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DEVELOPING A REDUCED RISK MANAGEMENT
PROGRAM TO CONTROL ALTERNARIA DAUCI AND
CERCOSPORA CAROTAE ON CARROTS IN MICHIGAN

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DEVELOPING A REDUCED RISK MANAGEMENT PROGRAM TO CONTROL *ALTERNARIA DAUCI* AND *CERCOSPORA CAROTAE* ON CARROTS IN MICHIGAN

By

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ABSTRACT

DEVELOPING A REDUCED RISK MANAGEMENT PROGRAM TO CONTROL *ALTERNARIA DAUCI* AND *CERCOSPORA CAROTAE* ON CARROTS IN MICHIGAN

By

Elizabeth Ann Dorman

Alternaria blight (*Alternaria dauci* (Kühn) Groves and Skolko) and Cercospora blight (*Cercospora carotae* (Pass.) Solheim), incite disease on carrot leaves and petioles. Tops weakened by disease break off during mechanical harvesting, leaving roots in the ground. A survey of Michigan carrot growers in 2001 gathered baseline information on the current management practices of commercial carrot production and adoption of IPM. The survey indicated a reliance using chlorothalonil to manage foliar blight disease. A field investigation was conducted in 2001 and 2002 growing seasons to determine if Tom-Cast disease-forecasting model could be used to time fungicide sprays. Tom-Cast was tested at spray thresholds of 10, 15, 20 disease severity value (DSVs). A copper-based fungicide approved for use in organic production (Kocide 2000), a reduced risk systemic fungicide (Quadris), and a standard commercial fungicide (Bravo Ultrex), were used alone or alternated with each other, significantly reduced foliar blight in both years. In 2001, using Tom-Cast (DSV=15) to trigger sprays decreased the number of applications required compared to a calendar-based schedule, while providing comparable disease control. In 2002, with an early occurrence of disease and an increase in disease pressure, application intervals of some fungicide programs had to be shortened (DSV=10). The results suggest that coupling azoxystrobin and/or copper hydroxide with Tom-Cast can be a reliable alternative to conventional programs.

DEDICATION

To my parents,
for instilling in me
an appreciation and love
for the nature world
from a very young age.

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LITERATURE REVIEW

Introduction. *Daucus carota* is a member of the Umbelliferous family, and is thought to have originated from Afghanistan and Turkestan (12). Early records of cultivation methods date back to the tenth century in Asia Minor. Europe was introduced to purple and yellow carrots in the eleventh century (12).

Each year 125,000 acres of carrots are planted in the United States (2). In 2001, Michigan harvested 6,300 acres, ranking third and fifth in production of fresh market and processing carrots, respectively (2, 21). In Michigan, processing carrot production is primarily located in Muskegon, Newaygo and Oceana counties, while fresh market carrots are primarily produced in Montcalm and Lapeer counties (8).

Carrots are produced in temperate regions and are grown in deep, well-drained muck and mineral soils (12, 44). They are vulnerable to extreme environmental conditions, such as heat, soil compaction, water stress and saturation. Although young seedlings can withstand mild frosts, they can be severely damaged by high temperatures (44). Normally a biennial, the carrot plant produces a fleshy storage root in the first year of growth and achieves marketable size within 70 to 150 days. This storage root is widely recognized for its high carotene content (12).

Most carrots are harvested with equipment that undercuts the roots while gripper belts simultaneously grasp the foliage and lift the plants and roots from the soil. Rapid post-harvest cooling is essential to extend and maintain shelf life of roots. However, in some carrot production regions the roots may be field-stored over the winter with a straw cover protection (12).

Alternaria blight (*Alternaria dauci* (Kühn) Groves & Skolko) and Cercospora blight (*Cercospora carotae* (Pass.) Solheim) are common foliar diseases found wherever carrots are grown (12). Cercospora and Alternaria blights can lower yields by reducing leaf area available for photosynthesis, resulting in decreased root weight (20). Both foliar blights can also indirectly reduce yields during mechanical harvesting, when weakened foliage results in roots left in the ground (12, 20, 32).

Michigan carrot growers currently rely on fungicides for disease management in carrot production. The fungicides, iprodione and chlorothalonil, are currently registered for foliar blight control, but are B2 carcinogens and face an uncertain future as a result of the Food Quality Protection Act (FQPA) and some processor restrictions. Reducing pesticide use may help maintain future contracts with some processors (1).

Alternaria leaf blight. Alternaria leaf blight was first described on carrots in Germany in 1855 (32). *Alternaria dauci* is classified in the form-subdivision Deuteromycotina, form-class Hyphomycetes and was previously referred to as *Alternaria carotae* (Ellis and Langlois) J.A. Stevenson and Wellman (14).

Alternaria dauci typically produces solitary obcavate conidia having a beak up to 3 times the length of the body of the spore. Young conidia are at first pale olivaceous brown, often becoming dark brown with age and measuring 100-450 µm in length and 16-25 µm in diameter. Conidia develop from a pale olivaceous brown conidiophore measuring up to 80 µm long and 6-10 µm thick (13). *Alternaria dauci* has a small host range, infecting carrots and their wild Umbelliferae relatives including; "Giant Carrot" (*Daucus maximus*), false caraway (*Ridolfia segetum*), and *Caucalis tenella* (27, 32). Parsley may also serve as a host when conditions are especially favorable (32).

Alternaria dauci infects petioles and leaves, resulting in small dark brown to black spots with a yellow border forming along leaflet margins. When lesions coalesce, entire leaflets die and/or petioles become girdled (8, 20, 32). Foliar lesions caused by *A. dauci* resemble those resulting from infection by *C. carotae*. However, *A. dauci* lesions are differentiated by an irregular border that surrounds a dark brown necrotic center (8, 20).

Alternaria dauci is known as a diurnal sporulator. In addition to its high humidity and temperature requirements (8 to 28°C, with optimum at 24°C in nature), it has two distinct phases of sporulation dependent on light (31). During the inductive phase, light triggers the formation of the conidiophores, while conidia are inhibited by light and are formed only during a period of darkness in what is known as the terminal phase (22, 31). Ideal light conditions for sporulation within a 24 hr cycle in vitro, are alternations of 8 hrs of light and 16 hrs of darkness or 12 hrs of light and 12 hrs of darkness (45), with a minimum daylength of 4 hrs (34). Optimum irradiation wavelengths have been determined for conidiophore and conidia development at 370-510 and 210 nanometers, respectively (45).

Conidia are disseminated by wind, running and splashing water, farm machinery and field workers (8, 20), during the morning hours when humidity decreases and temperature and wind speed increase (20). Free moisture is required for germination (8, 20), which typically occurs within 1-3 hrs of inoculation under favorable conditions (31). *Alternaria dauci* spores germinate after 1 hour at optimum temperature (28°C), but require more time at cooler or warmer temperatures (31). Germination of *A. dauci* spores in vitro occurs between 15 to 30°C, whereas the maximum growth of germ tubes occurs between 25 to 30°C (22).

Twelve to 24 hrs of leaf wetness is required for infection. Cloudy weather and senescent leaves also make carrot leaves more susceptible to infection (22). Infection occurs within 8 to 12 hr at temperatures of 16-25°C (12), the optimum temperature being 28°C (20, 32). The pathogen can survive in or on seed and can overwinter on weed hosts (e.g. Queen Anne's Lace) or diseased crop residues persisting in the soil up to 1 year (8, 12, 20, 30).

During culture and storage, colony growth characteristics, pathogenicity, and ability to sporulate may change (34). A medium made from dried carrot leaves allows reliable culture, storage, and production of conidia (34). On agar media, a pH from 6.0 to 6.5 was found to be optimal for mycelial production, while a pH near 7 was optimal for conidial production (34). Mycelial growth rate was proportionate to temperature from 12 to 28°C, although significant growth was observed as low as 12°C (34).

Cercospora leaf blight. Cercospora leaf blight was first described on carrots in Italy in 1889 (32). *Cercospora carotae* is classified in the form-subdivision Deuteromycotina, form-class Hyphomycetes (14).

Cercospora carotae typically produces cylindrical colorless to slightly colored conidia with 1 to 6 transverse septa ranging in size from 2.2 to 2.5 × 40 to 110 µm (32, 35). The conidia are borne successively at the tips of conidiophores that measure 2.2 to 2.5 µm in diameter (20, 32). Cercospora leaf blight is currently distributed worldwide. However, it is most prevalent in temperate zones infecting only species found in the genus *Daucus*, specifically *Daucus carota* (cultivated carrot), *D. maritimus* (wild carrot with pink umbels), *D. pulcherrimus*, *D. pusillus* (American wild carrot), *D. hispanicus*, and *D. gingidium* (32).

Cercospora carotae infects the foliage and petioles (32) causing small circular lesions that may enlarge into small, tan, brown, or almost black spots with a necrotic center surrounded by a chlorotic border (20). Lesions are primary located along leaflet margins and cause lateral curling (32). As the lesions increase in size and coalesce, entire leaflets become blighted and die and petioles collapse from girdling (20, 35). Disease symptoms can appear 3 to 5 days after inoculation depending on cultivar and temperature (32).

Conidia are abundantly produced at temperatures from 19 to 36°C (optimum 28°C) with a minimum leaf wetness period 12 hrs (10, 20). Conidiophores arise in groups from a pseudostroma in the substomatal cavity, usually emerging through stomata or rupturing the stomatal opening (20, 35).

Once conidia have been dispersed by wind, splashing rain, farm machinery and workers, infection occurs when spores penetrate through stomatal openings (20). Germinated spores can prefer a dry period of 3 hrs with initial and final wet periods of 24 and 12 hrs; respectively, resulting in more lesions per plant than a period of continuous wetness (39 hrs) (9). The penetrating hypha often enlarge after it has entered the stomata, plugging the stomatal cavity. The advancing hyphae usually invade the mesophyll before advancing laterally in the epidermis within 5 days of penetration (35). A minimum of 24 hr of leaf wetness is required to induce infection. However, interrupting a wet period can significantly reduce infection (9). In contrast to *A. dauci*, younger carrot leaves are more susceptible to *C. carotae* infection than senescent leaves (19, 20). *Cercospora carotae* overwinters on and in seed, in diseased host debris and on wild carrot and other host plants (20).

In culture, *C. carotae* grows and sporulates best in 6 to 12 days on carrot leaf agar at pH from 5 to 6.5 and temperatures from 19 to 28°C (20, 35).

Leaf blight management strategies. *Alternaria dauci* and *C. carotae* are managed similarly using cultural and chemical controls (1). To minimize overwintering inoculum, carrot residue may be tilled and turned under immediately after harvest to hasten decomposition. Michigan growers use a 2 to 3 year crop rotation with non-host crops and do not establish new fields near previously infested areas. By choosing disease tolerant cultivars and using seed that is certified, tested, and treated, disease incidence can be reduced (20, 32).

Alternaria dauci and *C. carotae* can be controlled by regular applications of registered chemical fungicides, including chlorothalonil and iprodione (Bravo Ultrex 82.5WDG at 1.6 kg a.i./ha, Syngenta Crop Protection, Inc., Greensboro, NC; Rovral 4F at 1.75 L a.i./ha, Bayer CropScience, Research Triangle Park, NC; or Iprodione 4L AG at 1.75 L a.i./ha, Micro Flo Company LLC, Memphis, TN; respectively) which are considered to be B2 carcinogens (7). Iprodione is a systemic fungicide that may be used as a seed treatment or applied every 7 to 10 days after carrot emergence (8). Chlorothalonil, a commonly used protectant fungicide, is used in field applications and may be applied through irrigation equipment (8).

Copper-based fungicides currently registered for commercial and organic carrot production include; copper ammonium carbonate (Copper Count N at 6.5 L a.i./ha, Mineral Research and Development Corp. Charlotte, NC), copper hydroxide (Kocide

2000 53.8DF at 1.7 kg a.i./ha, Griffin LLC, Valdosta, GA; Kocide 4.5 LF 0.63 L a.i./ha Griffin LLC, Valdosta, GA; and Champ DP at 1.5 kg a.i./ha, Agtrol International, Houston, TX), copper sulfate (Basicop at 3.9 kg a.i./ha, Griffin LLC, Valdosta, GA), and copper resinate (Tenn-Cop 5E at 4.7 L a.i./ha, Griffin LLC, Valdosta, GA) (7). Currently, copper based fungicides when used alone do not control disease at a commercially acceptable level when disease pressure is significant (1, 6).

Disease forecasting models. In 1978, a computerized forecasting system for *Alternaria solani* (Ellis & G. Martin) Sorauer on tomato (FAST), was developed to identify periods when environmental conditions are favorable for tomato early blight development. It is based on daily environmental parameters: maximum and minimum air temperature, hours of leaf-wetness, maximum and minimum temperature during wetness periods, hours of relative humidity greater than 90%, and rainfall. The FAST system requires fewer fungicide applications compared with weekly spray schedules to obtain the same level of disease control (16, 23). However, the model is complex and the equipment required is awkward and prone to problems (16). The FAST system has also been tested in Spain for scheduling fungicide applications to control necrotic spotting on pear caused by *Stemphylium vesicarium* (Wallr.) E. Simmons (26).

In 1985, a modified FAST program called Tom-Cast was developed to aid in the management of anthracnose (*Colletotricum coccodes* (Wallr.) Hughes), Septoria leaf spot (*Septoria lycopersici* Speg.) and early blight (*A. solani*) on tomatoes (16). Tom-Cast does not include the rain model of FAST, but includes the duration of leaf wetness and average air temperature during the wetness periods to calculate a daily disease severity value (DSV) of 0 to 4, corresponding to conditions unfavorable to highly favorable for *A.*

solani conidial formation (29). When DSVs accumulate to a predetermined threshold, fungicides are applied and the DSV is reset. The number of fungicide sprays may be reduced by as much as 50% without compromising fruit quality or yield by using Tom-Cast (16). Tom-Cast has been used in Michigan asparagus for control of purple spot (*Stemphyllium vesicarium* (Wallr.) E. Simmons) (25). Preliminary research has been conducted with this system to manage foliar blight caused by *A. dauci* and *C. carotae* on carrots (Hausbeck, unpublished data).

Nitrogen management. Carrots utilize both indigenous and applied nitrogen at soil depths greater than 30 cm (39). Excess nitrogen increases top biomass for healthy carrot tops to aid in harvesting when carrots are lifted out of the ground. However, baby food processors are concerned about high levels of nitrogen in carrot roots that can occur when using excess nitrogen (40). Several studies have found that increased levels of nitrogen do not increase carrot yields (37, 39). High nitrogen levels can also lead to higher residual nitrogen in the soil for the following growing season, such that pre-plant fertilization might not be necessary (39).

Mature carrot leaves are more susceptible to *A. dauci* than younger leaves (33). High levels of nitrogen increase plant vigor, delay maturity (36) and increase the period of meristematic activity, thereby limiting disease (5). When an inadequate amount of nitrogen is applied, incidence of leaf blight is significantly higher (39). A single rate of N, P, and K or split applications did not influence the incidence of Alternaria leaf blight in one year, but significantly affected it the next (42). Greenhouse studies showed that doubling the rate of fertilization decreased disease severity caused by *A. dauci* by 10 to 15%, while reducing nitrogen by half increased disease severity by 23 to 30%. However, field studies showed applications of excess fertilizer alone were not advantageous and were found to be an impractical means to enhance host resistance to *A. dauci* when compared to fungicide treated plots (37).

Three synthetic fertilizers are commonly used in commercial production. Urea (17-44-0) is the cheapest and most commonly used solid nitrogen fertilizer. Up to 30% of the urea applied can be lost as a gas following rainfall if not rapidly incorporated into the soil (15, 24). Ammonium nitrate is broadcast on the surface (24) and moves into the soil where leaching and denitrification is more likely (15). Anhydrous ammonia, the least expensive nitrogen fertilizer, can have significant nitrogen losses when applied to soil that is too dry or too wet (15, 24). Anhydrous ammonia can also cause changes in soil pH in and around the injection band, killing many organisms and rendering organic matter more soluble (24).

Organic production systems more commonly use compost as a source of nutrients. During composting, much of the nitrogen is converted into more stable organic forms and is released slowly into the soil (24). Good compost has an added benefit of having a number of microorganisms that can fix nitrogen from the air and making it available to plants. Up to 120 pounds of nitrogen can be fixed per acre per year under ideal conditions (38). Composts have also been found to suppress root and leaf diseases of plants (18). Disease incidence can be significantly reduced by 41% with soil amended with 75% compost (41).

Nutrients applied to the foliage are readily available and more easily utilized by the plant than when applied to the soil. Foliar nutrients increase rates of photosynthesis, thereby stimulating and increasing nutrient absorption (up to 80%). In comparison, when nitrogen and anhydrous ammonia are applied, 30% and 15%, respectively, enters the plant through foliage (38).

A common foliar fertilizer used in organic systems is that made from fish solubles containing water-soluble vitamins, particularly the Bs, as well as proteins, amino acids, trace minerals, phosphorus, magnesium and calcium (17). Fish soluble nutrients applied weekly or biweekly intervals stimulated vegetative growth and delayed flowering and fruit-ripening by 5-8 days depending upon concentration and frequency of application (3). The results indicate that fish fertilizers are equal or superior to inorganic nutrient and commercial-grade fertilizer.

