Validation of a disease forecasting model to manage late blight (Septoria) in celery

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Horticulture Australia VG06047

(November 2008)

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Purpose of project:
This project details the outcomes of a 2 year study of late blight of celery which investigated efficacy and economics of the TomCast disease forecasting model for timing fungicide sprays to control late blight without reducing quality or yield.

Report completed: November 2008.

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Table of contents

Media Summary

Model tackles sprays for celery late blight

Research has evaluated modifications to a computer model that can reduce the number of sprays for control of late blight in celery. Late blight is a fungal disease that attacks the leaves and stalks of celery crops as they mature. Celery is usually sprayed weekly to control late blight, which can result in up to 16 sprays being applied per crop.

The model showed that savings on sprays could be made in the early stages of crop production, before the plant canopy closed in. Most savings were made on winter crops. In these crops the model predicted a saving of up to 8 sprays.

The model is called TomCast and it uses weather data to forecast the appearance of late blight in crops. Temperature and leaf wetness data are collected by a weather station positioned in the crop and fed into a computer-based model. The model determines when to spray and when not to spray for late blight. If conditions are favourable for late blight and provided no sprays have been used in the last 7 days, then a spray is recommended. If conditions are not favourable for late blight then the model shows that no sprays are required.

Growth chamber studies showed the fungus produced spores at 8 °C. By modifying the model to start at this lower temperature beyond canopy closure, it was possible to also save sprays during the later phase of crop production. Although there are additional hardware and monitoring costs, the reduced spray program under the model, was as economical as weekly fungicide applications.

At present for winter celery crops the model calculates the need to spray when temperatures exceed 13 °C. Our research recommends a systemic fungicide 10 weeks after planting or at canopy closure and then the use of the model at a lower temperature of 8 °C to calculate the need for further spraying. More research is required to confirm the trial is repeatable in both summer and winter celery crops.

An economic analysis indicated that TomCast, when used as an IPM tool could increase profits by 0.78%.

Evaluations of alternative disease predictive models such as the Septoria and Cercosproa models indicated they either overestimated or underestimated the need to spray.

Laboratory experiments demonstrated that Vapour Pressure Deficit (VPD) calculations are not an alternative for leaf wetness sensors for use in disease predictive models.

Research by scientists at DPI's Knoxfield Centre was supported by funds from the Vegetable Industry, Horticulture Australia Ltd, the Department of Primary Industries Victoria and the Federal Government.

Technical Summary

Celery (*Apium graveolens*) is an intensively managed crop due to exceedingly high aesthetic standards and low damage thresholds. Late blight, caused by the fungus *Septoria apiicola* Speg., is a major foliage disease of celery. The high disease pressure from late blight in commercial celery crops is managed by weekly spraying with contact fungicide sprays, up to 16 times after transplanting. Growers are keen to reduce pesticide applications to minimise production costs, even if by only one spray. The public is also demanding fewer pesticides and less contamination of the environment.

During this 2-year study, two trials were conducted to evaluate modifications to the disease forecasting model TomCast. This model is a decision support tool for timing fungicide sprays for late blight control in celery. The model converts temperature and leaf wetness data, collected by a weather station in the crop, into disease severity values (DSVs) which are accumulated to reach a threshold for spray applications. An economic analysis appraised the cost effectiveness of the model for reducing sprays without compromising yield or quality.

The major findings were:

- The TomCast disease-predictive model for late blight in celery which estimates disease activity commences at 13 °C, requires modification, as our growth chamber studies demonstrated spore release was substantial at 10 °C, measurable at 8 °C, but sparse at 5 °C.
- The TomCast model is very effective as a decision support tool in the early stages of crop growth prior to canopy closure, where it can save 6–8 sprays with spray thresholds of 10 or 15 DSVs for winter grown crops. At 10 weeks, first lesions or canopy closure (whichever comes first), application of a registered systemic fungicide followed by weekly applications of chlorothalonil will produce an economic yield equal to weekly sprays, with yields based either on grower estimates or incidence data. An increase in profitability of 0.78% was achieved with the 10 DSV spray threshold of TomCast.
- This is the first report of the TomCast model being deployed until harvest, by reducing the start temperature to 8 °C at either 10 weeks, or first lesions or canopy closure (which ever comes first). This protocol reduced the number of sprays by 5 to control the disease and produced an economical yield, based on incidence data.
- The Disease Doctor™ computer program designed to deliver the TomCast model was validated and produced similar or better control of Septoria late blight than the Excel equivalent.
- Desk-top simulations of the Septoria predictor and Cercospora model, which have been touted as alternatives to TomCast for Septoria late blight control, overestimated or underestimated the number of sprays required, respectively, and are consequently inferior to TomCast.
- Gibberellic acid may have the potential to enhance late blight control as two applications in glasshouse trials considerably reduced lesion size and the number of pycnidia on lesions.
- Vapour Pressure Deficit (VPD) cannot be use to replace leaf wetness sensors under field conditions due to air movement.
- A fuzzy logic model which estimates leaf wetness based on measurement of temperature, relative humidity and wind speed predicted periods of leaf wetness under field conditions with an accuracy of only 75%.

Recommendations for future work:

1. Conduct a comprehensive field trial with the modified TomCast model on a commercial scale and in a commercial crop and report actual yield data, for all seasons and locations.
2. Test Gibberellic acid in field trials.
3. Refine the fuzzy logic model to replace leaf wetness sensors or alternatively develop a new generation leaf wetness sensors.
4. Refine the TomCast model using a lower start temperature. Based on our work, the active temperature range is 8–17 °C, which has a lower start temperature than the current model (13 °C

Chapter 1

Introduction

1.1 Disease predictive models

The influence of weather on disease is well known (Jones 1986). Disease predictive models are a mathematical description of an attempt to forecast the future development or appearance of a disease in a crop, based on climatic measurements made within the crop (Madden and Ellis 1988, Parry 1990, Galea and Minchinton 2005). Models can be based on climatic variables such as temperature, relative humidity, leaf wetness etc. and on an understanding of how the fungus reproduces and infects under field conditions (Fritt *et al.* 1989).

There are several motivations for use of disease predictive models (Fry and Fohner 1985). They can increase income by reallocating disease management resources to other areas of production. The risk of large unexpected crop losses is reduced. They provide the means to lower pesticide application to crops, which alleviates concerns for human health and pollution of the environment. Disease predictive models may assist in the management of fungicide resistance strategies by assisting the grower to identify the most appropriate timing for the application of systemic (curative) compounds. Consequently they are an ideal tool for integrated pest management (IPM).

Factors that contribute to growers' adoption of predictive models are (Kable, 1991; Maloy 1993, Polley 1983):
1. Significant economic losses are associated with the crop disease.
2. Economically viable control measures must be available.
3. Seasonal variability may make the appearance of the disease difficult to predict.
4. There must be validation of the model under local field conditions.
5. The system must be readily available to end-users.

Growers must be confident that measurable benefits can be expected from using the model that would be unavailable without its use. Attributes that will ensure the success of a model include: (1) reliability, (2) cost effectiveness, (3) simplicity, (4) importance to the industry, (5) usefulness and (6) availability (Campbell and Madden, 1990).

1.2 Current limitations of disease predictive models

There are a number of issues associated with disease predictive models:
1. They predict sporulation or infection based on historical microclimatic data, which means that the response time to apply fungicides may be limited.
2. They can overestimate sporulation or infection events. If the disease is not present in the crop and there are no obvious sources of spores in the field or farming area, the microclimate data can still predict sporulation or infection events.
3. They may require the tolerance of very low levels of symptoms in the field, as it may not be economically viable to completely eradicate the disease from the crop.

The accuracy of models could be improved by:
(i) Incorporating predicted microclimate or meteorological data into the model so it was truly a 'forecast' of expected events.
(ii) Thresholds for spraying obviously need to be set below the actual sporulation and infection parameters of the pathogen so contact, preventative fungicide applications can be employed. Generally models predict either sporulation or infection, however, the accuracy of models would be enhanced if they predicted both sporulation and infection. Spore trapping alongside collection of microclimate data would enhance predictive models.
(iii) The use of systemic fungicides with curative activity to remove infections, which may have taken place due to the lag time between:

(a) collection of microclimate data and output from the predictive model,
(b) the output from the model and the time to organize spraying of the crop.

1.3 Evolution of models for Septoria late blight on celery

The motivation for the development of a predictive model for Septoria late blight arose from concerns about the cost of production and the effects of pesticides on human health and the environment (Mathieu and Kushalappa 1993). Early field observations on the epidemiology of late blight showed that meteorological conditions had a huge impact on disease development. High rates of infection were associated with periods of heavy rainfall and average monthly temperatures below 25ºC (Berger 1970). Models have been developed for late blight based on *in vitro* studies and field observations. A weather station in the crop collects microclimate data which is fed into the models. Some models have been validated in the field and assessed for their economic viability.

A number of disease predictive models, based on either spore production or infection, have been developed and trialed to time fungicide sprays for late blight control in celery (Pitblado 1992, Mudita and Kushalappa 1993, Lacy 1994, Lacy *et al.* 1996, Reitz *et al.* 1999). An existing integrated pest management scouting program in Quebec initiates fungicide sprays for late blight only when the disease first appears in the field. Late blight can appear 30 days after transplanting but usually appears between 40-60 days. This program reduced the number of sprays applied from 10 fewer than 7 per crop in Canada (Mudita and Kushalappa 1993). In Australia late blight appears in summer and winter grown crops at approximately 40 and 70 days after transplanting, respectively (Minchinton et al 2005). Similarly, in Australia, preliminary trials with a predictive model indicated savings in spray applications could be made early in the crop's life (Minchinton et al 2005).

1.3.1 The action threshold model

Mudita and Kushalappa (1993) recognised that the disease appeared later in the crop's life and tried to delay spraying until a disease threshold was reached. They applied the first spray to transplanted seedlings at blight incidence levels of 0, 2, 4, 8 and 16% and then sprayed weekly. Yield losses occurred at all initial blight incidences, so it was not advisable to wait for the disease to appear before applying the contact fungicide, chlorothalonil. A systemic fungicide with curative activity may have been more successful as a first spray in their program. Interestingly there was no significant yield loss between 0 and 2% initial blight incidence.

1.3.2 The disease severity model

Mathieu and Kushalappa (1993) developed an infection model based on disease severity at various temperatures and ranges of leaf wetness. The number of lesions increased with temperatures of 10, 15 and 20 ºC but declined at 25 and 30 ºC and with increased hours of leaf wetness (12, 24, 48, 72 and 96 hr). The responses were divided into four disease severity values using cluster analysis, representing 'very low', 'low', 'moderate' and 'severe infection'. However, further research is needed to define and validate spray thresholds in the field and to evaluate infections below 10 ºC.

1.3.3 The Septoria predictor model

An infection model based on 12hr-leaf wetness was developed by Lacy (1994). Lesions formed on inoculated celery leaves within a period of 15 days only after 24 hrs of continuous or interrupted (12 hr wet - 12hr dry - 12hr wet) dew at 21 ºC. Fungicides were applied at a threshold of greater than or equal to 12 hrs of leaf wetness, if no sprays had been applied in the past 7 days, up to canopy closure and thereafter weekly fungicides sprays are applied. Temperature was not included in the model, as it was not a limiting factor in Michigan, where the model was developed. Temperatures below 10 ºC and above 30 ºC could be limiting factors at other locations. In 3 years of field trials in Michigan the model reduced by 2 the number of sprays of chlorothalonil per crop compared to weekly spraying, without sacrificing efficacy of disease control. Later trials in Michigan using the Septoria predictor generally saved 1-2 sprays (Bounds and Hausbeck 2004, Bounds and Hausbeck 2006a, Bounds and Hausbeck 2006b, Bounds and Hausbeck 2007) and at times 3-5 sprays when spraying commenced 4 weeks after planting (Bounds and Hausbeck 2008). Further north in Ontario only one spray was avoided with the Septoria predictor (Trueman *et al.* 2006, 2007). Fungicides applied with the model

were generally chlorothalonil and a strobilurin. The Septoria predictor is considered to give control of late blight equal to weekly sprays (Trueman *et al.* 2007), although Bounds and Hausbeck (2007) found the results could be inconsistent.

1.3.4 The Cercospora model

An infection model to predict *Cercospora apii*, the cause of early blight in celery, was developed by Berger (1969a, 1969b). The original model used temperature, relative humidity (RH) and a spore trap, but later versions have omitted the spore trap. The current version consists of applying a fungicide spray if all the following criteria are met (Bounds and Hausbeck 2007, Raid *et al.* 2007):

1. No fungicides applied during the previous 7 days;
2. ≥ 12h of ≥ 90% RH were recorded the previous day (0700 yesterday to 0600 today);
3. Mean temperature was at least 15 but not above 27°C during the previous day (0700 yesterday to 0600 today);
4. Temperatures 3 days ago were ≥ 12°C, or if the temperatures fall below 12°C the mean night temperature (2200 to 0700) on each of the 2 succeeding nights was ≥ 15°C with a mean RH ≥ 95%.

The Cercospora model has been trialled in Michigan on several occasions for control of late blight and reduced the number of sprays by 2 to 6. Parameters measured such as incidence of late blight and yield of celery are often higher but not significantly different from levels of control achieved with weekly spray programs (Bound and Hausbeck 2004, 2007). Again, fungicides applied with the model were generally chlorothalonil and a strobilurin. Bounds and Hausbeck (2007) reported the Cercospora model could produce inconsistent control of late bight.

1.3.5 The TomCast model

The TomCast disease-forecasting model is based on sporulation and was modified from the earlier FAST model of Madden *et al.* (1978). FAST was originally developed to predict the sporulation of *Alternaria solani* on tomatoes and is based on periods of leaf wetness and temperature which score disease severity values (DSVs); (Table 1.1). A scale of DSVs is derived from the number of hours of leaf wetness in a temperature range. Daily DSVs are calculated at 11.00am and accumulated until a spray threshold is reached. A period of two hours leaf dryness is required to interrupt a leaf wetness period. If leaf wetness extends 3 hours beyond 11.00 am (i.e. 2.00 pm), then it is included in the 11.00 am calculations. When a nominated threshold is reached, an appropriate fungicide is sprayed to prevent late blight. If conditions are not conducive to sporulation and the threshold is not reached then fungicides are not sprayed.

Table 1.1 The TomCast disease predictive model (Reproduced from Madden *et al.* 1978)

Mean temperature (°C)	Leaf wetness periods (in hours) required to produce daily disease severity values				
13-17	0-6	7-15	16-20	21+	
18-20	0-3	4-8	9-15	16-22	23+
21-25	0-2	3-5	6-12	13-20	21+
26-29	0-3	4-8	9-15	16-22	23+
DSV	0	1	2	3	4

DSV = Disease Severity Values (scored 0-4).
0 = conditions unfavourable for spore formation.
4 = conditions highly favourable for spore formation.

Since its inception TomCast has been evaluated for predictions of several diseases such as *Septoria lycopersici* and *Colletotrichum coccodes* on tomatoes (Pitblado 1992, Gillespie *et al.* 1993); *Cercospora carotae* and *Alternaria dauci* on carrots (Bounds *et al.* 2006, 2007; Rogers and Stevenson 2006); *Septoria apiicola* on celery (Reitz *et al.* 1999, Trueman *et al.* 2005, 2006, 2007, Bounds and Hausbeck 2007, 2008); *Stemphylium vesicarium* on asparagus (Myer *et al.* 2000) and *Stemphylium* spp. on tomatoes (Bolkan and Reinert 1994).

DSV thresholds to commence spraying were initially high when TomCast was first evaluated as a decision support tool to manage spray applications for late blight, but DSV thresholds now suggested are much lower. Reitz *et al.* (1999) reduced by one the number of fungicide sprays for late blight using an initial threshold of DSV30 reducing to DSV20 at canopy closure for celery grown in California. A conservative accumulation of DSV20 is now recommended in the US (Phillips 2005). In Michigan, Bounds and Hausbeck (2006a, 2006b, 2007) working on artificially infected crops used a TomCast spray threshold of DSV10 and reduced by 1–5 the number of sprays until canopy closure, whilst maintaining yields comparable to weekly sprays programs. They found DSV15 produced inconsistent yields and DSV20 had unacceptable levels of disease compared with weekly spray programs. A DSV20 was suggested as a spray threshold for natural infections of late blight. More sprays could be saved (2–6) if spraying did not commence until 4 weeks after transplanting using the TomCast spray threshold of DSV10. Trueman *et al.* (2006, 2007) working with inoculated crops in Ontario found that TomCast spray thresholds of DSV10 reduced by 1–3 the number of sprays, DSV15 and DSV20 reduced by 2–5 the number of sprays up till canopy closure, but the latter exhibited too much disease. In Australia more sprays were saved but only in the early stages of crop production prior to canopy closure. In summer crops the number of sprays were reduced ny 3-5 using TomCast DSV15, 20 and 25; and by 7–8 sprays in winter crops using TomCast DSV10, 12, 15 and 20 with no difference in late blight when compared with the weekly spray schedule (Minchinton *et al.* 2005).

All celery produced for Campbell's Soup Company in the USA now uses the TomCast model to time fungicide sprays for late blight. Growers using the model have reduced the number of sprays by 9–12 per year, but the spray threshold is not stated (Bolkan and Reinert 1994). TomCast was successfully used in the Netherlands to improve the timing of chlorothalonil sprays (Schepers and Meiers 1998).

1.4 Chemical usage with predictive models

Chlorothalonil, or a combination of chlorothalonil and copper, both of which have multi-site activity, were the fungicides generally sprayed with the disease predictive models (Mudita and Kushalappa 1993, Phillips 2005). Benomyl, chlorothalonil and propiconazole (DMI) were used by Reitz *et al.* (1999). More recently an array of strobilurin fungicides or combinations of a strobilurin and chlorothalonil (Grumet and Hausbeck 2003, Bounds and Hausbeck 2007, 2008), or strobilurin and boscalid were alternated (Trueman *et al.* 2007). Combinations of a systemic fungicide and chlorothalonil are considered to give the best control of late blight (McDonald 2004). Overseas, when disease predictive model thresholds have been used to time fungicide sprays for late blight control, there was a tendency for excessive use of strobilurin fungicides, even though they may be alternated with contact fungicides.

1.5 Economics of predictive models to control late blight

In California, savings of $US45/ha using a TomCast spray threshold of DSV30 reducing to DSV20 at canopy closure were reported by Reitz *et al.* (1999). In Michigan, a TomCast spray threshold of DSV10 until canopy closure saved $US213–215/ha and the Septoria predictor saved $US71/ha (Bounds and Hausbeck 2007, 2008). In Ontario, TomCast DSV10 saved $C87–169/ha and the Septoria predictor model saved $C41–76/ha, depending on the spray program (Trueman *et al.* 2007). Grumet (2003) noted the TomCast model saved the most money, followed by the Cercospora model and lastly the Septoria predictor. All authors, except Reitz (1999) based the economics of the models only on the cost of fungicides. Reitz (1999) also included application, shipping and scouting cost, but the latter were considered negligible. None of the researchers included depreciation and operating costs of the weather stations or interpretation of the model predictions.

1.6 Deployment issues associated with weather stations and late blight models

Weather data for input into models to predict late blight is always collected on a microclimate level which necessitates a weather station in each planting or crop of celery. Even though the cost of weather stations has declined over the years, they are still considered too expensive by growers to place one into each planting or crop.

To reduce the cost of weather stations there is the potential to collect data from one station and use it to predict disease thresholds in several crops in an area. Weather stations in crops are also subject to mechanical damage from machinery. Sensors are exposed to weathering and corrosion by pesticides, which can generate unreliable data, especially leaf wetness data. An option to avoid mechanical damage and share weather station data between crops to reduce costs was to locate the weather station in turf outside, but near the crop. The main contributor to leaf wetness is dew and its formation in turf and crops is similar in temperate zones (Gleason *et al.* 1997, Kim *et al.* 2002, 2006, Sentelhas *et al.* 2005). This scenario may not be appropriate for Australian celery crops as they are overhead irrigated, often at different times and a weather station located outside the crop may not record leaf wetness associated with irrigation. Also Minchinton *et al.* (2005) working with the DownCast predictive model on spring onions reported variation in weather data collected in crops planted only a week apart and variation in data collected across a bay, which consequently produced different spray predictions. Additionally there is generally only one leaf wetness sensor on a weather station which is moved upward as the canopy grows, so leaf wetness of the lower canopy, especially in older celery crops, is not taken into account. There is a need to find a new generation, more robust leaf wetness sensor, less susceptible to weathering, or a method of calculating or estimating leaf wetness in the entire canopy.

Another issue is the historical rather than forecast nature of the data collected. The historical nature of predictive models albeit only 24 hours old, may not give growers sufficient warning to organize spray applications for crops to control fungal diseases. Pathogens can often set up processes of infection within 3 hours, for example *Peronospora parasitica* (Channon and Hampson 1968). If there is a risk the pathogen may have already infected the crop then systemic rather than protectant fungicides are necessary. The repeated used of systemic fungicides increases the risk of pathogens developing fungicide resistance.

1.6.1 Data and data access

To overcome problems of weather station costs, deployment and the historical nature of weather data collected on site in the microclimate, several models have been developed to calculate and collect leaf wetness and other weather data parameters in advance. These are: (i) Vapor pressure deficit (VPD); (ii) models to forecast site specific leaf wetness duration, and (iii) the SkyBit™ e-weather forecasts.

VPD identifies when condensation and consequently leaf wetness is likely to occur. It requires the measurement of air temperature inside the canopy and air temperature and RH outside the canopy. It can be calculated using a mathematical model or read from a graph. One of its main applications is to predict condensation in glasshouses (Prenger and Ling 2000).

Three models have been developed to forecast site specific leaf wetness duration for input into disease predictive models; the classification and regression tree/stepwise linear discriminant model (CART/SLD/wind or CART; Gleason *et al.* 1994, Kim *et al.* 2002), the fuzzy logic model (FL; Kim *et al.* 2004); and the corrected fuzzy logic model (CFL; Kim *et al.* 2005). The CART model input variables are dew point depression, wind speed and RH. The input variables for the FL model are air temperature, RH and wind speed. The CFL model requires the same inputs as the FL model but consists of a correction factor for systematic errors in input data based on statistical analysis of historical data. These models can use either on site or remote data and could access data from many already deployed weather stations which do not have leaf wetness sensors attached.

SkyBit™ is a site specific electronic weather information service for the United States, northern Mexico and southern Canada. It provides 3-hourly forecasts for a number of parameters such as temperature, RH, rainfall, wind speed and direction etc. over 0–48 hours and can directly generation spray thresholds (DSVs) for the TomCast disease predictive model. The accuracy of forecast may be satisfactory for processing crops, such as tomatoes, where the whole plant is not harvested only the fruit, and as it is for processing, the quality of the fruit does not have to be perfect. The forecasts,

however, may not be accurate enough for crops of high aesthetic standards where the whole plant is harvested, such as celery.

Simulations to predict spray thresholds were conducted for the Melcast and TomCast models to compare the CART, FL, CFL and SkyBit™. These models were useful when site specific data was not available (Kim *et al.* 2002). The CART model was the most accurate and consistent for estimating leaf wetness duration but the accuracy needed to be improved for site-specific forecasts in practice (Kim *et al.* 2006). Similar information is available from the Australian Bureau of Meteorology (BOM).

If any of these models or data collection methods were to be used to generate leaf wetness duration then the effects of overhead irrigation on duration of leaf wetness need to be taken into account. To minimize effects of overhead irrigation on leaf wetness duration, crops would have to be irrigated at dawn when dew would normally be expected to occur on crops. The advantage of accessing forward leaf wetness duration, even if only estimated, could impact on disease predictive models by predicting when a spray threshold could be reached. This scenario would give a grower time to organize spraying a crop with cheaper protectant fungicides before a sporulation or infection event rather than using more expensive systemic fungicides after the potential infection or sporulation event.

1.7 Celery

Celery (*Apium graveolens* L.) is an intensively managed crop due to exceedingly high aesthetic standards and low damage thresholds. It requires weekly fungicide applications for control of late blight. Up to 16 fungicides sprays can be applied after seedlings are transplanted from the glasshouse at 8 weeks of age. The high cost of chemicals and labour and the frequency of spraying are a major cost for growers. Growers are constantly seeking ways to reduce the cost of production, whilst maintaining control of the disease without reducing yield or quality.

Nationally the cost of fungicide applications is estimated at $1.7M (chapter 4) in an industry which grew 991ha of celery and had a gross value of $42.2 M in 2007 (Table 1.2).

