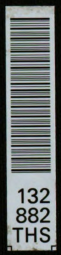

This is to certify that the

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Using TOMCAST, a disease forecasting system, for timing fungicide sprays for purple spot of asparagus

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Mary K. Hausbeck
Major professor

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USING TOMCAST, A DISEASE FORECASTING SYSTEM, FOR TIMING FUNGICIDE SPRAYS FOR PURPLE SPOT OF ASPARAGUS

By

Monica P. Meyer

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ABSTRACT

USING TOMCAST, A DISEASE FORECASTING SYSTEM, FOR TIMING FUNGICIDE SPRAYS FOR PURPLE SPOT OF ASPARAGUS

By

Monica P. Meyer

Purple spot disease (causal agent: *Stemphylium vesicarium* (Wallr.) Simmons) affects asparagus worldwide causing lesions on spears and fern. This disease is relatively new in Michigan and has developed as a result of the adoption of a no-till cropping system. Various fungicide regimes were compared for their efficacy in controlling this disease. Calendar-based fungicide spray schedules were used as a control. TOMCAST, a disease forecasting system originally developed to predict the occurrence of *Alternaria solani* on tomato was tested in three commercial asparagus fields in Michigan for its applicability in predicting purple spot disease on asparagus. The disease pressure in two newly-established asparagus fields was unusually severe in 1997 with 15,500 lesions/unsprayed fern, and moderate in 1996 with 4,000 lesions/unsprayed fern. A mature field showed moderate disease pressure in 1996 and 1997 with a maximum of 2,300 lesions/unsprayed fern. Using TOMCAST 15 DSV eliminated a minimum of two sprays compared to calendar-based schedules and provided similar levels of disease control. The 14-day treatment produced higher yield than the 7- and 10-day treatments when the yields were combined for both years. The results suggest that the use of TOMCAST could potentially reduce grower reliance on fungicides to control purple spot disease on asparagus.

ACKNOWLEDGMENTS

I would like to thank my major advisor, Dr. Mary Hausbeck for her financial support and guidance throughout my program. My committee members, Dr. Jack Kelly and Dr. Larry Olsen, provided me with suggestions that were very helpful and much appreciated.

All of the members of the Hausbeck lab participated in the asparagus project in one way or another. The help and patience of all of you especially during the tedious task of data collection is appreciated. I owe a special thanks to Brian Cortright and Bill Quackenbush for the long hours involved in managing my field equipment and spraying my experimental plots. Dr. Robert Podolsky was an invaluable source of statistical help, and I can not thank him enough. I would like to thank Norm Myers, John Bakker, and Mary Jo Bakker for their help in Oceana County. I would also like to thank the Oceana County asparagus growers, Tom and Rick Oomen, for use of their commercial field for my experimental plots.

Finally, I would like to thank my husband for encouraging me to follow my aspirations. He is truly a blessing in my life.

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LITERATURE REVIEW

Introduction

Ninety-five percent of asparagus grown in the United States is produced by California, Washington, and Michigan (Elmer et al., 1996). In 1995, Michigan ranked third nationally for asparagus production at 10,545 kg which was 11.2% of the total U.S. production (Michigan Department of Agriculture, 1995). Within Michigan, the west central area (Oceana Co.) produces the most asparagus (8,227 kg) (Michigan Agricultural Statistics Service, 1992) with 175 farms with 9,700 acres. Average yields are 682 kg. per acre in a mature field. The all-male hybrids can yield 1,818 kg. or more per acre (Zandstra et al., 1992).

Asparagus Production

Commercial asparagus fields have been established prior to the 1980s using open-pollinated cultivars, such as 'Mary Washington', 'Martha Washington', or 'Viking KB3'. These cultivars are dioecious and have been replaced by hybrids (Zandstra et al., 1992). Advancements in tissue-culture technology for asparagus have helped with the development of clonal hybrids (Zandstra et al., 1992). Male and female parents are selected and micropropagated. They are placed in seed-production blocks that have one male plant for each four to five female plants (Zandstra et al., 1992).

All-male hybrids are preferable because the food and energy that goes into the production of fruit in dioecious varieties is available for transport into the storage roots. All-male hybrids are currently available from New Jersey, Germany and the Netherlands.

The New Jersey varieties are typically recommended for Michigan (Zandstra et al., 1992).

Asparagus is a perennial crop that grows best in a temperate zone. Spring frosts occurring after spears have emerged destroy these spears and delay subsequent spear development. Since early spears tend to be larger than later spears, so the loss of the early production can significantly reduce total yields (Zandstra et al., 1992). Deep freezes that occur during winter can injure crowns, so they must be planted at least 20.3-cm deep for protection (Zandstra et al., 1992).

Asparagus will grow well on any soil that drains well, especially sands and sandy loams with organic matter and moisture-holding capacity (Zandstra et al., 1992). The soil pH is ideal at 6.8, and asparagus will tolerate soil pH down to 6.0. However, a pH below 6.0 favors *Fusarium* (*Fusarium proliferatum* T. Matsushima and *F. oxysporum* Schlechtend.:Fr.) crown rot (Zandstra et al., 1992).

Crowns should be established on land that has not had asparagus grown on it before to avoid *Fusarium* crown rot and other diseases. The land should be free of perennial and annual weeds before planting. The field should have good drainage, and manure should be spread (15 to 20 tons per acre) and a cover crop like Sudangrass or clover should be planted (Zandstra et al., 1992). In the fall before planting, the cover crop should be plowed down, and winter wheat or rye should be planted. About 250 lb each of $P_2 05$ and $K_2 0$ per acre should be available in the soil when the asparagus is planted.

Planting should take place as early in the spring as possible. Large, one-year-old, disease-free crowns are ideal. The crowns need to be spaced 0.15-m apart, center to center, in rows 1.24- to 1.55-m apart. This will require 9,000 to 10,000 crowns per acre.

Furrows, made with a middle-buster plow, should be 20- to 25-cm deep. The crowns need to be covered with 2.5- to 5-cm of soil the day of planting (Zandstra et al., 1992).

Asparagus is managed with a no-tillage system, because of the damage that tilling causes to the crowns. This damage provides *Fusarium* with avenues to infect the crowns. Herbicides are required to control weeds, so in the spring, the fern is chopped as low as possible and herbicides are applied (Zandstra et al., 1992).

Asparagus Harvest and Postharvest

Asparagus is not harvested until the third year after planting the crowns. Limited harvest occurs until the plants are five years old (Zandstra et al., 1992). New varieties may be able to tolerate more than 24 harvests per year, but older varieties should not be harvested more than 24 times. Buds need to be left to develop plenty of fern growth.

