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

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VIC Department of Primary
Industries

Project Number: VG04016

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

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Purpose of project:

This project details the outcomes of a 12-month 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 2005.

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Media Summary

Model tackles sprays for celery late blight

Research has evaluated 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 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. The model predicted a saving of 7-8 sprays on winter crops and 3-5 sprays on summer crops but only in the early growth stages.

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 were favourable for late blight and provided no sprays had been used in the last 7 days, then a spray should be applied. If conditions were not favourable for late blight then the model shows that no sprays should be applied.

To date the model is only suitable for early stages of crop production before canopy closure. More research is required to make it suitable for later stages of growth. Options to enhance the model's performance are:

- (a) Application of a systemic fungicide with curative activity at canopy closure, followed by lower spray thresholds or weekly sprays of preventative fungicides.
- (b) Determining the lowest temperature for late blight symptoms to appear in the crop and then lowering the temperature threshold which triggers spray applications.
- (c) Evaluation of alternative disease predictive models.

If successful the model would be an economical means of reducing chemical sprays without compromising yield or quality.

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

Technical Summary

Celery (*Apium graveolens*) is a crop that needs to be intensively managed due to exceedingly high aesthetic standards required 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 12 month study, two trials were conducted to evaluate the disease forecasting model TomCast as 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 model was very effective as a decision support tool only in the early stages of crop growth prior to canopy closure. The model was not suited to later stages of growth.
- Most savings on sprays were made on winter grown crops. Spray thresholds of 10-20 DSVs could reduce 7-8 fungicide applications in winter.
- In summer grown crops spray thresholds of 15-25 DSVs reduced 3-5 fungicide applications.
- Efficacy data was obtained for the systemic fungicide difenoconazole (Score).
- The use of the TomCast model would be economical in the early stage of crop growth, before canopy closure, but has not yet been shown to be economical in the late stage.

Recommendations for future work:

- (i) A hypothetical spray program is proposed which requires field validation.
 - 20 DSVs till canopy closure, then apply a systemic fungicide, followed by weekly prophylactic sprays.
 - Trial TomCast at 20 DSVs, apply a systemic fungicide at canopy closure, followed by reduced spray thresholds of 10 and 12 DSVs using commercial air-assisted spray rigs.
 - Determine the lower temperature threshold for *S. apiicola* to sporulate and infect celery and incorporate these parameters into the TomCast model, or alternatively broaden the lower temperature range in the model from 13-17°C to 10-17°C and trial with 10 and 12 DSVs beyond canopy closure.
- (ii) Validate the computer version of the model.

Chapter 1

Introduction

1.1 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 expensive for growers. Growers are constantly seeking ways to reduce the cost of production, whilst maintaining control of the disease without reducing yield or quality. It also raises health issues about exposure to unnecessary chemical residues for consumers and workers.

Nationally the cost of fungicide applications must be substantial in an industry which grew 1043ha of celery in 2001 (Table 1). The ABS production figures are given in Table 1.1. One grower reported production of 6500 boxes/ha at 16 kg/box and 10-11 bunches/box. A box of celery wholesales for about \$9.00/box at the farm gate (T. Schreurs pers. comm.).

Table 1.1 Production and value of celery industry in Australia (2001, ABS)

State	Area (ha)	Area (%)	Production (tonne)	Yield (tonne/ha)	Production (%)
Victoria	557.6	53.45	28,263.6	50.7	62.6
Queensland	222.9	21.36	11,887.0	53.3	26.3
Western Australia	200.0	19.17	2,996.7	15.0	6.6
South Australia	34.5	3.31	922.7	26.8	2.0
New South Wales	15.2	1.46	688.0	45.2	1.5
Tasmania	13.1	1.25	367.3	28.1	0.8
Total	1,043		45,125		

1.2 The Disease – Late Blight

The fungus *Septoria apiicola* Speg. causes the disease late blight of celery (*Apium graveolens* L.) and celeriac (*Apium graveolens* var. *rapaceum* DC.). It is a major foliage disease causing losses of 50 – 90% in commercial crops (Lacy and Cortright, 1992; Sherf and MacNab, 1986). Crop losses from late blight are associated with defoliation, slower growth rates, increased labour 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 (Cerkauska, 1994; Mudita and Kushalappa, 1993; Sutton and Waterston 1966; Walker, 1952).

1.2.1 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 10mm 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 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). A study of world-wide isolates of the large and small spot forms lead to the recognition of only one species (Gabrielson and Grogan, 1964).

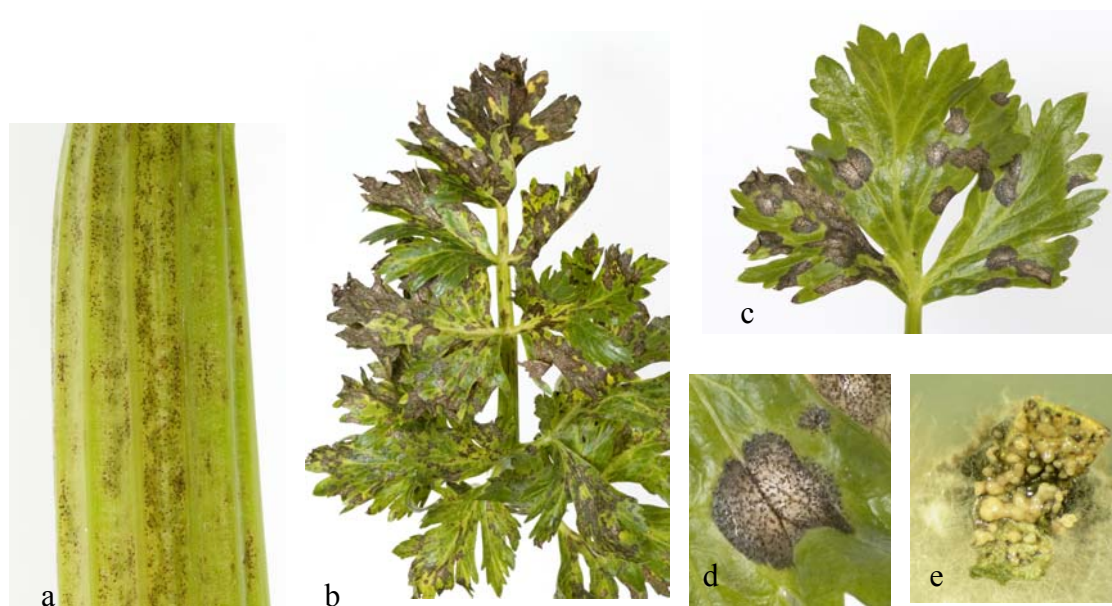


Figure 1.1 Symptoms of late blight. (a), Lesions on petiole; (b), leaf spots and blight on leaf; (c), leaflet with leaf spots; (d), close-up of leaf spot showing dot-like pycnidia; (e), gelatinous tendrils of conidia oozing out of pycnidia in culture.

1.2.3 Dispersal

S. apiicola is dispersed by seed, crop debris and adjacent infected crops. Seed is a major means of *S. apiicola* dispersal. 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; Hausbeck, 2002; Cerkauskas, 1994). 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 (Sherf and MacNab, 1986; Sutton and Waterston, 1966; 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.

1.2.4 Disease development

1.2.4.1 Spore germination

Spores germinate on water agar within 12 hr at 20-22.5°C. The temperature range is 5-25°C, with no germination at 30°C after 30 hrs (Sheridan, 1968a). As long as relative humidity (RH) was above 95%, free water was not required for germination (Sheridan, 1968a), but on celery leaves spores generally germinate and infect in a thin film of water, possibly from the formation of dew (Schein, 1964).

1.2.4.2 Infection

The fungus directly penetrates the epidermis or enters the plant via the stomata (Hausbeck, 2002; Donovan et al, 1990). 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 (18°C) 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 20°C and increasing periods of leaf wetness up to 96 hrs, increased numbers of lesions formed, but at 25°C and 30°C fewer lesions were formed.

High amounts of precipitation promoted disease development (Berger, 1970, Sheridan, 1968a; Walker, 1952), 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 resistant celery, 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).

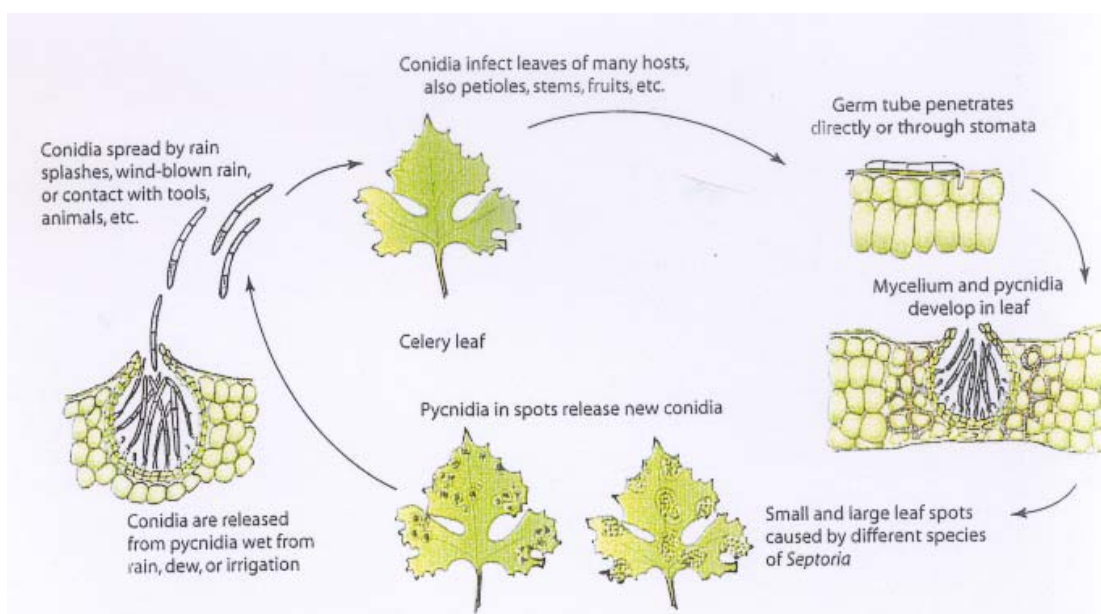


Figure 1.2 Life-cycle of *Septoria apiicola* (modified from Agrios, 2005).
Conidia (spores).

