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Extension of an integrated management strategy for celery mosaic virus in celery crops in Western Australia

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Agriculture Western Australia

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HAL Project VG01017 - Extension of an integrated management strategy for celery mosaic virus in celery crops in Western Australia

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Media Summary

Celery mosaic virus (CeMV) causes a serious disease of celery world wide. The virus is transmitted by aphids causing symptoms of plant stunting, severe vein clearing and leaf up curling in celery plants. Shelf life is reduced and both yield and quality impaired. All currently grown varieties of celery are susceptible. Build up and spread of CeMV infection is favoured by continuous cropping all year round. The sowing of new crops next to old infected ones favours rapid spread of CeMV infection from old to new plantings and gradual build up of infection levels over time. The situation is made worse were different celery growers properties are in close proximity to one another.

CeMV was first confirmed infecting celery in Western Australia in 1997. In subsequent years the virus was introduced onto the majority of celery growers properties in the Perth metropolitan area. Properties with recent infection only showed low levels of infection <10%. However on properties where introductions of virus were noted two to three years ago incidences often exceed 80% in individual crops. The survival of the celery industry in WA was being severely threatened.

An action group was formed consisting of growers that were seriously affected by this disease outbreak, plant virology and extension experts from Agriculture Western Australia with the vegetable industry development officer for WA of HAL, as a facilitator. The affected growers agreed to institute a three month period completely free of celery and related crops to eliminate the virus source on their combined properties. This required that no live plant material of celery or related susceptible crops (e.g. celeraic, coriander, dill, fennel, parsley) be present on any of these properties for a period of three months. This included any new celery seedlings. Old crop residues were also to be removed and any volunteer celery plants emerging rigorously destroyed.

After the end of the celery free period, the first celery crops were transplanted on the five properties and 12 weeks later these crops were harvested. No CeMV was detected whatsoever in these crops where seven months previously incidences of CeMV were greater than 90%. Moreover, for the next year, no CeMV has been detected in celery crops in the area. It is anticipated that eventually CeMV will spread back again. When this occurs our integrated disease management strategy, should help to keep levels down while virus incidences are low. If this were to fail to keep down infection sufficiently, another celery free period would then be needed. Those localities with properties with high incidences (i.e. >10%) are recommended to adopt a celery free period. Those with low incidences should use the integrated disease management strategy for CeMV to minimise spread which includes: introducing only healthy transplants; avoiding spread from finished crops; avoiding spread from nearby crops; manipulating planting dates; using roguing within crops; minimising spread from Apiaceous weeds or volunteer celery; employing barrier and inter-row crops; and using crop rotation.

Technology transfer strategy and methodology/activities

Farmnote

A factsheet was written for local celery growers which described the virus and symptoms it causes in celery, how the virus spreads and what growers can do to control the disease. This factsheet was either hand delivered or posted to all leafy vegetable growers in WA through the Vegetable Industry Development Officer mailout system.

Website

The CeMV fact sheet has been available on the DAWA web site since late last year and can be accessed on http://www.agric.wa.gov.au and located by searching for information on celery.

Workshops

Three workshops were held for growers over the duration of the project.

Two introductory workshops were held early in the phase of the project to inform growers both north and south of the Perth metropolitan area of the current project. The meeting north of the river was well attended by over 20 growers, horticultural industry representatives and Department of Agriculture Vegetable Advisors. The meeting south of the river was less well attended however this reflects the smaller proportion of growers in this area. The meetings were facilitated by David Ellement (WA Vegetable Industry Development Officer) and presentations were given by Lindrea Latham (Project Leader), Roger Jones (Principal Plant Virologist DAWA) and Frank Borgogno (local grower with personal experiences of CeMV in his celery crop). There was also an opportunity within the meetings for general discussions amongst the growers, industry representatives, advisors and researchers. Upon arrival growers were provided with a copy of the CeMV fact sheet and other general agronomic information pertaining to the culture of celery in Western Australia. All growers who where unable to make it to the evening meetings were sent a copy of the CeMV fact sheet and a covering letter detailing the contents of the meeting.

Lindrea Latham presented information on:
Celery Mosaic Virus: What is it? Where does it come from? How much is there of it? What can it do to your profitability? What can you do about it?