Table 1.2 Production and value of celery industry in Australia (2006-07, ABS)

State	Area (ha)	Area (%)	Production (tonne)	Yield (tonne/ha)	Production (%)	Gross Value ($M)
Victoria	661	66.7	38,828	54	26.0	30.2
Queensland	125	12.6	7,119	57	27.5	6.7
Western Australia	150	15.1	4,545	30	14.5	4.5
South Australia	27	2.7	275	10	4.8	0.2
New South Wales	13	1.3	174	13	0.6	0.2
Tasmania	14	1.4	600	43	20.7	0.6
Total	991		51,041	207		42.2

1.8 The Disease – Septoria Late Blight

The fungus *Septoria apiicola* Speg. causes the disease late blight of celery (*Apium graveolens* L.) and celeriac (*Apium graveolens* var. *rapaceaum* DC.). It is a major foliage disease causing losses of 50–90% in commercial crops (Sherf and MacNab, 1986, Lacy and Cortright 1992). Crop losses from late blight are associated with defoliation, slower growth rates, increased labor costs for trimming diseased leaves and petioles, and post harvest rots. Late blight occurs worldwide and generally forms on older leaves later in the crop's life (Walker, 1952, Sutton and Waterston 1966, Mudita and Kushalappa, 1993, Cerkauskas, 1994).

1.8.1 Symptoms

Symptoms of late blight initially appear as chlorotic spots on leaves and petioles, which later turn necrotic (Fig. 1.1). They can range up to 10 mm in size. Spots on heavily infected leaves may coalesce causing leaf blight and later death. Embedded in the spots are black pimple-like pycnidia

containing long flexuous or rod-shaped, 3–5 septate conidia (spores) (Sutton and Waterston 1966). There are estimated to be about 1500 to 5400 spores per pycnidium, on average 56 pycnidia per spot and 2,000 spots per plant, thus up to half a billion spores could be produced on one plant (Lin 1939). Ten or more spores are necessary for an infection (Sherf and MacNab 1986). No sexual stage has been reported (Sutton and Waterston 1966, Hausbeck, 2002). Early descriptions of *Septoria* on celery suggested there were two distinct species associated with symptoms of large and small spots (Cochran 1932), but a study of world-wide isolates of the large and small spot forms lead to the recognition of only one species (Gabrielson and Grogan 1994).

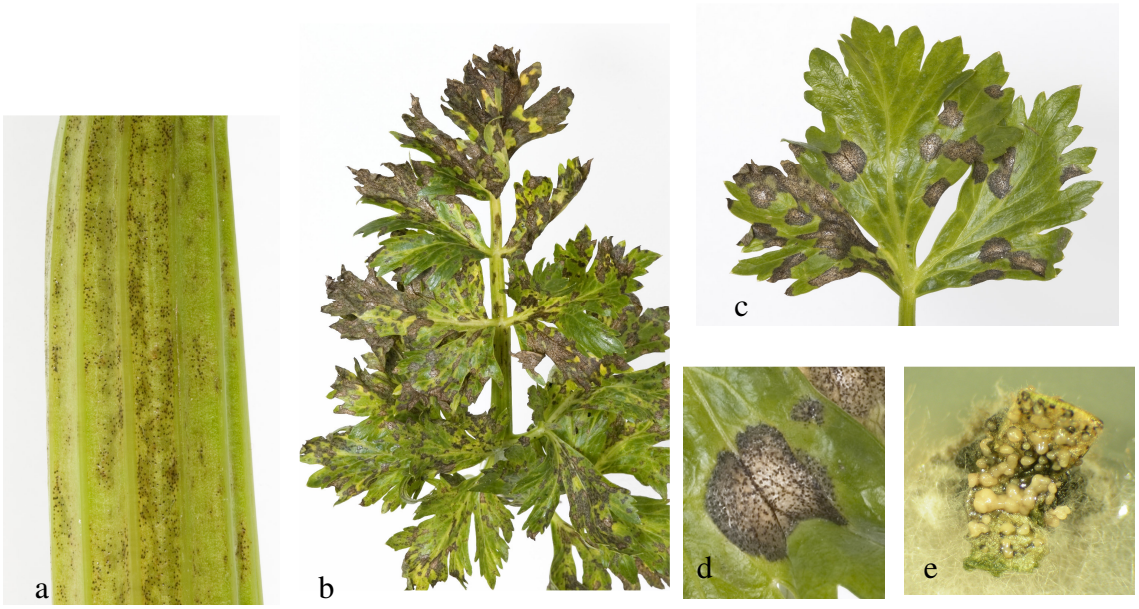

Fig 1.1 Symptoms of late blight. (a), Lesions on petiole; (b), leaf spots and blight on leaf; (c), leaflet with leaf spots; (d), close-up of leaf spot showing dot-like pycnidia; (e), gelatinous tendrils of conidia oozing out of pycnidia in culture.

1.8.2 Dispersal

S. apiicola is dispersed by seed, crop debris and adjacent infected crops. The mycelium of *S. apiicola* has not been found inside seed (endosperms and embryos), but has been detected on the outside of seeds in pericarps and testas (Sheridan 1966, Cerkauskas, 1994, Hausbeck 2002). Pycnidia can be found on seed, but their viability decreases with time. Mycelium and pycnidia can survive on stored seed up to 15 months (Sheridan 1966), but not longer than 2 years (Sutton and Waterston 1966). Viability of contaminated celery seed can drop to 2%, 8 months after harvest (Sutton and Waterston 1966). When contaminated seed germinates, infected seed coats may remain attached to the cotyledons and when these are wet, spores ooze from them onto cotyledons resulting in infection (Cerkauskas 1994).

The fungus can survive in crop debris for 11 months, in buried crop debris for 18 months but not for more than 2 years (Sutton and Waterston 1966). Spores, however, only survived for 7 months in crop debris (Maude and Shuring 1970). Survival is shorter during warmer conditions. In the absence of host plant tissue, spores only survived for 6 weeks (Sutton and Waterston 1966, Sherf and MacNab 1986, Cerkauskas, 1994).

In the field, spores are exuded from pycnidia in long gelatinous tendrils during wet weather. They are dispersed by irrigation water, rain splash, wind driven rain (Fritt *et al.* 1989), by contact with machinery, animals or workmen's tools (Linn 1939) especially as the canopy closes over (Chupp and Sherf 1960). In this way the spores are readily moved from plant to plant and crop to adjacent crop.

1.8.3 Disease development

1.8.3.1 Spore germination

Spores germinate on water agar within 12 hr at 20–22.5ºC. The temperature requirement for germination is 5–25ºC, with no germination at 30ºC after 30 hrs (Sheridan 1968a). If relative humidity (RH) is above 95%, free water is not required for germination (Sheridan 1968a), but on celery leaves spores generally germinate and infect in a thin film of water, eg. dew (Schein 1964).

1.8.3.2 Infection

The fungus directly penetrates the epidermis or enters the plant via the stomata (Donovan *et al.* 1990, Hausbeck 2002). After infection, hyphal growth is intercellular and occasionally intracellular when leaves are necrotic (Donovan *et al*. 1990). During warm conditions, 21–27°C, the time from infection to lesion appearance is 7–8 days. At cooler temperatures (18ºC) lesions take 12 days to appear. Mathieu and Kushalappa (1993) quantified the relationship between leaf wetness and temperature in growth chamber studies. They found at temperatures of 10, 15 and 20ºC and increasing periods of leaf wetness up to 96 hrs, increased numbers of lesions, but at 25ºC and 30ºC fewer lesions were formed.

High levels of precipitation promoted disease development (Walker 1952, Sheridan, 1968a, Berger 1970), and relative humidity below 90% limited infection (Sheridan 1968a). In the field infection did not occur when mean RH was < 90% for 2 days following inoculation (Sheridan,1968b).

The time from infection to spore production is generally 10–12 days (Cerkauskas 1994). Lesions develop on susceptible celery in 10 days whilst in more resistant celery varieties, lesions can take 16–21 days to develop (Hausbeck 2002). Late blight generally forms on older leaves later in the crop's life (Walker 1952, Cerkauskas 1994). It can appear as early as 30 days after transplanting but more commonly at 40–60 days (Mudita and Kushalappa 1993). Late blight is a polycyclic disease. It can complete its lifecycle many times during the crop's life (Fig. 1.2).

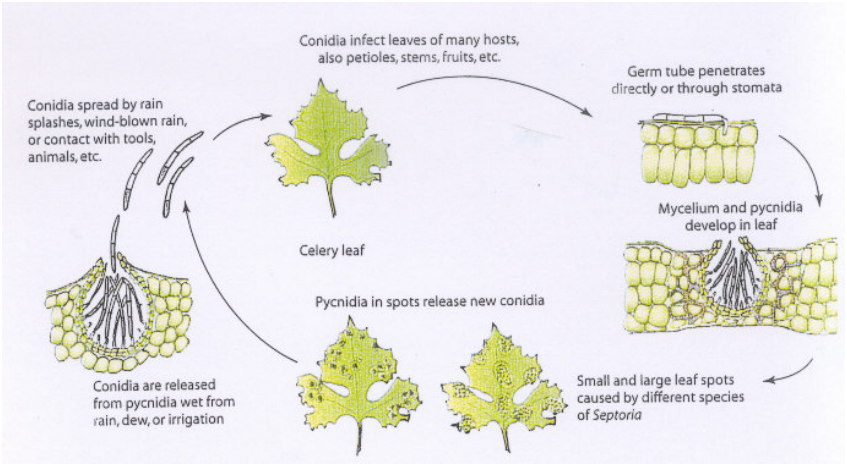

Fig 1.2 Life-cycle of *Septoria apiicola* (modified from Agrios 2005).

1.9 Controls

1.9.1 Chemicals

Early, fungicide control of late blight centered on inorganic compounds, Bordeaux and other copper based fungicides and later moved to the dithiocarbamate and cyclicimide fungicides which have multi-site activity (Avcare). The introduction of systemic fungicides appears to have occurred in three phases. Firstly fungicides from the benzimidazole activity group were introduced, then the DMI triazoles activity group and more recently the strobilurin activity group. All greatly improved control of late blight, however, fungal resistance and occasionally fungicide phytoxicity occurred.

Other chemical options such as, adjuvants, antibiotics and bio-controls have been trialed but with variable results.

Protectant fungicides for late blight control have included were Bordeaux, tribase copper, copper hydroxide, sulphur, chlorothalonil, maneb, ziram, zineb, nabam, propineb, captafol, anilazine, and captan (Chupp and Sherf, 1960, Sutton and Waterston 1966, Lacy, 1973, Aloj and Garibaldi 1982, Sherf and MacNab 1986, Chinchilla and Mora 1986, Lacy and Cortright, 1992). Their application was usually recommended on a 7–14 day preventative spray schedule, but under conditions of very high disease pressure they gave only partial control and some growers applied 3 or more chemical sprays per week to control late blight (Berger 1970, Sherf and MacNab 1986). Today chlorothalonil is probably the most commonly applied protectant fungicide for late blight, but it is classified as a B2 carcinogen, so many celery growers are keen to reduce its usage (Bounds and Hausbeck 2007).

The early systemic fungicides for late blight control included benomyl, carbendazim and thiophanate-methyl (Paulus *et al.* 1970, 1979, 1980, Vulsteke and Meeus 1981, 1986). The emergence of fungal resistance to benomyl and carbendazim (Paulus *et al.* 1979, Gladders and McKeown 1985), led to spraying contact and systemic fungicides either in combination or alternation, such as benomyl + chlorothalonil, or benomyl alternated with chlorothalonil (Paulus *et al.* 1979, 1980, Vulsteke and Meeus 1981, 1986). Fungicide resistance did not always eventuate but Spanish isolates of *Septoria* were still sensitive to benomyl and carbendazim in the early 1990s (Sorribas and Izquierdo 1992).

Later systemic fungicides used for late blight control have largely come from the triazole group. Propiconazole showed curative and eradicative activity along with diclobutrazole, penconazole, myclobutanil, flusilazole, fenarimol, tebuconazole and triadimenol (di Marco 1987, Wicks 1989, 1990, Amer *et al.* 1993a, 1993b). Propiconazole, flutriafol, and combinations of propiconazole and contact fungicides (anilazine or chlorothalonil) have been effective against late blight in the field (Brunelli *et al.* 1989, Wicks 1989, 1990, Amer *et al.* 1993a, 1993b). Penconazole, myclobutanil and flusilazole were unsuitable for late blight control in the field, although they were effective on glasshouse seedlings (Wicks 1989). The addition of adjuvants to low concentrations of carbendazim, flutriafol and propiconazole produced efficacy as good as or better than the fungicide sprayed alone (Amer *et al.* 1992, 1993a). However, addition of adjuvants triadimenol and tebuconazole reduced their efficacy of (Amer *et al.* 1993b).

More recently the strobilurin group of fungicides which includes azoxystrobin, pyroclostrobin, and trifloxystrobin or combinations of them with contact fungicides, has been extensively trialed (Hausbeck *et al.* 2002, Bounds and Hausbeck 2004, 2007, 2008). All have had excellent efficacy, but the frequency of sprays, sometimes up to nine per crop, raises the risk of fungi developing resistance to this fungicide group (FRAC 2005). They have been designated as 'reduced health risk' by the US EPA, but exclusive use has lead to resistance in cucurbit powdery and downy mildews (McGrath, unpublished).

Alternative options for late blight control have been variable. *In vitro* trials demonstrated that the antibiotics kasugamycin and polyoxin-B were highly effective for *S. apiicola* (Sorribas and Izquierdo 1992). The biocontrols *Trichoderma harzianum* partially controlled late blight when applied weekly or 5 days before inoculations with the fungus but gave no control after inoculation with *S. apiicola* in glasshouse trials (Ciccarese *et al.* 1995). Field trials with Messenger (harpin) or Serenade (*B. subtilis)* alternated with chlorothalonil and applied over 10 weeks did not improve control of late blight compared with only chlorothalonil sprays (Bounds and Hausbeck 2004). Phosphonic acid had no efficacy for late blight control in Queensland (Heaton and Dullahide 1990), nor did neem kernal extract (Rovesti *et al.* 1992).

1.9.2 Seed treatments

Seed is considered a major source of *S. apiicola* inoculum and a number of methods have been developed to produce pathogen-free seed. The fungus generally does not survive on seed for more

than two years, so storage of seed for this period of time generally eliminates contamination. A seed soak in 0.2% thiram for 24 hr at 30ºC or a hot-water at 47–49ºC for 30 min. reduced inoculum (Walker 1952, Cerkauskas 1994, Hausbeck 2002). Maude (1970) reported the thiram seed treatment was superior to a hot water treatment of 50ºC for 25 min. (Bant and Storey 1952, Maude 1964). In addition it had no adverse effect on germination compared with the hot water treatment. Wilson (1974) found more losses in germination with thiram 0.25% for 24 hr at 30ºC compared with a hot water treatment of 50ºC for 30 min. An alternative to thiram was a captan dusting reported by Dullahide (1979). A combination of plant growth regulators (PGRs) and a benomyl seed soak at 20ºC for 24 hr completely eliminated *S. apiicola* from seed and broke dormancy (Humpherson-Jones *et al.* 1984, Gott *et al.* 1989). Aerated steam completely eradicated *S. apiicola* from seed, however, an expensive machine is a prerequisite for this treatment (Navaratnam *et al.* 1980).

1.9.3 Genetics

Resistance in celery to *S. apiicola* is recessive and polygenic (Bohme 1960). It has been recognized for some time that wild *Apium* species are sources for resistance in celery (Ochoa and Quiros 1989). Edwards *et al.* (1996) developed a visual key of symptoms to identify resistance to *S. apiicola*, which they found in wild celery lines, lovage and parsley. Some resistance was identified in celery varieties crossed with wild celery, and in the variety Giant Red, but none was found in other celery varieties tested. Breeding for resistance to *S. apiicola* has been undertaken with both conventional and molecular approaches (Moravec *et al.* 1988, Quiros 1993). Donovan *et al.* (1993) found resistant celery had higher essential oil contents, which were inhibitory to *S. apiicola* and suggested they could be used as a tool to identify resistant varieties. Perhaps the most interesting source of resistance was identified from somaclonal variants. Plants regenerated from single cells or cluster of cells showed variation in responses to *S. apiicola* ranging from susceptible to resistant, which suggests that not all plant cells are uniformly susceptible to the pathogen (Wright and Lacy 1985, 1988, Rappaport *et al.* 1991, Donovan *et al.* 1994, Evenor *et al.*1994).

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Chapter 2

The effect of temperature on the release of *Septoria apiicola* conidia from pycnidia

Summary

Contemporary disease-predictive models for late blight in celery have a low temperature threshold of 13 °C. It is well established that spore germination occurs below that temperature, however, the release of spores from pycnidia at lower temperatures has not been investigated fully, or dismissed as minimal. This chapter details growth chamber studies investigating spore release from pycnidia at temperatures below that indicated by the current model and found that spore release was substantial at 10 °C, with a measurable release at 8 °C, but little at 5 °C. This indicates that the present-day disease-predictive model for late blight in celery needs to be revised urgently.

2.1 Introduction

The most recent disease predictive models for late blight in celery caused by *Septoria apiicola* focus on both spore production and germination, but not on infection (Phillips 1991). The most popular disease-predictive model is TomCast, which is derived wholly from an earlier model FAST, described for Alternaria leaf spot in tomato (Madden *et al.* 1978). This model has a range between 13 °C and 29 °C, assigning disease severity values (DSVs) depending on the mean temperature and the duration of leaf wetness (see Chapter 1). However, germination of *S. apiicola* at low temperatures is well known, with pycnidiospores germinating at temperatures as low as 5 °C, and as high as 27 °C (Sheridan 1968). With this in mind, the low temperature limits of spore release were investigated to test the boundaries of the current, most popular, disease-predictive model, over a 24-hr period and are described below.

2.2 Materials and methods

2.2.1 Celery plant seedlings

Celery seedlings (cv. Summit) were supplied by Boomaroo Nurseries (Lara, Victoria, Australia). These were potted individually into 10-cm pots with sterile potting mix. Seedlings were allowed to establish for at least 3-4 weeks before inoculation with *S. apiicola*.

2.2.2 Preparation of *S. apiicola* inoculum and inoculation of celery seedlings

Fresh samples of celery showing symptoms of late blight were collected from infected fields as required. Leaves were placed in a stomacher bag with sterile distilled water in a 1:10 ratio to a maximum of 5 g / 50 mL. Preliminary data suggested that treatment of samples for one minute in a stomacher lab blender was sufficient to extract the conidia from the pycnidia in late blight lesions without substantial cellular debris contaminating the sample. Conidia numbers were calculated using a haemocytometer and spore concentration was adjusted to between 10^5 and 10^6 conidia per mL with sterile distilled water before inoculation.

Celery seedlings were sprayed with a hand-held mister with the prepared inoculum until runoff and seedlings were individually bagged with stomacher bags and sealed with rubber bands to retain moisture. Seedlings were placed in growth chambers set at 20 °C and 100 % RH (relative humidity) for 24-hrs for maximal infection. Seedlings were then placed in a glasshouse (temperature range 10 °C–27 °C) until lesion and pycnidial development.

2.2.3 Spore release at set temperatures

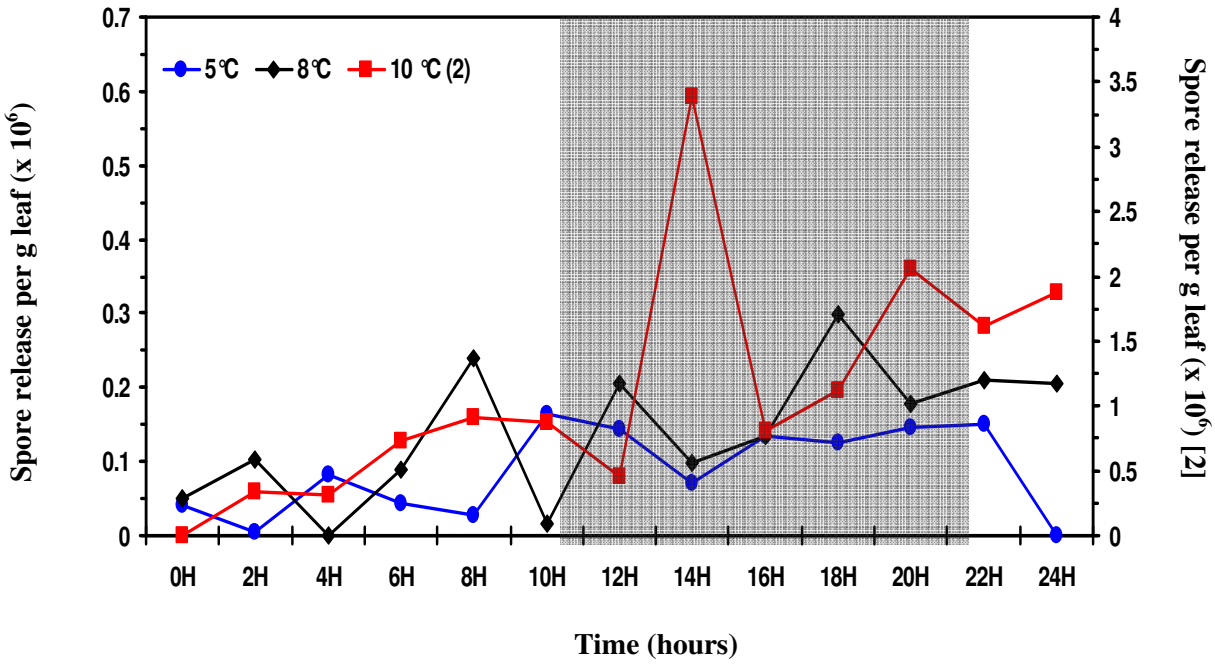
Celery seedlings with well-established lesions and pycnidia were individually bagged in stomacher bags sealed with rubber bands. Seedlings were placed in growth cabinets or a chamber set at the selected temperatures of 5 °C, 8 °C, 10 °C or 20 °C for a full 24-hr period with a 12/12 day night cycle (Fig. 2.1).

At two-hourly intervals, 8 plants were assessed for spore release in the following manner. Plants were debagged and 1 g of infected leaf was placed inside the bag with 10 mL of water. Leaf samples were then placed in a stomacher for 60 sec. to wash spores present on the leaf surface, representing spore release. Samples were then screened through a sieve to remove leaf debris and 3 drops of aniline blue was added to samples to kill the spores. Samples were stored at 4 °C until ready to be analysed. Spore numbers in all samples were calculated using a haemocytometer counting chamber with at least 10 aliquots per sample counted. In some cases, leaf samples containing lesions and pycnidia were also visually assessed under a dissecting microscope for release of spores.

2.3 Results

Tracking of spore release from pycnidia over a 24-hr period is shown in Fig. 2.1. The grey area in the figure represents the 12-hr night cycle, from 7 pm to 7 am. There was little change over a 24-hr period at 5 °C, but there was a four-fold increase in spore release (2 x 10^5 spores g^{-1} leaf wet weight, compared to 5 x 10^4 g^{-1} leaf at T_0) at 8 °C and a substantial number of spores were evident after 24 hrs at 10 °C (1.87 x 10^6 spores g^{-1} leaf). Peaks in spore release numbers are also apparent (14, 20 hours at 10 °C; 8, 12, 18 hrs at 8 °C).

Fig. 2.1 Spore release from pycnidia over a 24-hr period at set temperatures



2.4 Discussion

The model for Septoria late blight in celery is derived wholly from the previous disease-predictive model FAST (Madden *et al.* 1978), used for the prediction of early blight in tomatoes caused by *Alternaria solani*, even to using the same table for calculating disease severity values (DSVs) (see Chapter 1). The models used thus far focus on spore production, not on the infection cycle. According to FAST, the calculation of DSVs is both temperature- and leaf wetness-dependent, with a range of 13 °C to 29 °C (Phillips 1991). Furthermore, Phillips (1999) stated: "There is a lower

thermal threshold of 13 degrees C (70 degrees F), below which disease development is so minimal as to be inconsequential".

The current research suggests this is not the case, with substantial numbers produced at both 8 °C (46 °F) and 10 °C (50 °F), well below the lowest temperature threshold for the present model. This leads to the conclusion that the existing model needs urgent re-evaluation, with further research required to explor the temperature limits of spore formation, in contrast to germination, for a far more accurate representation of model parameters in order to be relevant and useful to growers. Other researchers have also questioned present-day models, demonstrating that late blight infection can occur at low temperatures (5 °C and 10 °C), with much shorter leaf wetness periods than previously thought, albeit with lower severity than under optimum conditions (Green *et al.* 2002). This observation was confirmed by later research (Tvede unpublished) which clearly demonstrated penetration of celery leaf stomata and thus infection at temperatures as low as 8 °C. Thus, a model incorporating both spore production and infection would be more relevant for this particular disease, since both have been demonstrated at temperatures lower than the existing model.