1.3 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, Galea and Minchinton, 2005; Parry, 1990). 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.

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).

1.3.1 Issues with disease predictive models

There are a number of issues associated with disease predictive models:

1. They predict sporulation or infection based on historical data, even though it is 12-24 hr old microclimate data. By the time the meteorological data is fed into the model the fungal pathogen could already have sporulated or infected the crop.
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:
 - (a) the lag time between collection of microclimate data and output from the predictive model,
 - (b) the lag time between the output from the model and the time to organise spraying of the crop.

1.3.2 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 25°C (Berger, 1970). Models have been developed for late blight based on *in vitro* studies and field observations. Some 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 (Mudita and Kushalappa, 1993; Lacy, 1994; Lacy et al, 1996; Pitblado, 1992; 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 to less than 7 per crop (Mudita and Kushalappa, 1993).

1.3.3 The action threshold model

Mudita and Kushalappa (1993) recognised the disease appeared later in the crop's life and tried to delay spraying till 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. Unfortunately yield losses occurred at all initial blight incidences, so it was not possible 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.

1.3.4 Infection models

Mathieu and Kushalappa (1993) developed a disease severity model based on studies of disease development at various temperatures and ranges of leaf wetness. The number of lesions increased with temperatures of 10, 15 and 20°C but declined at 25 and 30°C with increasing hours of leaf wetness (12, 24, 48, 72 and 96 hr). The responses were divided into four disease severity values on the basis of cluster analysis, representing 'very low', 'low', 'moderate' and 'severe infection'. Temperatures below 10°C and leaf wetness periods of less than 12 hr require testing to refine the model. Further research is needed to define and validate spray thresholds in the field.

An infection model based on 12hr-leaf wetness was developed by Lacy (1994). Lesions formed on celery leaves only after 24 hrs of continuous or interrupted 12 hr wet/ 12hr dry/ 12hr wet leaf wetness periods after inoculation at 21°C for up to 15 days afterwards. 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. It is not clearly spelt out whether the 12 hrs is 12 consecutive hrs or a cumulation of 12 hrs of leaf wetness. In 3 years of field trials the model reduced 2 sprays of chlorothalonil per crop compared to weekly spraying, without sacrificing efficacy of disease control. Temperature was not included in the model, as it was not a limiting factor in Michigan, where the model was developed. Temperatures below 10°C and above 30°C could be limiting factors at other locations.

1.3.5 The sporulation model

Reitz et al (1999) analysed the economics of both insect and fungal management in commercial celery crops grown in the USA. Spray threshold for late blight were based on the TomCast model (Pitblado, 1992). Although 9 fungicides were applied to the crop, only 4 were specific for late blight. Fungicide sprays for late blight were reduced by one spray from 4 to 3, using an initial threshold of 30 DSVs reducing to 20 DSV's at canopy closure. The saving of one spray was valued at \$US45/ha/crop. A conservative accumulation of 20 DSV's is now recommended in the US (Phillips, 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 9-12 sprays per year, but the spray threshold is not stated (Bolkan and Reinert, 1994). TomCast was successfully used in the Netherlands to improve the efficacy of chlorothalonil sprays (Schepers and Meiers, 1998).

The TomCast disease-forecasting model was modified from the earlier FAST model of Madden et al (1978). FAST was originally developed to predict the sporulation of *Alternaria solani*, *Septoria lycopersici* and *Colletotrichum coccodes* on tomatoes and is based on periods of leaf wetness and temperature which score disease severity values (DSVs) (Table 1.1). A weather station in the crop collects temperature and leaf wetness data. A scale of DSVs is derived from the 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 hrs beyond 11.00 am (ie 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

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

DSV = Disease Severity Values (scored 0-4).

0 = conditions unfavourable for spore formation.

4 = conditions highly favourable for spore formation.

1.4 Chemicals

Early fungicide control for late blight centred 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 from the benzimidazole and DMI triazole activity groups, greatly improved control of late blight, but brought consequences of fungal resistance and fungicide phytotoxicity. Other chemical options such as bio-controls, adjuvants and antibiotics have been trialed but with variable results. Chlorothalonil, with multi-site activity, is the fungicide generally sprayed with the disease predictive models (Lacy, 1994; Phillips, 2005; Mudita and Kushalappa, 1993).

Protectant fungicides for late blight control were Bordeaux, tribase copper, copper hydroxide, sulphur, chlorothalonil, maneb, ziram, zineb, nabam, propineb, captafol, anilazine, and captan (Sutton and Waterston, 1966; Chupp and Sherf, 1960; Lacy, 1973; Sherf and MacNab, 1986; Chinchilla and Mora, 1986; Lacy and Cortright, 1992; Aloj and Garibaldi, 1982). 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).

The early systemic fungicides for late blight control were 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 (Gladders and McKeown, 1985; Paulus et al, 1979), led to spraying contact and systemic fungicides in either combination or alternation, such as benomyl + chlorothalonil, or benomyl alternated with chlorothalonil (Paulus et al, 1979, 1980; Vulsteke and Meeus, 1981, 1986). It appears, however, that in the early 1990s Spanish isolates of *Septoria* were still sensitive to benomyl and carbendazim (Sorribas and Izquierdo, 1992).

More recently systemic fungicides for late blight control have largely come from the triazole group. Propiconazole showed curative and eradicated activity along with diclobutrazole, penconazole, myclobutanil, flusilazole, fenarimol, tebuconazole and triadimenol (Amer et al, 1993a, 1993b; di Marco, 1987; Wicks, 1990; 1989). Propiconazole, flutriafol, and combinations of propiconazole and contact fungicides (anilazine or chlorothalonil) were effective against late blight in the field (Amer et al, 1993a, 1993b; Brunelli et al, 1989; Wicks, 1990, 1989). 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 to systemic fungicides was not consistent as they had a negative effect on triadimenol and tebuconazole (Amer et al, 1993b).

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). *Trichoderma harzianum* partially controlled late blight when applied weekly or 5 days before inoculations with the fungus and had no control after inoculations with *S. apiicola* in glasshouse trials (Ciccarese et al, 1995). Phosphonic acid had no efficacy for late blight control in Queensland trials (Heaton and Dullahide, 1990), nor did was neem kernal extract (Rovesti et al, 1992).

1.5 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 30°C or a hot-water dip at 47°C - 49°C for 30 min. reduced inoculum (Hausbeck, 2002; Cerkauskas, 1994; Walker, 1952). Maude (1970) reported the thiram seed treatment was superior to a hot water treatment of 50°C for 25 min. in controlling seed borne infection (Maude, 1964; Bant and Storey, 1952). 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 30°C compared with a hot water treatment of 50°C 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 20°C for 24 hr completely eliminated *S. apiicola* from seed and broke dormancy (Gott et al, 1989; Humpherson-Jones et al, 1984). Aerated steam completely eradicated *S. apiicola* from seed, however, an expensive machine is a prerequisite for this treatment (Navaratnam et al, 1980).

1.6 Resistance

Resistance in celery to *S. apiicola* is recessive and polygenic (Bohme, 1960). It has been recognised for some time that wild *Apium* species are sources for resistance in celery (Ochoa and Quiros, 1989). Breeding for resistance to *S. apiicola* has been undertaken with both conventional and molecular approaches (Quiros, 1993; Moravec et al, 1988). 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 (Evenor et al, 1994; Donovan et al 1994; Rappaport et al, 1991; Wright and Lacy, 1985, 1988).

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Chapter 2

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

Summary

This chapter reports on an evaluation of the TomCast disease predictive model for late blight of celery in two field trials during summer and winter 2005 in Victoria. TomCast was very effective as a decision support tool in the early stages of crop growth prior to canopy closure, but not in later stages of growth. Most savings on sprays were made on winter grown crops, where spray thresholds of 10-20 DSVs (disease severity values) could reduce fungicide applications by 7-8. In summer grown crops spray thresholds of 15-25 DSVs reduced fungicide applications by 3-5. A hypothetical spray program, based on TomCast is proposed and requires validation in the field.

2.1 Introduction

Celery (*Apium graveolens*) is an intensively managed crop due to exceedingly high aesthetic standards and low damage thresholds (Reitz et al, 1999). A major foliage disease of celery is late blight caused by the fungus *Septoria apiicola* Speg. Late blight can cause losses of 50-70% in commercial crops where it is managed by weekly spraying (Sherf and MacNab, 1986; Lacy and Cortright, 1992). Up to 16 fungicide sprays can be applied after transplanting in Australia. Growers are keen to reduce the cost of production including pesticide applications, even if by only one spray. Additionally, the public is demanding fewer pesticides be used and less contaminated of the environment.

A number of disease predictive models, based on either spore production or infection, have been developed to better time fungicide sprays for late blight control in celery (Mudita and Kushalappa, 1993; Lacy, 1994; Lacy et al, 1996; Pitblado, 1992; Reitz et al, 1999). In Quebec, fungicide spraying for late blight starts only when integrated pest management (IPM) scouts first detect disease in the field. Late blight can appear 30 days after transplanting but usually appears between 40-60 days. This IPM program reduced the number of sprays from 10 to fewer than 7 per crop (Mudita and Kushalappa, 1993).

Mudita and Kushalappa (1993) tried to delay spraying till 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. Unfortunately yield losses occurred at all initial blight incidences, so it was not possible 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.

Mathieu and Kushalappa (1993) developed a disease severity model based on disease development over a range of temperatures and leaf wetness duration. The number of lesions increased with temperatures of 10, 15 and 20°C with increasing hours of leaf wetness, but declined at 25 and 30°C. Unfortunately the thresholds for this 'infection' model were never validated in the field.