Roger Jones presented information on:
Control of Celery Mosaic Virus 'Dispersing the myth that spraying to control aphids can control celery mosaic virus'

Frank Borgogno spoke on hands on experience with managing a devastating outbreak of celery mosaic virus and the success of introducing a celery free period

The final workshop was held in conjunction with the of the National Vegetable Pathology Working Group (NVPWG) meeting (VG01018). An evening meeting was held in late May where the final findings of the project were disseminated to growers. Growers were invited from both north and south of Perth and approximately 40 growers attended plus industry representatives. Also present were approximately 20 delegates from the NVPWG meeting including state IDO's and national vegetable pathology researchers. Growers were again informed about the disease and components of an integrated disease strategy for when disease incidence is low and the usefulness of a celery free period when disease incidence is greater than 10%.

Refereed Scientific Journal Articles (See Appendix A)

Latham LJ, and Jones RAC (2003) Incidence of *Celery mosaic virus* in celery crops in south-west Australia and its management. *Australasian Plant Pathology* (submitted)

Extension articles – (See appendix B)

Latham L. (2001) Celery mosaic virus. *Leafy Crops Newsletter* Vol 1 No2. pp.6

Latham LJ and Jones RAC (2001) Managing the CeMV threat. *Good Fruit and Vegetables* Vol. 11 No. 11 p. 46.

Latham L and Jones RAC (2001) A success story in vegetable disease control. *Ag Brief* 11, 3

Latham L.(2001) Control of celery mosaic virus in celery: A success story. *Leafy Crops Newsletter* Vol 1 No3. pp.3

Latham L, Jones R (2001) Celery Mosaic Virus. *Fact Sheet. Agriculture Western Australia* No.15

Latham L (2001) Virus-free celery brings returns. *Good Fruit and Vegetables* 12 (5): 43.

Conference abstracts – (see Appendix B)

Latham LJ, Jones RAC (2001) Control of celery mosaic virus: a success story. In *Contributed Papers Horticulture Program Leading today, shaping tomorrow. Biennial Conference* Mandurah Quays Resort, WA 18-19 September 2001 p22

Latham LJ, Jones RAC (2001) Survey of celery crops and alternative hosts for celery mosaic virus. In *Contributed Papers Horticulture Program Leading today, shaping tomorrow. Biennial Conference* Mandurah Quays Resort, WA 18-19 September 2001 p23-4

Evaluation and measurement of outcomes – impact and adoption

Farmnote

The factsheet was designed in an easy to use format for celery growers. It was written in laymans terms that could be easily understood. It also contained pictures that could be used to easily identify the symptoms of CeMV in celery crops. It clearly set out control measures available to growers and when the different strategies should be adopted.

The fact sheet along with a covering letter was mailed out through the vegetable industry development officer to all known celery growers in Western Australia. We had minimal feed back from growers on the fact sheet but every grower was contacted and had access to the information if required.

Website

The fact sheet was also placed onto the Department of Agriculture web site. This is allows growers with access to the internet to access the current information available on CeMV control at anytime. Approximately 15% of vegetable growers in Western Australia currently have access to the internet and retrieve information through this system. The numbers are increasing steadily and it is an area of huge future growth and rapid dissemination of up to date information.

Workshops

The workshops provide an ideal environment for researchers, industry representatives and researchers to interact in a semi-formal environment. The two workshops at the commencement of the project were organised to be central to celery growing areas so that growers did not have far to travel. Monday evenings were found to be a good time for growers as they have finished daylight work commitments and often have this night free. Early evening is also a good time if food is provided.

The workshop in the northern metropolitan area attracted about 20 growers and in the southern area six growers. These turnouts reflect proportionally the number of celery growers from each area and is approximately 50% of the total number of celery growers.

The evening was introduced by David Ellement (Vegetable Industry Development Officer). Technical presentations were made by Lindrea Latham (Vegetable Virologist, Department of Agriculture) and Dr Roger Jones (Principal Virologist, Department of Agriculture). The final speaker was Frank Borgogno (local celery grower). The combination of industry representatives, researchers and growers was an excellent mix and ensured the night was a success. The technical information was given by the researchers, the link provided by David Ellement and the personal message from Frank Borgogno. Constructive question time and discussion was held as the final part of the workshop where information freely flowed.

Frank Borgogno's personal testimony of his experiences with CeMV and the adoption of a celery free period resulted in grower confidence in the likelihood of success in controlling this disease. Growers are often hesitant to share information with other growers. They do not want other growers to know they have a problem and then if they solve their problems they are often hesitant again to share information on the solution. Frank Borgogno was an exception to this rule, and his willingness to share his experiences was of great significance to the success of this project.