Toxins produced by *Alternaria*. The genus *Alternaria* is known to produce low-molecular-weight compounds called toxins that cause histological and physiological changes in the host (31). Host-specific toxins contribute to their virulence or pathogencity (28), and most importantly, determine their host range by having high biological activity toward only the host of the toxin producing pathogen (43). Many of the pathotypes of *A. alternata* produce host-specific toxins such as AM-toxin from *A. alternata* on apple; AL-toxin from tomato, and AF-toxin from strawberry (31). Non-selective toxins, a factor in pathogenesis, exhibit differential toxicity toward various plant species or cultivars, but their toxicity is not necessarily correlated with virulence and host range. Non-selective toxins such as zinniol, alternaric acid, radicinil, radicinol and tentoxin are produced by several pathogens, affect several hosts and are not a prerequisite for infection (31).

Zinniol, the causal agent of common leaf spot and seedling blight of zinnia, sunflower and marigolds, was isolated from culture filtrates, mycelium and cell walls of

A. dauci. This non-specific toxin could also be detected during spore germination and early growth phases (4). Zinniol production seems to be a common characteristic of large-spored, long-beaked *Alternaria* spp. The evolutionary conservation of zinniol production in pathogenic large-spored *Alternaria* spp. may be indicative of its importance in pathogenesis (11).

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SECTION I

A SURVEY ON THE IPM PRACTICES AND PESTICIDE USE OF CARROT GROWERS IN MICHIGAN

INTRODUCTION

Each year 125,000 acres of carrots are planted in the United States (1). In 2001, Michigan harvested 6,300 acres, ranking third and fifth nationally in production of fresh market and processing carrots, respectively (1, 3). In Michigan, processing carrot production is primarily located in Muskegon, Newaygo and Oceana counties, while fresh market carrots are primarily produced in Montcalm and Lapeer counties (2).

The objective of this survey was to gather baseline information on the current management practices of commercial carrot producers, and determine the level of adoption of integrated pest management (IPM) methods in Michigan.

MATERIALS AND METHODS

A survey developed by University of Wisconsin (4) was used to assess IPM practices among Michigan growers. A private consultant distributed the surveys to 12 commercial carrot growers in west Michigan in the fall of 2002. Growers were asked to select a specific field representative of carrot production on their farm and to answer questions based on that field. In some instances, general information regarding farming and pest management practices was requested. The survey included questions regarding current cropping techniques, implementation of IPM strategies, carrot cultivars grown and pesticide usage. The survey was divided into six sections, including specific field and farm information, field scouting, weed control, insect control, disease control and soil fertility. Sections pertaining to the control of pests included a series of questions that were directed towards the management activities occurring prior to and during the 2001 carrot crop on the selected field. The survey format and summary are found in a table in Appendix I.

RESULTS

Specific Field and Farm Information. The carrot acreage in Michigan represented by the 10 growers who responded to the survey equated to 1,940 acres. Individual farm or operation size varied from 500 acres to 30 acres, with the average operation between 200 to 300 acres. The field size selected to represent the typical carrot cropping practices ranged from 12 to 125 acres, and the average field size was 25 to 40 acres.

Carrots produced in Michigan are grown for cut and peel (fresh market) or dicing and slicing (processing), with primary emphasis on dicer and cut and peel varieties. The most common dicer varieties grown included Goliath and Recoleta, with cultivars Danver, Early Gold, Canada, Carson and Bergen grown in limited quantities. The more commonly grown cut and peel varieties were Prime Cut, 7-11, Triple Play, and Sugar Snax. About half of the growers store harvested carrots on location, whereas the other growers harvest and send the carrots by truckload to a processing plant.

Carrots are planted in Michigan starting from mid-April to early June and emerge 12-15 days later. Carrots are most frequently rotated with corn, squash (zucchini and winter squash), cucumbers, and wheat. Carrots are typically grown every 3-4 years, although one grower used a two-year carrot rotation. A few growers rotated vegetable crops such as broccoli, peppers, snapbeans and potatoes with carrots. With the exception of one grower who used wheat, all operations utilized nurse crops of either oats or barley to provide a wind protection during early growth stages of the plants. The fields were irrigated using a hard hose traveler or a center pivot and water was applied as needed.

Two growers used soil fumigation, one applied in October 1997 and the other in October 2000.

Field scouting. With the exception of two growers, the scouting was typically initiated before or within four days of emergence, and all growers began scouting within four weeks of planting. On average, 25 scouting trips were conducted during the growing season, with three growers (growers A, C and G) having the highest number of trips, 45, and one grower (grower F) having the lowest number of trips, seven (Figure 1). The farm owner/manager, a certified independent crop consultant or farm supply dealer representative were primarily responsible for scouting (Figure 2). Typically, 20-30 minutes were spent on a scouting trip.

All surveyed growers scouted their field to detect any new developing pest problems and to determine when pest levels reach or exceed established thresholds. Many growers used scouting to monitor pre-existing pest problems, to check the effectiveness of previously implemented control measures, and to reduce the amount of pesticide used in order to minimize environmental impacts.

Scouting was typically conducted by following specific patterns throughout the field, including the borders and interior of the field. To monitor carrot fields for pests and weeds, many growers used informal observations during routine farm practices, focusing on the edge of the field.

Records of scouting varied from no written or electronic information recorded, to information recorded in a computer file or spreadsheet. Most of the growers kept written records in a file to track changes in pest pressure over time.

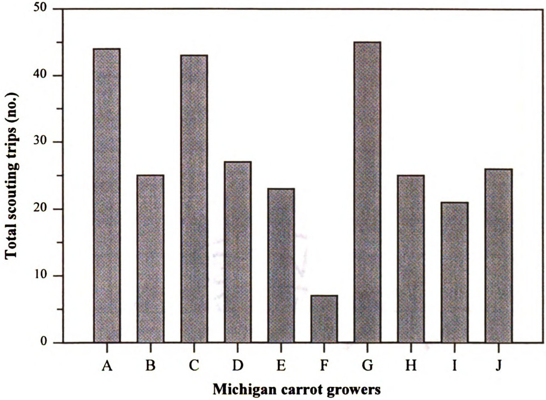

Figure 1. Total number of scouting trips completed for each surveyed carrot grower's selected field in 2001.

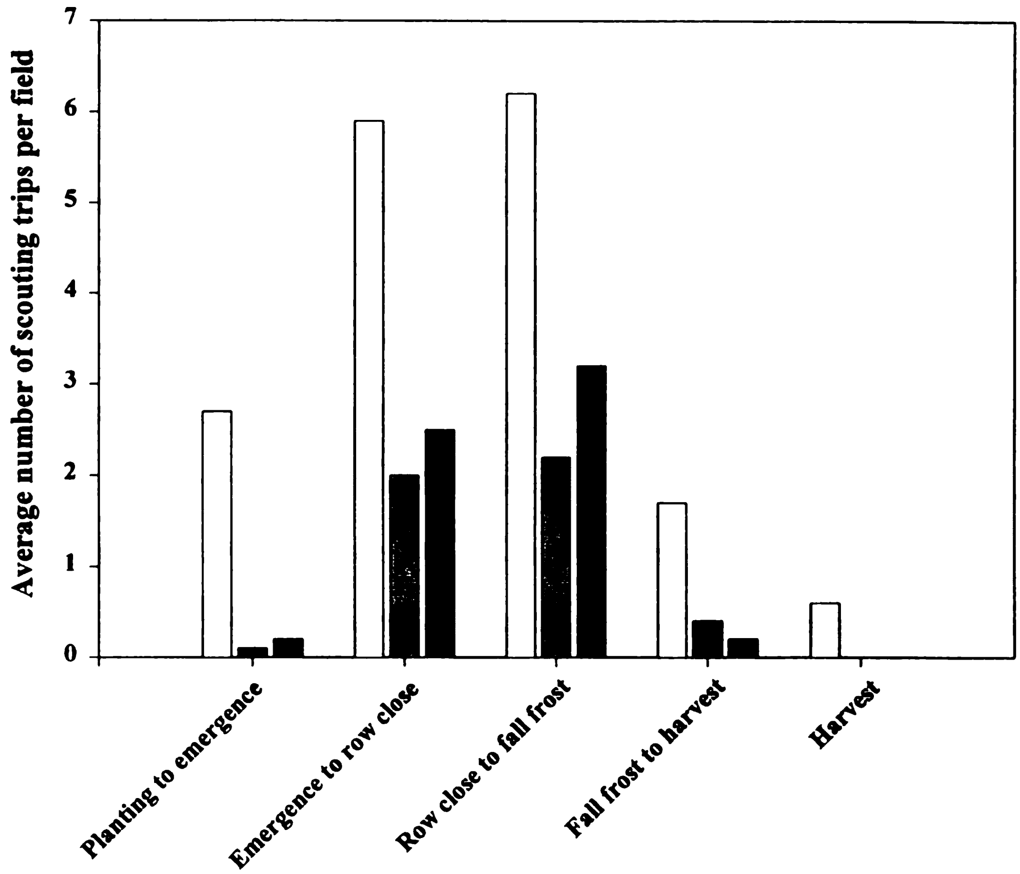

Figure 2. Average number of scouting trips conducted per field by the farm owner (□), an independent crop consultant (■) or farm supply dealer representative (■) during each stage of the growing season on the selected field in 2001.

All growers, except two, relied upon information supplied or distributed by Michigan State University for pest control decisions regarding insects and diseases. None of the growers surveyed utilized electronic information when making pest management decisions. All growers, except one, relied heavily upon their own personal knowledge of pest biology when managing insects and diseases. Weather data played an important role in timing fungicide applications to control diseases for all but two growers (Figure 3).

For three growers, pesticide decisions for disease and insects were based upon scouting information or reports 100% of the time. The remaining growers felt the percentage was around 70% for disease and insects. All ten growers surveyed based pesticide decisions for weed control upon scouting information 55% of the time.

Occasionally, actions were taken in absence of scouting reports, when a concern existed that scouting could not track a rapidly developing pest problem. Pest management was sometimes withheld even though scouting information recommended action, such as when the activity period for a pest was nearly complete and the cost of the control would exceed the returns from the pest control action. Sometimes the profit margin would be so small that the grower could not afford to use pesticides, even when it was recommended to do so.

Commercial carrot growers were asked how often their pest management decisions resulted in chemical, cultural and biological control practices. Overall, decisions to use chemical control occurred 45% of the time, while decisions to use cultural and biological methods each occurred 25-30% of the time.

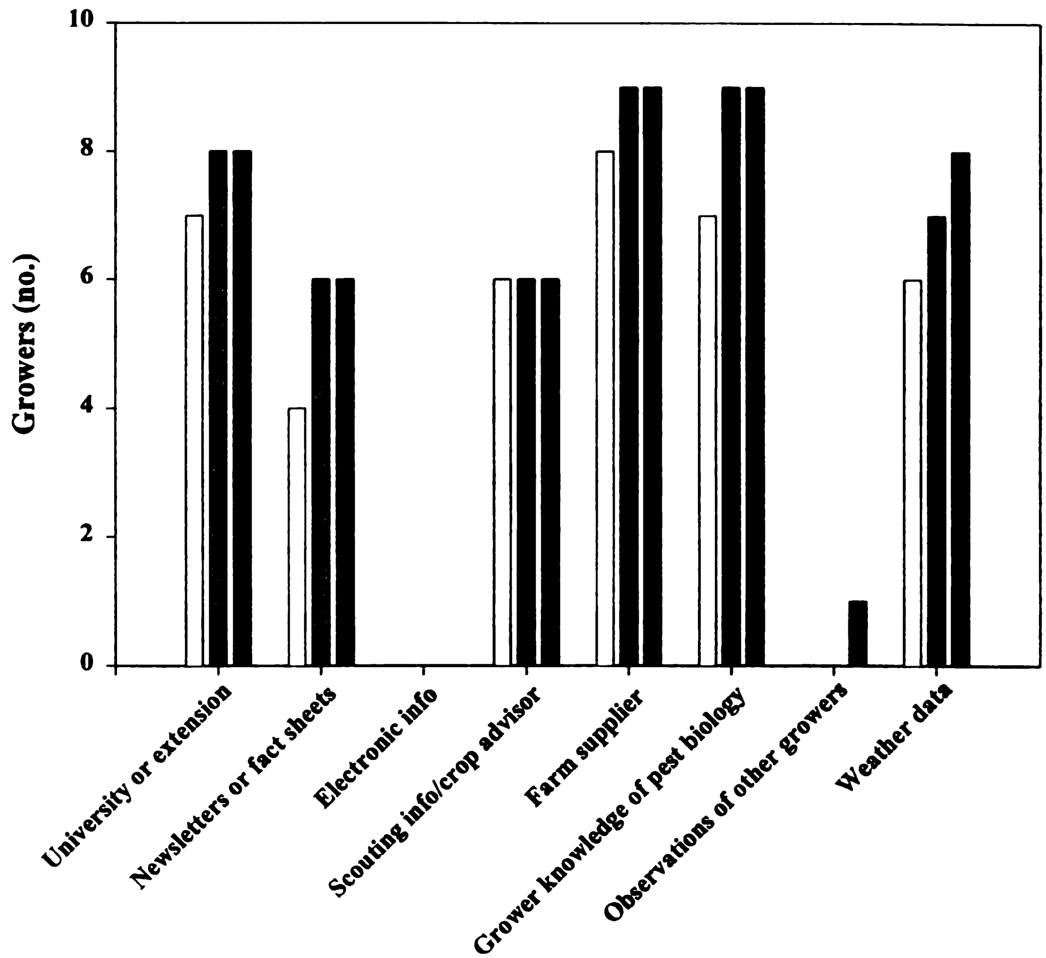

Figure 3. Sources of information used by Michigan carrot growers when making decisions on when and how to treat weeds (□), insects (■) and diseases (■) on the selected field in 2001.

Weeds. Weeds of concern to Michigan carrot growers include annual grasses and broadleaf and perennial species. Crabgrass, foxtail and fall panicum were the primary annual grasses. Pigweed, lambsquarters, ragweed and wild carrot were the annual broadleaves of concern. Nutsedge and quackgrass were the perennial weeds causing problems.

Prior to planting, selected fields were planted with a fall cover crop. Field edges were also tilled or mowed in spring to prevent weed spread. Some growers have altered the crop rotation in past four years or selected herbicides in preceding crops to reduce weed pressure in carrots.

Once carrots had emerged only three growers cultivated the field. All surveyed growers used cover crops, however only six used cover crops to aid in weed control; all others used them for wind protection. Spot spraying of herbicides was done in all but three fields on average of once a year. Application of herbicides to entire fields occurred on average three times a year. One to three applications of linuron (Lorox DF 0.75 to 2.0 lb/A, Griffin L.L.C., Valdosta, GA) were applied before, during, and after planting to control annual grasses and broadleaf weeds. Post planting applications of fluazifop-P-butyl (Fusilade DX from 8-16 oz/A 1-2 times per year, Syngenta Crop Protection, Inc., Greensboro, NC) and metribuzin (Sencor DF at 1/3 oz/A once a year, Bayer CropScience, Research Triangle Park, NC) were other products used to control grasses and broadleaf weeds, respectively (Table 1).

The aster leafhopper was of primary concern to growers. A few growers reported moderate pressure from aphids, with other insects such as carrot weevil, cutworms and grubs occurring only occasionally. All of the growers, with exception of one, scouted

Table 1. Summary history of pesticide use on the specific field for the carrot growers surveyed in Michigan during the 2001 growing season.

Product applied	Product amount applied per acre	Timing of application	Volume (GPA) of application	# Applications per season	Primary pest targeted by pesticide applied
Herbicide					
Lorox DF	0.75 lb to 2.0 lb/A	before, during and post planting	6-40	1-3	weeds
Fusilade DX	8 to 16 oz/A	post planting	6-40	1-2	weeds
Sencor DF	1/3 oz/A	post planting	6-20	1	weeds
Insecticide					
Asana XL	5 to 7.5 oz/A	post planting	6-40	2-5	leafhoppers
Baythroid 2E	1.6 to 2.5 oz/A	post planting	6-20	2-5	leafhoppers
Fungicide					
Bravo Ultrex WS or WDG	1.25 to 2 pt/A or 1.3 to 2 lb/A	post planting	6-20	1-2	leafspot (*Alternaria* and *Cercospora*)
Champ Formula DP or 2F	1 to 1.25 lb/A or 1 to 4 pt/A	post planting	6-20	1-3	leafspot (*Alternaria* and *Cercospora*)
Quadris F	5.12 to 7 oz/A	post planting	6-20	1-3	leafspot (*Alternaria* and *Cercospora*)
Tenn-Cop 5E	1 pt/A	post planting	6-20	2	leafspot (*Alternaria* and *Cercospora*)

All pesticides were applied by the farm owner using ground rig sprayer with exception of one grower who had a custom applicator apply a fungicide by an airplane.

insects by using a sweep net. Some growers made general observations of their own as a scouting method.