A 12hr-leaf wetness model base on 'infection' was developed by Lacy (1994). 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. In 3 years of field trials the model reduced 2 sprays per crop compared to weekly spraying without sacrificing efficacy of disease control. Temperature was not included in the model.

Reitz et al (1999) analysed the economics of both insect and fungal management in celery crops in the USA. Spray thresholds were based on the TomCast model (Pitblado, 1992), which was modified from the earlier FAST model of Madden et al (1978). The TomCast disease predictive model is based on periods of leaf wetness and temperature and scores disease severity values (DSVs) that promote fungal sporulation (see Material and Method this chapter). They found that fungal sprays for late blight could be reduced from 4 to 3 using an initial threshold of 30 DSVs reducing to 20 DSVs at canopy closure. In a trial in a commercial crop one spray valued at \$US45/ha was saved. A conservative accumulation of 20 DSVs is now recommended in the US (Phillips 2005).

All celery produced for Campbell's Soup Company in the USA now uses the TomCast model to time fungicide sprays for late blight (Bolkan and Reinert, 1994), resulting in 9-12 fewer sprays per year. When TomCast indicates conditions are conducive for late blight a spray is applied and when conditions are not conducive for late blight, crops are not sprayed.

This chapter reports on evaluations of the TomCast model for late blight control in celery compared with grower's weekly spray practices in two trials at Clyde, Victoria.

2.2 Materials and methods

2.2.1 The TomCast model

DSVs are the hours of leaf wetness in a specified temperature range (Table 2.1). Daily DSVs are calculated at 1100 hrs, and accumulated till a spray threshold is reached. A period of 2 hrs leaf dryness is required to interrupt a leaf wetness period. A period of 1 hr of leaf dryness is not considered sufficient to interrupt leaf wetness calculations. If leaf wetness extends for 3 hrs beyond 1100 hrs (ie to 1400) then it is included in the previous day's DSV calculations.

Table 2.1 The TomCast disease predictive model (Madden et al, 1978)

Mean temperature (°C)	Leaf wetness periods (hr) 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.

2.2.2 Weather stations

A ModelT weather station (Western Electronics) was placed in the irrigation line of the celery crops and recorded average leaf wetness, temperature, relative humidity and total rainfall at 30 min. intervals. The leaf wetness sensor was placed in the celery crop and its height adjusted as the crops grew.

2.2.3 Chemical application

Chemicals were applied with a single cone nozzle SPX brown No 12 by a Sylvan Selectra 12v knapsack (Sylvan 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 2.2).

Table 2.2 Information on chemicals applied in the trials

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

2.2.4 Field trial No 1

Eight week old celery seedlings of cv Hornet were supplied courtesy of South Pacific Seeds from Boomaroo Nurseries, Lara, Victoria and planted on 12 January 2005 at 100 Campbells Road Clyde, Victoria. The trial was laid out in a randomised block design of 8 blocks each containing 4 spray 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 four different spray triggers; a weekly spray with the industry spray schedule of mancozeb + cupric hydroxide + Hortiwet[™] alternated with chlorothalonil, a spray at 15 DSVs, 20 DSVs or 25 DSVs with the same industry spray schedule (Table 2.2 and 2.3).

Table 2.3 Spray schedule for trial No 1

	Week/Date											
	1	1	2	3	4	5	6	7A	8	9	10	11A
Spray threshold	12/01/05	14/01/05	21/01/05	28/01/04	4/02/05	11/02/05	18/02/05	25/02/05	4/03/05	11/03/05	18/03/05	23/03/04
Weekly	P	HKM	B	HKM	B	HKM	B	HKM	B	HKM	B	-
15 DSV's	P	-	HKM 25 Jan	-	B 1 Feb	-	HKM 23 Feb	-	-	B 16 Mar	-	-
20 DSV's	P	-	HKM 27 Jan	HKM 29 Jan	-	B 15 Feb	-	-	-	HKM 16 Mar	-	-
25 DSV's	P	-	-	-	-	-	-	B 1 Mar	-	-	-	-

P, planted; HKM, Hortiwet[™] + cupric hydroxide + mancozeb; B, chlorothalonil; -, not applicable

2.2.5 Field trial No 2

Eight week old celery seedlings of cv Hornet were supplied courtesy of Boomaroo Nurseries Lara, Victoria and planted on 31 March 2005 at 100 Campbells Road, Clyde, Victoria. The trial was laid out in a randomised block design of 6 blocks each containing 7 (plots). The 7 treatments are described in detail in Tables 2.2 and 2.4, and include the standard industry practice of weekly sprays of mancozeb + cupric hydroxide + Hortiwet[™] alternated with chlorothalonil.

2.2.6 Assessment

Field trial No 1 was assessed weekly up to week 7 and then at week 11. At weeks 7 and 11, 6 guard plants were left at the beginning and end of each plot and every second plant was assessed till 10 plants had been scored. Field trial No 2 was assessed weekly up to week 10 then at week 15. At weeks 10 and 15, there were 2 guard plants at the beginning and end of each plot and 10 adjacent plants were scored. Yield was assessed at week 18 (8/8/2005).

Assessments were made of incidence, percentage of plants with symptoms and severity of late blight. Severity was measured on a scale of 0-5, where 0 = no lesions/leaf; 1 = 1-10 lesions/leaf; 2 = 11-20 lesions/leaf; 3 = 20-100 lesions/leaf; 4 = over 100 lesions/leaf and 5 = blighted leaf. A yield assessment was made on 8/8/2005 courtesy of Mr T. Schreurs and plants were rated as marketable (81.75 t/ha), 50% marketable (40.875 t/ha) or unmarketable (0 t/ha). Data was analysed by analysis of variance except for disease incidence at 11 weeks in trial No 2 which was analysed by logistic regression analysis due to their binomial nature.

Table 2.4 Spray schedule for trial No. 2

Spray threshold DSV	Week/Date																		
	0P	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	1/04/2005	8/04/2005	15/04/2005	22/04/2005	29/04/2005	6/05/2005	13/05/2005	20/05/2005	27/05/2005	3/06/2005	10/06/2005	17/06/2005	24/06/2005	1/07/2005	8/07/2005	15/07/2005	22/07/2005	29/07/2005	8/08/2005
Weekly	B	HKM	B	HKM	B	HKM	B	HKM	B	HKM	B	HKM	B	HKM	B	B	HKM	B	-
10	B	-	B	-	-	-	B	-	-	-	-	-	-	-	-	-	-	-	-
			16 Apr				13 Apr												
12	B	-	B	-	-	-	-	-	-	-	B	-	-	-	-	-	-	-	-
			18 Apr								11 Jun								
15	B	-	-	B	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
				25 Apr															
20	B	-	-	-	-	-	B	-	-	-	-	-	-	-	-	-	-	-	-
							13 Apr												
20 Std	B	-	-	-	-	-	HKM	-	-	-	-	-	-	-	-	-	-	-	-
							13 Apr												
B/S	B	S	-	-	-	S	-	-	-	-	S	-	B	-	B	B	B	B	-
													27 Jun						

The trial was assessed for incidence and severity of late blight weekly up to and including week 10, then at week 15 (14/07/2005). Yield was assessed at week 18 (5/08/2005).

DSV, Disease severity value; P, planted; H, Hortiwett™; K, cupric hydroxide; M, mancozeb; B, chlorothalonil; S, difenoconazole; -, no treatment; Std, industry standard treatment consisting of Hortiwett™, mancozeb and cupric hydroxide.

2.3 Results

2.3.1 Field Trial No. 1

Late blight was first observed in the trial on 23/02/2005 (week 6). Up to the first appearance of late blight at week 6, 6 weekly sprays were as effective in controlling the disease as 3, 2, or one sprays applied by the TomCast model spray thresholds of 15, 20 and 25 DSV's, respectively (Fig 2.1, Table 2.5). The weekly spray schedule of mancozeb + copper hydroxide + Hortiwett™ alternated with chlorothalonil showed the lowest incidence and severity of late blight throughout the trial (Table 2.5). After week 6 spraying on the predictions of the TomCast spray thresholds, with the industry standard spray program, did not control late blight. Due to high disease pressure the trial was abandoned at week 11 (23/03/2005).

Fig 2.1 Mean incidence of late blight as the crop ages, Trial No.1, Summer 2005

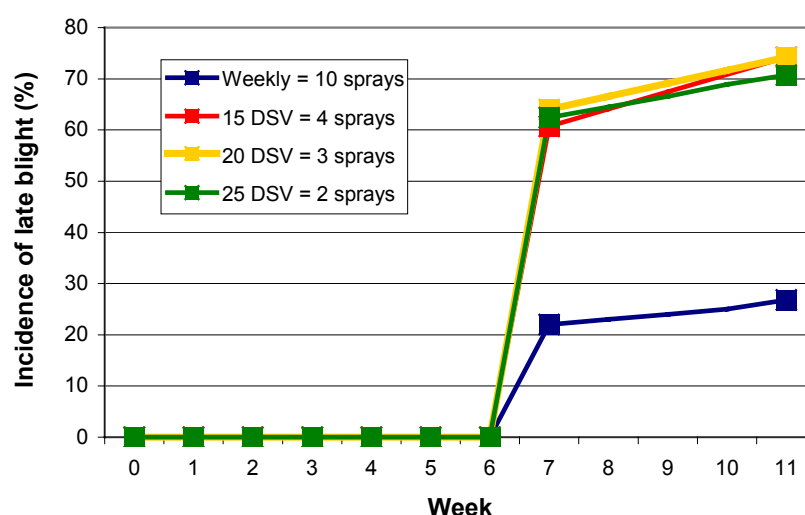


Table 2.5 Effect of spray thresholds on incidence and severity of late blight in celery trial No. 1, Summer 2005

Spray threshold	Week 7 ((25/02/2005)			Week 11 (23/03/2005)		
	Mean incidence (%)	Mean severity	No. sprays	Mean Incidence (%)	Mean severity	No. sprays
Weekly	22.0 a	0.22 a	6	26.8 a	0.32 a	10
15 DSVs	60.7 b	1.41 b	3	74.2 b	2.98 c	4
20 DSVs	64.0 b	1.79 c	2	74.2 b	3.18 d	3
25 DSVs	62.4 b	1.74 bc	1	70.7 b	2.81 b	2
l.sd	7.48	0.350		6.59	0.1324	

Mean numbers followed by the same letter do not differ significantly at the 5% level.