The final workshop was a much larger event with approximately 75 growers, researchers and industry representatives attending. It was an opportunity for growers to again listen to research findings, ask questions and share their personal experiences with CeMV. The larger group made the forum slightly more formal but after the meeting many informal beneficial discussions were made.

Celery Working group in Wanneroo

The formation of the 'Celery working Group' in Wanneroo is again a good blend of researchers, growers and a facilitator (the industry development officer, David Ellement). This group was highly effective in coming up with a solution with which suited everyone. The group agreed that the disease incidence had reached such a level that only drastic measures would stand any chance of success. The affected growers therefore all agreed to institute a three month period completely free of celery and related crops to eliminate the virus source on their combined properties. This conclusion was reached based on information from the researchers and previous experience from overseas. This required that no live plant material of celery or related susceptible crops (e.g. celeraic, coriander, dill, fennel, parsley) be present on any of their properties from the end of September to the first week of January. This included any new celery seedlings. Old crop residues were also to be removed and any volunteer celery plants emerging rigorously destroyed. After the end of the celery free period, the first celery crops were transplanted on the five properties and in early April these crops were harvested. No CeMV was detected whatsoever in these crops where seven months previously incidences of CeMV were greater than 90%. Moreover, no CeMV has been detected in celery crops in the area for the past year. It is anticipated that eventually CeMV will spread back again. When this occurs the integrated disease management strategy devised in this project should help to keep levels down while virus incidences are low. If this were to fail to keep down infection sufficiently, another celery free period would then be needed. Meanwhile, this group of growers by working together have regained their niche local and export markets and their reputations for producing high quality celery. The added bonus is that they have reduced costs and increased their profit margins by not spraying to control aphids.

Visits to growers properties

Despite the distribution of factsheets to individual growers and the success of the workshops often the most success way of informing growers of the best ways to manage virus diseases on their properties is to have 'one to one' consultations with them on their properties. Twenty five growers properties were visited and their crops surveyed for CeMV as part of this project. It was during these visits that integrated management strategies were discussed with growers and plans put into place for each individual farm. Sometimes it is as simple as showing growers early symptoms in plants, describing how the aphid vector moves through the crop, discussing planting programs to ensure that successive celery crops are not planted next to one another or explaining the importance of quickly destroying any infected plant material. The usefulness of individual consultations should not be underestimated.

Discussion

By using the available knowledge on the symptoms, spread, and distribution of CeMV in other parts of the world an effective extension program was implemented in Western Australia for the control of CeMV in celery crops. A combination of a number of strategies, including written and verbal, were used to convey to growers, the available control options for CeMV in celery crops. Growers were then assisted by researchers to make decisions on the 'best bet' management strategies for their individual properties. With growers strictly following recommendations the incidence and distribution of CeMV has been greatly reduced in celery crops in WA.

Recommendations

Celery growers with CeMV in localities with properties with high incidences (i.e. >10%) are recommended to adopt a celery free period. Those with low incidences should use the integrated disease management strategy outlined below for CeMV to minimise spread.

Integrated disease management strategy

1. Purchase healthy seedlings from virus-tested nurseries for transplanting. Alternatively, propagate directly from seed on site. This will stop infection entering with transplants from contaminated nurseries.
2. Promptly destroy finished crops with herbicide, burn, plough deeply under or harvest and remove. Action will remove a potent external source of virus infection for spread to other crops.
3. No overlapping crop sowings in close proximity or sequential plantings side by side. Employ safe planting distances from potentially infected crops. Plant upwind of potential sources. Will minimises a major external virus infection source for spread to crop.
4. Select planting dates to avoid exposure of young seedlings at their vulnerable, young growth stage to annual peak aphid populations. Diminishes infection of plants at their vulnerable young growth stage. Plants infected later are less damaged and yield more.
5. Remove all crop plants with visible virus symptoms. Most effective if removed before virus spread starts. Removes internal virus infection sources for spread to other plants.
6. Spray selective herbicides on celery crop and neighbouring crops to remove weeds. Control weeds and volunteer celery on nearby land and ensure that previous crops are sprayed with herbicide or ploughed deeply under before transplanting. Removes internal and external virus infection sources for spread to new plantings.
7. Surround celery crop with non-host barrier crop (e.g. brassica). Sow non-host inter-row crop with celery crop. Aphids landing on and probing non-host barrier and inter-row crops loose infectivity before landing on celery crop. Inter-row crops provide ground cover which decreases aphid landing rates.
8. Rotate celery and other susceptible crops with non-host crops (e.g. cabbage, cauliflower, lettuce etc.). Breaks infection cycle by removing virus source.
9. Neighbouring farms in production region cooperate to provide ‘Apiaceous crop and weed free period’ of three months for entire region. Other non-host crops can be planted during this time. Ultimate control measure is all else fails. Breaks infection cycle over entire region by removing all herbaceous growing plant sources.

