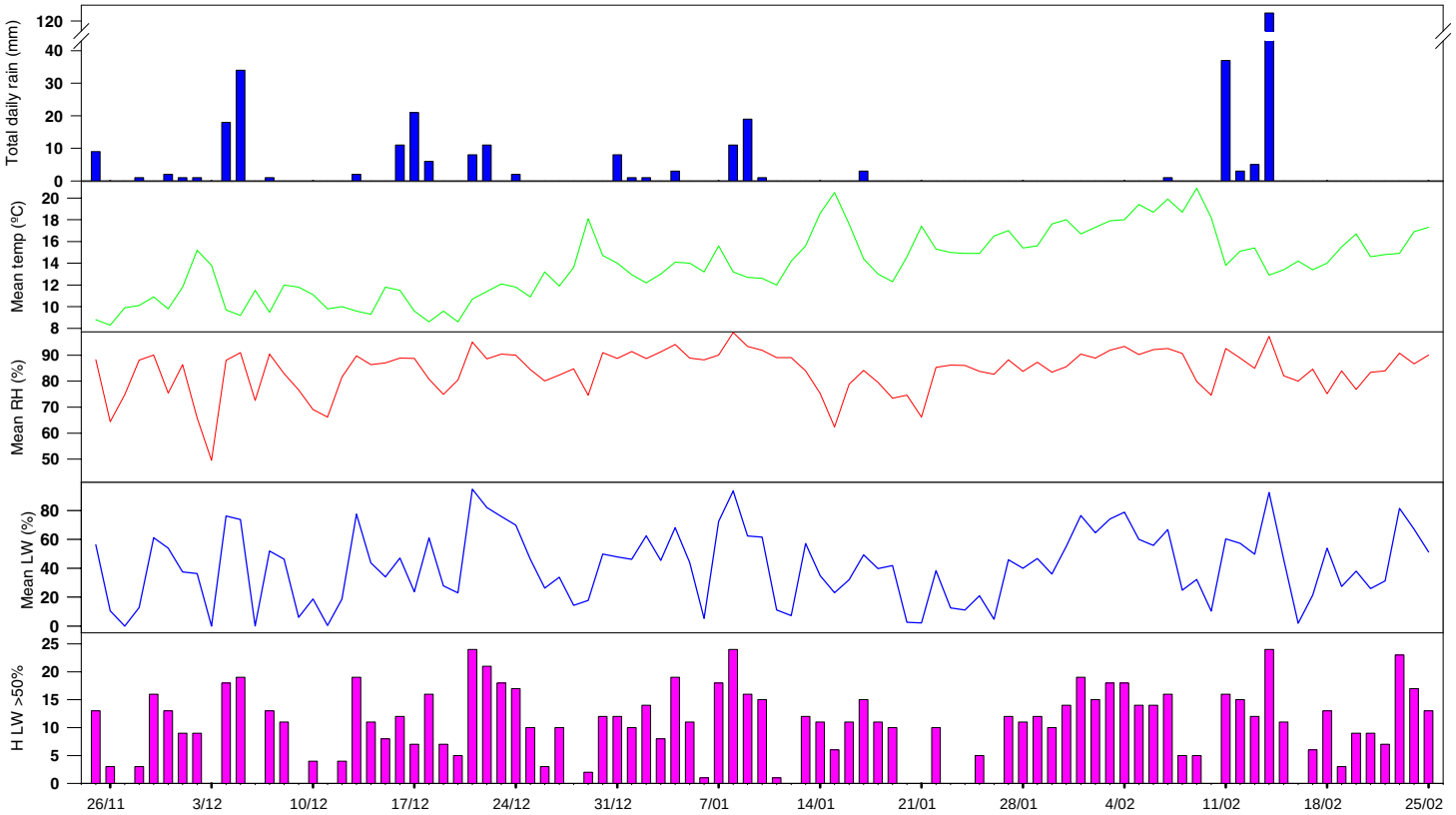

Figure 9: Weather summary obtained from the weather station at the St Andrews trial site.

4.6 Summary of Trial 1 (property of Mr Rob McIlraith, St Andrews, South Canterbury)

The plots in this trial never reached any significant moisture stress levels. The mean maximum soil moisture deficit was 69 mm. Previous research has shown that critical soil moisture deficit causing plant stress is 88 mm. The weather data collected from the trial site showed that in December it rained more than twice as much (124 mm) as the average 10-year rainfall for Timaru (55 mm); both mean minimum and maximum temperatures were less than long the long-term averages.

Overall, fungicide had the greatest effect on Ascochyta blight severity in this trial. There was less disease on whole plants, stems and pods in fungicide-treated plots than in untreated plots. Irrigation and ripping only had a slight effect on Ascochyta scores and, at times, interacted with the fungicide treatments. Ascochyta severity was sometimes more severe when either ripping or irrigation were used than when neither or both were used.

Overall, downy mildew was more severe early in the growing season, with almost every plant having symptoms. Some systemic infection was also noted. Plots treated with fungicide had less downy mildew than untreated plots. The fungicide treatment decreased the number of dead leaves on plants.

The fungicide applications resulted in a 76% increase in seed yield, through increased mean numbers of pods/plant and peas/pod. Further analysis of yield components showed that, in general, only spraying with fungicide had an effect on further yield component parameters. In some cases ripping also had an effect, also resulting in an increase in yield, but the effect of fungicide was always greater than the effect of ripping.

Weather conditions this season appeared conducive to the spread of Ascochyta blight. Weather data for early in the season were not available due to late arrival of the weather station equipment. Data were collected from 25 November onwards and showed that rainfall in December was more than twice as much as long-term average for Timaru. December was also cooler than the long-term average. There were 22 rainy days from 25 November until 19 January, with more than 12 hours of high (more than 50%) leaf wetness, providing ideal conditions for the spread of *M. pinoides*.

5 Trial 2 (property of Mr Bruce Garrett, Ladbrooks)

5.1 Treatments

This trial was with the processing pea cultivar Durango. The trial had eight treatments, consisting of all combinations of two levels of each of three factors:

- **sowing date** (9 October or 2 November 2004): to expose crops to different weather conditions and thereby produce higher and lower yields and differing risk of Ascochyta infection;
- **inoculation** (with and without inoculation with *Mycosphaerella pinoides*): to produce crops with higher and lower levels of Ascochyta infection. Four different isolates of *M. pinoides* were used: one isolate was from the seed used in the trial, the other three were from the Crop & Food Research mycology culture collection. These three isolates were collected from a Winton, Southland, Ascochyta nursery in 2000, 2001, and 2002. The techniques followed for inoculum preparation and inoculation were based on the methodology outlined in Tivoli et al. (1996). This involved culturing the fungus on barley grain previously placed in plastic autoclave bags or glass containers, moistened and autoclaved twice at 121°C for 1 h at 24 h intervals. Treated plots were inoculated by applying the infected grain (300 g/ plot) on 23 November and 8 December 2004;
- **fungicide** (with and without fungicide applications to control foliar diseases): to produce contrasting levels of the disease. A best practice pesticide regime was applied to the treated plots at approx 2-week intervals by NZ Arable, commencing at the three node stage of crop growth in each of the two sowing date treatments. Six fungicide applications were made to the treated plots during crop growth.

5.2 Field layout

32 plots – four replicates of the eight treatments.

- The trial was laid out as a Latinised row and column design, such that there was a whole replicate of the treatments in each row of plots and also a replicate in each set of four rows by two columns of plots. However, only the major blocking (row replicates) was taken into account in the statistical analyses of data (treating the layout as a randomised block design).
- Each plot consisted of two drill-strips, each 10 m long and 1.2 m (eight rows) wide.
- There was a buffer strip on both sides of each plot to keep different sowing dates separate and to provide some isolation between treatments with different levels of disease.

- A weather station (Campbell Scientific CR10X) was placed next to the trial and the following weather data were collected hourly: temperature and relative humidity at 1.4 m height, soil temperature (10 cm below soil surface), leaf wetness, rainfall and solar radiation.

5.3 Crop management

- The paddock was tested to ensure a low risk of Aphanomyces infection. The soil at the trial site was a Wakanui silt loam.
- The site was ploughed from long-term pasture about 2 weeks before sowing, and cultivated to produce a good seed bed.
- The first sowing was planted on 9 October and the second on 2 November. The 128 drill-strips were sown by Plant Research (NZ) Ltd's seeder.
- Treated seed of the processing cultivar Durango was sown at 235 kg/ha (282 g/strip; mean seed weight = 194 mg; germination = 90%; effective field emergence assumed to be 95%) with the aim of achieving a population of about 100 plants/m^2.
- A seed test was carried out on 100 randomly chosen seeds. Seeds were surface sterilised for 10 min using a solution of 1% sodium hypochlorite, rinsed in sterile water and left to dry on filter paper. They were plated in Petri dishes containing PDA and incubated at room temperature for 9 days. Percentage germination of seed and infection by fungi were recorded. Germination was 100% and infection with *Ascochyta pisi* or *Mycosphaerella* was 1%.
- No fertiliser was applied and, apart from the treatments, the trial was managed as the surrounding crop. The trial could have been irrigated if necessary, but no irrigation was applied during the trial period.
- Regular fungicide applications started on 5 and 19 November on the first and second sowings respectively (Tables 13A and B).
- Inoculum was produced in bulk in the laboratory on autoclaved barley grain. It was applied to treated plots (300 g per plot) on 23 November and 8 December.

Table 13A: Fungicide spray application schedule for the first sowing (9 October 2004) of Trial 2 (Garrett property, Ladbrooks). Products and rates applied, and weather conditions at application are indicated.

Spray	Date	Product	Rate	Water rate	Weather conditions
1	5 Nov 2004	Sereno	1.5 kg/ha	250 L/ha	Air temp: 15°C
		Carbendazim	0.5 kg/ha		RH: 65%
		Karate Zeon	40 ml/ha		Cloud cover: 100%
					Wind: 0 km/h N
					Drying cond.: OK
2	19 Nov 2004	Sereno	1.5 kg/ha	250 L/ha	Air temp: 18°C
		Carbendazim	0.5 kg/ha		RH: 65%
		Karate Zeon	40 ml/ha		Cloud cover: 25%
					Wind: 5-10 km/h NW
					Drying cond.: fast
3	3 Dec 2004	Sereno	1.5 kg/ha	250 L/ha	Air temp: 19°C
		Carbendazim	0.5 kg/ha		RH: 65%
		Karate Zeon	40 ml/ha		Cloud cover: 10%
					Wind: 5-10 km/h NE
					Drying cond.: fast
4	17 Dec 2004	Sereno	1.5 kg/ha	250 L/ha	Air temp: 15°C
		Amistar	0.75 L/ha		RH: 70%
		Folicur	0.44 L/ha		Cloud cover: 75%
		Karate Zeon	40 ml/ha		Wind: 5 km/h N
					Drying cond.: good
5	29 Dec 2004	Sereno	1.5 kg/ha	250 L/ha	Air temp: 19°C
		Amistar	0.75 L/ha		RH: 60%
		Folicur	0.44 L/ha		Cloud cover: 25%
		Karate Zeon	40 ml/ha		Wind: 5-10 km/h NW
					Drying cond.: fast

Table 13B: Fungicide spray application schedule for the second sowing (2 November 2004) of Trial 2 (Garrett property, Ladbrooks). Products and rates applied, and weather conditions at application are indicated.