Asparagus harvest in Michigan typically begins around the middle of May and continues through late June. An asparagus field should remain productive for up to 17 years. Asparagus is harvested by hand-snapping or by riding on picking aids (Zandstra et al., 1992). Asparagus that is picked for processing is picked by bending the spear until it breaks, whereas spears picked for fresh market are snapped near the ground to keep the spears more uniform in size (around 20-cm long). Harvesting occurs every day to every other day, depending on the temperature. Asparagus can grow at a rate of 2.5-cm an hour when temperatures reach 26.7 C or warmer, so on warm days harvesting will be on a daily basis (Zandstra et al., 1992).

In Michigan, the maximum length of spears for processing should not exceed 19.1-cm and they must be 0.12-cm or more in diameter 12.7-cm below the tip. Fresh

market spears should be a minimum of 0.15-cm in diameter, and minimum length is 17.8-cm (Zandstra et al., 1992). Fresh market spears need to be cooled as soon as possible after harvesting at 0 to 2.2 C at 95% relative humidity. The quality of spears will be maintained in these conditions for two to three weeks. Processing spears should be kept in a cold storage while waiting to be shipped (Zandstra et al., 1992).

Purple spot disease

Purple spot disease affects asparagus worldwide and gets its name from the numerous purplish lesions that are found on the spears as a result of infection (Lacy, 1982). The fungal organism responsible for purple spot disease, *Stemphylium vesicarium* (Wallr.) Simmons, has been isolated from asparagus spears in California (Falloon, et al., 1984), Washington (Johnson and Lunden, 1984), Michigan (Lacy, 1982), New Zealand (Sing, 1977), France (Blancard et al., 1984), and Switzerland (Gindrat et al., 1984). Lesions are found predominantly on the windward side of the spears, because blowing sand causes wounding which creates an avenue for infection by *S. vesicarium* (Lacy, 1982). Although wounds allow an avenue for more rapid infection, they are not necessary, since *S. vesicarium* uses natural epidermal openings such as stomata to penetrate plants (Johnson and Lunden, 1986). Using scanning electron microscopy, it was observed that germ tubes from ascospores or conidia penetrated the spears exclusively through stomata (Falloon, et al., 1987). Epidermal cells collapsed around the point of penetration to form a slightly sunken lesion (Falloon et al., 1987).

Environmental factors play a significant role in disease severity. According to a greenhouse study the most severe fern infection occurs under conditions of low light,

100% relative humidity, one week of 26-28 C before inoculation, and two days of leaf wetness at 14 C during the infection period (Menzies et al., 1991). Purple spot was worse in the field during the early part of the harvest season when rain occurred and temperatures ranged between 1.1 and 20 C (Falloon et al., 1987). Plant age also affects disease severity (Menzies et al., 1991). Small differences in the shoot-emergence date, and therefore, tissue age at inoculation greatly influence tissue susceptibility. As the tissue ages, susceptibility decreases. In California, disease severity was correlated positively with rainfall events (Falloon et al., 1987), if temperatures were between 0 and 20 C, respectively. When atmospheric concentrations of conidia and ascospores of *S. vesicarium* were monitored with Burkard volumetric spore traps in no-till asparagus fields, peak concentrations of ascospores usually were associated with rainfall, and purple spot disease developed on spears when harvesting followed rainfall-prompted ascospore discharge by 48 hours or more (Hausbeck, 1993).

Falloon et al. (1984) looked at the overwintering structures of *S. vesicarium* on the field debris from the previous year, and suggested that pseudothecia are the means by which the fungus overwinters and is the main source of wind-borne ascospores causing spear infection early in the spring. Burial or removal of the previous year's fern growth reduces severity of purple spot on spears (Elmer et al., 1996). Burial does not necessarily decompose the pseudothecia before harvest, but it prevents ascospores and conidia from becoming airborne (Elmer et al., 1996). However, the damage caused to crowns during debris burial may provide avenues for infection by *Fusarium proliferatum* f. sp. *asparagi*, the causal agent of crown and root rot. Cover crop mulches and wind barriers that reduce

blowing sand might be effective in disease management (Elmer et al., 1996).

Purple spot contributes to the diseases causal to asparagus decline by damaging the fern during the growing season, causing defoliation of the cladophylls (Elmer et al.,1996). The destruction of photosynthetically active fern tissue reduces the potential photosynthate translocated to the crown and storage roots. Thus, smaller and fewer spears emerge the next year, affecting spear quality and marketability (Elmer et al., 1996).

A two-year study conducted by Johnson and Lunden (1992) looked at the effects on yield of premature defoliation due to rust (*Puccinia asparagi* DC. In Lam. & DC.). Rust significantly reduced total weight of spears in susceptible cultivars such as 'Mary Washington' and 'WSU-1'. Cultivars with slow-rusting resistance, such as 'Jersey Giant' and 'UC-157', had no significant yield loss due to rust (Johnson and Lunden, 1992). Conway et al. (1990) noted that reductions in yield are correlated with the amount of Cercospora blight (*Cercospora asparagi* Sacc.) developing on the fern during the summer (Conway et al., 1990).

***Pleospora herbarum*, the teliomorph of *S. vesicarium*.**

Ascostomata are scattered and are immersed to erumpent in the tissue of the host. Ascospores are globose and somewhat flattened (100-500μ diameter). Asci are bitunicate, cylindrical to clavate 90-250 x 20-50μ, with eight irregularly distichous ascospores. Ascospores are light to dark yellow brown, ellipsoid to clavate, 7-septate, slightly constricted at the three primary transverse septa, finally muriform and 26-50 x 10-20μ in size (Commonwealth Mycological Institute, 1967).

In culture, aerial mycelium is filamentous, sparse, hyaline to brown, branched,

5-8μ wide. Thicker hyphae develop later on the surface of the agar darker in color.

The Stemphylium conidial state has erect flexuous conidiophores 1-7 septate, 20-72 x 4-6μ, pale brown to brown, with a swollen apical sporogenous cell 7-11μ diameter, and slightly roughened toward the apex. They possess a single apical pore 5-8μ in diameter. Several successive sporogenous cells may form by proliferation through the apical pore (CMI, 1967).

Conidia are oblong, olive to brown, ovoid to subdoliiform, occasionally constricted at 1-3 transverse septa and at the 1-3 longitudinal septa if these are complete, 19·5 x 28·5μ with a single basal pore 8μ in diameter and a rougher outer wall (CMI, 1967).

Disease forecasting and calendar-based chemical control of purple spot disease.