The health of the carrot crop was closely managed in all operations to avoid insect infestation. None of the surveyed growers used time of planting as a means to avoid insect injury. Only one grower used spot treating as a method to manage insects on their carrot field by applying insecticide once to small areas. Eight of the ten growers applied insecticides only when thresholds levels were surpassed, with one grower applying three sprays. Four growers chose to apply insecticides three weeks before harvest, and the remaining six did not. The most commonly used insecticide, esfenvalerate (Asana XL 5.0 to 7.5 oz/A, E.I. duPont de Nemours & Co., Inc, Wilmington, DE), was applied two to five times after carrots were planted to control leafhopper populations. Two growers applied emulsified pyrethroid (Baythroid 2E at 1.6 to 2.5 oz/A, Bayer CropScience, Research Triangle Park, NC) two to five times per season (Table 1).

Four of the ten growers frequently relied upon leafhopper migration information to determine the necessity for insecticide applications. Most growers used leafhopper counts per 100 sweeps. A few growers utilized infectivity tests of local and general leafhopper populations, while taking into account susceptibility of the carrot variety planted.

Root knot nematode was not significant to any carrot growers' operations, with the exception of one grower who had an occasional problem in his field. Soil testing for root knot nematode was not routinely practiced by any of the carrot growers surveyed, with the exception of one.

Diseases. Growers were asked to rate disease severity in their field using a scale of 1 to 4 where 1 = no disease is present, 2 = disease incidence is low, 3 = disease incidence is moderate with less than 50% of the plants are infected, and 4 = disease incidence is high with more than 50% of the plants are infected. Five out of ten growers gave leaf blight a rating of 3, while four out of ten growers rated leaf blight a 2. Only one grower considered leaf blight to be a severe problem with a rating of 4. Most growers rated aster yellows of low significance, with only occasional problems with the disease. White mold and damping off were the other diseases of concern, but only occasionally.

Scouting for plant diseases on some farms began in mid-May and for the majority of growers began in mid to late June into July. All but one grower specifically selected carrot varieties for their known disease tolerance or resistance characteristics. Only one grower made a special effort to remove or bury carrot culls located on or near their operation. Four of ten growers altered or changed their crop rotation to lower the potential for soil-borne pathogens.

The majority of growers had concerns about damage to carrots at harvest, so adjusting the harvesting equipment was an important part of minimizing unnecessary root damage or loss. All but one grower managed the health and fertility of their carrot crop through fertilizer and fungicide applications, not only for favorable yield, but also to resist plant diseases. One grower used biological agents. All of the growers, who required some form of irrigation, managed it so as to minimize favorable conditions for pathogen attack. Half of the growers relied heavily upon scouting information from their fields or Michigan State University recommendations for decisions regarding fungicide applications. Four out of ten growers used fungicides only after disease symptoms were present in the field. Eight of ten growers adjusted their spray programs according to disease resistant cultivars and four of those eight growers also blocked their varieties according to specific resistance characteristics. The most commonly used fungicide, chlorothalonil (Bravo Weather Stik SC at 1.35 to 2 pts/A or Bravo Ultrex WDG 1.3 to 2 lb/A, Syngenta Crop Protection, Inc., Greensboro, NC), was applied two to eight times per season (Figure 4). One to three applications per season of either copper hydroxide (Champ Formula DP or 2F at 1.0 to 1.25 lb/A or 1 to 4 pt/A, Nufarm Americas Inc., Burr Ridge, IL) or azoxystrobin (Quadris F at 5.12 to 7 fl oz/A, Syngenta Crop Protection, Inc., Greensboro, NC) are fungicides also used by carrot growers to control foliar blight diseases (Table 1).

Soil fertility. Seven of ten growers surveyed produced carrots on sand with 2% or less organic matter, while the other three growers grew carrots on silt loam. Soils were tested in 3 out of 10 operations on a yearly basis, while the remaining growers tested soils every 2-3 years. All of the growers surveyed applied lime to maintain a soil pH above 5.6.

Two growers applied less than 100 lb of nitrogen (N) to their field, seven growers applied 100-150 lb N/A and one grower applied 165 lb N/A. Nitrogen was applied to the fields as a pre-plant and sidedress application, with half of the growers also applying nitrogen as a foliar treatment.

Phosphorus and potassium were generally applied as a pre-plant application, however, the specific quantities of these nutrients varied greatly between growers. Phosphorus (P_2O_5) was applied prior to planting at a rate between 45-200 lb P_2O_5/A. Most of the growers surveyed applied potassium in the form of potash (K_2O) prior to

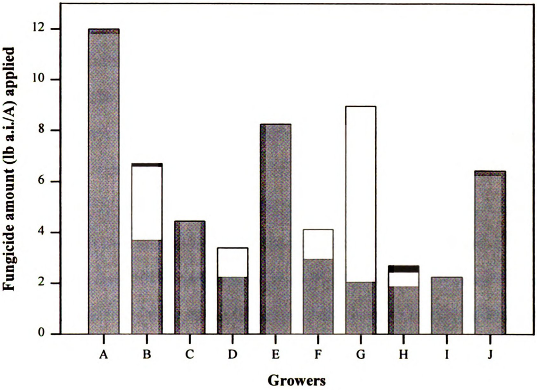

Figure 4. The amount (lb a.i./A) of chlorothalonil (▩), copper hydroxide (□), azoxystrobin (■) applied to a selected surveyed growers' carrot production field to control Alternaria and Cercospora blight.

planting at a rate between 150-250 lb K_2O/A while one grower chose to apply potash at 400 lb/A.

Nine out of ten growers applied boron at 1 to 4 lb B/acre as a pre-plant supplement. The majority of the 8 growers who applied manganese used 1 to 4 lb of Tech Magnum/A as a foliar treatment. Half of the surveyed growers added sulfur at variable rates to the selected field.

CONCLUSION

Results from this survey suggest that commercial carrot growers are implementing many IPM strategies to reduce cost and minimize environmental impacts. Growers are receiving the information they need to solve their problems from a variety of sources, including newsletters, university and extension publications, farm supplier dealers and crop advisors. Many of the pest management decisions are based upon scouting practices and current weather data. With this baseline information on current pest management practices in commercial carrot production, research can focus on IPM strategies currently not being utilized and monitor progress towards implementing additional management practices in the future.

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SECTION II

USING A REDUCED RISK FUNGICIDE, COPPER AND A DISEASE FORECASTER TO MANAGE FUNGAL FOLIAR BLIGHTS ON CARROTS

INTRODUCTION

Each year 50,600 hectares of carrots are planted in the United States (2). In 2001, Michigan harvested 2,550 hectares ranking third and fifth nationally in production of fresh market and processing carrots, respectively (2, 16).

Alternaria blight (*Alternaria dauci* (Kühn) Groves & Skolko) and Cercospora blight (*Cercospora carotae* (Pass.) Solheim) are common foliar diseases found wherever carrots are grown (9). Cercospora and Alternaria blights can lower yields by reducing leaf area available for photosynthesis, resulting in decreased root weight (13). Both foliar blights can also indirectly reduce yields during mechanical harvesting when weakened petioles result in roots left in the ground (9, 13, 24).

Cercospora carotae infects the foliage and petioles (24) causing small circular lesions that may enlarge into tan, brown, or almost black spots with a necrotic center surrounded by a chlorotic border (13). Lesions are located primarily along leaflet margins and cause lateral curling (24). As the lesions increase in size and coalesce, entire leaflets become blighted and die and petioles collapse from girdling (13, 26). Disease symptoms can appear 3 to 5 days after inoculation depending on cultivar and temperature (24).

Alternaria dauci infects petioles and leaves resulting in small dark brown to black spots with a yellow border forming along leaflet margins. When lesions coalesce, entire leaflets die and/or petioles become girdled (7, 13, 24). Foliar lesions caused by *A. dauci* resemble those resulting from infection by *C. carotae*. However, *A. dauci* lesions are differentiated by an irregular border that surrounds a dark brown necrotic center (7, 13). While *A. dauci* prefers senescent leaves for infection, *C. carotae* is more commonly found infecting younger leaf tissue (12, 13). Both pathogens can survive in or on seed and can overwinter on weed hosts (e.g. Queen Anne's Lace) or diseased crop residues persisting in the soil up to 1 year (7, 9, 13).

Alternaria dauci and *C. carotae* are managed similarly (1) using cultural and chemical controls. To minimize overwintering inoculum, carrot residue may be tilled and turned under immediately after harvest to hasten decomposition (1, 13, 24). Michigan growers use a 2 to 3 year crop rotation with non-host crops and do not establish new fields near previously infested areas (13, 24). *Alternaria dauci* and *C. carotae* can be controlled by regular applications of registered chemical fungicides including chlorothalonil (Bravo) and iprodione (Rovral), which are classified as B2 carcinogens. Iprodione is a systemic fungicide used as a seed treatment and a foliar spray that may be applied every 7 to 10 days after carrots emerge (7). Chlorothalonil is a commonly used protectant fungicide applied as a foliar spray or through irrigation equipment (7). Chlorothalonil and iprodione face an uncertain future as a result of the Food Quality Protection Act (FQPA) and some processor restrictions. Reducing growers' reliance on pesticides, especially those classified as B2 carcinogens, may help retain future contracts with some processors (1). Azoxystrobin (Quadris) is a newly registered fungicide that is considered to be reduced-risk. Due to disease resistance concerns it is registered for use in alternation with other fungicides. Copper-based fungicides are also registered for commercial production and some formulations are allowed in certified organic carrot production, including copper ammonium carbonate, copper hydroxide, copper sulfate, and copper resinate (5). Copper-based fungicides when used alone may not adequately control disease when pressure is severe (1, 4).

Environmental conditions play a significant role in foliar blight. Free moisture is required for conidial germination of *Alternaria*, which typically occurs within 1-3 hours after inoculation under favorable conditions (23). For infection to occur, 12 to 24 hours of leaf wetness between 16-25°C is required. In 1978, a computerized forecasting system for *Alternaria solani* (Ellis & G. Martin) Sorauer on tomato (FAST), was developed to identify periods when environmental conditions are favorable for early blight development. It is based on the following daily environmental parameters: maximum and minimum air temperature, hours of leaf-wetness, maximum and minimum temperature during wetness periods, hours of relative humidity greater than 90%, and rainfall. The FAST system requires fewer fungicide applications compared with weekly spray schedules to obtain the same level of disease control (10, 17). However, the model is complex and the equipment required is awkward and prone to problems (10). The FAST system has also been tested in Spain for scheduling fungicide applications to control necrotic spotting on pear caused by *Stemphylium vesicarium* (Wallr.) E. Simmons (19).

In 1985, a modified FAST program called Tom-Cast was developed to aid in the management of anthracnose (*Colletotricum coccodes* (Wallr.) Hughes), Septoria leaf spot (*Septoria lycopersici* Speg.) and early blight (*A. solani* Sorauer) on tomatoes (10). Tom-Cast does not include the rain model of FAST, but includes the duration of leaf wetness and average air temperature during the wetness periods to calculate a daily disease severity value (DSV) of 0 to 4, corresponding to conditions unfavorable to highly favorable for *A. solani* conidial formation (20). When DSVs accumulate to a predetermined threshold, fungicides are applied and the DSV is reset. In tomatoes, the number of fungicide sprays may be reduced by as much as 50% without compromising fruit quality or yield by using Tom-Cast (10). Tom-Cast has been used in Michigan asparagus for control of purple spot (*Stemphyllium vsicarium* (Wallr.) E. Simmons) (18). Preliminary research has been conducted with this system to manage foliar blight caused by *A. dauci* and *C. carotae* on carrots (Hausbeck, unpublished data).

The objective of this research was to determine whether Tom-Cast could be used to time fungicide sprays for management of Alternaria and Cercospora blight. Incorporating a fungicide that is reduced risk (Quadris) or may be used in an organic production system (copper hydroxide) in conjunction with the Tom-Cast predictor was of particular interest.

MATERIALS AND METHODS

Experimental design and treatments. Carrots (cv. Heritage) were planted (65.62 seed/meter) on a Houghton-muck soil at the MSU Muck Research Farm near Bath, MI on 14 May 2001 and 21 May 2002. The experimental design was a randomized complete block with four 49.4-m blocks containing 29 treatments randomly assigned within each block. Each treatment was contained within a three row (spaced 0.5-m apart) raised bed 7.2-m in length with three buffer rows between treatments. There was an average of 136 plants within each 7.2-m row.

The fungicides copper hydroxide (Kocide 2000 53.8DF at 0.91 kg a.i./ha, Griffin LLC, Valdosta, GA), chlorothalonil (Bravo Ultrex at 82.5WDG at 1.30 kg a.i./ha, Syngenta Crop Protection, Inc., Greensboro, NC) and azoxystrobin (Quadris 2.08SC at 0.11 kg a.i./ha, Syngenta Crop Protection, Greensboro, NC) were applied in the following programs: (i) control (no sprays); (ii) copper hydroxide; (iii) copper hydroxide alternated with azoxystrobin; (iv) cholorothalonil alternated with copper hydroxide; (v) azoxystrobin, (vi) azoxystrobin alternated with chlorothalonil; (vii) chlorothalonil; (viii) azoxystrobin alternated with chlorothalonil alternated with copper hydroxide. Fungicides were applied with a CO_2 powered backpack boom sprayer operated at 2.8 kg/cm^2 through three D3 hollow-cone nozzles (Teejet, Chicago, IL) spaced 45.8 cm apart and calibrated to deliver 473 L/ha.

All treatments were initiated on 29 June 2001 and 2 July 2002 when the canopy within a row closed. Subsequent sprays were made at 7-day intervals (2001, 13 sprays; 2002, 13 sprays), or according to Tom-Cast with a threshold of 10 DSV (2001, 13 sprays; 2002, 10 sprays), 15 DSV (2001, 8 sprays; 2002, 7 sprays) or 20 DSV (2001, 6 sprays; 2002, 5 sprays). The Tom-Cast program used the duration of leaf wetness and the average air temperature during the wetness period for each 24-hr period (11:00 A.M. to 11:00 A.M.) to determine a DSV of 0 to 4, corresponding to an environment unfavorable to highly favorable for foliar blight development (20). Hourly averages of the leaf wetness duration and temperature were collected using a digital data recorder (WatchDog Leaf Wetness and Temperature Logger 3610TWD; Spectrum Technologies, Inc., Plainfield, Illinois). The environmental sensor was oriented north at a 45° angle and positioned in the upper 75% of canopy in the center of an unsprayed bed.

Weed and insect pests were managed according to standard production practices (28). A pre-plant fertilizer 9-23-0 at 454 kg/ha and 227 kg/ha of 0-0-61 was applied on 27 April. Three applications of 28% liquid nitrogen (9.5 L/ha) and TechMag (1.7 kg/ha) were made on 28 June, and 5 and 27 July. Overhead sprinkler irrigation was applied as needed.

In 2001, the average maximum and minimum temperature for the growing season was 24.87°C and 13.64°C, respectively, with a sum of 37.41 cm of rainfall. The weather conditions differed significantly in 2002 compared to 2001 with 24.16 cm of rainfall with the average maximum and minimum temperature being 26.93°C and 13.65°C, respectively. In 2001, 55% of the total rainfall occurred in early in the growing season, May and June. During those same months in 2002 only 40% to the total rainfall was accumulated.

Assessment of disease. The combined effect of Alternaria and Cercospora leaf and petiole blight were assessed visually each week from 2 August through 28 September in 2001 and 22 July through 30 September in 2002. Foliar and petiole disease assessments were based within 3-m of the center treatment row. Foliar disease was assessed by estimating the leaf area infected (0, 1, 5, 10, 20, 40%) using a pictorial disease damage key (25). Incidence (the percentage of plants with infected petioles) of petiole blight was determined by marking diseased plants at weekly intervals. Severity of disease on the petioles was rated according to the following scale: 1 = no lesions per plant, 2 = 1-5 lesions per plant, 3 = 6-20 lesions per plant, 4 = 21-50 lesions per plant, 5 = >50 lesions per plant. The overall health of the petioles was estimated, using a scale of 0 (healthy) to 10 (dead). Area under the disease progress curve (AUDPC) was calculated to express the cumulative incidence of leaf and petiole infection occurring over a 57 and 70-day period in 2001and 2002, respectively according to the method of Shaner and Finney (1997):

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

in which Y_i = percent foliar blight at the ith observation, X_i = time (days) at the ith observation, and n = total number of observations. Roots were hand-harvested and weighed (kg) from within 3-m of the center treatment row on 28 September 2001 and 2 October 2002.

Economic assessment. The cost of each fungicide program was calculated by multiplying number of applications per year by the cost ($30.02/ha and $24.91/ha per application of chlorothalonil in 2001 and 2002, respectively, $33.75/ha and $32.32/ha per application of azoxystrobin in 2001 and 2002, respectively and $10.90/ha per application of copper hydroxide for both years) (Wilbur Ellis Co., *personal communication*).

