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USING SCOUTING AND DISEASE FORECASTERS TO MANAGE FOLIAR BLIGHTS OF CARROTS

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ABSTRACT

USING SCOUTING AND DISEASE FORECASTERS TO MANAGE FOLIAR BLIGHTS OF CARROTS

By

Ryan Scott Bounds

Fungal foliar blights of carrots, caused by *Alternaria dauci* and *Cercospora carotae*, result in necrotic lesions on leaves and petioles that may cause defoliation, decreasing the efficiency of mechanical harvest. Fungicides are applied every 7 to 10 days, regardless of weather conditions or disease pressure. The objectives of these studies were to evaluate Tom-Cast and other disease forecasters for timing sprays and to determine when to apply the first spray based on field scouting and disease incidence thresholds. The Tom-Cast system was the most effective and reliable disease forecaster tested, resulting in a fungicide savings of $47.25 and $54.88 per acre in 2001 and 2002, respectively, compared with the 7-day schedule, while providing similar blight control. Chlorothalonil alternated with azoxystrobin was applied every 10 days or according to Tom-Cast with a threshold of 15, 20, or 25 disease severity values (DSVs). Sprays for these programs were initiated prior to symptom development, or when foliage was infected at a trace, 5%, or 10% level. Up to four sprays were omitted saving $46.05 and $41.85 per acre in 2001 and 2002, respectively, and comparable disease control was achieved by initiating applications when a trace amount of the foliage was blighted and applying subsequent sprays according to Tom-Cast 15 DSV, compared with the 10-day spray schedule initiated prior to disease development.

DEDICATION

In memory of Louis Willard Harper (1936-2001), former Crops Club advisor and professor of Crop Science at California Polytechnic State University, San Luis Obispo. Thank you for all your inspiration.

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TABLE OF CONTENTS

LIST OF TABLES..........vi

LIST OF FIGURES..........xii

LITERATURE REVIEW 1
- Introduction 2
- *Alternaria dauci* 3
- *Cercospora carotae* 6
- Disease Control Strategies 8
- Disease Scouting 11
- Disease Forecasting 12
- Literature Cited 16

CHAPTER I. COMPARING DISEASE FORECASTING SYSTEMS FOR TIMING FUNGICIDE APPLICATIONS TO CONTROL ALTERNARIA AND CERCOSPORA BLIGHTS OF CARROTS......20
- Abstract 21
- Introduction 22
- Materials and Methods 24
- Results 30
- Discussion 35
- Literature Cited 38

CHAPTER II. TIMING FUNGICIDE APPLICATIONS ACCORDING TO FIELD SCOUTING AND TOM-CAST TO CONTROL ALTERNARIA AND CERCOSPORA BLIGHTS OF CARROTS..........39
- Abstract 40
- Introduction 41
- Materials and Methods 43
- Results 51
- Discussion 92
- Literature Cited 96

APPENDIX A. SUMMARY OF WEATHER DATA, FUNGICIDE APPLICATION DATES, AND FINAL DISEASE ASSESSMENTS FOR FIELD STUDIES IN 2001 AND 2002..........98

APPENDIX B. PESTICIDE APPLICATION EQUIPMENT STUDIES IN 2001......113

LIST OF TABLES

Table **Page**

CHAPTER I. COMPARING DISEASE FORECASTING SYSTEMS FOR TIMING FUNGICIDE APPLICATIONS TO CONTROL ALTERNARIA AND CERCOSPORA BLIGHTS OF CARROTS

1. Effect of disease caused by *A. dauci* and *C. carotae* on yield of 'Cellobunch' carrots left untreated or sprayed with the fungicide chlorothalonil (1.29 kg a.i./ha) applied every seven days or according to disease forecasters and number of fungicide applications and cost of fungicide programs in 2001 and 2002..............28

2. Effect of disease caused by *A. dauci* and *C. carotae* on the area under the disease progress curve for petiole and leaf blight on 'Cellobunch' carrots left untreated or sprayed with the fungicide chlorothalonil (1.29 kg a.i./ha) applied every seven days or according to disease forecasters in 2001 and 2002..............................31

3. Effect of disease caused by *A. dauci* and *C. carotae* on petiole health of 'Cellobunch' carrots left untreated or sprayed with the fungicide chlorothalonil (1.29 kg a.i./ha) applied every seven days or according to disease forecasters in 2001 and 2002..34

CHAPTER II. TIMING FUNGICIDE APPLICATIONS ACCORDING TO FIELD SCOUTING AND TOM-CAST TO CONTROL ALTERNARIA AND CERCOSPORA BLIGHTS OF CARROTS

4. Summary of disease assessment variables that were not normally distributed and accompanying transformations used to normalize variables.........................50

5. Number of fungicide applications and cost of fungicide programs per acre for 'Early Gold', 'Cellobunch', and 'Prime Cut' carrots left untreated or sprayed with chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) initially applied based on disease incidence thresholds and reapplied every 7 or 10 days or according to Tom-Cast in 2001 and 2002.................................52

6. Effects of spray initiation timings and application intervals on yield of 'Prime Cut' carrots treated with the fungicides chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) when initiated prior to disease development (0%) or at disease levels of trace, 5%, or 10% and reapplied at 7 or 10 day intervals or according to Tom-Cast at 15, 20, or 25 disease severity values (DSV) used to control foliar blights caused by *A. dauci* and *C. carotae* in 2002.............. 53

LIST OF TABLES (cont'd)

Table **Page**

7. Effect of the fungicides chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) when initiated prior to disease development (0%) or at disease levels of trace, 5%, or 10% and reapplied at 10-day intervals or according to Tom-Cast at 15, 20, or 25 disease severity values (DSV) on yield of 'Early Gold' carrots infected with *A. dauci* and *C. carotae* in 2001 and 2002...... **54**

8. Effect of the fungicides chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) when initiated prior to disease development (0%) or at disease levels of trace, 5%, or 10% and reapplied at 10-day intervals or according to Tom-Cast at 15, 20, or 25 disease severity values (DSV) on yield of 'Cellobunch' carrots infected with *A. dauci* and *C. carotae* in 2001 and 2002......**55**

9. Effect of the fungicides chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) when initiated prior to disease development (0%) or at disease levels of trace, 5%, or 10% and reapplied at 10-day intervals or according to Tom-Cast at 15, 20, or 25 disease severity values (DSV) on yield of 'Prime Cut' carrots infected with *A. dauci* and *C. carotae* in 2001.................. **56**

10. Effects of spray initiation timings and application intervals on the area under the disease progress curve for petiole and leaf blights caused by *A. dauci* and *C. carotae* on 'Early Gold' carrots treated with the fungicides chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) when initiated prior to disease development (0%) or at disease levels of trace, 5%, or 10% and reapplied at 10 day intervals or according to Tom-Cast at 15, 20, or 25 disease severity values (DSV) in 2001 and 2002..**60**

11. Effect of spray initiation timings for each application interval on the area under the disease progress curve of petiole blight caused by *A. dauci* and *C. carotae* on 'Early Gold' carrots treated with the fungicides chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) when initiated prior to disease development (0%) or at disease levels of trace, 5%, or 10% and reapplied at 10-day intervals or according to Tom-Cast at 15, 20, or 25 disease severity values (DSV) in 2001..**63**

12. Effects of spray initiation timings and application intervals on the area under the disease progress curve and final ratings for petiole health of 'Early Gold' carrots treated with the fungicides chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) when initiated prior to disease development (0%) or at disease levels of trace, 5%, or 10% and reapplied at 10 day intervals or according to Tom-Cast at 15, 20, or 25 disease severity values (DSV) for control of *A. dauci* and *C. carotae* in 2001 and 2002....................................... **64**

LIST OF TABLES (cont'd)

Table **Page**

13. Effect of spray initiation timings for each application interval on the final petiole health evaluation assessing disease caused by *A. dauci* and *C. carotae* on 'Early Gold' carrots treated with the fungicides chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) when initiated prior to disease development (0%) or at disease levels of trace, 5%, or 10% and reapplied at 10-day intervals or according to Tom-Cast at 15, 20, or 25 disease severity values (DSV) in 2001 .... **67**

14. Effects of spray initiation timings and application intervals on the area under the disease progress curve for petiole and leaf blights caused by *A. dauci* and *C. carotae* on 'Cellobunch' carrots treated with the fungicides chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) when initiated prior to disease development (0%) or at disease levels of trace, 5%, or 10% and reapplied at 10 day intervals or according to Tom-Cast at 15, 20, or 25 disease severity values (DSV) in 2001 and 2002 ....**71**

15. Effects of spray initiation timings and application intervals on the area under the disease progress curve and final ratings for petiole health of 'Cellobunch' carrots treated with the fungicides chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) when initiated prior to disease development (0%) or at disease levels of trace, 5%, or 10% and reapplied at 10 day intervals or according to Tom-Cast at 15, 20, or 25 disease severity values (DSV) for control of *A. dauci* and *C. carotae* in 2001 and 2002......................................**73**

16. Effects of spray initiation timings and application intervals on the area under the disease progress curve for petiole and leaf blights caused by *A. dauci* and *C. carotae* on 'Prime Cut' carrots treated with the fungicides chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) when initiated prior to disease development (0%) or at disease levels of trace, 5%, or 10% and reapplied at 10 day intervals or according to Tom-Cast at 15, 20, or 25 disease severity values (DSV) in 2001..**79**

17. Effect of spray initiation timings for each application interval on the area under the disease progress curve of petiole blight caused by *A. dauci* and *C. carotae* on 'Prime Cut' carrots treated with the fungicides chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) when initiated prior to disease development (0%) or at disease levels of trace, 5%, or 10% and reapplied at 10-day intervals or according to Tom-Cast at 15, 20, or 25 disease severity values (DSV) in 2001...**81**

LIST OF TABLES (cont'd)

Table **Page**

18. Effects of spray initiation timings and application intervals on the area under the disease progress curve for petiole and leaf blights caused by *A. dauci* and *C. carotae* on 'Prime Cut' carrots treated with the fungicides chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) when initiated prior to disease development (0%) or at disease levels of trace, 5%, or 10% and reapplied at 7 or 10 day intervals or according to Tom-Cast at 15, 20, or 25 disease severity values (DSV) in 2002.......... **83**

19. Effect of spray initiation timings for each application interval on the area under the disease progress curve of petiole blight caused by *A. dauci* and *C. carotae* on 'Prime Cut' carrots treated with the fungicides chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) when initiated prior to disease development (0%) or at disease levels of trace, 5%, or 10% and reapplied at 7 or 10 day intervals or according to Tom-Cast at 15, 20, or 25 disease severity values (DSV) in 2002.......... **85**

20. Effect of spray initiation timings for each application interval on the area under the disease progress curve of leaf blight caused by *A. dauci* and *C. carotae* on 'Prime Cut' carrots treated with the fungicides chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) when initiated prior to disease development (0%) or at disease levels of trace, 5%, or 10% and reapplied at 7 or 10 day intervals or according to Tom-Cast at 15, 20, or 25 disease severity values (DSV) in 2002.......... **88**

21. Effects of spray initiation timings and application intervals on the area under the disease progress curve and final ratings for petiole health of 'Prime Cut' carrots treated with the fungicides chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) when initiated prior to disease development (0%) or at disease levels of trace, 5%, or 10% and reapplied at 7 or 10 day intervals or according to Tom-Cast at 15, 20, or 25 disease severity values (DSV) for control of *A. dauci* and *C. carotae* in 2002.......... **90**

APPENDIX A. SUMMARY OF WEATHER DATA, FUNGICIDE APPLICATION DATES, AND FINAL DISEASE ASSESSMENTS FOR FIELD STUDIES IN 2001 AND 2002

22. Weather data and Disease Severity Values (DSV) from the Michigan State University Muck Soils Experimental Farm during the 2001 and 2002 growing seasons.......... **99**

23. Dates of chlorothalonil (1.29 kg a.i./ha) applications on 'Cellobunch' carrots in 2001.......... **100**

LIST OF TABLES (cont'd)

Table **Page**

24. Dates of chlorothalonil (1.29 kg a.i./ha) applications on 'Cellobunch' carrots in 2002 .... **101**

25. Summary of the effects of disease caused by *A. dauci* and *C. carotae* on petiole blight, leaf blight, and yield of 'Cellobunch' carrots left untreated or sprayed with the fungicide chlorothalonil (1.29 kg a.i./ha) applied every seven days or according to disease forecasters in 2001 and 2002 .... **102**

26. Weather data and Disease Severity Values (DSV) from the trial site near Fremont, MI during the 2001 and 2002 growing seasons **103**

27. Dates of fungicide applications on 'Early Gold' and 'Cellobunch' carrots using chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) in 2001 .... **104**

28. Dates of fungicide applications on 'Early Gold' and 'Cellobunch' carrots using chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) in 2002 .... **105**

29. Dates of fungicide applications on 'Prime Cut' carrots using chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) in 2001 .... **106**

30. Dates of fungicide applications on 'Prime Cut' carrots using chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) in 2002 .... **107**

31. Summary of the effects of disease caused by *A. dauci* and *C. carotae* on petiole blight, leaf blight, and yield of 'Early Gold' carrots left untreated or sprayed with the fungicides chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) when initiated prior to disease development (0%) or at disease levels of trace, 5%, or 10% leaf blight and reapplied at 10 day intervals or according to Tom-Cast at 15, 20, or 25 disease severity values (DSV) in 2001 and 2002 .... **109**

32. Summary of the effects of disease caused by *A. dauci* and *C. carotae* on petiole blight, leaf blight, and yield of 'Cellobunch' carrots left untreated or sprayed with the fungicides chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) when initiated prior to disease development (0%) or at disease levels of trace, 5%, or 10% leaf blight and reapplied at 10 day intervals or according to Tom-Cast at 15, 20, or 25 disease severity values (DSV) in 2001 and 2002 .... **110**

LIST OF TABLES (cont'd)

Table **Page**

33. Summary of the effects of disease caused by *A. dauci* and *C. carotae* on petiole blight, leaf blight, and yield of 'Prime Cut' carrots left untreated or sprayed with the fungicides chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) when initiated prior to disease development (0%) or at disease levels of trace, 5%, or 10% leaf blight and reapplied at 7 or 10 day intervals or according to Tom-Cast at 15, 20, or 25 disease severity values (DSV) in 2001 and 2002..**111**

APPENDIX B. PESTICIDE APPLICATION EQUIPMENT STUDIES IN 2001

34. Effect of nozzle type on foliar blights caused by *Alternaria dauci* and *Cercospora carotae* on 'Goliath' carrots in 2001..**116**

35. Effect of fungicides on foliar blights caused by *Alternaria dauci* and *Cercospora carotae* on 'Goliath' carrots in 2001..**117**

36. Effect of nozzle type on foliar blights caused by *Alternaria dauci* and *Cercospora carotae* on 'Goliath' carrots in 2001..**120**

37. Effect of fungicides on foliar blights caused by *Alternaria dauci* and *Cercospora carotae* on 'Goliath' carrots in 2001..**121**

LIST OF FIGURES

Figure **Page**

CHAPTER I. COMPARING DISEASE FORECASTING SYSTEMS FOR TIMING FUNGICIDE APPLICATIONS TO CONTROL ALTERNARIA AND CERCOSPORA BLIGHTS OF CARROTS

1. Disease progress curves for petiole and leaf blight caused by *A. dauci* and *C. carotae* on 'Cellobunch' carrots left untreated or treated with the fungicide chlorothalonil (1.29 kg a.i./ha) applied every 7 days or according to disease forecasters in 2001 and 2002 33

CHAPTER II. TIMING FUNGICIDE APPLICATIONS ACCORDING TO FIELD SCOUTING AND TOM-CAST TO CONTROL ALTERNARIA AND CERCOSPORA BLIGHTS OF CARROTS

2. Disease progress curves for leaf blight caused by *A. dauci* and *C. carotae* on 'Early Gold' carrots left untreated or treated with chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) applied prior to blight symptom development (0%) or at disease levels of trace, 5%, 10% and reapplied every 10 days or according to Tom-Cast using intervals of 15, 20, or 25 DSVs in 2001 and 2002 58

3. Disease progress curves for petiole blight caused by *A. dauci* and *C. carotae* on 'Early Gold' carrots left untreated or treated with chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) applied prior to blight symptom development (0%) or at disease levels of trace, 5%, 10% and reapplied every 10 days or according to Tom-Cast using intervals of 15, 20, or 25 DSVs in 2001 and 2002 59

4. Disease progress curves for petiole blight caused by *A. dauci* and *C. carotae* on 'Cellobunch' carrots left untreated or treated with chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) applied prior to blight symptom development (0%) or at disease levels of trace, 5%, 10% and reapplied every 10 days or according to Tom-Cast using intervals of 15, 20, or 25 DSVs in 2001 and 2002 68

5. Disease progress curves for leaf blight caused by *A. dauci* and *C. carotae* on 'Cellobunch' carrots left untreated or treated with chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) applied prior to blight symptom development (0%) or at disease levels of trace, 5%, 10% and reapplied every 10 days or according to Tom-Cast using intervals of 15, 20, or 25 DSVs in 2001 and 2002 69

LIST OF FIGURES (cont'd)

Figure **Page**

6. Disease progress curves for leaf blight caused by *A. dauci* and *C. carotae* on 'Prime Cut' carrots left untreated or treated with chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) applied prior to blight symptom development (0%) or at disease levels of trace, 5%, 10% and reapplied every 10 days or according to Tom-Cast using intervals of 15, 20, or 25 DSVs in 2001 and 2002....76

7. Disease progress curves for petiole blight caused by *A. dauci* and *C. carotae* on 'Prime Cut' carrots left untreated or treated with chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) applied prior to blight symptom development (0%) or at disease levels of trace, 5%, 10% and reapplied every 10 days or according to Tom-Cast using intervals of 15, 20, or 25 DSVs in 2001 and 2002....77

8. Disease progress curves for petiole and leaf blight caused by *A. dauci* and *C. carotae* on 'Prime Cut' carrots left untreated or treated with chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) applied prior to blight symptom development (0%) or at disease levels of trace, 5%, 10% and reapplied every 7 days in 2002.... 78

LITERATURE REVIEW

Introduction

In 2001, Michigan harvested 6,300 acres of carrots (*Daucus carota* L. var. *sativa* DC.) that yielded 115,500 tons for use in fresh market and processing (NASS, 2003). Carrots grown for the fresh market were grown on 4,800 acres and valued at $23.2 million. Carrots for processing were grown on 1,500 acres and valued at $2.2 million. Michigan ranks third and fifth for production of fresh market and processing carrots, respectively, and the state ranks third in total carrot production. California, Washington, Colorado, Texas, and Wisconsin rank first, second, fourth, fifth, and sixth, respectively, in total carrot production (NASS, 2003).

Michigan carrots are grown in deep, well-drained mineral and muck soils. Carrots are planted during mid-April to mid-June and are harvested from the beginning of August through November. Carrots are harvested by a machine that loosens the soil and simultaneously grips the foliage, pulling the roots from the soil (Zandstra et al., 1986).

In Michigan, Alternaria leaf blight and Cercospora leaf blight are the most common pathogens affecting carrot foliage. *Alternaria dauci* (Kühn) Groves & Skolko (Groves and Skolko, 1944) is favored by periods of warm, wet environmental conditions (Doran and Guba, 1928). Similarly, *Cercospora carotae* (Passerini) Solheim is favored by warm periods and high relative humidity. Environmental conditions that enhance the growth of these pathogens frequently occur during the carrot-growing season in Michigan. Both pathogens cause foliar blight resulting in a reduction of photosynthetic capacity and weakening the petioles and foliage needed for mechanical harvest. Carrot tops weakened by blight are easily detached from the root when gripped by mechanical harvesters, resulting in unharvested carrots (Gillespie and Sutton, 1979; Strider, 1963).

Traditionally, blights are controlled through the use of protectant fungicides applied every 7 to 10 days, from July through September (Gillespie and Sutton, 1979). Calendar-based spray schedules typically require 5 to 9 applications and may result in unneeded sprays, increasing production costs (Gillespie and Sutton, 1979), and the likelihood of pathogens developing chemical insensitivity (Bolkan and Reinert, 1994).

Alternaria dauci

Alternaria dauci is distributed worldwide (Rotem, 1994) and is considered a preeminent foliar pathogen in most carrot-growing regions (Hooker, 1944; Maude, 1966; Netzer and Kenneth, 1969; Scott and Wenham, 1973). The fungus was first reported in the United States as *Macrosporium carotae* Ellis & Langlois (Ellis and Langlois, 1890). The pathogen has a limited host range, infecting only wild carrot (*Daucus carota* L.) and cultivated carrot (*Daucus carota* L. var. *sativa* DC.), both in the family Apiaceae (Doran and Guba, 1928). The fungus is classified in the phylum Deuteromycota, order Hyphomycetes, and family Dematiaceae (Rotem, 1994).

Conidiophores of *A. dauci* are olive-brown, septate, simple or branched, variable in length, and 6-10μ in diameter. Conidia are dark olive-brown, obclavate, with long beaks, having 7-10 transverse septa and few longitudinal septa, born singly or in short chains, and 150-250μ long by 15-25μ in diameter (Groves and Skolko, 1944). In general, *A. dauci* is capable of producing spores at all temperatures that occur during the growing season (Strandberg, 1977). Conidia germinate over a wide temperature range from 16° to 28° C, but germinate best at 22° to 24° C (Doran and Guba, 1928). Hooker (1944) concluded that maximum mycelial growth occurs at 28° C, and most conidia germinate between 20° and 37° C. Sporulation is favored by darkness, a minimum leaf wetness duration of 10 h, and temperatures from 11 to 23° C (Langenberg, 1975).

Though often confused with *C. carotae*, *A. dauci* generally infects older foliage (Doran and Guba, 1928; Hooker, 1944; Maude, 1966), producing dark brown to black irregularly shaped lesions along leaf margins. Under favorable conditions, blight symptoms develop four to six days after inoculation and sporulation occurs within eight to ten days (Strandberg, 1977). Chlorosis surrounding the Alternaria lesion is more pronounced than that caused by *C. carotae* (Hooker, 1944). The lesions expand and join together, producing a blighted or burned appearance on the foliage. Severely infected petioles may become girdled and disengage from the root.

A. dauci can infect all parts of the carrot inflorescence (Strandberg, 1983), resulting in contaminated seed. Mycelium may penetrate the inner layer of the pericarp tissue, and conidiophores protrude through the pericarp (Netzer and Kenneth, 1969). Conidia adhering to the surface of seeds can germinate after 9 months (Strandberg, 1983) or up to 30 months (Netzer and Kenneth, 1969) when stored at ambient conditions; thus, infected seeds serve as a source of long-term primary inoculum (Strandberg, 1983). When seeds are infected with *A. dauci*, pre or post-emergence damping-off may occur (Maude, 1966; Neergaard, 1945; Netzer and Kenneth, 1969). Infected seedlings may increase inoculum levels and contribute to early season leaf blight epidemics (Strandberg, 1984).

Concentrations of airborne *A. dauci* conidia and weather variables were recorded in an area of intensive carrot production in Ontario (Langenberg et al., 1977). Peak numbers of conidia were trapped between 1300 hours and 1500 hours. The declining number of trapped conidia after 1500 hours were not correlated with weather variables, but were assumed to be an indication of the number of mature conidia available for dispersal. Release of *A. dauci* conidia was correlated with increasing temperatures, increasing wind, decreasing RH, and drying of the foliage. Rain removed airborne conidia from the air and contributed to prolonged periods of leaf wetness, which reduced the number of airborne conidia by restricting spore liberation. Although wind temporarily increased spore liberation and numbers of airborne conidia, extensive high winds damaged conidiophores and resulted in few trapped conidia following the wind period (Langenberg et al., 1977).

Other field studies indicate that plentiful amounts of conidia are produced following nights of 95-100% RH or leaf wetness for 8-12 hours (Strandberg, 1977). Spore abundance is not well correlated with hours of RH above 95%, but hours of leaf wetness are correlated with number of conidia trapped. Following daybreak, and when the RH fell below 80%, conidia are liberated and disseminated by wind. Wind speeds 2-3 m/sec are needed to dislodge large numbers of conidia (Strandberg, 1977).

Seasonal differences in the onset and development of Alternaria blight epidemics have been observed. Doran and Guba (1928) found that young carrot plants (up to eight weeks) were moderately resistant to infection, but susceptibility increased with plant age. Hooker (1944) observed that older leaves were more susceptible to infection, causing the disease to progress more rapidly at the end of the season. Zimmer and McKeen (1969) suggested that the interaction of photoperiod and temperature was the cause of seasonal differences. Strandberg (1977) attributed late season epidemics to the increased duration of leaf wetness, typical during the cool, longer nights of late summer and early fall.