Peaks in spore numbers over the 24-hr period probably relate to pycnidia maturing at different rates within lesions. Phillips (1991) quotes KH Lin (1936) stating that potentially "half a billion spores can be produced on one plant", while Sherf and McNab (1986) reported only 10 spores were necessary for infection, which, considering the cyclic nature of this particular disease, shows the potential devastation that this represents. Peaks of spore numbers in the night period evident at both 8 and 10 °C may indicate a diurnal pattern, where most spores are released after maturation, a similar pattern to other phytopathogenic fungi (e.g. downy mildew of lettuce; Raid and Datnoff 2003).

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Chapter 3

Evaluation of the TomCast disease predictive model for reducing the number of fungicide sprays for late blight on celery in Australia

Summary

The disease predictive model TomCast reduced by up to 8 the number of sprays for Septoria late blight on celery in the early stages of crop production but till now has not been used in the later stages of crop production. A computer based delivery program for TomCast called Disease Doctor™ was developed in consultation with growers. The start temperature for the model in the later phase of crop production was lowered for the first time, resulting in 7 fewer sprays with no reduction in the grower's estimated yields. This model was ranked as the most economical. The model spray thresholds were 10 DSV 13 °C plus a systemic fungicide at week 10 then 10 DSV 8 °C until harvest, which resulted in 8 fewer sprays in the early stages of crop production and 7 fewer in the latter stages. This is the first report of the TomCast disease predictive model being successfully used to predict Septoria late blight up to harvest. The most effective methods of controlling Septoria late blight based on incidence only, were weekly fungicide applications based on TomCast at 10 or 15 DSV 13 °C plus a systemic fungicide at week 10 followed by weekly fungicide sprays and these ranked 3, 4 and 8 in order of being the most economical (Chapter 4). Fungicide applications prior to week 10 may not be necessary. In desk-top studies the Septoria predictor over estimated and the Cercospora model underestimated the number of sprays required for Septoria late blight control.

3.1 Introduction

Celery has a high aesthetic standard as the whole plant is harvested for market. Septoria late blight, a major disease of celery, is difficult to control once it appears in crops. Spores of the causal fungus, *Septoria apiicola,* are splash-dispersed and consequently the disease spreads quickly under overhead irrigation. Celery crops are sprayed weekly to manage Septoria late blight and this can results in 16 sprays applied at weekly intervals during the crop's life. Due to the rapidity of spread and severity if uncontrolled, any symptoms of Septoria late blight observed in celery crops cause growers to be alarmed.

Researchers in Canada and the USA have evaluated 3 models in inoculated field trials to predict the appearance of Septoria late blight in celery crops with a view to reducing the number of fungicides required to control the disease, whilst maintaining crop quality. The models tested were the Septoria predictor, the Cercospera model and the TomCast model. All models reduced the number of fungicides applied by 1–5 and in most cases with no significant differences in yields to weekly spray programs, but models are not deployed beyond canopy closure overseas (Bounds and Hausbeck 2006, 2007, Trueman *et al.* 2006, 2007). The TomCast model is considered to be the most consistent and economical followed by the Cercosproa model and the Septoria predictor (Grumet 2003). Temperature is not included on the Septoria predictor, some allowances are made for temperatures below 12 °C in the Cercospora model while the TomCast model only commences calculating at 13 °C (Berger 1969b, Madden *et al.* 1978, Lacy 1994).

Preliminary evaluations of the TomCast model in Australia on naturally infected celery crops only reduced sprays only in the early stages of crop production prior to canopy closure. In a summer crop 3–5 sprays fewer were required using TomCast DSV15, 20 and 25; and 7–8 sprays fewer in a winter crop using TomCast DSV10, 12, 15 and 20 with no difference in late blight, when compared with the weekly spray schedule. Australian growers report Septoria late blight is a problem in winter when temperatures are as low as 10 °C (Tim Harslett, pers. com.).

This chapter reports work on:

- Evaluating modifications to the temperature threshold and spray thresholds (DSVs) of the TomCast model;
- Extending the model beyond canopy closure and;
- Validating of a computer program (Disease Doctor™) for growers to access the model as a management tool for Septoria late blight on naturally-infected summer and winter celery crops in Victoria.
- Undertaking desktop evaluations of the Septoria predictor and the Cercospora model on summer and winter field collected weather data for comparison with the TomCast model.

3.2 Material and methods

3.2.1 The TomCast model

Refer to Table 1.1 of Chapter 1.

3.2.2 Weather stations

A ModelT weather station (Western Electronics) was placed in each celery crop and it recorded average leaf wetness, temperature, relative humidity and total rainfall at 30 min. intervals. The leaf wetness sensor was placed in the celery crop at an angle of about 10° facing south, to maximize leaf wetness, and its height adjusted as the crops grew.

3.2.3 Chemicals and application

Chemicals were applied with a single cone nozzle SPX brown No 12 by a Sylvan Selectra 12v knapsack (Silvan Pumps and Sprayers (Aus) Pty. Ltd.). Fungicides were applied at a volume of 1000L/ha in trial No 1. In trial No. 2 fungicides were initially applied at 500L/ha at the seedling stage, followed by 1000L/ha (Table 3.1).

Table 3.1 Information on chemicals applied in the Victorian trials

Trade name	Active ingredient	Company	Rate	Rate /ha
Barrack 720®	Chlorothalonil	CropCare (Syngenta)	180ml/100L	500L[A]–1000L[B]
Hortiwett™	Alkylaryl polyglygol ether	Nipro	25mL/100L	
Kocide®	Cupric hydroxide	Griffin	200g/100L	
Mancozeb DF®	Mancozeb	Kendon	200g/100L	
Score®	Difenoconazole	Syngenta	25mL/100L	

[A], prior to canopy closure; [B], post canopy closure

3.2.4 Field trial No 1 Summer

Eight week old celery seedlings of cv Hornet were supplied courtesy of Boomaroo Nurseries, Lara, Victoria and planted on 12 January 2007 at 100 Campbells Road Clyde, Victoria. The trial was laid out in a randomised block design of 8 blocks each containing 6 treatments (plots). Plot sizes were 7.5 m long x 1.5 m wide and contained 68 plants, planted 2 rows per bed on raised beds. The treatments were six different spray triggers as described in Tables 3.1 and 3.2.

3.2.5 Field trial No 2 Winter

This trial was planted with 8 week old celery seedlings of the grower's (Mr Tom Schreurs) own selection, on 25 May 2007 at 100 Campbells Rd Clyde, Vic. The trial occupied two bays, one on either side of a dirt track. Each bay contained 4 replicates of 12 treatments, each arranged in 2 adjacent bed of 6 plots each. Each plot contained a treatment. The replicates were laid out alongside the dirt track (Appendix 1). Plot sizes were 7.5 m long x 1.5 m wide and contained 68 plants, planted 2 rows per bed on raised beds. The 12 treatments are described in Tables 3.1 and 3.3. Treatment 9 was abandoned due to high disease pressure, no spray thresholds were reached, but to reduce spread of Septoria two systemic sprays followed by weekly sprays of a contact fungicide were applied.

3.2.6 Field trials Nos 3 and 4 in Queensland

Both trials were planted at Harsletts Farm, Harslett Road, Amiens QLD, with the grower's own seed. The 2007 trial was planted on 3/01/07 and harvested on 1/4/07, whilst the 2007–08 trial was planted on 26/8/07 and harvested on 28/2/08. Both trials were observational only, conducted by the growers and laid out at one treatment per land either side of an irrigation line. There were 4 beds per land with 4 rows of celery per bed. Weather data was collected by an ADCOM weather station which ran the TomCast model. Chemical treatments were a combination of Mancozeb® (mancozeb), Polyram® (metiram) and Bravo® (chlorothalonil) at the label rate.

3.2.7 Assessment

The incidence (percentage) of plants with Septoria late blight was assessed weekly for both the summer and winter field trials in Victoria. In the summer trial, 10 'guard' plants were left at the beginning of each row of each plot and the next 10 plants were thoroughly examined for late blight. The final assessment was made on 11/4/2007 at week 13. In the winter field trial, all plants were assessed weekly for disease until 24/10/2007 at week 22.

Severity of Septoria late blight was also assessed at week 22 in the winter trial, using the following scoring system: 0 = no late blight, 1 = late blight on the lower older foliage only, 2 = 1–5 lesions of late blight on upper foliage, 3 = 5–10 late blight lesions on upper foliage but the plant would still be marketable; 4 = more than 10 late blight lesions on upper and lower foliage; and 5 = symptoms of blight on whole plant.

The marketability of field trial No 1 summer was not assessed as no Septoria developed on plants. Marketability of field trial No. 2 winter was assessed during week 24 by Mr Tom Schreurs and Dr E Minchinton on a scale of 0-5, where 0–1 = harvestable with no significant losses, 1–2 = harvestable but up to 10% losses but acceptable, 2–3 = 30% loss and not acceptable, 3–5 = greater than 30% loss and not marketable.

Crop yield is based on an estimated 85 tonnes/ha for a crop displaying no crop loss from Septoria late blight (Minchinton *et al.* 2005). The Victorian trials were not harvested as they were required by the grower for other purposes.

3.2.8 Analysis

Incidence from the winter trial only was analysed. The AREPMEASURES procedure in Genstat Release 10 was used. This procedure carries out a repeated measures analysis of variance which adjusts the statistical tests for the correlation of the data over time. Both incidence and severity data at week 22 were analysed using the ANOVA procedure in Genstat and the means are presented in Table 3.4.

3.2.9 Desk-top evaluation of the Sesptoria predictor and the Cercospora model

Weather data from field trials 1 and 2 were placed in an Excel file. To evaluate the Septoria predictor, the number of times 12 or more hours of leaf wetness occurred was recorded as described in Chapter 1 section 1.3.3. The Cercospora model was evaluated as described in Chapter 1 section 1.3.4. In both simulations, new sprays were indicated if the predictor or model predicted infection and no sprays had been applied in the past 7 days. Both the model and predictor assume any fungicides sprayed onto foliage would have 7 days residual activity.

Table 3.2 Spray schedule for field trial No 1 in summer

Treatment No.	Pre-canopy closure	Canopy closure or 1st spots systemic (+/-)	Post canopy closure	Date sprayed													Harvest
				12/01/2007 planted	17/01/2007 wk 1	24/01/2007 wk 2	31/01/2007 wk 3	7/02/2007 wk 4	14/02/2007 wk 5	21/02/2007 wk 6	28/02/2007 wk 7	7/03/2007 wk 8 Canopy closure	14/03/2007 wk 9	21/03/2007 wk 10	28/03/2007 wk 11	4/04/2007 wk 12	11/04/2007 wk 13
1	Weekly MKH/B	-	Weekly	B	MKH	B	MKH	B	MHK	B	MHK	B	MKH	B	29/03/2007 MKH	B	-
2	15 DSV MKH/B	+	Weekly	B	-	22/01/2007 MKH	30/01/2007 B	8/02/2007 MKH	16/02/2007 B	S	MKH	B	MKH	B	29/03/2007 MKH	B	-
3	15 DSV DD MKH/B	+	10 DSV	B	-	22/01/2007 MKH	30/01/2007 B	8/02/2007 MKH	16/02/2007 B	S	MKH	B	-	MKH	-	-	-
4	15 DSV MKH/B	+	10 DSV	B	-	22/01/2007 MKH	30/01/2007 B	-	16/02/2007 B	S	MKH	B	17/03/2007 MKH	25/03/2007 B	-	-	-
5	15 DSV B + K(1/2 wkly)	+	10 DSV	B	-	22/01/2007 B + K	30/01/2007 B	8/02/2007 B + K	16/02/2007 B	S	B + K	B	17/03/2007 B	25/03/2007 B + K	-	-	-
6	20 DSVs MKH/B	+	10 DSV	B	-	25/01/2007 MKH	3/02/2007 B		MHK	S	B	8/03/2007 MKH	-	22/03/2007 B	-	-	-

B = Barrack®, H = Hortiwett™, K = Kocide®, M = Mancozeb®, S = Score®

Table 3.3 Spray schedule for field trial No 2 in winter

Treatment No.	Pre-canopy closure	Canopy closure or 1st spots systemic (+/-)	Post canopy closure to harvest	Date or week of fungicide application																			
				25/05/07 wk 1	06/06/07 wk 2	13/06/07 wk 3	20/06/07 wk 4	27/06/07 wk 5	04/07/07 wk 6	11/07/07 wk 7	18/07/07 wk 8	25/07/07 wk 9	01/08/07 wk 10 1 st spots	08/08/07 wk 11	15/08/07 wk 12	22/08/07 wk 13	29/08/07 wk 14	05/09/07 wk15	12/09/07 wk 16	19/09/07 wk 17	26/09/07 wk 18	03/10/07 wk 19	10/10/07 wk 20	17/10/07 wk 21	24/10/07 wk22
1	Weekly	-	Weekly	BV	07/06/07 MHK	13/06/07 B	20/06/07 MHK	28/06/07 B	03/07/07 MHK	10/07/07 B	16/07/07 MHK	23/07/07 B	30/07/07 MHK	06/08/07 B	14/08/07 MHK	20/08/07 B	27/08/07 MHK	05/09/07 B	13/09/07 MHK	17/09/07 B	24/09/07 B	01/10/07 B	08/10/07 B	17/10/07 B	23/10/07 B
2	10 DSV 13°C	+	Weekly	BV	-	-	-	-	-	-	-	-	01/08/07 S	06/08/07 B	14/08/07 MHK	20/08/07 B	27/08/07 MHK	05/09/07 B	13/09/07 MHK	18/09/07 B	24/09/07 B	02/10/07 B	08/10/07 B	17/10/07 B	23/10/07 B
3	10 DSV 13°C	+	10 DSV 13°C	BV	-	-	-	-	-	-	-	-	01/08/07 S	-	-	-	-	-	-	-	-	-	-	-	-
4	10 DSV13°C	+	10 DSV 8°C	BV	-	-	-	-	-	-	-	-	01/08/07 S	-	-	-	26/08/07 MHK	-	12/09/07 B	-	26/09/07 B	-	06/10/07 B	-	26/10/07 B
5	10 DSV 13°C DD	+	10 DSV 13°C DD	BV	-	-	-	-	-	-	-	-	01/08/07 S	-	-	-	-	-	-	-	-	-	-	-	-
6	10 DSV 13°C DD	+	10 DSV 8°C DD	BV	-	-	-	-	-	-	-	-	01/08/07 S	-	-	-	26/08/07 MHK	08/09/07 B	-	17/09/07 B	-	01/10/07 B	-	-	21/10/07 B
7	10 DSV 8°C	-	10 DSV 8°C	BV	-	14/06/07 MHK	-	-	05/07/07 B	-	-	-	-	06/08/07 MHK	-	-	01/09/07 B	-	14/09/07 MHK	-	27/09/07 B	-	13/10/07 B	-	-
8	15 DSV 8°C	-	15 DSV 8°C	BV	-	-	-	28/06/07 MHK	-	-	-	-	-	06/08/07 B	-	-	-	08/09/07 C	-	-	27/09/07 C	-	-	-	21/10/07 B
9	15 DSV 13°C	-	15 DSV 13°C 2 Score, Weekly	BV	-	-	-	-	-	-	-	-	-	-	-	-	28/08/07 S	05/09/07 S	13/09/07 MHK	18/09/07 B	24/09/07 B	02/10/07 B	08/10/07 B	17/10/07 B	23/10/07 B
10	15 DSV 13°C	+	Weekly	BV	-	-	-	-	-	-	-	-	01/08/07 S	06/08/07 B	14/08/07 MHK	20/08/07 B	27/08/07 MHK	05/09/07 B	13/09/07 MHK	17/09/07 B	24/09/07 B	02/10/07 B	08/10/07 B	17/10/07 B	23/10/07 B
11	15 DSV 13°C	+	15 DSV 8°C	BV	-	-	-	-	-	-	-	-	01/08/07 S	-	-	-	-	03/09/07 MHK	-	-	26/09/07 B	-	-	20/10/07 B	-
12	15 DSV 13°C	+	15 DSV 13°C	BV	-	-	-	-	-	-	-	-	01/08/07 S	-	-	-	-	-	-	-	-	-	-	-	-

BV = Bavistin®, B = Barrack®, H = Hortiwett™, K = Kocide®, M = Mancozeb®, S = Score®

3.3 Results

3.3.1 Field Trial No 1 Summer

No symptoms of Septoria late blight were observed in the summer trial on this site which had not been planted to celery for 5 years.

3.3.2 Field Trial No 2 Winter

Late blight was first observed in the trial at 10 weeks on 1/8/2007, just prior to canopy closure (Fig. 3.1). This site was last planted to celery 2 years ago. More Septoria occurred in one bay than the other bay. The standard industry practice of weekly sprays with protectant fungicides completely controlled the disease (Fig. 3.2, Table 3.4). Treatments with a systemic sprayed at first lesions followed by weekly protect sprays (treatments 2 and 10), had a higher but not significantly different incidence and severity of late blight compared with the industry standard practice of weekly sprays (treatment 1). The incidence of Septoria late blight with most treatments gradually increased over time, but interestingly treatments 2 and 10 showed an increase at week 16 to 12% and 25%, respectively, but a declining incidence thereafter.

Fig. 3.1 Appearance of celery canopy at 10 weeks (left), 12 weeks (centre) and at 13 weeks (right).

Evidence of canopy closure was evident at 12 weeks and complete by 13 weeks.

Up to week 10, disease incidence was the same in treatments receiving zero, one or two and 8 weekly sprays of the standard industry spray practice. Treatment 8 (DSV15 8 °C) had 7 fewer sprays compared with the industry standard, treatment 7 (DSV10 8 °C) had 6 fewer sprays compared with the industry standard and all other treatments had 8 fewer sprays compared with the standard industry weekly spray program (Table 3.4).

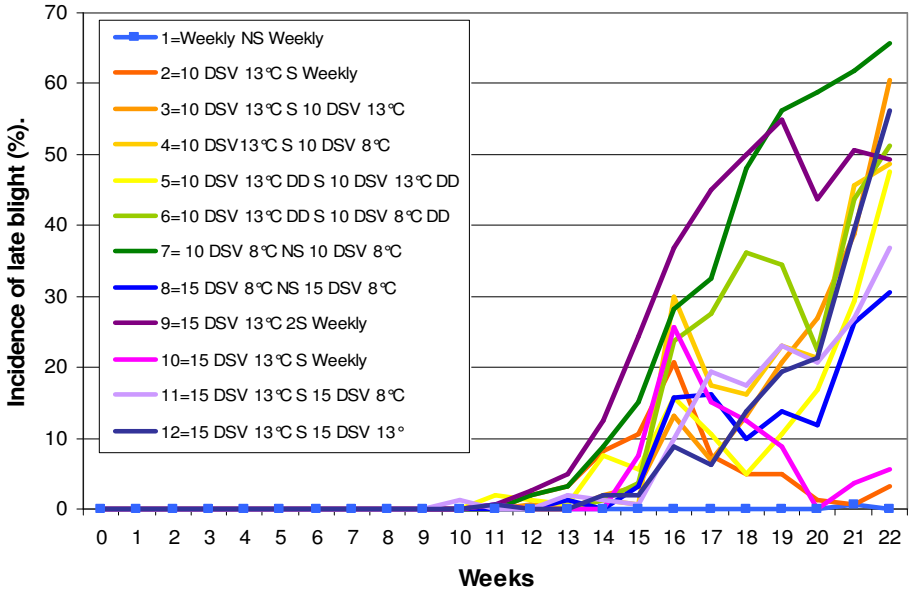
From week 10 or first lesions onwards, only treatments 1 (weekly sprays applications), 2 and 10 produced the highest control of the incidence and severity of the disease with no significant differences between them (Table 3.4). By the final assessment at week 22, treatment 2 (DSV10 13 ºC + systemic weekly) and treatment 10 (DSV15 13 ºC + systemic weekly) produced average incidences and severities of late blight which did not differ statistically from the standard industry weekly spray program (Table 3.4). By week 22 all other spray programs had incidences and severity of late blight which were significantly higher than the standard industry weekly spray program.

Table 3.4 Evaluation of the spray thresholds for use with the TomCast disease predictive model to control Septoria late blight on celery, winter 2007 Victoria

Treatment No.	Spray threshold or schedule			No. sprays		Total No. sprays	Average incidence at week 22 (%)		Average severity at week 22 (%)		Mean marketability (scale 0-3)	Crop loss (%)	Market able crop (%)	Grower estimated yield (tonnes/ha)	Yield[B] (tonnes/ha)
	Pre-canopy closure	Canopy, first lesions, 10 weeks +/- systemic	Post-canopy closure	Pre lesions	Post leions										
1	Weekly	-	Weekly	8	13	21	0.0	a[A]	0.0	a	0	0	100	85.0	85.00
2	10 DSV 13°C	+	Weekly	0	13	13	3.1	a	0.04	a	0	0	100	85.0	82.37
10	15 DSV 13°C	+	Weekly	0	13	13	5.6	ab	0.09	a	0	2	98	83.3	80.24
6	10 DSV 13°C DD	+	10 DSV 8°C DD	0	6	6	30.6	bc	0.36	a	0.3	0	100	85.0	58.99
11	15 DSV 13°C	+	15 DSV 8°C	0	4	4	36.9	cd	0.68	a	1.3	2	98	83.3	53.64
5	10 DSV 13°C DD	+	10 DSV 13°C DD	0	1	1	47.5	cde	1.06	b	2.5	30	70	59.3	44.63
4	10 DSV13°C	+	10 DSV 8°C	0	6	6	48.8	cde	1.02	b	1.4	2	98	83.3	43.52
9	15 DSV 13°C	++ (late)	[15 DSV 13°C] 2 Score, Weekly	0	9	9	49.4	cde	0.68	a	0.6	0	100	85.0	43.01
7	10 DSV 8°C	-	10 DSV 8°C	2	5	7	51.2	cde	1.32	bc	1.8	2	98	83.3	41.48
12	15 DSV 13°C	+	15 DSV 13°C	0	1	1	56.2	de	1.20	bc	3.2	70	30	25.5	37.23
3	10 DSV 13°C	+	10 DSV 13°C	0	1	1	60.6	de	1.44	bc	3.3	70	30	25.5	33.49
8	15 DSV 8°C	-	15 DSV 8°C	1	4	5	65.6	e	1.78	c	2.3	30	70	59.5	29.24
lsd 5%							25.28		0.696						

Severity Scale 0-5: 0 = no late blight, 1 = late blight on the lower older foliage only, 2 = 1–5 lesions of late blight on upper foliage, 3 = 5–10 late blight lesions on upper foliage but the plant would still be marketable; 4 = greater than 10 late blight lesions on upper and lower foliage; and 5 = symptoms of blight on whole plant.
[A], Numbers followed by different letters differ significantly; [B], Yield = 85-(85xIncidence/100); DD, Disease Doctor ™ program
DSV, disease severity value; [ ], spray omitted

Fig 3.2 Efficacy of various spray thresholds of the TomCast disease predictive model to control Septoria Late Blight



3.3.2.1 Disease Doctor™ program

Disease Doctor™ and the Excel macro calculated the same number of sprays for each of the two spray thresholds (treatments 4 and 6 and treatments 5 and 3; Table 3.5). There were no significant differences in incidence of the late blight disease between treatments 3, 4, 5 and 6 (Table 3.5), but all were significantly higher than the standard industry weekly spray program. The Disease Doctor™ program treatment 5 had a significantly lower severity of late blight than its Excel equivalent, treatment 3. The Disease Doctor™ program treatment 6 had a significantly lower severity of late blight than its Excel equivalent, treatment 4. The timing of the spray applications, however, varied between the Disease Doctor™ program and its Excel equivalent (Fig 3.3). Disease Doctor™ spray threshold treatments (DSV's) were generally predicted earlier than the Excel equivalent spray threshold treatments. This situation may be associated with rounding off. An example of the screen display for the Disease Doctor™ program is shown in Fig. 3.4.