Statistical analysis of foliar and petiole blight disease assessments. Each year of the experiment represents a randomized complete block design. Data were analyzed with an analysis of variance (ANOVA) with a linear model that included treatment, year, treatment by year, and rep nested within year as factors using the Proc GLM procedure of the Statistical Analysis System (SAS Institute, Cory, NC). The year*treatment interaction was not significant for any variable, so results were pooled over years. The design becomes a split-plot in time when both years are combined. 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 examined using Levene's Robust Test by conducting an ANOVA on the absolute value of the residuals. All of the variables were transformed using Y = log(variable +1), except for final petiole health, which was transformed using Y = sqrt(variable + 1). While the other variables did not meet both assumptions, the transformed variables improved the fit to normality in all cases.

The 29 treatments examined in this experiment represent a seven (fungicides) by 4 (application intervals) factorial with an untreated control as the 29th treatment. All variables showed a significant difference among the 29 treatments, and these differences were examined by decomposing the treatment sum of squares into four component sum of squares: (1) the difference between the average of the spray treatment programs and the untreated control; (2) differences between fungicides; (3) differences between application intervals; (4) an interaction between fungicides and application intervals. The interaction between fungicide and application intervals was not significant ($P > 0.05$) for all variables. As such, the main effects of fungicide and application interval were examined using Tukey's HSD to determine which fungicide or application interval had the best mean.

The variability of yield within years was strikingly different. As a result, yield was analyzed separately by year, using an ANOVA of a randomized complete block experiment. The ANOVA was calculated using the Proc GLM procedure of SAS, and residuals were used to examine the assumptions of normality and equal variances as above. Yield met both the assumptions of normality and equal variances without transformation. Differences in mean yield between the 29 treatments were examined in the same manner as for the other variables.

RESULTS

Petiole disease incidence. In 2001, disease symptoms occurred 77 days after planting with 78% of the petioles blighted within 7 weeks (Figure 4). Disease pressure was more severe in 2002 compared to 2001 with disease symptoms occurring 63 days after planting with all petioles becoming blighted within 7 weeks (Figure 4). According

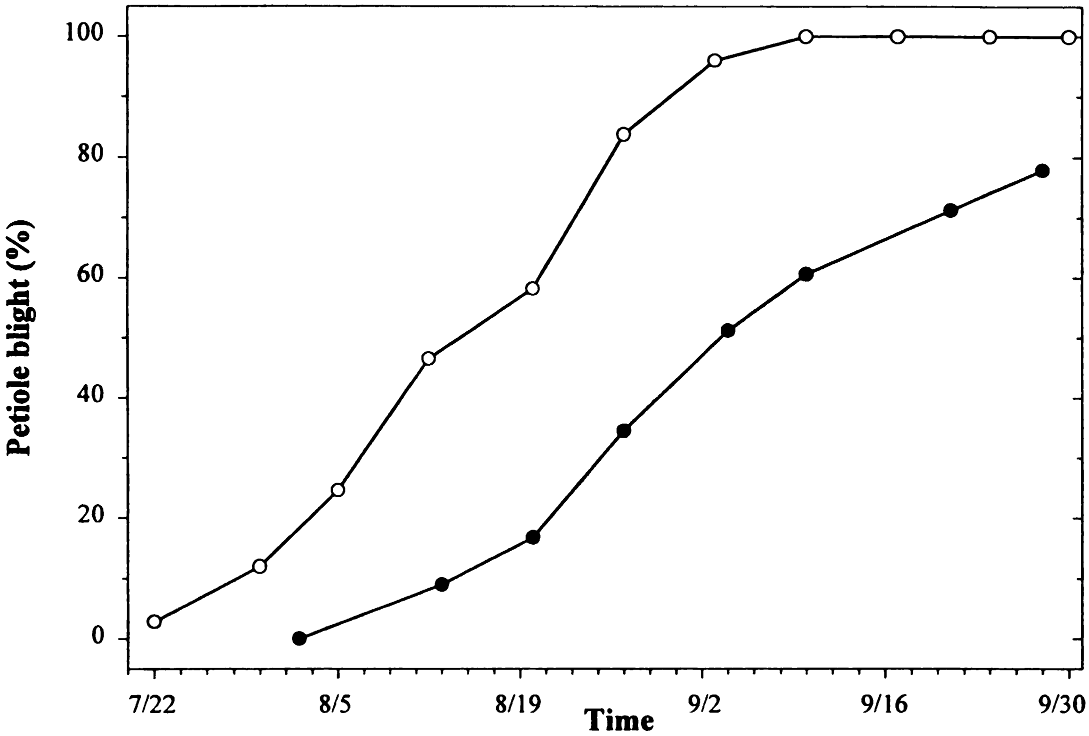


Figure 5. Progression of Alternaria and Cercospora petiole disease incidence (%) on carrots of the untreated plots at the MSU Muck Research Farm in 2001 (●) and 2002 (○).

to AUDPC data, all fungicide treatments significantly reduced incidence of petiole blight in comparison to the untreated control ($P = 0.001$, Table 2). The AUDPC values indicated that the disease incidence on plants treated every 7-days or according to Tom-Cast 10 DSV were not significantly different from each other (Table 2). However, both the 7-day and Tom-Cast 10 DSV programs were significantly more effective than the Tom-Cast 15 and 20 DSV programs in limiting petiole disease incidence according to AUDPC values (Table 2). Plants treated with copper hydroxide had a significantly higher incidence of petiole blight compared to all other fungicide programs except for plants treated with copper hydroxide/chlorothalonil (Table 2, Figure 6 and 7).

Petiole health. At the end of the season, untreated plants were significantly more diseased than those treated with fungicides ($P = 0.001$, Table 3). Petiole health of the untreated plants were 9.00 and 7.25 in 2001 and 2002, respectively (Table 4). In 2001 and 2002 when fungicides were applied, the lowest petiole health rating observed was 1.75 and 3.25, respectively (Table 4). Petiole health of plants treated every 7-days or according to Tom-Cast 10 DSV was similar, and significantly better than plants treated with fungicide according to Tom-Cast 15 and 20 DSV (Table 3). All fungicides were significantly more effective than copper hydroxide in maintaining petiole health (Table 3, Figure 8).

Petiole disease severity. At the end of the season, untreated plants had a petiole severity of 2.75 and 4.50 in 2001 and 2002, respectively (Table 4). The AUDPC values indicated that the severity of petiole blight was significantly greater for the untreated plants than those treated with fungicides ($P = 0.001$, Table 2). At the end of the 2001 and 2002, the lowest petiole severity rating was 0.25 and 1.75, respectively (Table 4). Based

Table 2. The area under the disease progress curve (AUDPC) and contrast results, where 2001 and 2002 data are combined, comparing application intervals and fungicide product used when assessing petiole and foliar blight caused by *Alternaria dauci* and *Cercospora carotae* on carrots.

	Number of applications		AUDPC (disease*day)[x]					
			Petiole blight					
Treatment	**2001**	**2002**	**Incidence**		**Severity**		**Foliar blight**	
Application interval								
7-day	13	13	53.83 a[z]		95.06 a		52.63 a	
Tom-Cast 10 DSV	13	10	54.92 a		92.57 a		49.39 a	
Tom-Cast 15 DSV	8	7	122.25 b		101.88 ab		70.51 ab	
Tom-Cast 20 DSV	6	5	219.70 b		108.47 b		104.65 b	
Fungicide[y]								
Copper hydroxide			359.90 c		115.83 c		149.39 b	
Azoxystrobin alternate copper hydroxide			67.36 ab		92.08 ab		63.42 ab	
Chlorothalonil alternate copper hydroxide			162.99 bc		106.22 bc		86.72 ab	
Azoxystrobin			85.30 ab		99.12 ab		48.41 a	
Azoxystrobin alternate chlorothalonil			47.24 a		90.31 a		50.90 a	
Chlorothalonil			84.29 ab		101.71 abc		54.33 a	
Azoxystrobin alternate chlorothalonil alternate copper hydroxide			50.27 a		92.31 ab		50.43 a	
Contrasts			F *value*	P *value*	F *value*	P *value*	F *value*	P *value*
Untreated			40.58	<.0001	62.7	<.0001	107.33	<.0001
Fungicide			7.38	<.0001	6.28	<.0001	13.40	<.0001
Interval			11.52	<.0001	6.87	0.0002	16.19	<.0001
Fungicide*interval interaction			0.59	0.9037	0.65	0.8561	1.35	0.1613

[x] Disease caused by *Alternaria dauci* and/or *Cercospora carotae* was assessed.
[y] Treatment (a.i./ha): copper hydroxide at 0.91 kg; azoxystrobin at 0.11 kg; chlorothalonil at 1.3 kg.
[z] Means within a column followed by the same letter are not significantly different according to Tukey HSD ($\alpha = 0.05$).

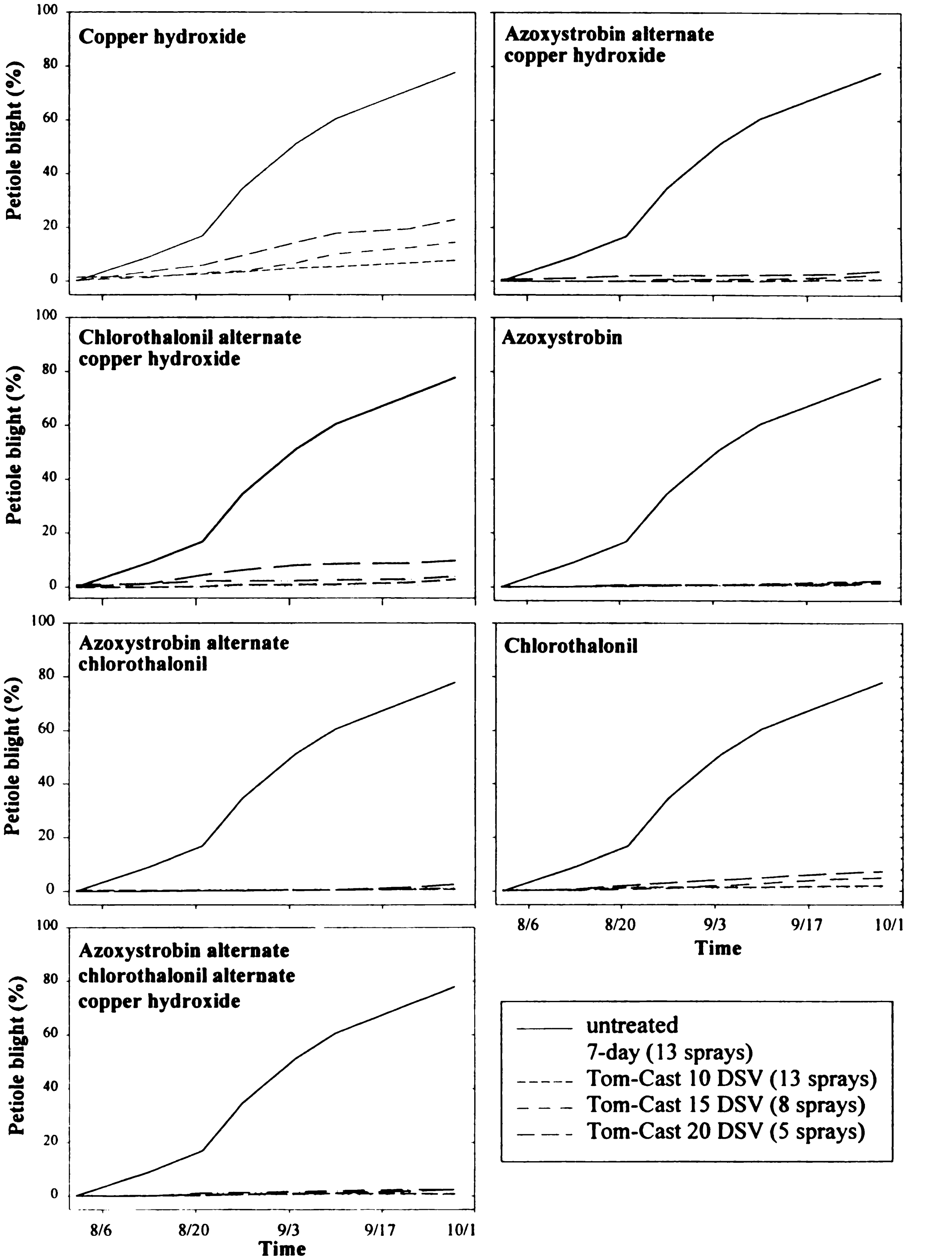


Figure 6. Mean petiole disease incidence in 2001 after applying foliar fungicides every 7 days or according to Tom-Cast disease predictor after accumulation of 10, 15 or 20 disease severity values (DSV).

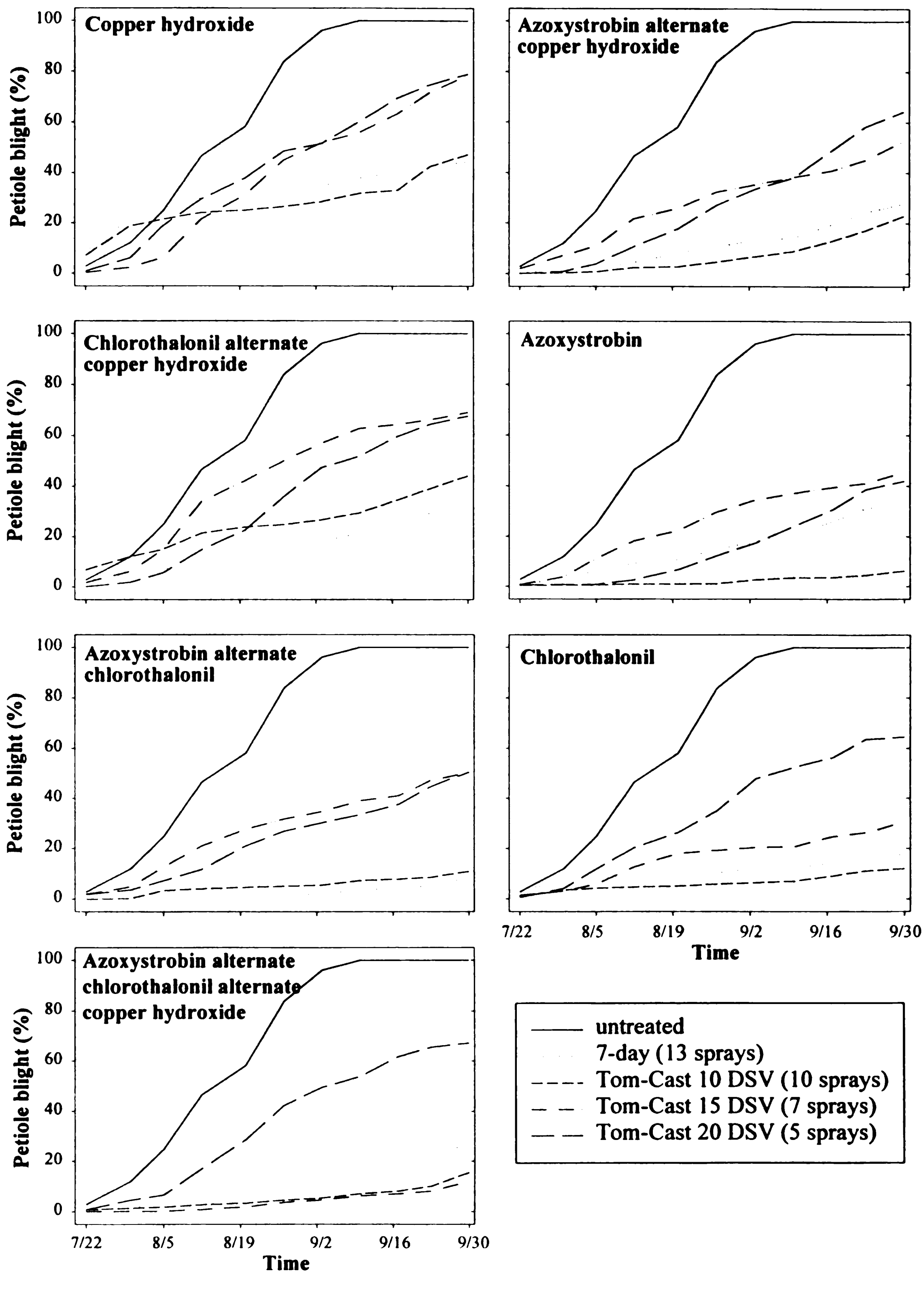


Figure 7. Mean petiole disease incidence in 2002 after applying foliar fungicides every 7 days or according to Tom-Cast disease predictor after accumulation of 10, 15 or 20 disease severity values (DSV).

Table 3. The main effect of application interval and foliar fungicide application on the final petiole health rating date when 2001 and 2002 data are combined and summary of contrasts results comparing application intervals and fungicide product used when assessing petiole health on carrots.

Treatment	Number of applications 2001	Number of applications 2002	Petiole health	
Application interval				
7-day	13	13	3.39 a[y]	
Tom-Cast 10 DSV[x]	13	10	3.43 a	
Tom-Cast 15 DSV	8	7	4.02 b	
Tom-Cast 20 DSV	6	5	4.88 c	
Fungicide[z]				
Copper hydroxide			5.13 b	
Azoxystrobin alternate copper hydroxide			3.72 a	
Chlorothalonil alternate copper hydroxide			4.13 a	
Azoxystrobin			3.75 a	
Azoxystrobin alternate chlorothalonil			3.97 a	
Chlorothalonil			3.44 a	
Azoxystrobin alternate chlorothalonil alternate copper hydroxide			3.38 a	
Contrasts			F *value*	P *value*
Untreated			11.43	<.0001
Fungicide			8.74	<.0001
Interval			21.73	<.0001
Fungicide*interval interaction			1.28	0.2068

[x] Disease caused by *Alternaria dauci* and/or *Cercospora carotae* was assessed.