Cercospora carotae

Cercospora carotae occurs in temperate regions and is considered an important foliar pathogen in most carrot-producing areas (Arcelin and Kushalappa, 1991; Thomas, 1943). *C. carotae* has a wide host range in the genus *Daucus*, infecting wild and cultivated carrots (*Daucus carota* L. and *Daucus carota* L. var. *sativa* DC.), *D. hispanicus* Gouan, *D. maritimus* Lam., *D. pulcherrimus* Koch ex DC., *D. maximus* Desf., *D. gingidium* L., and *D. pusillus* Mich. (Thomas, 1943). The fungus is classified in the phylum Deuteromycota, order Hyphomycetes, and family Dematiaceae (Solheim, 1929).

Conidiophores of *C. carotae* are light yellow-brown, amphigenous, simple, straight to subflexous, non-stromatic, with minute conidial scars near the tip, and 15-45μ long by 3-5μ in diameter. Conidia are at first cylindrical then become narrowly obclavate, bacilliform, hyaline to subhyline, continuous or obscurely 1-8 septate, and 30-115μ long by 2-3μ in diameter (Solheim, 1929).

The life cycle of *C. carotae* is similar to that of *A. dauci*. *C. carotae* grows rapidly between 19° and 28° C, and maximum germination is observed at 16° to 28° C. Sporulation occurs between 13° and 28° C but requires free moisture (Thomas, 1943). Hooker (1944) made similar findings; the majority of conidia germinated at 20° to 32° C, and the optimum temperature for mycelial development was 28° C. Wind is assumed as the primary disseminating agent of *C. carotae*. Thomas (1943) collected conidia on agar plates, exposed for 3 min, located 3, 30, and 92 m downwind from severely blighted carrot fields.

Infection occurs only through stomata via a germ tube (Thomas, 1943). Lesions may occur on the foliage and first appear as pinpoint chlorotic spots that expand and generate necrotic centers. Generally, lesions located away from the edge of the leaf are circular, and lesions along leaf margins and petioles are elongate. A light gray or silvery mass of conidia may be observed macroscopically on lower surfaces of the lesion during periods of high humidity. Lesion expansion and sporulation continues until spots coalesce and the leaflet is killed (Thomas, 1943).

The relationship of temperature and leaf wetness duration on infection of *C. carotae* was examined using a quantitative model developed under controlled experimental conditions (Carisse and Kushalappa, 1990). In general, infection occurs following 12 h of leaf wetness at temperatures 16, 20, 24, 28, and 32° C, and increases with wetness duration, except at 32° C where infection decreases with increasing periods of leaf wetness. Leaf wetness duration of 24 h and temperatures between 20 and 28° C are required to promote extensive infection of *C. carotae*. Maximum numbers of lesions were produced in growth chambers held at 16, 20, 24, and 28° C with 96 h of leaf wetness (Carisse and Kushalappa, 1990).

Carisse and Kushalappa (1992) examined the influence of interrupted wet periods and relative humidity on infection by *C. carotae*. An interrupted wet period consisted of 24 h of initial leaf wetness and 12 h of final leaf wetness, separated by a dry period of 3, 6, 12, 18, 24, 30, or 36 h. Continuous leaf wetness durations were 36, 39, 42, 48, 54, 60, 66, and 72 h. In general, fewer lesions per plant were produced during interrupted wet periods than continuous wet periods. However, plants subjected to the 3 to 24 h dry periods, except for the 12 h dry period, produced more lesions than plants held at continuous leaf wetness for 36 h. Therefore, germinated spores can survive dry periods and resume infection when subjected to an additional wetness period. The number of lesions per plant increased with temperatures of 16 to 28° and with an increase in humidity level (Carisse and Kushalappa, 1992).

Carisse et al. (1993) investigated the effect of temperature and duration of different moisture conditions on sporulation of *C. carotae*. No sporulation occurred at a relative humidity $\leq$92%, but abundant conidia were produced under leaf wetness, 96% RH, and 96% RH preceded by 12 h of leaf wetness. Sporulation increased with increasing duration of moisture period or leaf wetness and increasing temperature from 16 to 28° C. Maximum sporulation was observed at 28° C after 96 h of leaf wetness, although all temperature-moist conditions sporulated after 48 h. In general, numerous conidia were produced after 48 h of leaf wetness at 20 to 28° C. The temperature range for conidial infection is similar to that for sporulation, therefore, temperatures between 16 and 32° C accompanied by leaf wetness or RH $\geq$96% for 24 h are considered favorable periods for sporulation of *C. carotae* (Carisse et al., 1993).

Disease Control Strategies

Alternaria and Cercospora leaf blights are managed through crop rotation, disease-free seed, tolerant cultivars, and fungicide applications. Crop rotation was recommended by Doran & Guba (1928) to obtain partial control of *A. dauci* and *C. carotae* because these fungi overwinter in the soil and on infected carrot debris and may infect subsequent carrot plantings. Deep plowing or the destruction of infected carrot tops and planting of non-host crops following carrot production is encouraged to prevent high levels of inoculum deposition in the soil. However, *C. carotae* was recovered ten months after infected carrot leaves were placed in wire containers and buried 10 and 15 cm below the soil surface (Thomas, 1943). *A. dauci* survived longer on petioles on the surface of the soil than on petioles buried at depths of 10 and 20 cm, although the experiment duration was only five months (Netzer and Kenneth, 1969). Survival of *A. dauci* is negatively correlated with increasing soil moisture (Pryor et al., 2002). Fallow carrot fields in a warm, dry carrot production area in California allowed *A. dauci* to survive on infected foliage on and below the soil surface for up to one year; reduced survival was observed in irrigated alfalfa and rose fields and in a warm, moist carrot field in Florida. Plowing under of infected carrot residue hastens decomposition thereby reducing survival, and may be more beneficial for cooler carrot production areas where decomposition rates are slower (Pryor et al., 2002). Volunteer carrot plants (Pryor et al., 2002) and alternate hosts provide a source of inoculum for present and future carrot plantings and should be removed from carrot-growing areas (Doran and Guba, 1928).

Seed treatments reduce damping-off of carrot plants, but these measures may not entirely eradicate *A. dauci* from carrot seed. Maude (1966) claimed complete eradication of *A. dauci* from carrot seeds by a 24-hour soak at 30° C in a 0.2% thiram suspension, without compromising seed germination. Strandberg (1984) repeated Maude's experiment with a larger number of seeds and a more sensitive assay method and observed Alternaria blight symptoms, indicating that the seed treatment did not entirely eradicate the pathogen. The use of 0.5% iprodione seed-soak for 24 hours at 30° C apparently eradicated *A. dauci* from medium sized seed samples, but 0.01% infected seedlings were detected in a larger seed sample using a similar assay method (Strandberg, 1984). Although hot water seed treatments have been tested (Strandberg, 1988), this application alone is incapable of eliminating *A. dauci* without harming the seed (Strandberg and White, 1989). In commercial carrot production, planting large quantities of treated carrot seeds may result in several hundred infected plants per hectare, sufficient to cause an Alternaria blight epidemic (Strandberg, 1984).

Cultivar resistance to *A. dauci* and C. *carotae* was examined for 50 unsprayed carrot varieties and breeding selections in 1999 (James et al., 1999). Forty percent of the cultivars examined produced AUDPC (Area Under the Disease Progress Curve) values that were significantly less than the susceptible standard varieties. All 50 cultivars showed symptoms of blight, and no cultivars displayed complete resistance to both *A. dauci* and *C. carotae*. In another study, Strandberg et al. (1972) evaluated 331 carrot varieties from 31 countries for resistance to *A. dauci* and found nine varieties capable of containing blight symptoms for the entire growing season without any fungicidal application. Cercospora-tolerant plants exhibit fewer and smaller lesions than susceptible cultivars (Angell and Gabelman, 1968). Cultivars with complete resistance to *A. dauci* or *C. carotae* have not been identified, but blight tolerant cultivars are available.

Santos et al. (2000) examined the use of gibberellic acid (GA) applications to control Alternaria blight. Applications of (GA) or iprodione decreased the severity of blight and increased the top and root weights compared to the untreated control. Disease severity decreased linearly with an increase in GA concentration, although the high GA concentration (250 mg/L) increased the amount of foliage at the expense of root mass. The reduction in disease severity of the GA treated plants may be a result of the increase in leaf length and more upright appearance of plants, allowing greater air circulation through the crop canopy (Santos et al., 2000).

Fungicides are relied on as disease control tools. Traditionally, blights are controlled through the use of protectant fungicides applied every 7 to 10 days, from July through September (Gillespie and Sutton, 1979). Currently, two protectant active ingredients (chlorothalonil and copper-based fungicides) and two systemic active ingredients (iprodione and azoxystrobin) are registered to control Alternaria and Cercospora (iprodione not registered) leaf blights in Michigan (Bird et al., 2002). Fungicide resistance of *A. dauci* to iprodione has been reported (Fancelli and Kimati, 1991). In addition, iprodione and chlorothalonil are pesticides classified as B2 carcinogens and are scheduled for review by the EPA under the Food Quality Protection Act (FQPA). The future availability of these products is uncertain. One Michigan food processor does not allow the use of iprodione on carrots because it is a B2 carcinogen and residues are a concern. Azoxystrobin (Quadris, Syngenta Crop Protection, Greensboro, NC), a recently registered reduced risk systemic fungicide, is an effective tool to control Alternaria and Cercospora blights in rotation with protectant fungicides (Hausbeck et al., 2000; James and Stevenson, 1999). Use of this product in rotation with protectant fungicides already used by Michigan growers may reduce the number of B2 carcinogenic fungicide applications.

Most growers employ disease management practices to reduce the occurrence and development of Alternaria and Cercospora blights, otherwise, harvesting losses are often incurred. For example, a Wisconsin study reported the standard weekly fungicide program yielded 15.7 tons/A while the untreated plot yielded 11.7 tons/A and resulted in 23.8% unmarketable carrots (James and Stevenson, 1999).

Disease Scouting

Growers and agricultural consultants utilize field scouting to monitor pests, soil moisture, projected yield, and other various aspect of a field or the crop grown in the field. Such observations often contribute to the decision making process for implementing management strategies. One disease forecasting system used to time sprays for controlling *A. dauci* on carrots incorporates the use of field scouting to determine when the first fungicide application should be made (Gillespie and Sutton, 1979). Fields are scouted and the first fungicide spray is applied when blight symptoms developed on 1 to 2% of the foliage. This level of disease was selected because it was the first observable stage of Alternaria blight. In each of four years, one to three spays were saved by delaying the initial fungicide application until blight symptoms were detected by scouting compared with the standard fungicide schedule (Gillespie and Sutton, 1979).

A tomato Integrated Pest Management (IPM) program advised that fields should be scouted one or two times per week for diseases and insects (Keinath et al., 1996). Fungicide sprays to control early blight (*Alternaria solani*) were initiated when 3 to 6% of the leaf area showed symptoms of disease. The IPM scouted plots were initially sprayed 42 days after the standard weekly fungicide schedule commenced. The delay in initiating the IPM treatment resulted in higher disease severity and a reduction in yield of extra large fruit compared to the weekly fungicide schedule. Management of early blight using scouting in the tomato IPM program was unsuccessful, but may be improved by lowering the spray initiation threshold to 1 to 3% leaf area blighted (Keinath et al., 1996).

Disease Forecasting

European studies in the early to mid-1900s on infection periods for *Plasmopara viticola* and *Phytophthora infestans* represented the beginning of disease forecasting. Other terms describing the concept of disease forecasting include disease predictive schemes and disease warning systems, but the term "disease forecasting" will be used here. Most disease forecasting systems rely on weather variables (Zadoks, 1984), in conjunction with the biology and epidemiology of the pathogen, to predict infection or developmental periods of the disease on a particular host (Krause and Massie, 1975). Forecasting systems are appropriate for diseases that are economically significant, somewhat variable between seasons, controlled by available and economical methods, and known to depend on specific weather factors, as investigated by laboratory or other experiments (Bourke, 1970). Furthermore, disease-forecasting systems are suited for IPM systems. The potential benefits from using disease-forecasting systems include cost effective disease control, increased attention of farmers to the biology of the cropping system, and reduced environmental contamination (Johnson, 1987).

A disease forecasting model was created to 1) identify environmental conditions that favor the development of early blight on tomato, and 2) enhance the efficiency of fungicide use (Madden et al., 1978). FAST (Forecaster of *Alternaria solani* on Tomato) uses daily values for maximum and minimum air temperature, hours of leaf wetness, maximum and minimum air temperatures during the leaf wetness period, hours of relative humidity greater than 90%, and rainfall (Madden et al., 1978). Field studies proved the weather-prompted FAST system to be as effective as standard spray regimes for controlling early blight (Madden et al., 1978). FAST was subsequently evaluated for predicting infection periods and timing fungicide applications for control of *Stemphylium vesicarium* on pear (Montesinos, 1992). Commercial orchard studies showed that FAST resulted in 28-38% fewer fungicide applications, compared with the standard 7-day commercial schedule, while maintaining the same level of disease control (Montesinos, 1992).

The FAST system was modified by R.E. Pitblado to meet the needs of Ontario tomato growers for controlling early blight (*Alternaria solani* Sorauer), septoria leaf spot (*Septoria lycopersici*), and fruit anthracnose (*Collectotricum coccodes*) (Pitblado, 1988, 1992). The refined system, Tom-Cast (TOMato disease foreCASTer), calculates daily disease severity values (DSVs) based on hours of leaf wetness and the average air temperature during the wetness period. Sprays are initiated when the DSV reaches a threshold value, and, after spraying, the DSV is reset to zero (Pitblado, 1992).

Tom-Cast was evaluated as a disease management tool for timing fungicide applications to control purple spot (*Stemphylium vesicarium*) on asparagus (Meyer et al., 2000). The Tom-Cast spray program prompted an equal or fewer number of sprays and provided better disease control than the 14-day standard program. Additionally, some newly established asparagus plots managed according to Tom-Cast resulted in increased fern stands (Meyer et al., 2000).

Gillespie and Sutton (1979) developed a predictive system for timing fungicide applications for the control of Alternaria leaf blight on carrots. The criteria of the system were to: 1) apply the initial fungicide application after 1 to 2% of the foliage showed symptoms of blight; 2) apply subsequent fungicide applications only when the 36 hour predicted weather favored the development of blight; and 3) apply fungicide at no more than a minimum of 7 or 10 days (Gillespie and Sutton, 1979). Commercial field experiments showed that two to four weather-timed sprays proved the predictive system controlled blight as effectively as six or seven weekly applications. In addition, this program eliminated the need for one to three sprays before the blight symptoms reached 1 to 2% (Gillespie and Sutton, 1979).

A disease forecasting system has been developed for timing sprays to control *Cercospora apii* (Fres.) on celery (Berger, 1969a, 1969b). A hygrothermograph and spore trap were used to identify sporulation periods. Sporulation increased following nights when temperatures ranged from 15 to 30° C and the relative humidity was near 100% for 8 or more hours. Fewer spores were caught following nights when the temperature dropped below 15° C regardless of the duration of high humidity. If temperatures fell below 12° C, two consecutive nights with humidity levels near 100% and temperatures ranging from 15 to 30° C were required for *C. apii* to resume significant sporulation. Five to fifteen sprays were saved during the 1968 winter growing season by utilizing the disease forecaster to time fungicide applications (Berger, 1969b).

There is substantial evidence that disease forecasting systems can reduce the number of fungicide applications per season or increase the efficacy of sprays by prompting sprays only when the environment is conducive for disease development. Disease forecasting systems may be appropriate for managing Alternaria and Cercospora blights in Michigan.

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CHAPTER I.

COMPARING DISEASE FORECASTING SYSTEMS FOR TIMING FUNGICIDE APPLICATIONS TO CONTROL ALTERNARIA AND CERCOSPORA BLIGHTS OF CARROTS

ABSTRACT

Alternaria dauci and *Cercospora carotae* cause foliar blight of carrots and can reduce the harvestable yield in severely blighted fields. Traditionally, fungicides are applied every 7 to 10 days, regardless of weather conditions or disease pressure. The objective of this study was to evaluate available disease forecasting systems for timing fungicide sprays to limit foliar blights, including 1) a modified disease forecaster previously tested for timing sprays to control *Cercospora apii* on celery, 2) an Alternaria disease forecaster designed to time sprays for controlling *A. dauci* on carrots but not yet tested in Michigan, and 3) Tom-Cast, originally developed to predict the occurrence of diseases on tomatoes. Chlorothalonil was applied every seven days or according to the forecasting systems in 2001 and 2002. Sprays applied according to Tom-Cast 15 DSV resulted in a fungicide savings of $47.25 and $54.88 per acre in 2001 and 2002, respectively, compared with the 7-day schedule, while providing similar blight control. The number of sprays was reduced when fungicides were applied according to modified predictive systems for Alternaria and Cercospora compared with the 7-day schedule, but acceptable blight control was not always achieved. The Tom-Cast disease forecaster was easy to use and reliable for determining the appropriate timing of fungicide applications on carrots.

INTRODUCTION

Alternaria dauci (Kühn) Groves & Skolko and *Cercospora carotae* (Passerini) Solheim infect the leaves and petioles of carrots (*Daucus carota* L. var. *sativa* DC.) causing a foliar blight that contributes to harvesting losses. Alternaria blight symptoms initially appear as irregularly shaped necrotic lesions along leaf margins (Hooker, 1944). Symptoms of Cercospora blight are more distinct and appear as small, pinpoint necrotic lesions surrounded by a chlorotic halo (Thomas, 1943). Both fungi are capable of infecting carrot petioles and cause tan to black colored lesions surrounded by a light tan or gray halo. Petiole infection occurs when favorable conditions are maintained for long durations inside the dense crop canopy. If favorable conditions persist, entire leaflets and petioles become blighted and will not withstand the pull of mechanical harvesters. An increase in harvesting difficulty and yield reduction occurs when severely blighted foliage detaches from the root during mechanical harvest or when plants are defoliated by blights (Gillespie and Sutton, 1979; Strider, 1963).

Carrot growers in Michigan are advised to apply registered fungicides at 7 to 14 day intervals following crop emergence (Bird et al., 2002). However, calendar based spray schedule do not take into account when environmental conditions are unfavorable for blight development and needless sprays can be applied.

Numerous disease forecasting systems exist that alert growers when a fungicide spray is needed based on environmental conditions. One such system has been developed for timing sprays to control *Cercospora apii* (Fres.) on celery (Berger, 1969a, 1969b). A hygrothermograph and spore trap were used to identify sporulation periods. Sporulation increased following nights when temperatures ranged from 15 to 30° C and the relative humidity (R.H.) was near 100% for eight or more hours. Fewer spores were caught following nights when the temperature dropped below 15° C regardless of the duration of high humidity. If temperatures fell below 12° C, two consecutive nights with humidity levels near 100% and temperatures ranging from 15 to 30° C were required for *C. apii* to resume significant sporulation. Five to fifteen sprays were saved during the 1968 winter growing season by utilizing the disease forecaster to time fungicide applications (Berger, 1969b).

Gillespie and Sutton (1979) developed a disease forecasting system to time fungicide applications for controlling Alternaria blight of carrots. The criteria of the system included the following: 1) apply the initial fungicide application after 1 to 2% of the foliage showed symptoms of blight; 2) apply subsequent fungicide applications only when the 36 hour predicted weather favored the development of blight; and 3) apply fungicide at no more than a minimum of 7 or 10 days. To determine if the upcoming 36 hours were favorable for blight development, the system used forecasted weather information to produce an infection index that was calculated by comparing forecasted temperatures and estimated leaf wetness durations. Regional forecasts of rain, cloud cover, and wind speeds were used to derive the leaf wetness duration. Commercial field experiments showed that two to four weather-timed sprays controlled blight as effectively as six or seven weekly applications. In addition, this program eliminated the need for one to three sprays before the blight symptoms reached 1 to 2% compared with the standard fungicide schedule (Gillespie and Sutton, 1979).

The Tom-Cast disease forecasting system is a modified version of F.A.S.T. (Forecaster for *Alternaria solani* Sorauer on Tomato). Tom-Cast was designed to include control for anthracnose fruit rot (*Collectotrichum coccodes* (Wallr.) Hughes) and Septoria leaf spot (*Septoria lycopersici* (Speg)) in addition to early blight (*Alternaria solani* Sorauer) (Pitblado, 1988). For each 24-hour period (11:00 AM to 11:00 AM), Tom-Cast uses the hours of leaf wetness and the average temperature during the wetness periods to calculate a Disease Severity Value (DSV) ranging from 0 to 4, corresponding to environmental conditions unfavorable to highly favorable for disease development. Daily DSV values are summed and accumulate until a threshold value is reached, a fungicide spray is applied, and the DSV total is reset to zero (Pitblado, 1988, 1992).

With increases in production costs and public concerns regarding pesticide use, it is desirable to evaluate Integrated Pest Management (IPM) methods for managing Alternaria and Cercospora blights of carrots. Improved methods for determining the appropriate timing of fungicide applications are needed to make blight control more cost effective without compromising quality and yield. The objective of this study was to evaluate available disease forecasting systems for timing sprays to limit foliar blights, including 1) a modified disease forecaster previously tested for timing sprays to control *Cercospora apii* on celery, 2) an Alternaria disease forecaster designed to time sprays for controlling *A. dauci* on carrots but not yet tested in Michigan, and 3) Tom-Cast, originally developed to time sprays for controlling diseases on tomatoes.

MATERIALS AND METHODS

Plot establishment. Plots were established at the Michigan State University Muck Soils Experimental Farm in Bath, Michigan in 2001 and 2002. Beds were formed and 'Cellobunch' carrot seeds were planted on 14 May 2001 and 21 May 2002 in Houghton Muck soil, previously planted with potato. Seeds were spaced 1.43 cm apart in rows spaced 45.7 cm apart on three-row raised beds measuring 162.6 cm from center to center. Plant populations were 631,583/ha (2001) and 484,971/ha (2002). All treatment plots were 6.1 m long. One and a half meter sections of unsprayed carrots separated treatment plots within beds, and one bed of carrots was left untreated between treatment beds. Natural inoculum was relied on for infecting plants. Weeds, insects, and fertilization requirements were managed according to standard production practices (Bird et al., 2002; Warncke et al., 1992; Zandstra, 2002). Plots were sprinkler irrigated as needed.

Weather monitoring. Hourly measurements of temperature, relative humidity, and leaf wetness duration were obtained using a digital data recorder (WatchDog Temperature and Relative Humidity Logger 3684; Spectrum Technologies, Inc., Plainfield, Illinois) placed in the field prior to row closure in mid-June. The external leaf wetness sensor (WatchDog Leaf Wetness Sensor 3666; Spectrum Technologies, Inc., Plainfield, Illinois) was located in the upper 75% of the crop canopy in the center of an unsprayed bed at a 45° angle facing north. Data were downloaded every other day to a laptop computer using a computer program (Specware 6.01; Spectrum Technologies, Inc., Plainfield, Illinois) equipped to calculate DSVs for the Tom-Cast system. The program was set to record temperatures from 0 to 100° C and to detect leaf wetness whenever moisture was present on the leaf wetness grid. A summary of weather data and DSV accumulation from the trial site in 2001 and 2002 is listed in Appendix A (Table 22).

Disease forecasting programs and fungicide treatments. A modified version of the *C. apii* disease forecasting system was tested in this study. The modified system omitted the spore trap and relied solely on hourly measurements of temperature and relative humidity. A fungicide spray was applied if all of the following criteria were met: 1) no fungicide was applied during the past seven days; 2) $\geq$ 12 hours of R.H. $\geq$ 90% were recorded the previous day (0700 yesterday to 0600 today); 3) temperatures ranged 15-27° C during previous day; 4) temperatures during the past three days were $\geq$ 12° C or, if the temperature was below 12° C, the night temperatures (2200 to 0700) on the two succeeding nights (yesterday and the day before yesterday; yesterday being 2200 last night until 0700 this morning) were $\geq$ 15° C and had R.H. $\geq$ 95%. Modifications to the original forecasting system were made according to recommendations (M.L. Lacy, *unpublished data*).

Sprays were applied according to a modified disease forecaster designed to time sprays for controlling *A. dauci* on carrots (Gillespie and Sutton, 1979). In the present study, fungicides were applied only after 1 to 2% of the foliage displayed disease symptoms, with a minimum reapplication interval of seven days. Subsequent sprays were applied the day before forecasted rain or before nights when the forecasted minimum temperature was $\geq$ 16° C.

The Tom-Cast disease forecasting systems was tested for timing sprays to control Alternaria and Cercospora blights. For each 24-hour period (11:00 AM to 11:00 AM), Tom-Cast used the hours of leaf wetness and the average temperature during the wetness periods to calculate a DSV ranging from 0 to 4, corresponding to environmental conditions unfavorable to highly favorable for disease development (Pitblado, 1992). Daily DSVs were summed and accumulated until a threshold value of 15 DSV was reached, a fungicide spray was applied, and the DSV total was reset to zero.