Table 3.5 Comparison of the Disease Doctor™ program with the Excel equivalent

Treatment No.	Spray threshold or schedule			No. sprays		Total No. sprays	Average incidence at week 22 (%)		Average severity at week 22 (%)	
	Pre-canopy closure	Canopy closure or 1st spots +/- Systemic	Post canopy closure or 1st spots to harvest	Pre spots	Post spots					
1	Weekly	-	Weekly	8	13	21	0.0	a[A]	0.0	a
6	10 DSV 13°C DD	+	10 DSV 8°C DD	0	6	6	30.6	bc	0.36	b
5	10 DSV 13°C DD	+	10 DSV 13°C DD	0	1	1	47.5	cde	1.06	d
4	10 DSV13°C Excel	+	10 DSV 8°C Excel	0	6	6	48.8	cde	1.02	cd
3	10 DSV 13°C Excel	+	10 DSV 13°C Excel	0	1	1	60.6	de	1.44	e
lsd 5%							25.28		0.349	

Severity Scale 0-4: 0=0 no spot on plant; 1= spots on lower older leaves near ground leaves not harvested; 2= spots on middle level leaves - probably not harvested; 3= 1–10 spots on upper harvestable leaves; 4= >10 spots on upper harvestable leaves and heavy infection on middle leaves, would be expected to affect harvest.

[A], Numbers followed by different letters differ significantly.

Fig 3.3 Frequency of sprays between Disease Doctor™ and the Excel TomCast program for treatments 4 and **6**

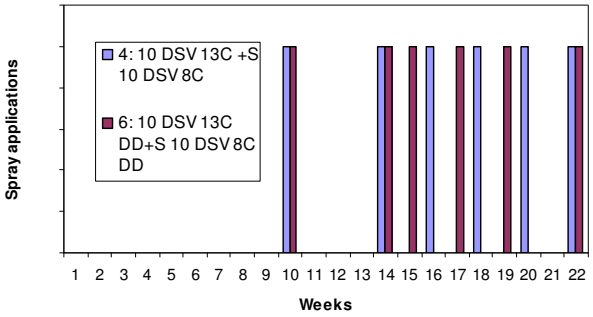
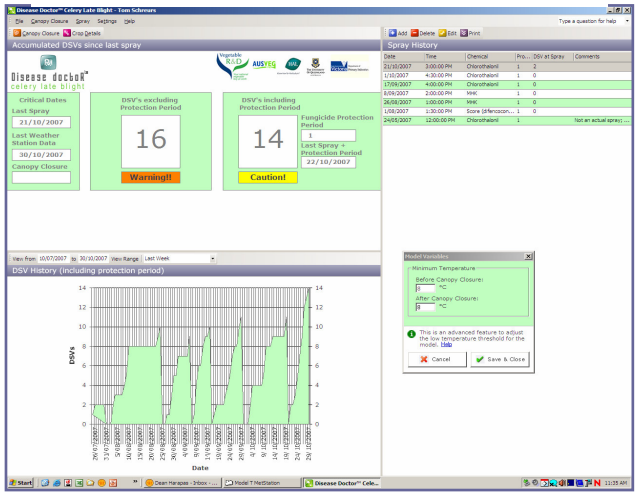


Fig 3.4 An example of the screen display for the Disease Doctor™ program for 8 °C



3.3.2.2 Commencing the TomCast model at 8 ºC or 13 ºC, prior to first lesions

Prior to first lesions at 10 weeks, using the TomCast model with a starting temperature of 13 ºC, as per the existing model, produced no spray thresholds for either the DSV10 or DSV15 treatments. Commencing the model, using a lower temperature of 8 ºC with either DSV15 or DSV10 spray thresholds, produced one or 2 sprays applications prior to first lesions with treatments 8 and 7, respectively (Table 3.4).

3.3.2.3 Systemic fungicide application at first lesion

Those TomCast model treatments which had a systemic fungicides application generally had a lower, although not necessarily significantly different, incidence and severity of late blight compared to those with no systemic fungicide application (Table 3.4). The effect of the systemic was probably masked by the post-lesion treatments. Although some treatments (9 and 12) were originally designed to test the efficacy of the systemic fungicide applications, technical issues hindered the procedure.

3.3.2.4 Protectant fungicides

The protectant fungicides and wetter (MHK) were replaced by another protectant fungicide chlorothalonil after week 16, as there was a perception that chlorothalonil had more efficacy towards late blight than MHK. Some of the treatments did show a decline or reduced rate of increase of late blight such as treatments 2, 10 and 8, when sprayed with chlorothalonil.

3.3.2.5 Finishing the TomCast model with 8 ºC or 13 ºC, post first lesions

At post-first lesions, lowering the commencement temperature for the model from 13 ºC to 8 ºC increased the number of sprays applied by the model from one spray with 13 ºC, treatments numbered 3, 5 and 12, to 4, 5, 6, 7 and 9 sprays with treatments numbered 11, 8, 4 and 6, and 7 respectively (Table 3.4). A spray threshold of DSV10 8 ºC, post first lesions generally resulted in fortnightly sprays e.g. treatments 4, 6 and 7. A spray threshold of DSV15 8 ºC, post-first lesions, generally resulted in a spray every 3 weeks, e.g. treatments 8 and 11.

3.3.2.6 Crop loss, marketability and yield

Treatments 1, 2 and 10 produced the highest estimated yields based on incidence and the most economical were treatments 1, 2 and 10 (Chapter 4). The grower-estimated yields were highest for treatments 1, 2, 6 and 9, but there was no difference in the economics between treatments 6, 9, 1, 2, 11, 7, 4 and 10 (Chapter 4), (Table 3.4). Treatments with low crop losses had high marketability and *vice versa*. Generally grower estimates of very high and very low yields corresponded to the estimated high and low yields based on incidence (Table 3.4). Exceptions were treatments 4, 9, 7 and 8 which the grower rated higher than the estimated yields. Time between the assessment of incidence

and the assessment of yield by the grower was 2 weeks, which may account for some of the differences in the two methods of assessing yield.

3.3.3 Queensland trials

No Septoria Late Blight developed in either of the Queensland trials (Table 3.6). In these trials the number of sprays was reduced by 1–6.

Table 3.6 Evaluation of spray thresholds for use with the TomCast disease predictive model to control Septoria late blight on celery in Queensland 2007–2008

Year	Treatment	Pre-canopy closure	Canopy closure or 1st spots (+/- systemic)	Post-canopy closure to harvest (weekly sprays)	No. sprays	Incidence of Septoria
2007	Control (unsprayed)	-	-	-	0	0
	Weekly	MPB	+	MPB	9	0
	Disease Doctor DSV 10	MPB	+	MPB	6	0
	TomCast DSV 10	MPB	+	MPB	7	0
	TomCast DSV 15	MPB	+	MPB	5	0
	TomCast DSV 20	MPB	+	MPB	4	0
2007–08	Weekly	MPB	+	MPB	10	0
	TomCast DSV 10	MPB	+	MPB	9	0
	TomCast DSV 15	MPB	+	MPB	7	0
	TomCast DSV 20	MPB	+	MPB	4	0

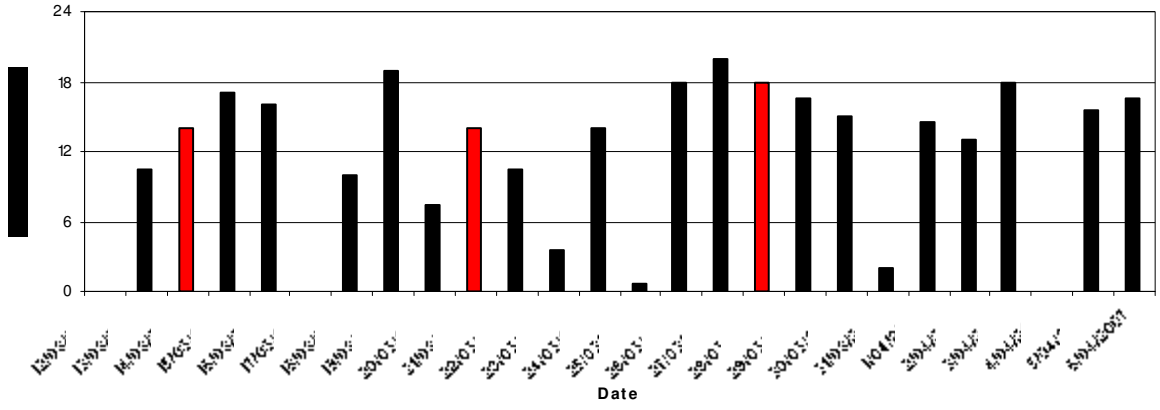
MPB, Mancozeb, P, Polyram, B, Barrack

3.3.4 Desktop evaluation of the Septoria predictor and Cercospora model

The Septoria predictor forecast 11 spray events in trial No. 1 summer, whilst there were 12 weekly sprays applied to this trial (Fig. 3.5). It forecast 20 spray events in trial No. 2 winter, whilst there were 21 weekly spray applied to this trial. There were 8 spray events forecast prior to 1/08/07 when the first lesions were observed in the trial and 12 spray events forecast after first lesion appearance. The saving of one spray was made post-first lesion appearance. The Septoria predictor forecast the reduction of only one spray application compared to weekly sprays.

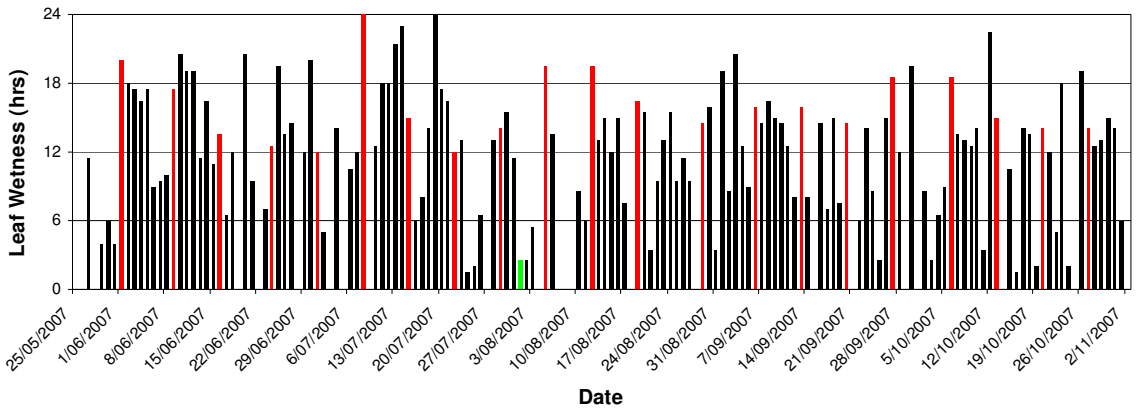
The Cercospora model forecast only one spray in trial No. 2 winter which occurred on 31 August 2008 between the last spray and harvest. It is highly unlikely it would have controlled late blight as treatments 3 and 12, which had only one spray, had very high incidences of and severities of late blight. In trial No. 1 summer, the Cercospora model forecast four sprays, one at canopy closure and four post canopy closure (Fig 3.7), but no Septoria late blight developed in the trial.

Fig 3.5 Desktop evaluation of the Septoria predictor (Lacy 1994) with the weather data set from trial No. 1



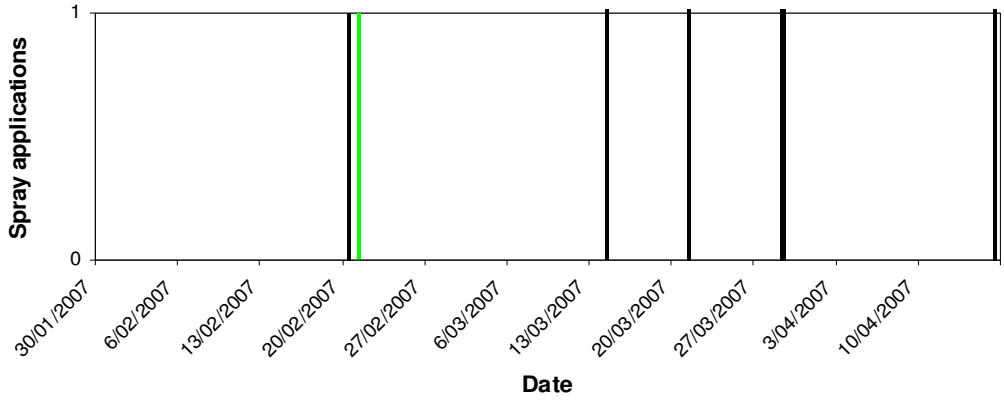
Black bars, hours of leaf wetness; red bars, hours of leaf wetness in excess of 12 hours; green bar, time first lesions appeared in the trial.

Fig 3.6 Desktop evaluation of the Septoria predictor (Lacy 1994) with the weather data set from trial No. 2



Black bars, hours of leaf wetness; red bars, hours of leaf wetness in excess of 12 hours; green bar, time first lesions appeared in the trial

Fig 3.7 Desktop evaluation of the Cercospora model (Berger 1969b, Bounds and Hausbeck 2007 and Raid *et al.* 2008) with the weather data set from trial No. 1



Black bars estimated spray events based on the Cercospora model; green bar, canopy closure

3.4 Discussion

3.4.1 Starting temperatures for TomCast for Septoria late blight of celery

This is the first evaluation of the TomCast disease predictive model where a lower temperature threshold of 8 °C for Septoria late blight in celery has been trialled. Using a starting temperature of 8 °C, only one or two sprays were predicted up to week 10 (first lesions), and these sprays turned out to be unnecessary. Whereas the higher starting temperature of 13 °C did not predict any sprays and none were necessary under the prevailing conditions of the trials. There was no advantage in spraying according to the model starting at 8 °C, as spraying according to the model starting at 13 °C or applying weekly sprays gave best results. The appearance of the disease in the crop in the first 10 weeks may not be related to temperature around 8 °C.

Post 10 weeks with a starting temperature of 8 °C, there were 7 – 9 fewer sprays depending on DSV thresholds, but all had a significantly high incidence and severity of late blight compared with weekly sprays (treatments 4, 6, 7, 8 and 11). However, only four of these treatments (numbers 4, 6, 7 and 11) had optimal or slightly less than optimum grower yields. The exception was treatment 8, which had no systemic fungicide spray. Consequently if TomCast is to be used post 10 weeks, or at first lesions, or canopy closure then a systemic fungicide spray is required at this point in time. A higher frequency of systemic fungicide sprays would probably give better control of the disease as it has done overseas (McDonald 2004, Trueman *et al.* 2007, Bounds and Hausbeck 2007, 2008), but

issues with resistance management could arise (FRAC 2005). However, yield data based on incidence suggested yields would be much lower if TomCast was run for the whole trial.

Post 10 weeks with a starting temperature of 13 °C, no sprays were predicted irrespective of DSV threshold (treatments 3, 5 and 12), but all theses treatments had a significantly higher incidence and severity of late blight and grower yield estimates were generally the lowest, as were the yields based on incidence. A starting temperature for the model of 13 °C post-canopy closure was too high. Overseas higher DSV thresholds are generally used in drier regions and lower DSV thresholds are generally used in wetter regions, or where trials have been artificially inoculated, which suggests where a high disease pressure is expected lower DSV thresholds should be used (Reitz *et al.* 1999; Bounds and Hausbeck 2007; Trueman 2007).

Irrespective of the spray threshold (DSV) or temperature to start the model, TomCast overestimated the number of sprays prior to first lesions (10 weeks) and under-estimated the number of sprays post first lesion (10 weeks or canopy closure) and did not achieve control of incidence and severity of late blight equivalent to weekly spraying.

3.4.2 Disease Doctor™

The Disease Doctor™ DSV10 13 °C + systemic fungicide + DSV10 8 °C treatment (treatment 6), was the most economical, based on grower-estimated yield, despite having a significantly higher incidence and severity of late blight compared with weekly spray treatments which had little late blight. It predicted spray events before its Excel calculated equivalent (treatment 4) which must have been better timed, as it produced a slightly better estimated yield. If celery growers are prepared to tolerate small sacrifices in yields, an incidence of 30% and low severity of late blight, the crop will be more economical to produce. This is, however, extrapolated from the results of only one trial.

3.4.3 Septoria late blight

Interestingly, symptoms of Septoria late blight first appeared at 10 weeks in the current winter trial as they did in a similar winter trial (VG04016, Minchinton *et al.* 2005). The winter trial of 2005 was planted on 1/4/2005, harvested on 8/8/2005, and week 10 occurred in 10/6/2005; whilst the winter trial of 2007 was planted on 25/5/2007, harvested on 24/10/2007 and week 10 occurred 1/8/2007. One option for commencement of sprays could be to start scouting crops from 9 weeks and if Septoria is observed, commence spraying with one or two systemic fungicide applications and from then onwards with contact fungicides. This program would assume a threshold of zero lesions and is similar to an early program used in Canada (Mudita and Kushalappa, 1993).

The lack of late blight in the summer trial of 2007, compared with the summer of 2005, could be due to low inoculum levels; no celery with Septoria late blight had grown on the site for 5 years. *S. apiicola* can survive in soil for 2 years (Sutton and Waterston 1966), but this work suggests it may not survive loner than that. Perhaps the model should commence with a ‘decision tree’ or Bayesian-type model, e.g. if no celery on the site for greater than 2 years, use a higher DSV threshold; alternatively scout the crop near canopy closure and commence sprays if late blight is observed.

3.4.3 Fungicides

Both chlorothalonil and mancozeb + cupric hydroxide + Hortiwett™ are currently used in rotation by the industry to control late blight. Better efficacy of control of late blight was obtained when using only weekly sprays of chlorothalonil. When chlorothalonil and mancozeb + cupric hydroxide + Hortiwett™ were alternated (treatments 2 and 10), the incidence of late blight rose, but when weekly sprays reverted to only chlorothalonil, incidence dropped. Mancozeb + cupric hydroxide + Hortiwett™ are probably better suited for application in the early stages of crop production when bacterial leaf spot may also be an issue, as copper would be expected to have efficacy for bacterial disease.

In the event that eradicant action is required for Septoria late blight (treatment 9) then two applications of a systemic fungicide followed by weekly applications of a contact fungicide (chlorothalonil) produced excellent results. Although treatment 9 still produced a high incidence of late blight (50%), it had a low severity (0.68), a high grower-estimated yield and an economic ranking of 2 (chapter 4). The high incidence was of concern to growers viewing the trial at the field day. Consequently delaying the first spray until week 14 when disease incidence was 15% on average would not be acceptable to growers.

The application of more than one systemic fungicide may have given better control of Septoria late blight, but to avoid resistance this group of fungicides are limited to two applications per crop. Better control of the disease in the latter stages of crop production may have been achieved if two systemic fungicides were applied instead of one. Overseas, azoxystrobin is alternated with chlorothalonil with good results, but strobilurins are not registered in Australia for Septoria late blight on celery and this is unlikely to change.

3.4.4 Desk-top evaluation of the Septoria predictor and Cercospora model

The Septoria predictor, which is an infection model to predict *Septoria apiicola*, overestimated the number of sprays to control late blight in the summer trial. In the winter trial pre-canopy closure, it also overestimated sprays, but possibly not post-canopy closure, as only weekly sprays controlled the disease during this period. This model had virtually the same number of sprays as the weekly program. It also demonstrated that infection models can overestimate disease if there are no lesions to produce spores for infection.

The Cercospora model, an infection model to predict *Cercospora apii*, underestimated the number of sprays required to control Septoria late blight in the winter trial as it predicted only one spray and overestimated the number required in the summer trial. Treatments in the winter trial with only one spray (numbers 3 and 12) did not control Septoria late blight. Low temperatures in the field during winter contributed to the under-prediction of sprays. This suggests that Cercospora (early blight) is not likely to be a problem on winter-grown celery in Victoria, and indicates the model is not suitable for Septoria late blight control.

3.5 References

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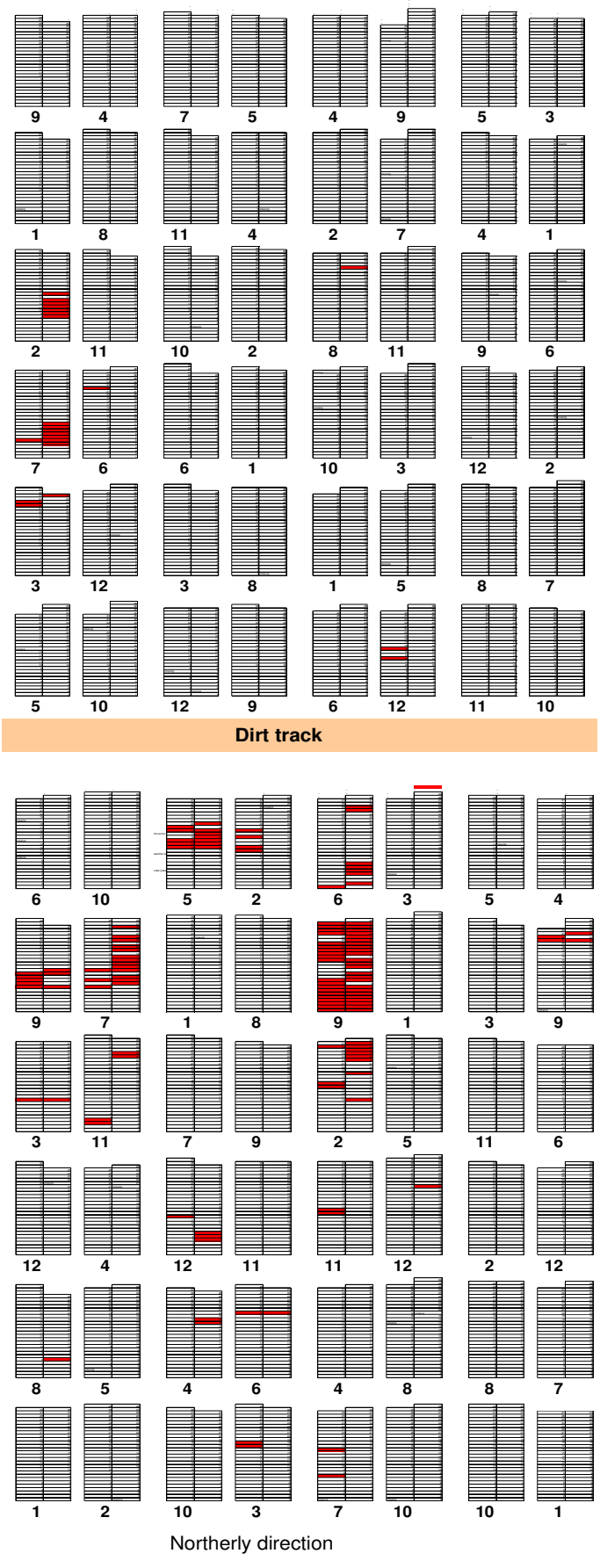
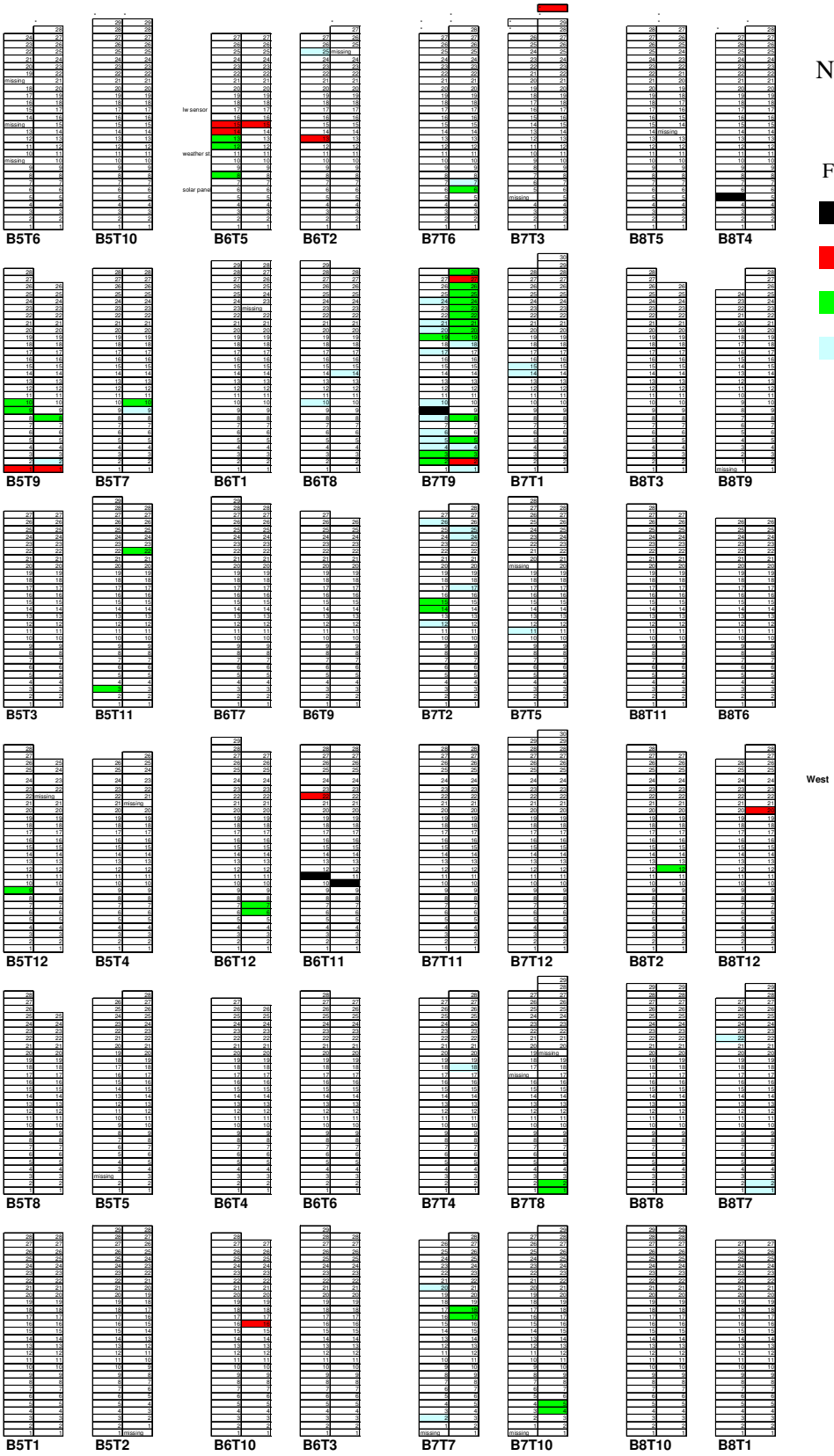
Appendix 1 Maps of incidence of Septoria Late Blight in the winter trial of 2007 at 14 weeks



Bay 1 top and bay 2 bottom. Numbers refer to treatments. Red coloured grids represent diseased plants

Maps of incidence of Septoria Late Blight in bay 2 of the winter trial of 2007



Numbers refer to treatments

First appearance of disease

- Week 10
- Week 11
- Week 12
- Week 13

West

Chapter 4

An Economic analysis of the TomCast disease predictive model for reducing the number of fungicide sprays to minimize the impact of late blight on celery - Trial 2 Winter

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Summary

An economic analysis of trial 2 (Chapter 3) was undertaken to determine the efficacy of using the TomCast disease predictive model for reducing the number of sprays to control Septoria late blight infections on celery by calculating the net benefits of treatments, their contribution to net profit and their comparative profitability rank. Based on both grower estimated yields and incidence data TomCast at 10 DSV 13 °C + systemic fungicide + weekly fungicides (treatment 2) and TomCast at 15 DSV 13 °C - systemic fungicide + weekly fungicide (treatment 10) had a similar profitability to the weekly spray program (Control). The grower estimated yields suggested there was no difference in TomCast and its Excel calculated equivalent at 10 DSV 13 °C + systemic + 10 DSV 8 °C (treatments 6 and 4), but there were some differences when yield was based on incidence data.