[y] Means within a column followed by the same letter are not significantly different according to Tukey HSD (α = 0.05).

[z] Treatment (a.i./ha): copper hydroxide at 0.91 kg; azoxystrobin at 0.11 kg; chlorothalonil at 1.3 kg.

Table 4. Mean summary of petiole and foliar blight caused by *Alternaria dauci* and *Cercospora carotae* on 28 September 2001 and 30 September 2002 after applying foliar fungicides every 7-days or according to the Tom-Cast disease predictor.

	Number of sprays		Petiole blight						Foliar blight (%)	
			Incidence (%)		Severity[x]		Health[y]			
Treatment[w]	2001	2002	2001	2002	2001	2002	2001	2002	2001	2002
Untreated	--	--	77.86	100.00	2.75	4.50	9.00	9.25	25.00	32.50
Copper hydroxide										
7-day	13	13	10.05	44.32	1.00	2.25	4.75	4.75	7.75	5.25
10-DSV[z]	13	10	7.73	47.04	1.00	2.75	3.00	5.50	1.00	9.00
15-DSV	8	7	14.38	76.82	1.25	3.50	3.50	7.00	4.25	22.50
20-DSV	6	5	22.92	78.81	1.25	4.00	4.50	8.00	5.75	25.00
Azoxystrobin/ copper hydroxide										
7-day	13	13	1.21	27.70	0.50	2.00	2.75	3.50	3.00	3.00
10-DSV	13	10	0.79	25.20	0.50	2.00	3.00	4.25	2.00	4.00
15-DSV	8	7	2.65	52.63	0.75	2.25	2.50	4.75	3.00	5.25
20-DSV	6	5	3.89	64.27	0.75	2.75	3.25	5.75	3.00	12.50
Chlorothalonil/ copper hydroxide										
7-day	13	13	9.73	29.54	1.00	2.25	3.25	3.75	3.25	5.75
10-DSV	13	10	2.32	43.98	1.00	2.25	2.00	4.25	1.00	4.25
15-DSV	8	7	2.96	69.07	0.75	3.00	3.00	6.00	4.25	14.00
20-DSV	6	5	15.44	67.68	1.25	3.00	4.50	6.25	5.75	10.25
Azoxystrobin										
7-day	13	13	0.55	32.91	0.50	2.00	2.50	4.50	2.00	5.75
10-DSV	13	10	2.23	6.29	0.75	2.00	2.75	5.25	1.00	6.75
15-DSV	8	7	2.22	45.43	1.00	2.25	2.50	5.00	1.00	4.00
20-DSV	6	5	1.51	41.94	1.00	2.25	3.00	4.50	4.00	3.25
Azoxystrobin/ chlorothalonil										
7-day	13	13	1.19	8.40	0.25	2.00	2.00	3.75	1.00	2.00
10-DSV	13	10	0.76	10.85	0.75	2.00	2.75	4.50	2.00	2.00
15-DSV	8	7	1.07	50.36	0.50	2.25	2.50	6.00	2.00	4.25
20-DSV	6	5	2.51	50.44	0.75	2.75	3.00	7.25	4.25	16.25

Table (cont'd)

Treatment[x]	Number of sprays		Petiole blight						Foliar blight (%)	
			Incidence (%)		Severity[y]		Health[z]			
	2001	2002	2001	2002	2001	2002	2001	2002	2001	2002
Chlorothalonil										
7-day	13	13	1.47	17.84	0.75	1.75	1.75	3.75	1.00	3.25
10-DSV	13	10	1.97	12.03	0.50	1.75	2.00	3.25	0.75	1.00
15-DSV	8	7	4.86	32.23	0.75	2.50	2.50	4.75	2.00	10.50
20-DSV	6	5	7.27	64.40	1.00	3.75	2.75	6.75	3.00	30.25
Azoxystrobin/ chlorothalonil/ copper hydroxide										
7-day	13	13	0.57	26.71	0.50	2.00	2.25	4.25	2.00	6.25
10-DSV	13	10	0.70	15.50	0.50	2.00	2.00	3.50	1.00	3.00
15-DSV	8	7	2.38	11.87	0.75	2.00	2.50	3.75	2.00	2.00
20-DSV	6	5	2.34	67.13	0.75	3.00	3.25	5.50	4.25	9.00

[w] Treatment (a.i./ha): copper hydroxide at 0.91 kg; azoxystrobin at 0.11 kg; chlorothalonil at 1.3 kg.
[x] Petioles rated on a scale of 1-5, where 1 = no lesions, 2 = 1-5 lesions, 3 = 6-20 lesions, 4 = 21-50 lesions, and 5 = >50 lesions per plant.
[y] Petioles rated on a scale of 1-10, where 1 = healthy and 10 = dead.
[z] Disease severity value.

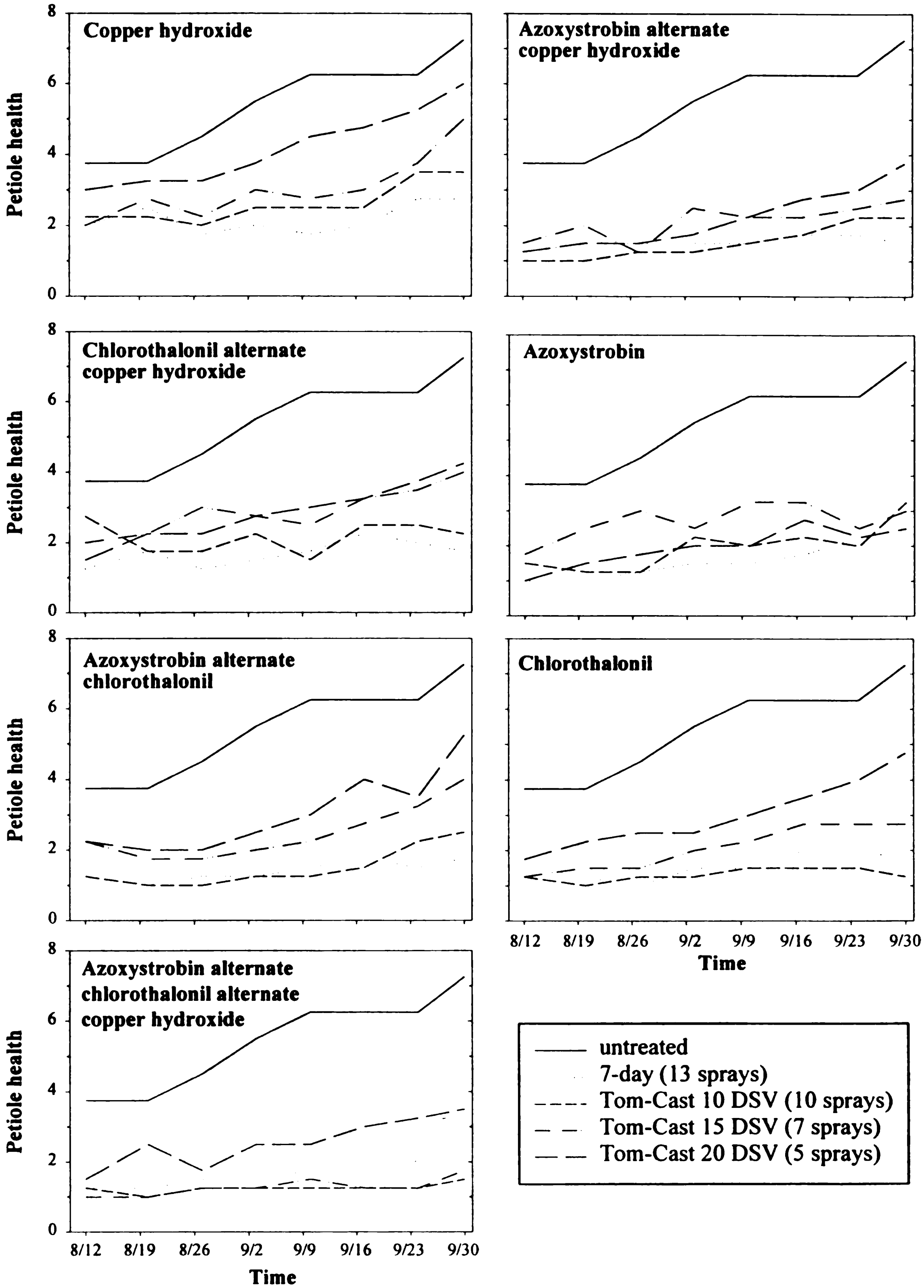


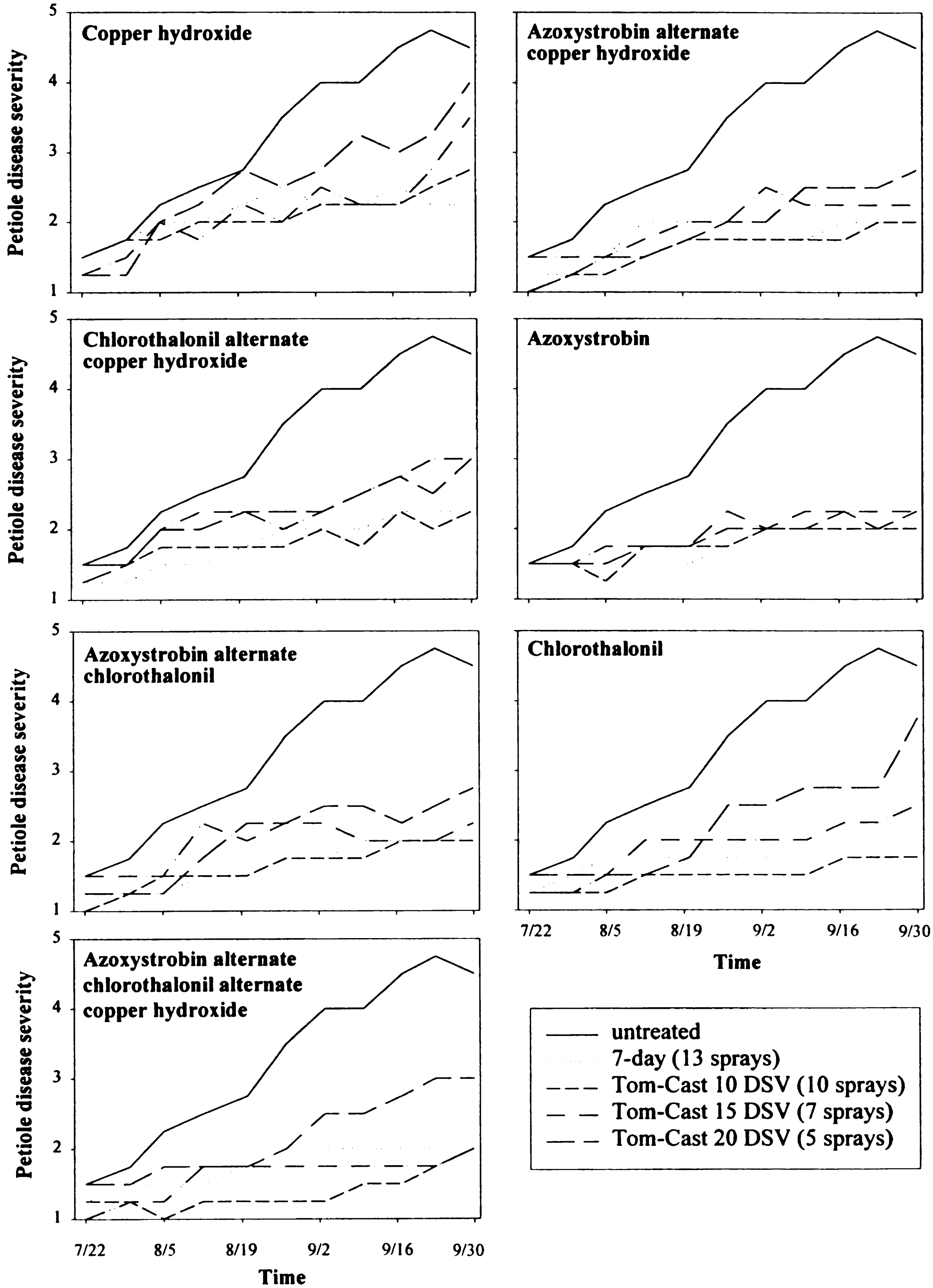
Figure 8. Mean petiole health (1-10: 1 = healthy, 10 = dead) in 2002 after applying foliar fungicides every 7 days or according to Tom-Cast disease predictor after accumulation of 10, 15 or 20 disease severity values (DSV).

on AUDPC data, the disease severity on the petioles was similar for plants treated every 7 days or according to Tom-Cast 10 or 15 DSV (Table 2). Treating plants according to Tom-Cast 15 DSV was not significantly different than using any of the other application intervals (Table 2). The AUDPC values for petiole disease severity of plants treated with copper hydroxide, chlorothalonil/copper hydroxide or chlorothalonil alone were similar (Table 2, Figure 9).

Foliar blight. At the last disease assessment, untreated plants had 25 and 33% of the foliage blighted in 2001 and 2002, respectively (Table 4). Foliar blight was more severe for untreated plants than for plants treated with fungicides (Table 2, $P = 0.001$) according to the AUDPC values. At the end of the 2001 and 2002, the lowest foliar blight incidence was 0.75% and 1%, respectively (Table 4). Foliar blight of plants treated every 7-days was similar to that of plants treated with fungicides according to Tom-Cast 10 or 15 DSV (Table 2). The AUDPC values for foliar blight of plants applied with copper hydroxide, azoxystrobin/copper hydroxide or chlorothalonil/copper hydroxide were statistically similar (Table 2, Figure 10).

Yield. In 2001, the yield from the untreated plants was significantly reduced compared to plants treated with fungicide (Table 5, $P = 0.0001$). The yield from plants treated every 7-days was significantly increased compared to plants treated according to Tom-Cast 15 or 20 DSV (Table 5). The yields from plants treated with copper hydroxide or chlorothalonil/copper hydroxide were significantly reduced compared to plants treated with chlorothalonil, azoxystrobin/chlorothalonil/copper hydroxide or azoxystrobin/copper hydroxide (Table 5). In 2002, the yield from the untreated plants did not differ significantly from other treatments ($P = 0.7290$).

Figure 9. Mean petiole disease severity (1-5: 1 = no lesions, 2 = 1-5 lesions, 3 = 6-20 lesions, 4 = 21-50 lesions, 5 = > 50 lesions) in 2002 after applying foliar fungicides every 7 days or according to Tom-Cast disease predictor after accumulation of 10, 15 or 20 disease severity values (DSV).



Copper hydroxide
Azoxystrobin alternate copper hydroxide
Chlorothalonil alternate copper hydroxide
Azoxystrobin
Azoxystrobin alternate chlorothalonil
Chlorothalonil
Azoxystrobin alternate chlorothalonil alternate copper hydroxide
Petiole disease severity
1
2
3
4
5
7/22
8/5
8/19
9/2
9/16
9/30
Time
untreated
7-day (13 sprays)
Tom-Cast 10 DSV (10 sprays)
Tom-Cast 15 DSV (7 sprays)
Tom-Cast 20 DSV (5 sprays)

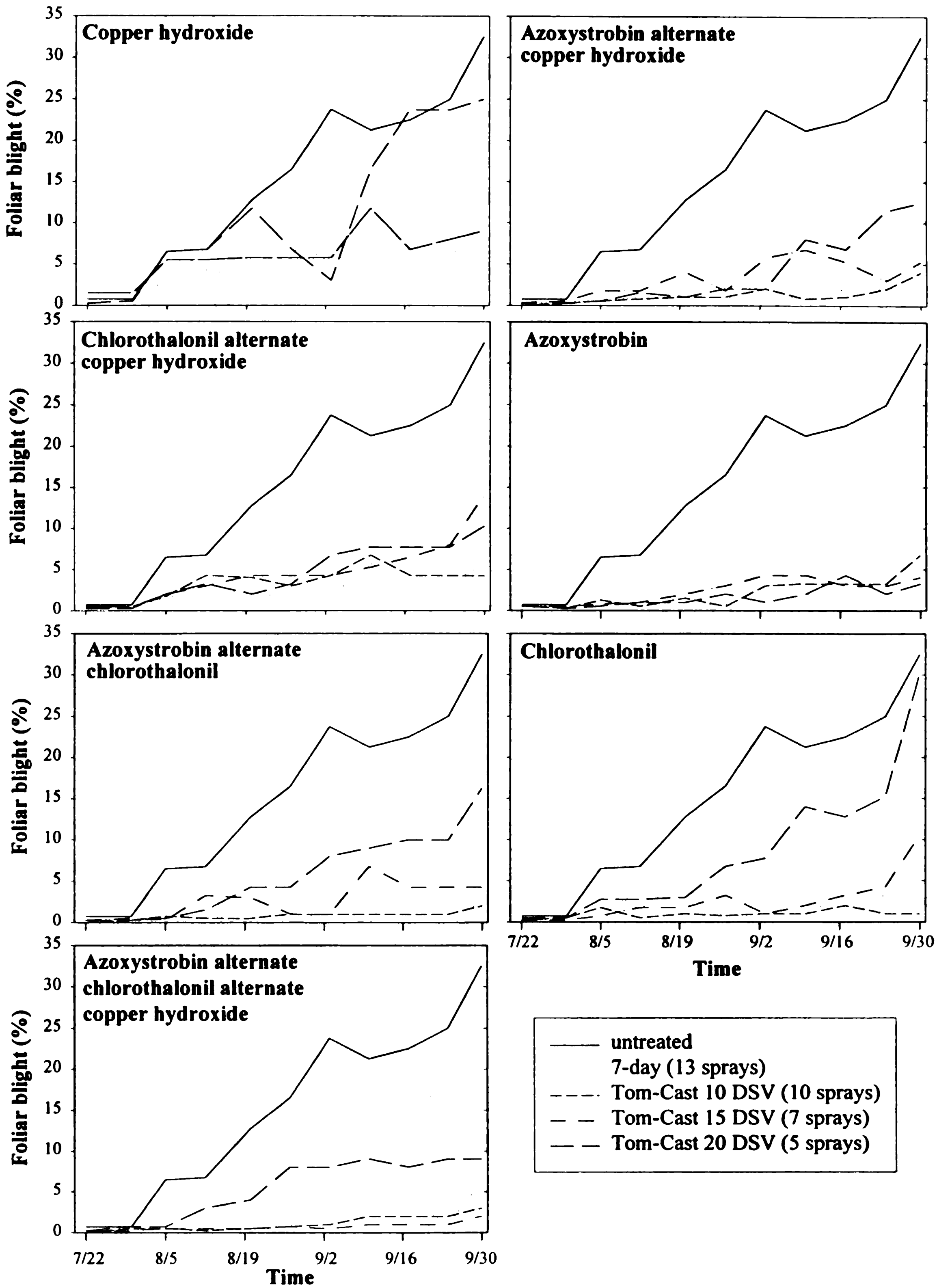


Figure 10. Mean foliar blight incidence in 2002 after applying foliar fungicides every 7 days or according to Tom-Cast disease predictor after accumulation of 10, 15 or 20 disease severity values (DSV).