Montesinos and Vilardell (1992) evaluated the applicability of a forecaster for *Alternaria solani* on tomato (FAST) for predicting infection periods and timing fungicide applications for managing *S. vesicarium* on pear. The FAST Forecasting system incorporates two empirical models based on the following daily environmental parameters: maximum and minimum air temperature, hours of leaf wetness, maximum and minimum temperature during the wetness period, hours of relative humidity higher than 90% and rainfall (Madden et al., 1978). The results showed that 25-35% fewer fungicide applications were necessary when the FAST forecaster was used than when a 7-day commercial schedule was used (Montesinos and Vilardell, 1992). TOMCAST, a simplified version of FAST, uses hourly temperature and leaf wetness values to calculate Daily Disease Severity Values (DSVs). This disease model was designed for the control

of early blight, Septoria leaf spot, and anthracnose fruit rot on tomato (Pitblado, R.E., 1992).

Many different fungicides have been tested for effectiveness in controlling foliar disease on asparagus. According to a study by Hausbeck and Kusnier (1995), chlorothalonil applied every seven days effectively controlled purple spot.

Stemphylium on other crops

Necrotic spotting of pear, caused by *S. vesicarium*, is a disease of economic importance in Mediterranean production areas (Montesinos and Vilardell, 1992). Montesinos et al. (1995) conduced a study that tested the optimal temperature range (C) and wetness duration (h) necessary for infection of *S. vesicarium* on pear fruit and leaves. Disease severity ranged from 0 to 14.6 mean lesions per fruit and 0 to 3.5 mean lesions per leaf. Maximum disease severity was found at 20 to 25 C with 18 to 24 h of wetness duration (Montesinos et al., 1995).

A new leaf disease of onion (*Allium cepa* L.) in New York caused by *S. vesicarium* was discovered by Shishkoff and Lorbeer (1987). Miller et al. (1978) reported that losses in Texas onion crops due to *S. vesicarium* were as high as 90%, most damage occurring after rains lasting more than 24h. The affected onion leaves had water-soaked lesions that coalesced to girdle the leaves, with pseudothecia forming on dead tissue (Shishkoff and Lorbeer, 1987). Disease developed on wounded and on nonwounded leaves. The number of lesions per leaf increased with the number of hours of exposure to free moisture in the mist chamber at 20 C, appreciable damage occurring only when moisture could be seen on the foliage. When onion plants of the same age were

inoculated, there was a slightly greater incidence of disease on rubbed leaves compared with nonrubbed leaves, and a greater incidence of disease on the oldest leaves compared with the youngest leaves (Shishkoff and Lorbeer, 1989). The results indicated that disease can occur after 18-24 h of exposure to moisture after inoculation (Shishkoff and Lorbeer, 1989).

Studies have been conducted on Stemphylium leaf spot on alfalfa. One study involved using different relative virulence and inoculum concentrations of *S. botryosum*, in which differences in disease severity on alfalfa were demonstrated by changes in the number, but not the size, of lesions on leaves (Cowling and Gilchrist, 1980). From this same study, it was shown that relative virulence of the pathogen appears to be determined before or during penetration, and successful infection resulted in lesions with dimensions that were limited by factors other than relative virulence of the pathogen.

A study conducted by Cowling et al. in 1981 looked at symptom differences between Stemphylium leaf spot on alfalfa in Eastern North America and in California. The results indicate that the distinctive symptom differences of Stemphylium leaf spot of alfalfa recognized in the eastern areas of North America and California (Cowling, 1980, Cowling and Gilchrist, 1980 and Graham et al., 1979) are due to inherent differences between the pathogens, and not the environments or cultivars characteristic of the two regions. There are also significant differences in disease severity detected among cultivars (Thal and Campbell, 1987).

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INTRODUCTION

Ninety-five percent of asparagus grown in the United States is produced by California, Washington, and Michigan (Elmer et al., 1996). In 1995, Michigan ranked third nationally for asparagus production at 10,545 kg which was 11.2% of the total U.S. production (Michigan Department of Agriculture, 1995).

Purple spot disease affects asparagus worldwide causing purplish lesions on the spears (Lacy, 1982). The causal agent of purple spot disease, *Stemphylium vesicarium* (Wallr.) Simmons (teliomorph *Pleospora herbarum*), has been isolated from asparagus spears in California (Falloon et al., 1984), Washington (Johnson and Lunden, 1984; Johnson and Lunden, 1986), Michigan (Evans and Stephens, 1984; Lacy, 1982), New Zealand (Falloon, 1982), France (Blancard, et al., 1984), and Switzerland (Gindrat et al., 1984). Purple spot lesions are often found predominantly on the windward side of the spears, because blowing sand causes wounding, creating an avenue for infection, by *S. vesicarium* (Lacy, 1982). Wounds, however, are not necessary for infection since *S. vesicarium* uses natural epidermal openings such as stomata to penetrate asparagus (Johnson and Lunden, 1986).

Purple spot disease can affect asparagus fern, causing death and premature defoliation which may result in reduced photosynthesis. Johnson and Lunden (1992) examined the effects of premature defoliation on yield due to rust (*Puccinia asparagi* D.C. In Lam. & D.C.). Rust significantly reduced total weight of spears for susceptible cultivars such as 'Mary Washington' and 'WSU-1.' Cultivars with slow-rusting

resistance, such as 'Jersey Giant' and 'UC-157' had no significant yield loss due to rust (Johnson and Lunden, 1992). Reductions in yield are also correlated with the amount of Cercospora blight (*Cercospora asparagi*, Sacc.) developing on the fern during the summer (Conway et al., 1990).

Environmental conditions play a significant role in purple spot disease severity on spears and fern. In a greenhouse study, the most severe fern infection occurred under conditions of low light, 100% relative humidity, one week of 26-28 C before inoculation, and two days of leaf wetness at 14 C during the infection period (Menzies et al., 1991). In the field, purple spot disease is favored during the early part of the harvest season following rainfall events and when temperatures are between 1.1 and 20 C (Falloon et al., 1987). Menzies et al. (1991) demonstrated that as the tissue ages, susceptibility to *S. vesicarium* decreases.

Pseudothecia of *Pleospora herbarum* overwinter on the previous summer's fern debris lying on the soil surface (Evans and Stephens, 1984 and Falloon et al., 1984), providing a source of inoculum for spear infection (Falloon et al., 1984). Atmospheric concentrations of conidia and ascospores of the purple spot pathogen were monitored using Burkard volumetric spore traps in two no-till asparagus fields (Hausbeck, 1993). Peak concentrations of ascospores in the atmosphere were usually associated with rainfall and purple spot disease developed on spears when harvesting followed rainfall-prompted ascospore discharge by 48 hours or more. Burial or removal of the previous year's fern growth reduced severity of purple spot on spears by preventing ascospores and conidia from becoming airborne (Elmer et al., 1996).