Chlorothalonil (Bravo Ultrex 82.5WDG at 1.29 kg a.i./ha, Zeneca Ag Products, Wilmington, DE) was applied to all treatment plots, excluding the control. Fungicides were applied with a CO_2 backpack sprayer (R & D Sprayers, Opelousas, LA) equipped with three Teejet XR11002VS flat-fan nozzles (Spraying Systems Co., Wheaton, IL) spaced 45.7 cm apart, operating at 344.8 kPa, and delivering 467.6 liters/ha. Sprays were applied every seven days or according to the modified Cercospora predictor, the modified Alternaria predictor, or Tom-Cast using a threshold of 15 DSVs. Treatment plots were arranged in a randomized complete block design and replicated four times.

Initial sprays for the weekly schedule and Tom-Cast were applied prior to blight symptom development on 2 July 2001 and 8 July 2002. The modified Cercospora predictor prompted the first application on 24 July 2001 and 11 July 2002. Initial sprays for the Alternaria predictor occurred when the 1 to 2% blight threshold was reached on 14 August 2001 and 4 August 2002. In 2001, the 7-day schedule, modified Cercospora predictor, modified Alternaria predictor, and Tom-Cast treatments received 13, 4, 5, and 8 chlorothalonil applications, respectively. In 2002, the 7-day schedule, modified Cercospora predictor, modified Alternaria predictor, and Tom-Cast treatments received 13, 7, 6, and 6 chlorothalonil applications, respectively. The total cost of each fungicide program was calculated by multiplying the number of applications by the cost of chlorothalonil used (Table 1). Dates of fungicide applications are listed in Appendix A (Tables 23 and 24).

Disease assessment. All disease assessments were made from the center 3.05 m of the middle row of each plot. Leaf blight severity was determined biweekly (2001) or weekly (2002) using an expanded Alternaria leaf blight assessment key (Strandberg

Table 1. Effect of disease caused by *A. dauci* and *C. carotae* on yield of 'Cellobunch' carrots left untreated or sprayed with the fungicide chlorothalonil (1.29 kg a.i./ha) applied every seven days or according to disease forecasters and number of fungicide applications and cost of fungicide treatments in 2001 and 2002.

Treatment	**Yield (kg)**[z]	**2001**		**2002**	
		# Sprays	**Cost/A**[y]	**# Sprays**	**Cost/A**
Untreated	11.09 b[x]	0	0.00	0	0.00
7-day	13.45 ab	13	122.85	13	101.92
Mod. Cercospora Predictor	14.15 a	4	37.80	7	54.88
Mod. Alternaria Predictor	13.41 ab	5	47.25	6	47.04
Tom-Cast 15 DSV	13.81 a	8	75.60	6	47.04

Source	F *value*	P *value*
Treatment	4.48	0.0076

[z] Carrots from the center 3.05 m of the middle row of each plot were hand-harvested, the foliage was removed at the crown, and roots were weighed to determine yield on 2 October 2001 and 2002.

[z] Cost/A was determined using a fungicide cost of chlorothalonil (Bravo Ultrex 82.5WDG) at \$6.75/lb (2001) and \$5.60/lb (2002). Cost/A does not include labor, fuel, or machinery costs.

[y] Means within a column followed by the same letter are not significantly different according to Tukey's Studentized Range test (HSD; P = 0.05).

1988). Plots were visually assessed as having 0, 1, 5, 10, 20, or 40% leaf blight, and the key was expanded to estimate 60, 80, and 100% leaf blight. Petiole disease incidence was determined biweekly (2001) or weekly (2002) by counting the number of plants with one or more lesions. Petiole disease severity was evaluated concurrently with petiole disease incidence using the following scale: 1 = average of 0 to 5 lesions per plant; 2 = 6 to 20 lesions; 3 = 21 to 50 lesions; 4 = more than 50 lesions; 5 = dead. An additional petiole rating was conducted to estimate the overall health, amount of dead and living petioles, and condition of petioles for harvest. Petiole health was determined on the day before harvest in 2001 and weekly in 2002 starting 2 September and continuing with other disease evaluations until harvest. The following scale (1-10) was used to assess petiole health: where 1 = petioles healthy and vigorous to 10 = petioles unhealthy, weak, or dead. The area under the disease progress curve (AUDPC) was calculated to express the cumulative disease incidence on petioles, severity of disease on petioles, leaf blight, and petiole health (2002 only) by the calculation described by Shaner and Finney (1977):

$$AUDPC = \sum_{i=1}^{n} [(Y_{i+n_1} + Y_i)/2][X_{i+1} - X_i]$$

where Y_i = percent foliar blight, percent petiole blight, or petiole health rating at the *i*th observation, X_i = time (days) at the *i*th observation, and n = total number of observations. Carrots in the center 3.05 m of the middle row of each plot were hand-harvested, the foliage was removed at the crown, and roots were weighed to determine yield on 2 October 2001 and 2002. Leaves showing blight symptoms were periodically removed from untreated buffer rows and examined under magnification (200X) in the laboratory to confirm the presence of *A. dauci* and/or *C. carotae*.

Statistical analysis. Data for all disease assessments and yield were analyzed with analysis of variance (ANOVA) using the Proc GLM procedure of the Statistical Analysis System (SAS Institute, Cory, NC) in which a linear model including treatment, year, year by treatment, and replicate nested within year were factors. The assumptions of normality and equal variances were examined using the residuals from the ANOVA. Normality was examined using the Proc Univariate procedure of SAS, and the equal variance assumption was assessed by plotting the residuals. The AUDPC data for petiole blight incidence were not normally distributed and were transformed to normality using: square root (AUDPC). There were significant year by treatment interactions for the AUDPC data for petiole blight severity and the petiole health data from the final rating, so analyses were done separately for each year using an analysis of a randomized complete block experiment. Data were analyzed using a linear model that included treatment and replicate as factors using the Proc GLM procedure of SAS. Treatment effects were examined using Tukey's Studentized Range (HSD) test.

RESULTS

The 7-day schedule was the most costly fungicide program (Table 1), since it required 13 applications. In 2001, the modified Cercospora predictor, modified Alternaria predictor, and Tom-Cast disease forecaster eliminated nine, eight, and five applications, respectively, saving $85.05, $75.60, and $47.25 per acre compared with the 7-day schedule. In 2002, the modified Cercospora predictor, modified Alternaria predictor, and Tom-Cast disease forecaster eliminated six, seven, and seven applications, respectively, saving $47.04, $54.88, and $54.88 per acre compared with the 7-day schedule.

Table 2. Effect of disease caused by *A. dauci* and *C. carotae* on the area under the disease progress curve for petiole and leaf blight on 'Cellobunch' carrots left untreated or sprayed with the fungicide chlorothalonil (1.29 kg a.i./ha) applied every seven days or according to disease forecasters in 2001 and 2002.

Treatment[z]	AUDPC (disease*day)[y]							
	Petiole blight						Leaf blight	
	Incidence[x]		Severity[w]					
			2001		2002			
Untreated	2780.02	c[v]	66.50	b	169.93	b	979.13	b
7-day	79.26	a	28.00	a	75.00	a	42.38	a
Mod. Cercospora Predictor	515.96	b	28.00	a	75.00	a	88.88	a
Mod. Alternaria Predictor	1874.22	c	29.75	a	93.13	a	153.38	a
Tom-Cast 15 DSV	308.34	ab	28.00	a	75.00	a	58.63	a
Source	F *value*	P *value*	F *value*	P *value*	F *value*	P *value*	F *value*	P *value*
Treatment	38.34	<.0001	59.25	<.0001	49.60	<.0001	44.06	<.0001

[z] Treatments received the following number of sprays: Untreated = 0; 7-day = 13 in 2001 and 2002; Modified Cercospora Predictor = 4 and 7 in 2001 and 2002, respectively; Modified Alternaria Predictor = 5 and 6 in 2001 and 2002, respectively; Tom-Cast 15 DSV = 8 and 6 in 2001 and 2002, respectively.

[y] AUDPC = area under the disease progress curve. Data sets from 2001 and 2002 were pooled when the year*treatment interaction was not significant ($P > 0.05$).

[x] Data were transformed using square root (AUDPC) to stabilize the variance. The table shows back-transformed data.

[w] Data from each year were analyzed separately due to a significant year*treatment interaction.

[v] Means within a column followed by the same letter are not significantly different according to Tukey's Studentized Range test (HSD; $P = 0.05$).

Leaf blights were detected in plots during the first week of August in 2001 and 2002 (Figure 1). Petiole blight progressed rapidly during August 2002 when the incidence of petiole blight in untreated plots went from 4% to 97% in a 29-day period from 4 August through 2 September. The incidence of petiole blight in untreated plots reached 84.2% and 100% on 22 September 2001 and 8 September 2002, respectively (Figure 1). A summary of final disease assessments is listed in Appendix A (Table 25).

According to the AUDPC data, all fungicide treatments were equally effective in significantly reducing petiole blight severity and leaf blight compared with the untreated (Table 2). The AUDPC data of petiole blight incidence indicated that the Tom-Cast system was comparable to the 7-day schedule and the modified Cercospora predictor. The 7-day schedule significantly reduced the incidence of petiole blight compared with the modified Cercospora predictor. Disease in the untreated plots and the modified Alternaria predictor plots did not differ (Table 2).

Untreated plots reached final petiole health ratings of 8.25 and 8.50 in 2001 and 2002, respectively and were significantly different from all of the fungicide treatments (Table 3). The petiole health data suggest that all fungicide treatments were similar, and according to the AUDPC data reduced disease compared with the untreated plots. In 2001, the 7-day schedule and Tom-Cast improved petiole health compared with the modified Alternaria predictor. Tom-Cast was also similar to the modified Cercospora predictor, which had a significantly higher petiole health rating compared to the 7-day schedule. In 2002, the modified Cercospora predictor and Tom-Cast application schedules were not significantly different from the 7-day schedule. Although the modified Cercospora predictor and Tom-Cast treatments were comparable to the

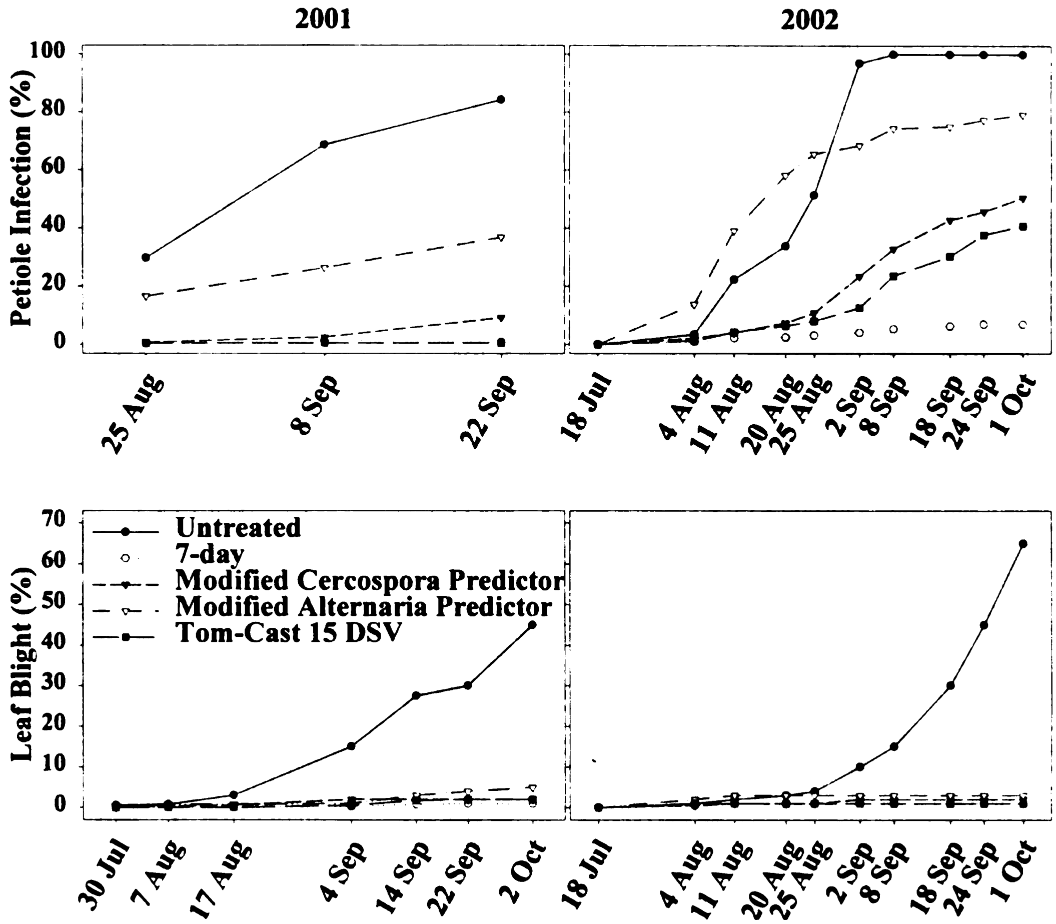

Figure 1. Disease progress curves for petiole and leaf blight caused by *A. dauci* and *C. carotae* on 'Cellobunch' carrots left untreated or treated with the fungicide chlorothalonil (1.29 kg a.i./ha) applied every 7 days or according to disease forecasters in 2001 and 2002.

Table 3. Effect of disease caused by *A. dauci* and *C. carotae* on petiole health of 'Cellobunch' carrots left untreated or sprayed with the fungicide chlorothalonil (1.29 kg a.i./ha) applied every seven days or according to disease forecasters in 2001 and 2002.

Treatment[z]	Petiole health[y]					
	AUDPC (disease*day)[x]		Final rating[w]			
	2002		2001		2002	
Untreated	199.38	b[v]	8.25	d	8.50	c
7-day	64.50	a	1.00	a	2.25	a
Mod. Cercospora Predictor	75.13	a	3.00	b	3.00	ab
Mod. Alternaria Predictor	88.88	a	5.25	c	3.50	b
Tom-Cast 15 DSV	76.25	a	2.00	ab	2.75	ab
Source	F *value*	P *value*	F *value*	P *value*	F *value*	P *value*
Treatment	30.02	<.0001	161.16	<.0001	101.13	<.0001

[z] Treatments received the following number of sprays: Untreated = 0; 7-day = 13 in 2001 and 2002; Modified Cercospora Predictor = 4 and 7 in 2001 and 2002, respectively; Modified Alternaria Predictor = 5 and 6 in 2001 and 2002, respectively; Tom-Cast 15 DSV = 8 and 6 in 2001 and 2002, respectively.

[y] Petiole health was evaluated using a 1 to 10 scale; where 1 = petioles healthy and vigorous to 10 = petioles unhealthy, weak, or dead.

[x] AUDPC = area under the disease progress curve.

[w] Data from each year were analyzed separately due to a significant year*treatment interaction.

[v] Means within a column followed by the same letter are not significantly different according to Tukey's Studentized Range test (HSD; P = 0.05).

modified Alternaria predictor, the Alternaria predictor resulted in significantly more disease than the 7-day schedule (Table 3).

The analysis of yield indicated a significant treatment effect (Table 1). All fungicide-treated plots were similar to one another, but the untreated had significantly lower yields than the modified Cercospora predictor and Tom-Cast treatments.

All disease forecasters provided similar disease control compared with the 7-day schedule by limiting the AUDPC for petiole blight severity, petiole health, and leaf blight. However, the modified Cercospora and Alternaria predictors were not always as effective as Tom-Cast in limiting the AUDPC for petiole blight incidence and improving the final petiole health rating.

DISCUSSION

Carrot growers in Michigan have been concerned that they may be applying fungicides more frequently than needed and when environmental conditions do not favor blight development. An alternative method of scheduling fungicide applications was needed. The goal of this study was to determine if disease forecasting systems could be used to effectively time fungicide applications to control Alternaria and Cercospora blights without compromising yield.

Although the Tom-Cast disease forecaster generally eliminated the least number of sprays compared with the other forecasting systems tested, it was the most effective in consistently limiting disease when compared to the 7-day schedule. In addition, Tom-Cast was the most reliable and simple disease forecaster tested in this study. The hourly measurements of leaf wetness and temperature during the wetness periods were downloaded to a laptop computer equipped with the Specware program that calculated the DSV accumulation each day. The automated system eliminated the tedious calculations required to time sprays according to the modified Cercospora predictor. The use of in-field environmental measurements was a benefit of Tom-Cast disease forecaster when compared with the modified Alternaria predictor. For example, the leaf wetness sensor detected the moisture generated by irrigation events, thereby extending the hours of leaf wetness used in the DSV calculation.

The modified Cercospora predictor required daily monitoring once the 7-day spray interval expired. If at least 12 hours with R.H. $\geq$90% had occurred and temperature requirements were met, several other measurements from the previous two and three days had to be considered before a spray was prompted. The calculation process was not automated using a computer program and required a considerable amount of time that growers would likely avoid.

The modified Alternaria predictor required a spray the day before forecasted rain assuming seven days had passed since the last fungicide application. Plots at the muck farm were irrigated, but irrigation was not considered as a rain event in this study. If irrigation was considered as a rain event, the modified Alternaria predictor would have prompted several more sprays because plots were irrigated once and sometime twice a week during July and August. The projected number of sprays applied according to the modified Alternaria predictor would have been similar to that of the 7-day schedule if overhead irrigations were considered as rain events.

The yield measurements recorded in this study does not reflect yields that may be recorded in a commercial production situation where carrots are mechanically harvested. All carrots in 3.05 m of the center row were hand harvested, whereas yield losses may have become increasingly evident if plots were harvested mechanically. Based on observations from mechanically harvested commercial carrot fields, yield reduction occurs frequently when the final petiole health is a rating of five or above.

Disease forecasting is a viable and economical alternative to the calendar-based fungicide schedule currently used in Michigan. The disease forecasters tested in this study prompted fewer sprays than the 7-day treatment, but did not always provide disease control similar to the 7-day schedule. The Tom-Cast disease forecasting system controlled disease as effectively as the 7-day schedule while reducing the number of sprays by 38 and 54% in 2001 and 2002, respectively. The adoption of disease forecasting systems will likely depend on the reliability and simplicity of the particular system. Tom-Cast was a dependable and economical system for timing fungicide sprays to control Alternaria and Cercospora blights of carrots.

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CHAPTER II.

TIMING FUNGICIDE APPLICATIONS ACCORDING TO FIELD SCOUTING AND TOM-CAST TO CONTROL ALTERNARIA AND CERCOSPORA BLIGHTS OF CARROTS

ABSTRACT

Fungal foliar blights of carrots, caused by *Alternaria dauci* and *Cercospora carotae*, result in necrotic lesions on leaves and petioles that may cause defoliation, decreasing the efficiency of mechanical harvest. Traditionally, fungicides are applied every 7 to 10 days, regardless of weather conditions or disease pressure. The primary objectives of this study were to evaluate the Tom-Cast disease forecasting system for timing fungicide sprays to control foliar blights, and to determine when to apply the first spray based on field scouting and disease incidence. Chlorothalonil alternated with azoxystrobin was applied every 10 days or according to Tom-Cast with a threshold of 15, 20, or 25 disease severity values (DSVs). Sprays for these programs were initiated prior to symptom development, or when foliage was infected at a trace, 5%, or 10% level. Up to four sprays were omitted saving $46.05 and $41.85 per acre in 2001 and 2002, respectively, and comparable disease control was achieved by initiating applications when a trace amount of the foliage was blighted and applying subsequent sprays according to Tom-Cast 15 DSV, compared with calendar-based sprays initiated prior to blight symptom development. Field scouting and the Tom-Cast disease forecaster appear to be valuable tools for determining the appropriate timing of fungicide applications on carrots while making blight control more cost effective.

INTRODUCTION

Alternaria dauci (Kühn) Groves & Skolko and *Cercospora carotae* (Passerini) Solheim, the fungi causing Alternaria blight and Cercospora blight, are the two prominent foliar pathogens that affect carrots (*Daucus carota* L. var. *sativa* DC.) in Michigan (Hausbeck and Harlan, 2003) and other areas (Arcelin and Kushalappa, 1991; James and Stevenson, 1999). Symptoms of *A. dauci* normally develop along leaf margins but can also affect the petioles and are characterized by irregularly shaped necrotic lesions. Small, pinpoint necrotic lesions caused by *C. carotae* are initially surrounded by a chlorotic halo and develop on the leaves or petioles. A dense crop canopy provides conditions favorable for disease development prompting Alternaria and Cercospora lesions to coalesce. If entire leaflets and petioles become blighted, they may not be able to withstand the pull of mechanical harvesters, and unharvested carrots will remain in the soil.

Carrots in Michigan are grown for fresh market, processing, and the cut and peel market. The three production systems use specific cultivars, plant spacing, and plant populations for their respective uses (Zandstra et al., 1986). Although no disease resistant cultivars are available, there are cultivars that exhibit levels of genetic tolerance to foliar blights (James et al., 1999; Strandberg et al., 1972).

Recommendations for controlling Alternaria and Cercospora blights in Michigan are to apply registered fungicides at 7 to 14 day intervals after carrot seedlings have emerged (Bird et al., 2002). Typically, growers will follow the recommended spray interval, but they will rarely apply their first fungicide spray before the plants are large enough to touch within the rows. Michigan carrot growers rely on two B2 carcinogenic fungicides, chlorothalonil and iprodione, to control Alternaria and Cercospora blights. Pesticides classified as B2 carcinogens are scheduled for review by the EPA under the Food Quality Protection Act (FQPA), and the future availability of these products is uncertain. One Michigan food processor does not allow the use of iprodione on carrots because it is a B2 carcinogen and residues are a concern. In addition, fungicide resistance of *A. dauci* to iprodione has been reported (Fancelli and Kimati, 1991). Azoxystrobin (Quadris, Syngenta Crop Protection, Greensboro, NC), a recently registered reduced risk systemic fungicide, is an effective tool to control Alternaria and Cercospora blights in rotation with protectant fungicides (Hausbeck et al., 2000; James and Stevenson, 1999). Use of this product in rotation with protectant fungicides already used by Michigan growers may reduce the number of B2 carcinogenic fungicide applications.

A disease forecasting system (FAST) was developed for timing fungicide applications to control early blight on tomato caused by *Alternaria solani* (Ellis & G. Martin) Sorauer (Madden et al., 1978). The forecaster uses a series of environmental inputs to alert growers as to when these conditions favor early blight development, and to subsequently prompt fungicide applications. Tom-Cast, a modification of FAST, warns growers when to control anthracnose fruit rot (*Collectotrichum coccodes* (Wallr.) Hughes) and Septoria leaf spot (*Septoria lycopersici* (Speg)) as well as *A. solani*. For each 24-hour period (11:00 AM to 11:00 AM), Tom-Cast uses the hours of leaf wetness and the average temperature during the wetness periods to calculate a Disease Severity Value (DSV) ranging from 0 to 4, corresponding to environmental conditions unfavorable to highly favorable for disease development. Daily DSV values are summed and accumulated until a threshold value is reached, a fungicide spray is applied, and the DSV total is reset to zero (Pitblado, 1992).

The objectives of this study were to 1) determine whether the Tom-Cast disease forecasting system can be used to time fungicide applications to control Alternaria and Cercospora blights of carrots, 2) set the critical DSV threshold for timing fungicide applications according to Tom-Cast, and 3) determine whether field scouting and disease incidence thresholds can be used to initiate spray programs.

MATERIALS AND METHODS

Plot establishment. Plots were established at the Michigan State University Muck Soils Experimental Farm in Bath, Michigan and at a commercial carrot field in Fremont, Michigan in 2001 and 2002. Beds at the Muck Soils Experimental Farm (hereafter referred to as the research farm) were formed and carrot seeds of the fresh market cultivar 'Cellobunch' and the processing cultivar 'Early Gold' were planted on 14 May 2001 and 21 May 2002 in Houghton Muck soil, previously planted with potato. Seeds were spaced 2.54 cm ('Early Gold') and 1.43 cm ('Cellobunch') apart in rows spaced 45.7 cm apart on three-row raised beds measuring 162.6 cm from center to center. Plant populations of 'Early Gold' were 431,657/ha (2001) and 418,775/ha (2002), and populations of 'Cellobunch' were 609,047/ha (2001) and 510,043/ha (2002). The study located in Fremont (hereafter referred to as the commercial field) was established with carrot seeds of the cut and peel cultivar 'Prime Cut' planted on 28 May 2001 and 6 June 2002 in Granby Mucky Sand, previously planted with corn. Seeds were placed 3.25 cm apart in four seed lines per row with rows spanning 15.2 cm and centered 43.2 cm apart in three-row raised beds measuring 172.7 cm from center to center. Plant populations were 1,444,156/ha (2001) and 1,328,887/ha (2002). All treatment plots were 6.1 m long. One and a half meter sections of unsprayed carrots separated treatment plots within beds, and one bed of carrots was left untreated between treatment beds. Natural inoculum was relied on for infecting plants. Weeds, insects, and fertilization requirements were managed according to standard production practices (Bird et al., 2002; Warncke et al., 1992; Zandstra, 2002). Plots were sprinkler irrigated as needed.