2.3.2 Field Trial No. 2

Late blight first appeared in the trial at week 10 (3/06/2005) (Fig 2.2). Up to week 9, 9 weekly sprays of the industry spray program controlled late blight as effectively as one or two sprays of chlorothalonil applied by the TomCast model spray thresholds of 10, 12, 15 and 20 DSVs.

At week 10 the weekly spray program had the lowest incidence and severity of late blight, but did not differ significantly from the 20 DSVs HKM and B/S treatments with 2 and 3 sprays respectively. When the industry spray program of mancozeb + cupric hydroxide + Hortiwett™ (20 DSV HKM) was compared with chlorothalonil at a spray threshold of 20 DSVs there was no significant difference in either control of late blight or yield of celery (Fig 2.2, Table 2.6).

By week 15 foliage symptoms of late blight were significantly lower in the weekly and B/S treatments compared with other treatments, which was reflected in significantly higher yields at week 18 (Fig 2.3, Table 2.6). The B/S spray program, which included the systemic fungicide, had half the number of sprays as the weekly spray program. The 12 DSV treatment produced the significantly highest marketable yield of all the TomCast spray thresholds.

Fig 2.2 Mean incidence of late blight as the crop ages Trial No. 2, winter 2005

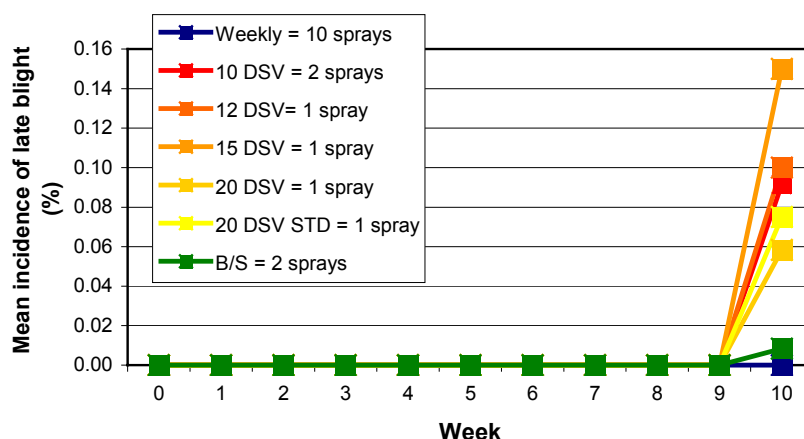


Fig 2.3 Mean incidence of late blight as the crop ages in Trial No. 2 winter 2005

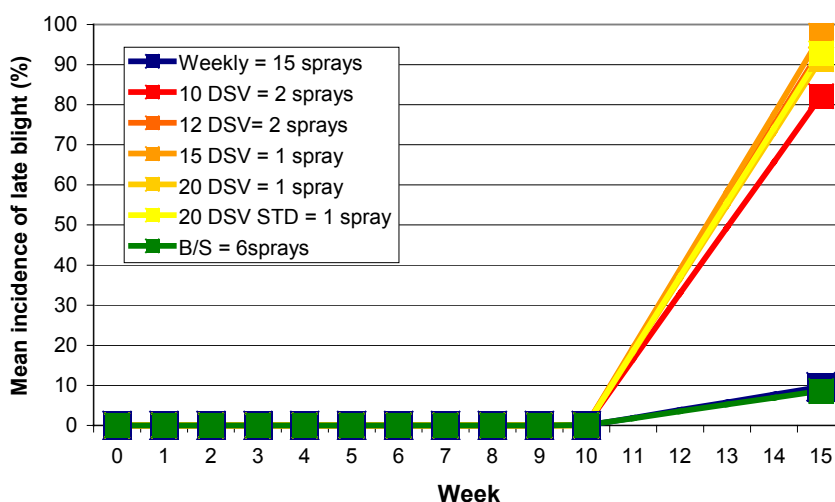


Table 2.6 Effect of spray schedules on incidence and severity of late blight in celery trial No. 2 winter 2005

Spray threshold	Week 10 (8/06/2005)					Week 15 (14/07/2005)				Week 18 (5/08/2005)		
	Log mean incidence	Mean incidence (%) ^A	Log mean severity	Mean severity ^A	No. sprays	Mean incidence (%)	Log mean severity	Mean severity ^A	No. sprays	Mean marketable yield (%)	Marketable Yield (t/ha)	No. Sprays
Weekly	-5.56	0.11 a	-7.948	0.02 a	9	9.65 a	-5.14	0.005 a	15	100 a	81.75	17
10 DSVs	-3.74	1.89 bc	-5.549	0.34 bc	2	82.15 b	-0.75	0.473 b	2	38.58 c	31.02	2
12 DSVs	-3.26	3.34 c	-4.634	0.92 c	1	93.89 b	-0.68	0.506 bc	2	64.76 b	52.07	2
15 DSVs	-3.06	4.21 c	-4.413	1.16 d	1	97.21 b	0.28	1.318 c	1	18.50 c	14.88	1
20 DSVs	-3.15	3.78 c	-4.769	0.80 c	1	91.40 b	-0.58	0.559 bc	1	34.78 c	27.97	1
20 DSVs HKM	-4.48	0.64 abc	-6.573	0.09 abc	2	92.79 b	-0.21	0.814 bc	1	29.37 c	23.61	1
S/B	-4.87	0.27 ab	-7.163	0.03 abc	3	8.63 a	-5.48	0.004 a	6	98.35 a	79.08	8
lsd	1.474		1.988				1.003			21.15		

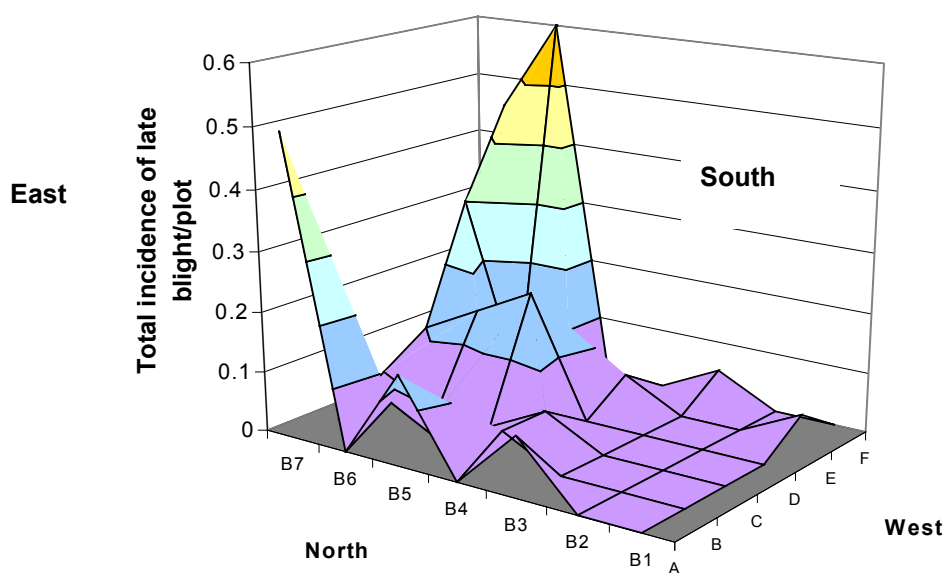
^A, data on original scale; DSV, diseases severity value; H, HortiwettTM; K, cupric hydroxide; M, mancozeb; B, chlorothalonil; S, difenoconazole.

Mean numbers followed by the same letter do not differ significantly at the 5% level.

2.3.2.1 Spread of incidence of late blight across trial No. 2

It was apparent when assessing trial No. 2 that the eastern side of the trial had less late blight than the western side of the trial (Fig 2.4). The eastern side of the trial was adjacent to the ploughed in, abandoned trial No. 1. The south eastern 3 rows were across a track from a crop of seed celery with symptoms of late blight.

Fig 2.4 Three dimensional view of the total incidence (%) of late blight and position in Trial No. 2 at week 10, winter 2005



B1-B7, replicated blocks 1 to 7; A-E, treatments within blocks.
Note incidence of lat blight is on one side of the trial site.

2.3.2.2 Spread of late blight within plots of trial No. 2

At week 10 symptoms of late blight appeared on a group of plants in either the east or west side of the celery beds, but it rarely occurred on plants in both rows of the bed (Table 2.7). Often one plant had a higher severity rating than adjacent plants in the row and it appeared that the disease could have started on one plant and moved to adjacent plants as the canopy closed along the row (Fig 2.5). In a few instances plants on both side of the bed showed symptoms of late blight (Table 2.7). It is possible that the disease spread across rows as the canopy commenced to close at week 10 (Fig 2.6).