Acknowledgments

Financial support for this project was provided by Horticulture Australia Limited and the Department of Agriculture, Western Australia. We also wish to acknowledge the 'Celery Growers Group' in Wanneroo and the celery growers in Western Australia who cooperated by allowing us onto their properties to collect celery samples and who willingly shared information regarding their current celery growing practices.

Appendix A – Paper submitted to Australasian Plant Pathology for consideration

Incidence of CeMV in celery crops and management strategies for sustainable cropping.

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Abstract

Surveys were done in 1997 and 2000, to determine the incidence of *Celery mosaic virus* (CeMV) in celery crops in south-west Australia. In 1997, crops growing on 4/13 farms sampled in the Perth metropolitan region were found infected and one farm had crops with infection incidences of 33-57%. By 2000, all 12 farms sampled were infected and five of them had crops with infection incidences of 43-96%. Factors that led to increased incidence of CeMV were intensive, all year round production with sequential side-by-side planting of celery crops all year round. In 2001 a 'celery free period' was instigated for 3 months on five adjoining farms where CeMV-infection incidences exceeded 80% in individual crops. No CeMV was found subsequently on these farms over a 12 month period. An integrated approach to management of CeMV in celery crops is described which can help avoid the need for control using a 'celery free period'.

Additional keywords: potyvirus, *apium virus Y*, surveys, incidence, virus reservoirs, control.

Introduction

Celery mosaic virus (CeMV) causes a damaging disease of celery *(Apium graveolens)* worldwide. It is spread by aphids in a non-persistent manner but seed transmission is not recorded. The symptoms of CeMV in celery plants include severe vein clearing of leaves, leaf up-curling, leaf chlorosis and plant stunting. Plants that become infected in the early to middle part of their growing cycle are unmarketable while plants that become infected late may be marketable but with a reduced shelf life (Shepard and Grogan 1967, 1971; Pemberton and Frost 1986; Alberts, Francki and Dietzgen 1989; Raid and Zitter 2002). Spread of CeMV is favoured by sequential overlapping side-by-side plantings of celery all year round without a cropping break and by close proximity of celery farms to one another (Latham and Jones 2001d; Raid and Zitter 2002).

In South Australia in the 1980's the celery industry was devastated by CeMV (Alberts et al. 1989) and only in recent years has started to re-emerge. In Victoria, for the past 4-5 years, celery growers have been struggling to control epidemics of CeMV in celery (Traicevski et al. 1999). The virus is also established in celery crops on the Darling Downs in Queensland (Moran et al. 2002). Although there was an early record from 1981 of a potyvirus infecting celery in the Perth metropolitan region of Western Australia (Price and McLean 1986), CeMV

was not confirmed infecting celery crops in the region until November 1997. This paper describes surveys done in 1997 and 2000 to determine the incidence of CeMV in celery crops in south-west Australia and identify factors that lead to epidemics. A successful 'celery free period' approach to CeMV control was documented for the first time in Australia. An integrated approach to managing CeMV was devised to help avoid the need for a 'celery free period'. Brief summaries of parts of this work have been reported (Latham 2001; Latham and Jones 2001a, b, c).

Materials and methods

Virus isolates and antisera

CeMV isolate WA-1 from pervious work (Latham *et al.* 2003) was maintained in plants of celery by sap inoculation. This culture of CeMV was used as a positive control in enzyme-linked immunosorbent assay (ELISA). Polyclonal antiserum to CeMV was obtained from DSMZ, GmbH, Germany and a generic monoclonal antibody specific to most potyviruses from Agdia Inc., USA.