Weather monitoring and disease forecasting. Hourly measurements of temperature and leaf wetness duration were obtained using a digital data recorder (WatchDog Leaf Wetness and Temperature Logger 3610TWD; Spectrum Technologies, Inc., Plainfield, Illinois) located in the upper 75% of the crop canopy in the center of an unsprayed bed at a 45° angle facing north. Data recorders were place in the plots prior to row closure in mid-June. Data were downloaded every other day to a laptop computer using a computer program (Specware 6.01; Spectrum Technologies, Inc., Plainfield, Illinois) equipped to calculate DSVs for the Tom-Cast system. The program was set to record temperatures from 0 to 100° C and to detect leaf wetness whenever moisture was present on the leaf wetness grid. Summaries of weather data and DSV accumulation from the trial sites are listed in Appendix A (Tables 22 and 26).

Chlorothalonil (Bravo Ultrex 82.5WDG at 1.29 kg a.i./ha, Zeneca Ag Products, Wilmington, DE) alternated with azoxystrobin (Quadris 2.08F at 0.11 kg a.i./ha, Syngenta Crop Protection, Greensboro, NC) were applied to all treatment plots, excluding the control. Fungicides were applied with a CO_2 backpack sprayer (R & D Sprayers, Opelousas, LA) equipped with three Teejet XR11002VS flat-fan nozzles (Spraying Systems Co., Wheaton, IL) spaced 45.7 cm apart, operating at 344.8 kPa, and delivering 467.6 liters/ha.

Fields were scouted for disease symptoms using a disease damage index key (Strandberg, 1988), and spray programs were initiated prior to symptom development (0%), or when disease was evident on a trace amount, 5%, or 10% of the foliage. Initial sprays at the research farm occurred on 2 July (0%), 30 July (trace), 15 August (5%), and 25 August (10%) in 2001 and 8 July (0%), 19 July (trace), 1 August (5%), and 13 August (10%) in 2002. Initial sprays were applied at the commercial field on 8 July (0%), 20 July (trace), 25 July (5%), and 1 August (10%) in 2001 and 15 July (0%), 22 July (trace), 5 August (5%), and 19 August (10%) in 2002. Subsequent sprays were applied every 10 days or according to Tom-Cast at intervals of 15, 20, or 25 DSVs. In 2002, a 7-day fungicide schedule was included in the commercial field study to reflect the typical application schedule followed by commercial (cut and peel) carrot growers in the area. Treatment plots were assigned to each variety and replicated four times in a randomized complete block design.

At the research farm, Tom-Cast prompted eight, six, and five sprays in 2001 and six, five, and four sprays in 2002 for the 15 DSV, 20 DSV, and 25 DSV thresholds, respectively, for spray programs initiated prior to disease symptom development. Five, four, and three sprays (2001 and 2002) were applied for the Tom-Cast 15, 20, and 25 DSV thresholds, respectively, for sprays programs initiated when a trace amount of blight symptoms developed. Fungicide sprays initiated when 5% of the foliage was blighted resulted in three, two, and two sprays in 2001 and four, three, and two sprays in 2002 for the Tom-Cast 15, 20, and 25 DSV thresholds, respectively. Two, one, and one spray(s) in 2001 and three, two, and two sprays in 2002 were applied for the Tom-Cast 15, 20, and

25 DSV thresholds, respectively, for treatments initiated when 10% blight symptoms developed. Ten-day spray interval treatments initiated prior to disease symptom development scheduled nine applications in 2001 and 2002. Ten-day spray interval treatments initiated when a trace amount of blight symptoms developed resulted in six and eight applications in 2001 and 2002, respectively. Ten-day spray interval treatments initiated when 5% of the foliage was blighted prompted four and seven applications in 2001 and 2002, respectively. Ten-day spray interval treatments initiated when 10% blight symptoms developed scheduled three and five applications in 2001 and 2002, respectively. Dates of fungicide applications are listed in Appendix A (Tables 27 and 28).

At the commercial field, Tom-Cast prompted nine, seven, and five sprays in 2001 and eight, six, and five sprays in 2002 for the 15 DSV, 20 DSV, and 25 DSV thresholds, respectively, for spray programs initiated prior to disease symptom development. Eight, six, and five sprays in 2001 and seven, six, and four sprays in 2002 were applied for the Tom-Cast 15, 20, and 25 DSV thresholds, respectively, for sprays programs initiated when a trace amount of blight symptoms developed. Fungicide sprays initiated when 5% of the foliage was blighted resulted in seven, five, and four sprays in 2001 and five, four, and three sprays in 2002 for the Tom-Cast 15, 20, and 25 DSV thresholds, respectively. Six, five, and four sprays in 2001 and four, three, and three sprays in 2002 were applied when sprays were initiated when 10% blight symptoms developed for the Tom-Cast 15, 20, and 25 DSV thresholds, respectively, for treatments initiated when 10% blight symptoms developed. Ten-day spray interval treatments initiated prior to disease development scheduled nine and eight applications in 2001 and 2002. Ten-day spray interval treatments initiated when a trace amount of blight symptoms developed resulted in seven and eight applications in 2001 and 2002, respectively. Ten-day spray interval treatments initiated when 5% of the foliage was blighted prompted seven and six applications in 2001 and 2002. Ten-day spray interval treatments initiated when 10% of the foliage was blighted scheduled six and five applications in 2001 and 2002, respectively. Sprays were applied on a 7-day schedule at the commercial field in 2002 only. Twelve, eleven, nine, and seven sprays were applied on a 7-day schedule for treatments that started prior to blight occurrence or when a trace amount, 5%, or 10% of the foliage was diseased, respectively. Dates of fungicide applications are listed in Appendix A (Tables 29 and 30).

Disease assessment. All disease assessments were made from the center 3.05 m of the middle row of each plot at the research farm and from carrots in the four seed lines of the middle 1.52 m of the center row in the commercial field. Leaf blight severity was assessed biweekly (research farm only, 2001) or weekly using an expanded Alternaria leaf blight assessment key (Strandberg, 1988). Plots were visually assessed as having 0, 1, 5, 10, 20, or 40% leaf blight, and the key was expanded to estimate 60, 80, and 100% leaf blight. Petiole disease incidence was determined biweekly (research farm only, 2001) or weekly by counting the number of plants with one or more lesions. Petiole disease severity was evaluated concurrently with petiole disease incidence using the following scale: 1 = average of 0 to 5 lesions per plant; 2 = 6 to 20 lesions; 3 = 21 to 50 lesions; 4 = more than 50 lesions; 5 = dead. An additional petiole rating was conducted to estimate the overall health, amount of dead and living petioles, and condition of petioles for harvest; petiole health was not recorded in 2001 at the commercial field.

Petiole health was determined on the day before harvest at the muck farm in 2001 and weekly at the research farm and commercial field in 2002 starting on 27 August and 26 August, respectively and continuing with the other disease evaluations until harvest. The following scale (1-10) was used to assess petiole health: from 1 = petioles healthy and vigorous to 10 = petioles unhealthy, weak, or dead. The area under the disease progress curve (AUDPC) was calculated to express the cumulative disease incidence on petioles, severity of disease on petioles, leaf blight, and petiole health (2002 only) by the calculation described by Shaner and Finney (1977):

$$AUDPC = \sum_{i=1}^{n} [(Y_{i+n1} + Y_{i})/2][X_{i+1} - X_{i}]$$

where Y_i = percent foliar blight, percent petiole blight, or petiole health rating at the *i*th observation, X_i = time (days) at the *i*th observation, and n = total number of observations. Carrots in the center 3.05 m of the middle row of each plot were hand-harvested, the foliage was removed at the crown, and roots were weighed to determine yield on 2 October 2001 and 3 October 2002 at the research farm and 27 September 2001 and 8 October 2002 in the commercial field. Leaves showing blight symptoms were periodically removed from untreated buffer rows and examined under magnification (200X) in the laboratory to confirm the presence of *A. dauci* and/or *C. carotae*.

Statistical and economic analysis. 'Early Gold' and 'Cellobunch' varieties were individually analyzed as single experiments with replicates across years, and the experiment was designed as a split-plot in time, with each year's data representing a randomized complete block design. Data for all variables were initially analyzed using analysis of variance (ANOVA) in which a linear model including treatment, year, year by treatment, and replicate nested within year as factors was analyzed using the Proc GLM procedure of the Statistical Analysis System (SAS Institute, Cory, NC). The assumptions of normality and equal variances were examined using the residuals from the ANOVA. Normality was examined using the Proc Univariate procedure of SAS, and the equal variance assumption was assessed by plotting the residuals. Data that did not pass normality tests were transformed (Table 4).

When the year by treatment interaction was significant for a variable, analyses were done separately for each year using an analysis of a randomized complete block experiment. Data were analyzed using a linear model that included treatment and replicate as factors using the Proc GLM procedure of SAS (SAS Institute, Cory, NC).

The 17 treatments examined in the 'Early Gold', 'Cellobunch', and 'Prime Cut' (2001 only) experiments represent a four (initiation timings) by four (application intervals) factorial with an untreated control as the 17^{th} treatment. Twenty-one treatments were tested on 'Prime Cut' in 2002, due to the addition of a 7-day application interval, representing a four (initiation timings) by five (application intervals) factorial with an untreated control as the 21^{st} treatment. The 'Prime Cut' experiments during 2001 and 2002 were analyzed separately using a linear model that included treatment and replicate as factors using the Proc GLM procedure of SAS.

When the ANOVA indicated a significant difference among the treatments, the differences among the treatments were examined by decomposing the treatment sum of squares into four component sum of squares: (1) the difference between the average of the spray treatments and the untreated control; (2) differences between initiation timings; (3) differences between application intervals; (4) an interaction between initiation timings and application intervals. When the analyses did not detect a significant interaction

Table 4. Summary of disease assessment variables that were not normally distributed and accompanying transformations used to normalize variables.

Cultivar Non-normal variable[z]	Transformation	Back-transformed means displayed
'Early Gold'		
Petiole blight severity AUDPC	log (AUDPC + 1)	Table 10
Leaf blight AUDPC	square root (AUDPC)	Table 10
Petiole blight incidence 2001 AUDPC	square root (AUDPC)	Tables 10 and 11
'Cellobunch'		
Petiole blight severity AUDPC	--	Table 14
Leaf blight AUDPC	log (AUDPC + 1)	Table 14
'Prime Cut'		
Petiole blight severity 2001 AUDPC	--	Table 16

[z] 'Cellobunch' petiole blight severity AUDPC and 'Prime Cut' petiole blight severity 2001 AUDPC could not be normalized with a transformation. Statistical analyses for these variables were conducted using non-normal, non-transformed data and means displayed in tables represent non-normal, non-transformed data.

between initiation timings and application intervals, the main effects of initiation timing and application interval were examined using the Waller-Duncan Bayesian k-ratio t-test (Steel et al., 1997) to determine which initiation timing or application interval had the best mean. When a significant initiation timing by application interval interaction occurred, the effect of initiation timings for each application interval were determined using the Waller-Duncan Bayesian k-ratio t-test.

The total cost of each fungicide program was calculated by multiplying the number of applications by the cost of the fungicide used (Table 5). Fungicide costs for one application of chlorothalonil were $9.45 and $7.84 per acre in 2001 and 2002, respectively; one application of azoxystrobin cost $13.58 and $13.08 per acre in 2001 and 2002, respectively.

RESULTS

The effect of treatment was highly significant for all disease assessments on the three cultivars examined. Treatments significantly affected yield of 'Prime Cut' carrots in 2002 (Table 6), but did not affect yield of 'Early Gold' (Table 7), 'Cellobunch' (Table 8), or 'Prime Cut' carrots in 2001 (Table 9). For each cultivar, all fungicide-treated plots had significantly less disease on leaves and petioles compared with the untreated plots. Timing the initial fungicide application based on scouting for leaf blight thresholds of 0%, trace, 5%, and 10% had a highly significant effect on all disease assessments for the three cultivars examined. Application interval significantly affected most disease assessments, but did not affect: 'Early Gold' AUDPC data for petiole blight incidence in 2002; 'Cellobunch' AUDPC data for petiole blight incidence; 'Cellobunch' AUDPC data for petiole blight severity; 'Prime Cut' AUDPC data for petiole blight severity in 2002.

Table 5. Number of fungicide applications and cost of fungicide treatments per acre for 'Early Gold', 'Cellobunch', and 'Prime Cut' carrots left untreated or sprayed with chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) initially applied based on disease incidence thresholds and reapplied every 7 or 10 days or according to Tom-Cast in 2001 and 2002.

Application schedule and initiation		'Early Gold' and 'Cellobunch'				'Prime Cut'			
		2001		2002		2001		2002	
		# Sprays	Cost/A[z]	# Sprays	Cost/A	# Sprays	Cost/A	# Sprays	Cost/A
Untreated		0	0.00	0	0.00	0	0.00	0	0.00
7 day	0%	--	--	--	--	--	--	12	125.53
	Trace	--	--	--	--	--	--	11	112.45
	5%	--	--	--	--	--	--	9	91.53
	10%	--	--	--	--	--	--	7	70.61
10 day	0%	9	101.56	9	91.53	9	101.56	8	83.69
	Trace	6	69.08	8	83.69	7	78.53	8	83.69
	5%	4	46.06	7	70.61	7	78.53	6	62.77
	10%	3	32.48	5	49.68	6	69.08	5	49.68
Tom-Cast 15 DSV	0%	8	92.11	6	62.77	9	101.56	8	83.69
	Trace	5	55.51	5	49.68	8	92.11	7	70.61
	5%	3	32.48	4	41.84	7	78.53	5	49.68
	10%	2	23.03	3	28.76	6	69.08	4	41.84
Tom-Cast 20 DSV	0%	6	69.08	5	49.68	7	78.53	6	62.77
	Trace	4	46.06	4	41.84	6	69.08	6	62.77
	5%	2	23.03	3	28.76	5	55.51	4	41.84
	10%	1	9.45	2	20.92	5	55.51	3	28.76
Tom-Cast 25 DSV	0%	5	55.51	4	41.84	5	55.51	5	49.68
	Trace	3	32.48	3	28.76	5	55.51	4	41.84
	5%	2	23.03	2	20.92	4	46.06	3	28.76
	10%	1	9.45	2	20.92	4	46.06	3	28.76

[z] Cost/A was determined using fungicide costs of: chlorothalonil (Bravo Ultrex 82.5WDG) at $6.75/lb (2001) and $5.60/lb (2002); azoxystrobin (Quadris 2.08F) at $280.00/gal (2001) and $270.00/gal (2002). Cost/A does not include labor, fuel, machinery, or scouting costs.

Table 6. Effects of spray initiation timings and application intervals on yield of 'Prime Cut' carrots treated with the fungicides chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) when initiated prior to disease development (0%) or at disease levels of trace, 5%, or 10% and reapplied at 7 or 10 day intervals or according to Tom-Cast at 15, 20, or 25 disease severity values (DSV) used to control foliar blights caused by *A. dauci* and *C. carotae* in 2002.

Treatment	**Yield (kg)**[z]	
Initiation timing		
0%	5.50	a[y]
Trace	5.75	a
5%	5.10	b
10%	4.77	b
Application interval		
7 day	5.38	a[x]
10 day	5.32	a
Tom-Cast 15 DSV	5.19	a
Tom-Cast 20 DSV	5.39	a
Tom-Cast 25 DSV	5.14	a
Source	F *value*	P *value*
Treatment	2.70	0.0016
Initiation timing	10.47	<.0001
Application interval	0.58	0.6803
Timing*interval interaction	1.44	0.1738
Untreated vs. treated	3.00	0.0886

[z] Carrots from the center 3.05 m of the middle row of each plot were hand-harvested, the foliage was removed at the crown, and roots were weighed to determine yield on 8 October 2002.

[y] Initiation timing means followed by the same letter are not significantly different according to Waller-Duncan Bayesian k-ratio t-test (k-ratio = 100).

[x] Application interval means followed by the same letter are not significantly different according to Waller-Duncan Bayesian k-ratio t-test (k-ratio = 100).

Table 7. Effect of the fungicides chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) when initiated prior to disease development (0%) or at disease levels of trace, 5%, or 10% and reapplied at 10-day intervals or according to Tom-Cast at 15, 20, or 25 disease severity values (DSV) on yield of 'Early Gold' carrots infected with *A. dauci* and *C. carotae* in 2001 and 2002.

Treatment	**Yield (kg)**[z]	
Untreated	13.34	
10 day		
0%	14.62	
Trace	15.51	
5%	14.90	
10%	13.39	
Tom-Cast 15 DSV		
0%	14.57	
Trace	14.26	
5%	13.90	
10%	13.40	
Tom-Cast 20 DSV		
0%	15.04	
Trace	15.86	
5%	13.91	
10%	13.56	
Tom-Cast 25 DSV		
0%	14.82	
Trace	14.29	
5%	13.78	
10%	13.81	
Source	F *value*	P *value*
Treatment	1.33	0.1968

[z] Carrots from the center 3.05 m of the middle row of each plot were hand-harvested, the foliage was removed at the crown, and roots were weighed to determine yield on 2 October 2001 and 3 October 2002.

Table 8. Effect of the fungicides chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) when initiated prior to disease development (0%) or at disease levels of trace, 5%, or 10% and reapplied at 10-day intervals or according to Tom-Cast at 15, 20, or 25 disease severity values (DSV) on yield of 'Cellobunch' carrots infected with *A. dauci* and *C. carotae* in 2001 and 2002.

Treatment	**Yield (kg)**[z]	
Untreated	9.70	
10 day		
0%	12.03	
Trace	11.17	
5%	12.06	
10%	11.23	
Tom-Cast 15 DSV		
0%	11.83	
Trace	11.63	
5%	10.90	
10%	10.59	
Tom-Cast 20 DSV		
0%	12.39	
Trace	11.15	
5%	11.45	
10%	12.15	
Tom-Cast 25 DSV		
0%	12.23	
Trace	10.81	
5%	10.25	
10%	10.28	
Source	F *value*	P *value*
Treatment	1.62	0.0775

[z] Carrots from the center 3.05 m of the middle row of each plot were hand-harvested, the foliage was removed at the crown, and roots were weighed to determine yield on 2 October 2001 and 3 October 2002.

Table 9. Effect of the fungicides chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) when initiated prior to disease development (0%) or at disease levels of trace, 5%, or 10% and reapplied at 10-day intervals or according to Tom-Cast at 15, 20, or 25 disease severity values (DSV) on yield of 'Prime Cut' carrots infected with *A. dauci* and *C. carotae* in 2001.

Treatment	Yield (kg)[z]
Untreated	7.53
10 day	
0%	9.03
Trace	9.67
5%	9.77
10%	10.23
Tom-Cast 15 DSV	
0%	9.07
Trace	9.46
5%	9.76
10%	9.05
Tom-Cast 20 DSV	
0%	9.22
Trace	9.67
5%	9.27
10%	9.99
Tom-Cast 25 DSV	
0%	9.33
Trace	8.58
5%	8.61
10%	8.32

Source	F *value*	P *value*
Treatment	1.38	0.1897

[z] Carrots from the center 3.05 m of the middle row of each plot were hand-harvested, the foliage was removed at the crown, and roots were weighed to determine yield on 27 September 2001.

The interaction of initial spray timings and application intervals was significant (P < 0.05) for the following variables: 'Early Gold' AUDPC data for petiole blight incidence in 2001; 'Early Gold' data for the final petiole health rating in 2001; 'Prime Cut' AUDPC data for petiole blight incidence in 2001; 'Prime Cut' AUDPC data for petiole blight incidence in 2002; 'Prime Cut' AUDPC data for leaf blight in 2002. The significant interaction of initiation timing and application interval indicated that the disease control provided by the application intervals was dependent on the time of the initial fungicide application.

Assessment of initial spray timing on 'Early Gold' carrots. The time of initial disease occurrence and progression of disease in untreated plots were different for the two years this study was conducted. Leaf blight was detected on 30 July and 18 July in 2001 and 2002, respectively (Figure 2). Levels of disease increased, where 100% petiole infection was observed on 4 September 2002 (Figure 3). In 2001, untreated plots reached 89.5% petiole infection on 28 September. A summary of final disease assessments is listed in Appendix A (Table 31).

The AUDPC data suggest that spray programs that were initiated prior to blight occurrence or when the first sign of disease was detected significantly reduced the incidence of petiole blight in 2002 and percentage of leaf blight throughout the growing season compared with spray programs that were initiated when 5 or 10% disease symptoms occurred (Table 10). Petiole blight severity was significantly higher for spray programs that were initiated when 5 or 10% leaf blight was detected compared with spray programs that were initiated prior to disease or at the first disease detection. Petiole blight severities of spray programs initiated when a trace amount of leaf blight developed

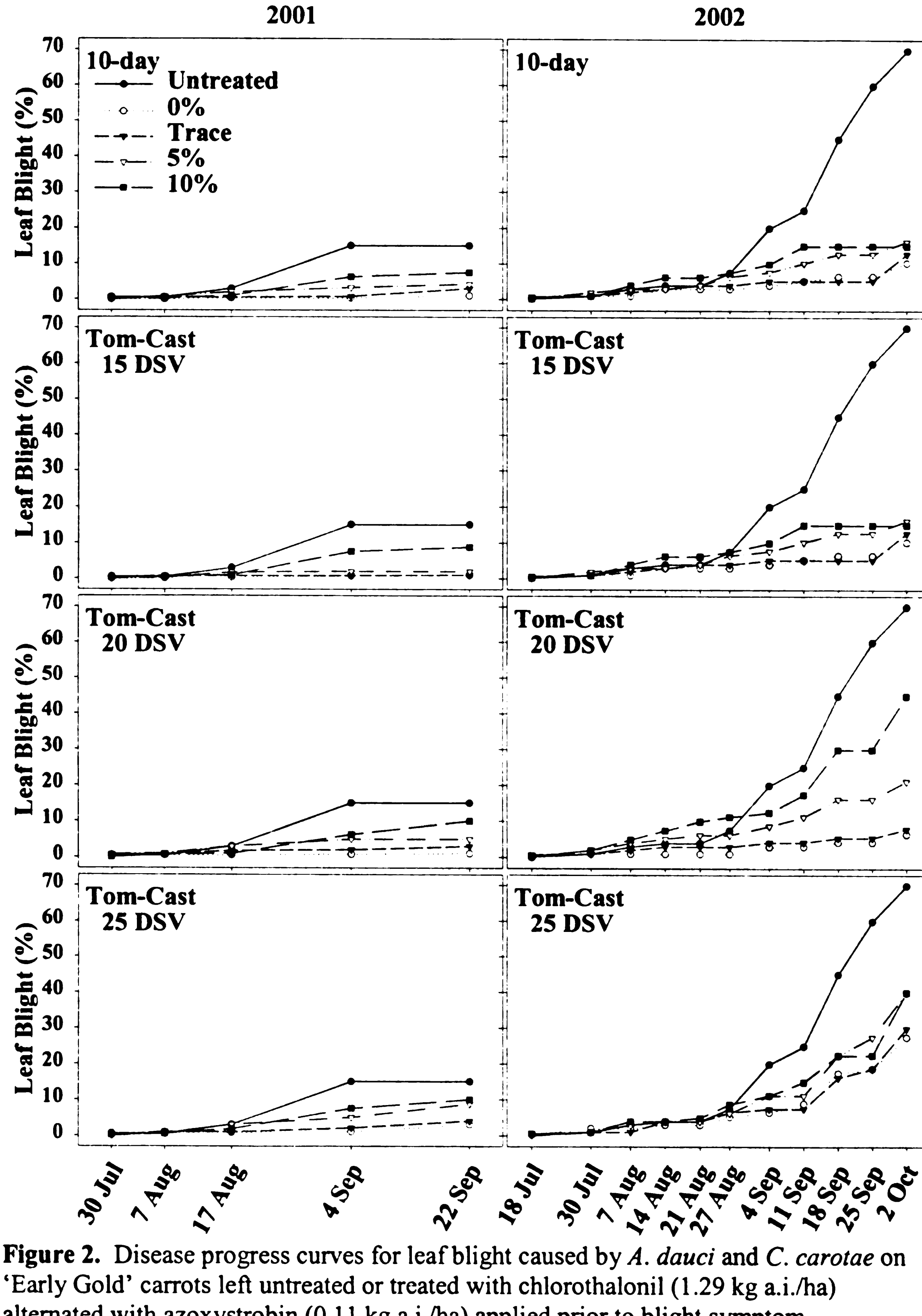

Figure 2. Disease progress curves for leaf blight caused by *A. dauci* and *C. carotae* on 'Early Gold' carrots left untreated or treated with chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) applied prior to blight symptom development (0%) or at disease levels of trace, 5%, 10% and reapplied every 10 days or according to Tom-Cast using intervals of 15, 20, or 25 DSVs in 2001 and 2002.