4.1 Introduction

This chapter reports an economic analysis of Field Trial No 2 carried out at a site on Campbells Road, Clyde, Victoria, from 1 June 2008 until harvesting 22 weeks later on 23 October 2008. Details about the trial have been discussed in Chapter 3. The approach used to determine the efficacy of using the TomCast disease predictive model for reducing the number of sprays to control late blight infections on celery was to calculate the net benefits of the treatments used in the trial as their contributions to net profit for the celery growing business. This approach assumes that changes in variable costs for the treatments will comprise changes in the cost of fungicides and their cost of application, the cost of crop inspections, harvesting and packaging costs and the costs for repairs and maintenance of the weather station used as an integral part of the TomCast disease predictive model. All other variable costs such as the costs of tillage and bedding, herbicide costs for controlling weeds, costs of fertilizer, costs of labour and any other variable costs for growing celery, will be the same for the Control and the treatments. The only changes in overhead costs were the extra costs for using a weather station for all treatments other than the Control which relied on weekly fungicide sprays to reduce the impact of late blight in celery. Income at the farm gate for the Control and treatments differed and was calculated as yields multiplied by the market price for celery. Contribution to profitability was calculated by deducting variable and overhead costs from farm gate income for the various treatments. A secondary aim was to determine changes in contribution to profitability as a result of using the Disease Doctor™ program to interpret data from the TomCast model as opposed to using data generated from its Excel® equivalent.

4.2 An economic analysis of various treatments to minimize the incidence of late blight in winter grown celery

4.2.1 Spray program and cost of chemicals for minimizing the incidence of late blight

Table 4.1 shows the spray program used in the trial whilst Table 4.2 and Table 4.3 show the costs per hectare of the chemicals employed for the various treatments. Table 4.4 reveals the costs per hectare of the chemicals and their application, assuming a cost for spaying of $12.00 per hectare.

Table 4.1 Spray program for celery TomCast trial no. 2

Treatment	Pre-canopy closure	Canopy closure[a] or 1st spots +/- systemic[b]	Post canopy closure to harvest	Week 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1	Control	-	Weekly		MHK[d]	B[e]	MHK	B	MHK	B	MHK	B	MHK	B	MHK	B	MHK	B	MHK	B	B	B	B	B	B
2	10 DSV[c] 13°	+	Weekly										S[f]	B	MHK	B	MHK	B	MHK	B	B	B	B	B	B
3	10 DSV 13°C	+	10 DSV 13°C										S												
4	10 DSV13°C	+	10 DSV 8°C										S				MHK		B		B		B		B
5	10 DSV 13°C DD	+	10 DSV 13°C DD[g]										S												
6	10 DSV 13°C DD	+	10 DSV 8°C DD										S				MHK	B		B		B			B
7	10 DSV 8°C	-	10 DSV 8°C			MHK			B					MHK			B		MHK		B		B		
8	15 DSV 8°C	-	15 DSV 8°C					MHK						B				B			B				B
9	15 DSV 13°C	-	15 DSV 13°C														S	S	MHK	B	B	B	B	B	B
10	15 DSV 13°C	+	Weekly										S	B	MHK	B	MHK	B	MHK	B	B	B	B	B	B
11	15 DSV 13°C	+	15 DSV 8°C										S					MHK			B			B	
12	15 DSV 13°C	-	15 DSV 13°C										S												

a Canopy closure occurred during week 10 **b Systemic fungicide was Score applied during week 10** **c Disease Severity Value**
d Mancozeb DF® + Kocide® + Hortiwet™ **e Barrack 720®** **f Score** **g Disease Doctor Program**

Table 4.2 Cost of chemicals for treatments to reduce the incidence of late blight in celery

Trade name	Active ingredient	Rate of application per ha. Pre canopy closure	Post canopy closure	Cost of chemical per Litre/kilogram	Cost of chemical per ha. Pre canopy closure	Post canopy closure
Barrack 720®	Chlorothalonil	1.8 L	3.6 L	$26.95	$48.51	$97.02
Mancozeb DF®	Mancozeb	1.2 kg	2.4 kg	$9.15	$10.98	$21.96
Kocide®	Cupric hydroxide	1.2 kg	2.4 kg	$18.40	$22.08	$44.16
Hortiwet™	Alkylaryl polyglycol ether	60 ml	120 ml	$9.30	$0.56	$1.12
Score	Difenoconazole	400 ml	800 ml	$168.30	$67.32	$134.64

Table 4.3 Cost of treatments per hectare to reduce the incidence of late blight

Treatment	Chemicals	Number of applications	Cost per application[a]	Total cost of application	Average cost of chemical per application	Total cost of chemicals	Total cost of treatment
			$/ha	$/ha	$/ha	$/ha	$/ha
1 (Control)	MHK [b]	8	12	96	46.23	370	1,689
	Barrack	13	12	156	82.09	1,067	
2	Score	1	12	12	67.32	67	1,298
	Barrack	9	12	108	97.02	873	
	MHK	3	12	36	67.24	202	
3	Score	1	12	12	67.32	67	79
4	Score	1	12	12	67.32	67	595
	MHK	1	12	12	67.24	67	
	Barrack	4	12	48	97.02	388	
5	Score	1	12	12	67.32	67	79
6	Score	1	12	12	67.32	67	595
	MHK	1	12	12	67.24	67	
	Barrack	4	12	48	97.02	388	
7	MHK	3	12	36	56.03	168	592
	Barrack	4	12	48	84.89	340	
8	MHK	1	12	12	33.62	34	482
	Barrack	4	12	48	97.02	388	
9	Score	2	12	24	134.64	269	1,027
	MHK	1	12	12	67.24	67	
	Barrack	6	12	72	97.02	582	
10	Score	1	12	12	67.32	67	1,298
	MHK	3	12	36	67.24	202	
	Barrack	9	12	108	97.02	873	
11	Score	1	12	12	67.32	67	377
	MHK	1	12	12	67.24	67	
	Barrack	2	12	24	97.02	194	
12	Score	1	12	12	67.32	67	79

a Cost @ $12 per application b Tank mixed chemicals

4.2.2 Other variable costs

(i) Crop inspections: For treatments 2 to 12 using the TomCast disease predictive model it was assumed that 16 crop inspections would be required, each taking 20 minutes for a cost of $70 per hour.

(ii) Harvesting: The cost for harvesting 10 kilogram of celery was estimated to be $1.20.

(iii) Packaging: The cost for packaging 10 kilogram of celery was estimated at 60 cents for the highest yielding treatments, Treatment 1 (Control) and Treatments 2, 8, 9, and 10. However, for the lower yielding treatments, a premium was added to account for the need to discard unmarketable stems that were damaged from infection with late blight fungi. The cost for packaging 10 kilogram of celery was estimated at 63 cents for Treatments 4 and 6. For Treatment 7 the cost was 66 cents and 70 cents for Treatments 3, 5 and 12.

4.2.3 Extra overhead costs of the weather station

Table 4.4 shows the extra overhead cost per hectare of using the weather station on all treatments except the Control (weekly sprayings). The table assumes that the capital cost of the weather station that could be used for 5 hectares of celery was $2,500 and that it would be written off, that is, depreciated to a value of zero dollars, over a period of 10 years. The after tax opportunity cost of owning the weather station was assumed to amount to 20 per cent of its average value over the 10 year period.

Table 4.4 Extra overhead costs of the weather station used for 5 hectares of celery

Year	Investment at start of year	Annual depreciation	Investment at end of year	Average investment	Interest at 20% per annum
	$	$	$	$	$
1	2,500	250	2,250	2,375	475
2	2,250	250	2,000	2,125	425
3	2,000	250	1,750	1,875	375
4	1,750	250	1,500	1,625	325
5	1,500	250	1,250	1,375	275
6	1,250	250	1,000	1,125	225
7	1,000	250	750	875	175
8	750	250	500	625	125
9	500	250	250	375	75
10	250	250	0	125	25
Average		250			250

The extra average depreciation for one hectare of celery was $50 and the extra cost for interest was also $50 for one hectare. Adding the two produced an extra overhead cost of $100 for one hectare of celery.

4.2.4 Farm gate income

Farm gate incomes shown in Table 4.6 and Table 4.7 are equal to the yield in kilogram per hectare multiplied by the price per kilogram.

Yield

Yield was estimated by two methods. The first was the yield for the treatments estimated by the grower, based on the proportion of the crop that would have been marketable. This method assumed that a treatment unaffected by late blight would yield 85 tonnes per hectare.

The second was a derived yield based on incidence of disease on celery at the time that the treatments would have been harvested, and was calculated as: Yield = 85 tonne/ha – (85 tonne/ha x disease incidence/100).

The yields in kilogram per hectare for the two methods of estimation are shown in Table 4.5

Table 4.5 Yields for the Control and treatments for the two different methods of estimation

Treatment	Yield based on marketability assessed by the grower	Yield based on incidence of disease
	Kg/ha	Kg/ha
1 (Control)	85,000	85,000
2	85,000	82,370
3	25,500	33,490
4	83,300	43,520
5	59,500	44,630
6	85,000	58,990
7	83,300	41,480
8	59,500	29,240
9	85,000	43,010
10	83,300	80,240
11	83,300	53,640
12	25,500	37,230

Price

Farming is a risky business and many of the sources of risk to do with climate and institutions cannot be controlled by the farm manager. Nor do individual farmers have the capacity to control prices received for their produce. In this analysis, the price received at market for celery was treated as an uncertain variable. A normal distribution curve was postulated for celery prices over time having a mean value of $1.15 per kilogram with minimum and maximum values of 60 cents and $1.70 per kilogram respectively. Excel® computer spreadsheets were used to calculate contribution to profitability for the various treatments. Price variability was handled by linking Excel® to a Crystal Ball® Monte Carlo simulation model. The Crystal Ball® Monte Carlo simulation model carries out multiple trials by repeatedly sampling values from the probability distribution for the uncertain variable which in this instance is price for celery. Note that the same price for each treatment out of the normal distribution was selected for each trial. The total number of trials or iterations was ten thousand. After completing the simulation, the final output was a forecast chart showing the average, maximum, minimum and the coefficient of variability for the contribution to profitability of the various treatments.

4.3 Results of the economic analysis

The results of the economic analysis for reducing the incidence of late blight on celery represented as the average contribution to profitability for the various fungicide treatments using the TomCast disease predictive model are shown in Table 4.6 for yield estimated by the grower and Table 4.7 for yield derived from disease incidence for the treatments. Their ranking relative to the Control is also revealed. In Figure 4.1 the relative average contributions to farm profitability calculated from the mean price of $1.15 per kilogram of celery are displayed for yields based on grower estimate of yield. The relative average contributions to farm profitability for derived yields based on disease incidence for the treatments are shown in Figure 4.2.

Table 4.6 Difference in average contribution to profitability per hectare, difference in percentage contribution of the treatments to profitability compared to that of the Control and their comparative rankings. Yields for treatments based on grower's estimate.

Treatment	Total cost of applying fungicides	Yield	Crop inspections	Harvesting	Packaging	Overhead costs for weather station	Repairs and maintenance of weather station	Farm gate income	Contribution to profitabilty	Difference in profitability	Ranking
	$/ha	kg/ha	$/ha	$/ha	$/ha	$/ha	$/ha	$/ha	$/ha		
1 (Control)	1,689	85,000		10,200	5,100	0		97,750	80,761	0.00%	3
2	1,298	85,000	336	10,200	5,100	100	25	97,750	80,691	-0.09%	4
3	79	25,500	336	3,060	1,851	100	25	29,325	23,873	-70.44%	=10
4	595	83,300	336	9,996	5,028	100	25	95,795	79,715	-1.29%	7
5	79	59,500	336	3,060	1,851	100	25	29,325	23,873	-70.44%	=10
6	595	85,000	336	10,200	5,100	100	25	97,750	81,394	0.78%	1
7	592	83,300	336	9,996	5,028	100	25	95,795	79,718	-1.29%	6
8	482	59,500	336	7,140	3,891	100	25	68,425	56,451	-30.10%	9
9	1,027	85,000	336	10,200	5,100	100	25	97,750	80,962	0.25%	2
10	1,298	83,300	336	9,996	5,028	100	25	95,795	79,012	-2.17%	8
11	377	83,300	336	9,996	5,028	100	25	95,795	79,933	-1.02%	5
12	79	25,500	336	3,060	1,851	100	25	29,325	23,873	-70.44%	=10

Table 4.7 Difference in average contribution to profitability per hectare, difference in percentage contribution of the treatments to profitability compared to that of the Control and their comparative rankings. Yields derived from incidence of disease on treatments.

Treatment	Total cost of applying fungicides	Yield	Crop inspections	Harvesting	Packaging	Overhead costs for weather station	Repairs and maintenance of weather station	Farm gate income	Contribution to profitabilty	Difference in profitability	Ranking
	$/ha	kg/ha	$/ha	$/ha	$/ha	$/ha	$/ha	$/ha	$/ha		
1 (Control)	1,689	85,000		10,200	5,100	0		97,750	80,761	0%	1
2	1,298	82,370	336	9,884	4,988	100	25	94,726	78,094	-3%	2
3	79	33,490	336	4,019	2,375	100	25	38,514	31,580	-61%	11
4	595	43,520	336	5,222	2,993	100	25	50,048	40,776	-50%	7
5	79	44,630	336	5,356	3,059	100	25	51,325	42,369	-48%	6
6	595	58,990	336	7,079	3,864	100	25	67,839	55,840	-31%	4
7	592	41,480	336	4,978	2,871	100	25	47,702	38,801	-52%	9
8	482	29,240	336	3,509	2,100	100	25	33,626	27,075	-66%	12
9	1,027	43,010	336	5,161	2,963	100	25	49,462	39,850	-51%	8
10	1,298	80,240	336	9,629	4,895	100	25	92,276	75,993	-6%	3
11	377	53,640	336	6,437	3,575	100	25	61,686	50,837	-37%	5
12	79	37,230	336	4,468	2,610	100	25	42,815	35,196	-56%	10

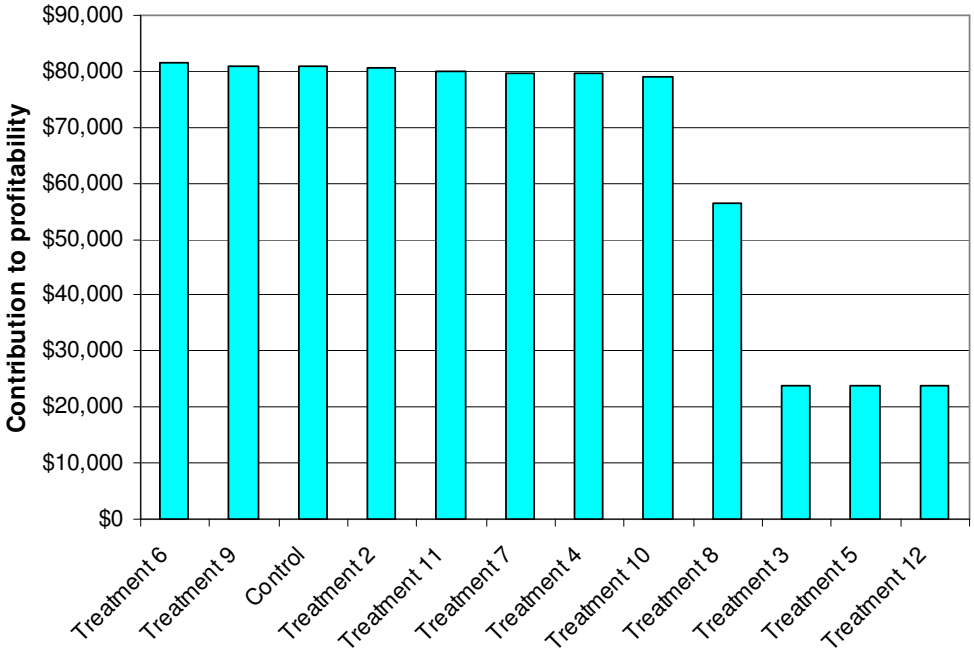

Figure 4.1 Average contributions to profitability for the Control and treatments. Yields based on grower's estimates of marketability.

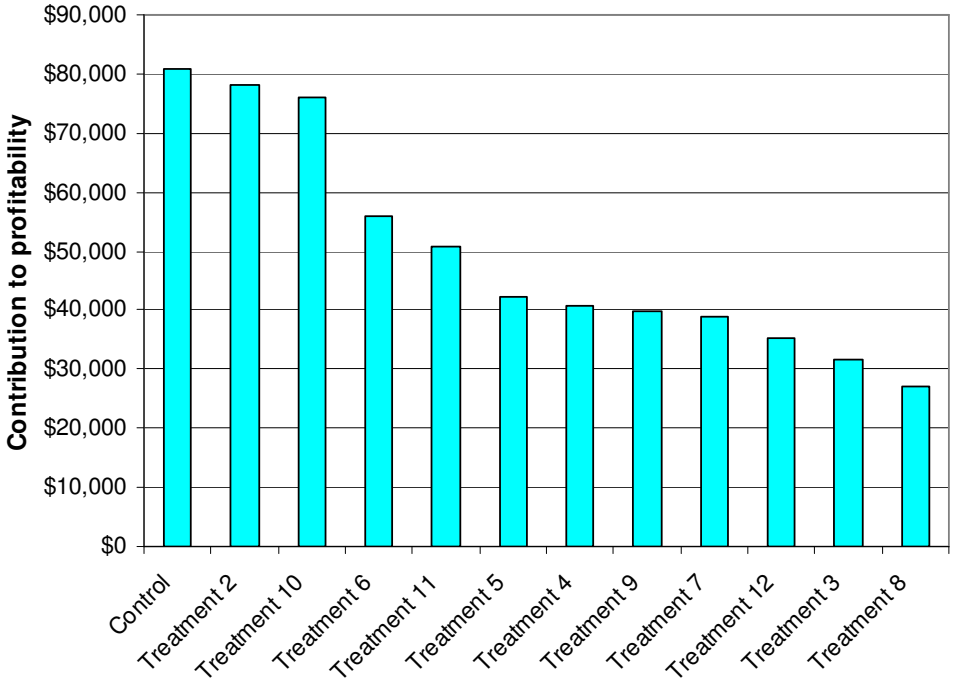

Figure 4.2 Average contributions to profitability for the Control and treatments. Yields derived from incidence of disease.

4.4 Discussion and Conclusions

From Table 4.6 and Figure 4.1, there was no appreciable difference in economic terms between the Control (Treatment 1) and Treatments 2, 4, 6, 7, 9, 10, and 11. Similarly, from Table 4.7 and Figure 4.2, the average contributions to profitability for the Control and Treatments 2 and 10 were about the same. By comparing the results of the analyses based on the two methods for estimating yields, the dominant treatments from an economic point of view were the Control, Treatment 2 and Treatment 10.

Again, by comparing the economic results displayed in Figure 4.1 and Figure 4.2, the treatments with the lowest contribution to profitability were Treatments 3, and 12. Those treatments had only one application of fungicide being Score, the systemic fungicide. The lowest contribution to profitability from Figure 1 was also Treatment 5 which too, received only one application of Score. Treatment 5 shown in Figure 4.2 had a contribution to profitability of 47.5 percent below that of the Control and 20 per cent above that of Treatment 12. The conclusion was that one application of Score was insufficient to protect celery from the development of late blight.

From an economical and environmental point of view, the best treatments were Treatment 2 and Treatment 10. They shared the best economic returns with the Control, but the number of sprays was reduced by 38 percent from 21 to 13. That is, minimizing the impact of late blight on celery by reducing the number of sprays had a positive effect on the environment.

Where yields were based on grower's estimate of marketability (Table 4.6 and Figure 4.1), the use of the Disease Doctor™ program for Treatment 5 and Treatment 6 showed no advantage for its use compared with Treatment 3 and Treatment 4 that used the Excel® equivalent because the contributions to profitability were the same. However, where yields were derived from incidence of disease, (Table 4.7 and Figure 4.2), Treatments 5 and 6 had a slightly higher contribution to profitability than Treatments 3 and 4. The effectiveness of the Disease Doctor™ program over the Excel® equivalent was inconclusive.

The conclusions of this trial are extremely relevant to the Australian celery producing industry. In 2001/2002, the total area of production for Australia was 911 hectares. From that area, 43,312 tonnes were produced, an average of 47 tonnes per hectare. For the year 2007/2008, the preliminary estimate for the area of production was 991 hectares. Estimated production was 51.041 tonnes, an average estimated yield of 52 tonnes per hectare. Victoria produced 65 per cent of the Australian area and yield of celery. The important conclusion of this trial was that by employing the TomCast predictive model, economic and environmental benefits would accrue to the national industry through a reduction in the amount of fungicides applied without suffering a loss in contribution to profitability for the individual farms within the industry. Environmental benefits means a reduction in the number of fungicide sprays that provides less exposure of workers and consumers to pesticides and less pollution of the environment. The latter would occur through a build up of residues from chlorothalonil, the active ingredient in Barrack 720® and copper contained in Kocide®. Of the superior group of treatments displayed in Figure 4.1 and 4.2, the best were Treatments 2 and 10 where the number of fungicide sprays was reduced by 38 percent compared with the number of sprays used for the Control that required weekly applications of fungicides.

Chapter 5

Investigation of alternative approaches to the use of Leaf Wetness sensors for disease prediction systems.

Summary

Calibration of electronic leaf wetness sensors is possible by measuring the weight of water deposited (gravimetric means). This approach allows for meaningful comparison of performance. The standard for measurement should be in terms of density of water present on the measurement surface (g H_2O/cm^2). Under still air conditions VPD gave excellent correlation to leaf wetness, however, this is not effective under field conditions where air movement occurs. Vapour Pressure Deficit (VPD) could be considered for use in protected cropping environments. A fuzzy logic model which estimates leaf wetness based on measurement of temperature, relative humidity and wind speed proved that it was able to predict periods of leaf wetness under field conditions, however, the accuracy of this model was found to be at best only 75%, and somewhat short of the 96% accuracy reported by the authors of the system. It is possible that this system could be fine-tuned to give better performance under local conditions.