Table 5. Average weight (kg) of carrot roots harvested during 2001 and 2002 growing seasons after applying foliar fungicides every 7-days or according to the Tom-Cast disease predictor.

Treatment	Yield (kg)/3-m			
	2001[v]		2002[w]	
Application interval				
7-day	13.02 b[x]		14.08	
Tom-Cast 10 DSV[y]	12.67 ab		13.23	
Tom-Cast 15 DSV	12.22 a		14.00	
Tom-Cast 20 DSV	12.18 a		13.30	
Fungicide[z]				
Copper hydroxide	11.60 a		14.75	
Azoxystrobin alternate copper hydroxide	13.02 b		13.88	
Chlorothalonil alternate copper hydroxide	11.55 a		13.86	
Azoxystrobin	12.44 ab		13.53	
Azoxystrobin alternate chlorothalonil	12.73 ab		13.53	
Chlorothalonil	13.05 b		13.11	
Azoxystrobin alternate chlorothalonil alternate copper hydroxide	13.26 b		12.60	
Contrast	*F value*	*P value*	*F value*	*P value*
Untreated	25.02	<.0001	0.12	0.7290
Fungicide	6.77	<.0001	1.97	0.0790
Application interval	3.84	0.0125	1.65	0.1847
Fungicide*application interval	1.61	0.0756	0.69	0.8325

[v] In 2001, the yield from the untreated (8.72 kg) differed significantly from the other treatments (P = 0.0001)

[w] In 2002, the yield from the untreated (10.71 kg) did not differ significantly from the other treatments (P = 0.7290).

[x] Means within a column followed by the same letter are not significantly different according to Tukey HSD ($\alpha = 0.05$).

[y] Disease severity value

[z] Treatment (a.i./ha): copper hydroxide at 0.91 kg; azoxystrobin at 0.11 kg; chlorothalonil at 1.3 kg.

Economic analysis. The fungicide cost ranged from $65.38 and $55.49 per hectare (copper hydroxide applied according to Tom-Cast 20 DSV) to $435.59 and $420.17 per hectare (azoxystrobin applied every 7-days or according to Tom-Cast 10 DSV) in 2001 and 2002, respectively. When fungicides were applied according to Tom-Cast 15 DSV, $126 and $136 per hectare were saved when compared to applying fungicides every 7 days in 2001 and 2002, respectively. In 2002, the fungicide cost per hectare saved was $71.66 when fungicides were applied according to Tom-Cast 10 DSV compared to applying fungicides every 7 days (Table 6). In 2001, when azoxystrobin/copper hydroxide, chlorothalonil/copper hydroxide or azoxystrobin/chlorothalonil/copper hydroxide treatment programs were applied every 7 days, $90.32, $114.75, and $59.08 per hectare was saved, respectively, when compared to applying chlorothalonil every 7-days (Table 6).

Table 6. The number of sprays applied and fungicide cost per hectare after applying foliar fungicides every 7-days or according to Tom-Cast disease predictor in 2001 and 2002.

	Number of sprays		Fungicide cost ($/ha)	
Treatment	**2001**	**2002**	**2001**[y]	**2002**[z]
Untreated	--	--	0.00	0.00
Copper hydroxide				
7-day	13	13	141.66	141.66
10-DSV[z]	13	10	141.66	108.97
15-DSV	8	7	87.18	76.28
20-DSV.	6	5	65.38	54.49
Azoxystrobin/copper hydroxide				
7-day	13	13	299.98	291.63
10-DSV	13	10	299.98	216.09
15-DSV	8	7	177.62	161.97
20-DSV	6	5	133.21	118.76
Chlorothalonil/copper hydroxide				
7-day	13	13	275.54	239.74
10-DSV	13	10	275.54	179.02
15-DSV	8	7	163.68	132.32
20-DSV	6	5	122.76	96.52
Azoxystrobin				
7-day	13	13	435.59	420.17
10-DSV	13	10	435.59	323.21
15-DSV	8	7	268.05	226.24
20-DSV	6	5	201.04	161.60
Azoxystrobin/chlorothalonil				
7-day	13	13	414.68	383.99
10-DSV	13	10	414.68	292.07
15-DSV	8	7	254.12	208.75
20-DSV	6	5	190.59	150.34
Chlorothalonil				
7-day	13	13	390.29	323.80
10-DSV	13	10	390.29	249.08
15-DSV	8	7	240.18	174.35
20-DSV	6	5	180.14	124.54
Azoxystrobin/chlorothalonil/copper hydroxide				
7-day	13	13	331.21	304.82
10-DSV	13	10	331.21	236.70
15-DSV	8	7	212.38	168.57
20-DSV	6	5	148.85	125.35

[y] In 2001, based on cost/unit from Wilbur Ellis, Hart, MI: chlorothalonil = $3.06/kg., copper hydroxide = $1.33/kg., azoxystrobin = $73.50/L.

[z] In 2002, based on cost/unit from Wilbur Ellis, Hart, MI: chlorothalonil = $2.54/kg., copper hydroxide = $1.33/kg., azoxystrobin = $70.88/L.

DISCUSSION

Alternaria dauci and *C. carotae* can be managed by regular foliar applications of fungicides that protect the foliage and maintain yield (9, 13, 24). In Michigan, some carrot growers use a 7-day calendar-based fungicide spray program regardless of environmental conditions. Furthermore, the fungicides chlorothalonil and iprodione that are relied on by the industry are classified as B2 carcinogens and will be reviewed by EPA in accordance with FQPA. In agriculture, especially among baby food processors, it has become a priority to develop a more sustainable disease management program. Identifying effective fungicides that could displace some application of these B2 carcinogens is important to the viability of the industry. Strategies to reduce the use of chlorothalonil by implementing a reduced risk fungicide and a disease forecasting system to time fungicide applications are presented by this study.

Growing carrots in Michigan requires an effective disease management program to protect against foliar blight. In Michigan, carrots are harvested with equipment that undercuts the roots while gripper belts simultaneously grasp the foliage and lift the plants and roots from the soil (9). Yields during mechanical harvesting can be reduced when roots are left in the ground due to weakened foliage caused by foliar blights (9, 13, 24).

The yield was not severely affected by treatment regimes during the course of this study. The yield in fungicide treated plots were 20% (2001) and 22% (2002) higher compared to untreated plots. Since the carrots were harvested manually, the yields reflect only the effects of the pathogen on plant growth and root development. If the carrots were harvested mechanically, there may have been more of a difference in yields due to carrot plants with weakened diseased petioles having roots left in the ground.

A disease forecasting system that accurately prompts fungicide sprays could reduce fungicide applications and consequently costs, while maintaining commercial level of disease control. In our study, Tom-Cast at 15 DSV triggered 6 sprays (2001) or 5 sprays (2002) compared to 13 sprays at the 7-day interval. The 7-day and Tom-Cast 10 DSV intervals were significantly better than the Tom-Cast 15 DSV interval in controlling petiole disease incidence. However, when the severity of petiole blight and foliar blight assessments are considered, Tom-Cast 15 DSV provided a similar level of control as the calendar 7-day and Tom-Cast 10 DSV programs. The Tom-Cast 20 DSV programs consistently provided less control than the 7-day and Tom-Cast 10 DSV programs. However, in some years where disease occurs late and incidence is low, as in our 2001 study, a Tom-Cast 20 DSV interval may be appropriate. When disease occurs early and is, severe as in our 2002 study, application intervals may need to be shortened to a 7-day or Tom-Cast 10 DSV. In such situations, fungicide sprays may not always be reduced when using Tom-Cast. Scouting allows early disease detection and is an important partner to disease forecasting.

Growers using Tom-Cast to schedule fungicide applications should be aware of the system's limitations in controlling foliar blight and be prepared to make additional fungicide applications if significant disease pressure from pathogens not included in the model occur. In our study, the treatment programs were assessed where carrots were moderately spaced apart at 65.6 seed/meter. If the seeds are planted closer together, disease pressure may increase and the Tom-Cast DSVs may need to be reduced. Other pathogens such as *Pythium* spp. (damping off), *Thanatephorus cucumeris* (telemorph of *Rhizoctonia solani)* and *Xanthomonas campestris* pv. *carotae* (bacterial blight) observed in both years of our study across the state would not be controlled using the Tom-Cast system and would require additional applications of fungicides.

Chlorothalonil is the most commonly applied foliar fungicide used in commercially grown carrots to manage *A. dauci* and *C. carotae*. To displace some B2 carcinogenic applications, chlorothalonil was rotated with copper hydroxide and/or azoxystrobin. Although copper-based fungicides are inexpensive (costing 50% less than chlorothalonil), when applied alone they may not provide adequate control when conditions are highly favorable for disease. In our study based on petiole blight assessments, copper hydroxide alternated with azoxystrobin controlled disease at a commercially acceptable level and would permit mechanical harvesting. However, based on petiole and foliar blight assessments, copper hydroxide used in alternation with chlorothalonil was as effective at controlling disease as using either product by alone. A program alternating all three fungicides effectively controlled disease compared to using copper hydroxide alone, while displacing a greater number of B2 applications.

Azoxystrobin, a systemic fungicide, must be rotated with fungicides of differing modes of action due to resistance concerns (3). Data from this project corroborates with other studies showing that alternating azoxystrobin with either copper hydroxide or chlorothalonil can limit foliar disease compared to using chlorothalonil alone, when sprays are applied according to a calendar-based program (8, 11, 14, 15). The lowest labeled rate of azoxystrobin (0.07 kg a.i.) was used in our study because it is the preferred rate of growers in Michigan due to product cost. Previous studies have shown that using the lower rate of azoxystrobin in alternation with chlorothalonil provided similar levels of control compared to the highest rate (0.16 kg a.i.) labeled for use on carrots (8, 11, 14). Since azoxystrobin is expensive, using Tom-Cast can reduce the overall cost of including azoxystrobin. An example includes a 7-day program of azoxystrobin alternated with chlorothalonil that costs $383.99/ha versus the same fungicides applied according to Tom-Cast 15 DSV at $208.75/ha. Using a three-way program reduces the cost further to $168.57/ha.

Other methods for managing foliar blight in carrots include using disease tolerant cultivars when available (22). There are many important criteria besides resistance to foliar blight that are specific to each of the carrot industries. For instance, yield, color, and brittleness are key for the processing industry. For the fresh market or cut and peel industry, shape of the root, size of the core and sugar content are key characteristics. Biocontrol agents such as Messenger (Eden Bioscience Corp., Bothell, WA) and Serenade (AgraQuest Inc., Davis, CA) are available to growers to control disease but they may not provide adequate protection especially against Cercospora leaf blight (8, 21). Watery compost extracts, often called compost teas, act directly in varying degrees to suppress both germination and growth of plant pathogenic organisms on plant surfaces (6, 27). In a separate study, compost tea was applied every 7-days and was found to not significantly limit foliar blight on carrots under standard commercial practices (Dorman and Hausbeck, 2001 unpublished data).

Based on data from this study, the use of Tom-Cast appears to be a promising alternative to calendar-based spraying in commercial carrot fields. Petiole health, which is critical for mechanical harvesting, can be maintained by using disease forecasting and reduced risk fungicides. Applying fungicides according to the disease predictor, Tom-Cast, has the potential to significantly reduce the number of sprays necessary to provide economic control of foliar blight in Michigan. However, under severe disease pressure, reduced protection resulting from a reduced number of sprays may result in yield losses.

The results from this study provide growers disease management programs that include coupling azoxystrobin and/or copper hydroxide with Tom-Cast as a reliable alternative to conventional programs (i.e. chlorothalonil applied every 7-days) while providing comparable foliar blight control.

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APPENDIX I

Table 7. Summary of specific field and farm information for surveyed carrot growers in Michigan during the 2001 growing season.

IPM survey question	**Current carrot cropping information or grower attitudes and practices**
Field locations for production of carrots in Michigan.	Carrots are primarily grown in the western portions of the state in Mason, Mescosta, Newago, and Oceana counties.
Size of the field selected for typical carrot production.	The field size selected to represent the typical carrot cropping practices ranged from 12 to 125 acres, and the average field size was 25 to 40 acres.
What is the total acreage being planted with carrots?	The carrot acreage in Michigan represented by ten growers surveyed was 1,940 acres. Individual farm or operation size varied from 500 acres to just 30 acres, with the average operation between 200 to 300 acres in size.
What varieties do commercial carrot growers typically grow?	Cultivars commonly grown included Apache, Cheyene, Danver, Indiana, Triple Play, The cultivars 7-11, Goliath, Prime Cut, Ricolletta, and Sugar Snax were most widely grown. Other cultivars grown in limited quantities included Bergen, Bolero, Canada, Carson, Early Gold, and Fontana.
Which market are these carrot varieties intended to target?	Carrots produced in Michigan are grown for cut and peel (fresh market) or dicing (processing), with the primary emphasis on dicer varieties.
Were carrots from the selected field stored at site of operation?	About half the growers store harvested carrots on location, whereas the other growers harvest and send the carrots by truckload to a processing plant.
Date on which carrots are typically sown in the selected fields.	Carrots are planted in Michigan starting from mid-April to early June and emerge 12-15 days later.

Table (cont'd).

IPM survey question	Current carrot cropping information or grower attitudes and practices
What is the typical crop rotation of carrots on the selected field?	Most growers rotated their crop schedule with carrots every 3 to 4 years, with one grower choosing a 2-year carrot rotation.
What other crops have been planted previously on the selected field in the years prior to carrots?	Carrots are most frequently rotated in Michigan with corn, squash (zucchini and winter squash), cucumbers, and wheat. A few growers rotated vegetable crops such as broccoli, peppers, snapbeans and potatoes with carrots.
During typical rotation, how far was the current carrot crop from the closest previous carrot crop?	During typical operations on the selected fields, carrots are generally within 400 yards of the nearest previous carrot crop on larger farms and greater than 800 yards away on smaller farms.
What type of irrigation was employed on the selected fields and how frequently was water applied?	The fields were irrigated using a hard nose traveler or a center pivot and water was applied as needed.
Was a cover crop interplanted with carrots, and if so what type?	With the exception of one grower who used wheat, all operations utilized cover crops of either oats or barley to provide a windbreak during early growth stages of the plants.
Is soil fumigation for nematode control a routine practice? If so, when was the field last fumigated?	Two growers used soil fumigation, one applied in October 1997 and the other in October 2000.

Table 8. Summary of field scouting practices for surveyed carrot growers in Michigan during the 2001 growing season.