Table 2.7 Emergence of late blight in trial No. 2 plots

Plant position	No. times late blight occurred in a plot (%)
East side of bed only	21.4
West side of bed only	11.9
Both sides of the bed	0.7
Neither side of bed	59.5

Fig 2.5 Mean severity of late blight on plants in a 20 DSV plot, east v/s west side of the bed at 10 weeks, trial No. 2, winter 2005

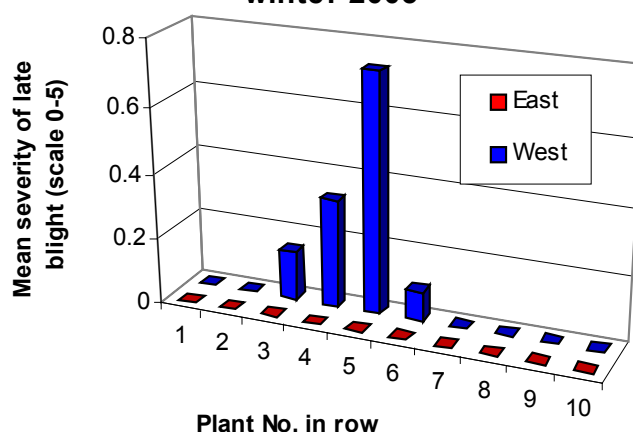
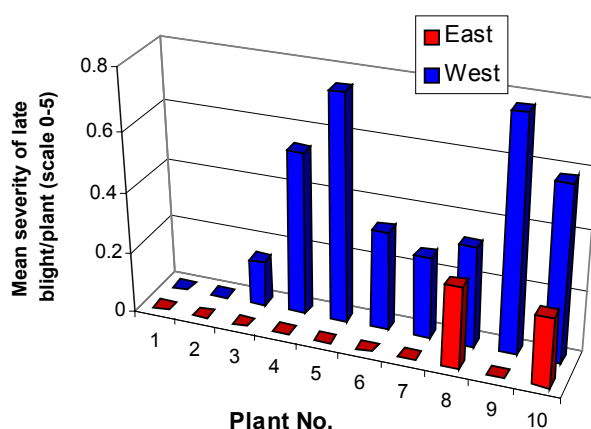


Fig 6 Mean seveeity of late blight on plants in a 10 DSV plot, east v/s west side of the bed at week 10 trial No.2 winter 2005



2.4 Discussion

2.4.1 Model evaluations

Reductions of the number of sprays applied to control late blight are achievable using a TomCast threshold of 20 DSVs in winter grown crops and 25 DSVs in summer grown crops, in the early stages of crop growth prior to canopy closure. Beyond canopy closure none of the TomCast thresholds trialed were effective. The best treatments from canopy closure onwards were the weekly spray program or the B/S treatment. It is possible that TomCast could be used to time fungicide sprays up to canopy closure, then apply a systemic fungicide to remove any *Septoria* infections, followed by weekly sprays of the industry standard spray program or chlorothalonil, but verification is required with field trials. The biggest reductions in sprays can be made in winter grown crops.

The trials reported here in achieved reductions of 3-5 sprays at week 6 in summer and 7-8 sprays at week 9 in winter during the early stages of crop growth. Beyond this period, when the canopy starts to close over, TomCast thresholds of 15, 20 and 25 DSVs in summer and 10, 12, 15 and 20 DSVs in winter had no efficacy in controlling late blight. Factors contributing to the model's lack of performance after canopy closure may be:

- (i) Poor cover of crop with the fungicides applied by the knapsack sprayer,
- (ii) The need for a systemic fungicide with curative activity, if the disease is observed in the crop,
- (iii) Another unknown microclimate factor influencing late blight infections,
- (iv) A lower initial temperature in the TomCast model to trigger DSV scoring.
- (v) Placement of the temperature sensor on the irrigation line rather than in the crop,
- (vi) An additional model based on 'infection' to complement the TomCast model, which is based on spore formation (sporulation).

It has long been recognised that it is easier to control late blight in young crops than older celery crops (Chupp and Sherf, 1960; Walker, 1952). Late blight can appear in crops 30 days after transplanting, but more frequently at 40-60 days (Mudita and Kushalappa, 1993). Our trials indicated that up to 7-8 sprays could be saved prior to canopy closure, which is considerably greater than the 1-2 sprays of Mudita and Kushalappa (1993), or the one spray of Reitz et al, (1999) but fewer than the 9-12 sprays of Bolkan and Reinet (1994). Overseas research using predictive models to time fungicide sprays does not state where in the crop's life the savings on fungicide sprays occurred (Mudita and Kushalappa, 1993; Lacy, 1994; Lacy et al, 1996; Reitz et al, 1999). Although Mudita and Kushalappa (1993) appear to have recognised the importance of the initial stage of infection for commencing spraying, their use of a contact fungicide only, would not control a polycyclic disease once it was established in the crop. The apparently slow appearance of the disease in the early stages of the crop's life in our trials suggests it is a window of opportunity to reduce sprays.

In the US thresholds trialed for late blight were 30 DSVs at transplanting reducing to 20 DSVs at canopy closure (Reitz et al, 1999). A 20 DSV threshold was suggested by Phillip (2005), while Bolkan and Reinet (1994) reported 35 DSVs reducing to 20 DSVs for tomato and carrot crops but did not state the threshold for late blight in celery. The Australian trials found similar thresholds to those used in the US were useful in the early stage of crop growth. In our summer trial (trial No. 1), 2 sprays applied with 25 DSVs were as effective as 6 weekly sprays, whilst in the winter trials (trial No. 2), one spray at 20 DSVs was as effective as 9 weekly sprays. It is possible that our DSVs could be higher in the early stages of crop growth, or in fact may not be needed at all during this period. However, omitting fungicide sprays in the early stage of crop growth may increase their susceptibility to early blight caused by *Cercospora apii* and bacterial blight caused by *Pseudomonas syringae* pv *apii*.

In our winter trial the TomCast model predicted few sprays beyond canopy closure, largely due to temperatures below 13 °C. Mathieu and Kushalappa (1993) reported symptom development of late blight at temperatures of 10°C with 12 hours of leaf wetness. If the initial temperature range in the TomCast model was 10-17 °C rather than 13-17 °C (Table 2.1), then more spray thresholds would have been predicted and better control of late blight beyond canopy closure may have been achieved.

Carry over of inoculum in crop debris, spread by splash dispersal from adjacent infected crops and from plant to plant is well-recognised (Sutton and Waterston, 1966; Fritt et al, 1989; Chupp and Sherf, 1960). There is evidence from trial No.2 that this may have contributed to a higher disease pressure than would normally have existed, thus providing excellent conditions for evaluating a disease predictive model.

2.4.2 Chemicals

Where predictive models have been validated in the field the fungicide sprayed was usually the contact fungicide, chlorothalonil (Lacy, 1994; Phillips, 2005; Mudita and Kushalappa, 1993). The problem with using contact fungicides with disease predictive models is that infection may take place prior to fungicide application. The contact fungicides do not penetrate into the leaves and have no curative activity.

Reitz et al (1999) sprayed a combination of chlorothalonil and the systemic fungicides benomyl (Benlate), 2,6 dichloro-orthoaniline (Dichloran), or propiconazole (Tilt). In Australia benomyl is no longer considered effective due to fungicide resistance issues and no longer available, while 2,6 dichloro-orthoaniline has been withdrawn from sale, possibly due to residue problems. Propiconazole is registered for late blight in Australia but growers report phytotoxicity problems in the form of leathery leaves (Tim Harslett pers. comm.). A combination of 3 sprays of difenoconazole (Score), a systemic DMI fungicide similar to propiconazole, and 6 of chlorothalonil produced the same marketable yield as 18 weekly sprays of contact fungicides (trial No.2). It is probable that 2 of the Score sprays, applied when no symptoms were observed and well before canopy closure, were unnecessary.

2.4.3 Issues with disease predictive models

It is imperative sprays are applied at the time thresholds are reached or just before as spraying them later can lead to higher levels of disease. In trial No.2 a 15 DSV was predicted but no sprays could be applied due to rainfall. By the time spraying took place a higher threshold had been reached. As a consequence the mean severity of late blight at week 10 was significantly higher for 15 DAV's (1.16d) compared with 20 DSV's (0.80c). The 15 DSV also had a higher mean incidence of late blight at 10 and 15 weeks and a higher severity and lower mean marketable yield at 18 weeks compared with the 20 DSV, although differences were not significant.

One of the issues associated with disease predictive models is their prediction of sporulation or infection based on historical data even though it is 12-24 hr old microclimate data. By the time the meteorological data is fed into the model the fungal pathogen could already have sporulated or infected the crop. The accuracy of models could be improved by incorporating predicted microclimate or meteorological data into a model. If TomCast thresholds are used to time fungicide sprays for late blight then a 'watch' should be kept on the forecasted weather. If heavy rain is forecast near a threshold then a spray should be applied. Pitblado (1992) reported growers would spray for processing tomato diseases before the threshold was reached. If a spray is missed due to weather, then a systemic with curative activity will be necessary to clear up any infections, which may have established.

Another problem with disease predictive models is they can also overestimate sporulation or infection events, as they assume a source of disease is already present in the crop. Given the experience of trial No. 2, where previous and adjacent crops appear to have influenced disease levels and the work of Mudita and Kushalappa (1993), this may not be an issue for late blight.

2.4.4 Future Directions

The TomCast model has the potential to reduce fungicide sprays for controlling late blight in celery crops. It now requires validation in commercial crops in different growing regions in Australia. Possible areas of future research are:

- (i) Investigate whether the use of the TomCast model till canopy closure, application of a systemic fungicide, followed by either weekly contact fungicide applications or lower threshold sprays of 10 or 12 DSVs; is as effective as weekly spraying throughout.
- (ii) Use of a higher range of DSV thresholds in the early stages of crop growth.
- (iii) Evaluate a lower temperature range, e.g. 5°C or 10°C - 17°C, in the first 'Mean temperature' category of the TomCast model.
- (iv) Evaluate Lacy's (1994) model of 12 hr leaf wetness.
- (v) Evaluate the infection model of Mathieu and Kushalappa (1993).

2.5 References

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Chapter 3

Economic analysis of trial 2 of the TomCast disease predictive model for reducing the number of fungicide sprays used to control late blight on celery

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Summary

This chapter reports on an economic analysis which appraised the cost effectiveness of the TomCast disease predictive model for late blight to reduce sprays without compromising yield or quality. At this stage use of the model would be economical in the early state of crop growth but not beyond. Based on work in chapter 2, a hypothetical ‘Optimum Treatment’ was proposed which if validated by field trials would be cost effective.