Fungicides are used routinely to manage purple spot disease on asparagus. Mancozeb fungicides are registered for use and typically provide control (Hausbeck and Kusnier 1995), however, large processors refuse to buy spears if the previous season's fern has been treated with mancozeb (personal communication, Campbell Soup Co.). Because of this problem, Michigan obtains a yearly section 18 Specific Exemption for chlorothalonil. Chlorothalonil applied every seven days consistently and effectively controls purple spot disease (Hausbeck and Kusnier, 1995). Montesinos and Vilardell (1992) evaluated the applicability of a disease forecaster for predicting infection periods and timing fungicide applications for control of *S. vesicarium* on pear. The FAST forecasting system was developed to manage *Alternaria solani* on tomato, and it incorporates two empirical models based on the maximum and minimum air temperature, hours of leaf wetness, maximum and minimum temperature during the wetness period, hours of relative humidity higher than 90% and rainfall (Madden et al., 1978). The results from the study conducted by Montesinos and Vilardell (1992) showed that 28-38% fewer fungicide applications were necessary when the FAST forecaster was used compared with a 7-day fungicide application schedule (Montesinos and Vilardell, 1992).

TOMCAST is a simplified version of FAST utilizing the duration of leaf wetness and the average temperature during the leaf wetness period to identify environmental conditions favorable for *A. solani* development (Pitblado, 1992).

The objective of this research was to assess the efficacy and economics of genetic resistance and fungicides applied according to conventional schedules or TOMCAST for purple spot disease control in asparagus.

MATERIALS AND METHODS

Evaluation of TOMCAST and conventional programs using chlorothalonil and mancozeb in a newly established asparagus field. Two-year-old crowns of 'Jersey Giant' and 'Jersey Knight' were established in Benona sand fields in Oceana County, Michigan in 1995. The cultivars were spaced 0.4-km apart. Crowns were spaced 30.77-cm apart within the rows and 3.91-m spacing between rows. The experimental design for each cultivar was a randomized complete block with four 175.85-m blocks containing nine treatments randomly assigned within each block. Each treatment was contained within 19.54-m row sections in the blocks with two buffer rows between treatment rows and 7.82-m buffers between treatments within the rows. The fungicides chlorothalonil (Bravo Weather Stik at 2.5 kg active ingredient (a.i.)/ha., ISK Bioscience, Mentor, OH) and mancozeb (Penncozeb 75DF at 2.25 kg a.i./ha., Elf Atochem, Philadelphia, PA) were applied with a CO_2 backpack sprayer operated at 40 psi through two XR Tee-Jet 8004 flat-fan nozzles calibrated to deliver 373.0 L/ha.

Mancozeb or chlorothalonil treatments were applied at 7-day intervals (1996, 10 sprays; 1997, 8 sprays), 10-day intervals (1996, 7 sprays; 1997, 6 sprays), 14-day intervals (1996, 5 sprays; 1997 4 sprays), or applied according to TOMCAST with a threshold of 15 disease severity values (DSV) (1996, 4 sprays; 1997, 4 sprays). Calendar-based sprays were initiated when the plants produced secondary branching and the cladophylls were beginning to emerge (3 July 1996, 30 June 1997).

The TOMCAST program uses the duration of leaf wetness and the average air

temperature during the wetness period for each 24-hr period (11AM to 11AM) to determine a DSV of 0 to 4 corresponding to an environment unfavorable to highly favorable for *A. solani* conidial formation (Pitblado, 1992).

Hourly averages of leaf wetness and temperature data were collected with a digital recorder (Omnidata DP223; Omnidata International, Inc., Logan, Utah). The digital recorder was located approximately 400-m from the 'Jersey Knight' experimental plot, and approximately 565-m from the 'Jersey Giant' experimental plot. The leaf wetness sensor was placed approximately 30-cm above the ground.

Yield and assessment of disease on spears in a newly established asparagus field. In 1996, spears were harvested on 19, 20, 23, 26, and 29 May, and 1, 3, and 7 June. In 1997, spears were harvested on 23, 26, 29 May, and 1, 3, 6, 8, 10, 12, 14, 16, 19, and 21 June. The spears were hand picked and yield was measured by weight for each treatment. The spears were assessed for disease; a ranking system from 1 to 5 corresponding to no disease and severe infection, respectively, was used. According to these ratings, the following criteria were used to rank the spears, or place them in the appropriate disease class: 1=no symptoms; 2=1-20 lesions on each spear; 3=21-50 lesions on each spear; 4=51-90 lesions on each spear; 5= more than 90 lesions on each spear. A disease severity index (DSI) was calculated for each harvest by modifying the formula of Sherwood and Hagadorn (1958):

$$DSI = \frac{\Sigma(\text{disease class} \times \text{no. of spears in that class})100}{\text{Total no. of spears} \times 5}$$

Treatment effects on disease severity were tested for 1996 and 1997 using an analysis of variance of a randomized complete block design with DSI as the dependent variable.

Treatment effects on total two-year spear yield (1996 and 1997) were analyzed using an analysis of a randomized complete block design (ANOVA). The treatments were subsequently compared using the following orthogonal contrasts: (1) untreated control contrasted with any treatment receiving a spray; (2) chlorothalonil contrasted with mancozeb; (3) 7-day schedule contrasted with 10- and 14-day schedules; (4) 10-day contrasted with 14-day schedules; (5) the difference between the 7-day schedule and the 10- and 14-day schedules compared between the fungicides; (6) the difference between the 10- and 14-day schedules compared between fungicides.

Assessment of disease on fern in a newly established asparagus field. On 13 September 1996 and 15 September 1997, four fern were harvested randomly from each treatment within each cultivar and the total number of purple spot lesions were counted. In 1997, because of the severe disease pressure, a fern ranking system was utilized to assess defoliation of the cladophylls. The ranking ranged from 1 to 5 according to the following criteria: 1=healthy plant with no defoliation; 2=1-20% defoliation; 3=21-50% defoliation; 4=51-80% defoliation; 5=more than 80% defoliation and plant death.

Treatment effects on lesion numbers were tested for 1996 and 1997 using an analysis of variance of a randomized complete block design. For 1996 and 1997, the treatments were subsequently compared using the following orthogonal contrasts:

(1) untreated control compared with any treatment receiving a spray; (2) chlorothalonil contrasted with mancozeb; (3) TOMCAST contrasted with the 7-day schedule; (4) TOMCAST and 7-day schedules were compared with the 10- and 14-day schedules; (5) 10-day schedule contrasted with the 14-day schedule; (6) the difference between TOMCAST and 7-day schedules, contrasted between fungicides; (7) the difference between TOMCAST/7-day schedule and 10-/14-day schedules, compared between fungicides; (8) the difference between 10- and 14-day schedules compared between fungicides. The data used in the 1996 analysis of treatment effects on lesion number were not normally distributed and were transformed to normality using the following equation: $\sqrt{}$(lesion number +1). The 1997 data were not normally distributed and were transformed to normality using the following equation: log (lesion number +1). The 1997 data analyzed for rank, or amount of defoliation, were not normally distributed and were transformed to normality as follows: $\sqrt{}$(rank +1).