Enzyme-linked immunosorbent assay

Celery leaf samples were extracted (1g/20mL) in phosphate buffered saline saline (10 mM potassium phosphate, 150 mM sodium chloride), pH 7.4, containing 5 mL/L of Tween 20 and 20 g/L of polyvinyl pyrrolidone and tested using CeMV antiserum by double antibody sandwich ELISA as described by Clark and Adams (1977). To detect potyvirus infection, leaf samples were extracted (1g/20mL) in carbonate buffer and tested using generic potyvirus monoclonal antibody by the antigen-coated indirect ELISA protocol of Torrance and Pead (1986). Each sample extract was tested in duplicate wells in microtitre plates and appropriate infected and healthy leaf samples were included in paired wells as controls. The substrate used was 0.6mg/mL of *p*-nitrophenyl phosphate in 100ml/L of diethanolamine, pH 9.8. Absorbance values (A_{405nm}) were measured in a Multiskan plate reader (Labsystems, Finland) and values more than twice those of healthy leaf sap were considered to represent infected plants.

Surveys

During October and November in 1997, and in November and December in 2000, large-scale surveys were done of celery and related crops growing in the Perth metropolitan region. Twenty two farms were sampled, 16 from northern and six from southern districts. For each celery crop, 100 newly emerged shoots were collected at random every five paces down several rows. At least one celery crop/farm was sampled but in both years on some farms other crops representing different times of planting and cultivars were also sampled. Also, individual samples were sometimes collected from plants with suspect symptoms. In addition in both 1997 and 2000, 700 samples were collected randomly from each of two celery seedling nurseries. Also, 200 random samples were collected from two crops on a farm at Manjimup. Parsley and dill crops, possible alternative hosts of CeMV, were sampled if present on the farms visited. Samples were taken back to the laboratory and tested by ELISA using CeMV antiserum only (1997) or both CeMV antiserum and generic potyvirus monoclonal antibody (2000). Samples were initially tested in groups of ten but when incidences were high, they were regrouped for retesting at appropriate lower levels or retested individually. Samples with virus-like symptoms were tested individually. Percentage virus incidence from grouped sample test results was estimated using the formula of Gibbs and Gower (1960).

Celery free period – case history

In 2000, five neighbouring celery growing farms at Wanneroo in the northern Perth metropolitan region, all had high incidences of CeMV infection that exceeded 80% in at least one crop per farm. One was part of the 2000 survey for CeMV but incidences at the other four were assessed visually for virus symptoms. All were suffering such severe financial problems from CeMV infection, that they were about to give up growing celery. All farmers involved agreed to institute a 3 month period completely free of celery and related crops. From the last week of September 2000 to the first week of January 2001, no live plant material of celery (including new seedlings) or related Apiaceous crops (e.g. coriander, dill, fennel, parsley) was present on any of these five farms. Old crop residues were also removed and any volunteer celery or related Apiaceous plants emerging rigorously destroyed. Weed control was thorough. At the end of this period, new celery crops grown from seedlings were transplanted. For one full year, all celery crops on these farms were monitored monthly for reappearance of CeMV. For this, all crops were observed for typical CeMV symptoms. In addition, 100 leaf samples were collected at random from one crop/farm on each visit and tested for CeMV presence by ELISA.

Results

Surveys

In 1997, celery crops on four of the thirteen farms sampled in the Perth metropolitan region were found infected with CeMV (Table 1). Only one farm in Balcatta had high infection incidences (33-57% in different crops) while the other three infected farms, all in the Wanneroo region, only had traces of CeMV infection in their crops. The celery cultivars sampled in the 1997 survey were (numbers of crops in parentheses): American Stringless (6), Excelsior (1), Tendercrisp (22), and Yarralong (1). Three of these cultivars, Tendercrisp, Excelsior and Yarralong, were infected but cv. Tendercrisp had the most severe CeMV symptoms. No CeMV was detected in any celery sample from two vegetable seedling nurseries.

Table 1. Incidence and distribution of CeMV in celery crops in the Perth metropolitan region in 1997