Spray	Date	Product	Rate	Water rate	Weather conditions
1	19 Nov 2004	Sereno	1.5 kg/ha	250 L/ha	Air temp: 18°C
		Carbendazim	0.5 kg/ha		RH: 65%
		Karate Zeon	40 ml/ha		Cloud cover: 25%
					Wind: 5-10 km/h NW
					Drying cond.: fast
2	3 Dec 2004	Sereno	1.5 kg/ha	250 L/ha	Air temp: 19°C
		Carbendazim	0.5 kg/ha		RH: 65%
		Karate Zeon	40 ml/ha		Cloud cover: 10%
					Wind: 5-10 km/h NE
					Drying cond.: fast
3	17 Dec 2004	Sereno	1.5 kg/ha	250 L/ha	Air temp: 15°C
		Carbendazim	0.5 kg/ha		RH: 70%
		Karate Zeon	40 ml/ha		Cloud cover: 75%
					Wind: 5 km/h N
					Drying cond.: good
4	29 Dec 2004	Sereno	1.5 kg/ha	250 L/ha	Air temp: 19°C
		Amistar	0.75 L/ha		RH: 60%
		Folicur	0.44 L/ha		Cloud cover: 25%
		Karate Zeon	40 ml/ha		Wind: 5-10 km/h NW
					Drying cond.: fast

5.4 Measurements

- **Soil moisture** content profiles were measured each week by Hydro Services in all plots of two treatments: no inoculum/with fungicide and with inoculum/without fungicide (these treatments were expected to be the highest and lowest yielding treatments for both sowing dates). The neutron tube access tubes were placed to a depth of 1.0 m and readings were taken every week at six different depths: 0-200, 200-300, 300-400, 400-500, 500-600, and 600-800 mm using a CPN 503DR neutron probe. Results were used to schedule irrigations and to determine the effects of the treatments on (a) crop water use, (b) patterns of water extraction from the root zone, and (c) timing and severity of water deficit.
- **Disease incidence** and severity were assessed during vegetative growth and during pod-fill. Plants were harvested from plots and assessed in the laboratory for Ascochyta blight and downy mildew severity (see Appendices I to V). Stems, individual leaves, stipules, and pods were

scored at each node for Ascochyta, and leaf and stipule tissues at each node were given an overall score for downy mildew. Nodes with dead leaves were scored as dead. The first full assessment was carried out on 24 November (46 days after sowing) for the October sowing, and on 29 December (57 days after sowing) for the November sowing. At this assessment, each node of 10 plants per plot was scored. Every plot was assessed. An intermediate assessment was carried out on 8 December 2004. At this assessment, all four plots from replicate 4 that were inoculated with *Mycosphaerella* were assessed. Ten plants per plot were scored, as for the first full assessment. A second intermediate assessment was carried out on 19 January 2005. At this assessment, two plots from the first sowing were scored for Ascochyta severity. A second full Ascochyta assessment was carried out on 7 January (90 days after sowing) for the October sowing and on 22 January (81 days after sowing) for the November sowing. Downy mildew was assessed as present or absent. In some cases, no data were obtained from some plants in a plot because of plant breakage during transport, with a maximum of 2 plants missing in a plot.

- **Crop growth stages** were assessed for 10 plants randomly selected from the guard rows of one replicate, for one October- and one November-sown plot. Different plots were used at each assessment, with assessments done approximately weekly from 11 November 2004. Vegetative and reproductive stages (Knott 1987) were recorded.
- **Crop growth** was measured twice, at first flower and at mid pod-fill growth stages in each sowing (about TR = 105). The two measurements on the first sowing date plots were done on 2 December and 7 January, and on the second sowing date plots on 30 December and 31 January. Each time, all plants in a 0.5 m^2 quadrate were removed from each plot and growth characteristics (plant populations, biomass, leaf area index, numbers of nodes, first flowering node, numbers of branches, numbers of pods, numbers of peas/pod, pod and pea weights, leaf and stem fresh and dry weights) were measured.

Yield was measured at two stages for each sowing:

1. ***Process pea yield*** was measured at about TR = 105. A 2 m^2 quadrat was removed from the sampling drill-strip of each plot, peas removed with a mini-viner, and yield and TR score were measured. This was done for plots from the first sowing date on 10 January, and for the second sowing date on 28 January.
2. ***Seed yield*** was measured at maturity, both on 1 m^2 quadrat samples and on combine samples harvested from the second drill-strip of each plot by Plant Research (NZ) Ltd. This was done for plots from the first sowing date on 27 January, and for the second sowing date on 16 February.

- **Ascochyta *infection in harvested seed*** was measured after harvest. Samples from each plot were supplied to the plant pathology laboratory to test for the presence of *Ascochyta* spp. The methodology used was as recommended by ISTA (International Rules for Seed Testing 7-005 (2002): Detection of *Ascochyta pisi* on *Pisum sativum* (Pea)). Fifty seeds

were randomly taken from each of the samples and surface sterilised using a solution of 1% sodium hypochlorite (available chlorine) for 10 min, followed by draining. Ten seeds were placed on each Petri dish containing PDA (potato dextrose agar). Plates were incubated at 20^{0}C and examined for colony growth after 7 days. No Ascochyta was found.

- ***Crop stress measured as percentage of reflected light*** was measured on 27 January 2005 in the November sowing plots using the multispectral radiometer (CROPSCAN, Inc. Fargo, ND). Cropscan Radiometer System is a remote sensing system designed to detect, measure, record and analyse energy in selected portions of the electromagnetic spectrum. The amount and quality of light reflected from a crop canopy are dependent on both the crop species and the condition of the crop. Stresses of various kinds (e.g. pests, diseases, nutrient deficiencies and drought) affect reflectance. The radiometer is therefore particularly useful as an objective and efficient means of estimating the impact of any condition that affects plant health, yield, or quality of the crop. The features of the system are upward- and downward-facing sensors that measure both incoming and reflected radiation, which interfaces with the CROPSCAN DLC, a multichannel Data Logger Controller. Two readings for each of the 8 wavelengths per plot were made, and averaged to one value per plot. The results of 810 nm are given in Section 5.6.

- ***Weather data*** were collected from a Campbell Scientific CR10X weather station that measured hourly temperature and relative humidity at 1.4 m height, soil temperature (10 cm below soil surface), leaf wetness, rainfall and solar radiation. The weather station was placed in the field site on 24 November and weather data from midnight 25 November were used in this project. Long-term means (1975-1991) for Broadfield's weather station were used to allow comparisons of this season's weather variables with long-term means.

5.5 Statistical analyses

- **Soil moisture** measurements were taken in all plots of two treatments: no inoculum/with fungicide and with inoculum/without fungicide for both sowing dates. Soil measurements were taken regularly from 23 November. For the October-sown plots, soil probe measurements ceased on 20 January, but they were continued for nearly 4 weeks more for November-sown plots, with the last measurement taken on 15 February. The mean, maximum, and total deficits over dates were calculated for each plot. Each of these was strongly affected by the greater number of measurements taken for the November-sown plots, in particular because soil moisture deficit was high in February. These plot summaries were analysed with analysis of variance. Only soil moisture deficits are explored here.

- **Ascochyta** was not present before January, so only data from the second full assessment were analysed. Average scores were calculated for each assessed plant (averaging over nodes for pods, stipules, leaves and stem scores), and then the average of these scores per plot was calculated. Average plot scores were also calculated for Pod 1, Pod 2 and

stem. Scores for Leaf 1 and Leaf 2 and Stipule 1 and Stipule 2 were zero in the majority of cases, so these were not included in the analyses. The plot averages were analysed with analysis of variance.

- **Average downy mildew** scores were calculated for each assessed plant (averaging over nodes), and then the average score of these per plot was calculated. The first full assessment for the two sowing dates was analysed with analysis of variance.
- **The percentage of plants with disease** was calculated for each plot. For the two full assessments, these were analysed with a binomial generalised linear model (McCullagh & Nelder 1989). The effect of sowing date, Mycosphaerella inoculation and fungicide were assessed in the analysis of deviance in this analysis, similarly to analysis of variance. In the table of results, 95% confidence limits are presented with the percentage infected plants. These were calculated as part of the analysis. Since only one replicate was assessed for the intermediate assessment, no formal statistical comparisons were possible.
- **The number of nodes and dead nodes** for each plant were calculated using the downy mildew data. The mean number of nodes per plant for the plants from each plot was then calculated. The percentage of dead nodes per plot was calculated as 100 x (total dead nodes per plot) / (total number of nodes per plot). This gave a plot average weighted by the total number of nodes per plant, which was, in practice very close to percentage mean dead for each plant for each plot. Mean numbers of nodes were analysed with analysis of variance. The percentage of dead nodes was analysed in the same way as the percentage of disease plants, using a binomial generalised linear model.
- **Growth stages**: Since growth stages were only assessed from one plot per sowing date at any assessment, and the plots sampled were chosen at random ignoring the treatments, no formal comparison could be made. Therefore, the average score (vegetative and reproductive growth stage) was calculated for each sowing and sampling date. A standard error of these means was calculated from the separate standard deviations for each sowing and sampling date (excluding the first date for the November sowing). The 95% confidence limits on the graph were calculated from these pooled standard errors.
- **Percent reflectance**: The results for percent reflectance at the 810 nm wavelength were analysed with analysis of variance.

All analyses were carried out with GenStat (GenStat Committee 2005).

5.6 Results

5.6.1 Soil moisture deficit

Changes in soil moisture deficit over time followed similar patterns for all plots (Fig. 10). In the last month, after measurements on the October-sown plots ceased, moisture deficit was high in all plots. The major differences in maximum, mean and total soil moisture deficits were related to sowing date, with a higher deficit for November-sown crops for each (P=0.007, 0.052, 0.002) respectively. These higher values are strongly related to the larger number of assessments done, particularly as the deficit was noticeably higher in February. However, the analyses were also heavily affected by one very low value (Plot 1) and one very high value (Plot 8) for all three measurements: both of these plots were in Replicate 1 on the ends of the replicate, and both in November-sown crops. Therefore, to assess the influence of these plots, the analysis was repeated, excluding all the data for Replicate 1. With the removal of these data, the sowing date effect remained (P<0.001 for all measurements), but the estimated random variability was substantially lower (as reflected in the smaller LSDs in Table 14). There was some evidence of treatment effects: for the November sowing, the deficit was lower when the treatments (fungicide, *Mycosphaerella* inoculation) were applied than when they were not applied (P=0.088, 0.026, 0.021 for maximum, mean, minimum for the sowing date X treatment interaction).