Evaluation of TOMCAST DSV thresholds using chlorothalonil in a mature asparagus field. 'Viking KB3' asparagus established in Benona sand fields in Oceana County, Michigan in 1984 was used during the 1996 and 1997 study. Crowns were spaced 30.77 cm apart within rows with 3.91-m spacing between rows. The experimental design was an incomplete block with eight blocks containing two treatments randomly assigned within each block and were separated by a buffer plot. The treatments consisted of untreated, or treated with chlorothalonil (Bravo 2.5 kg a.i./ha) at 7-day intervals, or according to TOMCAST with a threshold of 12 or 15 DSV. Each of the eight blocks consisted of one row containing three 11.72-m plots with one buffer row between each

block. Each block was staggered 11.72-m from the previous block. Fungicide applications were made with a CO_2 backpack sprayer operated at 40 psi through two XR Tee-Jet 8004 flat-fan nozzles calibrated to deliver 373.0 L/ha. Calendar-based sprays were initiated when the plants produced secondary branches and the cladophylls were beginning to emerge (17 July 1996, 30 June 1997).

Hourly averages of leaf wetness and temperature data were collected with a digital recorder (Omnidata DP223; Omnidata International, Inc., Logan, Utah) with the leaf wetness and temperature sensors located in a buffer row and placed approximately 30 cm above the ground.

Assessment of disease on fern in a mature asparagus field. Four fern were selected randomly from each treatment within each cultivar and were harvested on 10 September 1996 and 8 September 1997. The total number of purple spot lesions was counted on each fern for each treatment. In 1997, because of the severe disease pressure, a fern ranking system was utilized to assess fern defoliation. The ranking ranged from 1 to 5, corresponding to no defoliation and severe defoliation, respectively. The fern were ranked according to the following criteria: 1=healthy plant with no defoliation; 2=1-20% defoliation; 3=21-50% defoliation; 4=51-80% defoliation; 5=more than 80% defoliation and plant death.

Treatment effects on fern were tested using an analysis of variance of a randomized complete block design. There were significant differences among treatments, so the following contrasts were used to compare them: (1) untreated control compared with any treatment receiving a spray; (2) TOMCAST compared with the 7-day schedule;

(3) TOMCAST 12 DSVs compared with TOMCAST 15 DSVs.

RESULTS

Yield and disease severity on spears in a newly established asparagus field. When 'Jersey Knight' spear yields were combined for 1996 and 1997, treatment yields differed significantly (p=0.0110) (Tables 1 and 2), so orthogonal contrasts were utilized as a multiple comparison test. When fungicide was applied every 14 days, yields were significantly higher than when fungicide was applied every 10-days (p=0.0019, Table 3). When chlorothalonil was applied, the 10 and 14-day treatments produced significantly more yield than the 7-day treatment (p=0.0356, Table 3). There was only one year of yield data for the TOMCAST treatments, so these data are not included. There were no significant yield differences among the fungicide treatments (p=0.1420) for 'Jersey Giant' (Table 2).

Harvest date was the only factor that had a significant effect on disease severity for either 'Jersey Knight' and 'Jersey Giant' in 1996 and 1997 (Tables 4 and 5). Disease severity on spears was not significantly influenced by treatment in either year for either cultivar.

Assessment of disease on fern in a newly established asparagus field. The efficacy of the treatment programs differed significantly (p=0.0001) in both years for 'Jersey Knight' (Tables 6 and 7), so orthogonal contrasts were utilized as a multiple comparison test. The weekly fungicide regime resulted in 10 (1996) or 8 (1997) fungicide applications (Table 6). Using TOMCAST eliminated a minimum of 4 and 2 sprays compared to a weekly or 10-day application regime, respectively. In 1996 and 1997,

significantly fewer lesions occurred on treatments receiving fungicide sprays compared with the untreated control (p=0.0001, Table 8). In 1997, chlorothalonil was more effective in controlling purple spot disease than mancozeb (p=0.0002, Table 8), the TOMCAST and 7-day treatments provided better control than the 10- and 14-day treatments in 1997 (0.0001, Table 8), and the 10-day treatment provided better control than the 14-day treatment in 1997 (p=0.0062, Table 8).

In 1997, when ranking asparagus fern for disease severity (cladophyll defoliation), the difference due to the spray programs was significant (p=0.0001) for 'Jersey Knight' (Tables 9 and 10), so orthogonal contrasts were utilized as a multiple comparison test. The amount of defoliation was significantly greater in the untreated control than for any treatments (p=0.0001, Table 11). Chlorothalonil provided better disease control than mancozeb (p=0.0024, Table 11). Defoliation was significantly reduced in the TOMCAST and the 7-day treatments compared to the 10- and 14-day treatments (p= 0.0001, Table 11). The 10-day treatment was significantly more effective in limiting defoliation than the 14-day treatment (p=0.0034, Table 11).

The efficacy of the treatment programs differed significantly (p=0.0001) in both years for 'Jersey Giant' (Table 6 and 12), so orthogonal contrasts were utilized as a multiple comparison test. In both years, any treatment that received fungicide sprays had significantly fewer lesions than the untreated control (p=0.0001, Table 13). The 7-day treatment provided significantly better control than the TOMCAST treatment in both years (p=0.0036 1996; p=0.0001 1997, Table 13). In 1997, chlorothalonil provided better disease control than mancozeb (p=0.0001, Table 13). The TOMCAST and 7-day

treatments provided significantly better disease control than the 10- and 14-day treatments in 1997 (p=0.0001, Table 13).

In 1997, when ranking asparagus fern for disease severity (cladophyll defoliation), the difference due to the treatments was significant (p=0.0001) for 'Jersey Giant' (Tables 9 and 10), so orthogonal contrasts were utilized as a multiple comparison test. Defoliation was significantly higher in the untreated control compared with all other sprayed treatments (p=0.0001, Table 11). Defoliation was significantly higher in the TOMCAST treatment than the 7-day treatment (p=0.0485, Table 11).

Disease assessment on fern in a mature asparagus field. In 1996 and 1997, there were significant differences between the treatments, so orthogonal contrasts were utilized as a multiple comparison test (p=0.0001, Tables 14 and 15). Eight applications of chlorothalonil were made according to the 7-day schedule (Table 14). Using TOMCAST resulted in eliminating a minimum of 4 sprays (DSV=12) or 5 sprays (DSV=15). In both years, any treatments that received fungicide sprays had significantly fewer lesions than the untreated control (p=0.0001, 1996; p=0.0001, 1997, Table 15). In 1996, TOMCAST treatments provided significantly less disease control than the 7-day spray schedule (p=0.0001, Table 15), although the TOMCAST 12 and 15 DSV disease control did not differ significantly from each other due to treatment (Table 15).