5.1 Introduction

The measurement of leaf wetness is an essential requirement for many disease forecasting systems. The TomCast model for predicting Septoria leaf blight in celery (Madden et al. 1978) is an example of a model for which the measurement of leaf wetness duration is a critical element of its ability to predict the activity of the pathogen within a crop. Free water on the leaf surface provides the moisture required for fungal spores to germinate which is the first step in the infection process. Accurate determination of the length of this "leaf wetness period" allows the disease model to determine whether or not the leaf surface has been wet for sufficient time for germination and infection to successfully occur. Leaf wetness periods which are too short (below the critical length for that given temperature range) lead to germination failure thus preventing infection. An extensive review of the role that leaf wetness plays in plant disease epidemiology is covered by Huber and Gillespie (1992).

Electronic leaf wetness sensors have remained virtually unchanged in design over the last few decades. They largely consist of parallel electrodes attached to an artificial or simulated leaf surface. The surface can take the form of a flat plane or a cylinder. Materials used to manufacture the sensor are often plastic or resin composite (PC board) and sometimes woven canvas cloth. Leaf wetness is measured as a function of the electrical conductance across the surface, which results from the amount of moisture or free water present. Hence a dry surface has a very low electrical conductance. As the amount of moisture levels increase, the ability to conduct an electrical current also increases.

A major flaw in the design of electrical conductance leaf wetness sensors is that their performance gradually fails over time due to sensor aging. New sensors are highly sensitive to small changes in surface wetness. However, this sensitivity tends to decrease rapidly due to corrosion and contamination of the electrode surfaces (which in general are gold plated) as a result of exposure to salts, soil particles and agricultural sprays (Fig. 5.2.1). In particular, copper based fungicides have the potential to alter the electrical conductivity profile of leaf wetness sensors. Some researchers have overcome these limitations by coating electronic leaf wetness sensors with acrylic paint emulsions (Sentelhas et al. 2004) which improves both precision and sensitivity of the device, and may also protect against corrosion.

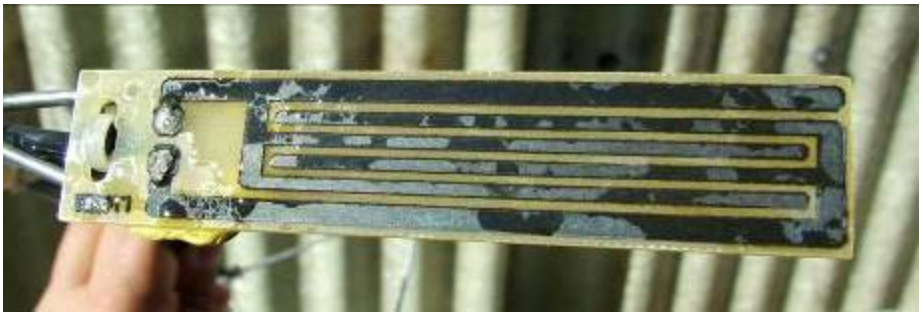

Fig. 5.2.1 A leaf wetness sensor showing signs of corrosion

Another limitation of the effective use of leaf wetness sensors is the lack of meaningful calibration of these devices. There is little doubt that commercial sensors which measure temperature, relative humidity, rainfall, solar radiation and wind speed are calibrated and provide data in units of measurement which are standardised. However, most leaf wetness sensor manufacturers admit that their calibration process is at best arbitrary, consisting of the selection of a value at which the sensor is deemed to move from a condition of being "dry" to "wet". There appears to be little incentive to standardise these measurements as most disease forecasting algorithms do not refer to leaf wetness beyond the binary states of "dry" or "wet". Standardisation of sensor calibration could improve the consistency of performance of disease forecasting systems, particularly when considering the range of weather stations produced by commercial manufacturers.

This chapter reports on work which:

- Investigates the process for calibration of a range of currently existing electrical leaf wetness sensors;
- Investigates the possibility of estimating leaf wetness measurement by Vapour Pressure Deficit (VPD) readings;
- Investigates the a model for estimating leaf wetness using temperature, relative humidity and wind speed using a fuzzy logic model (Kim et al., 2004).

5.2 Gravimetric Calibration of Leaf Wetness Sensor

5.2.1 Objective

The objective of these trials was to develop a methodology for the standardised calibration of leaf wetness sensors and to develop calibration curves for a limited range of sensors and to compare their performance under standardised conditions.

5.2.2 Materials and Methods

An electronic data logger (IDL data acquisition system, La Trobe University) was used to record information from the three leaf wetness sensors examined (Model T, Fig. 5.2.2; Environdata, Fig. 5.2.4 and Monitor Sensors Fig 5.2.5). Leaf wetness was measured as arbitrary "Leaf Wetness Units" which is a measure of electrical conductance (conductance is inversely related to the electrical resistance of the leaf wetness sensor). Leaf wetness sensors were mounted horizontally on a wire platform (Fig. 5.2.2) attached to the weighing pan of an electronic balance accurate to three decimal places (0.001 g). The weighing pan was shielded from the effects of air movement by a protective skirt overlaid by a lid through which the wire platform passed.

Distilled water was incrementally applied to the mounted leaf wetness sensors as a fine mist using an airbrush sprayer operating at 200Kpa (Fig. 5.2.3) at room temperature (22 - 25 ^{o}C). Readings taken

from the balance between applications (30 seconds apart) allowed accurate determination of the amount of water applied to the leaf wetness sensors and were recorded along with the associated (electronic) leaf wetness reading recorded by the data logger. The surface area of each leaf wetness sensor was determined by measurement. The amount of water applied to the leaf wetness sensors was calculated as gH_2O/cm^2. Multiple wetting runs were performed (up to 5 replications per sensor) with data sets combined for analysis.

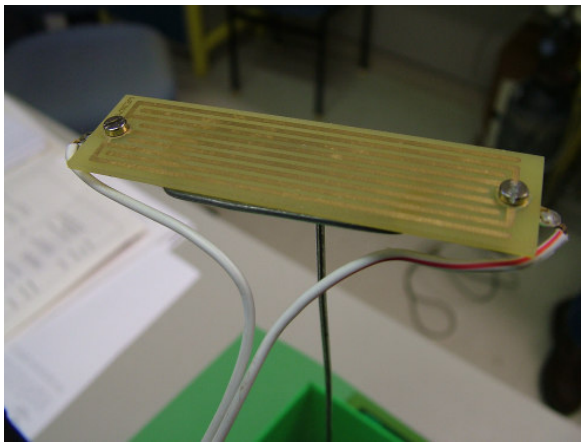

Fig. 5.2.2 Model T leaf wetness sensor mounted on testing frame

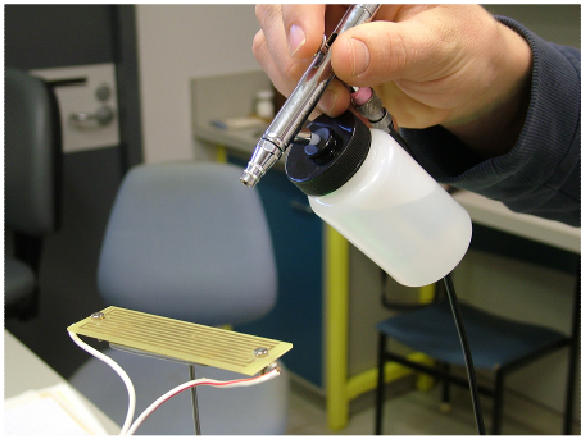

Fig. 5.2.3 Application of distilled water to a leaf wetness sensor by airbrush sprayer

Fig. 5.2.4 Environdata leaf wetness sensor

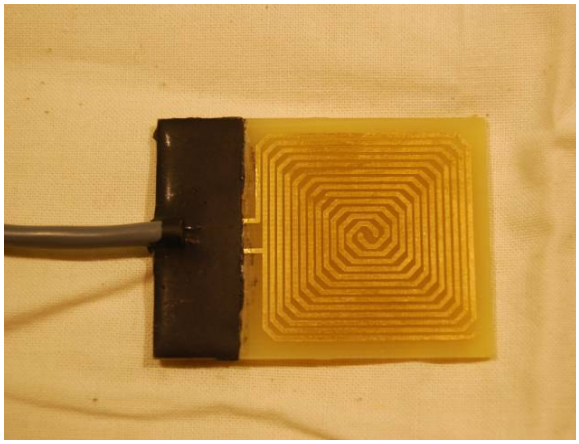

Fig. 5.2.5 Monitor Sensors leaf wetness sensor

5.2.3 Results

Calibration curves for all three sensors although similar in outline represented sigmoid functions indicating that they behaved similarly, although each had its own unique calibration function. The high R^2 values for these equations (ranging from 0.86 to 0.96) indicated that there was a high degree of fit between the data points. It was clearly shown that all three leaf wetness sensors could be calibrated to provide readings of leaf wetness in standardised units (g H_2O/cm^2).

The operational range within which these sensors worked showed significant differences. The Model T sensor (Fig. 5.2.6) worked within the range of 0 to 0.01 g H_2O/cm^2 indicating that it was highly sensitive to small changes in surface water. Whereas the Environdata sensor (Fig 5.2.7) operated over the greatest range (0 to 0.08 g H_2O/cm^2) and the device from Monitor Sensors (Fig. 5.2.8) operated at an intermediate range (0 to 0.04 g H_2O/cm^2).

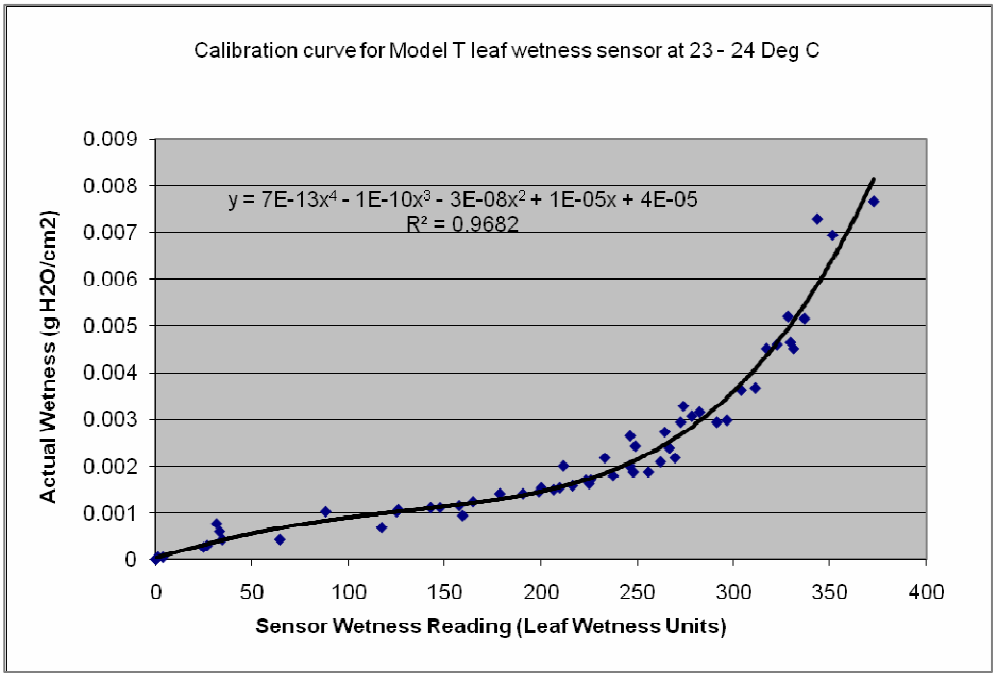

Fig. 5.2.6 Calibration curve for Model T leaf wetness sensor

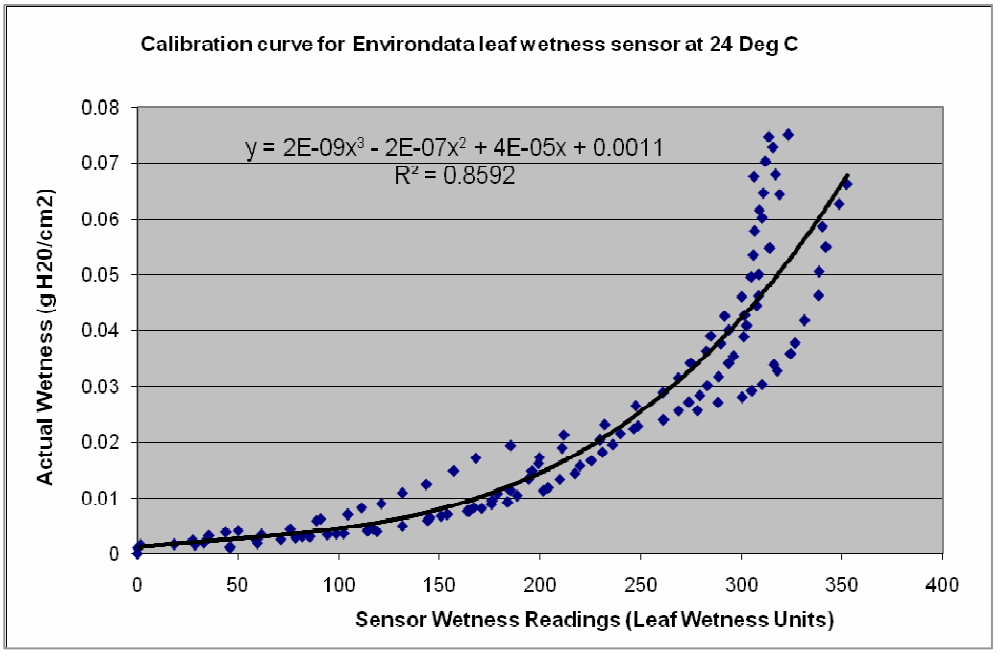

Fig. 5.2.7 Calibration curve for Environdata leaf wetness sensor

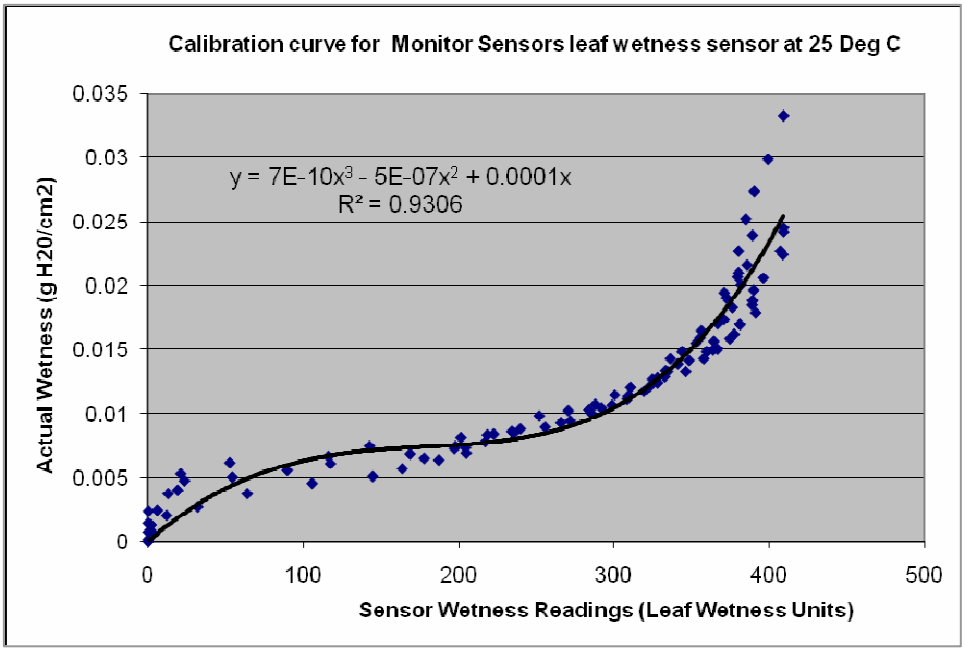

Fig. 5.2.8 Calibration curve for Monitor Sensors leaf wetness sensor

5.2.4 Discussion

The calibration curves for the leaf wetness sensors based on plastic PC boards (Model T & Monitor Sensors) both produced sigmoid curve calibration responses with high R^2 values indicating high levels of precision in their performance. The greater level of variability in the data (R^2 = 0.86) for the Environdata sensor is most likely due to the canvas material used in the construction of the sensor, which although is intended to be more leaf like in appearance produced less precise prediction of leaf wetness at the more saturated end of its performance range.

These results have clearly demonstrated that it is possible to calibrate all three examples of leaf wetness sensors in a meaningful way that would allow for standardised comparison of performance under field conditions. It would be appropriate for this approach to be used as a standard by manufacturers, and would also allow researchers to more accurately pinpoint the critical threshold levels of leaf wetness required for field infection by plant pathogens.

Although differences in sensitivity were found between sensors produced by different manufacturers, it is likely that some variation was caused by sensor aging. The Model T sensor used in this study was supplied new by the manufacturer, while the units manufactured by Monitor Sensors and Environdata had both been previously used in laboratory testing. It is likely that the calibration curves for leaf wetness sensors would be subject to gradual drift as the individual units age as a result of environmental exposure. The calibration procedure developed for this study would enable such shifts in performance to be meaningfully determined.

5.3 Evaluating the relationship between Vapour Pressure Deficit (VPD) and actual leaf wetness

5.3.1 Introduction

Vapour Pressure Deficit or VPD is a physical measure of the difference between the amount of moisture in the air, and how much water the air can hold at that temperature. This function is temperature dependent as warm air is capable of holding more moisture than cold air. For this reason, the measurement of relative humidity alone is of little value when estimating the true amount of available water in the air. VPD is a useful measurement for understanding biological activity, particularly when it comes to the behaviour of plant pathogens. Once air becomes saturated, which occurs when the VPD approaches a value of zero, water condenses on the plant surface forming dew. This dew provides the free water or leaf wetness required for fungal spores to germinate, and the resulting germ tube can then invade the plant initiating plant infection. VPD has been used as a substitute for leaf wetness readings to estimate infection activity of plant pathogens such as grape downy mildew and botrytis grey mould. This has been particularly useful in glasshouse grown crops. VPD is calculated using temperature and relative humidity which are easily and accurately measured using reliable sensors which are less prone to error than leaf wetness sensors.

5.3.2 Objective

The objective of this work was to determine if VPD could be used as a reliable substitute for actual leaf wetness measurements.

5.3.2 Materials and Methods

A leaf wetness sensor (Model T) was mounted on the top of a frame containing sensors to measure temperature and relative humidity (Fig. 5.3.1). Leaf wetness data, temperature and relative humidity were recorded at 30 second intervals by a data logger (IDL, La Trobe University).

The sensor frame was sealed within a 2 L plastic dew deposition chamber containing cotton wool wadding moistened with distilled water and allowed to equilibrate to room temperature (approximately 20 °C). The chamber containing the sensors was then placed inside a refrigerator operating at approximately 2-4 °C. The gradual cooling process was required to simulate dew deposition on the leaf wetness sensor as would occur under still air (non-aspirated) field conditions. This procedure was repeated several times after drying off the leaf wetness sensor by wiping with alcohol moistened tissue and allowing the whole apparatus to come back to room temperature.

In a second series of experiments, a miniature electronic fan (approx diameter 40 mm) was mounted at the end of the sensor housing to promote low velocity air flow (aspirated condition) within the dew deposition chamber. The apparatus was put through several cool down cycles with all data being recorded as described above.

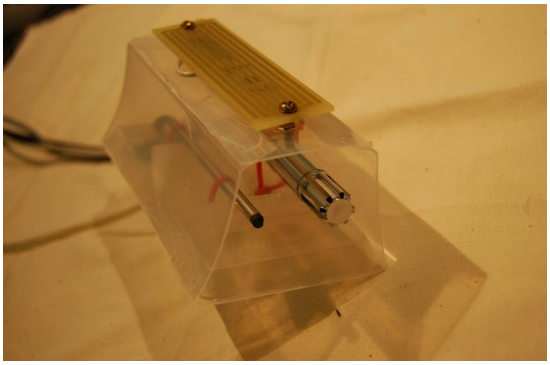

Fig. 5.3.1 Sensor frame with leaf wetness sensor mounted top most, relative humidity sensor below right and temperature sensor below left.

Actual leaf wetness was determined from the leaf wetness calibration equation for the Model T leaf wetness sensor in section 5.2.3. VPD was calculated as the difference between vp_{sat} and vp_{air} (Equation 1). vp_{sat} is calculated using Equation 2 which require the temperature data while vp_{air} (Equation 3) is calculated using the relative humidity data.

Equation 1
VPD = $vp_{sat} - vp_{air}$

Equation 2
$vp_{sat} = e^{A/T+B+CT+DT^2+ET^3+F\ln T}$ kPa
where
$A = -1.88x10^4$ $B = -13.1$ $C = -1.5x10^{-2}$ $D = 8x10^{-7}$ $E = -1.69x10^{-11}$ $F = 6.456$
T – Temperature of the air in K, T(K) = T(°C) + 273.15

Equation 3
$vp_{air} = vp_{sat}$ * relative humidity

5.3.3 Results

Dew build-up on the leaf wetness sensors clearly occurred as the VPD values fell towards zero (Fig. 5.3.2) over the course of each run. The amounts of dew actually deposited on the leaf wetness sensors in the dew deposition chamber were extremely small (less than 0.0006 g H_2O/cm^2), however, this build-up was steady and consistent between experiments. The equation describing the relationship between VPD and actual leaf wetness (shown in fig. 5.3.2) had an extremely high R^2 value (0.937).

These experiments repeated with a miniature fan to create airflow within the dew deposition chamber did not result in dew forming at any occasion, even though VPD fell to almost 0 kPa. Hence leaf wetness did not occur when the air mass was kept moving.

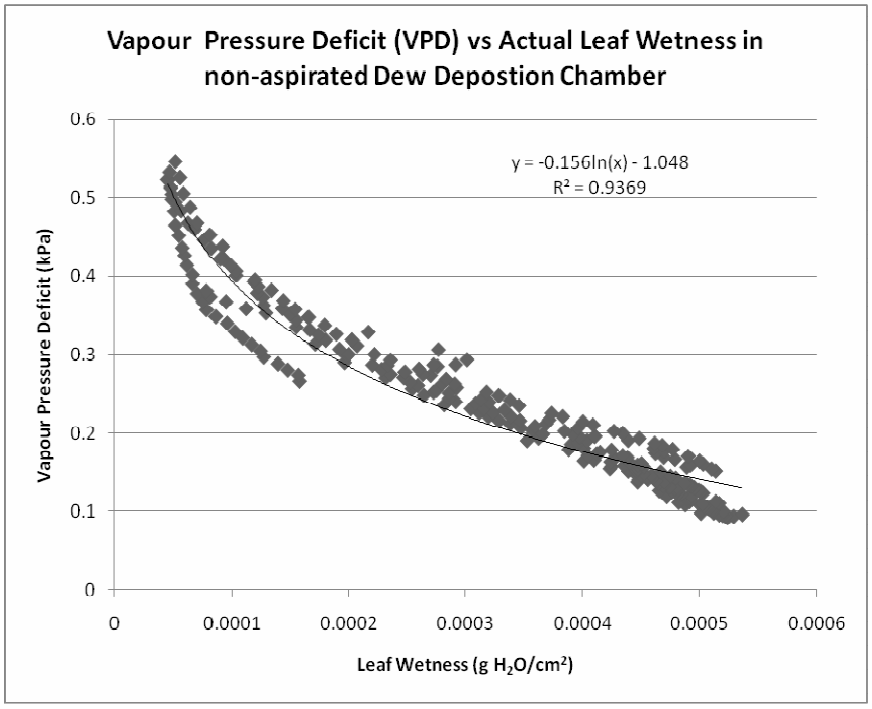

Fig 5.3.2 Relationship between Vapour Pressure Deficit and actual leaf wetness measured in a non-aspirated dew deposition chamber.

5.3.4 Discussion

The use of the dew deposition chamber successfully demonstrated that under still air conditions, VPD can be correlated to actual leaf wetness as measured with a leaf wetness sensor with a high degree of confidence. However, in conditions where air movement occurs, dew does not form readily on surfaces, even under highly saturated atmospheric conditions (e.g. where VPD is approaching 0 kPa). This means that VPD is only a good substitute for leaf wetness measurements under still air conditions. A monitoring process using VPD alone would not be capable of estimating leaf wetness unless measurement of air movement was also taken into consideration. The use of VPD as an estimate of fungal plant pathogen activity in protected (greenhouse) cropping systems is well established as air movement is limited in these circumstances. In such situations, it is also possible to increase air movement through the use of mechanical vent opening devices and extraction fans as VPD falls to critical levels.