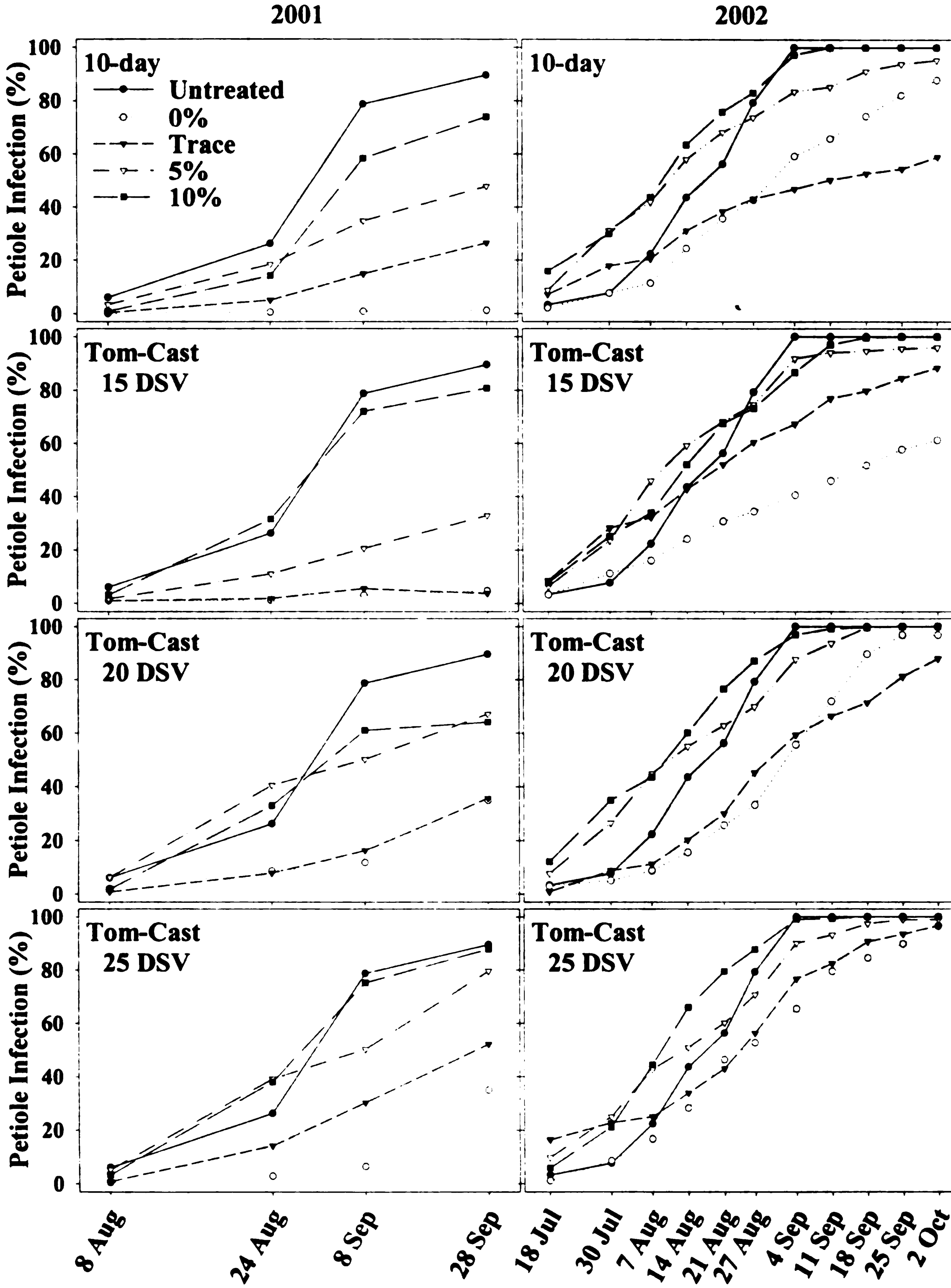

Figure 3. Disease progress curves for petiole blight caused by *A. dauci* and *C. carotae* on 'Early Gold' carrots left untreated or treated with chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) applied prior to blight symptom development (0%) or at disease levels of trace, 5%, 10% and reapplied every 10 days or according to Tom-Cast using intervals of 15, 20, or 25 DSVs in 2001 and 2002.

Table 10. Effects of spray initiation timings and application intervals on the area under the disease progress curve for petiole and leaf blights caused by *A. dauci* and *C. carotae* on 'Early Gold' carrots treated with the fungicides chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) when initiated prior to disease development (0%) or at disease levels of trace, 5%, or 10% and reapplied at 10 day intervals or according to Tom-Cast at 15, 20, or 25 disease severity values (DSV) in 2001 and 2002.

Treatment	AUDPC (disease*day)^{z}							
	Petiole blight							
	Incidence^{y}				Severity^{x}		Leaf blight^{w}	
	2001^{v}		2002					
Initiation timing								
0%	182.52		3135.55	a^{u}	67.27	a	122.91	a
Trace	502.70		3560.89	a	68.27	a	163.95	b
5%	1448.41		4953.66	b	89.08	b	283.71	c
10%	2226.42		5291.83	b	106.47	c	411.75	d
Application interval								
10 day	737.01		4072.30	a^{t}	77.42	a	196.24	a
Tom-Cast 15 DSV	657.31		4138.72	a	77.17	a	186.85	a
Tom-Cast 20 DSV	1013.47		4189.81	a	83.18	ab	250.88	b
Tom-Cast 25 DSV	1336.85		4541.10	a	87.73	b	306.56	c
Source	F *value*	P *value*	F *value*	P *value*	F *value*	P *value*	F *value*	P *value*
Treatment	18.54	<.0001	6.60	<.0001	19.32	<.0001	22.30	<.0001
Initiation timing	70.49	<.0001	29.30	<.0001	64.21	<.0001	56.96	<.0001
Application interval	7.50	0.0003	1.17	0.3315	4.97	0.0030	10.54	<.0001
Timing*interval interaction	3.20	0.0041	1.43	0.2022	0.89	0.5329	0.37	0.9446
Untreated vs. treated	33.90	<.0001	1.30	0.2602	93.49	<.0001	150.92	<.0001

^{z} AUDPC = area under the disease progress curve. Data sets from 2001 and 2002 were pooled when the year*treatment interaction was not significant (P>0.05).

^{y} Data from each year were analyzed separately due to a significant year*treatment interaction.

^{x} Data were transformed using log (AUDPC + 1) to stabilize the variance. The table shows back-transformed data.

Table 10 (cont'd).

[w] Data were transformed using square root (AUDPC) to stabilize the variance. The table shows back-transformed data.

[v] The effects of initiation timing and application interval were not examined due to a significant timing*interval interaction. Data were transformed using square root (AUDPC) to stabilize the variance. The table shows back-transformed data.

[u] Initiation timing means within a column followed by the same letter are not significantly different according to Waller-Duncan Bayesian k-ratio t-test (k-ratio = 100).

[t] Application interval means within a column followed by the same letter are not significantly different according to Waller-Duncan Bayesian k-ratio t-test (k-ratio = 100).

were not significantly different than the spray programs initiated prior to disease development (Table 10).

The analysis of AUDPC means for petiole blight incidence in 2001 indicated significant spray initiation timing by application interval interaction (Table 10). This suggested that the differences observed in the application intervals were dependent on the spray initiation timing. Initiation timings for the 10-day application interval were all significantly different from one another with spray programs initiated at lower blight incidence thresholds providing better disease control (Table 11). For the Tom-Cast 15 and 25 DSV application intervals, respectively, initiation timings were similar for sprays initiated prior to blight occurrence and when a trace of disease symptoms were detected, and were significantly lower than initiation timings of 5 and 10%, which also differed from one another. Tom-Cast 20 DSV spray programs that started when 5 or 10% blight occurred were similar but the AUDPC of these were significantly higher compared with programs that were initiated when blight was first detected. Also, the AUDPC of the Tom-Cast 20 DSV interval that started when disease was detected was higher than the AUDPC of the program that was initially sprayed prior to blight symptom development (Table 11).

The AUDPC data suggest that petiole health was significantly improved by applying the initial fungicide prior to disease detection or when disease symptoms were first detected compared with spray programs initiated at 5 or 10% leaf blight threshold (Table 12). In 2002, final petiole health ratings indicated no significant difference between spray programs initiated prior to blight symptom development and spray programs initiated when the first sign of disease symptoms were detected. Both the 5 and

Table 11. Effect of spray initiation timings for each application interval on the area under the disease progress curve of petiole blight caused by *A. dauci* and *C. carotae* on 'Early Gold' carrots treated with the fungicides chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) when initiated prior to disease development (0%) or at disease levels of trace, 5%, or 10% and reapplied at 10-day intervals or according to Tom-Cast at 15, 20, or 25 disease severity values (DSV) in 2001.

Application interval **Initiation timing**	**Petiole blight incidence** **AUDPC (disease*day)**[z]
10 day	
0%	23.54 a[y]
Trace	531.59 b
5%	1309.56 c
10%	1980.04 d
Tom-Cast 15 DSV	
0%	113.28 a
Trace	165.99 a
5%	811.42 b
10%	2550.12 c
Tom-Cast 20 DSV	
0%	134.76 a
Trace	513.11 b
5%	2354.31 c
10%	1985.52 c
Tom-Cast 25 DSV	
0%	725.61 a
Trace	966.79 a
5%	1523.94 b
10%	2418.96 c

[z] AUDPC = area under the disease progress curve. Data were transformed using square root (AUDPC) to stabilize the variance. The table shows back-transformed data.

[y] Means within each application interval followed by the same letter are not significantly different according to the Waller-Duncan Bayesian k-ratio t-test (k-ratio = 100).

Table 12. Effects of spray initiation timings and application intervals on the area under the disease progress curve and final ratings for petiole health of 'Early Gold' carrots treated with the fungicides chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) when initiated prior to disease development (0%) or at disease levels of trace, 5%, or 10% and reapplied at 10 day intervals or according to Tom-Cast at 15, 20, or 25 disease severity values (DSV) for control of *A. dauci* and *C. carotae* in 2001 and 2002.

	Petiole health					
Treatment	**AUDPC (disease*day)**[z]		**Final rating**[y]			
			2001[x]		**2002**	
Initiation timing						
0%	133.47	a[w]	2.50		5.00	a
Trace	135.00	a	3.56		4.88	a
5%	174.28	b	5.94		6.06	b
10%	188.34	b	7.19		6.94	c
Application interval						
10 day	141.31	a[v]	4.13		4.81	a
Tom-Cast 15 DSV	143.19	a	3.88		5.19	a
Tom-Cast 20 DSV	172.38	b	5.19		6.56	b
Tom-Cast 25 DSV	174.22	b	6.00		6.31	b
Source	F *value*	P *value*	F *value*	P *value*	F *value*	P *value*
Treatment	9.50	<.0001	16.46	<.0001	11.25	<.0001
Initiation timing	22.38	<.0001	54.66	<.0001	21.66	<.0001
Application interval	9.35	0.0001	11.48	<.0001	16.58	<.0001
Timing*interval interaction	0.98	0.4653	2.36	0.0268	0.79	0.6296
Untreated vs. treated	47.96	<.0001	43.64	<.0001	58.13	<.0001

[z] AUDPC = area under the disease progress curve. Data from 2001 and 2002 were pooled because the year*treatment interaction was not significant (P>0.05).

[y] Data from each year were analyzed separately due to a significant year*treatment interaction.

[x] The effects of initiation timing and application interval were not examined due to a significant timing*interval interaction.

Table 12 (cont'd).

[w] Initiation timing means within a column followed by the same letter are not significantly different according to Waller-Duncan Bayesian k-ratio t-test (k-ratio = 100).

[v] Application interval means within a column followed by the same letter are not significantly different according to Waller-Duncan Bayesian k-ratio t-test (k-ratio = 100).

10% spray initiation thresholds differed from one another and differed from the lower spray initiation thresholds (Table 12).

The analysis of the final petiole health rating in 2001 indicated a significant interaction between spray initiation and application interval (Table 12). This suggested that the differences observed in the application intervals were dependent on the spray initiation timing. Initiation timings of 5 or 10% leaf blight were similar for the 10-day spray schedule and Tom-Cast 20 DSV treatment, but were significantly higher than the program started at a trace of blight symptoms (Table 13). Programs that were initiated prior to disease development significantly improved petiole health compared with the program started at a trace amount of blight. Tom-Cast 15 DSV programs initiated prior to disease development or when a trace amount developed were similar and were significantly lower than programs initiated when 5% blight appeared. The program started when 10% blight developed was significantly higher compared with the program initiated when 5% blight developed. All of the spray initiation timings for the Tom-Cast 25 DSV treatment were different, and final ratings increased as the spray initiation threshold increased (Table 13).

Assessment of initial spray timing on 'Cellobunch' carrots. Disease progressed rapidly on 'Cellobunch' carrots during both years of this study. The incidence of petiole blight was observed on 5% and 36% of the untreated plants on 8 August 2001 and 7 August 2002, respectively (Figure 4). Untreated plots reached 84% and 100% petiole blight incidence on 28 September 2001 and 4 September 2002, respectively. Leaf blight in 2001 progressed from 4% on 17 August to 50% on 22 September (Figure 5). In 2002, severe leaf blight developed during the period of 11 September through 2 October

Table 13. Effect of spray initiation timings for each application interval on the final petiole health evaluation assessing disease caused by *A. dauci* and *C. carotae* on 'Early Gold' carrots treated with the fungicides chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) when initiated prior to disease development (0%) or at disease levels of trace, 5%, or 10% and reapplied at 10-day intervals or according to Tom-Cast at 15, 20, or 25 disease severity values (DSV) in 2001.

Application interval **Initiation timing**	**Final** **Petiole health**[z]
10 day	
0%	1.50 a[y]
Trace	3.00 b
5%	6.00 c
10%	6.00 c
Tom-Cast 15 DSV	
0%	2.25 a
Trace	1.50 a
5%	4.25 b
10%	7.50 c
Tom-Cast 20 DSV	
0%	2.00 a
Trace	4.50 b
5%	6.75 c
10%	7.50 c
Tom-Cast 25 DSV	
0%	4.25 a
Trace	5.25 b
5%	6.75 c
10%	7.75 d

[z] Petiole health was evaluated using the following scale; where 1 = petioles healthy and vigorous to 10 = petioles unhealthy, weak, or dead.

[y] Means within each application interval followed by the same letter are not significantly different according to the Waller-Duncan Bayesian k-ratio t-test (k-ratio = 100).

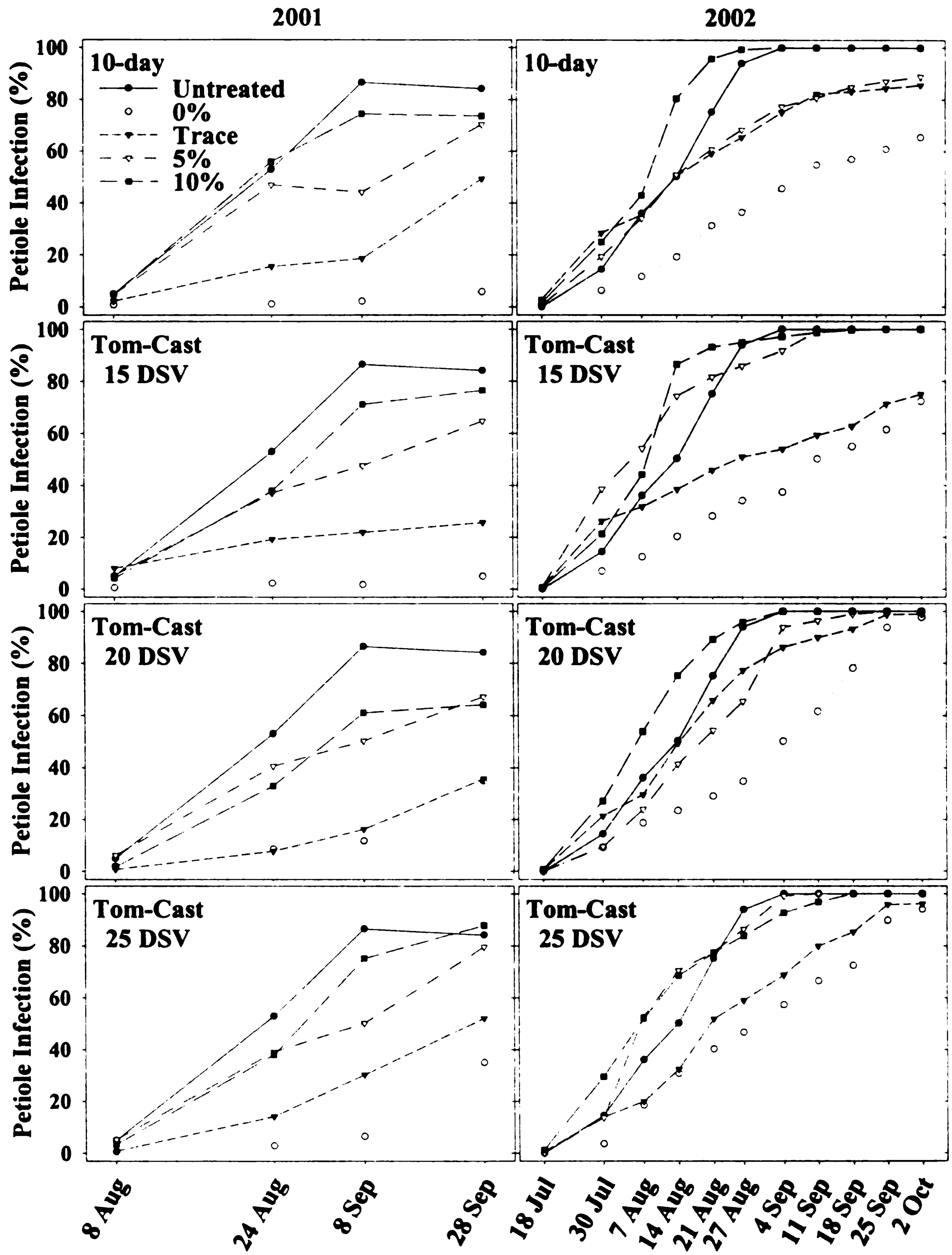

Figure 4. Disease progress curves for petiole blight caused by *A. dauci* and *C. carotae* on 'Cellobunch' carrots left untreated or treated with chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) applied prior to blight symptom development (0%) or at disease levels of trace, 5%, 10% and reapplied every 10 days or according to Tom-Cast using intervals of 15, 20, or 25 DSVs in 2001 and 2002

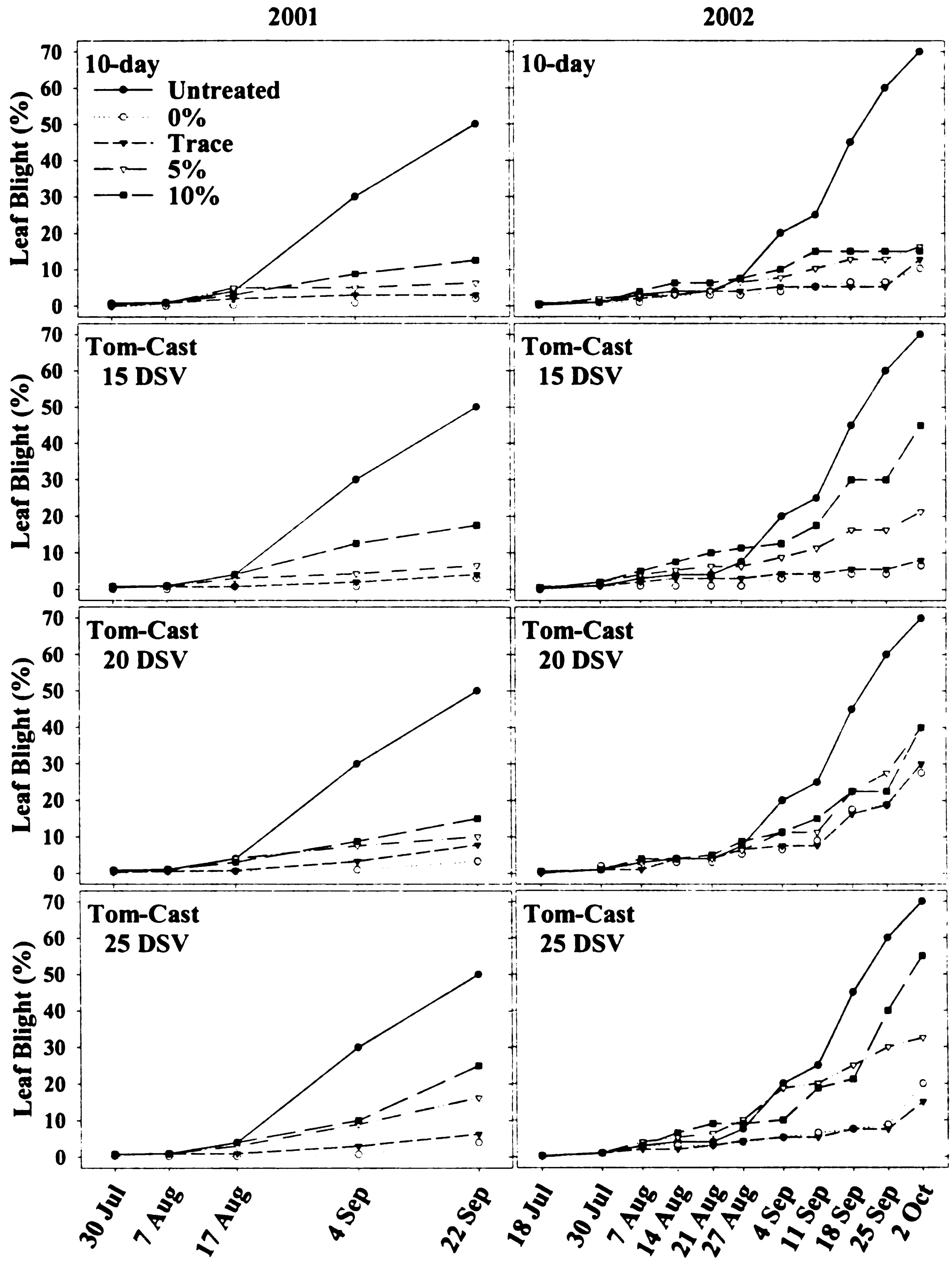

Figure 5. Disease progress curves for leaf blight caused by *A. dauci* and *C. carotae* on 'Cellobunch' carrots left untreated or treated with chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) applied prior to blight symptom development (0%) or at disease levels of trace, 5%, 10% and reapplied every 10 days or according to Tom-Cast using intervals of 15, 20, or 25 DSVs in 2001 and 2002.

when disease in untreated plots progressed from 25 to 70% (Figure 5). A summary of final disease assessments is listed in Appendix A (Table 32).

According to the AUDPC data, spray programs initiated prior to blight occurrence were most effective in limiting the incidence of petiole blight and leaf blight, and no similarities were observed among the initiation timings (Table 14). Spray programs initiated when a trace amount of blight developed were effective in limiting petiole blight severity and did not differ from programs that started prior to blight occurrence. The 5% initiation timing was significantly different from both the lower thresholds, and it provided significantly better disease control compared with the 10% initiation timing (Table 14).

The petiole health data suggest that programs initiated prior to disease or when a trace amount of blight developed significantly lowered the AUDPC compared to the 5 and 10% initiation timings, which did not differ (Table 15). In 2001, spray programs initiated prior to blight occurrence improved final petiole health compared with later initiation timings, which differed from one another. In 2002, spray programs initiated when a trace amount of blight developed were effective in improving petiole health and did not differ from programs that started prior to blight occurrence. The 5% initiation timing was significantly different from both the lower thresholds. The 5% initiation timing provided significantly better disease control than the 10% initiation timing (Table 15).

Assessment of initial spray timing on 'Prime Cut' carrots. Disease was detected on 20 July 2001 and 22 July 2002 in the commercial field studies. Leaf blight in untreated plots reached 60% by 27 September in 2001 and 45% by 30 September in 2002

Table 14. Effects of spray initiation timings and application intervals on the area under the disease progress curve for petiole and leaf blights caused by *A. dauci* and *C. carotae* on 'Cellobunch' carrots treated with the fungicides chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) when initiated prior to disease development (0%) or at disease levels of trace, 5%, or 10% and reapplied at 10 day intervals or according to Tom-Cast at 15, 20, or 25 disease severity values (DSV) in 2001 and 2002.