Table 1. Average weight (g) of spears per harvest during 1996 and 1997 in a newly established commercial asparagus field with two cultivars when fern was not treated the year prior or treated with chlorothalonil or mancozeb according to a calendar schedule or according to the TOMCAST disease predictor during 21 July to 30 August 1995 and 3 July to 3 September 1996.

	Spear weight (g)/harvest[z]			
Treatment/spray interval (days)	**'Jersey Knight'**		**'Jersey Giant'**	
	1996[y]	**1997[x]**	**1996**	**1997**
Untreated	149.50	164.13	202.13	186.62
Mancozeb[w]/7-day	140.16	196.06	227.69	215.34
Mancozeb/10-day	151.69	156.29	220.54	209.56
Mancozeb/14-day	161.75	195.22	208.53	213.23
Mancozeb/TOMCAST 15 DSV[v]	------	150.66	------	215.81
Chlorothalonil[u]/7-day	149.41	166.99	226.07	239.21
Chlorothalonil/10-day	125.16	194.89	217.53	213.41
Chlorothalonil/14-day	169.28	210.83	249.13	241.50
Chlorothalonil/TOMCAST 15 DSV	------	189.20	------	230.74

[z]The length of row harvested was 6.1 m.
[y]Harvested eight times.
[x]Harvested thirteen times.
[w]Applied at 2.5 kg a.i./ha.
[v]DSVs are disease severity values.
[u]Applied at 2.25 kg a.i./ha.

Table 2. Summary of analysis of variance for total spear yield for 1996 + 1997 for both cultivars.

	'Jersey Knight'				'Jersey Giant'			
Source	**DF**	**SS**	**F Value**	**P Value**	**DF**	**SS**	**F Value**	**P Value**
Treatment	6	2216397	3.9	0.0110*	6	3474838	1.87	0.1420
Block	3	106885	0.4	0.7693	3	1181981	1.27	0.3142
Error	18	1692527	-----	-----	18	5579607	-----	-----
Total	27	4015810	-----	-----	27	10236427	-----	-----

Table 3. Summary of contrast results for total spear yield for 1996 + 1997 for 'Jersey Knight'.

Contrast	DF	SS	F Value	P Value[z]
Untreated vs. all	1	334285	3.6	0.0756
Chlorothalonil vs. mancozeb	1	2481	0.0	0.8728
7-day vs. 10-/14-day	1	152889	1.6	0.2185
10- vs. 14-day	1	1241553	13.2	0.0019*
Fung*(7- vs. 14-day)	1	48013	5.2	0.0356*
Fung*(10- vs. 14-day)	1	175	0.0	0.9660

[z]Asterisk denotes significance

Table 4. Summary of analysis of variance from purple spot disease severity index data for spears from 'Jersey Knight' for 1996 (8 harvests) and 1997 (13 harvests).

	1996				1997			
Source	**DF**	**SS**	**F**	**P Value**	**DF**	**SS**	**F**	**P Value**
Treatment	6	7.38	0.45	0.8388	8	3366.35	0.71	0.6775
Harvest	7	489.04	25.94	0.0001*	12	1485660.96	25.29	0.0001*
Harvest*Treat	42	71.76	0.63	0.9561	96	315248.36	0.67	0.9892
Block	3	5.90	0.73	0.5352	3	19230.81	1.31	0.2713
$Error_a$	18	49.70			24	140293.79		
$Error_b$	146	393.17			308	1507618.62		
Total	222	1017.50			451	3517476.38		

*Denotes significant P Value.

Table 5. Summary of analysis of variance from purple spot disease severity index data for spears from 'Jersey Giant' for 1996 (8 harvests) and 1997 (13 harvests).

	1996				1997			
Source	**DF**	**SS**	**F**	**P Value**	**DF**	**SS**	**F**	**P Value**
Treatment	6	48735.04	0.56	0.7569	8	275065.84	0.76	0.6414
Harvest	7	1223938.04	17.77	0.0001*	12	3456824.64	6.34	0.0001*
Harvest*Treat	42	353939.12	0.86	0.7156	96	4091952.41	0.94	0.6391
Block	3	164361.26	5.57	0.0012	3	121451.81	0.89	0.4461
$Error_a$	18	261447.24	1.48	0.1064	24	1088107.33	1.00	0.4689
$Error_b$	147	1446613.41			312	14178612.23		
Total	223	3499034.11			455	23208594.82		

*Denotes a significant P Value.

Table 6. Number of purple spot lesions on 'Jersey Knight' and 'Jersey Giant' fern from newly-established fields when not treated or treated with chlorothalonil or mancozeb according to a calendar schedule or according to the TOMCAST disease predictor during 1996 and 1997.

Treatment/spray interval	Number of applications		Purple spot lesions			
			'Jersey Knight'		'Jersey Giant'	
	1996	1997	1996	1997	1996	1997
Untreated	-----	-----	4573	15643	3631	15254
Mancozeb[z]/7-day	10	8	685	778	142	486
Mancozeb/10-day	7	6	572	2989	203	3356
Mancozeb/14-day	5	4	517	6807	549	2213
Mancozeb/ TOMCAST 15 DSV[y]	4	4	537	1232	1375	2279
Chlorothalonil[x]/7-day	10	8	102	401	56	166
Chlorothalonil/10-day	7	6	426	1191	472	535
Chlorothalonil/14-day	5	4	323	3882	312	1993
Chlorothalonil/ TOMCAST 15 DSV	4	4	218	605	248	718

[z]Applied at a rate of 2.25 kg a.i./ha.
[y]Applied at a rate of 2.5 kg a.i./ha.
[x]Disease severity value.

Table 7. Summary of analysis of variance for average lesion numbers on 'Jersey Knight' fern.

	1996				1997			
Source	**DF**	**SS**	**F Value**	**P Value**	**DF**	**SS**	**F Value**	**P Value**
Treatment	8	29449.8	8.7	0.0001**	8	175.1	20.7	0.0001**
Block	3	3910.2	14.5	0.0001**	3	10.8	8.2	0.0001**
$Error_a$	24	10188.1	4.7	0.0001**	24	25.4	2.4	0.0011**
$Error_b$	107	9599.9	-----	------	107	46.7	-----	-----
Total	142	53123.2	-----	------	142	257.6	-----	-----

Table 8. Summary of contrast results for average lesion numbers on 'Jersey Knight' fern.