The plots did not reach any significant moisture stress, but in November-sown plots there was a slight deficit during pea maturation, a period during which soil moisture levels are not important. The mean maximum soil moisture deficit reached was 90 mm and the maximum individual plots was 110 mm.

Yield was weakly related to deficit, with larger yields in general when the deficit was lower (Fig. 11). Two plots (November, sprayed, in reps 3 and 4) had higher yields given the deficit than for the rest of the trial. The correlations (r) between yield and deficit were -0.54, -0.60 and -0.60 for maximum, mean and total soil moisture deficits respectively.

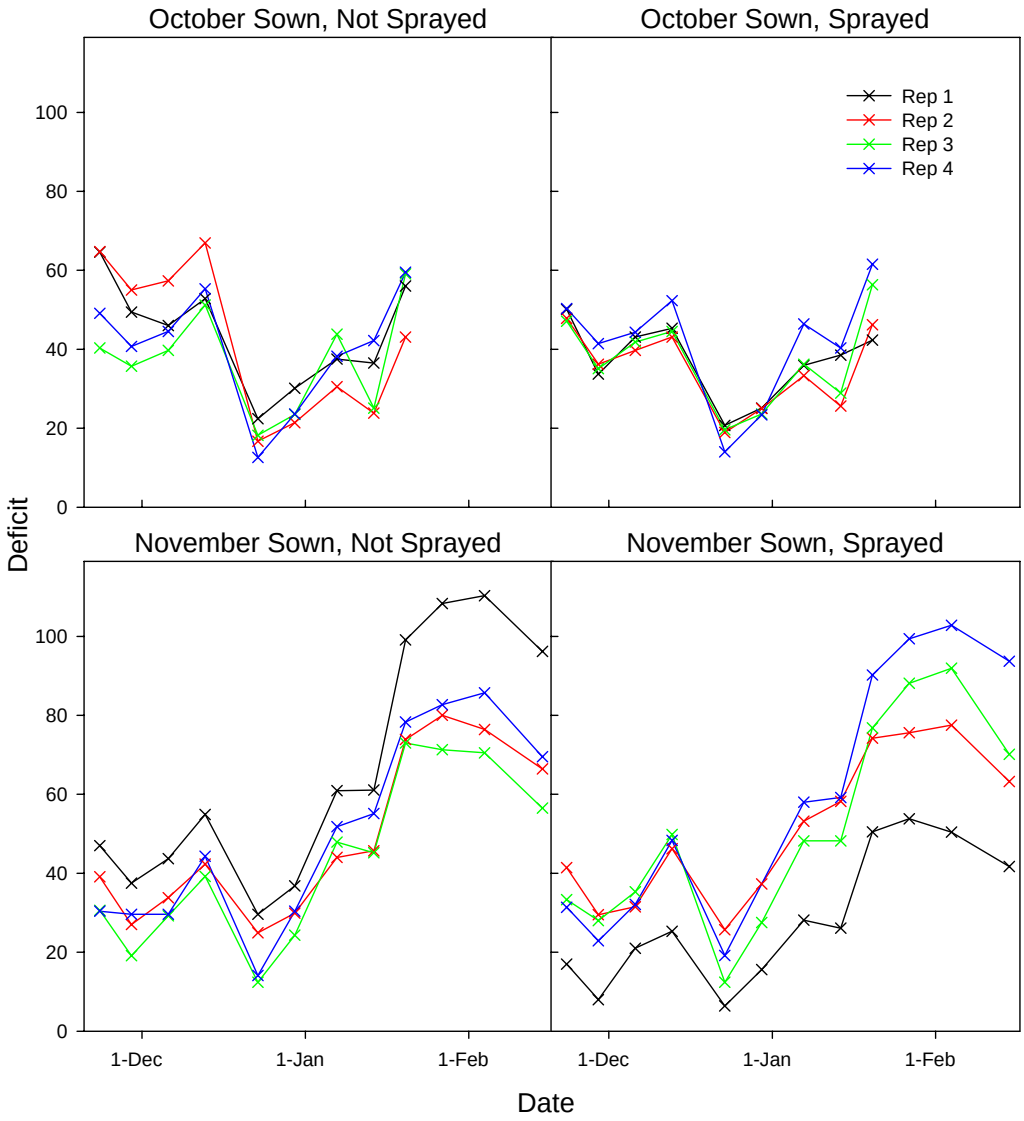

Figure 10: Probe moisture measurements over time for each measured plot (Ladbrooks).

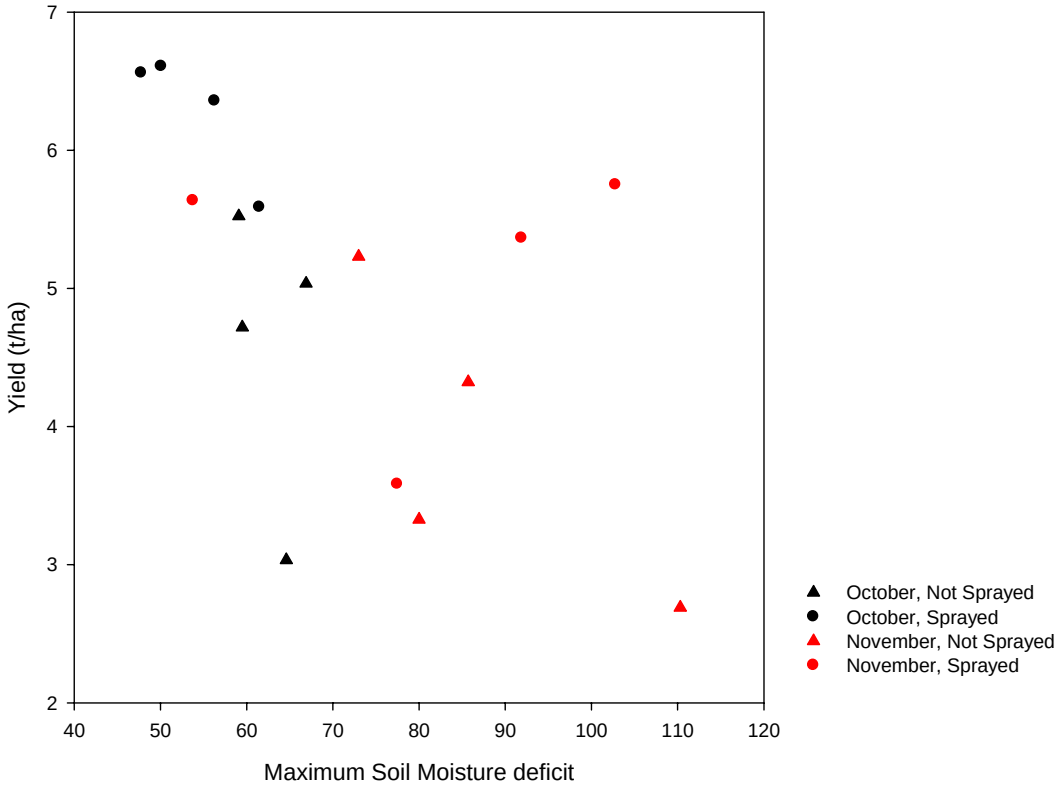

Figure 11: Relationship between yield and maximum soil moisture deficit for the Ladbrooks trial.

Table 14: Ladbrooks, mean summaries of soil moisture deficit (all data, excluding the data for replicate 1).

			All data			Rep 1 excluded		
Sowing date	Fungicide	Inoculum	Max	Mean	Total	Max	Mean	Total
Oct	Nil	With	62.52	41.03	369.25	61.83	40.06	360.57
Oct	With	Nil	53.92	37.71	339.38	55.20	37.88	340.93
Nov	Nil	With	87.25	51.86	622.38	79.57	47.34	568.03
Nov	With	Nil	81.50	47.58	556.05	90.73	53.89	626.77
LSD 5%			24.36	14.82	167.77	15.15	5.16	43.74
df			9			6		

5.6.2 *Ascochyta blight*

Asochyta blight was first noted on 7 January in the October-sown plots and on 22 January in the November-sown plots. Average plant Ascochyta blight severity score varied with sowing date, fungicide and *Mycosphaerella* inoculation treatments (P=0.023 for the three-way interaction). Scores were lower for both sowing dates, with and without inoculation when fungicide was applied, but the reduction varied (Fig. 12, Table 15). The greatest amount of Ascochyta was in the November sowing in the *Mycosphaerella*-inoculated plots when there was no fungicide, and the least was in the October sowing in the uninoculated plots where fungicide was applied. Inoculation had little effect on the October sowing when fungicide was not applied; there was a similar pattern in the November sowing, but when fungicide was applied.

Stem scores varied between sowing dates (P=0.003) and were affected by fungicide (P=0.034) and *Mycosphaerella* inoculation (P<0.001), but these factors had largely independent effects (no interaction was statistically significant at the 5% level; Fig. 12, Table 15). Stem Ascochyta score was greater in the November sowing (6.8 compared to 4.9 on average) or in the absence of fungicide (7.6 compared to 4.2 with fungicide on average), or when Ascochyta was inoculated (6.5 compared to 5.2 with no inoculation, on average).

Severity on both pods 1 and 2 was heavily affected by *Mycosphaerella* inoculation, and fungicide, and varied also between sowing dates (P=0.002 and P=0.023 for pods 1 and 2 respectively; Fig. 12, Table 15). The pattern for the two pods was very similar, with very low average scores for fungicide-sprayed pods. There was no Ascochyta on unsprayed, uninoculated plots in the October sowing, with a slight infection (average score below 0.2) in the October, inoculated, sprayed plots. In the November sowing, there was slightly more Ascochyta on unsprayed plots in the absence of fungicide (average score around 0.2), but a much greater infection level when the plot was both unsprayed and inoculated (average scores of 1.5 and 0.75 for the two pods).

Table 15: Mean Ascochyta scores for each treatment.