Treatment	AUDPC (disease*day)[z]					
	Petiole blight					
	Incidence		Severity[y]		Leaf blight[x]	
Initiation timing						
0%	1616.37	a[w]	71.13	a	104.74	a
Trace	2576.02	b	78.86	a	168.22	b
5%	3579.84	c	105.30	b	357.05	c
10%	4113.90	d	136.94	c	538.88	d
Application interval						
10 day	2910.39	a[v]	90.61	a	197.74	a
Tom-Cast 15 DSV	2860.60	a	97.45	a	197.75	a
Tom-Cast 20 DSV	2998.47	a	100.58	a	298.51	b
Tom-Cast 25 DSV	3116.66	a	103.58	a	288.43	b
Source	F *value*	P *value*	F *value*	P *value*	F *value*	P *value*
Treatment	9.11	<.0001	12.37	<.0001	12.31	<.0001
Initiation timing	42.12	<.0001	47.68	<.0001	43.47	<.0001
Application interval	0.43	0.7288	1.66	0.1803	4.28	0.0070
Timing*interval interaction	0.72	0.6881	1.27	0.2613	0.72	0.6877
Untreated vs. treated	11.55	0.0010	38.49	<.0001	47.14	<.0001

[z] AUDPC = area under the disease progress curve. Data sets from 2001 and 2002 were pooled since there were no significant year*treatment interactions ($P > 0.05$).

[y] Data could not be transformed to normality.

[x] Data were transformed using log (AUDPC + 1) to stabilize the variance. The table shows back transformed data.

Table 14 (cont'd).

[w] Initiation timing means within a column followed by the same letter are not significantly different according to Waller-Duncan Bayesian k-ratio t-test (k-ratio = 100).

[v] Application interval means within a column followed by the same letter are not significantly different according to Waller-Duncan Bayesian k-ratio t-test (k-ratio = 100).

Table 15. Effects of spray initiation timings and application intervals on the area under the disease progress curve and final ratings for petiole health of 'Cellobunch' carrots treated with the fungicides chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) when initiated prior to disease development (0%) or at disease levels of trace, 5%, or 10% and reapplied at 10 day intervals or according to Tom-Cast at 15, 20, or 25 disease severity values (DSV) for control of *A. dauci* and *C. carotae* in 2001 and 2002.

Treatment	Petiole health: AUDPC (disease*day)[z]		Petiole health: Final rating[y] 2001		Petiole health: Final rating[y] 2002	
Initiation timing						
0%	118.72	a[x]	2.50	a	5.25	a
Trace	121.06	a	3.50	b	5.56	a
5%	170.25	b	6.44	c	6.69	b
10%	192.47	b	7.69	d	7.44	c
Application interval						
10 day	132.63	a[w]	4.25	a	5.38	a
Tom-Cast 15 DSV	137.69	ab	4.25	a	5.69	a
Tom-Cast 20 DSV	166.22	b	5.63	b	6.75	b
Tom-Cast 25 DSV	165.97	b	6.00	b	7.13	b
Source	F *value*	P *value*	F *value*	P *value*	F *value*	P *value*
Treatment	5.17	<.0001	13.83	<.0001	6.37	<.0001
Initiation timing	14.77	<.0001	52.89	<.0001	15.12	<.0001
Application interval	3.56	0.0210	7.47	0.0003	10.32	<.0001
Timing*interval interaction	0.79	0.6307	0.79	0.6302	0.87	0.5554
Untreated vs. treated	20.62	<.0001	33.06	<.0001	17.83	<.0001

[z] AUDPC = area under the disease progress curve.

[y] Data from each year were analyzed separately due to a significant year*treatment interaction.

[x] Initiation timing means within a column followed by the same letter are not significantly different according to Waller-Duncan Bayesian k-ratio t-test (k-ratio = 100).

Table 15 (cont'd).

[w] Application interval means within a column followed by the same letter are not significantly different according to Waller-Duncan Bayesian k-ratio t-test (k-ratio = 100).

(Figure 6). In 2001, the incidence of petiole blight in untreated plots was 19% on 2 August and increased to 92% by 28 August (Figure 7). In 2002, the incidence of petiole blight in untreated plots was 24% on 5 August and progressed to 85% by 19 August (Figure 7). A 7-day application schedule was included in the 2002 commercial field trial, and it controlled disease effectively when applications were initiated at low disease thresholds (Figure 8). A summary of final disease assessments is listed in Appendix A (Table 33).

The 2001 leaf blight AUDPC data indicated that programs started when 5% blight symptoms developed provided significantly less disease control than programs initiated at earlier disease thresholds but significantly limited leaf blight compared with programs started when 10% blight developed (Table 16). Spray programs initiated when 10% blight developed resulted in a higher AUDPC for petiole blight severity compared with the programs that started at lower disease incidence thresholds. Treatments that were initiated prior to disease, when a trace amount of disease was detected, or when 5% leaf blight occurred did not differ in limiting petiole blight severity (Table 16).

The analysis of AUDPC for petiole blight incidence in 2001 indicated a significant interaction between the initiation timing and the application intervals, suggesting that the differences observed in the application intervals was dependent on the spray initiation timing (Table 16). The initiation timing for the 10-day and Tom-Cast 20 DSV intervals, respectively, differed from one another, with the programs started prior to blight occurrence providing the highest disease control (Table 17). When following the Tom-Cast 15 DSV application interval, the spray thresholds of 5 and 10% blight did not differ and provided significantly less disease control compared with the program that was

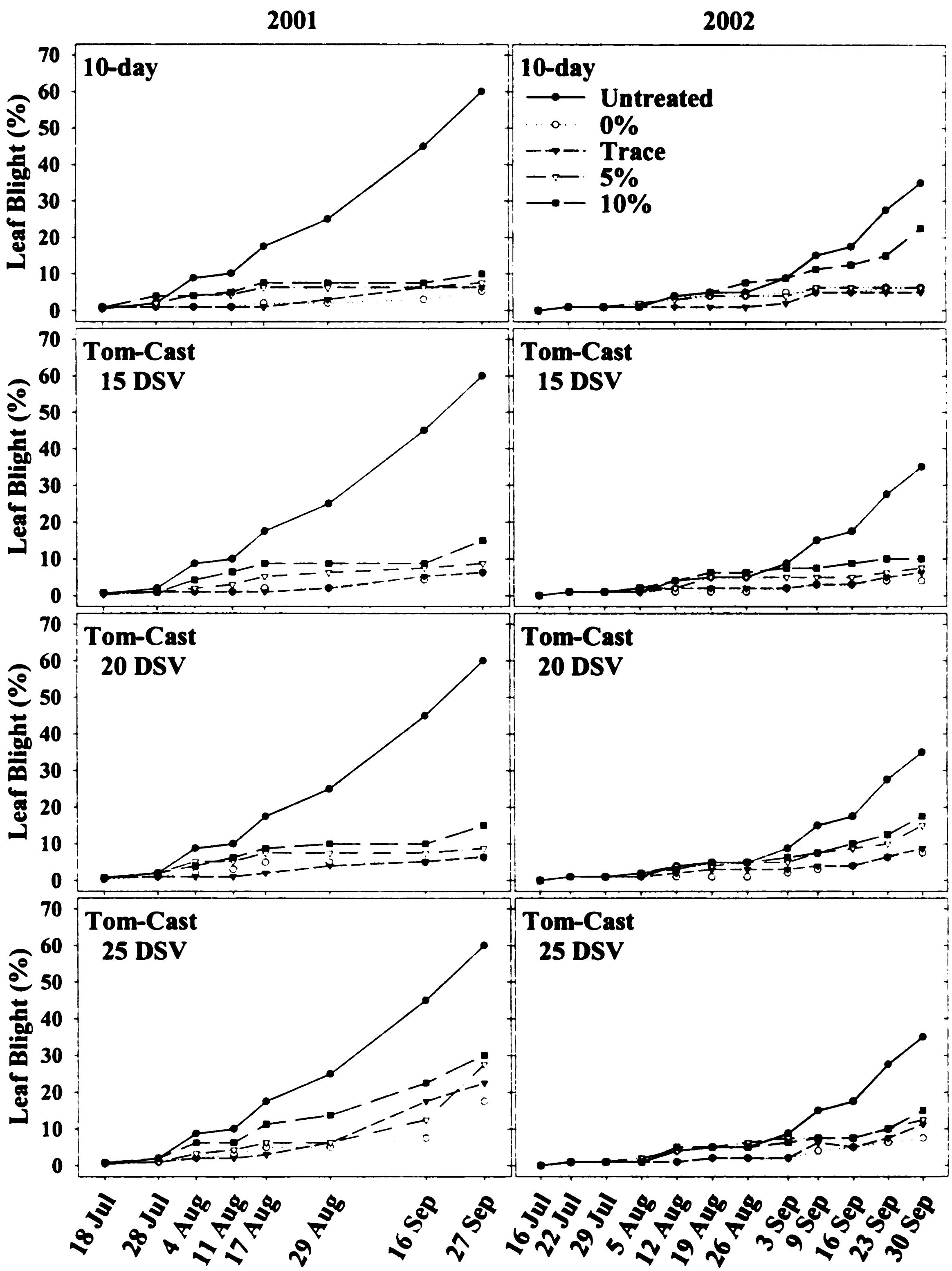

Figure 6. Disease progress curves for leaf blight caused by *A. dauci* and *C. carotae* on 'Prime Cut' carrots left untreated or treated with chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) applied prior to blight symptom development (0%) or at disease levels of trace, 5%, 10% and reapplied every 10 days or according to Tom-Cast using intervals of 15, 20, or 25 DSVs in 2001 and 2002.

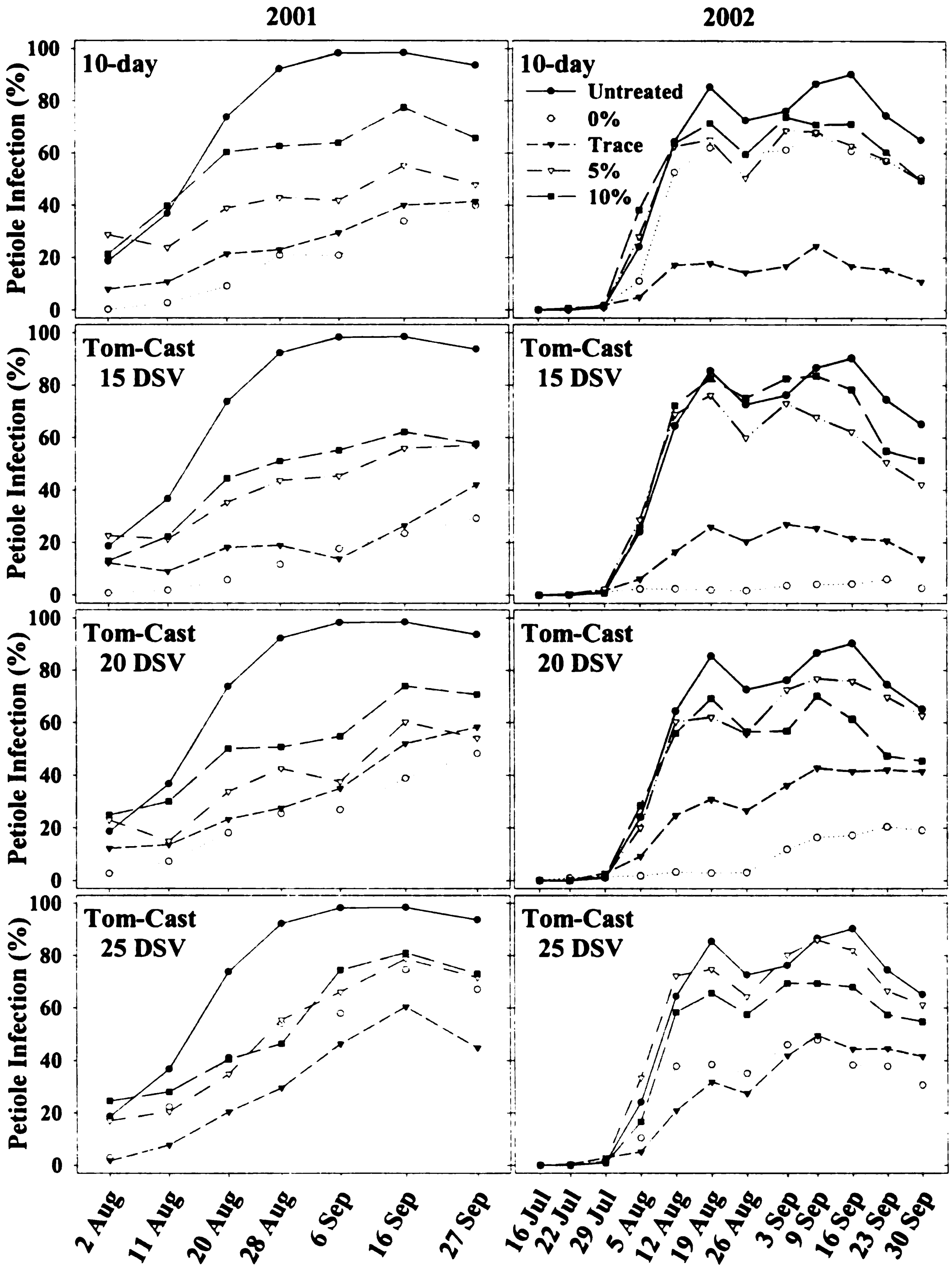

Figure 7. Disease progress curves for petiole blight caused by *A. dauci* and *C. carotae* on 'Prime Cut' carrots left untreated or treated with chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) applied prior to blight symptom development (0%) or at disease levels of trace, 5%, 10% and reapplied every 10 days or according to Tom-Cast using intervals of 15, 20, or 25 DSVs in 2001 and 2002.

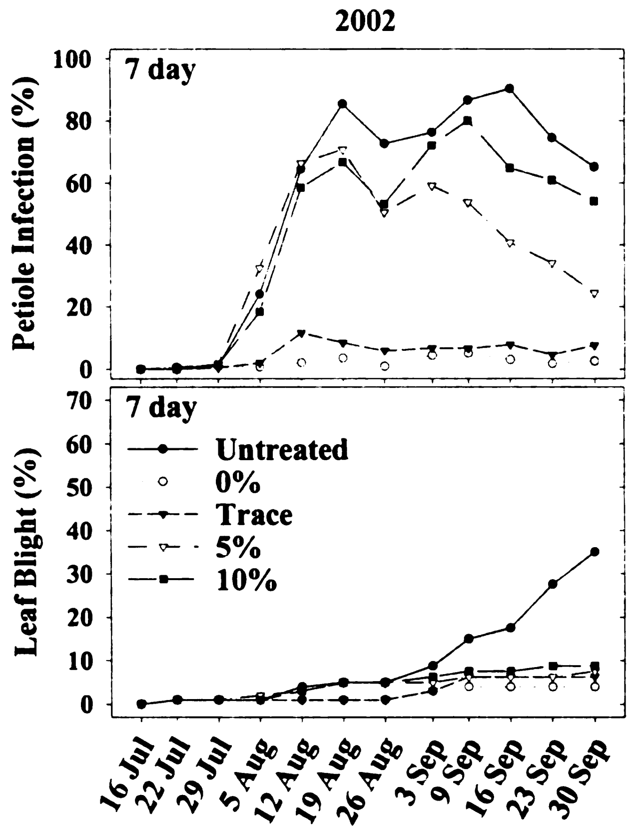

Figure 8. Disease progress curves for petiole and leaf blight caused by *A. dauci* and *C. carotae* on 'Prime Cut' carrots left untreated or treated with chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) applied prior to blight symptom development (0%) or at disease levels of trace, 5%, 10% and reapplied every 7 days in 2002.

Table 16. Effects of spray initiation timings and application intervals on the area under the disease progress curve for petiole and leaf blights caused by *A. dauci* and *C. carotae* on 'Prime Cut' carrots treated with the fungicides chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) when initiated prior to disease development (0%) or at disease levels of trace, 5%, or 10% and reapplied at 10 day intervals or according to Tom-Cast at 15, 20, or 25 disease severity values (DSV) in 2001.

Treatment	AUDPC (disease*day)[z]					
	Petiole blight					
	Incidence[y]		Severity[x]		Leaf blight	
Initiation timing						
0%	1473.38		56.69	a[w]	238.66	a
Trace	1539.65		57.69	a	283.59	a
5%	2405.70		58.97	a	418.06	b
10%	2957.47		68.84	b	607.83	c
Application interval						
10 day	2010.61		58.94	a[v]	288.53	a
Tom-Cast 15 DSV	1672.56		57.69	a	296.59	a
Tom-Cast 20 DSV	2072.02		60.41	ab	364.97	a
Tom-Cast 25 DSV	2621.01		65.16	b	598.06	b
Source	F *value*	P *value*	F *value*	P *value*	F *value*	P *value*
Treatment	14.58	<.0001	28.00	<.0001	25.93	<.0001
Initiation timing	34.17	<.0001	9.76	<.0001	21.18	<.0001
Application interval	10.30	<.0001	3.31	0.0277	16.16	<.0001
Timing*interval interaction	2.55	0.0174	0.74	0.6707	0.97	0.4771
Untreated vs. treated	76.85	<.0001	402.04	<.0001	294.20	<.0001

[z] AUDPC = area under the disease progress curve.

[y] The effects of initiation timing and application interval were not examined due to a significant timing*interval interaction.

[x] Data could not be transformed to normality.

[w] Initiation timing means within a column followed by the same letter are not significantly different according to Waller-Duncan Bayesian k-ratio t-test (k-ratio = 100).

Table 16 (cont'd).

[v] Application interval means within a column followed by the same letter are not significantly different according to Waller-Duncan Bayesian k-ratio t-test (k-ratio = 100).

Table 17. Effect of spray initiation timings for each application interval on the area under the disease progress curve of petiole blight caused by *A. dauci* and *C. carotae* on 'Prime Cut' carrots treated with the fungicides chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) when initiated prior to disease development (0%) or at disease levels of trace, 5%, or 10% and reapplied at 10-day intervals or according to Tom-Cast at 15, 20, or 25 disease severity values (DSV) in 2001.

Application interval **Initiation timing**	**Petiole blight incidence** **AUDPC (disease*day)**[z]
10 day	
0%	1049.92 a[y]
Trace	1434.77 b
5%	2276.12 c
10%	3281.62 d
Tom-Cast 15 DSV	
0%	742.57 a
Trace	1090.16 b
5%	2294.45 c
10%	2563.06 c
Tom-Cast 20 DSV	
0%	1377.56 a
Trace	1810.05 b
5%	2175.69 c
10%	2924.79 d
Tom-Cast 25 DSV	
0%	2723.46 b
Trace	1823.63 a
5%	2876.55 bc
10%	3060.42 c

[z] AUDPC = area under the disease progress curve.

[y] Means within each application interval followed by the same letter are not significantly different according to the Waller-Duncan Bayesian k-ratio t-test (k-ratio = 100).

initiated when a trace amount of disease was detected. The highest disease control was achieved when the initial application was made prior to blight symptom development and subsequent applications were made according to Tom-Cast 15 DSV. This program differed from the initiation timing where sprays were applied following blight detection. Tom-Cast 25 DSV spray programs initiated when a trace amount of disease was detected resulted in higher disease control compared to programs that were initiated prior to blight symptom development or when disease was evident on 5% of the foliage. Programs that started when 5% of the foliage was blighted did not differ from programs that were initiated when 10% leaf blight occurred (Table 17).

The 2002 AUDPC data suggest that spray programs initiated when a trace amount of blight symptoms were detected effectively limited petiole blight severity and were comparable with the programs that were initiated prior to blight development (Table 18). Programs that started when 5 or 10% blight developed did not differ and were significantly different than programs that were initiated at lower blight incidence thresholds (Table 18).

There was a significant interaction between initiation timing and application interval for AUDPC of petiole blight incidence in 2002, indicating that the differences observed in the application intervals depended on the spray initiation timing (Table 18). Seven-day spray programs that were initiated prior to disease occurrence did not differ from programs that were started after a trace amount of disease was present (Table 19). Programs that were started when 5% blight developed were significantly less effective in controlling blight compared with programs that were initiated at lower initiation timings, and the 5% blight initiation timing provided significantly better disease control compared

Table 18. Effects of spray initiation timings and application intervals on the area under the disease progress curve for petiole and leaf blights caused by *A. dauci* and *C. carotae* on 'Prime Cut' carrots treated with the fungicides chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) when initiated prior to disease development (0%) or at disease levels of trace, 5%, or 10% and reapplied at 7 or 10 day intervals or according to Tom-Cast at 15, 20, or 25 disease severity values (DSV) in 2002.

Treatment	AUDPC (disease*day)[z]					
	Petiole blight					
	Incidence[y]		Severity		Leaf blight[x]	
Initiation timing						
0%	1270.19		84.75	a[w]	189.10	
Trace	1298.86		79.68	a	206.20	
5%	3548.66		115.35	b	334.95	
10%	3605.29		121.90	b	424.03	
Application interval						
7 day	1757.80		94.09	a[v]	258.31	
10 day	2825.82		102.88	a	315.75	
Tom-Cast 15 DSV	2261.90		98.72	a	253.38	
Tom-Cast 20 DSV	2375.62		98.75	a	305.84	
Tom-Cast 25 DSV	2932.58		107.66	a	309.56	
Source	F *value*	P *value*	F *value*	P *value*	F *value*	P *value*
Treatment	14.48	<.0001	7.33	<.0001	18.95	<.0001
Initiation timing	63.92	<.0001	33.02	<.0001	52.01	<.0001
Application interval	6.51	0.0002	1.52	0.2089	3.05	0.0236
Timing*interval interaction	4.08	0.0001	1.51	0.1454	2.13	0.0278
Untreated vs. treated	22.91	<.0001	23.27	<.0001	185.10	<.0001

[z] AUDPC = area under the disease progress curve.

[y] The effects of initiation timing and application interval were not examined due to a significant timing*interval interaction.

[x] The effects of initiation timing and application interval were not examined due to a significant timing*interval interaction.

Table 18 (cont'd).

[w] Initiation timing means within a column followed by the same letter are not significantly different according to Waller-Duncan Bayesian k-ratio t-test (k-ratio = 100).

[v] Application interval means within a column followed by the same letter are not significantly different according to Waller-Duncan Bayesian k-ratio t-test (k-ratio = 100).

Table 19. Effect of spray initiation timings for each application interval on the area under the disease progress curve of petiole blight caused by *A. dauci* and *C. carotae* on 'Prime Cut' carrots treated with the fungicides chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) when initiated prior to disease development (0%) or at disease levels of trace, 5%, or 10% and reapplied at 7 or 10 day intervals or according to Tom-Cast at 15, 20, or 25 disease severity values (DSV) in 2002.

Application interval Initiation timing	Petiole blight incidence AUDPC (disease*day)[z]
7 day	
0%	167.20 a[y]
Trace	403.85 a
5%	2953.36 b
10%	3506.80 c
10 day	
0%	3207.73 b
Trace	935.06 a
5%	3414.87 bc
10%	3745.63 c
Tom-Cast 15 DSV	
0%	203.17 a
Trace	1206.41 b
5%	3573.35 c
10%	4064.68 d
Tom-Cast 20 DSV	
0%	616.44 a
Trace	1933.81 b
5%	3670.45 c
10%	3281.77 c
Tom-Cast 25 DSV	
0%	2156.40 a
Trace	2015.16 a
5%	4131.24 c
10%	3427.55 b

[z] AUDPC = area under the disease progress curve.

[y] Means within each application interval followed by the same letter are not significantly different according to the Waller-Duncan Bayesian k-ratio t-test (k-ratio = 100).

with programs that were initiated when 10% blight developed. Ten-day spray programs that were initiated when a trace amount of disease developed provided better disease control than programs initiated prior to blight development or when sprays were applied at the 5% blight threshold. Programs that were initiated when 10% blight developed provided the least disease control, and were not significantly different from the programs that were started when 5% blight symptoms developed. Tom-Cast 15 DSV spray programs that were initiated prior to disease symptom development were most effective in controlling disease. Programs that were initiated when a trace amount of disease was detected, when 5% blight developed, and when 10% blight developed were all significantly different from one another, with the least control provided by the 10% initiation timing. Tom-Cast 20 DSV program significantly reduced petiole blight incidence more effectively compared with programs that were initiated at a trace amount of disease. Programs that were initiated when 5 or 10% blight developed did not differ, however, both programs did not control disease as effectively as the programs that were initiated when a trace amount of disease was detected. Tom-Cast 25 DSV programs that were initiated prior to blight symptoms or when disease was evident on a trace amount of the foliage did not differ, and provided better disease control than programs started when 10% blight developed. Programs that were started when 5% blight symptoms occurred were the least effective in controlling disease, and were significantly different than programs initiated when 10% blight developed (Table 19).

There was a significant interaction between the initiation timing and the application interval for AUDPC of leaf blight in 2002, indicating that the differences observed in the application intervals depended on the spray initiation timing (Table 18).