		1996			1997		
Source	**DF**	**SS**	**F Value**	**P Value[z]**	**SS**	**F Value**	**P Value[z]**
Untreated vs. all	1	27020.9	63.7	0.0001*	71.1	67.3	0.0001*
Chlorothalonil vs. mancozeb	1	1598.3	3.8	0.0642	20.8	19.6	0.0002*
TOMCAST vs. 7-day	1	98.1	0.2	0.6351	1.4	1.3	0.2600
TOMCAST/7 vs. 10-/14-day	1	187.9	0.4	0.5122	3.1	69.2	0.0001*
10- vs. 14-day	1	12.5	0.03	0.8650	9.5	9.0	0.0062*
Fung*TOMCAST/7-day	1	62.7	0.2	0.7042	0.01	0.01	0.9179
Fung*(TOMCAST/7- vs. 10-/14-day)	1	412.2	0.97	0.3343	0.01	0.01	0.9130
Fung*(10- vs. 14-day)	1	7.6	0.02	0.8947	0.0	0.01	0.9380

[z]Asterisk denotes significance

Table 9. Average fern defoliation rankings for 'Jersey Knight' and 'Jersey Giant' for 1997.

Treatment/spray interval	'Jersey Knight'	'Jersey Giant'
Untreated	5	4.8
Mancozeb[z]/7-day	2	1.5
Mancozeb/10-day	2.8	2.5
Mancozeb/14-day	4	2.8
Mancozeb/ TOMCAST 15 DSV[y]	2.6	2.7
Chlorothalonil[x]/7-day	2	2
Chlorothalonil/10-day	2.3	2
Chlorothalonil/14-day	3	2
Chlorothalonil/ TOMCAST 15 DSV	1.6	2

[z]Applied at a rate of 2.25 kg a.i./ha.
[y]Applied at a rate of 2.5 kg a.i./ha.
[x]Disease severity value.

Table 10. Summary of analysis of variance for fern defoliation ranking for both cultivars in 1997.

	'Jersey Knight'				'Jersey Giant'			
Source	**DF**	**SS**	**F Value**	**P Value**	**DF**	**SS**	**F Value**	**P Value**
Treatment	8	9.2	12.8	0.0001*	8	7.7	8.6	0.0001*
Block	3	0.5	5.8	0.0010*	3	1.3	16.6	0.0001*
$Error_a$	24	2.2	3.0	0.0001*	24	2.7	4.2	0.0001*
$Error_b$	108	3.3	-----	-----	107	2.9	-----	-----
Total	143	15.2	-----	-----	142	14.6	-----	-----

Table 11. Summary of contrast results comparing the efficacy of the treatment regimes in controlling defoliation.

		'Jersey Knight'			'Jersey Giant'		
Source	**DF**	**SS**	**F Value**	**P Value[z]**	**SS**	**F Value**	**P Value[z]**
Untreated vs. all	1	4.8	52.8	0.0001*	6.2	55.1	0.0001*
Chlorothalonil vs. mancozeb	1	1.0	11.5	0.0024*	0.3	2.6	0.1229
TOMCAST vs. 7-day	1	0.0	0.3	0.6146	0.5	4.3	0.0485*
TOMCAST/7- vs. 10-/14-day	1	2.1	22.9	0.0001*	0.2	1.5	0.2342
10- vs. 14-day	1	1.0	10.6	0.0034*	0.0	0.1	0.7849
Fung*TOMCAST/7-day	1	0.3	2.9	0.1005	0.3	3.0	0.0946
Fung*(TOMCAST/7- vs. 10-/14-day)	1	0.0	0.29	0.5935	0.2	2.15	0.1557
Fung*(10- vs. 14-day)	1	0.1	0.9	0.3516	0.0	0.2	0.7025

[z]Asterisk denotes significance

Table 12. Summary of analysis of variance for average lesion numbers on 'Jersey Giant' fern.

	1996				1997			
Source	**DF**	**SS**	**F Value**	**P Value**	**DF**	**SS**	**F Value**	**P Value**
Treatment	8	26487.2	10.0	0.0001**	8	236.5	29.0	0.0001**
Block	3	2253.6	11.7	0.0001**	3	50.0	43.8	0.0001**
$Error_a$	23	7594.4	5.1	0.0001**	24	24.4	2.67	0.0003**
$Error_b$	105	6763.4	-----	-----	107	40.7	-----	-----
Total	139	42907.9	-----	-----	142	352.1	-----	-----

Table 13. Summary of contrast results comparing treatments for average lesion numbers on 'Jersey Giant' fern.

		1996			1997		
Source	**DF**	**SS**	**F Value**	**P Value[z]**	**SS**	**F Value**	**P Value[z]**
Untreated vs. all	1	19490.6	302.6	0.0001*	122.7	120.6	0.0001*
Chlorothalonil vs. mancozeb	1	1237.3	3.8	0.0653	44.5	43.8	0.0001*
TOMCAST vs. 7-day	1	3470.9	10.5	0.0036*	44.4	43.7	0.0001*
TOMCAST/7- vs. 10-/14-day	1	9.0	0.03	0.8701	20.6	20.3	0.0001*
10- vs. 14-day	1	64.7	0.2	0.6622	0.5	0.5	0.4863
Fung*TOMCAST/7-day	1	872.5	2.6	0.1177	0.06	0.06	0.8084
Fung*(TOMCAST/7- vs. 10/14-day)	1	681.3	2.1	0.1643	0.6	0.6	0.4546
Fung*(10- vs. 14-day)	1	468.6	1.4	0.2457	2.7	2.6	0.1192

[z]Asterisk denotes significance.

Table 14. Number of purple spot lesions on 'Viking KB3' fern from a mature commercial field when not treated or treated with chlorothalonil every seven days or according to the TOMCAST disease predictor during 1996 and 1997.

Treatment/spray interval	Number of applications		Purple spot lesions		Defoliation ranking[x]
	1996	1997	1996	1997	1997
Untreated	----	----	388	2358	2.7
Chlorothalonil[z]/7-day	8	8	24	80	1
Chlorothalonil /TOMCAST 12 DSV[y]	3	4	85	72	1.2
Chlorothalonil /TOMCAST 15 DSV	2	3	93	59	1

[z]Applied at a rate of 2.5 kg a.i./ha.
[y]Disease severity value.
[x]Ranking from 1 to 5 corresponding to no defoliation and severe defoliation, respectively.

Table 15. Analysis of variance and orthogonal contrasts for number of purple spot lesions on 'Viking KB3' fern from a mature commercial asparagus field when not treated or treated with chlorothalonil every seven days or according to the TOMCAST disease predictor during 1996 and 1997.

		1996			1997		
Source	**DF**	**SS**	**F Value**	**P Value**	**SS**	**F Value**	**P Value**
Treatment	3	33.24	15.21	0.0001*	120.98	48.25	0.0001*
Block	7	8.59	1.68	0.1333	11.41	1.95	0.0799
Contrast	**DF**	**Contrast SS**	**F Value**	**P Value**	**Contrast SS**	**F Value**	**P Value**
Untreated vs. all	1	27.73	38.07	0.0001*	79.47	95.08	0.0001*
TOM[z] vs week	1	15.30	21.00	0.0001*	0.1227	0.15	0.7031
12 vs 15 DSV	1	2.41	3.30	0.0749	0.4574	0.55	0.4627

* P value is significant.
[z]TOMCAST 12 and 15 DSV.