3.1 Introduction

This chapter reports an economic analysis of a trial (trial No. 2) carried out at a site on Campbells Road, Clyde, Victoria, from 31 March 2005 until harvesting in August, 18 weeks after planting. Details about the trial have been discussed in Chapter 2, trial No.2. The approach used was to calculate the net benefits of the treatments used 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 application for controlling late blight, and changes in harvesting and packaging costs. All other variable costs such as the costs of tillage and bedding, herbicide for controlling weeds, fertiliser, labour and any other variable costs for growing celery, will be the same for the control (weekly) and the treatments. The only change in overhead costs will be extra expenses associated with using a weather station for all treatments other than the control, which relies on weekly sprays to control late blight in celery. Income at the farm gate will differ too, and will be dependent on changes in yield, since a price of 58 cents per kilogram of celery sold was assumed for the trial.

Having analysed the contributions to profitability for the results of trial 2, the next task was to devise a hypothetical control program termed the ‘Optimum Treatment’ that would involve the use of a weather station to bring about a minimisation in the use of fungicide sprays for controlling late blight in celery and provide a contribution to total farm profitability which would be similar to that of using weekly sprays. An additional benefit in using the ‘Optimum Treatment’ would be that labour previously utilised for carrying out spraying could be released for carrying out other profitable tasks on the farm.

3.2 An economic analysis of various treatments to minimise the incidence of late blight in winter grown celery

3.2.1 Spray program and cost of chemicals for minimising the incidence of late blight

Table 2.4 (Chapter 2) shows the spray program for trial No. 2. Table 3.2 and Table 3.3 show the costs per ha of the chemicals used for the various treatments. Table 3.4 reveals the costs per ha of the chemicals and their application and assumes a cost for spraying of \$12.00 per ha. Note that Tilt™ is included in Table 3.2 because it was included in the Optimum Treatment referred to later in this paper.

Table 3.2 Cost of chemicals for treatments to reduce the incidence of late blight in celery

Trade name	Active ingredient	Rate of application per ha	Cost of chemical per unit	Cost of chemical per ha
Barrack720 [®]	Chlorothalonil	1.8 L	\$24.50/L	\$44.10
Mancozeb DF [®]	Mancozeb	2.00 kg	\$18.00/kg	\$36.00
Kocide [®]	Cupric hydroxide	2.00 kg	\$13.25/kg	\$26.50
Hortiwett [™]	Alkylaryl polyglycol ether	250 ml	\$12.60/L	\$3.15
Score	Difencconazole	250 ml	\$153.00L	\$38.25
Tilt [®]	Propiconazole	500 ml	\$81.00L	\$40.5

Table 3.4 shows the extra cost per ha of using the weather station on all treatments except the control (weekly spraying). The table assumes that the capital cost of the weather station that could be used for 5 ha's 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.

The extra average depreciation per ha for one ha of celery would be \$50 per ha which was the same value as the extra opportunity cost per ha at an after tax interest rate of 20 percent per annum.

Table 3.5 reveals the contributions to profitability per ha for the weekly (control) and the various treatments which are comprised of their farm gate incomes less variable costs and less the extra overhead costs of owning the weather station.

Notice that in Table 3.5, the income per ha for the 10 DSVs, 15 DSVs, 20 DSVs, and 20 DSVs + HKM are all the same. This was because statistical analysis of the data showed there was no difference between their yields per ha.

From Table 3.5, the economic analysis of the results for trial No. 2 showed that the Score/Barrack treatment produced the highest contribution to profitability. The second greatest contribution to profitability was the weekly (control) spray program followed by the 12 DSVs treatment with the remaining treatments scoring a ranking of equal 4th best.

Table 3.3 Cost per ha of treatments to reduce the incidence of late blight

Treatment	Chemicals	Number of applications	Cost per application ^a (\$/ha)	Total cost os application (\$/ha)	Cost of chemical per application (\$/ha)	Total cost of chemicals ^c (\$/ha)	Total cost of treatment ^d (\$/ha)
Weekly (control)	Barrack	10	12	120	44.10	441.00	1,182.20
	Mancozeb ^b	8			36.00	288.00	
	Kocide ^b	8	12	96	26.50	212.00	
	Hortiwett ^b	8			3.15	25.20	
10 DSVs	Barrack	3	12	36	44.10	132.30	168.30
12 DSVs	Barrack	3	12	36	44.10	132.30	168.30
15 DSVs	Barrack	2	12	24	44.10	88.20	112.20
20 DSVs	Barrack	2	12	24	44.10	88.20	112.20
20+HKM	Barrack	1	12	12	44.10	44.10	133.75
	Mancozeb ^b	1			36.00	36.00	
	Kocide ^b	1	12	12	26.50	26.50	
	Hortiwett ^b	1			3.15	3.15	
S/B	Barrack	6	12	72	44.10	264.60	487.35
	Score	3	12	36	38.25	114.75	
Optimum	Tilt	1	12	12	40.50	40.50	643.60
	Barrack	5	12	60	44.10	220.50	
	Mancozeb ^b	4			36.00	144.00	
	Kocide ^b	4	12	48	26.50	106.00	
	Hortiwett ^b	4			3.15	12.60	

^a, Cost @ \$12.00 per application (includes, labour, fuel etc; ^b, tank mixed chemicals; ^c, Number of applications x cost of chemical per application; ^d, Total cost of chemicals + total cost of application.

Table 3.4 Extra overhead costs of the weather station used for 5 ha's 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	2,200	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

Table 3.5 Difference in contribution to profitability per ha, difference in percentage contribution of the treatments to profitability compared to that of the control and their comparative rankings

Treatment	Total cost of applying fungicides	Yield	Harvesting	Packing	Overhead costs for weather station	Far gate income	Contribution to profitability	Difference	Ranking
	\$/ha	kg/ha	\$/ha	\$/ha	\$/ha	\$/ha	\$/ha		
Weekly ^a	1,182	71,296	5,347	2,674	0	41,352	32,149	0	2
10 DSV	168	21,604	1,620	945	100	12,530	9,696	-70%	4
12 DSV	168	46,162	3,462	1,864	100	26,774	21,179	-34%	3
15 DSV	112	21,604	1,620	945	100	12,530	9,752	-70%	4
20 DSV	112	21,604	1,620	945	100	12,530	9,752	-70%	4
20 DSV HKM	134	21,604	1,620	945	100	12,530	9,731	-70%	4
S/B	487	71,296	5,347	2,674	100	41,352	32,744	2%	1

S/B, difenoconazole/chlorothalonil (Score/Barrack); DSV, disease severity value or spray threshold; HKM, Hortiwett™, Kocide, Mancozeb;

^a, weekly = control.

3.2.2 Derivation of the ‘Optimum Treatment’

In carrying out trial No. 2, it was noted that up until the end of week 9, there were no differences in the amount of infection of late blight between the weekly sprays (control) and the various treatments. In other words, the same degree for minimising the incidence of late blight could be effected with a reduced number of spraying. However, differences began to appear after week 10 when the canopy began to close over producing environmental conditions conducive to the development of the disease. It was during the period after week 10 when greater infection of celery with late blight for the treatments significantly reduced their yield compared to that of the Control, hence reducing their values for contribution to profitability per hectare.

Consequently, it has been proposed that an ‘Optimal Treatment’ may comprise placing a weather station amongst the celery for the first 9 weeks to monitor conditions favourable for the development of the pathogens. Then at the beginning of the 10th week shifting the weather station to another planting, and continuing with weekly spraying as depicted in Table 3.1 up until the time of harvest. Table 3.6 shows the results of the ‘Optimum Treatment’ compared to that of the weekly (control) assuming that their yields would be identical.

Table 3.6 Difference in percentage contribution to profitability per ha for using the weather station for 9 weeks followed by a systemic then weekly sprays until harvest (‘Optimum Treatment’) compared to that of the weekly (control)

Treatment	Total cost of applying fungicides	Yield	Harvesting	Packing	Extra overhead costs for weather station	Farm gate income	Contribution to profitability	Percentage change in contribution to profitability
	\$/ha	kg/ha	\$/ha	\$/ha	\$/ha	\$/ha	\$/ha	
Weekly (control)	1,182	71,296	5,347	2,674	0	41,352	32,149	
Optimum	644	71,296	5,347	2,674	100	41,352	32,587	2%

3.3 Discussion and conclusions

Table 3.5 revealed that there was very little difference in the efficacy for controlling late blight in celery between the weekly (control) and the Score/Barrack treatment. However, Score is not registered for use on celery to reduce the severity of that disease. The weekly (control), however, was far superior to any of the other treatments in minimising the incidence of late blight on celery, and consequently produced a larger contribution to profitability per ha. But the number of sprays used in controlling the disease was much greater compared to those used in the various treatments.

The development of a hypothetical ‘Optimum Treatment’ based on the evidence of trial No. 2 (Table 3.6) shows the contribution to profitability would be slightly greater than that of the weekly (control) spray program, but the number of sprays would be significantly reduced (10 compared to 18). This leads to the conclusion that monitoring the environmental conditions of the celery crop using the weather station then carrying out weekly sprays could provide the best level of net benefits where profitability was maintained and the number of spray applications were greatly reduced. The hypothetical ‘Optimum Treatment’ requires trialing and validating in the field to test its feasibility.

Chapter 4

Efficacy of difenoconazole (Score) for late blight control in celery

Summary

This chapter reports on a field trial conducted under conditions of natural infection, to evaluate the efficacy of the systemic DMI triazole fungicide, difenoconazole (Score) for control of late blight of celery. Difenoconazole was effective for late blight by reducing its incidence at 11 and 16 weeks, by reducing severity at 16 weeks and increasing yield at 18 weeks.

4.1 Introduction

The fungicide spray program commonly used by Victorian celery growers for late blight control consists of cupric hydroxide + mancozeb + Hortiwett™ alternated with chlorothalonil, sprayed on a weekly schedule. A systemic fungicide (propiconazole 'Tilt', Group C, DMI) is only sprayed when disease pressure is high. Celery growers in Victoria reported that this fungicide spray program does not consistently control late blight. They require a more effective fungicide when disease pressure from late blight is high.