IPM survey question	**Current carrot cropping information or grower attitudes and practices**
On what date did the scouting for weeds, insects and disease begin on the selected fields?	With the exception of two growers, the scouting process in carrots was typically initiated before emergence or within 4 days and all growers began scouting 4 weeks of planting.
How many scouting trips were conducted from planting to harvest and who performed the scouting?	On average 25 scouting trips were conducted during the growing season, with three growers having the highest number of trips (43 to 45) and the lowest being 7 trips. The farm owner/manager, a certified independent crop consultant or a farm supply dealer representative were primarily responsible for scouting.
On average, how much time was spent on each scouting trip?	Typically, 20-30 minutes were spent on a scouting trip.
For what reasons were the selected fields scouted?	All surveyed growers scouted their field to stay ahead of any new developing pest problems and to determine when pest levels reached or exceeded established thresholds. Many growers used scouting to monitor pre-existing pest problems, to check the effectiveness of previously implemented control measure and to reduce the amount of pesticide used in order to minimize environmental impacts.
What method was most frequently utilized to scout the selected fields?	Scouting was typically conducted by following specific patterns throughout the field including the borders and interior of the field. To monitor carrot fields for pests and weeds, many growers also use their informal observations during routine farm practices focusing on the edge of the field.
How were scouting reports or information kept track of and used on the selected fields?	Records of scouting varied from no written or electronic information recorded, to information recorded in a computer file or spreadsheet. Most of the growers kept written records in a file to track changes in pest pressure over time.
Was the information from a university expert or extension advisor followed?	All growers, except for two, relied upon information supplied or distributed by Michigan State University for pest control decisions regarding weeds, insects and diseases.

Table (cont'd).

IPM survey question	Current carrot cropping information or grower attitudes and practices
Was the information from newsletters or fact sheets used to treat pest problems?	Six out the ten growers surveyed relied heavily upon information supplied or distributed by newsletters for pest control decisions.
Was the growers own knowledge of pest biology used in decisions to control pests?	All growers except for one relied heavily upon their own personal knowledge of pest biology when managing insects, weeds and diseases.
Did weather data play an important part in pest control decisions?	Weather data played an important role in timing pesticide applications to control diseases and insects, for all but one grower.
What percent of pesticide decisions for plant disease, insects and weeds were based upon scouting information?	For three growers, pesticide decisions for plant disease and insects were based upon scouting information or reports 100% of the time. The remaining growers felt the percentage was around 70% for plant disease and insects. Pesticide decisions for weed control were based upon scouting information 55% of the time by all of the ten growers surveyed.
During the growing season, was an action ever taken to control pests in absence of scouting information? If so, what reason prompted that action to be taken?	Occasionally, actions were taken in absence of scouting reports when a concern existed that scouting could not track a rapidly developing pest problem.
During the growing season, was a pest management action ever not taken, even when scouting reports indicated to do so? If so, for what pests and for what reasons?	Pest management was sometimes withheld even though scouting information recommended action such as, when the activity period for a pest was nearly complete and the cost of control exceeded the returns from pest control action. Sometimes the profit margin would be so small that the grower could not afford to use pesticides even when it was recommended to do so.
On average, what percentage of pest control decisions would be regarded as cultural, biological and chemical?	Pest management decisions regarded as chemical ranked the highest with about 45% of control based upon pesticide application. Decisions regarded as cultural and biological were on average equal with about 25-30% of control being based upon crop rotation, field practices and cultivar selection.

Table 9. Summary of weed control practices for surveyed carrot growers in Michigan during the 2001 growing season.

IPM survey question	**Current carrot cropping information or grower attitudes and practices**
How were weeds typically managed prior to planting carrots in 2001?	Prior to planting, fields were planted with a fall cover crop. Field edges were also tilled or mowed in spring. Some growers altered the crop rotation in the past 4 years or selected herbicides in preceding crops to reduce weed pressure in carrots.
Were carrot fields cultivated after emergence and how many times on average?	Only three growers cultivated the field once carrots had emerged.
Were cover crops ever planted to aid in weed management?	All surveyed growers used cover crops, however only six used cover crops to aid in weed control, all others used them for wind protection.
Is spot spraying of herbicides on hot spots a normal practice and if so, how many times?	Spot spraying of herbicides was done in all but three fields on average of once a year.
How many times, on average are herbicides applied to the entire carrot field?	Whole field application of herbicides on average occurred 3 times a year.
What were the primary annual grasses, annual broadleaves and perennial weeds of concern in normal carrot operations?	Weeds of concern to Michigan carrot growers included annual grasses and broadleaves and perennial species. Crabgrass, foxtail and fall panicum were the primary annual grasses. Pigweed, lambsquarters, ragweed and wild carrot were the annual of concern. Nutsedge and quackgrass were the weeds causing problems.

Table 10. Summary of insect control practices for surveyed carrot growers in Michigan during the 2001 growing season.

IPM survey question	Current carrot cropping information or grower attitudes and practices
Prior to planting carrots, what were the most utilized practices to control the potential of insect build up?	To lower the potential for insect pests, growers typically buried crop residue from the previous year's crop to limit insect build up. Three to four growers selected resistant varieties based on last year's insect problems and manage the habitat in or around the field to enhance populations of beneficial insects.
What insects were of greatest pressure to carrot operations during the growing season?	The aster leafhopper was of primary concern to growers. A few growers reported moderate pressure with aphids, carrot weevil, cutworms and grubs presiding occasionally.
What are the two most common means of scouting for insects during carrot cropping?	All of the growers, with exception of one, scout insects by using a sweep net. Some growers make general observations of their own as a scouting method.
Was the health of the crop properly managed to avoid insect attack or invasion?	The health of the carrot crop was closely managed in all operations to avoid insect infestation.
Was planting time altered or managed to avoid insect attack or invasion?	None of the surveyed growers use timing of planting as a means to avoid insect injury.
Were insect population spot treated and if so, how many times?	Only one grower used spot treating as a method to manage insects on their carrot field by applying insecticide once to small areas.
Were insecticides only applied when threshold levels were surpassed? If so, how many times on average?	Eight of the ten growers applied insecticides only when thresholds levels were surpassed with one grower applying 3 sprays.
Are insecticides typically applied within three weeks before harvest?	Four growers chose to apply insecticides three weeks before harvest and the remaining six did not.

Table (cont'd).

IPM survey question	Current carrot cropping information or grower attitudes and practices
Was information on aster leafhopper migration used when determining spray timing and necessity?	Four of the ten growers frequently relied upon leafhopper migration information to determine the necessity for insecticide applications.
Were yellows infectivity tests conducted on local leafhopper populations?	None of the growers conducted infectivity tests on local leafhopper populations.
For aster leafhopper spray decisions, which components of the aster yellows index were used for determining spray decisions?	Most growers used leafhopper counts per 100 sweeps. A few growers also utilized infectivity tests of local and general leafhopper populations, while also taking into account susceptibility of the carrot variety planted.

Table 11. Summary of disease control practices for surveyed carrot growers in Michigan during the 2001 growing season.

IPM survey question	Current carrot cropping information or grower attitudes and practices
What was the pressure of Alternaria and Cercospora leaf blight on the selected field?	Half of the growers felt leaf blight was of medium pressure with less than 50% leaflets or plants infected. Four of ten growers rated leaf blights only an occasional problem or of low significance. One grower considered leaf blights of high pressure with over 50% leaflets or plants infected.
How significant was aster yellows presence in the selected field?	Most growers rated aster yellows of low significance, with only occasional problems with the disease.
What other plant diseases became a problem on the specified field and what was the pressure of that disease?	White mold and damping off were the other diseases of concern, but only showed up in their field occasionally. Root knot nematode was not significant to any carrot growers' operations with exception to one grower who had an occasional problem in their field.
When, during the growing season, did scouting for disease begin on the selected field?	Scouting for plant diseases on some farms began in the middle part of May and for the majority of growers began in mid to late June into July.
Were soil tests for plant parasitic nematodes conducted before planting?	Root knot nematode was of minimal concern to carrot growers. Soil testing for root knot nematode was not routinely practiced by any of the carrot growers surveyed with the exception of one.
Was quality seed selected for disease resistance planted in this field?	All but one grower specifically selected carrot varieties for their known disease tolerance or resistance characteristics.
Were carrot cull piles removed or buried prior to planting, to reduce initial disease spread?	Only one grower made a special effort to remove or bury carrot cull pile located on or near their operation.

Table (cont'd).

IPM survey question	Current carrot cropping information or grower attitudes and practices
Was it necessary to alter crop rotation to lower the potential for soil-borne disease?	Four of ten growers altered or changed their crop rotation to lower the potential for soil-borne pathogens.
Was all harvesting equipment adjusted to avoid damage to carrots during harvest?	The majority of growers had concerns about damage to carrots at harvest, so adjusting the harvesting equipment was an important part of minimizing unnecessary root damage or loss.
Was fertility managed for both yield and plant health to enhance resistance to disease?	All but one grower managed the health and fertility of their carrot crop through fertilizer and fungicide applications, not only for favorable yield, but also to resist plant diseases.
Were any biological agents applied to reduce, compete with, or control plant disease?	Biological agents were not utilized by any of the growers except one.
If a field was irrigated, was irrigation managed to minimize conditions favorable for disease?	All growers who required some form of irrigation, managed that irrigation so as to minimize favorable conditions for pathogen attack.
How were fungicides applied to the selected field? On a schedule regardless of university information, only when scouting recommended action, or only after disease damage was present?	Half of the growers relied heavily upon scouting information from their fields or Michigan State University recommendations for decision regarding fungicide applications. Four out of ten growers used fungicides only after disease symptoms were already present in the field.
Was the spray program adjusted or were varieties blocked according to their disease resistance characteristics?	Eight of ten growers adjusted their spray programs according to disease resistant cultivars and four of those eight growers also blocked their varieties according to specific resistance characteristics.

Table 12. Summary of soil fertility practices for surveyed carrot growers in Michigan during the 2001 growing season.

IPM survey question	Current carrot cropping information or grower attitudes and practices
What was the soil type found in the selected field? If organic muck, what was the % organic matter?	Seven of ten growers surveyed produced carrots on sand with 2% or less organic matter, while the other three growers grew carrots on silt loam.
How often are soil nutrient tests conducted on the selected field?	Soils are tested in 3 out of 10 operations on a yearly basis, with the remaining growers testing soils every 2-3 years.
How much total nitrogen was applied to the field and when did that application take place?	Two growers applied greater than 100 lb of nitrogen to their field, 7 growers applied 100-150 lb/acre and one grower applied 165 lb/acre. Nitrogen was applied to the fields as a pre-plant supplement and sidedress application. Half of the growers also applied nitrogen as a foliar treatment.
How much phosphorus and potassium was used on the field and when was it applied?	Phosphorus and potassium were generally applied as a pre-plant, however, the specific quantities of these nutrients applied varied greatly between growers. Phosphorus was applied prior to planting at a rate between 45-700 lb/acre. Potassium was added prior to planting at a rate of 150-400 lb/acre.
What types of micro-nutrients were applied to the field?	Many growers applied manganese, and boron at unspecified rates, as a pre-plant supplement or foliar application. Sulfur was also added to half of the grower's field at variable rates.

APPENDIX II

AN ATTEMPT TO DETERMINE THE VIRULENCE FACTOR OF *ALTERNARIA DAUCI* ON RESISTANT AND SUSCEPTIBLE CARROT VARIETIES

INTRODUCTION

Alternaria blight (*Alternaria dauci* (Kühn) Groves & Skolko) is a common foliar disease found wherever carrots are grown (4). Alternaria blight can lower yields by reducing leaf area available for photosynthesis, resulting in decreased root weight (6). Alternaria leaf blight can be managed chemically using fungicides or culturally by planting disease tolerant cultivars (6). However, these newly developed cultivars provide varying levels of disease control, and no carrot cultivars are entirely resistant to foliar blight (10).

Free moisture is required for germination (5), which typically occurs within 1-3 hours of inoculation under favorable conditions (11). *Alternaria dauci* spores germinate after 1 hour at optimum temperature (28°C) (11). The required number of hours of leaf wetness for infection to occur can range between 12 to 24 hours. Cloudy weather and senescent leaves also make carrot leaves more susceptible to infection (7). Infection occurs within 8 to 12 hr at temperatures of 16-25°C (4), the optimum temperature being 28°C (6, 12).

The genus *Alternaria* is known to produce low-molecular-weight compounds called toxins that cause histological and physiological changes in the host (11). Host-specific toxins contribute to their virulence or pathogenicity (9), and most importantly, determine their host range by having high biological activity toward only the host of the toxin-producing pathogen (15).

Non-selective toxins such as zinniol, alternaric acid, radicinil, radicinol and tentoxin are produced by several pathogens, affect several hosts and are not a prerequisite for infection (11). Zinniol, the causal agent of common leaf spot and seedling blight of zinnia, sunflower and marigolds, was isolated from culture filtrates, mycelium and cell walls of *A. dauci*. This non-specific toxin could also be detected during conidial germination and early growth phases (1). The evolutionary conservation of zinniol production in pathogenic large-spored *Alternaria* spp. may be indicative of its importance in pathogenesis (3).

The purpose of the first study was to determine whether different leaf wetness periods are required for *A. dauci* conidia to germinate on resistant and susceptible carrot varieties. The second objective was to relate susceptibility and inherent ability of resistance to toxin produced by *A. dauci* on resistant and susceptible carrot varieties.

MATERIALS AND METHODS

***Alternaria dauci* and plant cultures.** Isolate M_2-2 was obtained from diseased carrot leaves from the MSU Muck Research Farm near Bath, Michigan and maintained on silica gel (14) without losing its pathogenicity. Fungal isolates were grown on carrot leaf infusion agar (CLA) according to Strandberg (1987) at 24°C for 12 days with a 16-hr diurnal cycle provided by two 15 W cool white fluorescent tubes 0.25 m from the plates. Isolate M_2-2 sporulated under these conditions.

Carrot seedlings ('Early Gold' and 'Cascade') were grown in a research greenhouse on the campus of Michigan State University in 163 cm^3 cell packs containing Baccto soilless medium (Michigan Peat Company, Houston, TX) for 5-6 wk. Field observations indicate that 'Early Gold' is more resistant to Alternaria blight than 'Cascade.' Two to three week old seedlings were thinned to one plant per cell pack, watered daily and fertilized (Scotts Peters Professional® 20-20-20, Marysville, OH) 2-3 times a week.

Leaf wetness assay. Twelve-day-old cultures of *A. dauci* were flooded with 10 ml of sterile distilled water and gently scraped with a glass rod. The conidial suspension was adjusted to a concentration of 1 x 10^3 conidia/ml using a hemacytometer. A 5 µl droplet of conidial suspension was placed on a carrot leaflet ('Cascade') and incubated on moistened filtered paper in a glass petri plate in continuous darkness for 0.5, 1, 2, 3, 4, 8, 12, 16, 20, 24, 28, 32, 36 hour intervals.

Following incubation, leaflets were placed adaxial (inoculated) surface up, on filter paper moistened with ethanol/acetic acid (3:1) on a warm plate (warm to the touch) to be fixed and cleared (2). They were then rinsed with distilled water for 1 minute and stained with lactophenol cotton blue stain (100 ml lactophenol, 1 ml 1% aqueous cotton blue, 20 ml glacial acetic acid) for 30 sec. Stained leaflets were mounted carefully under a coverslip on a microscope slide in a lactoglycerol solution (1:1:1, lactic acid: glycerol:water by volume).

Phytotoxicity tests of culture filtrates on carrot leaflets. Two-to three-week old cultures of *A. dauci* were flooded with 10 ml of sterile distilled water and gently scraped with a glass rod. The conidial suspensions were adjusted for trials 1 and 2 to a concentration of 7 x 10^3 conidia/ml and 2 x 10^5 conidia/ml, respectively, using a hemacytometer (13). Two milliliters of the conidial suspension was transferred into 1 liter Roux bottle having 100 ml of a sterile liquid medium containing 3 g of L-asparagine, 30 g of sucrose, 1 g K_2HPO_4, 0.5 g of KCl, 0.5 g of $MgSO_4$ and 0.01 g $FeSO_4$ (1). The cultures were incubated for 3 wk at 27°C in the dark under stationary conditions after which the mycelial mats were removed by filtration using six layers of cheesecloth. The culture filtrates were freeze dried using a lyophilizer, reconstituted 20-fold and filter sterilized using a millipore filter (Millex® 0.22μm, Millipore, Molsheim, France). Control treatments included dilutions of uninoculated distilled water and asparagine solution. Culture filtrates were stored at -5°C in the dark.

Two separate trials were conducted with one set containing 1:2, 1:5, 1:10, 1:20 and another with 1:2, 1:10, 1:50, 1:100, 1:500 dilutions of the culture filtrate. Six-week-old seedlings and leaflets (trial 1 only) of 'Early Gold' and 'Cascade' were exposed to the various culture filtrate dilutions. The seedlings were excised at the soil line and placed in viasl containing 2 ml of diluted filtrate solution. On the carrot leaflets a 5 μl droplet of culture filtrate was placed on the surface and the inoculated leaflets were incubated on moistened filtered paper in a glass petri plate. Three replications were used for each cultivar and dilution combination in a completely randomized design. After 20-24 hrs at laboratory conditions of ambient temperature and natural plus fluorescent light, the seedlings were rated for the degree of phytotoxicity on a scale from one to four in which 1 = no symptoms, 2 = slight necrosis, 3 = moderate necrosis and wilting, and 4 = severe necrosis and wilting (8).