Farm No.	Location	Cultivar	No. of samples tested	CeMV	% infection
1	Balcatta	Tendercrisp	100	+	57
1	Balcatta	Excelsior	100	+	37
1	Balcatta	Yarralong	100	+	33
4	Wanneroo	Tendercrisp	100	+	<0.1 [a]
4	Wanneroo	Tendercrisp	100	+	<0.1 [a]
4	Wanneroo	Tendercrisp	100	+	<0.1 [a]
4	Wanneroo	Tendercrisp	100	+	<0.1 [a]
5	Wanneroo	Tendercrisp	100	+	<0.1 [a]
9	Wanneroo	Tendercrisp	100	+	<0.1 [a]
2	Wanneroo	Tendercrisp	100	-	0
2	Wanneroo	Tendercrisp	100	-	0
2	Wanneroo	Tendercrisp	100	-	0
3	Wanneroo	Tendercrisp	100	-	0
4	Wanneroo	Tendercrisp	100	-	0
6	Wanneroo	Tendercrisp	100	-	0
6	Wanneroo	Tendercrisp	100	-	0
7	Wanneroo	Tendercrisp	100	-	0
8	Wanneroo	American Stringless	100	-	0
8	Wanneroo	American Stringless	100	-	0
8	Wanneroo	American Stringless	100	-	0
9	Wanneroo	Tendercrisp	100	-	0
9	Wanneroo	Tendercrisp	100	-	0
10	Wanneroo	Tendercrisp	100	-	0
10	Wanneroo	Tendercrisp	100	-	0
10	Wanneroo	Tendercrisp	100	-	0
11	Wanneroo	American Stringless	100	-	0
11	Wanneroo	American Stringless	100	-	0
11	Wanneroo	American Stringless	100	-	0
12	Mandogalup	Tendercrisp	400	-	0
13	Mandogalup	Tendercrisp	400	-	0

[a] no virus detected in random sample of 100 shoots from different plants but symptom-affected plants found which tested positive for CeMV.

In 2000, celery plants infected with CeMV were found in crops on all of the 12 farms sampled in the Perth metropolitan region (Table 2). Infection incidences within crops ranged from <1% (approximately 50% of crops on farms visited) to 96%. On the same farm, individual crops that were about to be harvested often had CeMV incidences five fold higher than those in crops that were half way through their growing period. Two of the farms were sampled twice in 2000. Of these, one farm with no infection detected in early November 2000 had occasional plants infected with CeMV by late December. The other farm had 3% infection in a crop harvested in mid November but by mid December the infection incidence in a later planted crop was 43%. Only one of the 12 farms surveyed was among those sampled in 1997. This farm, in which CeMV was not detected then, had individual crops with up to 96% infection in 2000. The only farm at which CeMV was not detected in 2000 was in Manjimup, located 300km away from the other celery growing farms. No CeMV was found in any celery samples from the two vegetable seedling nurseries.

The celery cultivars sampled in the 2000 survey were (numbers of crops in parentheses): American Stringless (10), Tendercrisp (22), Tendercrunch (5), CEL8113 (1) and CEL8117 (1). All were susceptible as they became infected readily. CEL8117 was tolerant while the others were sensitive as they developed obvious symptoms but these were most severe in Tendercrisp and Tendercrunch. In 2000, when both a generic monoclonal potyvirus antibody and a CeMV specific polyclonal antiserum were used to test the samples, the generic potyvirus antibody failed to detect CeMV in samples from 5/24 celery crops tested.

Both parsley and dill were found infected with a potyvirus in 3/4 and 1/1 crops at three and one farms respectively but not with CeMV itself. The potyvirus in the curly parsley sample from Wattleup was later identified as Apium virus Y by Moran et al. (2002).

Celery Free Period

Although the five farms involved in the 'celery free period' all had CeMV incidences >80% in at least one crops before this period started, over one year, no CeMV whatsoever was observed or detected in any of their celery crops grown after the 'celery free period' finished.

Table 2. Incidence and distribution of CeMV and potyviruses in celery and related crops in the Perth metropolitan region in 2000