Sowing	*Myco*. inoc.	Fungicide	Average plant score	Pod 1	Pod 2	Stem
Oct	Nil	Nil	2.35	0.00	0.00	5.88
		With	0.51	0.07	0.03	2.71
	With	Nil	2.30	0.17	0.09	6.38
		With	1.34	0.10	0.07	4.74
Nov	Nil	Nil	1.97	0.24	0.22	8.27
		With	1.12	0.02	0.05	4.08
	With	Nil	3.01	1.15	0.75	9.90
		With	1.04	0.00	0.00	5.14
LSD 5% (df=21)			0.85	0.23	0.23	2.40

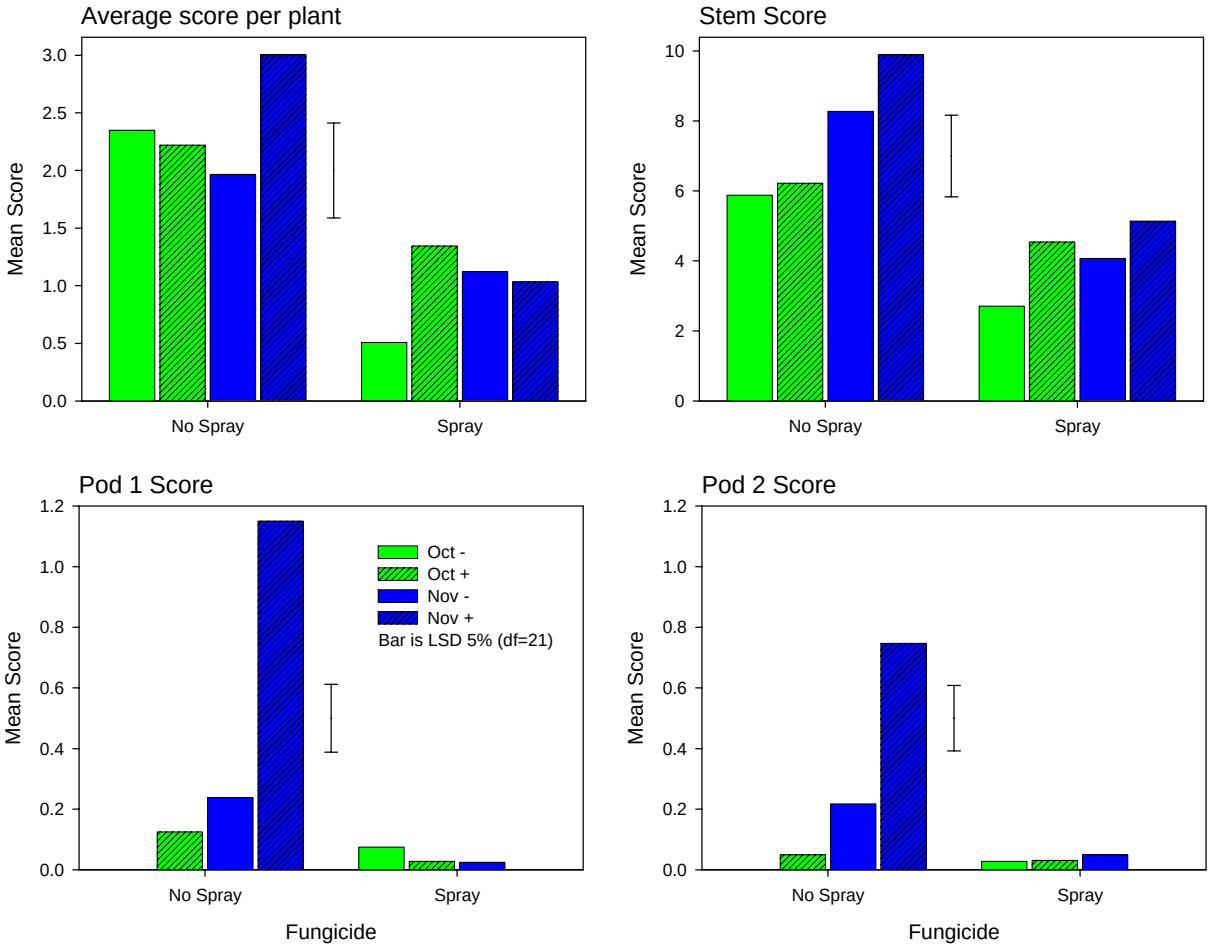

Figure 12: Mean Ascochyta scores on plants, stems and the first two pods.

5.6.3 Downy mildew

Average downy mildew plant score (Table 16, Fig. 13) varied with both sowing date and fungicide (*P*=0.029 for the interaction), but there were no statistically significant effects relating to *Mycosphaerella* inoculation (*P*>0.05). For the October sowing, downy mildew severity levels were substantially lower than for the November sowing, with average scores below 1 for the October sowing, and above 2 for the November sowing. Fungicide reduced disease scores, on average, but the effect was greater in the November sowing than in the October sowing. These differences were probably partly due to the longer time between sowing and the first full assessment for the November sowing (57 days) compared to the October sowing (46 days).

The percentage of infected plants varied with sowing date (*P*<0.001) in the first full assessment, but was not strongly affected by either *Mycosphaerella* inoculation or fungicide (*P*>0.02 or greater). All plants in the November sowing were infected, but only around 88% of plants in the October sowing showed some infection at the first full assessment. In contrast, at the second full assessment, the percentage of infected plants varied with both sowing date and with *Mycosphaerella* inoculation (*P*=0.029), with no effect of the fungicide

(*P*>0.05). Infection levels were higher in the October sowing than for the November sowing. Percentage infection with downy mildew was reduced by *Mycosphaerella* inoculation in both sowings, with a smaller reduction in the October sowing date (94% incidence of downy mildew on average compared to 100%), than in the November sowing (53% incidence compared to 63%).

Table 16: Downy mildew: mean plant scores and percentage of plants with infection for each treatment (95% confidence limits in brackets, for percentage infection.).

			First full assessment		Intermediate	Second full assessment
Sow date	*Myco* inoc.	Fung.	Average plant score	% of plants with infection	% of plants with infection	% of plants with infection
Oct	Nil	Nil	0.76	92.5 (79.2,97.6)		100.0 (91.0,100)
		With	0.38	85.0 (70.4,93.1)		100.0 (91.0,100)
	With	Nil	0.63	90.0 (76.2,96.2)	100.0	95.0 (82.1,98.7)
		With	0.20	85.0 (70.4,93.1)	100.0	92.1 (78.2,97.4)
Nov	Nil	Nil	3.26	100.0 (90.7,100)		56.4 (40.7,70.9)
		With	2.23	100.0 (91.0,100)		71.1 (54.9,83.2)
	With	Nil	3.20	100.0 (90.7,100)	20.0	50.0 (35.0,65.0)
		With	2.23	100.0 (90.3,100)	70.0	56.4 (40.7,70.9)
LSD 5% (df=21)			0.53			

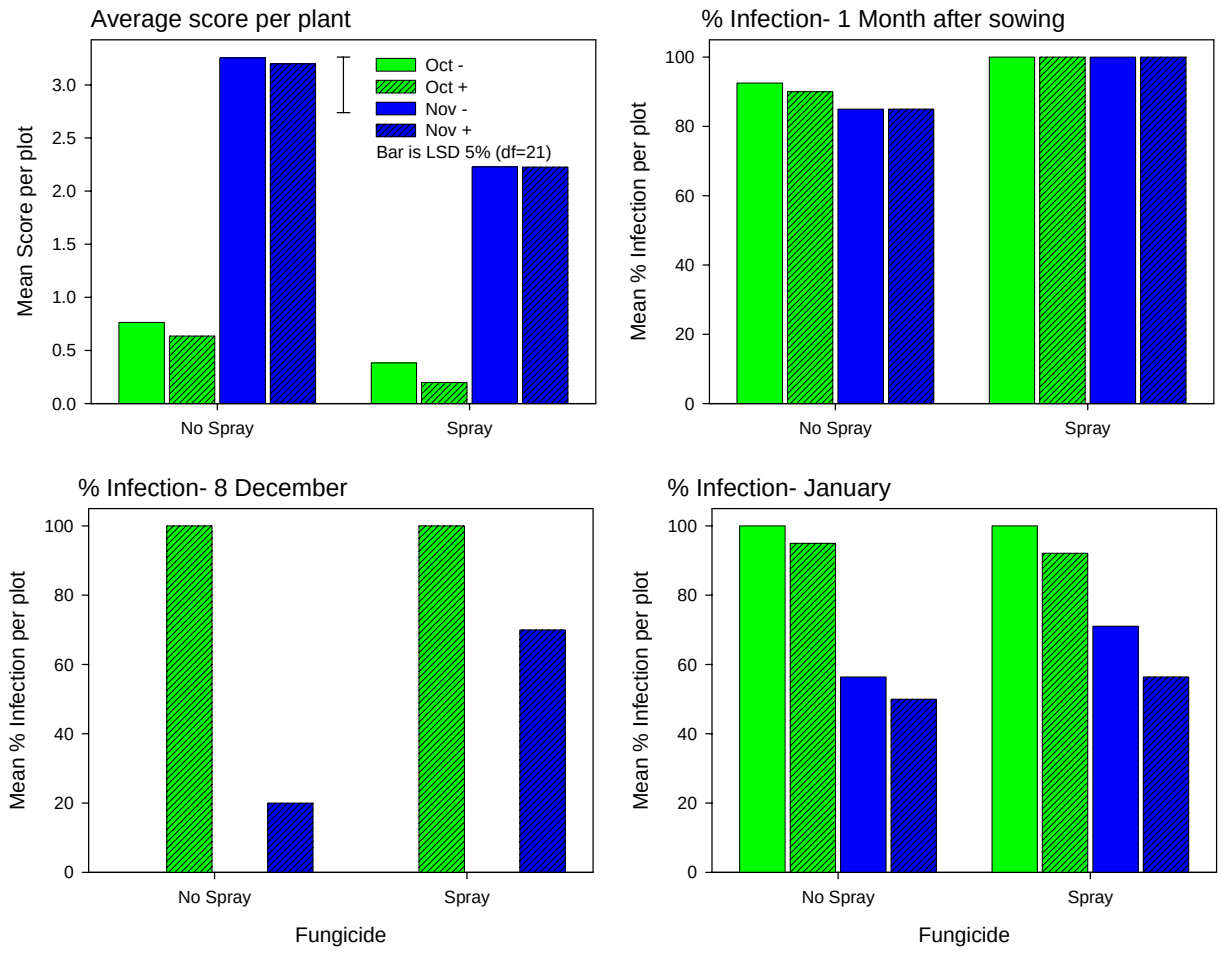

Figure 13: Downy mildew severity and incidence. (95% confidence limits for % infection not shown; + or – refers to Mycosphaerella *inoculation).*

5.6.4 Number of nodes, percentage of dead nodes

At the first full assessment, numbers of nodes varied with sowing date (*P*<0.001), but was not affected by either fungicide or *Mycosphaerella* inoculation (*P*>0.05, Table 17, Fig. 14). There were approximately two more nodes (mean = 10.9) in the November sowing date than in the October date (mean = 8.8), probably primarily reflecting the larger number of days between sowing and assessment. At this assessment, the percentage of dead nodes on the plants was affected by *Mycosphaerella* inoculation and fungicide applications in addition to sowing date. Overall, the percentage of dead nodes was substantially lower in the October sowing (below 1%, *P*<0.001) than in the November sowing (above 18% on average). The effect of inoculating with *Mycosphaerella* varied due to the fungicide applications (*P*=0.021), with little effect of inoculum when fungicide was used (4% dead nodes on average). However, the percentage of dead nodes increased when there was no fungicide and where inoculum had been applied (average of 14% dead nodes with no inoculum compared to 19% where inoculum had been applied).