Currently most fungicides registered for late blight control in Australia are contact fungicides, either coppers (cupric hydroxide, copper oxychloride and melpatcoppox) or dithiocarbamates (mancozeb, propineb, thiram, ziram or zineb). At present there is only one systemic fungicide, propiconazole (Tilt, DMI), registered for late blight on celery and some growers have complained of phytotoxicity and efficacy problems. The efficacy of propiconazole for late blight control of celery was demonstrated in Australia by Wicks (1989, 1990) and elsewhere by Brunelli et al (1989), Amer et al (1993a, b) and di Marco (1987).

At the suggestion of Victorian celery growers an efficacy trial was conducted with difenoconazole (Score), another of the DMI group of fungicides. This chapter reports on the efficacy of difenoconazole for late blight control in celery.

4.2 Materials and method

4.2.1 Trial

Celery cultivar Hornet was planted two rows to a bed on 31 March 2005 at a property in Clyde, Victoria. The trial was laid out as a single column of 14 plots made up to 7 blocks each containing two plots to each of which was randomly allocated one of two treatment either a control (water) or difenoconazole, sprayed according to the schedule in Table 4.1. Refer to Table 4.2 for fungicide application rates. Application volumes were 500ml/ha for the first three sprays and 1000L/ha for the last spray. Plot dimensions were 2m long by 1.5m wide. A commercial grower maintained the trial.

Table 4.1 Spray schedule and assessment date for the difenoconazole (Score) trial

Treatment	Date or week of treatment																			
	31/3/05	1/4/05	8/4/05	15/4/05	27/4/05	29/4/05	6/5/05	13/5/05	20/5/05	27/5/05	3/6/05	10/6/05	17/6/05	24/6/05	1/7/05	8/7/05	15/7/05	22/7/05	29/7/05	8/8/05
	0	0	1	2	3	4	5	6	7	8	9	10 A	11	12	13	14	15 A	16	17	18 Y
Water (control)		B	W	-	-	-	W	-	-	-	-	W	-	-	-	-	-	-	-	-
Difenoconazole	P	B	S	-	-	-	S	-	-	-	-	S	-	-	-	-	-	-	-	-

P, Plant; B, Barrack spray; S, Score spray; W, sprayed with water; A, assessment; Y, yield assessment.

Table 4.2 Information on chemicals used in the trial

Trade name	Active ingredient	Company	Rate
Barrack 720	Chlorothalonil	CropCare (Syngenta)	180 ml/100L
Score	Difenoconazole	Syngenta	25 ml/100L

4.2.2 Assessment

On 8/6/2005 six plants on each side of the row were assessed for late blight incidence (% of plants with late blight symptoms). On 15/7/2005 three plants on each side of the row were assessed for late blight incidence and severity, on a scale of 0-5 (Table 4.3). Yield was assessed on 8/8/2005 (week 18) by the grower and rated for harvest and estimated for yield as: 'unharvestable' (0 t/ha), 'poor' (3525 t/ha), 'average' (7050 t/ha) and 'harvestable' (10574 t/ha).

Table 4.3 Scale for severity of late blight lesions on celery leaves

Scale	No. lesions/leaf
0	0
1	1-10
2	11-20
3	21-100
4	>100
5	Blight

Severity measurements for each plot were the average score over all leaves assessed. Leaves were assessed from the youngest to the oldest and were counted only from the first leaf exhibiting disease. Incidence data were analysed by logistic regression methods and the severity and yield data were analysed using the standard t-test for testing the difference between two means. Analyses were carried out using Genstat 8.1 Lawes Agricultural Trust (Rothamsted Experimental Station).

4.3 Results

Late blight first appeared in the trial at week 9 (3/06/2005). At week 11 there was no significant difference in the incidence of late blight between the difenoconazole and water treatments (Table 4.4). But by week 16 there was a highly significantly lower incidence and severity of late blight in the Score treatment compared with the water treatments. At harvest the yield for difenoconazole was significantly higher than the yield for the water treatment.

Table 4.4 Efficacy of Score to control late blight of celery

Treatment	Week 11	Week 16	Week 18	
	8/06/05	15/07/05	8/08/05	8/08/05
	Predicted ^a incidence (%)	Predicted incidence (%)	Severity (scale 0-5)	Estimated Mean Yield (t/ha)
Water	13.10	48.81	2.03	2518
Difenoconazole	9.52	17.86	0.53	6546
Level of sig.	P>0.10 ^b	P<0.01 ^c	P<0.01 ^c	P = 0.09 ^c

^a, statistically generated mean; ^b, not significantly different; ^c, significantly different

4.5 Discussion

Difenoconazole was demonstrated to be effective for late blight control. More strategic timing of applications may increase its efficacy as a preventative. It has been reported to have curative activity (Karl Riedel, pers. comm.) and this would enhance its appeal for use with the TomCast disease predictive model. Currently difenoconazole is not registered for late blight on celery. There appears to be no current references in the literature concerning the efficacy of difenoconazole for late blight of celery, although the efficacy of other DMI triazole fungicides has been demonstrated (Wicks, 1989 and 1990; Amer et al, 1993b; di Marco, 1976).

Difenoconazole and propiconazole are both Group C fungicides. Only propiconazole is currently registered for late blight control. Consequently, if difenoconazole were to be registered for late blight control in celery, it should not be used in rotation with propiconazole, as it would hinder resistance management strategies. A systemic fungicide from another activity group may be useful as an alternative to propiconazole or difenoconazole, such as carbendazim (Amer et al, 1992), which is in Group A or one of the Group K strobilurins.

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Chapter 5

Feasibility of incorporating relative humidity into the model

Summary

This chapter reports on a preliminary assessment of the feasibility of using relative humidity in the predictive model. Relative humidities of over 90% for 2 days are reported in the literature to promote disease development. These conditions are rare events under local conditions. A more appropriate modification may be lowering the temperature threshold.

5.1 Introduction

The TomCast disease predictive model (Pitblado, 1992) uses temperature and leaf wetness to forecasts outbreaks of late blight (Phillips, 2005, Reitz et al, 1999). There are also references to relative humidity influencing late blight in the field. Sheridan (1968b) found infection did not occur in the field following inoculation when the mean relative humidity was <90% for 2 days. In the laboratory spores germinated at relative humidities between 96-100% and infected celery leaves at 94.5%, but not at 80% (Sheridan, 1968a). However, Schein (1964) pointed out that a drop of 1°C at relative humidities above 90% causes dew deposition. It is highly probable that laboratory work defining the sporulation and infection characteristics of *S. apiicola* above 90%RH may be misleading and field observations may be more reliable.

This chapter reports on the examination of the relative humidity component of the meteorological field data to determine the frequency and duration of relative humidity above 90% with a view to determining the feasibility of incorporating relative humidity into the predictive model.

5.2 Materials and methods

A ModelT weather station (Western Electronics) was placed in the irrigation line of the celery crops for trials 1 and 2 (Chapter 2) to record average leaf wetness, temperature and relative humidity and total rainfall at 30 min. intervals. The leaf wetness sensor was placed in the celery crop and its height adjusted as the crops grew. The duration of the summer trial was 11 weeks, whilst that of the winter trial was 18 weeks (Table 5.1). The relative humidity component of the meteorological data was examined to determine the length of time (hrs) that relative humidity was above 90% in the summer and winter field trials (Chapter 2). Relative humidity at or above 90% was used because (i) field observations suggested 90%RH for 2 days generated infection (Sheridan, 1968a) and (ii) specific relative humidities above 90% cannot be determined reliably (Schein, 1964).

5.3 Results

Examination of the meteorological data for the period 12/12/2004 to 23/3/2005 of trial No. 1, indicated that RH did not exceeded 90% for 48hrs or longer. It was only greater than 24hrs in duration on 3 occasions (Table 5.1). In the winter trial there was only one occasion where 90%RH was exceeded for 48hrs and temperatures during this period were very low (Table 5.1).

Table 5.1 Number of times RH% exceeded 90% in four time intervals

Trial	Dates	Ranges of hours			
		No. of times RH exceeded 90% (temperature range)			
		< 24hr	24 ≤ 36hr	36 < 48hr	≥ 48hr
Summer	18/1/05 - 23/3/05	51 (6.5-22.25°C)	1 (17.0-21.0°C)	2 (10.5-20.75°C)	0
Winter	31/3/05 - 8/8/05	82 (-1.0-20.75°C)	2 (9.25-17.25)°C	1 (4.5-13.25°C)	1 (2.7-11.0°C)

5.4 Discussion

Examination of the field data indicated that long periods of relative humidity were not recorded by positioning the weather station in irrigation lines. Only on one occasion did relative humidity exceed 90% for more than 48hrs.

If the relative humidity sensor, which is attached to the logger, had been placed in the crop rather than in the irrigation line, relative humidities greater than 90% for 48hrs may have been recorded more frequently, especially in the later stages of crop production. However positioning the logger in the crop is not feasible due to farming operations. The usefulness of relative humidity under these conditions is limited. Leaf wetness has more influence on infection than relative humidity as the rate of spore germination was highest in the presence of free water (Sheridan, 1968a).

A more appropriate refinement to the TomCast model would be lowering the threshold temperature at which scoring disease severity values (DSVs) commences. Spores germinated on agar between 5-25°C with an optimum of 20-22.5°C, and on leaves between 10-30°C (Sheridan, 1968a; Mathieu and Kushalappa, 1993; Sherf and MacNab, 1986). The TomCast model, based on spore formation, commences scoring DSV's at 13°C (Pitblado, 1992). Both Lacy (1994) and Sherf and MacNab (1986) reported that temperature was seldom a limiting factor for *S. apiiicola* infection. It would be very useful to determine the lower limits for spore production and infection on celery leaves and trial incorporating this information into the TomCast model.

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Chapter 6

Technology transfer and recommendations

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- Minchinton, E.J. Model tackles sprays for celery late blight. pending.
- Minchinton, E.J., Galea, V., Thomson, F. and Nadesan, S. (2006). Evaluation of the disease predictive model TomCast for timing fungicide sprays for late blight control in celery. Abstract submitted to AUSVEG Conference, Brisbane, May 2006.