Farm No.	Location	Cultivar	No. of samples tested	poty-virus	CeMV	% infection
Apium graveolens (celery)						
3	Wanneroo	Tendercrisp	30	+	+	96 [a,b]
17	Mandogalup	Tendercrisp	60	+	+	87
17	Mandogalup	CEL 8117	60	+	+	82
17	Mandogalup	Tendercrisp	60	+	+	73
18	Mandogalup	Unknown	59	+	+	71
16	Wattleup	Tendercrisp	39	NT	+	49
18	Mandogalup	Tendercrisp	60	+	+	45
19	Baldivis	American Stringless	30	+	+	43
23	Wanneroo	Tendercrisp	30	+	+	40
16	Wattleup	Tendercrisp	40	NT	+	20
18	Mandogalup	Tendercrisp	100	+	+	15
18	Mandogalup	Tendercrisp	100	+	+	11
18	Mandogalup	Tendercrisp	100	+	+	8
18	Mandogalup	Unknown	100	+	+	6
15	Yanchep	Tendercrunch	100	-	+ [c]	4
17	Mandogalup	Tendercrisp	100	+	+	4
18	Mandogalup	Tendercrisp	100	+	+	4
22	Gin Gin	American Stringless	100	NT	+	4
19	Baldivis	CEL 8113	100	+	+	3
19	Baldivis	Tendercrisp	100	+	+	2
19	Baldivis	Tendercrisp	100	+	+	2
20	Baldivis	Tendercrisp	100	-	+ [c]	2
15	Yanchep	Tendercrunch	100	-	+ [c]	1
15	Yanchep	Tendercrunch	100	-	+ [c]	1
19	Baldivis	Tendercrisp	100	+	+	1
19	Baldivis	Tendercrisp	100	+	+	1
21	Gin Gin	Tendercrisp	100	NT	+	1
21	Gin Gin	American Stringless	100	NT	+	1
22	Gin Gin	American Stringless	100	NT	+	1
14	Yanchep	Tendercrunch	100	NT	-	(<1%) [d]
14	Yanchep	Tendercrisp	100	NT	-	(<1%) [d]
14	Yanchep	American Stringless	100	NT	-	(<1%) [d]
14	Yanchep	Tendercrisp	100	-	-	0
14	Yanchep	American Stringless	100	NT	-	0
15	Yanchep	Tendercrunch	100	-	-	0
20	Baldivis	Tendercrisp	100	-	+ [c]	0
12	Mandogalup	Tendercrisp	400	-	-	0
21	Gin Gin	American Stringless	100	NT	+	0
22	Gin Gin	American Stringless	100	NT	-	0
22	Gin Gin	American Stringless	100	NT	-	0
Anethum graveolens (dill)						
24	Wanneroo	-	4	+ [e]	-	50
Petroselinium crispum (parsley)						
24	Wanneroo	-	13	+ [e]	-	8
24	Wanneroo	-	50	+ [e]	-	2
16	Wattleup	-	18	+ [e]	-	12
12	Mandogalup	-	100	-	-	0

NT = not tested
[a] = farm previously sampled in 1997 survey.
[b] = farms involved in 'celery free period'.
[c] = CeMV not detected by generic potyvirus antibody.
[d] = no virus detected in random sample of 100 leaves but symptom-affected plants found which tested positive for CeMV.
[e] = a positive potyvirus result with no CeMV detected indicates different potyvirus is present.

Discussion

Between 1997 and 2000, the incidence of CeMV increased rapidly in celery crops grown in the Perth metropolitan region. In 1997, only one out of the 4/13 farms found infected had high crop infection incidences (33-57%). By 2000, CeMV was found in all of the 12 farms surveyed. Individual crops on the two farms north of the Swan River had reached infection incidences >80% and CeMV was detected for the first time south of the river with individual crops reaching >87% incidences on four farms. A further seven farms both north and south of the Swan River had low crop infection incidences (<4%). On one farm at which no CeMV was detected in 1997, individual crop infection levels had reached 96% by 2000. This scenario of rapidly increasing infection is cause for concern as farms with low incidences are likely to experience rapidly accelerating epidemics if appropriate control tactics are not introduced.

Although neither vegetable seedling nursery sampled was found having celery seedlings infected with CeMV, the rapid spread of this disease to most celery growing farms indicates that a central distribution point, such as a seedling nursery, may have been responsible for the initial dissemination of the virus to previously uninfected farms. CeMV is not known to be seed-borne so infection is not thought to be introduced to new locations by sowing infected seed stocks. Two alternative hosts crops of CeMV (dill and parsley) growing in close proximity to CeMV-infected celery crops were sampled as part of the survey but not found to contain CeMV, although another potyviruses was present. This finding coupled with the success of employing a 'celery free period' suggests that other Apiaceae crops and related weeds did not constitute a significant CeMV infection source for spread to celery.

Due to their outstanding agronomic characteristics, celery cvv. Tendercrisp (autumn to spring crops) and American Stringless (summer crops) are the dominant cultivars grown in south-west Australia. However, they are both very susceptible to CeMV and develop severe symptoms when infected. There are no known CeMV-resistant cultivars although CEL1187 showed some tolerance. A long term option for control is to breed celery cultivars with resistance to CeMV. Breeding for single gene resistance to CeMV in celery is underway in the USA (D'Antonio et al. 2001). However this breeding process is only in the early stages, so, over the short term, control must depend entirely on cultural or chemical measures.