At the second full assessment, numbers of nodes were not affected by *Mycosphaerella* inoculation ($P>0.4$), but did vary between sowing dates and due to the fungicide applications ($P=0.032$ for the sowing date X fungicide interaction). There were fewer nodes on average in the October sowing (mean of 13.6) than in the November sowing (greater than 17), nodes decreased in this sowing by about 0.5 per plant due to the fungicide applications. For percentage of nodes with dead leaves, the effect of fungicide varied both due to *Mycosphaerella* inoculation and between sowing dates ($P=0.05$ in the 3-way interaction). The percentage of nodes with dead leaves was lower in the October sowing than in the November sowing, with less than 50% of nodes dead in October and more than 57% of nodes dead in the November sowing. *Mycosphaerella* inoculation had little effect on the percentage nodes with dead leaves in the November sowing, but there was a greater percentage of dead nodes in the absence of fungicide than when fungicide was applied. In the October sowing, inoculation had little effect in the absence of fungicide, with around 44% of nodes dead, but where fungicides were applied, more nodes were dead where *Mycosphaerella* inoculum was applied than in the equivalent uninoculated treatment (48% compared to 38%).

Table 17: Mean number of nodes and % dead nodes for each treatment (95% confidence limits in brackets, for % dead nodes).

			First assessment		Second assessment	
Sowing	*Myco* inoc	Fungicide	Nodes	% Dead nodes	Nodes	% Dead nodes
Oct	Nil	Nil	8.7	0.0 (0.0,1.1)	13.5	45.7 (39.8,51.8)
		With	8.7	0.3 (0.0,4.4)	13.9	38.0 (32.4,43.9)
	With	Nil	8.6	0.6 (0.1,4.0)	13.5	42.6 (36.8,48.6)
		With	9.0	0.0 (0.0,1.0)	13.8	47.5 (41.6,53.6)
Nov	Nil	Nil	10.9	25.1 (19.7,31.4)	17.4	65.1 (59.8,70.0)
		With	11.0	8.9 (5.7,13.5)	17.2	59.7 (54.4,64.8)
	With	Nil	10.8	34.8 (28.6,41.6)	17.6	67.4 (62.4,72.1)
		With	11.0	5.6 (3.1,9.7)	16.9	58.9 (53.5,64.0)
LSD 5% (df=21)			0.6		0.7	

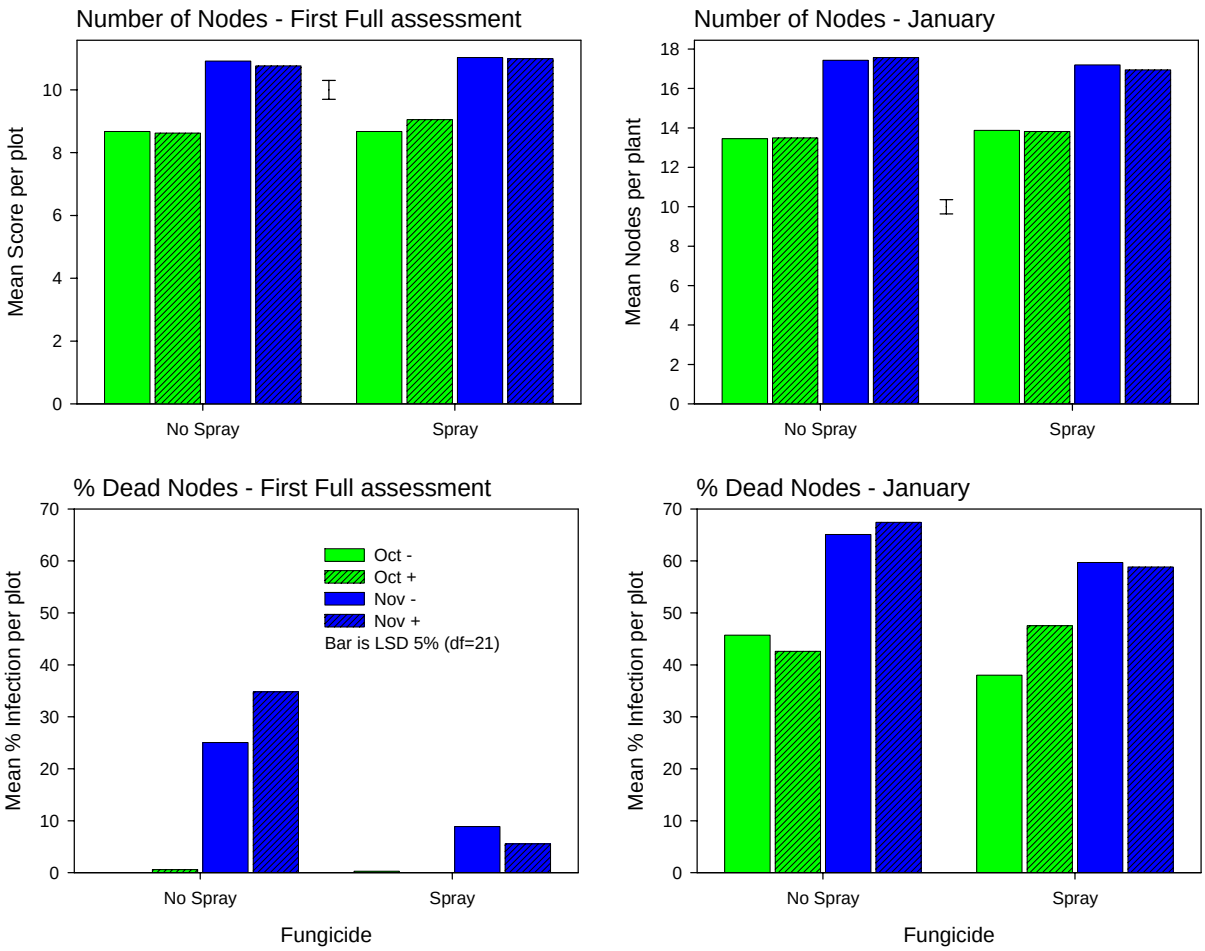

Figure 14: Numbers of nodes, and % dead nodes. (95% confidence limits for % dead not shown; + or – refers to Mycosphaerella *inoculation).*

5.6.5 Growth stage

Table 18 and Figure 15 summarise the mean growth stages (GS) for 10 plants taken from plots of each of the sowing dates at approx 1-week intervals during the trial. Plants from both sowings produced approx. 16 nodes (GS 116). Flowering (GS 201) for plants in the October sowing was first recorded on 1 December (53 days after sowing), and in the November sowing on 31 December (59 days after sowing).

Table 18: Mean growth stages for the two sowing dates.

	Vegetative stage		Reproductive stage	
Date	October	November	October	November
11/11/04	105.5	4.0[1]	*	*
17/11/04	108.4	102.5	*	*
24/11/04	110.2	104.3	*	*
01/12/04	110.6	105.3	201.4	*
08/12/04	111.5	106.2	203.7	*
15/12/04	112.0	108.2	204.5	*
22/12/04	115.7	109.9	205.6	*
31/12/04	116.6	113.1	206.0	201.9
05/01/05	115.2	114.2	206.4	203.6
13/01/05	115.1	114.1	207.0	205.0
19/01/05	115.1	116.1	208.8	206.2

*No plants at a reproductive stage.
[1]The growth stage at this assessment was at the germination and emergence stage.

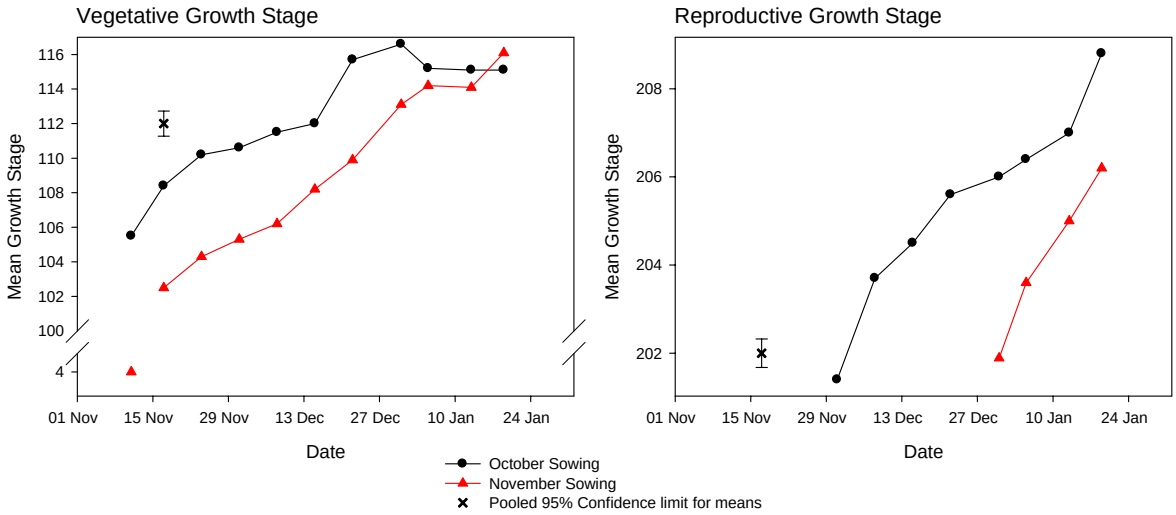

Figure 15: Mean growth stages, for each sowing date, assessed over three months.

5.6.6 *Vining yields*

Vining yield from the October sowing date was 12 tonnes/ha and from the November sowing date, 9 tonnes/ha. This represented a 33% lower vining yield from the later sowing.

5.6.7 *Grain yields*

The November sowing gave grain yields that were 17% greater than from the October sowing (Table 19). This was due to a 24% greater plant population in the late sowing than in the early sowing. Inoculation of plots with *Mycosphaerella* slightly decreased grain yields, an effect that was not statistically significant ($P > 0.05$). The fungicide applications resulted in a 21% increase in grain yield. This was due to increases in the mean number of pods/plant and mean seed weight.

Further analysis of yield components showed that sowing date and spraying with fungicide had an effect on yield component parameters. Treatment with fungicide increased yield. Sowing in October also increased the yield compared with the November sowing except for the variable total grain weight. The significant differences between spraying and not spraying, and October and November sowing date for each parameter are shown in Table 20.