DISCUSSION

Calendar-based fungicide spray schedules are currently used to control purple spot in commercial asparagus fields. A disease forecasting system that accurately prompts fungicide sprays could reduce fungicide applications while maintaining commercial disease control. A disease forecasting system (FAST) has been used successfully to time fungicide sprays for controlling *S. vesicarium* on pear (Montesinos and Vilardell, 1992). FAST utilizes hours of leaf wetness and the average temperature during wetness periods, mean air temperature, hours of relative humidity greater than 90%, and total rainfall (Madden et al, 1978). When used to manage *S. vesicarium* on pear, the FAST forecasting system resulted in disease control comparable to the 7-day application schedule with a reduction in fungicide sprays of 28-38% (Montesinos and Vilardell, 1992). TOMCAST, a disease forecasting system derived from FAST and originally developed to manage *A. solani* on tomato was tested in a preliminary trial to determine its applicability in managing purple spot disease on asparagus (Hausbeck, unpublished data).When studies were conducted regarding the epidemiology of *S. vesicarium* in commercial asparagus fields, it was noted that when *S. vesicarium* conidial counts were high atmospheric concentrations of *Alternaria* spp. were also high (Hausbeck, unpublished data).

The study reported here represents the first large scale research project to test the TOMCAST disease forecasting system in a commercial asparagus field. The disease pressure in the newly-established asparagus field in 1997 was unusually severe with 15,449 lesions/unsprayed fern. Disease pressure from *S. vesicarium* was moderate in 1996 with

4,102 lesions/unsprayed fern. Using TOMCAST resulted in eliminating a minimum of 4 and 2 sprays compared to a weekly or 10-day application regime, respectively. In both years, mancozeb and chlorothalonil treatments significantly limited purple spot disease on fern compared with the untreated control. Mancozeb and chlorothalonil have been shown to be effective against purple spot in previous studies (Hausbeck and Kusnier, 1994).

The 7-day and TOMCAST treatments were significantly better than the 10- and 14-day treatments in controlling disease and defoliation for both cultivars in 1996 and 1997. The TOMCAST treatment provided disease control comparable to the 7-day treatment for 'Jersey Knight' in 1996 and 1997, but not for 'Jersey Giant' in either year. 'Jersey Giant' was observed to be larger with a more dense canopy than 'Jersey Knight', potentially limiting fungicide coverage. In 'Jersey Giant', the TOMCAST treatments were significantly more defoliated than the 7-day treatment in 1997. The 10-day schedule and the TOMCAST treatment provided similar control in both years for both cultivars. Because of the expense of the fungicides, commercial growers typically follow a 10- to 14-day application interval. Furthermore, the Section 18 label that allows Michigan growers to use chlorothalonil limits the total number of applications to six when the lower rate is used.

The disease pressure in the mature field was moderate in 1996 and 1997 with a maximum of 2,300 lesions/unsprayed fern. The disease control provided by the TOMCAST treatments (12 and 15 DSV) was comparable to that of the 7-day schedule. Using TOMCAST resulted in eliminating a minimum of 4 sprays (DSV=12) or 5 sprays (DSV=15). Although the TOMCAST treatments (12 and 15 DSV) were significantly less effective than the 7-day schedule in 1996, the number of lesions for the TOMCAST treatments likely

represent acceptable disease control (<100/plant).

Fungicide treatments applied to the fern during 1995 and 1996 did influence the total spear yield when the total two-year yields were compared. The 14-day treatment yielded better than the 10- and 7-day treatments and these results were opposite of what was expected. However, because of the relatively low amount of foliar disease (maximum 100 lesions/unsprayed fern) during the 1995 growing season and the moderate disease in 1996 (4,000 lesions/unsprayed fern), the practical significance of these results are questionable. It is unknown what purple spot disease threshold on fern is necessary for spear yield losses to occur in subsequent years. Consecutive years of severe disease may be required before yield losses occur. Johnson and Lunden (1992) evaluated four asparagus cultivars after one and two years of rust (*Puccinia asparagi* De Candolle) infection. Rust significantly reduced total spear weight by 54% for the susceptible cultivars 'Mary Washington' and 'WSU-1' after the second year of premature defoliation. The slow-rusting resistance cultivars, 'Jersey Giant' and 'UC-157', had less yield loss (11%) following two years of rust infection (Johnson and Lunden, 1992). The effect of the severe disease pressure in 1997 resulting in 15,500 lesions/unsprayed fern may be observed in the 1998 yield. These results suggest the possibility that frequent fungicide sprays could negatively affect healthy asparagus fern. The manner in which spray frequency affects relatively healthy asparagus fern and impacts yield is unknown, however negative effects of spray frequency on relatively healthy fern could explain the increased yield in the 14-day treatment.

Disease severity on spears was affected only by harvest date. Falloon et al. (1987) reported an increase in disease on spears after periods of heavy rainfall. Hausbeck et al.

(1997) monitored atmospheric concentrations of *Pleospora allii* with Burkard volumetric spore traps in no-till commercial asparagus fields. Peak concentrations of ascospores were usually associated with rainfall events (Hausbeck et al., 1997). Purple spot disease developed on spears in the field when harvesting occurred $\geq$ 48 hours following ascospore discharge prompted by rainfall (Hausbeck et al., 1997). According to a study by Falloon et al. (1987), disease severity on spears is positively correlated with rainfall events, and disease increases after heavy rainfall at temperatures between 0 and 20 C. The rupture of asci, discharge, and germination of ascospores of *P. herbarum* is dependent on water (Atanasoff, 1919).

The use of TOMCAST provides a promising alternative to calendar-based spraying in commercial asparagus fields. Disease control between TOMCAST and the 7- and 10-day spray schedules was comparable with a maximum reduction of 6 (1996) or 4 (1997) sprays. In addition to saving money and preserving the environment, TOMCAST is a valuable tool in alerting growers that the environmental conditions are favorable for purple spot disease development. In a study conducted by Montesinos and Vilardell (1992) involving *S. vesicarium* on pear, it was shown that disease incidence was lower in plots of untreated trees in orchards that had been treated previously for several years than in orchards not previously treated . However, in commercial asparagus fields, disease pressure in any given growing season does not appear to be related to previous disease pressure. For instance, the mature asparagus field used in this study had been monitored since 1992 and not sprayed with fungicides. Fern lesions at the end of each of the growing seasons did not show a pattern of increasing each year as a result of inoculum buildup. Therefore, a grower cannot accurately predict the likelihood of purple spot disease based on the previous year's disease severity.

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