During the survey visits, management practices that favoured increased incidences of CeMV in crops were found to be: sequential plantings of celery crops side by side all year round; not harvesting or removing finished celery crops that were infected with CeMV; allowing volunteer CeMV-infected celery plants to re-sprout and grow near to new plantings; planting out vulnerable young seedlings at peak annual aphid population times of the year; and not roguing out plants with CeMV symptoms rigorously within crops. Based on this understanding of the epidemiology of CeMV, an integrated disease management strategy was devised for crop situations with low CeMV incidences (<10%) (Table 3). It consisted of introducing only healthy celery transplants; avoiding CeMV spread from finished or nearby crops; manipulating planting date to avoid exposure of young plants at peak annual aphid population times; roguing out symptom-affected celery plants from within crops; minimising possible spread from Apiaceous weeds or volunteer celery; sowing barrier or inter-row non-host crops; and using crop rotation with non-host crops. Although the individual component measures may only give small reductions in incidence when used on their own, if used correctly and together, their effects are complimentary providing a substantial level of control. Although judicious use of herbicides against volunteer celery and weed hosts is included, this strategy is environmentally responsible and sustainable, as it does not rely on insecticides to

Table 3 Integrated management strategies to minimise infection with celery mosaic virus in celery

Measure	How achieved	Mode of action	Ease of adoption for growers
Introduce only healthy transplants	Purchase seedlings for transplanting from virus-tested nurseries. Alternatively, propagate directly from seed on site.	Avoids infection entering with transplants from contaminated nurseries.	Difficult
Avoid spread from finished crops	Promptly destroy finished celery crop with herbicide, burn, plough deeply under or harvest and remove	Removes a potent external source of virus infection source for spread to other crops.	Easy
Use roguing within crop	Remove all crop plants with visible virus symptoms. Most effective if removed before virus spread starts.	Removes internal virus infection source for spread to other plants.	Easy
Avoid spread from nearby crops	No overlapping celery crop sowings in close proximity or sequential plantings side by side. Employ safe planting distances from potentially infected crops. Plant upwind of potential sources	Minimises a major external source of virus infection source for spread to crop	Easy
Minimise spread from weeds or volunteer celery	Spray selective herbicides on target crop and neighbouring crops to remove weeds and crop volunteers. Control weeds and volunteer celery on nearby land and ensure that previous crops are sprayed with herbicide or deep ploughed before re-transplanting celery seedlings.	Removes internal and external virus infection source for spread to new plantings	Easy
Manipulate planting date	Select planting dates to avoid exposure of young celery seedlings at their vulnerable, young growth stage to peak aphid populations.	Diminishes infection of plants at their vulnerable young growth stage. Plants infected later are less damaged and yield more.	Moderate
Employ barrier crops	Surround celery crop with non-host barrier crop. Sow tall non-host cover crop with target crop eg. cereal.	Barrier and cover crops diminish aphids landing on crop.	Moderate
Use crop rotation	Rotate celery and other susceptible crops with non-host crops (e.g. cabbage, cauliflower, lettuce etc.)	Breaks infection cycle by removing virus source	Moderate
Institute Apiacious free period	Neighbouring farms in production area cooperate to provide celery crop free period of three months for entire area. Other non-host crops can be planted during this time.	Breaks infection cycle over entire area by removing all herbaceous growing plant sources.	Difficult

control aphid vectors. A separate integrated management strategy was devised specifically for vegetable nurseries growing celery seedlings which involved: regular inspections for CeMV symptoms and sampling for virus testing to identify and remove infected seedlings; prompt removal of all celery and other Apiaceous crop seedlings beyond saleable size; removing all Apiaceous weeds within and near the nursery; use of aphid proof netting around propagating areas; and regular rotational use of different insecticides that are effective against aphids. Devising integrated disease management strategies for different situations involving the same aphid-borne virus was recently reviewed by Jones (2002, 2003) and we used the same approach here for CeMV and, separately, for carrot virus Y control in field crops (Latham and Jones 2003).

A 'celery free period' is a drastic measure and should only be considered as a last resort when infection incidences are so high that financial losses are crippling. Previously, this approach had been employed successfully in California, Florida and New Zealand. It focuses on removing celery, the primary source of inoculum (Milbrath and Ryan 1938; Milbrath 1948; Raid and Zitter 2002). It was used successfully in the Perth metropolitan region on a grouping of five nearby farms with individual crop incidences up to 96% and CeMV did not return to infect these farms during the one year monitoring period after its use. Eventually, CeMV will probably return but, when this occurs, the integrated disease management strategy recommended, should help to keep it at manageable levels preventing the need to resort to another 'celery free period'.

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Appendix B –technical reports, extension material and conference presentations