Table 19: Mean plot harvested seed yields and yield components for different treatments applied to plots of Durango peas in Trial 2.

Treatment	Plot yield (tonne/ha)	100 seed wt (g)	No of plants/m^2	No of pods/plant	No of peas/pod	Mean pea wt (mg)
Sowing date	(+17%)		(+24%)		(+9%)	(-6%)
October	4.85	21.4	91.0	5.6	7.0	190
November	5.67	21.5	112.6	5.4	7.6**	179
LSD (*P*=0.05)	0.28	0.54	9.1	0.5	0.4	6
Inoculation						
Nil	5.38	21.3	104.4	5.3	7.3	184
With	5.14	21.6	99.2	5.7	7.2	184
LSD (*P*=0.05)	0.28	0.54	9.1	0.5	0.4	6
Fungicide	(+21%)	(+6%)		(+20%)		(+8%)
Nil	4.75	20.8	104.6	5.0	7.3	177
With	5.77	22.1	99.0	6.0	7.3	192
LSD (*P*=0.05)	0.28	0.54	9.08	0.5	0.4	6

Table 20: Fungicide and sowing date main effect means (only significantly different variables presented).

Spray	Total plant fresh wt	Subsample fresh wt	Pod fresh wt	Pea no	Pea fresh wt	Pea dry wt
With	531.19	114.19	73.63	299.88	60.18	55.22
Nil	456.06	96.65	58.24	248.81	48.90	43.04
Spray	Bulk fresh wt	Bulk pea fresh wt	Pea no_1	Total grain wt	Total pods per m^2	Live pod no per m^2
With	417.00	216.82	1132.06	191.60	581.59	535.95
Nil	359.41	168.67	961.88	176.48	516.07	472.83
Spray	Total peas per m^2	Total live peas per m^2	Total no pods per plant	Pea dry wt per pod	Pea fresh yield	Pea dry yield
With	3922.21	2820.52	6.18	0.88	554.00	508.20
Nil	3443.13	2344.47	5.10	0.79	435.15	387.53
Spray	Pea fresh wt t per ha	Pea dry wt t per ha				
With	5.54	5.08				
Nil	4.35	3.88				
Sowing	Total plant fresh wt	Dead pod no	Dead pod fresh wt	Bulk fresh wt	Bulk pea fresh wt	Bulk pea no
Oct	532.29	6.31	1.25	425.10	221.02	1231.56
Nov	454.96	3.25	0.45	351.31	164.48	862.38
Sowing	Total grain wt	Total pods per m^2	Live pod no per m^2	Dead pod no per m^2	Total peas per m^2	Total live peas per m^2
Oct	178.49	599.55	538.53	61.03	4081.25	2901.79
Nov	189.59	498.11	470.25	27.86	3284.10	2263.20
Sowing	Mean no peas per pod	Pea fresh yield	Pea dry yield	Pea fresh wt t per ha		
Oct	7.56	556.21	497.70	5.56		
Nov	6.99	432.93	398.04	4.33		

5.6.8 Crop reflectance

The percentage of reflectance was measured using CropScan in the November-sown plots. Reflectance (Fig. 16) was highest in the plots treated with fungicide (P< 001), regardless of *Mycosphaerella* inoculation. Fungicide significantly affected reflectance, and this effect was modified by the *Mycosphaerella* inoculation (P=0.033 for the 2-way interaction). The lowest crop reflectance was in the nil fungicide plots that were inoculated with *Mycosphaerella* (Fig. 16). Reflectance in these plots was less than reflectance in unsprayed plots that were inoculated with *Mycosphaerella.* These results agree with the final Ascochyta disease scores. Cropscan was a useful method of assessing plant stress, but this technology has the limitation of requiring

clear (cloudless) weather conditions for measurements and requiring measurements to be done within two hours of solar noon.

5.6.9 *Ladbrooks weather data*

Weather data for the Ladbrooks site are presented in Figure 17 and Table 22. Weather data were collected by the weather station from 25 November. The total rainfall for the month of December at the trial site was 117 mm, more than twice the long-term average for Broadfields (Table 21). Rainfall for January (33 mm) was less at the trial site than the long-term average (50 mm), and February rainfall was considerable less than the long-term average. Mean, minimum and maximum temperatures for the month of December were less than long-term averages, but January and February means were similar to long-term averages (Tables 21 and 22). Mean daily leaf wetness and the number of hours per day when leaf wetness was more than 50% are shown in Figure 17. There were 37 rainy days out of 103 days from 25 November until 17 January. Furthermore, there were many continuous days for most of December and until mid-January when leaf wetness was more than 50% for 12 hours or more. Conditions at the end of November and in December appeared suitable for *M. pinoides* infection and spread, especially immediately after inoculation on 23 November and 8 December. Roger et al. (1999) have shown that a dry period following infection by pycnidiospores may prevent infection and disease development but ungerminated pycnidiospores remain viable and infection can resume after rewetting. At high inoculum concentration, the spore density compensated for the effects of dry periods..

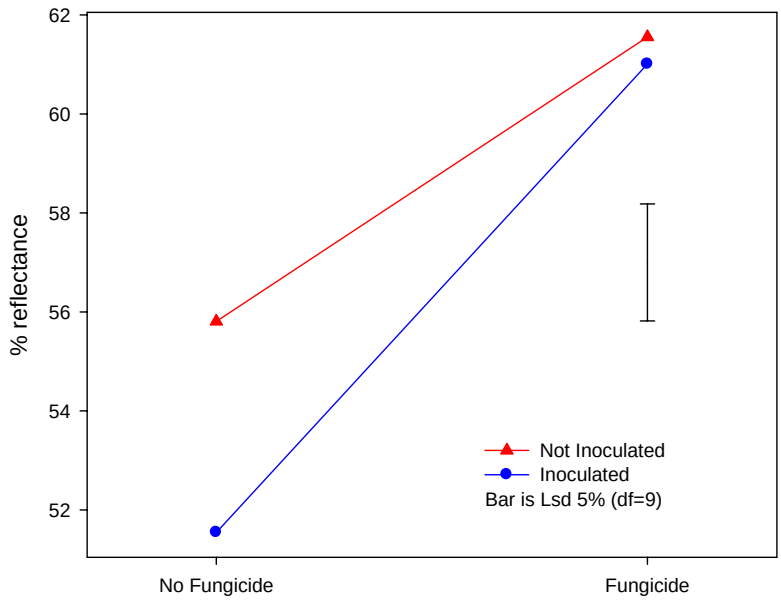

Figure 16: Percentage reflectance for each treatment in the November sowing, measured on 27 January 2005.

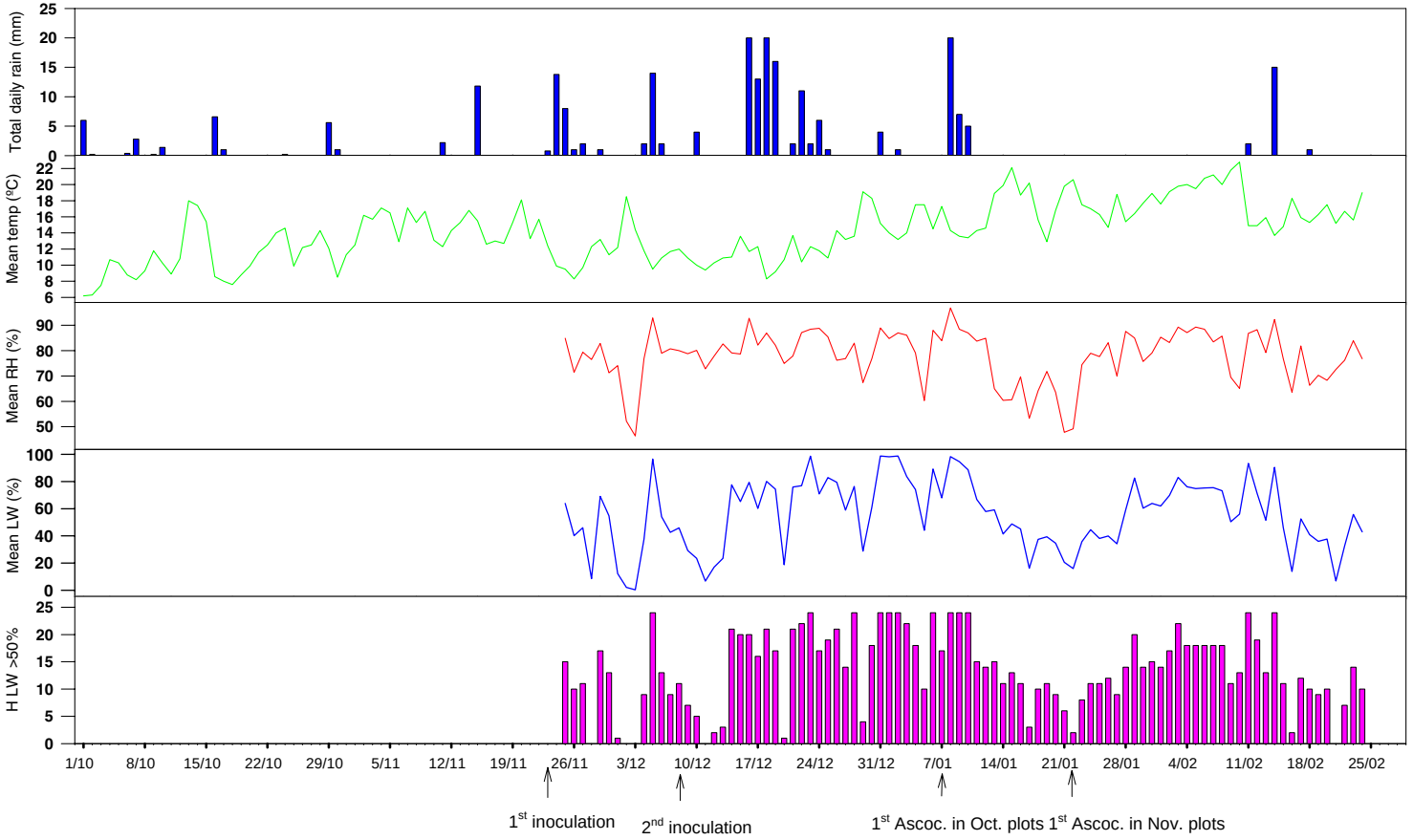

Figure 17: Weather data from the weather station located at the Ladbrooks trial (rainfall and mean temperature data prior to 25 November were taken from Broadfields weather station data): total daily rainfall, mean daily temperature, mean daily relative humidity, mean daily leaf wetness, and number of hours each day when leaf wetness was greater than 50%.

Table 21: Long-term means for Broadfields (1975-91).