5.4 Use of a Fuzzy Logic Model to predict Leaf Wetness

5.4.1 Introduction

A computational model for predicting leaf wetness based on measurements of temperature, relative humidity and wind speed (Kim et al. 2004) was evaluated under field conditions and the leaf wetness estimations compared with actual leaf wetness data from a leaf wetness sensor.

5.4.2 Materials and Methods

A data logger and sensors were kindly provided on loan by Monitor Sensors Australia (Pty Ltd) for this trial. The field site selected was in Toowoomba, Qld on a site owned by the University of Qld, (Latitude 27.58 Deg, Longitude 151.93 Deg). Quarter hourly readings of temperature, relative humidity, wind speed and leaf wetness were required for this study. Additionally, rainfall data was also collected. Air temperature and relative humidity were measured by sensors placed in a Stevenson screen (Fig. 5.4.1) at 1.5 m above ground level (Kim et al., 2004). Wind speed was measure by an anemometer at 3 meters above ground level (Fig. 5.4.2) and leaf wetness sensors were mounted at a 45^{o} angle on a stand 300 mm above ground level (Fig. 5.4.3) facing south. Kim et al. (2004) working in the northern hemisphere faced their leaf wetness sensors north (away from the equator).

Fig. 5.4.1 Stevenson screen containing temperature and relative humidity sensors

Fig. 5.4.2 Wind speed anemometer

Data was collected from the field site from January to February, 2008. A conversion program based on the fuzzy logic leaf wetness model (Kim et al., 2004) was kindly prepared as an Excel Spreadsheet with associated code modules by one of the authors (Kwang Soo Kim) and used to estimate binary leaf wetness (either dry or wet) for each of the 15 minute periods over a data set spanning 14 days (1317 readings). These data were compared to actual leaf wetness data collected from the leaf wetness sensor.

Fig. 5.4.3 Leaf wetness sensors

The Monitor Sensors leaf wetness sensor measures relative leaf wetness on a continuous scale from 0 to 100. The manufacturer sets an arbitrary value of 50 as being the point at which the leaf becomes "technically wet". After discussions with the manufacturer, it was decided that comparisons between the predicted binary (fuzzy logic) leaf wetness states and the actual leaf wetness data from the Monitor Sensors device could be made using several cut off values (65, 60, 55, 50, 45, 40, 35, 30, 25, 20, 15, 10 & 5 units). The number of occasions at which both the model, and the sensor agreed that conditions were either wet or dry could then be determined.

5.4.3 Results

Data from the temperature and relative humidity sensors and wind speed readings from the anemometer were converted by the fuzzy logic (Kim et al., 2004) program into predictions of leaf wetness (either a value of 0 for dry or a value of 1 for wet) as shown in column 5 of Table 5.4.1. Periods where leaf wetness was predicted by these calculations are shaded in brown. Similarly, periods where the leaf wetness sensor predicted wetness (column 6) are shaded in green.

The actual leaf wetness data measured by the leaf wetness sensor used in this experiment was measured in units ranging from 0 to 100. Pair-wise comparison made between the predicted leaf wetness states and the actual leaf wetness data (Table 5.4.1) interpreted using 13 different threshold levels indicated that fine tuning could improve the level of agreement between the two approaches (Table 5.4.2). Greatest agreement (74% of occasions) between the predicted leaf wetness state and the actual leaf wetness state determined by the leaf wetness sensor occurred when threshold levels of 15 and 20 units were used for the leaf wetness sensor. The level of agreement diminished slightly as the threshold levels fell below 15 units but more so as they increased above 20 units (Table 5.4.2).

Table 5.4.1 Sample data set illustrating the calculation of predicted lead wetness (using the fuzzy logic model) and actual leaf wetness as measured by a leaf wetness sensor. Shaded areas in each column indicate periods of predicted (brown) and actual (green) leaf wetness for threshold set at 20 units.

Date & Time	Temperature °C	R.H. %	Wind speed m/sec	Predicted Leaf Wetness Binary	Actual Leaf Wetness 0-100
30/01/2008 9:30	20.18	98.16	0.958	1	86.76
30/01/2008 9:45	20.36	98.68	0.844	1	83.45
30/01/2008 10:00	20.96	96.92	0.856	1	75.4
30/01/2008 10:15	20.7	97.22	0.656	1	63.34
30/01/2008 10:30	21.58	96.65	0.261	1	62.08
30/01/2008 10:45	21.76	96.11	1.083	1	68.79
30/01/2008 11:00	22.07	94.32	0.450	1	42.63
30/01/2008 11:15	22.74	91.97	0.758	1	0
30/01/2008 11:30	23.4	94.34	0.769	1	0
30/01/2008 11:45	23.47	88.34	1.206	0	0
30/01/2008 12:00	24.11	83.74	1.181	0	0
30/01/2008 12:15	24.23	81.19	2.233	0	0
30/01/2008 12:30	23.34	84.7	0.689	0	0
30/01/2008 12:45	23.45	85.45	0.472	0	0
30/01/2008 13:00	22.07	89.23	1.981	0	68.13
30/01/2008 13:15	20.58	94.16	0.922	1	69.64
30/01/2008 13:30	20.06	96.76	0.358	1	59.1
30/01/2008 13:45	20.54	97.06	0.300	1	34.72
30/01/2008 14:00	21.56	96.53	0.528	1	23.42
30/01/2008 14:15	21.99	92.54	0.892	1	3.81
30/01/2008 14:30	21.3	94.65	0.922	1	0.25
30/01/2008 14:45	21.28	94.38	1.031	1	0
30/01/2008 15:00	21.26	93.2	0.633	1	0
30/01/2008 15:15	21.1	93.89	0.617	1	0
30/01/2008 15:30	21.62	93.79	0.886	1	0
30/01/2008 15:45	21.72	93.64	0.769	1	0

Threshold	Agreement (%)
5	74.3
10	74.2
15	74.4
20	74.4
25	73.5
30	72.3
35	69.9
40	69.6
45	69.2
50	67.7
55	36.6
60	59.9
65	56.6

Table 5.4.2 Agreement between leaf wetness states predicted an fuzzy logic model and leaf wetness sensor at different threshold levels.

5.4.4 Discussion

Agreement between the fuzzy logic model and measured leaf wetness although quite good (almost 75%) was found to be greater (better than 96%) by Kim et al. (2004) in their original research. However, these same authors also indicated that accuracy of the model could be improved by the incorporation of correction factors and possibly, adjustment to local conditions. A key benefit of this approach is the standardised ability to estimate leaf wetness using only temperature, relative humidity and wind speed data which can be accurately and reliably measured by a range of weather stations, thereby overcoming the inconsistencies which exist in the ways in which leaf wetness sensors operate among different weather stations.

The fuzzy logic model shows great potential as a replacement for leaf wetness sensors, and further collaboration with the authors of this system (Kim et al. 2004) is currently underway.

5.5 General Discussion and Conclusions

The work on calibrating leaf wetness sensors indicated that among the three sensors investigated, variation existed in sensitivity and performance characteristics. A key outcome was the determination that gravimetric calibration of sensors using a standard measurement (g H_2O/cm^2) proves to be a more realistic way of comparing the behaviour of leaf wetness sensors. It is also likely that this standardised approach could be applied to measuring the amount of water required for infection of plant surfaces by fungal pathogens thereby improving the way in which disease prediction systems work.

The strong correlation between VPD and leaf wetness provides the possibility of eliminating the use of leaf wetness sensors under still air (i.e. greenhouse). This would allow VPD to be substituted for leaf wetness overcoming many of the issues of declining performance of leaf wetness sensors over time. However, dew formation does not occur when air movement is significant, and given that field grown crops are exposed to daily variations in wind speed, VPD could not be used as an effective substitute for leaf wetness measurements under these conditions.

The fuzzy logic model for estimating leaf wetness based on temperature, relative humidity and wind speed, has the potential to replace the need for leaf wetness sensors altogether. However, it predicts leaf wetness in a binary way (0 or 1) and it is not clear how this can be related to the system for determining true leaf wetness on a gravimetric basis. It is apparent that further work needs to be done to fine-tune this system to improve its accuracy, although the authors (Kim et al., 2004) indicate that prediction accuracy levels of in excess of 96% are possible.

5.6 Future Directions

Current leaf wetness sensor technology appears to have limitations in useability and the lack of a standardised approach to design and calibration among manufacturers serves to confuse the issue. The replacement of current leaf wetness sensor technology by either a better sensor using different technology or by an estimated measure of leaf wetness (i.e. fuzzy logic model) based on other standardised measurements would improve the accuracy and reliability of plant disease forecasting systems such as Disease Doctor™.

A new approach to leaf wetness measurement based on an ultrasonic device is currently being considered by Monitor Sensors Australia. Pilot research to develop a device to be used under field conditions is currently being negotiated. Prototype sensors will be compared with standard leaf wetness sensors to determine if they are capable of measuring true leaf wetness under laboratory and field conditions.

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Chapter 6

Preliminary evaluation of gibberellic acid to control Septoria Late Blight

Summary

The application of gibberellic acid (GA) to celery plants before infection with Septoria late blight resulted in a significant reduction in both the lesion size and the total number of pycnidia on infected leaves. The concentration of GA did not have an effect on any other measured parameters, however two applications of GA were better than a single application.

6.1 Introduction

Gibberallic acid (GA) is a plant hormone involved in many plant processes including cell division and elongation, flowering, seed germination, fruit set and delayed dormancy etc (Hooley 1994). GA can delay the onset of cell senescence and thus the onset of disease in post-harvest celery (Afek *et al.* 1995).

When GA was applied to carrot foliage it consistently reduced the area of leaf affected by *Alternaria dauci*, the causal agent of carrot leaf blight (Santos et al 2000). Only two applications of GA were required to produce control of leaf blight equivalent to four applications of the fungicide iprodine and significantly improved control over non treated plants. On carrots, GA produced plants with a more upright growth habit, longer leaves and wider petioles, but low concentrations did not reduce root weight.

Perez et al (1995) reported that applications of GA improved management of black spot of persimmon, caused by *Alternaria alternate*, by reducing the relative humidity around the infection court due to increased calyx erectness.

The environmental conditions for infection of carrot foliage and persimmon fruit by *A. dauci* and *A. alternata,* respectively, are similar conditions to that of *S. apiicola* of celery. The aim of the glasshouse trial was to determine if one or two applications of GA at three concentrations could reduce the impact of Septoria late blight on celery foliage.

6.2 Materials and methods

6.2.1 Preparation of GA

A stock solution of GA (250 mg mL-1) was prepared (GA3, Sigma-Aldrich) in distilled water and serial dilutions performed to give final concentrations of 250, 25 and 2.5 mg mL-^{1}.

6.2.2 Preparation of celery seedlings

Preparation of celery seedlings and *Septoria* inoculum are detailed in Chapter 2. Seedlings were kept separate from the inoculum source prior to the treatments listed below.

6.2.3 Trial design

Seedlings were labelled according to the design below and arranged into two groups within the glass house (Table 6.1). Each group consisted of 7 treatments, including a control, and at least 6 replicates of each group. Group 1 received one application of GA in week 1, with or without one application of *Septoria* in week 2. Group 1 controls were infected with *Septoria* in week 2. Group 2 received two applications of GA (week 1 and 3), with or without one application of *Septoria* in week 4. Group 2

controls were not infected with *Septoria*. Applications of both GA and Septoria were with a hand-held mister until runoff. After applications, both groups were completely randomised in the glasshouse and monitored for late blight development after week 4.

Table 6.2 Summary of treatments for celery plants

Group	GA concentration ($mg\ mL^{-1}$)	Time of application (weeks)			
		1	2	3	4
1	0	-	S	-	-
	2.5	GA	S	-	-
	25	GA	S	-	-
	250	GA	S	-	-
	2.5	GA	-	-	-
	25	GA	-	-	-
	250	GA	-	-	-
2	0	-	-	-	-
	2.5	GA	-	GA	S
	25	GA	-	GA	S
	250	GA	-	GA	S
	2.5	GA	-	GA	-
	25	GA	-	GA	-
	250	GA	-	GA	-

GA, Gibberellic acid application ; S, Septoria inoculated, -, no application

6.2.4.Assessment

After lesion development, plants were analysed for the following. The height (cm) and weight (g) of each plant was determined. The number of lesions per leaf, the number of lesions per plant and the size of lesions (mm) were assessed for each infected plant. Lesion area was determined, assuming a rectangular lesion and was applied to all lesions. Also, the number of pycnidia for each lesion was determined by use of a compound microscope.

6.2.3 Analysis

The analysis of the data was done in Genstat 10 using REML. The fixed terms in the model were the number of sprays and the concentration of GA and the interaction of these two terms. The data for the number of infected leaves were transformed using square root transformation prior to analysis. The data for lesion size were transformed using the log10 transform prior to analysis. As there was no significant difference between concentrations of GA the data were combined.

6.3 Results

In summary, two sprays of GA considerably reduced both the size of the lesions and the number of pycnidia, whereas one spray did not. But the two sprays only had a significant effect for some variables. The means are presented in Table 6.2.

The average number of pycnidia was significantly affected by the number of sprays of GA ($p<0.001$) but there was no difference between the different concentrations. Those plants sprayed twice had significantly fewer pycnidia.

The average number of lesions per leaf did not appear to be affected by the sprays. We analysed both total lesions per plant and average lesions per leaf and neither variable showed significant differences. However, the size of the lesions was significantly reduced by a second spray of GA ($p<0.001$). There was no difference in lesion size between the different concentrations. The size of lesions was halved with two sprays of GA.

The absolute number of infected leaves per plant appears to be reduced by a second spray ($p<0.001$). To confirm this effect, the proportion of infected leaves would be a better variable to analyse but this data was not available. Plant Height was not affected by the sprays.

Table 6.2 Effect of GA on the development of Septoria late blight on celery.

Number of GA sprays	Infected leaves (Sqrt)	No of infected leaves	Average No of pycnidia per leaf	Log of lesions Size	Size of lesions (sq mm)	Plant height (cm)	Average No of lesions per leaf	Total lesions per plant
0	2.733	7.9	84.4	1.413	30.9	26.8	1.5	12.9
1	2.951	9.0	111.1	1.402	25.7	26.2	1.9	16.6
2	1.810	4.8	32.3	0.736	7.7	26.5	1.9	12.9
p-value	<0.001	<0.001	<0.001	<0.001	<0.001	n.s.	n.s.	n.s.

ns, not significant

6.4 Discussion

GA adversely influenced the expression of Septoria late blight on foliage of celery in glasshouse trials and may have potential as an additional tool for control of the disease in the field. Our trial showed two applications of GA could significantly reduce the number of infected leaves, the size of lesions and the number of pycnidia per leaf, without affecting plant height. Santos et al (2000) also achieved a reduction in symptoms of Alternaria leaf blight on carrot with two applications of GA, but the timing of applications were irrelevant.

In our preliminary trial, various concentrations of GA had no effect on symptoms of Septoria late blight or plant morphology, but with *A. dauci* higher rates of GA had a greater effect in reducing symptoms and producing carrot plants with a more upright growth habit.

Santos et al (2002) also reported that two applications of GA produced equivalent control of Alternaria leaf blight as did the equivalent number of applications of the standard industry fungicide, iprodione. It would be interesting to trial GA in the field either alone or in combination with fungicides for control of Septoria late blight. GA is a naturally occurring plant hormone and not toxic (Hooley 1994). Its mode of actions, at least on Alternaria leaf blight of carrots, appears to be the production of more upright leaves thus reducing leaf wetness and RH in the crop (Santos et al 2000).

A similar scenario in celery could reduce leaf wetness which is critical for *S. apiicola* infection of celery. Thus GA may have a role to play in reducing Septoria Late Blight in celery crops in the field.

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Chapter 7

Survival of late blight (*Septoria apiicola*) in free water

Summary

Septoria apiicola spores require a leaf wetness period of at least 12 hours to germinate, but do not necessarily require free water. The survivability (or more precisely, viability) of *S. apiicola* spores after incubation in free water was assessed under optimum temperature conditions for infection. Spores survived up to the maximum time of incubation in free water, up to 4 days. It was also confirmed that spores need at least 12 hours in wet conditions for germination to occur.

7.1 Introduction

Sheridan (1968) established the benchmark for the optimum temperature of between 20–22.5 °C for germination of *Septoria apiicola*, and observed that high relative humidity (>96%) was also essential for germination. Furthermore, spores tend to germinate on and infect on celery leaves with a thin film of water on the leaf, probably as a result of the formation of dew (Schein 1964). Both the germination and infection parameters for late blight have been extensively investigated (e.g. Sheridan 1968, Berger 1970, Cerkauskas 1994) and is detailed in Chapter 1. The disease is well-known to be seed-borne, be splash-dispersed (Baker and Smith 1966, Berger 1970, Maude 1970), and survive in plant trash (Maude and Shuring 1970), but very little is known of the survivability of *S. apiicola* spores in free water, which may be another source of infection, although Lacy (1994) observed that spore germination on water agar plates and in suspended water droplets did not occur before 6 hours.

7.2 Materials and methods

7.2.1 Preparation of spore suspension

Diseased material showing symptoms of late blight was collected from the field and stored at 4 °C until required. Spore suspensions of *S. apiicola* were prepared by suspending 5g of shredded blight-infected leaves in 100 mL of sterile tap water, shaken for 1 min. and then filtered through a sterilised strainer into a fresh sterile container.

7.2.2 Time-course experiment

A 10 mL sample of the above was placed into each of 7 vials and each vial, apart from T_0 was placed in a growth cabinet set at 20 °C with a 12-12hr day-night cycle. At each time interval (0, 12, 24, 48, 72 and 96 hrs), a 200 µL sample was spread onto water agar plates (5 replicates) containing 200 mg L^{-1} tetracycline. Agar plates were incubated in the growth chamber for a further 24 hrs before being assessed for spore germination. After 24 hrs, each agar plate was visually assessed under low power for germinating spores. A total of at least 100 spores per plate was scored for germination and a percentage viability determined.

7.3 Results

Viable spores of *S. apiicola* were easily distinguished from non-viable spores as illustrated in Figure 7.1 showing a typical germinated spore (red arrow) present on the water agar, as well as a non-viable spore as a comparison (black arrow).

Average germination percentages over 5 plates are presented in Figure 7.2. Spore viability is low for spores that were in the water less than 12 hrs, and there was little difference in spore germination from

12-96 hrs. Visual examination of the water solutions showed that there was no spore germination in the water itself, even after four days. Germination of spores did not occur until after transfer to agar plates.

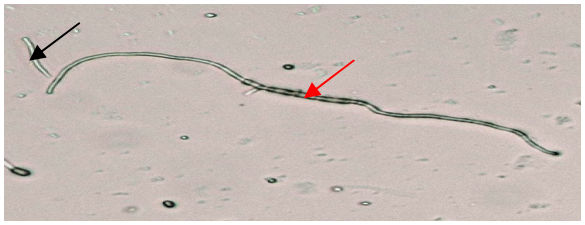
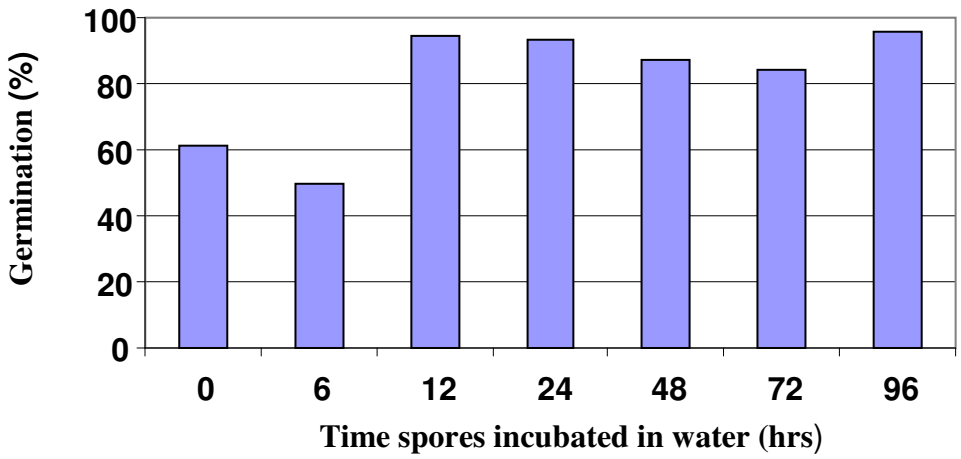


Fig 7.1 Germinated (red arrow) and un-germinated spore (black arrow)

Fig 7.2 Mean germination of *Septoria* spores over 96 hrs



7.4 Discussion

Prolonged periods of leaf wetness are required for infection by *S. apiicola*. Disease-predictive models for late blight in celery use a minimum 12-hr leaf wetness period to determine if infection has occurred (Mathieu and Kushalappa 1993, Lacy 1994, Bounds and Hausbeck 2007). Certainly, the current experiment confirms that exposure to free water for less than 12-hrs reduces the viability of *S. apiicola* conidia. We did not observe spore germination in free water, unlike Lacy (1994), but the low germination that was observed was attributed to the extensive population of bacteria and paramecia that were present in the water drops. Similar legions of microbes were also observed in the present investigation, and could well perform in a similar manner: "serving as a nutrient sink, depriving conidia of nutrients otherwise available to support germination" (Lacy 1994). The fact that *S apiicola* conidia were fully viable after 4 days in free water despite this native population shows that water in the field in bed channels or puddles could well be another source of infection for this particular disease, since it is also known that it can be spread by workers and machinery moving through a celery crop when it is still wet (Fritt *et al.* 1989).

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Chapter 8

General discussion and conclusions

The current research has clearly demonstrated spore release at temperatures below that assigned to the model TomCast, and others in use worldwide. At both 8 and 10 °C, there was a measurable increase in spore numbers over a 24-hr period, contradicting the earlier assertion that spore release was inconsequential below 13 °C (e.g. Phillips 1999). Only 10 spores are required for infection to be initiated (Sherf and McNab 1986), and as spores are spread by rain splash and celery plants are grown under over head irrigation; the disease has the potential to spread even at low temperatures.

It is also well established that spore germination can occur below the 13 °C threshold of the TomCast model (Sheridan 1968). In addition, infection by Septoria late blight was shown to occur (Tvede 2006), albeit at a lower severity level than optimum conditions (Green *et al.* 2002). However, infection at these lower temperatures cannot be discounted when investigating models for a polycyclic disease (Agrios 2005).

This investigation is the first to use the disease predictive model TomCast to harvest by reducing the start temperature in the latter phase of crop production to 8 °C. TomCast is an IPM option for Septoria late blight at either 10 or 15 DSV 13 °C – systemic fungicide at 10 weeks, first lesions or canopy closure (which ever comes first) - 10 DSV 8 °C up to harvest, as it reduced a total of 15 sprays. These modifications led to a comparable harvest, based on grower estimates but not on incidence estimates), when compared to the industry standard, since the loss in yield was offset by the reduction in chemical use and labour (see Chapter 4).

A less risky IPM strategy is to use TomCast at either 10 or 15 DSV 13 °C + systemic fungicide at 10 weeks, first lesions or canopy closure (which ever comes first) then revert to weekly sprays of the protectant fungicide. Whilst this strategy only reduced by 8 the number of sprays in the early phase of crop production, production was similar to the weekly spray program for both the grower and incidences estimates of yield (see chapter 4). The 10 DSV option increased profits the most, by 0.78%.

'Estimated' cost benefits:

Total cost of applying weekly fungicide sprays ……..= $1,689/ha
Cost of treatment 2 which improved profits by 0.78%
(10 DSV 13 °C + systemic fungicide at 10 weeks,
first lesions or canopy closure then weekly sprays
of the protectant fungicide)……. = $1,298/ha
Estimated benefit…….. = $391/ha
Estimated benefit industry wide, assuming 991 ha of production……= $0.5M approximately
On an industry basis the disease predictive model TomCast, used as an IPM tool, could save $391/ha or approximately $0.5M industry wide in fungicide sprays.

In laboratory trials *S apiicola* conidia were fully viable after 4 days in free water, which suggests that water on beds, in furrows, channels or puddles could be a means for inoculum to spread this disease. It is well known that late blight can be spread by workers and machinery moving through a wet celery crop. (Fitt *et al.* 1989).

Gibberellic acid may well be another piece of an IPM strategy against late blight, since 2 applications in glasshouse studies reduced both lesion size as well as total pycnidia numbers on infected leaves. If this could be applied in the field, it may lead to a dramatic reduction in the pathogen pool in celery crops and thus result in less severe outbreaks of Septoria late blight.