RESULTS

Leaf wetness assay. The leaflets that were incubated for 0.5 and 1 hour intervals had zero to very few germinated conidia. After two hours of incubation on moistened filtered paper, all of the conidia on the leaflets had germinated more than 10 germ tubes per conidium. The germ tubes grew to be two times the length of the spore after four hours of leaf wetness. After 24 hours of continuous leaf wetness, epidermal and mesophyll cells collapsed without hyphal penetration being observed, supporting the nectotrophic activity of *Alternaria dauci*.

Phytotoxicity tests of culture filtrates. Results from the first trial showed very little difference within the cultivars dilution treatments after 20 hours of at laboratory conditions (Table 13). There were some differences in the degree of phytotoxicity between the dilution and control within each cultivar. To obtain a dilution end point where there would be no phytotoxicity or symptom differences between the control and the dilution treatment, Trial 2 was conducted using higher dilutions (1:50, 1:100 and 1:500). The phytotoxicity results were inconclusive (Table 14).

Table 13. The degree of phytotoxicity on carrot seedlings (cv. Cascade and Early Gold) once exposed to various culture filtrate dilutions after 24 hours at laboratory conditions (Trial 1).

Treatment	phytotoxicity rating
Asparagine	2.67[z]
Water	1.00
'Cascade'	
1:2	4.00
1:5	3.00
1:10	2.67
1:20	1.33
'Early Gold'	
1:2	4.00
1:5	3.33
1:10	2.67
1:20	2.67

[z]Phytotoxicity rating on a scale of 1-4, where 1 = no symptoms, 2 = slight necrosis, 3 = moderate necrosis and wilting, and 4 = severe necrosis and wilting.

Table 14. Phytotoxicity rating and volume of liquid absorbed (ml) on carrot seedlings (cv. Cascade and Early Gold) once exposed to various culture filtrate dilutions after 24 hours at laboratory conditions (Trial 2).

Treatment	phytotoxicity rating	volume liquid absorbed (ml)
Asparagine	2.67	0.21
Water	1.00	1.09
'Cascade'		
1:2..................	1.17	0.18
1:10..................	1.33	0.58
1:50..................	1.67	0.46
1:100..................	1.33	0.79
1:500..................	1.00	0.52
'Early Gold'		
1:2..................	2.33	0.18
1:10..................	1.33	0.76
1:50..................	1.00	1.14
1:100..................	1.00	1.14
1:500..................	1.00	1.14

[z]Phytotoxicity rating on a scale of 1-4, where 1 = no symptoms, 2 = slight necrosis, 3 = moderate necrosis and wilting, and 4 = severe necrosis and wilting.

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APPENDIX III

EVALUATION OF ORGANIC AMENDMENTS TO SOIL AND FOLIAGE FOR CONTROL OF ALTERNARIA AND CERCOSPORA BLIGHT ON CARROT

INTRODUCTION

Alternaria blight (*Alternaria dauci* (Kühn) Groves & Skolko) and Cercospora blight (*Cercospora carotae* (Pass.) Solheim) are common foliar diseases found wherever carrots are grown (2). Cercospora and Alternaria blights can lower yields by reducing leaf area available for photosynthesis, resulting in decreased root weight (5). Both foliar blights can also indirectly reduce yields during mechanical harvesting when weakened foliage results in roots left in the ground (2, 5, 7)

Mature carrot leaves are more susceptible to *A. dauci* than younger leaves (8). High levels of nitrogen increase plant vigor, delay maturity (10) and increase the period of meristematic activity, thereby limiting disease (1). When an inadequate amount of nitrogen is applied, incidence of leaf blight is significantly higher (13). Greenhouse studies showed that doubling the rate of fertilizer decreased disease severity caused by *A. dauci* by 10 to 15%, while reducing nitrogen by half, increased disease severity by 23 to 30% (11).

Carrots utilize both indigenous and applied nitrogen at soil depths greater than 30 cm (13). Excess nitrogen increases top biomass for healthy carrot tops to aid in harvesting when carrots are lifted out of the ground (14). Nutrients applied to the foliage are readily available and more easily utilized by the plant than when applied to the soil (12). Foliar nutrients increase rates of photosynthesis, thereby stimulating and increasing nutrient absorption (to 80%) (12). In comparison, when nitrogen and anhydrous ammonia are applied, 30% and 15%, respectively, enters the plant through the foliage (12).

Organic production systems more commonly use compost as a source of nutrients. During composting, much of the nitrogen is converted into more stable organic forms and is released slowly into the soil (6). Good compost has an added benefit of having a number of microorganisms that can fix nitrogen from the air, making it available to plants. (12). Composts have also been found to suppress root and leaf diseases of plants (4). When soil is amended with 75% compost, disease incidence can be significantly reduced by 41% (15). A common foliar fertilizer used in organic systems is that made from fish solubles containing water-soluble vitamins, particularly the Bs, as well as proteins, amino acids, trace minerals, phosphorus, magnesium and calcium (3).

The purpose of this study was to determine the effects of organic amendments to the soil and foliage on the suppression of foliar blight infection on carrots in Michigan.

MATERIALS AND METHODS

Experimental design and treatments. Carrots (cv. Heritage) were planted on a Houghton-muck soil at the MSU Muck Research Farm near Bath, Michigan on 14 May 2001. The experimental design was a complete block with four 49.4-m blocks containing 32 treatments randomly assigned within each block. Each treatment was contained within a three row (spaced 0.5-m apart) raised bed 7.2-m in length with three buffer rows between treatments.

The soil was amended with a pre-plant fertilizer application of either composted chicken manure (2-5-3 + 10% Ca at 90 kg N/A, Herbruck Poultry Ranch, Saranac, MI) or monoammonium phosphate (MAP 11-53-0 at 24.7 kg N/ha) plus a topdress application of urea (46-0-0 at 51.9 kg N/ha) on 22 June. The foliage was treated by either using fish emulsion (2-3-3 plus kelp at 18.7 L/ha diluted 1:10, Sea Pal, Fort Bragg, CA), liquid fish hydrolysate (Drammatic™ Liquid Fish 2-5-1, at 18.7 L/ha, Dramm Corp., Manitowoc, WI) or nitrogen solution (28-0-0 at 5.7 kg N/ha). Each treatment was applied in following programs: (i) untreated (not fertilized), (ii) composted chicken manure, (iii) composted chicken manure plus fish emulsion, (iv) composted chicken manure plus fish hydrolysate, (v) composted chicken manure plus nitrogen solution, (vi) MAP with topdress, (vii) MAP with topdress plus fish emulsion, (viii) MAP with topdress plus liquid fish hydrolysate, and (ix) MAP with topdress plus nitrogen solution fertilizer.

The pre-plant applications were applied on 11 May 2001 using a hand spreader (model # 3500, Earthway Products Inc., Bristol, IN). The foliar fertilizer applications were initiated on 20 June 2001 using a hand pump pressure sprayer (Delta Industries, King of Prussia, PA) with subsequent sprays applied every 2 weeks (6 total applications). Weed and insect pests were managed according to standard production practices (16). Overhead sprinkler irrigation was applied as needed.

Nitrate monitoring. Soil samples were taken prior to application of all fertilizers on 14 June, 23 July, 14 August and 25 September 2001 and analyzed at the Soil Testing Laboratory at Michigan State University. On 8 August, 6 August and 10 September 2001, the petiole sap nitrate N concentrations of the youngest fully elongated leaf petioles were measured. Two petioles from each treatment were collected, cut into 1 cm segments and squeezed with a garlic press. Four drops of the sap was placed on the electrode surface of a Cardy Nitrate Meter (Spectrum Technologies, Inc. Plainfield, IL) to determine the nitrate-N concentration.

Assessment of disease. The combined effect of Alternaria and Cercospora leaf and petiole blight ratings were assessed visually each week from 3 August through 10

September in 2001. Foliar and petiole disease assessments were based within 3 m of the center treatment row. Foliar disease was assessed by estimating the leaf area infected (0, 1, 5, 10, 20, 40%) using a pictorial disease damage key (9). Incidence (the percentage of plants with infected petioles) of petiole blight was determined. Severity of disease on the petioles was rated according to the following scale: 1 = no lesions per plant, 2 = 1-5 lesions per plant, 3 = 6-20 lesions per plant, 4 = 21-50 lesions per plant, 5 = >50 lesions per plant. Roots were hand-harvested and weighed (kg) from within 3-m of the center treatment row on 11 September 2001.

RESULTS

Carrot petiole sap was extracted before and after a foliar fertilizer application and at harvest. The mean nitrate concentration decreased after a foliar application for all treatments except when MAP was applied to the soil and nitrogen solution was applied to the foliage. When fertilizer is not applied to the soil or foliage, the mean nitrate concentration in the petiole sap was lower than plants treated with fertilizer (Figure 11).

Treatments that were applied with a top-dress application had a slight increase in nitrate concentration in the soil while soil treated simultaneously with compost had a slight decrease in nitrate concentration (Figure 12). Soil that had not received any fertilizer application had the lowest nitrate concentration.

For this study the foliar disease incidence and severity was extremely high for all treatments. The mean petiole blight incidence for untreated plants (54.9 % infected) was actually lower than plants treated with soil and/or foliar fertilizer. There were no significant yield differences among the fertilizer treatments (Table 22, Figure 13).

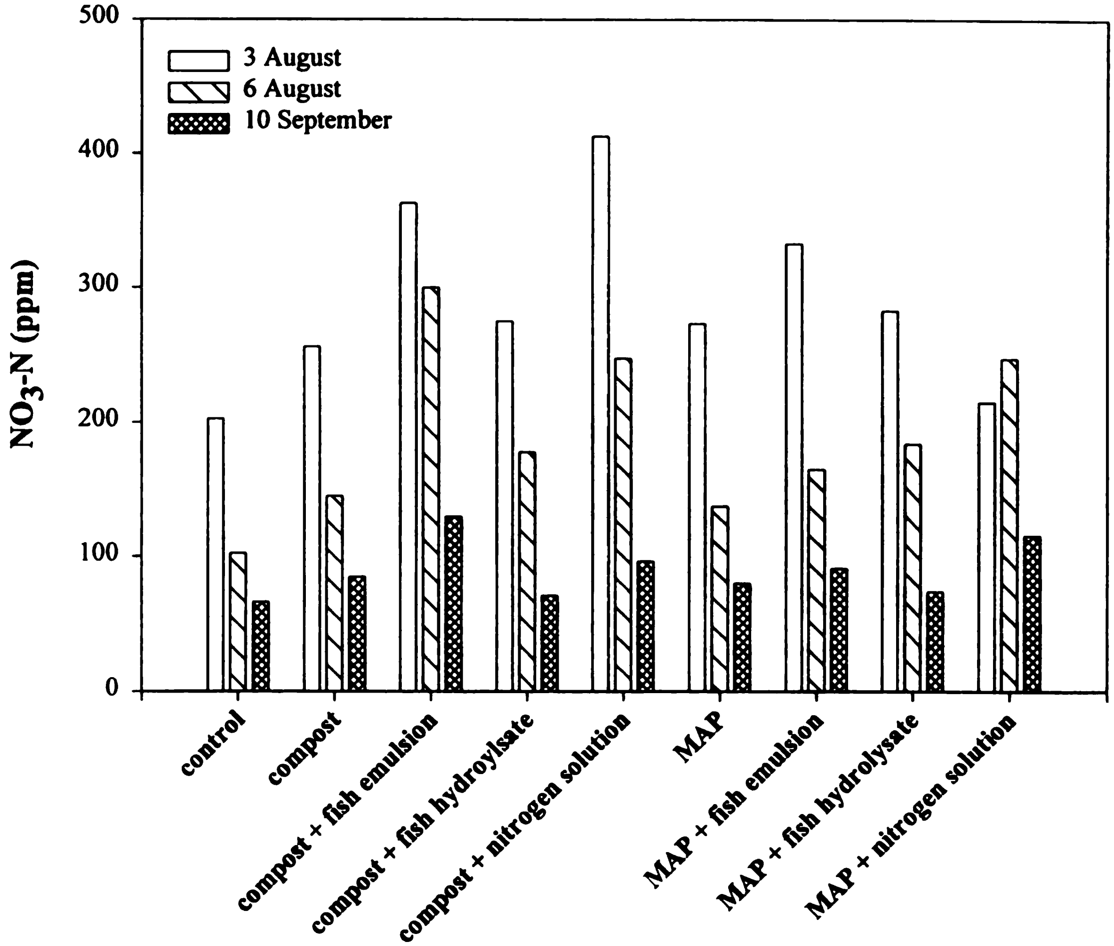

Figure 11. The mean nitrate-N concentration in carrot petiole sap following treatment with pre-plant and foliar fertilizer.

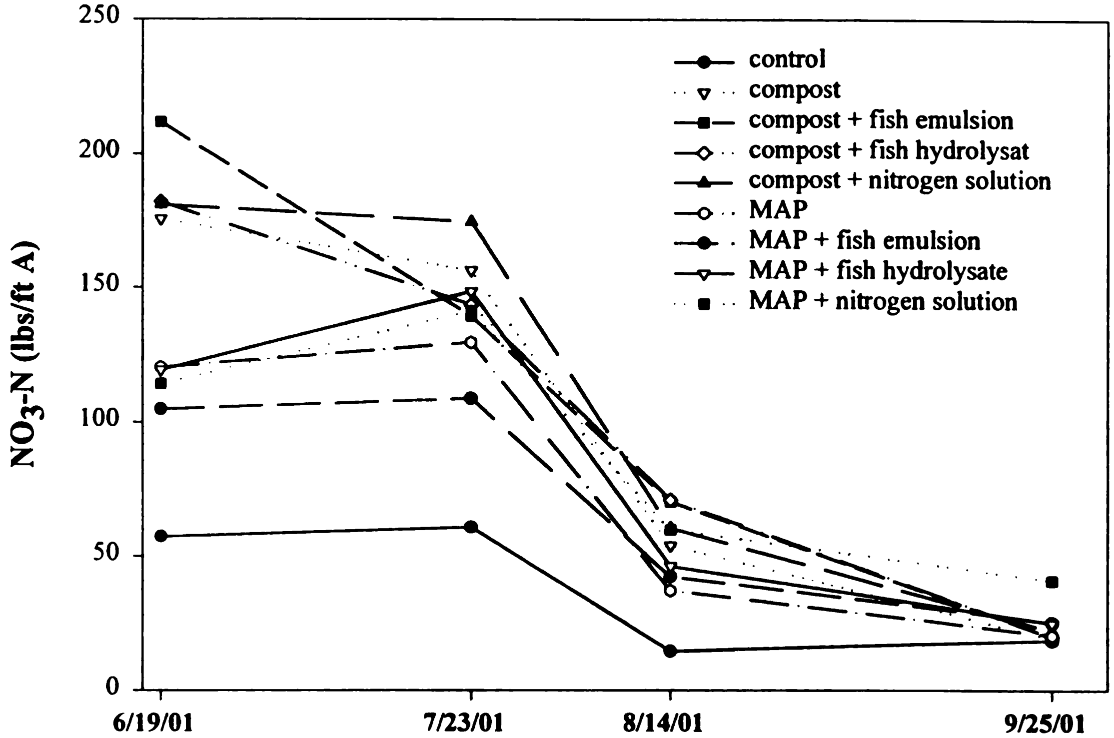

Figure 12. Mean NO_3-N concentration in soil samples from Muck Soil Research Farm following treatment with pre-plant and foliar fertilizer.

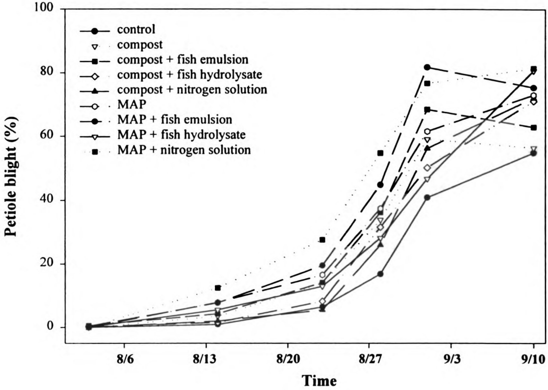

Figure 13. Mean petiole blight (%) in 2001 after applying fertilizer to the soil and foliage.

Table 15. The effect of pre-plant and foliar fertilizers on petiole blight, foliar blight and yield (kg) on 10 September 2001.

Treatment	Petiole blight Incidence (%)	Petiole blight Severity[z]	Foliar blight	Yield per 3 m row (kg)
control	54.87	3.00	6.25	10.72
compost	69.93	3.50	25.00	10.36
compost + fish emulsion	79.39	3.50	27.50	10.81
compost + fish hydroylsate	62.87	2.50	5.50	10.27
compost + nitrogen solution	69.12	3.00	10.25	10.88
MAP	72.05	3.50	20.00	10.99
MAP + fish emulsion	90.04	3.00	22.50	10.97
MAP + fish hydrolysate	58.36	3.25	13.75	11.05
MAP + nitrogen solution	84.39	4.00	27.50	9.77

[z]Petioles rated on a scale of 1-5, where 1 = no lesions, 2 = 1-5 lesions, 3 = 6-20 lesions, 4 = 21-50 lesions, and 5 = >50 lesions per plant.

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