Month	Solar	Rainfall	Penman	Tmax	Tmean	Tmin	VP	Windrun
January	669.6	50.3	153	22.6	17.0	11.4	13.7	12865
February	515.2	51.3	117.6	21.7	16.3	11.0	13.7	11116
March	421.6	58.9	96.2	20.1	15.0	9.9	13.2	11563
April	288.0	51.8	62.6	17.5	12.2	6.7	11.5	9840
May	176.7	50.4	43.7	13.8	8.7	3.7	9.1	9455
June	126.0	63.0	33.0	11.2	6.3	1.5	7.5	8310
July	145.7	73.7	37.1	10.7	6.1	1.4	7.3	9052
August	220.1	68.1	50.7	12.2	7.6	2.9	8.1	10540
September	339.0	40.1	68.6	14.2	9.2	4.3	9.1	10830
October	508.4	54.9	104.6	16.7	11.3	6.0	10.1	12307
November	603.0	55.7	123.9	18.4	13.1	8.0	11.1	11940
December	672.7	61.3	142.7	21.3	15.7	10.2	13.1	12245

Table 22: Data for 2004-05 season from Broadfields weather station, data from the field site in parentheses.

Month	Solar	Rainfall	Penman	Tmax	Tmean	Tmin	VP	Windrun
Oct	507.5	25.4	100.6	15.9	10.8	5.8	9.9	11852.2
Nov	302.4	31.0	61.4	17.5	12.4	6.3	10.3	6069.2
Dec	644.2	131.6 (117)	125.0	16.9 (16.9)	12.1 (12.3)	7.8 (8.1)	10.9	13138.7
Jan	722.2	33.6 (33)	150.3	21.7 (22.2)	16.3 (16.6)	11.5 (11.7)	13.6	11298.7
Feb	515.9	18.6 (18)	108.3	23.4 (23.9)	17.3 (17.8)	12.7 (13.1)	15.7	9624.2

5.7 Summary of trial 2 (property of Mr Bruce Garrett, Ladbrooks)

The majority of plots in this trial never reached significant moisture stress levels. The mean maximum soil moisture deficit was 90 mm, more than the 88 mm known to be the critical soil moisture deficit causing plant stress but this occurred during pea maturation. The weather data collected from the trial site showed that in December it rained more than twice as much (117 mm) as the average long-term rainfall for Broadfields (61 mm). The mean minimum temperature at the trial site was 8.1^{0}C, the overall mean temperature was 12.3^{0}C and mean maximum temperature was 16.9^{0}C, these were all lower than long-term means (10.2, 15.7 and 21.3^{0}C respectively).

Inoculation of plots with *Mycosphaerella* gave a small increase in Ascochyta blight.

Sowing date affected this disease, which was generally more severe in plots sown in November than those sown in October. Downy mildew was also affected by sowing date; incidence was greater in October-sown plots than those sown in November, but the disease was more severe in November-sown plots than those sown in October.

The fungicide applications reduced Ascochyta severity on all plant parts (stems, stipules, leaves and pods). Fungicide applications also reduced downy mildew severity.

Vining yields were 33% less from November-sown plots than those sown in October. Conversely, grain yield was 17% greater in November-sown plots than in October sowings. The fungicide applications resulted in a 21% increase in grain yield, through increased components of yield.

Weather conditions this season appeared conducive to the spread of Ascochyta blight and downy mildew.

6 *Key summary points from the first year*

- During the 2004/05 growing season, rainfall in December was more than twice the long-term average at both trial sites used in this study. Similarly, minimum and maximum temperatures were lower than long-term means. Incidence and severity of downy mildew and Ascochyta blight were high during this growing season. It is possible that the high rainfall and low temperatures during the first half of the growing season were conducive to the development of these diseases.
- Treatment with fungicide had by far the greatest effect on the severity of Ascochyta blight and downy mildew, the two predominant diseases found in the two field trials. The fungicide regime used was an experimental tool aiming to reduce foliar diseases of peas, but not designed as a practical or economic pea crop management method. Nevertheless, the treatments resulted in a 76% grain yield increase for field peas, and a 21% seed yield increase for vining peas. This strongly suggests that adequate control of foliar diseases can benefit pea crop productivity.
- Irrigation and ripping only had a slight effect on Ascochyta scores, and at times, these factors interacted with fungicide treatments. Ascochyta blight was sometimes more severe when either ripping or irrigation were used than when neither or both were used.
- Future research in this project should aim to confirm and quantify relationships between weather and disease, develop practical disease control strategies and continue to examine effects of water availability. In growing seasons where rainfall is closer to average and pea crops are probably under moisture stress, methods of improving root development and water uptake are more likely to affect pea yields.

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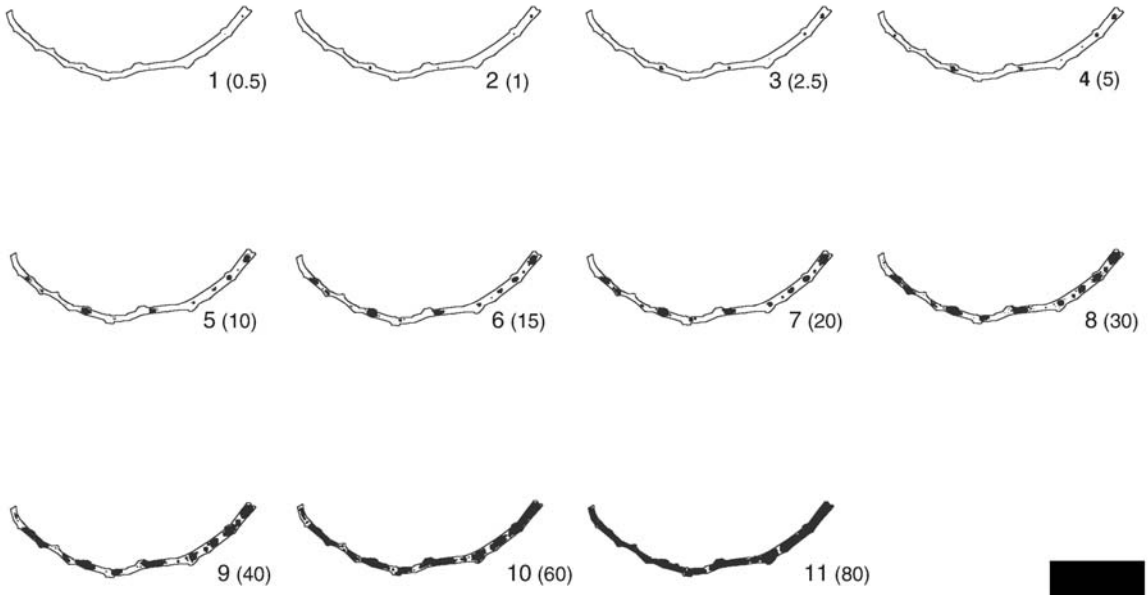
Appendix I

Disease severity key for Ascochyta – stem score



CROP & FOOD RESEARCH
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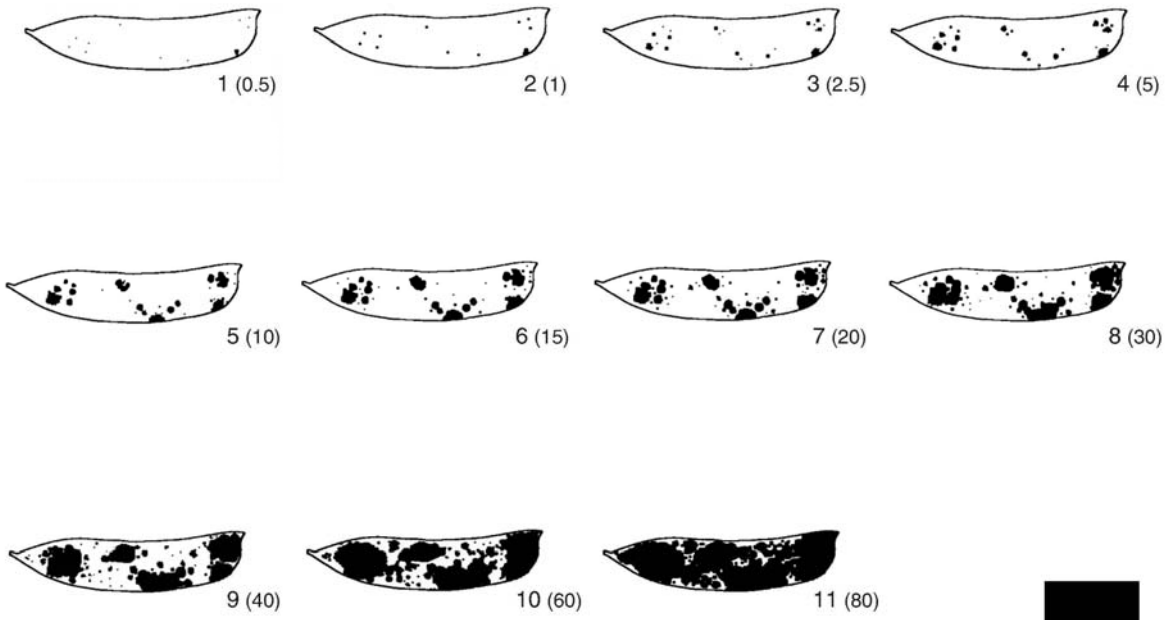
Ascochyta of pea - stem