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Chapter 9

Technology transfer and recommendations

Summary

This chapter reports the benefits of a project advisory group established to oversee research projects. This group increased communication and cooperation between growers, researchers and allied support businesses and resulted in an accelerated impact of research and development within the celery industry. Recommendations for future research are presented.

9.1 Introduction

The research reported herein is the result of collaboration between celery growers, industry advisory groups and project steering committees. These groups consisted of vegetable growers, crop consultants and chemical resellers, with diverse experiences which they brought to the project. The groups provided an opportunity for researchers to describe their approach and current progress thus promoting the impact of research and development projects. The advisory groups also enabled growers and allied industries to ensure that their needs were being met by the research project. The advisory group approach worked very well and is DPI's preferred method of engagement with the vegetable industry. This interaction and collaboration with growers and vegetable industry development officers (IDOs), along with the subcontracting of sections of work to industry experts has been of enormous benefit to the project. The IDOs identified celery growers in other states. The advisory committee encouraged the researchers to promote results of the research to growers nationally in industry publications.

9.2 Industry advisory groups

The Biosciences Research Division, Knoxfield Centre took the approach of inviting growers and private allied support business representatives to volunteer their time and join with researchers to plan and discuss celery Septoria late blight issues first hand. Not all growers were in the position of being able to volunteer their time due to the demands of growing and marketing vegetables and consequently the researchers are extremely grateful to those who were able to contribute. The celery growers were very supportive of the project and provided field sites for trials in two states, which was enormously appreciated by the researchers.

The advisory group members who supported project VG06047 were:

Silvio and Glenn Favero – Market Gardeners, Hillcrest Farm, Cranbourne, Vic.

Tom Schreurs – Market Gardeners, J. & J.M. Schreurs & Sons, Clyde, Vic.

Karl Riedel – Vegetable Crop Agronomist, EE Muir and Sons, Cranbourne, Vic.

Russell Lamattina – A and G Lamattina and Sons Market Gardeners, Boneo, Vic.

Mark Milligan – Farm Manager, A and G Lamattina and Sons, Market Gardeners, Boneo, Vic

Deborah Corrigan, G C Corrigan & Co Pty Ltd., Clyde, Vic.

Denise & Alex Harslett; Tim Harslett, Harslett Farm, Armeins, Qld

9.3 Dissemination of information to industry

The current project was enthusiastically received by all growers and new insights into the use of the disease predictive model TomCast, as an IPM tool to time fungicide applications for Septoria late blight were gleaned. Adults acquire information in different ways such as reading, talking and visual cues. Some forms of information distribution will be more useful or accessible than others. There are many methods for distributing information to growers, such as field days, industry publications, workshop meetings and steering committees. During the course of this project we have endeavoured to utilize a broad range of information delivery methods and takeevery opportunity to report to industry. Records of publications and extension activities are listed below.

9.4 Publication List VG06047

Publications

Anon (2006) Tackling late blight in celery with new technology. Australian Vegetables Review 2006, p 28.

Minchinton E (2006) Validation of a disease forecasting model to manage Septoria late blight in celery HAL VG06047, Grower Briefing Notes and minutes, 14p.

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Harapas D, Minchinton E, Galea V, Ure E, Thomson F, Partington D (2007). Less spraying for celery leaf blight. Poster, AUSVEG Conference, 30–31 May Sydney 2007.

Harapas D, Minchinton E, Galea V, Ure E, Thomson F, Partington, D. Less spraying for celery leaf blight. Abstract, 16th APPS Conference Adelaide, 2007.

Advisory committee meetings

Campbells Road Clyde 5 January 2007. Notes on 'An invitation to attend an Advisory Committee Meeting: Septoria on celery (new project)'.

Campbells Road Clyde 16 March 2007. Notes on 'An invitation to a vegetable meeting'.

Campbells Road Clyde 2 November 2007. Notes on 'An invitation to a field day'.

Crown Casino, Garden RoomS 2 & 3. 15 February 2008. Notes on 'The Australian Celery and SproutS growers Meeting. Septoria on celery'.

Field days & workshops - notes

Campbells Road Clyde 2 November 2007. Notes on 'An invitation to a field day: Septoria on celery'.

9.5 Feedback from advisory committee meetings and field days

January 2007

DC

Was happy with the time and venue chosen for the meeting. Thought that the meeting content was good and would be happy if future meetings were held in this manner. Thinks that the project is heading in the right direction.

DH

Within the project, would like the pressure deficit sensor to be used instead of the leaf wetness sensor because the leaf wetness sensor is too unreliable and the project coordinators will not be able to get people to use these sensors unless they are reliable. Thought the time and venue of the meeting were fine and that the booklet was good. So far, has had no septoria within the trial, even in the plot that has not been sprayed. Is thinking about locating the weather station in the next planting of celery next week because there is no disease in any plot so far. Felt that perhaps septoria is absent because of the stricter hygiene procedures being used and growing own seed this year. Last year experienced a lot of septoria and were treating seed with chlorine. This year seed was treated with hot water and no disease has occurred. This leads them to think that septoria may be seed borne rather than soil borne. Seeing if septoria is seed or soil borne could be the basis of a new research project, or an extension of the current one. Overall, is happy with the direction of the project so far.

TH
Would like to see the pressure deficit sensor used instead of leaf wetness sensor, as raised in the actual meeting. Was happy with the chosen meeting time and venue and thought the focus of the meeting was good. He was concerned about whether or not funding from DPI would occur for the project, and thought that if need be, growers may have to fund the project to keep it going.

TS
Thought that the meeting venue and time were fine. No outcomes from the project have occurred as of yet because there has been no septoria present, which may be due to weather conditions. Would like an infection of septoria to be looked at outside of the trial plots and different climates to be tested in terms of septoria prevalence to see if this has any effect on septoria presence and infection rates. He thought the booklet was fine. Would like to show growers the project content using a datashow projector and screen with Liz Minchinton going through the information on the screen, rather than only though the booklet so that it is easier for meeting attendees to follow.

March 2007

SF
Presentations were very interesting. It was good to hear what is happening out there and what could be applicable to our industry. In regards to the Celery project we were a bit unfortunate this year with the dry weather, we didn't have much problems with diseases as per normal year. Therefore it was bit hard on the project, we need more time to collate more data in average "normal" year. Place of meeting was just right, if we had more people it might have been overcrowded.

TS
He liked the presentation of our guest speakers. He was also impressed that those people made an effort to come to our meeting and tell us about their work with other horticultural industries (grapes and fruit trees). More importantly they heard about our industry and what problems we are facing in our intensive production systems. It is really important that people like them know how we do things and the way we do things in order to help us to improve. It is very important that technical people (scientist) visually see our production on the field. Like, for example, things that work in the grape industry may not be suitable for our industry. Radio transmitters, stake weather stations and DNA all those things are very exciting but are they going to work in our industry? And, if they are going to be relatively easy to use and not too expensive we will use it. With this new technology we need something durable that can be easily moved every 6-12 weeks. Like enviroscan in orchard work fine you do not have to move it but in veggies when you are moving every 6-12 weeks things start to break down, and you need to know how to set it up if you are moving. He would like to see these people again to show them around on the field. Meeting at place was fine with him as long as everyone is happy with that.

PG
It was great having those people from VPAC and NITCA telling us about their work, what their doing and what is available out there. If there is new development in the future that could be applicable to the veggie industry we would like to hear about it. New levy RD structure should address these issues,

bringing people like this to us (growers) that we can find out first hand what is going on. Liz's project is excellent keep up the good work.

DC
The presentations were very interesting. It gives you an idea where we are going. There is a question on how and when we will be there using that technology. Overall, this is the first positive step, would like to hear more about it in the future. Celery project has been fortunate this year with no diseases. She is very happy with Celery project progress, and the approach to new technology.

MB
Met with the celery growers group last week as a DPI representative from head office. Represented the A&E SIG which links technology providers and DPI scientists around the small scale technology area. The meeting was a chance to hear first hand some of the issues facing the industry and to better understand if there are any technologies available or likely to be available soon which would provide an answer to their issue, namely measuring soil moisture quickly and efficiently on a system that is mobile. The presentation from the other guest speakers gave a useful background to the discussion and I know that other growers were very interested in looking into it further. While it may seem to be a specific problem for the growers a solution for them on soil moisture would be valuable across other industries. There may be some almost ready systems out there and I have contacted some providers. Will arrange a meeting in the near future between these sensor company and the growers, through Liz of course.

November 2007

SM
This is the first time has attended the Celery field day, it was excellent, very well organised, run and presented. Unfortunately, had to leave early. Booklets that were received are a great tool and reference point (first time come across Tom-cast). Likes the disease predictive model as a concept and as an approach to fix (prevent) the problem. Tom-cast model will help growers and possibly businesses like ours. There is a real opportunity for consultants to run model or to have some assisting role. Trial was good with some clear differences between treatments. Keep up the good work. Would like to be invited for future similar events.

SF
Field day was very good. Likes the project very much, we are on the right track just needs to be implemented, and for that, we need affordable technology. Like for e.g. If can use one weather station per 4 plantings, that will reduce work load of moving equipment around and also costs associated with No. of weather stations that are used (hopefully technology may come down in price soon). One of the problems that growers are facing is a fear of technology; it does create extra work. Personally believe that this can work; need to convince next generation. It is very important that we continue with the research.

TS
Field day was very good, easy to understand (with provided material). One concern was survival of Septoria spores in recycled water. Would like to see some work done around that. In time with high disease pressure there will be spores in recycled water, in a drought we need any water that we can get. Using that water, will disease be spread? Learnt that Septoria does not always start from one spot, but has to be there (spores need to be present) and if conditions are right it will develop. Problem with this trial is do not know if the disease is there or not, if can inoculate celery with Septoria to make sure that disease is there. If disease is not, there is no need to spray.

RB
Field day was good, Victor's presentation was excellent. Liked the project the whole thing makes sense if growers can save two sprays per crop it is worth it. It is important that continue with the research, making Tom-Cast model grower friendly. In addition, technology needs to be affordable, reliable and robust. Maybe next time can have a live demonstration downloading data from weather

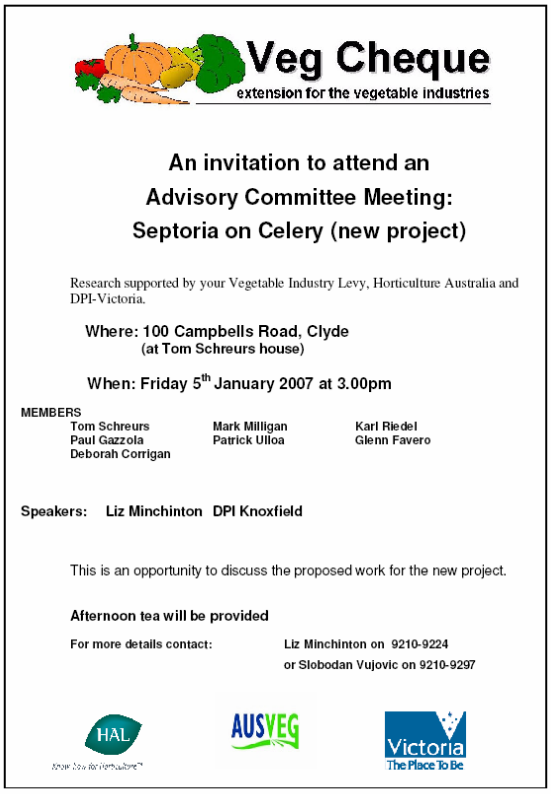
station to spreadsheet and interpreting what it means. It is a very interesting, challenging and rewarding project.

9.6 The major recommendations to growers from this work are:

- In winter crops the current TomCast Model will reduce the number of sprays by up to 8 and produce equivalent yields to weekly sprayed plants up to week 10;
- The TomCast Model can be used to harvest if the threshold is lowered to 10 DSV 8 °C post 10 weeks, but late blight may cause some crop losses;
- It is possible to delay spraying until week 10 in winter crops;
- If disease does eventuate in celery crops, 2 consecutive sprays of a registered systemic fungicide, followed by weekly sprays of a protectant fungicide should have minimal impact on yields.

9.7 Areas of future research which would benefit the industry are:

- Comprehensive field trials on commercial crops using commercial equipment from planting to harvest is required to attain true-value yields to fully evaluate the TomCast model;
- Significant spore release at both 8 and 10 °C demonstrates that the TomCast model needs modification encompassing a lower temperature threshold than the current 13 °C;
- Extensive growth cabinet studies on the lower temperature threshold is required for both spore release and spore germination;
- Evaluation of GA, to reduce disease development as IPM tool;
- Detailed investigation of spore survival in water, investigating the upper time limit for survival, as well as the temperature limits;
- Survival of spores up to four days in water poses a serious risk in disease spread due to the current reliance on recycled water for irrigation, which is becoming a permanent fixture in Australian agriculture.
- Review and modification of the TomCast model adapting it for Australian conditions;
- Pursuit of more robust and reliable leaf wetness sensors, weather station hardware and or methods of estimating leaf wetness
- Incorporation of forecast Bureau of Meteorology weather data into disease predictive models to give a forward estimate of expected spray thresholds;
- Investigation of a web-based depository for weather station data and model use.



Veg Cheque
extension for the vegetable industries

An invitation to attend an
Advisory Committee Meeting:
Septoria on Celery (new project)

Research supported by your Vegetable Industry Levy, Horticulture Australia and DPI-Victoria.

Where: 100 Campbells Road, Clyde
(at Tom Schreurs house)

When: Friday 5th January 2007 at 3.00pm

MEMBERS
Tom Schreurs, Paul Gazzola, Deborah Corrigan, Mark Milligan, Patrick Ulloa, Karl Riedel, Glenn Favero

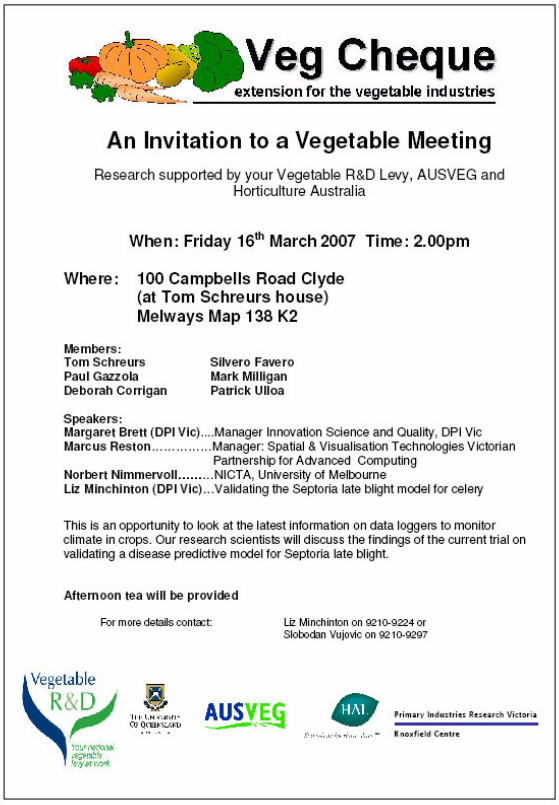
Speakers: Liz Minchinton DPI Knoxfield

This is an opportunity to discuss the proposed work for the new project.

Afternoon tea will be provided

For more details contact: Liz Minchinton on 9210-9224
or Slobodan Vujovic on 9210-9297

HAL AUSVEG Victoria The Place To Be



Veg Cheque
extension for the vegetable industries

An Invitation to a Vegetable Meeting

Research supported by your Vegetable R&D Levy, AUSVEG and Horticulture Australia

When: Friday 16th March 2007 Time: 2.00pm

Where: 100 Campbells Road Clyde
(at Tom Schreurs house)
Melways Map 138 K2

Members:
Tom Schreurs, Paul Gazzola, Deborah Corrigan, Silvero Favero, Mark Milligan, Patrick Ulloa

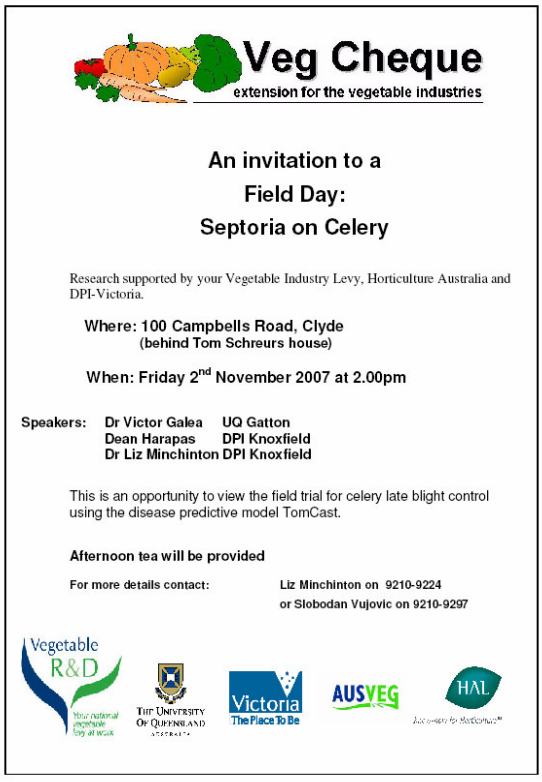
Speakers:
Margaret Brett (DPI Vic)....Manager Innovation Science and Quality, DPI Vic
Marcus Reston.....Manager: Spatial & Visualisation Technologies Victorian Partnership for Advanced Computing
Norbert Nimmervoll.....NICTA, University of Melbourne
Liz Minchinton (DPI Vic)...Validating the Septoria late blight model for celery

This is an opportunity to look at the latest information on data loggers to monitor climate in crops. Our research scientists will discuss the findings of the current trial on validating a disease predictive model for Septoria late blight.

Afternoon tea will be provided

For more details contact: Liz Minchinton on 9210-9224 or Slobodan Vujovic on 9210-9297

Vegetable R&D AUSVEG HAL Primary Industries Research Victoria Knoxfield Centre



Veg Cheque
extension for the vegetable industries

An invitation to a
Field Day:
Septoria on Celery

Research supported by your Vegetable Industry Levy, Horticulture Australia and DPI-Victoria.

Where: 100 Campbells Road, Clyde
(behind Tom Schreurs house)

When: Friday 2nd November 2007 at 2.00pm

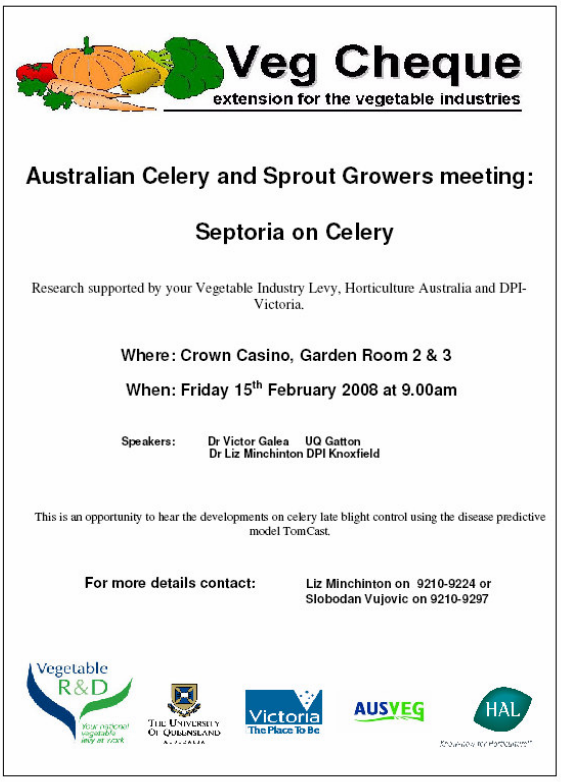
Speakers: Dr Victor Galea UQ Gatton
Dean Harapas DPI Knoxfield
Dr Liz Minchinton DPI Knoxfield

This is an opportunity to view the field trial for celery late blight control using the disease predictive model TomCast.

Afternoon tea will be provided

For more details contact: Liz Minchinton on 9210-9224
or Slobodan Vujovic on 9210-9297

Vegetable R&D The University Of Queensland Victoria The Place To Be AUSVEG HAL



Veg Cheque
extension for the vegetable industries

Australian Celery and Sprout Growers meeting:

Septoria on Celery

Research supported by your Vegetable Industry Levy, Horticulture Australia and DPI-Victoria.

Where: Crown Casino, Garden Room 2 & 3

When: Friday 15th February 2008 at 9.00am

Speakers: Dr Victor Galea UQ Gatton
Dr Liz Minchinton DPI Knoxfield

This is an opportunity to hear the developments on celery late blight control using the disease predictive model TomCast.

For more details contact: Liz Minchinton on 9210-9224 or
Slobodan Vujovic on 9210-9297

Vegetable R&D The University Of Queensland Victoria The Place To Be AUSVEG HAL

Front Pages of SCM notes and field day for VG06047

Poster presentation for both Ausveg 2007 and APPS 2007

DEPARTMENT OF PRIMARY INDUSTRIES

Primary Industries Research Victoria
Knoxfield Centre

Less spraying for celery leaf blight

D. Harapas[A], E. Minchinton[A], V. Galea[B], E. Ure, F. Thomson[A], and D. Partington[A]
[A]PIRVic, DPI Victoria - Knoxfield Centre, PB 15, Ferntree Gully DC, 3156, Vic.
[B]School of Agronomy and Horticulture, University of Queensland, Gatton Campus 4334

INTRODUCTION

The fungus *Septoria apiicola* is responsible for late blight in celery (Figure 1), and without intensive calendar spraying can cause losses of up to 90%. This project aims to devise ways of controlling celery late blight with less spraying and so minimise the costs and hazard to users and the environment.

Figure 1. Symptoms of late blight. Small brown spots develop on the older outer leaves. These quickly turn dark brown and may join to form larger spots. Losses are due to slower growth rates, post harvest rots and labour for trimming diseased shoots.

The TomCast model (Table 1) can be used to predict the likelihood of celery late blight. Applying fungicide at these times rather than on a weekly basis could mean fewer sprays. Weather stations (Figure 2) in celery crops are used to transmit temperature and leaf wetness readings for determining the Disease Severity Value (DSV).

METHOD

We performed a summer field experiment in Victoria and Queensland using different spraying treatments and DSV thresholds which were based on those described previously (1). Systemic fungicide was also applied at canopy closure, to reduce disease.

Recently the Disease Doctor™ computer program (Figure 3) has become available to facilitate growers' use of weather station telemetry with TomCast. We examined the software's output with a view to increasing its accuracy and user friendliness.

Table 1. TomCast model (2).

Mean temp. (°C)	Hours of leaf wetness required to produce daily Disease Severity Values (DSV) of:				
	0	1	2	3	4
13-17	0-6	7-15	16-20	21+	
18-20	0-3	4-8	9-15	16-22	23+
21-25	0-2	3-5	6-12	13-20	21+
26-29	0-3	4-8	9-15	16-22	23+

0 = conditions unfavourable for spore formation. 4 = conditions highly favourable for spore formation. DSV's are scored over a 24 hours period and accumulated until the threshold is reached, typically 20 DSV's.

Figure 2. A weather station used in this project. In the foreground is the solar panel unit which also contains the modem and transmitter for sending telemetry via the mobile phone network.

RESULTS AND DISCUSSION TO DATE

Unfortunately no late blight appeared on the crops, and no assessment of TomCast was possible. However, for the Victorian experiment, 5 fewer sprays at the 20 DSV threshold were needed when compared to weekly spraying.

The Disease Doctor™ program (Figure 3) was enhanced by: improving its help file, enabling it to operate on a computer network, and correcting a DSV calculation error.

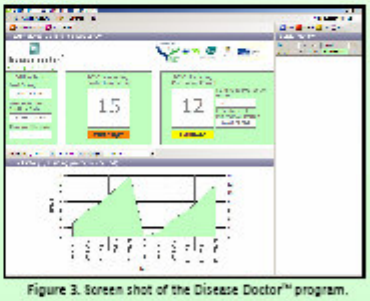


Figure 3. Screen shot of the Disease Doctor™ program.

Further field trials are planned, and so is an investigation on the use of vapour pressure deficit as a means for determining leaf wetness. This could negate the contamination and calibration issues of the leaf wetness sensor.

ACKNOWLEDGEMENTS AND REFERENCES

We would like to thank Tom Schreurs, Denise Harslett, and Alex Harslett for their help with the field trials, and Boomaroo Nurseries Pty Ltd for the celery seedlings.

1. Minchinton, E. (2005). Evaluation of disease forecasting model to manage late blight (*Septoria*) in celery. HAL report VC04016
2. Madden L., Pennypacker, S. P. and MacNab, A. A. (1978). FAST, a forecast system for