Using the 7-day and Tom-Cast 20 DSV applications intervals, respectively, programs that were initiated prior to disease development were most effective in controlled leaf blight (Table 20). Programs that were started when a trace amount of blight developed, when 5% blight developed, or when 10% blight developed were all significantly different from one another, with the 10% initiation timing resulting in the highest AUDPC. Ten-day spray programs that were started after a trace amount of blight developed were the most effective in controlling leaf blight compared with programs that were initiated prior to disease development or when 5% blight occurred. Programs that were started when 10% blight developed provided the least disease control and were significantly different from programs that were initiated prior to blight symptoms or when disease was evident on 5% of the foliage. Tom-Cast 15 DSV spray programs that were initiated when disease was apparent on a trace amount of the foliage were not significantly different than programs that were initiated prior to disease development. Programs that were started when 5% leaf blight occurred controlled leaf blight less effectively than programs started at earlier thresholds but were more effective than the programs that started when 10% blight occurred. Tom-Cast 25 DSV spray programs that were initiated prior to disease development provided the best disease control and were significantly different from programs that were started when a trace amount of the foliage was blighted. Programs that were initiated when 5 or 10% blight developed did not differ from one another, but were significantly less effective in controlling leaf blight than the programs initiated when a trace amount of blight developed (Table 20).

The 2002 AUDPC data of petiole health and final petiole health indicated that programs that were initiated prior to disease development were similar to programs that

Table 20. Effect of spray initiation timings for each application interval on the area under the disease progress curve of leaf blight caused by *A. dauci* and *C. carotae* on 'Prime Cut' carrots treated with the fungicides chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) when initiated prior to disease development (0%) or at disease levels of trace, 5%, or 10% and reapplied at 7 or 10 day intervals or according to Tom-Cast at 15, 20, or 25 disease severity values (DSV) in 2002.

Application interval Initiation timing	Leaf blight AUDPC (disease*day)[z]
7 day	
0%	159.00 a[y]
Trace	213.00 b
5%	310.38 c
10%	350.88 d
10 day	
0%	274.63 b
Trace	176.00 a
5%	284.50 b
10%	527.88 c
Tom-Cast 15 DSV	
0%	138.50 a
Trace	174.88 a
5%	286.50 b
10%	413.63 c
Tom-Cast 20 DSV	
0%	173.50 a
Trace	229.13 b
5%	388.50 c
10%	432.25 d
Tom-Cast 25 DSV	
0%	199.88 a
Trace	238.00 b
5%	404.88 c
10%	395.50 c

[z] AUDPC = area under the disease progress curve.

[y] Means within each application interval followed by the same letter are not significantly different according to the Waller-Duncan Bayesian k-ratio t-test (k-ratio = 100).

were sprayed when a trace amount of disease developed (Table 21). Sprays that were applied when 5% blight occurred provided less disease control compared with spray programs that were initiated at lower disease thresholds, but were more effective in improving petiole health than programs that were initiated when 10% blight symptoms occurred (Table 21).

Assessment of fungicide application interval on 'Early Gold' carrots. The main effect of application interval had a significant effect on all 'Early Gold' disease assessments except the AUDPC data for petiole blight incidence in 2002 (Table 10). Disease progressed rapidly in 2002 (Figure 3), and an increase in petiole blight resulted compared with the 2001 growing season. The AUDPC data suggest that the 10-day interval and Tom-Cast 15 DSV intervals limited petiole blight severity when compared with the Tom-Cast 25 DSV interval (Table 10). The Tom-Cast 20 DSV interval was similar to both the 10-day, Tom-Cast 15 DSV, and Tom-Cast 25 DSV intervals. Leaf blight AUDPC was controlled most effectively by the 10-day or Tom-Cast 15 DSV application intervals when compared to the Tom-Cast 20 or 25 DSV intervals, which differed from one another (Table 10).

The AUDPC and 2002 final rating data for petiole health suggest that the 10-day and Tom-Cast 15 DSV application intervals improved petiole health compared with the Tom-Cast 20 and 25 DSV intervals (Table 12). Spray programs using the Tom-Cast 20 or 25 DSV intervals did not differ and were the least effective in controlling disease (Table 12).

Assessment of fungicide application interval on 'Cellobunch' carrots. Application interval had no effect on the AUDPC values of petiole blight incidence or

Table 21. Effects of spray initiation timings and application intervals on the area under the disease progress curve and final ratings for petiole health of 'Prime Cut' carrots treated with the fungicides chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) when initiated prior to disease development (0%) or at disease levels of trace, 5%, or 10% and reapplied at 7 or 10 day intervals or according to Tom-Cast at 15, 20, or 25 disease severity values (DSV) for control of *A. dauci* and *C. carotae* in 2002.

	Petiole health			
Treatment	**AUDPC (disease*day)[z]**		**Final rating[y]**	
Initiation timing				
0%	125.93	a[x]	4.90	a
Trace	131.08	a	5.00	a
5%	157.30	b	6.10	b
10%	190.80	c	6.75	c
Application interval				
7 day	137.69	ab[w]	4.94	a
10 day	163.88	cd	6.06	bc
Tom-Cast 15 DSV	131.34	a	5.38	ab
Tom-Cast 20 DSV	151.69	bc	5.81	bc
Tom-Cast 25 DSV	171.78	d	6.25	c
Source	F *value*	P *value*	F *value*	P *value*
Treatment	5.90	<.0001	4.05	<.0001
Initiation timing	22.90	<.0001	14.26	<.0001
Application interval	6.02	0.0004	4.05	0.0056
Timing*interval interaction	0.70	0.7480	0.63	0.8068
Untreated vs. treated	16.89	<.0001	14.50	0.0003

[z] AUDPC = area under the disease progress curve.

[y] Petiole health was evaluated using the following scale; where 1 = petioles healthy and vigorous to 10 = petioles unhealthy, weak, or dead.

[x] Initiation timing means within a column followed by the same letter are not significantly different according to Waller-Duncan Bayesian k-ratio t-test (k-ratio = 100).

[w] Application interval means within a column followed by the same letter are not significantly different according to Waller-Duncan Bayesian k-ratio t-test (k-ratio = 100).

severity (Table 14). According to the AUDPC data, the 10-day and Tom-Cast 15 DSV intervals were similar and most effective in controlling leaf blight when compared with the Tom-Cast 20 and 25 DSV intervals, which did not differ (Table 14). Similarly, the 10-day and Tom-Cast 15 DSV intervals reduced the petiole health AUDPC compared with the Tom-Cast 20 and 25 DSV intervals, but the later intervals did not differ from the Tom-Cast 15 DSV schedule (Table 15). The final petiole health data suggest that the 10-day and Tom-Cast 15 DSV intervals were similar in 2001 and 2002 and improved petiole health compared with the Tom-Cast 20 and 25 DSV intervals, which did not differ (Table 15).

Assessment of fungicide application interval on 'Prime Cut' carrots. According to the 2001 AUDPC data, the 10-day, Tom-Cast 15 DSV, and Tom-Cast 20 DSV were equally effective in controlling petiole blight severity and leaf blight (Table 16). Tom-Cast 25 DSV was the least effective in controlling petiole blight severity and it did not differ from the Tom-Cast 20 DSV application interval. Additionally, Tom-Cast 25 DSV was not effective in controlling leaf blight and was significantly different from all other application intervals (Table 16).

In 2002, application interval did not have a significant effect on the AUDPC of petiole blight severity in 2002 (Table 18). The AUDPC of petiole health and final petiole health data suggest that Tom-Cast 15 DSV and the 7-day interval were most effective in limiting disease (Table 21). The AUDPC data indicate that the 7-day schedule was not significantly different than Tom-Cast 20 DSV. The 10-day schedule was similar to Tom-Cast 20 DSV and Tom-Cast 25 DSV, which provided the least disease control. The 2002 final petiole data suggest that the Tom-Cast 15 DSV interval did not differ from the 10-

day schedule or Tom-Cast 20 DSV. Tom-Cast 25 DSV, which was the least effective in improving petiole health, was not significantly different than the 10-day schedule or Tom-Cast 20 DSV application interval (Table 21).

DISCUSSION

Carrot growers in Michigan have been concerned about applying fungicides when environmental conditions do not favor blight development. The cost of these unneeded sprays became paramount as production costs continued to increase. It was desirable to develop methods for reducing fungicide input to economically produce carrots. The goals of this study were to investigate disease incidence thresholds determined by field scouting for timing the initial fungicide application and to examine the use of the Tom-Cast disease forecasting system for timing fungicide application intervals to control Alternaria and Cercospora blights on carrots.

The economic benefits of using field scouting to time initial sprays and using Tom-Cast to time subsequent sprays are exemplified in situations where growers do not use either disease management strategy. In 2001, standard 10-day fungicide schedules required nine sprays for each cultivar tested, whereas the number of applications was reduced to eight ('Early Gold' and 'Cellobunch') or remained the same with nine sprays ('Prime Cut') by using Tom-Cast 15 DSV to determine spray intervals. Applying the initial application when blight was first detected in the field saved an additional three sprays ('Early Gold' and 'Cellobunch') and one spray ('Prime Cut'). In 2002, standard fungicide schedules required nine sprays ('Early Gold' and 'Cellobunch') and eight sprays ('Prime Cut'), whereas the number of fungicide applications was reduced to six applications ('Early Gold' and 'Cellobunch') and or remained the same with nine applications ('Prime Cut') by using Tom-Cast 15 DSV to determine spray intervals. Applying the initial fungicide application when blight was first detected in the field saved one additional spray ('Early Gold', 'Cellobunch', and 'Prime Cut'). In seasons with conditions highly favorable for blight development, the Tom-Cast program may not reduce the number of sprays or production costs, but it may be beneficial in improving the timing of fungicide applications to prevent severe blight epidemics and crop loss.

Ben-Noon et al. (2001) examined timings of spray initiation for controlling *A. dauci* on carrots and attempted to create a disease threshold model describing when the first spray should be applied. Initial sprays were delayed until 14 and 28 days after the common management practice in the growing area. Higher fungicide efficacy was observed with spray schedules that were initiated earlier in the season relative to the first occurrence of disease. The model was not validated, and recommendations were made to apply fungicides in a prophylactic manner to achieve leaf blight control. The scouting studies conducted in this research indicated different results. The time of spray initiation was successfully delayed until the first detection of disease symptoms, without compromising disease control. In many cases, the scouting and Tom-Cast program resulted in disease control that was similar to standard fungicide schedules that were initiated prior to disease occurrence while eliminating up to four sprays per season.

The results of the present study agree with the findings of Gillespie and Sutton (1979). One to three sprays were omitted by delaying the initial fungicide application until blight symptoms developed on 1 to 2% of the foliage. Conversely, delaying the initial fungicide application is not recommended for other crops. Keinath et al. (1996) tested a scouting-based spray program for scheduling fungicide applications for controlling early blight of tomato. According to this spray program, fields were scouted twice per week until disease symptoms appeared on 3 to 6% of the foliage when a weekly fungicide program commenced. The scouting program delayed the initial fungicide application for 42 days and saved six sprays compared with the standard 7-day fungicide program. The scouting program resulted in lower yields of extra-large fruit and increased disease severity compared with the standard 7-day program. The negative impact of the scouting program presented a risk to growers, and it was recommended that growers continue to apply fungicides prior to disease occurrence (Keinath et al., 1996).

Tom-Cast has been used to successfully time fungicide applications for managing other pathogens of vegetable crops. Tom-Cast was evaluated as a disease management tool for timing fungicide applications to control purple spot (*Stemphylium vesicarium* (Wallr.) E. Simmons) on asparagus (Meyer et al., 2000). The Tom-Cast spray program prompted an equal or fewer number of sprays and provided better disease control than the 14-day standard program. Additionally, some newly established asparagus plots managed according to Tom-Cast resulted in increased fern stands (Meyer et al., 2000).

The yield measurements recorded in these studies do not reflect yields that may be recorded in a commercial production situation where carrots are mechanically harvested. All carrots in 3.05 m of the center row were hand harvested, whereas yield losses may have become evident if plots were harvested mechanically. Therefore, differences in yield (where applicable) are attributed to leaf blight's ability to reduce the photosynthetic capacity of plants. A large-scale field trial, where carrots are mechanically harvested, is needed to determine the effect of treatments on yield reduction attributed to the condition of foliage.

Tom-Cast should be used in conjunction with other effective IPM methods. Cultural controls, such as crop rotation and the plowing under of carrot residue following harvest, should continue to prevent *A. dauci* and/or *C. carotae* inoculum from accumulating in infected carrot foliar residues (Pryor et al., 2002). New fungicides, as they become available, should be tested for disease control efficacy when used in a scouting and Tom-Cast spray program. The results of these studies may prompt others to examine the effect of using systemic fungicides for the initial application when disease symptoms are present in the field. In addition, the use of disease scouting and Tom-Cast may be explored for use in other cropping systems.

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APPENDIX A

SUMMARY OF WEATHER DATA, FUNGICIDE APPLICATION DATES, AND FINAL DISEASE ASSESSMENTS FOR FIELD STUDIES IN 2001 AND 2002

Table 22. Weather data and Disease Severity Values (DSV) from the Michigan State University Muck Soils Experimental Farm during the 2001 and 2002 growing seasons.

Month	Average daily temperature (°C) 2001[z]	Average daily temperature (°C) 2002[y]	Average daily humidity (%) 2001	Average daily humidity (%) 2002	Total monthly precipitation (mm) 2001	Total monthly precipitation (mm) 2002	Total monthly DSV accumulation 2001	Total monthly DSV accumulation 2002
July	21.1	22.3	74.6	76.9	128.6	109.9	41	34
August	20.9	20.0	80.7	82.2	151.9	59.4	46	35
September	14.3	17.1	84.7	80.4	120.9	93.7	14	17
Summary	18.8	19.8	80.0	79.8	401.4	263.0	101	86

[z] Weather data in 2001 were recorded from 2 July through 28 September.

[y] Weather data in 2002 were recorded from 8 July through 30 September.

Table 23. Dates of chlorothalonil (1.29 kg a.i./ha) applications on 'Cellobunch' carrots in 2001.

Treatment	Application Dates													Total Applications
Untreated														0
7 day	2 Jul	9 Jul	16 Jul	22 Jul	30 Jul	6 Aug	14 Aug	20 Aug	27 Aug	3 Sep	11 Sep	18 Sep	24 Sep	13
Mod. Cercospora Predictor	24 Jul	14 Aug	23 Aug	11 Sep										4
Mod. Alternaria Predictor	14 Aug	23 Aug	30 Aug	3 Sep	20 Sep									5
Tom-Cast 15 DSV	2 Jul	18 Jul	24 Jul	1 Aug	9 Aug	20 Aug	31 Aug	20 Sep						8

Table 24. Dates of chlorothalonil (1.29 kg a.i./ha) applications on 'Cellobunch' carrots in 2002.

Treatment	Application Dates													Total Applications
Untreated														0
7 day	8 Jul	14 Jul	21 Jul	28 Jul	4 Aug	11 Aug	18 Aug	25 Aug	31 Aug	8 Sep	16 Sep	24 Sep	1 Oct	13
Mod. Cercospora Predictor	11 Jul	21 Jul	28 Jul	15 Aug	24 Aug	6 Sep	21 Sep							7
Mod. Alternaria Predictor	4 Aug	13 Aug	21 Aug	2 Sep	13 Sep	24 Sep								6
Tom-Cast 15 DSV	8 Jul	19 Jul	30 Jul	13 Aug	24 Aug	18 Sep								6

Table 25. Summary of the effects of disease caused by *A. dauci* and *C. carotae* on petiole blight, leaf blight, and yield of 'Cellobunch' carrots left untreated or sprayed with the fungicide chlorothalonil (1.29 kg a.i./ha) applied every seven days or according to disease forecasters in 2001 and 2002.

Treatment	Number of sprays		Petiole blight: Incidence (%)[z]		Petiole blight: Severity[y]		Petiole blight: Health[x]		Leaf blight (%)		Yield (kg)[w]	
	2001	2002	2001	2002	2001	2002	2001	2002	2001	2002	2001	2002
Untreated	0	0	84.2	100.0	3.0	4.0	8.3	8.5	45.0	65.0	13.7	8.5
7 day	13	13	0.8	7.0	1.0	1.0	1.0	2.3	1.0	1.0	14.5	12.4
Mod. Cercospora Predictor	4	7	9.2	50.5	1.0	1.0	3.0	3.0	2.0	2.0	16.1	12.2
Mod. Alternaria Predictor	5	6	36.8	79.2	1.3	1.5	4.8	3.5	5.0	3.0	15.7	11.1
Tom-Cast 15 DSV	8	6	0.5	40.9	1.0	1.0	2.0	2.8	2.0	1.0	16.8	10.8

[z] Percentage of carrots in the middle row of each treatment bed with one or more petiole lesions.

[y] Severity of petiole blight rated on a 1 to 5 scale; where 1 = 0-5 petiole lesions per plant, 2 = 6-20, 3 = 21-50, 4 = >50, and 5 = dead.

[x] Petiole health rated on a 1 to 10 scale; where 1 = petioles healthy and vigorous to 10 = petioles unhealthy, weak, or dead.

[w] Carrots from the center 3.05 m of the middle row were hand harvested, the tops were removed at the crown, and roots weighed on 2 Oct 2001 and 2002.

Table 26. Weather data and Disease Severity Values (DSV) from the trial site near Fremont, MI during the 2001 and 2002 growing seasons.

	Average daily temperature (°C)		Total monthly DSV accumulation	
Month	**2001**[z]	**2002**[y]	**2001**	**2002**
July	23.0	23.5	38	33
August	20.8	20.3	61	48
September	14.7	16.8	21	29
Summary	19.5	20.2	120	110

[z] Weather data in 2001 were recorded from 8 July through 27 September.

[y] Weather data in 2002 were recorded from 15 July through 30 September.

Table 27. Dates of fungicide applications on 'Early Gold' and 'Cellobunch' carrots using chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) in 2001.

Treatment Spray Initiation	Application Dates									Total Applications
Untreated										0
10 day										
0%	2 Jul	13 Jul	22 Jul	1 Aug	11 Aug	21 Aug	31 Aug	11 Sep	20 Sep	9
Trace	30 Jul	9 Aug	20 Aug	29 Aug	8 Sep	18 Sep				6
5%	15 Aug	25 Aug	4 Sep	14 Sep						4
10%	27 Aug	4 Sep	14 Sep							3
Tom-Cast 15 DSV										
0%	2 Jul	18 Jul	24 Jul	1 Aug	9 Aug	20 Aug	31 Aug	20 Sep		8
Trace	30 Jul	6 Aug	15 Aug	25 Aug	11 Sep					5
5%	15 Aug	25 Aug	11 Sep							3
10%	27 Aug	20 Sep								2
Tom-Cast 20 DSV										
0%	2 Jul	21 Jul	30 Jul	9 Aug	25 Aug	20 Sep				6
Trace	30 Jul	9 Aug	25 Aug	20 Sep						4
5%	15 Aug	27 Aug								2
10%	27 Aug									1
Tom-Cast 25 DSV										
0%	2 Jul	22 Jul	3 Aug	20 Aug	11 Sep					5
Trace	30 Jul	10 Aug	31 Aug							3
5%	15 Aug	8 Sep								2
10%	27 Aug									1

Table 28. Dates of fungicide applications on 'Early Gold' and 'Cellobunch' carrots using chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) in 2002.

Treatment Spray Initiation	Application Dates									Total Applications
Untreated										0
10 day										
0%	8 Jul	19 Jul	30 Jul	8 Aug	18 Aug	28 Aug	6 Sep	18 Sep	27 Sep	9
Trace	19 Jul	30 Jul	8 Aug	18 Aug	28 Aug	6 Sep	18 Sep	27 Sep		8
5%	1 Aug	11 Aug	21 Aug	31 Aug	10 Sep	21 Sep	1 Oct			7
10%	13 Aug	24 Sep	2 Sep	12 Sep	24 Sep					5
Tom-Cast 15 DSV										
0%	8 Jul	19 Jul	30 Jul	13 Aug	24 Aug	18 Sep				6
Trace	19 Jul	30 Jul	13 Aug	24 Aug	18 Sep					5
5%	1 Aug	15 Aug	27 Aug	21 Sep						4
10%	13 Aug	24 Aug	18 Sep							3
Tom-Cast 20 DSV										
0%	8 Jul	23 Jul	4 Aug	24 Aug	21 Sep					5
Trace	19 Jul	1 Aug	17 Aug	10 Sep						4
5%	1 Aug	17 Aug	10 Sep							3
10%	13 Aug	27 Aug								2
Tom-Cast 25 DSV										
0%	8 Jul	28 Jul	15 Aug	10 Sep						4
Trace	19 Jul	4 Aug	24 Aug							3
5%	1 Aug	24 Aug								2
10%	13 Aug	2 Sep								2

Table 29. Dates of fungicide applications on 'Prime Cut' carrots using chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) in 2001.

Treatment Spray Initiation	Application Dates									Total Applications
Untreated										0
10 day										
0%	8 Jul	18 Jul	28 Jul	8 Aug	17 Aug	27 Aug	6 Sep	18 Sep	25 Sep	9
Trace	20 Jul	1 Aug	9 Aug	20 Aug	29 Aug	10 Sep	18 Sep			7
5%	25 Jul	4 Aug	15 Aug	23 Aug	4 Sep	13 Sep	22 Sep			7
10%	1 Aug	11 Aug	21 Aug	31 Aug	10 Sep	22 Sep				6
Tom-Cast 15 DSV										
0%	8 Jul	21 Jul	28 Jul	2 Aug	8 Aug	17 Aug	27 Aug	6 Sep	22 Sep	9
Trace	20 Jul	25 Jul	2 Aug	8 Aug	17 Aug	27 Aug	6 Sep	22 Sep		8
5%	25 Jul	2 Aug	8 Aug	17 Aug	27 Aug	6 Sep	22 Sep			7
10%	1 Aug	8 Aug	17 Aug	27 Aug	6 Sep	22 Sep				6
Tom-Cast 20 DSV										
0%	8 Jul	22 Jul	1 Aug	9 Aug	20 Aug	31 Aug	22 Sep			7
Trace	20 Jul	31 Jul	8 Aug	20 Aug	31 Aug	22 Sep				6
5%	25 Jul	4 Aug	15 Aug	27 Aug	10 Sep					5
10%	1 Aug	9 Aug	20 Aug	31 Aug	22 Sep					5
Tom-Cast 25 DSV										
0%	8 Jul	23 Jul	4 Aug	17 Aug	31 Aug					5
Trace	20 Jul	31 Jul	11 Aug	27 Aug	10 Sep					5
5%	25 Jul	8 Aug	23 Aug	6 Sep						4
10%	1 Aug	11 Aug	27 Aug	10 Sep						4

Table 30. Dates of fungicide applications on 'Prime Cut' carrots using chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) in 2002.

Treatment Initiation	Application Dates												Total Applications
Untreated													0
7 day													
0%	15 Jul	22 Jul	29 Jul	5 Aug	12 Aug	19 Aug	26 Aug	3 Sep	9 Sep	17 Sep	23 Sep	30 Sep	12
Trace	22 Jul	29 Jul	5 Aug	12 Aug	19 Aug	26 Aug	3 Sep	9 Sep	17 Sep	23 Sep	30 Sep		11
5%	5 Aug	12 Aug	19 Aug	26 Aug	3 Sep	9 Sep	17 Sep	23 Sep	30 Sep				9
10%	19 Aug	26 Aug	3 Sep	9 Sep	17 Sep	23 Sep	30 Sep						7
10 day													
0%	15 Jul	25 Jul	3 Aug	14 Aug	23 Aug	3 Sep	12 Sep	23 Sep					8
Trace	22 Jul	31 Jul	12 Aug	20 Aug	30 Aug	9 Sep	21 Sep	30 Sep					8
5%	5 Aug	15 Aug	25 Aug	3 Sep	12 Sep	23 Sep							6
10%	19 Aug	30 Aug	9 Sep	21 Sep	30 Sep								5
Tom-Cast 15 DSV													
0%	15 Jul	22 Jul	29 Jul	5 Aug	16 Aug	25 Aug	3 Sep	21 Sep					8
Trace	22 Jul	29 Jul	5 Aug	16 Aug	25 Aug	3 Sep	21 Sep						7

Table 30 (cont'd).

Treatment Initiation	Application Dates						Total Applications
Tom-Cast 15 DSV							
5%	5 Aug	16 Aug	25 Aug	3 Sep	21 Sep		5
10%	19 Aug	26 Aug	7 Sep	21 Sep			4
Tom-Cast 20 DSV							
0%	15 Jul	26 Jul	3 Aug	16 Aug	28 Aug	17 Sep	6
Trace	22 Jul	31 Jul	14 Aug	26 Aug	9 Sep	30 Sep	6
5%	5 Aug	23 Aug	3 Sep	21 Sep			4
10%	19 Aug	28 Aug	17 Sep				3
Tom-Cast 25 DSV							
0%	15 Jul	29 Jul	14 Aug	28 Aug	21 Sep		5
Trace	22 Jul	3 Aug	23 Aug	9 Sep			4
5%	5 Aug	23 Aug	9 Sep				3
10%	19 Aug	3 Sep	30 Sep				3

Table 31. Summary of the effects of disease caused by *A. dauci* and *C. carotae* on petiole blight, leaf blight, and yield of 'Early Gold' carrots left untreated or sprayed with the fungicides chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) when initiated prior to disease development (0%) or at disease levels of trace, 5%, or 10% leaf blight and reapplied at 10 day intervals or according to Tom-Cast at 15, 20, or 25 disease severity values (DSV) in 2001 and 2002.