Appendix II

Disease severity key for Ascochyta – pod score

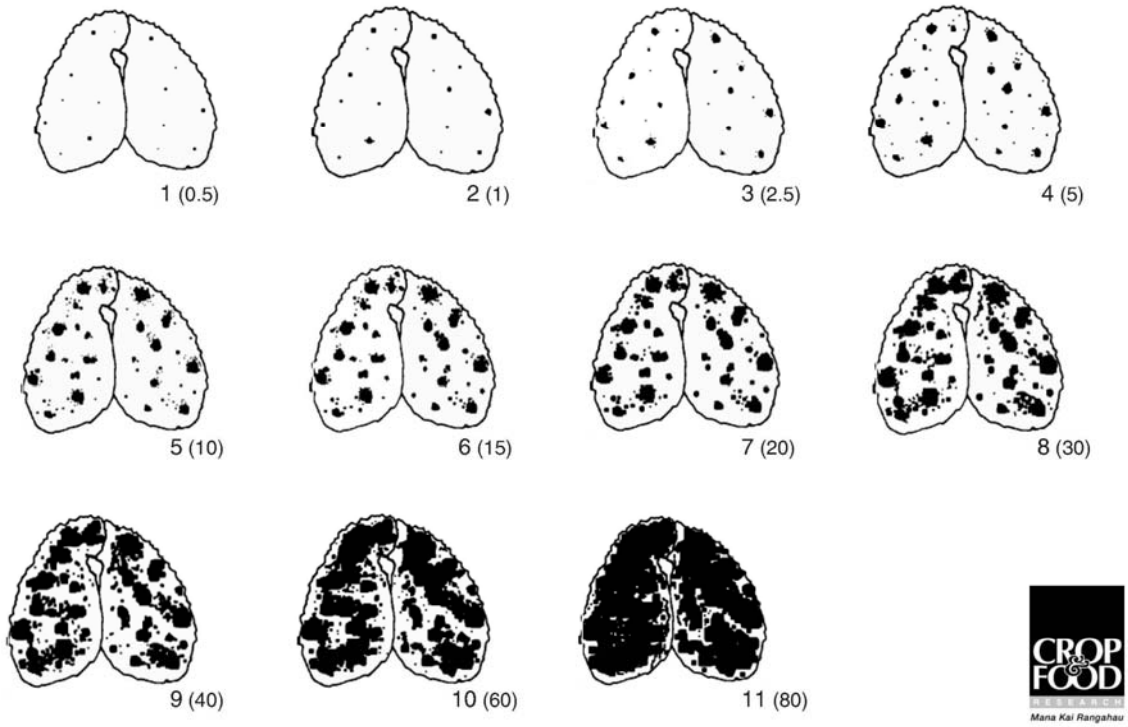


CROP & FOOD RESEARCH
Mana Kai Rangahau

Ascochyta of pea - pods susceptible

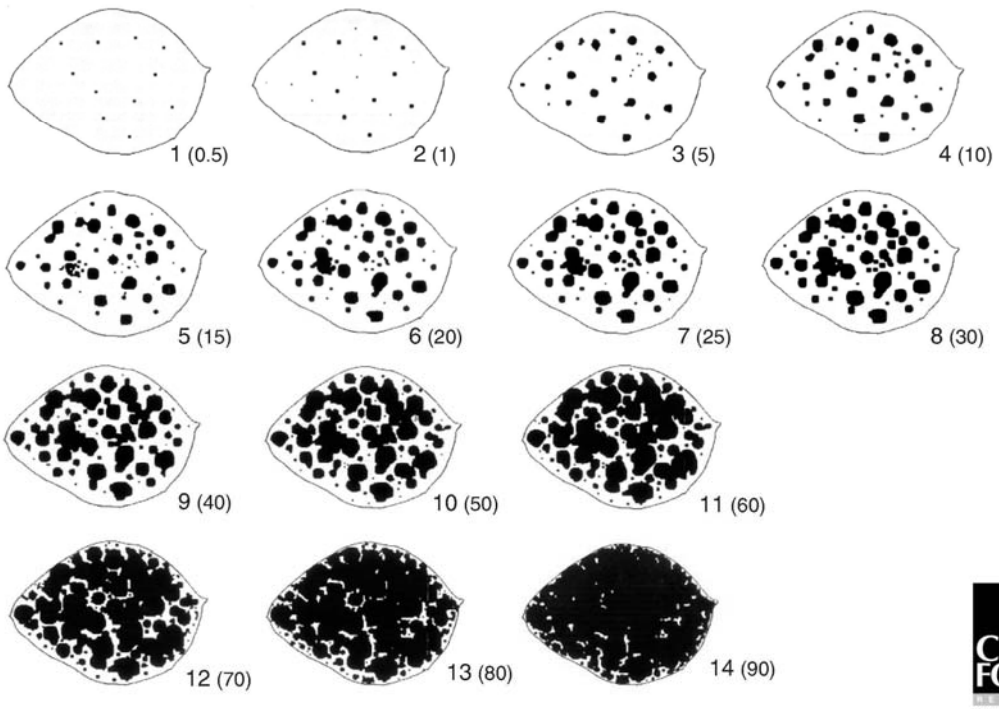
Appendix III

Disease severity key for Ascochyta – stipule score



Appendix IV

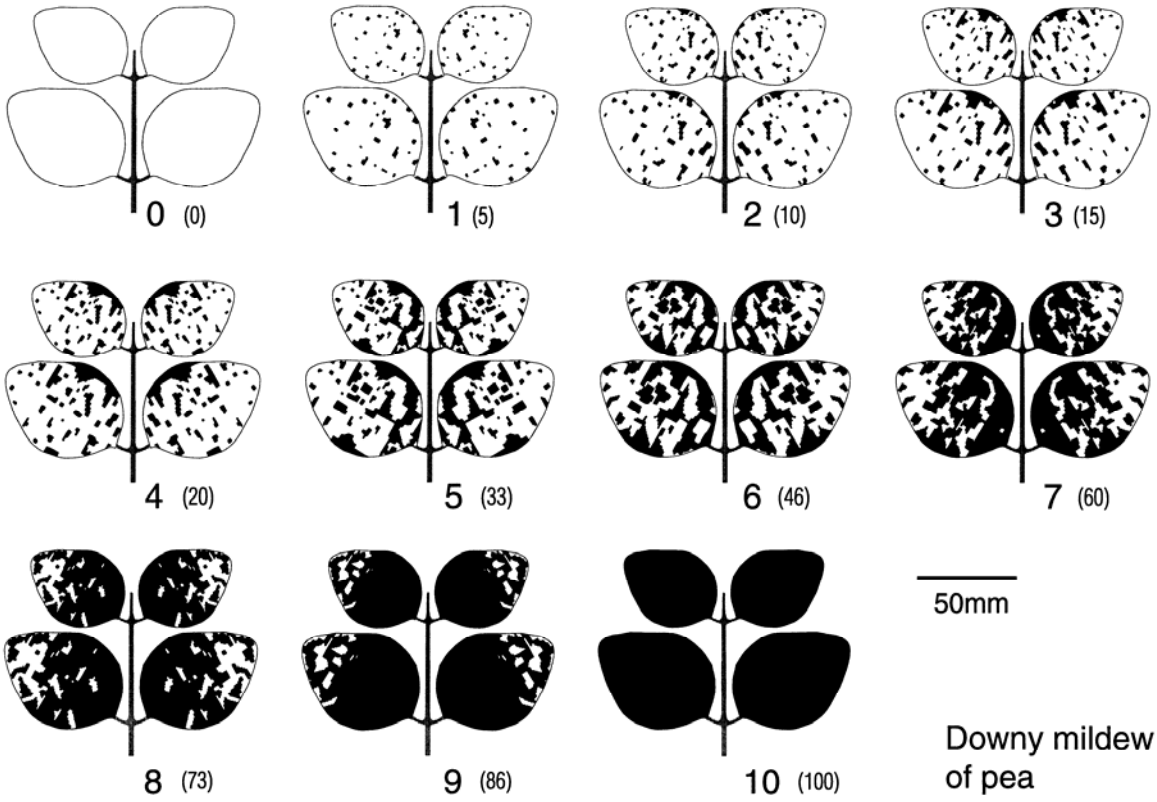
Disease severity key for Ascochyta – leaf score



Ascochyta of pea - leaf susceptible

Appendix V

Disease severity key for downy mildew



Appendix VI

Interim results from Trial 1: St Andrews

Severity and incidence of Ascochyta blight was assessed in the trial 23 December 2004 and 19 January 2005. Data from the 23 December assessment is presented here (Table 1). The irrigation and cultivation treatments had no effects on any of the disease parameters measured. The fungicide treatment did not affect mean number of nodes/plant, but at the time of the assessment, increased the mean number of pods/plant by 28%. This treatment reduced the mean number of nodes on plants with dead leaves by 25%, reduced the mean stem Ascochyta severity score by 68%, and reduced the mean pod severity score by 55%.

Table 1: Means of plant and disease parameters for different treatments applied to plots of Midichi peas in Trial 1 (plants removed from trial plots on 23 December 2004).

Treatment	Number of nodes/plant	No. nodes with dead leaves	Stem Asco score†	Number of pods/plant	Pod Asco score†
Irrigation					
Nil	21.2	11.8	6.3	9.4	2.9
Irrigated	21.4	12.2	6.4	9.4	2.9
LSD ($P = 0.05$)	0.4	1.2	0.7	0.7	1.2
Cultivation					
No deep rip	21.2	12.1	6.3	9.2	3.0
Deep ripped	21.3	11.8	6.4	9.5	2.8
LSD ($P = 0.05$)	0.9	0.6	0.6	0.9	0.4
Fungicide		(-25%)	(-68%)	(+28%)	(-55%)
Nil	21.3	13.7	9.1	8.2	4.0
Sprayed	21.3	10.3	3.6	10.5	1.8
LSD ($P = 0.05$)	0.9	0.6	0.6	0.9	0.4

† Ascochyta severity scores; 0 = no disease, 11 = >80% surface area affected

Appendix VII

Interim results from Trial 2: Ladbrooks

Plants from the November sowing had a mean number of nodes that was 26% greater than for the October sowing. Plants from the later sowing also had greater levels of Ascochyta blight than those from the October sowing. This was expressed, for the November relative to the October sowing, as 78% more nodes with dead leaves, a 42% increase in mean stem severity score, and a 36% increase in mean pod severity score.

Inoculation of plots with grain inoculum of *Mycosphaerella pinodes* increased the mean stem Ascochyta severity score by 25%, and the mean pod severity score by 230%. This treatment did not affect the numbers of nodes on plants with dead leaves, or the numbers of pods/plant.

The fungicide applications did not affect the mean number of nodes/plant or mean numbers of pods/plant. However, this treatment decreased the mean number of plants with dead leaves (-8%), the mean stem Ascochyta severity score (-46%) and the mean pod severity score (-78%).

Table 3: Means of plant parameters and Ascochyta blight assessments for different treatments applied to plots of Durango peas in Trial 2 (plants removed from plots on 7 January 2005 (October-sowing) and 21 January 2005 (November-sowing)).

Treatment	Number of nodes/plant	No. nodes with dead leaves	Stem Asco score†	Number of pods/plant	Pod Asco score
Sowing date	(+26%)	(+78%)	(+42%)	(+36%)	(+260%)
October	13.6	6.0	4.8	5.8	0.1
November	17.1	10.7	6.8	7.9	0.3
LSD ($P = 0.05$)	0.6	0.6	1.2	0.9	0.02
Inoculation			(+25%)		(+230%)
Nil	15.2	8.1	5.2	6.7	0.1
Plus inoculum	15.5	8.5	6.5*	7.0	0.3
LSD ($P = 0.05$)	0.6	0.6	1.2	0.9	0.02
Fungicide		(-8%)	(-46%)		(-78%)
Nil	15.3	8.7	7.6	6.6	0.3
Sprayed	15.4	8.0*	4.1	7.1	0.1
LSD ($P = 0.05$)	0.6	0.6	1.2	0.9	0.02

† Ascochyta severity scores; 0 = no disease, 11 = >80% surface area affected