Steering committee meetings

Cranbourne and Werribee, 6 & 7 January 2005. Notes on 'Predictive model to manage Septoria in celery project'.

Cranbourne and Werribee, 2005/6 – pending.

Field days & workshops - notes.

Campbells Road Clyde 2 March 2005. Notes on 'An invitation to attend a field day on late blight control in celery'.

Celery Growers Meeting Queensland, 10 February 2006 – pending

Report to celery growers nationally – pending with Notes '.

6.2 Feedback Celery Field day, Campbells Road Clyde 2 March 2005.

by Slobodan Vujovic

T

He thinks it was a good, successful field day. Trial was in good condition, everyone could see the differences between treatments. But then again T said it is hard for him to be objective because he is familiar with the trial. Time was good, midday is the best time to see the effects of diseases. Speakers were good and clear. His only concern was that some growers did not fully understand how DSV works.

G

Field day was good and successful. Plots were good especially weekly sprays. Time for the field day wasn't an issue. G likes to see unsprayed plot in the trial just to compare the impact of chemicals. He also liked to see other chemicals used in the model, to assess their effectiveness. G is concerned about the weather station and their reliability.

P

P was impressed with the trial. Speakers were very good. He would like to see the next trial with lower DSV 10 and 12, they look more realistically to work for our area. Time is always an issue with veg growers.

K

Very satisfied with field day, and grower's response (only disappointment was that growers from Mornington Peninsula couldn't come, it was too far). E.E & Muir staff that were present think field day was successful. K thinks that field days are the best tools that the department can use to showcase its achievements. "Picture speaks better than thousand words". Next step will be to work with Syngenta towards Score[®] registration. K would like to be involved (consulted) in the planning of next trial.

DEPARTMENT OF
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Vegetable Matters of Facts

Based on research funded by the vegetable growers levy,
Horticulture Australia and the Department of Primary Industries-Victoria

Number 23
July 2005



Celery

Septoria on Celery

Control of Septoria

- Avoidance of excessive N
- Healthy seed
 - hot water 48°C for 30 min
 - 0.2% Thiram at 30°C for 24hr
 - fungicide seed treatment
- Control disease in seed bed
- Remove volunteer plants
- Some tolerance but no resistance
- One year rotation



What is Septoria late blight

Septoria leaf spot or late blight is caused by the fungus *Septoria apiicola*. It is most pronounced during extended periods of leaf wetness.

What does Septoria look like?

Initially it develops as small brown spots on older outer leaves. These spots quickly turn dark brown to black and several small lesions may join to form a larger spot. Septoria can be seed transmitted but once in the field, it can be spread by water splash (irrigation or rain), farm machinery and field workers.

Critical weather conditions for Septoria are cool misty nights, heavy dews, dull days, summer showers, autumn rains. Currently grower's management options for controlling Septoria late blight are weekly (7-day) fungicide sprays.



Know how for Horticulture™

Evaluation of a disease forecasting model to manage late blight (*Septoria*) in celery VG-04016

A 12 months scoping study is evaluating the potential of using a weather-based disease predictive model, called TomCast, to time fungicide sprays for control of *Septoria* late blight in celery. Currently DPI Victoria is conducting trials to evaluate the TomCast forecasting model for *Septoria* late blight in celery. In North America celery sprayed by the TomCast disease predictive model has resulted in the reduction of one to three sprays per crop, without loss of quality or yield.

How it works?

A weather station in the field records temperature and leaf wetness information, which is fed into the TomCast model. When a designated threshold is reached a spray is applied. Crops are sprayed only when conditions are conducive to the disease rather than on a weekly (calendar) basis.

The TomCast Model

Where the model is used to time fungicide sprays for Late Blight in commercial crops, a threshold of 20 Disease Severity Values (DSV's) are accumulated prior to commencement of spraying with chlorothalonil. The DSV's are the hours of leaf wetness in a temperature range. Daily DSV's are calculated at 1100hrs, and added till a spray threshold is reached.

Mean temperature °C	Leaf wetness periods (hr)				
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.



Weather station used to collect temperature and leaf wetness information

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Useful Websites for more information:

<http://www.ipm.ucdavis.edu/DISEASE/DATABASE/celeryblight>

<http://www.ipm.ucdavis.edu/PMG/r104100111.html>

<http://www.gov.on.ca/OMAFRA/english/crops/facts>

Check us out and view our other fact sheets at:

<http://www.dpi.vic.gov.au/agvic/ihd/projects/vchq.htm>

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Evaluation of TOMCAST a Disease Predictive Model to Reduce Sprays for Late Blight Control in Celery

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Introduction

Celery (*Apium graveolens*) is an intensively managed crop due to exceedingly high aesthetic standards and low damage tolerance. A major foliage disease of celery is late blight caused by *Septoria apiicola* (Fig. 1). Late blight can cause losses of 50–90% in commercial crops where it is managed by weekly spraying. Celery grown for Campbell's Soup Company in the USA is produced using the TomCast disease predictive model to time fungicide sprays for late blight control (Bolkan and Reinert, 1994). When TomCast indicates that conditions are conducive for late blight, a spray is applied and when conditions are not conducive for late blight, crops are not sprayed. We report on the evaluation of TomCast in two trials against the industry weekly spray program for late blight control in celery crops at Clyde, Victoria.



Fig 1. Late Blight



Fig 2. Weather station on the trial site

Materials and Methods

The TomCast disease forecasting model is based on leaf wetness and temperature (Table 1). A weather station in the crop collects temperature and leaf wetness data (Fig 2). A scale of disease severity values (DSV's) is derived from the hours of leaf wetness in a temperature range. Daily DSV's are calculated at 11.00 am and added 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 hrs beyond 11.00 am (ie to 2.00 pm), then it is included in the 11.00am calculations. When a nominated threshold is reached, an appropriate fungicide is sprayed to prevent late blight. In the USA clorothalonil is used.

Table 1 TomCast disease predictive model (Madden *et al*, 1978)

Mean temperature (°C)	Leaf wetness periods (hr)				
	0-6	7-15	16-20	22+	
13-17	0-6	7-15	16-20	22+	
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's	0	1	2	3	4

DSV's = Disease Severity Values.

0=conditions unfavourable for spore formation.

4=conditions highly favourable for spore formation.

The model was tested in two separate trials, established in January 2005 (Summer) and April 2005 (Winter) commencing at transplanting using celery cv. Hornet. In the summer trial, thresholds of 10, 15, 20 and 25 DSV's were compared to weekly sprays of mancozeb + copper + Hortiwett™ alternating with chlorothalonil (industry standard). In the winter trial thresholds of 10, 12, 15, and 20 DSV's sprayed with chlorothalonil were evaluated against weekly and 20 DSV's threshold sprays using the industry standard. A systemic fungicide, difenoconazole, was sprayed at the first appearance of disease; then there after weekly or fortnightly sprays of chlorothalonil (B/S) were applied.

Results

Summer Trial:

Late blight first appeared at week 7. Up to week 7 the TomCast model could save 50-80% of sprays (3, 4 or 5 sprays) for late blight control (Fig. 3). At week 7 and onwards the weekly spray program was the most effective for late blight control.

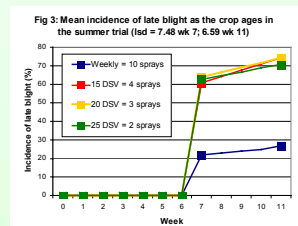
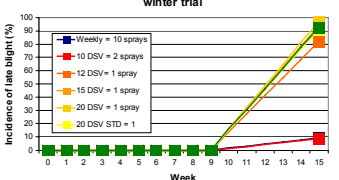


Fig 3 Mean incidence of late blight as the crop ages in the winter trial



Winter Trial:

Late blight first appeared at week 9. Up to week 9 the TomCast model could save 75%-88% of sprays (6 or 7 sprays). In the later stages of crop growth the industry standard and difenoconazole had the best efficacy to control late blight (Fig. 4).

Discussion

The TomCast model was most useful in the early stages of crop growth. When the TomCast model is used to time fungicide applications a crop scout should monitor celery crops as canopy closure commences. When late blight is first detected the spray schedule should either (a) change over to the industry standard spray program or (b) apply one spray of a systemic fungicide as a curative for any infections, then change over to the industry spray program.

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6.3 Recommendations

The major findings of this project were that the TomCast disease predictive model was very effective decision support tool for late blight control in celery. It has the potential to reduce fungicide sprays for the disease in the early stages of celery production prior to canopy closure. Most savings on sprays were made on winter grown crops. Setting spray thresholds at 10-20 DSVs reduced 7-8 fungicide applications in winter. In summer grown crops setting spray thresholds at 15-25 DSVs reduced 3-5 fungicide applications. At present the model is not suited to later stages of growth and further research should be largely directed in this area.

Possible areas of future research are:

- (i) Investigate whether the use of the TomCast model till canopy closure, application of a systemic fungicide, followed by either weekly contact fungicide applications or lower threshold sprays of 10 or 12 DSVs; is as effective as weekly spraying throughout.
- (ii) Use of a higher range of DSV thresholds in the early stages of crop growth and lower DSV thresholds at canopy closure.
- (iii) Application of fungicides with a commercial air-assist spray rig to enhance fungicide coverage.
- (iv) Evaluate lower temperature thresholds for *S. apiicola* sporulation and infection of celery, e.g. 5°C to 10°C and incorporated these parameters into TomCast model to the trigger the first 'Mean temperature' category of the model.
- (v) Evaluate Lacy's (1994) model of 12 hr leaf wetness.
- (vi) Evaluate the infection model of Mathieu and Kushalappa (1993), as it employed a lower temperature threshold to trigger spraying.
- (vii) Determine the efficacy, curative activity and residue status of alternative systemic fungicides to propiconazole and difenoconazole (Group C) such as carbendazim (Group A) or one of the strobilurins (GroupK) to prolong the effectiveness of the Group C fungicides and enhance the late blight control options especially when using the TomCast model.
- (viii) Validate the computer version of the model.
- (ix) Validate the model in commercial crops in different growing regions in Australia.

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