Application schedule and initiation		Number of sprays		Petiole blight: Incidence (%)[z]		Petiole blight: Severity[y]		Petiole blight: Health[x]		Leaf blight (%)		Yield (kg)[w]	
		2001	2002	2001	2002	2001	2002	2001	2002	2001	2002	2001	2002
Untreated		0	0	89.5	100.0	3.5	4.0	8.8	9.0	15.0	65.0	16.8	9.9
10 day	0%	9	9	1.2	87.7	1.0	1.3	1.5	4.0	1.0	7.5	15.5	13.8
	Trace	6	8	26.5	58.9	1.0	1.3	3.0	4.0	3.0	7.5	16.5	14.5
	5%	4	7	47.8	95.2	1.5	2.0	6.0	5.0	4.3	8.8	16.6	13.2
	10%	3	5	73.9	100.0	2.3	3.3	6.0	6.3	7.5	17.5	15.7	11.0
Tom-Cast 15 DSV	0%	8	6	4.7	61.2	1.0	1.3	2.3	4.0	1.0	6.5	17.0	12.2
	Trace	5	5	3.7	88.3	1.0	1.8	1.5	4.5	1.0	7.5	15.4	13.2
	5%	3	4	32.9	100.0	1.3	2.5	4.3	5.8	2.0	13.8	17.2	10.6
	10%	2	3	80.7	100.0	2.5	3.3	7.5	6.5	8.8	17.5	14.7	12.1
Tom-Cast 20 DSV	0%	6	5	6.0	96.8	1.0	3.0	2.0	6.5	1.0	15.0	17.5	12.6
	Trace	4	4	20.8	87.9	1.0	2.3	4.5	5.5	3.0	15.0	17.0	14.7
	5%	2	3	76.9	100.0	2.0	2.8	6.8	7.0	5.0	20.0	15.6	12.2
	10%	1	2	78.2	100.0	2.5	3.5	7.5	7.3	10.0	20.0	15.5	11.6
Tom-Cast 25 DSV	0%	5	4	41.3	96.4	1.3	2.3	4.3	5.5	3.0	15.0	16.2	13.4
	Trace	3	3	42.6	96.6	1.3	2.5	5.3	5.5	4.0	15.0	17.5	11.1
	5%	2	2	57.3	98.9	2.0	3.3	6.8	6.5	8.8	23.8	16.0	11.5
	10%	1	2	80.1	100.0	3.0	4.0	7.8	7.8	10.0	45.0	15.6	12.0

[z] Percentage of carrots in the middle row of each treatment bed with one or more petiole lesions.

[y] Severity of petiole blight rated on a 1 to 5 scale; where 1 = 0-5 petiole lesions per plant, 2 = 6-20, 3 = 21-50, 4 = >50, and 5 = dead.

[x] Petiole health rated on a 1 to 10 scale; where 1 = petioles healthy and vigorous to 10 = petioles unhealthy, weak, or dead.

[w] Carrots from the center 3.05 m of the middle row were hand harvested, the tops were removed at the crown, and roots weighed on 2 Oct 2001 and 3 Oct 2002.

Table 32. Summary of the effects of disease caused by *A. dauci* and *C. carotae* on petiole blight, leaf blight, and yield of 'Cellobunch' carrots left untreated or sprayed with the fungicides chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) when initiated prior to disease development (0%) or at disease levels of trace, 5%, or 10% leaf blight and reapplied at 10 day intervals or according to Tom-Cast at 15, 20, or 25 disease severity values (DSV) in 2001 and 2002.

Application schedule and initiation		Number of sprays		Petiole blight: Incidence (%)[z]		Petiole blight: Severity[y]		Petiole blight: Health[x]		Leaf blight (%)		Yield (kg)[w]	
		2001	2002	2001	2002	2001	2002	2001	2002	2001	2002	2001	2002
Untreated		0	0	84.1	100.0	3.8	4.0	9.0	8.5	50.0	70.0	10.6	8.8
10 day	0%	9	9	5.8	65.4	1.0	1.5	1.0	4.0	2.0	10.3	13.9	10.1
	Trace	6	8	49.4	85.4	1.3	1.5	3.0	5.3	3.0	12.8	12.1	10.3
	5%	4	7	70.3	88.8	1.5	2.0	5.8	5.8	6.3	16.3	13.0	11.1
	10%	3	5	73.6	100.0	3.0	3.3	7.3	6.5	12.5	15.0	12.4	10.1
Tom-Cast 15 DSV	0%	8	6	5.0	72.2	1.0	1.3	1.3	4.5	3.0	6.5	13.1	10.6
	Trace	5	5	25.6	74.9	1.3	1.5	2.5	4.5	4.0	8.0	12.0	11.3
	5%	3	4	64.6	100.0	1.8	2.8	6.0	6.0	6.5	21.3	13.1	8.7
	10%	2	3	76.5	100.0	3.0	3.8	7.3	7.8	17.5	45.0	12.0	9.2
Tom-Cast 20 DSV	0%	6	5	34.9	97.7	1.5	2.5	4.0	6.0	3.3	27.5	14.6	10.1
	Trace	4	4	35.7	100.0	1.5	3.0	3.5	6.3	7.8	30.0	11.3	11.0
	5%	2	3	67.2	100.0	1.8	3.3	7.0	7.3	10.0	40.0	12.8	10.1
	10%	1	2	64.1	100.0	3.0	4.0	8.0	7.5	15.0	40.0	13.8	10.5
Tom-Cast 25 DSV	0%	5	4	35.0	94.0	1.3	2.5	3.8	6.3	4.0	20.0	13.7	10.8
	Trace	3	3	52.1	96.1	1.5	2.5	5.0	6.3	6.3	15.0	12.4	9.3
	5%	2	2	79.6	100.0	2.8	4.0	7.0	7.8	16.3	32.5	12.0	8.6
	10%	1	2	87.8	100.0	3.3	4.0	8.3	8.0	25.0	55.0	11.1	9.5

[z] Percentage of carrots in the middle row of each treatment bed with one or more petiole lesions.

[y] Severity of petiole blight rated on a 1 to 5 scale; where 1 = 0-5 petiole lesions per plant, 2 = 6-20, 3 = 21-50, 4 = >50, and 5 = dead.

[x] Petiole health rated on a 1 to 10 scale; where 1 = petioles healthy and vigorous to 10 = petioles unhealthy, weak, or dead.

[w] Carrots from the center 3.05 m of the middle row were hand harvested, the tops were removed at the crown, and roots weighed on 2 Oct 2001 and 3 Oct 2002.

Table 33. Summary of the effects of disease caused by *A. dauci* and *C. carotae* on petiole blight, leaf blight, and yield of 'Prime Cut' carrots left untreated or sprayed with the fungicides chlorothalonil (1.29 kg a.i./ha) alternated with azoxystrobin (0.11 kg a.i./ha) when initiated prior to disease development (0%) or at disease levels of trace, 5%, or 10% leaf blight and reapplied at 7 or 10 day intervals or according to Tom-Cast at 15, 20, or 25 disease severity values (DSV) in 2001 and 2002.

Application schedule and initiation		Number of sprays		Petiole blight: Incidence (%)[z]		Petiole blight: Severity[y]		Petiole blight: Health[x]		Leaf blight (%)		Yield (kg)[w]	
		2001	2002	2001	2002	2001	2002	2001	2002	2001	2002	2001	2002
Untreated		0	0	93.6	65.1	4.0	3.3	--	7.8	60.0	35.0	7.5	4.8
7 day	0%	--	12	--	2.5	--	1.0	--	3.8	--	4.0	--	5.5
	Trace	--	11	--	7.6	--	1.0	--	4.8	--	6.3	--	5.8
	5%	--	9	--	24.5	--	1.8	--	5.8	--	7.5	--	4.8
	10%	--	7	--	54.1	--	2.0	--	5.5	--	8.8	--	5.5
10 day	0%	9	8	39.8	50.5	1.0	1.8	--	5.5	5.3	6.3	9.0	5.6
	Trace	7	8	41.4	10.8	1.0	1.0	--	5.3	6.3	5.0	9.7	5.7
	5%	7	6	47.8	49.4	1.3	1.5	--	6.0	7.5	6.3	9.8	5.3
	10%	6	5	65.8	49.5	1.5	2.5	--	7.5	10.0	22.5	10.2	4.7
Tom-Cast 15 DSV	0%	9	8	29.2	2.7	1.0	1.0	--	4.5	6.3	4.0	9.1	5.8
	Trace	8	7	42.0	13.9	1.3	1.0	--	4.8	6.3	6.3	9.5	5.6
	5%	7	5	57.1	42.1	1.3	1.8	--	6.3	8.8	7.5	9.8	5.2
	10%	6	4	57.6	51.4	1.3	2.3	--	6.0	15.0	10.0	9.1	4.1
Tom-Cast 20 DSV	0%	7	6	48.3	19.1	1.0	1.0	--	5.3	6.3	7.5	9.2	5.7
	Trace	6	6	58.3	41.5	1.0	1.3	--	4.8	6.5	8.8	9.7	5.9
	5%	5	4	54.1	62.7	1.3	2.3	--	6.0	8.8	15.0	9.3	5.0
	10%	5	3	70.7	45.4	1.8	2.0	--	7.3	15.0	17.5	10.0	5.0
Tom-Cast 25 DSV	0%	5	5	67.1	30.6	1.5	1.3	--	5.5	17.5	7.5	9.3	4.9
	Trace	5	4	44.7	41.6	1.5	1.5	--	5.5	22.5	11.3	8.6	5.8
	5%	4	3	71.6	61.2	1.5	2.5	--	6.5	27.5	12.5	8.6	5.3
	10%	4	3	73.1	54.7	2.0	2.5	--	7.5	30.0	15.0	8.3	4.5

[z] Percentage of carrots in the middle row of each treatment bed with one or more petiole lesions.

Table 33 (cont'd).

[y] Severity of petiole blight rated on a 1 to 5 scale; where 1 = 0-5 petiole lesions per plant, 2 = 6-20, 3 = 21-50, 4 = >50, and 5 = dead.

[x] Petiole health rated on a 1 to 10 scale; where 1 = petioles healthy and vigorous to 10 = petioles unhealthy, weak, or dead.

[w] Carrots from the center 1.52 m of the middle row were hand harvested, the tops were removed at the crown, and roots weighed on 27 Sep 2001 and 8 Oct 2002.

APPENDIX B

PESTICIDE APPLICATION EQUIPMENT STUDIES IN 2001

CARROT (*Daucus carota* 'Goliath')
Alternaria Blight; *Alternaria dauci*
Cercospora Blight; *Cercospora carotae*

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Evaluation of spray application equipment to manage foliar blights of carrot, 2001.

This study was conducted at a cooperator's farm in Oceana County, MI on a Freesoil sand field previously planted to corn. Carrot 'Goliath' seeds were planted on 27 Apr at a spacing of 1.75 in. to rows spaced 18 in. apart on three-row beds centered 64 in. apart. Treatment plots were seven beds wide and 40 ft long with 10 ft of unsprayed buffer between plots and one bed of unsprayed carrots on either side of the plot. The center bed of the plot was used as an untreated drive row, and the three beds to the left and right were sprayed with different spray nozzle systems. Fungicides were applied with a trailer spray rig equipped with two independent spray nozzle systems pulled by a 40 hp high clearance tractor traveling at 3 mph. The three treated beds on the left of the drive row were sprayed with a conventional boom elevated 12 to 16 in. above the crop canopy and equipped with eleven XR11003VS flat fan nozzles spaced 20 in. apart. Spray solutions were mixed in 5-gal tanks pressurized by CO_2 and calibrated to deliver 20 gal/A at a nozzle pressure of 20 psi. The three treated beds on the right of the drive row were sprayed with a boom located 4 to 5 ft above the crop canopy that was mounted with three air-assisted nozzles spaced 64 in. apart. The motor used to generate power for the air-assisted system was operated at a hydraulic pressure of 1600 psi that propelled the fans to spin at 5000 rpm. Spray solutions were mixed in a 30-gal tank and the boom was pressurized by a hydraulic roller pump calibrated to deliver 10 gal/A. Weeds, insects, fertilization, and irrigation were managed according to standard production practices. Five treatments were randomly assigned within each of four blocks. Nozzle type was not randomized for treatment plots because the tractor only traveled in one direction down the drive rows. As a result, nozzle type is confounded with direction of travel and consequently the side of the plot. The analyses assume that no systematic differences exist between the two sides of the plot. As a whole, the experiment represents a split plot design in which fungicide treatments are the whole plots and nozzle types are the sub-plots. Seven applications were made at 10-day intervals on 12 and 23 Jul; 2, 14, and 23 Aug; and 4 and 13 Sep. Disease assessments were recorded on 8 and 28 Aug; 15 and 29 Sep; and 9 Oct from the middle bed in the center 10 ft of the middle row from both sides of each plot. Carrots in the center 10 ft of the middle row of each plot were hand-harvested, the foliage removed at the crown, and roots weighed to determine yield on 9 Oct.

Disease pressure was light until 1 Sep, when a severe epidemic of Alternaria and Cercospora blights developed. The interaction between nozzle type and treatment was not significant for any of the data analyzed, so the best treatment did not depend on nozzle type. The air-assisted nozzles significantly reduced the percentage of plants with petiole lesions throughout the season based on the AUDPC and at the time of final evaluation compared with the conventional nozzles (Table 34). Disease severity on the petioles did not differ between nozzle types nor did petiole health. All fungicide regimes significantly reduced disease severity on petioles and improved petiole health compared with the untreated but did not significantly affect yield (Table 35). Quadris alternated with Bravo, regardless of nozzle type, significantly reduced the percentage of plants with petiole lesions compared with Quadris alternated with Kocide and the untreated control.

Table 34. Effect of nozzle type on foliar blights caused by *Alternaria dauci* and *Cercospora carotae* on 'Goliath' carrots in 2001.

	Petiole blight				
Nozzle type	AUDPC[z]	Incidence (%)[y]	Severity[x]	Petiole health[w]	Yield (lb)
Conventional...........................	644.8 b[v]	33.6 b	1.6	4.0	32.6
Air-assisted............................	611.0 a	31.1 a	1.6	4.0	32.4

[z] Area under the disease progress curve. AUDPC data were transformed using log(Y+1) to stabilize the variance. The table shows de-transformed data.

[y] Percentage of plants with one or more petiole lesions on 9 Oct. Data were transformed using log(Y+1) to stabilize the variance. The table shows de-transformed data.

[x] Severity of petiole blight rated on a 1 to 5 scale; where 1=0-5 petiole lesions per plant, 2=6-20, 3=21-50, 4=>50, and 5=dead. Variable could not be transformed to normality.

[w] Petiole health rated on a 1 to 10 scale; where 1=petioles healthy, vigorous to 10=petioles unhealthy, weak, or dead.

[v] Means within a column followed by the same letter or no letter are not significantly different according to Tukey's Studentized Range Test (P=0.05).

Table 35. Effect of fungicides on foliar blights caused by *Alternaria dauci* and *Cercospora carotae* on 'Goliath' carrots in 2001.

	Petiole blight						Petiole		
Treatment and rate/A (timing[z])	AUDPC[y]		Incidence (%)[x]		Severity[w]		health[v]		Yield (lb)
Untreated....................................	2562.1	b[u]	98.7	c	3.8	b	8.1	b	29.5
Bravo Ultrex 82.5WDG 1.4 lb (1,3,5,7)									
Kocide 2000 53.8DF 1.5 lb (2,4,6).........	99.7	a	6.9	ab	1.0	a	2.6	a	32.9
Quadris 2.08F 6.2 fl oz (1,3,5,7)									
Bravo Ultrex 82.5WDG 1.4 lb (2,4,6)......	59.6	a	5.8	a	1.0	a	2.6	a	32.2
Quadris 2.08F 6.2 fl oz (1,3,5,7)									
Kocide 2000 53.8DF 1.5 lb (2,4,6).........	291.7	a	35.1	bc	1.1	a	3.9	a	32.8
Quadris 2.08F 6.2 fl oz (1,4,7)									
Kocide 2000 53.8DF 1.5 lb (2,5)									
Bravo Ultrex 82.5WDG 1.4 lb (3,6).........	126.3	a	15.4	ab	1.0	a	2.6	a	35.1

[z] Timing: 1=12 Jul; 2=23 Jul; 3=2 Aug; 4=14 Aug; 5=23 Aug; 6=4 Sep; and 7=13 Sep.

[y] Area under the disease progress curve. AUDPC data were transformed using log(Y+1) to stabilize the variance. The table shows de-transformed data.

[x] Percentage of plants with one or more petiole lesions on 9 Oct. Data were transformed using log(Y+1) to stabilize the variance. The table shows de-transformed data.

[w] Severity of petiole blight rated on a 1 to 5 scale; where 1=0-5 petiole lesions per plant, 2=6-20, 3=21-50, 4=>50, and 5=dead. Variable could not be transformed to normality.

[v] Petiole health rated on a 1 to 10 scale; where 1=petioles healthy, vigorous to 10=petioles unhealthy, weak, or dead.

[u] Means within a column followed by the same letter or no letter are not significantly different according to Tukey's Studentized Range Test (P=0.05).

CARROT (*Daucus carota* 'Goliath')
Alternaria Blight; *Alternaria dauci*
Cercospora Blight; *Cercospora carotae*

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Evaluation of spray application equipment and reduced fungicide rates to manage foliar blights of carrot, 2001.

This study was conducted at a cooperator's farm in Oceana County, MI on a Freesoil sand field previously planted to corn. Carrot 'Goliath' seeds were planted on 27 Apr at a spacing of 1.75 in. to rows spaced 18 in. apart on three-row beds centered 64 in. apart. Treatment plots were seven beds wide and 40 ft long with 10 ft of unsprayed buffer between plots and one bed of unsprayed carrots on either side of the plot. The center bed of the plot was used as an untreated drive row, and the three beds to the left and right were sprayed with different spray nozzle systems. Fungicides were applied with a trailer spray rig equipped with two independent spray nozzle systems pulled by a 40 hp high clearance tractor traveling at 3.0 mph. The three treated beds on the left of the drive row were sprayed with a conventional boom elevated 12 to 16 in. above the crop canopy and equipped with eleven XR11003VS flat fan nozzles spaced 20 in. apart. Spray solutions were mixed in 5-gal tanks pressurized by CO_2 and calibrated to deliver 20 gal/A at a nozzle pressure of 20 psi. The three treated beds on the right of the drive row were sprayed with a boom located 4 to 5 ft above the crop canopy that was mounted with three air-assisted nozzles spaced 64 in. apart. The motor used to generate power for the air-assisted system was operated at a hydraulic pressure of 1600 psi that propelled the fans to spin at 5000 rpm. Spray solutions were mixed in a 30-gal tank and the boom was pressurized by a hydraulic roller pump calibrated to deliver 10 gal/A. Weeds, insects, fertilization, and irrigation were managed according to standard production practices. Fungicides were applied at 75% of the labeled rate and at the labeled rate. Seven treatments were included in this study: an untreated control, Bravo 82.5WDG applied at 1.1 and 1.4 lb/A; Kocide 53.8DF applied at 1.1 and 1.5 lb/A; and Quadris 2.08F applied at 4.7 and 6.2 fl oz/A. Treatments were randomly assigned within each of four blocks. Nozzle type was not randomized for treatment plots because the tractor only traveled in one direction down the drive rows. As a result, nozzle type is confounded with direction of travel and consequently the side of the plot. The analyses assume that no systematic differences exist between the two sides of the plot. As a whole, the experiment represents a split plot design in which fungicide treatments are the whole plots and nozzle types are the sub-plots. Treatments were compared by decomposing the treatment SS into four components to address the following questions: (1) Do the untreated plots differ from the average treated plot; (2) Is there a fungicide main effect that explains overall differences in the three fungicides used; (3) Is there a rate main effect that explains overall differences in the two rates used; and (4) Is there an interaction between fungicide and rate to explain if differences in the fungicides depend on rate at which the fungicide was applied? Seven applications were made at 10-day intervals on 12 and 23 Jul; 2, 14, and 23 Aug; and 4 and 13 Sep. Disease assessments were recorded on 8 and 28 Aug; 15 and 29 Sep; and 9 Oct from the middle bed in the center 10 ft of the middle row from both sides of each plot. Carrots in the center 10 ft of the middle row of each plot were hand-harvested, the foliage removed at the crown, and roots weighed to determine yield on 9 Oct.

Disease pressure was light until 1 Sep, when a severe epidemic of Alternaria and Cercospora blights developed. The interaction between nozzle type and treatment was not significant for any of the data analyzed, so the best treatment did not depend on nozzle type. Furthermore, since the previous interaction was not significant, the best nozzle type did not depend on the fungicide used or the rate applied. The air-assisted nozzles, irrespective of the fungicide or rate used, significantly reduced petiole blight and improved petiole health compared with the conventional nozzles (Table 36). The interaction between fungicide and rate was not significant for either petiole blight or petiole health, so the best fungicide did not depend on the rate applied. In addition, the main effect of rate was not significant. The significant main effect of fungicide indicates that Bravo and Quadris significantly reduced the AUDPC, petiole blight incidence, petiole blight severity, and improved petiole health compared with Kocide (Table 37). Bravo significantly reduced petiole blight incidence compared with Quadris. Yield was not significantly affected by nozzle type or treatment, but yield losses may have become evident if plots were harvested mechanically. Foliar blight control was improved by applying fungicides with the air-assisted nozzles, and the control provided by the fungicides was not affected by the rate applied.

Table 36. Effect of nozzle type on foliar blights caused by *Alternaria dauci* and *Cercospora carotae* on 'Goliath' carrots in 2001.

	Petiole blight				
Nozzle type	AUDPC[z]	Incidence (%)[y]	Severity[x]	Petiole health[w]	Yield (lb)
Conventional....................	730.7 b[v]	42.6 b	1.7 b	4.4 b	29.9
Air-assisted......................	509.8 a	31.2 a	1.4 a	3.8 a	31.0

[z] Area under the disease progress curve. AUDPC data were transformed using log(Y+1) to stabilize the variance. The table shows de-transformed data.

[y] Percentage of plants with one or more petiole lesions on 9 Oct. Data were transformed using log(Y+1) to stabilize the variance. The table shows de-transformed data.

[x] Severity of petiole blight rated on a 1 to 5 scale; where 1=0-5 petiole lesions per plant, 2=6-20, 3=21-50, 4=>50, and 5=dead. Variable could not be transformed to normality.

[w] Petiole health rated on a 1 to 10 scale; where 1=petioles healthy, vigorous to 10=petioles unhealthy, weak, or dead.

[v] Means within a column followed by the same letter or no letter are not significantly different according to Tukey's Studentized Range Test (*P*=0.05).

Table 37. Effect of fungicides on foliar blights caused by *Alternaria dauci* and *Cercospora carotae* on 'Goliath' carrots in 2001.

Fungicide	Petiole blight: AUDPC[z]	Petiole blight: Incidence (%)[y]	Petiole blight: Severity[x]	Petiole health[w]	Yield (lb)	Cost/A ($)[v]: 75% rate	Cost/A ($)[v]: Label rate
None...........................	2576.5 c[u]	100.0 d	3.3 c	7.6 c	27.3	0.00	0.00
Bravo Ultrex 82.5WDG....	74.1 a	7.3 a	1.0 a	1.9 a	29.8	51.98	66.15
Kocide 2000 53.8DF........	650.3 b	56.2 c	1.9 b	5.4 b	30.8	22.64	30.87
Quadris 2.08F................	158.3 a	15.6 b	1.0 a	3.1 a	32.2	72.05	95.05

[z] Area under the disease progress curve. AUDPC data were transformed using log(Y+1) to stabilize the variance. The table shows de-transformed data.

[y] Percentage of plants with one or more petiole lesions on 9 Oct. Data were transformed using log(Y+1) to stabilize the variance. The table shows de-transformed data.

[x] Severity of petiole blight rated on a 1 to 5 scale; where 1=0-5 petiole lesions per plant, 2=6-20, 3=21-50, 4=>50, and 5=dead. Variable could not be transformed to normality.

[w] Petiole health rated on a 1 to 10 scale; where 1=petioles healthy, vigorous to 10=petioles unhealthy, weak, or dead.

[v] Costs were calculated by multiplying the number of applications by the rate/A by the cost of the fungicide used (Bravo $6.75/lb, Kocide $2.94/lb, and Quadris $2.19/fl oz).

[u] Means within a column followed by the same letter or no letter are not significantly different according to Tukey's Studentized Range Test (P=0.05). The untreated means were compared with the average of the treated means using a contrast (P=0.05).