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INTEGRATING DISEASE PREDICTORS AND A REDUCED-RISK FUNGICIDE AND EVALUATING DISEASE THRESHOLDS FOR LATE BLIGHT MANAGEMENT IN CELERY

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Ryan Scott Bounds

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INTEGRATING DISEASE PREDICTORS AND A REDUCED-RISK FUNGICIDE AND EVALUATING DISEASE THRESHOLDS FOR LATE BLIGHT MANAGEMENT IN CELERY

By

Ryan Scott Bounds

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ABSTRACT

INTEGRATING DISEASE PREDICTORS AND A REDUCED-RISK FUNGICIDE AND EVALUATING DISEASE THRESHOLDS FOR LATE BLIGHT MANAGEMENT IN CELERY

By

Ryan Scott Bounds

Late blight, incited by the fungus *Septoria apiicola*, is the most important foliar disease of celery in Michigan and results in necrotic lesions on leaves and petioles that can reduce yields by up to 80%. Most celery growers begin applying the fungicide chlorothalonil one to three weeks after transplanting and reapply it at 7- to 10-day intervals to protect the crop, but some of these applications may not be needed early in the season or when environmental conditions do not favor disease development. The purpose of this research was to evaluate late blight management programs that reduce fungicide use and incorporate a new reduced-risk fungicide, azoxystrobin, which poses a lower risk to non-target organisms and the environment than chlorothalonil.

Disease predictors were evaluated, using a standard and a reduced-risk fungicide program, for managing late blight on 'Dutchess' celery in 2003 to 2005. The TOM-CAST 10-DSV predictor provided disease control that was comparable to the weekly application program during each year. It required up to five fewer sprays, while reducing fungicide costs up to $215/ha, compared to the weekly program. Other disease predictors, such as the Septoria predictor, Cercospora predictor, and TOM-CAST 15-DSV, also provided control similar to the weekly program, but their efficacy was less consistent than TOM-CAST 10-DSV and was often dependent on the fungicide program. The fungicide programs frequently provided similar control, but azoxystrobin alternated

with chlorothalonil was more effective than chlorothalonil alone when disease pressure was high in 2003.

Weekly sprays of azoxystrobin alternated with chlorothalonil were initiated early (one week after transplanting), preventively (four weeks after transplanting), or when disease symptom were detected at a trace, 5%, or 10% level on 'Dutchess' celery in 2003 and 2004. Preventive applications required three fewer sprays, reduced fungicide costs by up to $134/ha, and provided similar control compared to the early fungicide program. Delaying the initial application until any level of disease developed subsequently resulted in unacceptable levels of disease at harvest and cannot be recommended in Michigan due to the risk of extensive yield loss.

A reduced-risk fungicide program was initiated preventively and reapplied weekly or according to the Septoria predictor or TOM-CAST 10-DSV and was compared with a weekly management program initiated early at a research farm and a commercial field in 2004 and 2005. Combining the use of preventive initial applications with disease predictors reduced the number of sprays by two to six while providing similar disease control compared with the weekly fungicide program initiated early. At the commercial field, management programs that required fewer sprays were effective in managing early blight (incited by *Cercospora apii*) and crater rot (incited by *Rhizoctonia solani*).

This research identified effective disease management programs that require fewer fungicide sprays than the standard, calendar-based approach, while incorporating a reduced-risk fungicide. Reducing fungicide use in celery will likely have societal and environmental impacts that were not addressed in this study.

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LITERATURE REVIEW

Introduction

Celery (*Apium graveolens* L. var. *dulce* (Mill.) Pers.) is a cool season biennial plant in the *Umbelliferae* family. It is produced as an annual crop and consumed fresh or in processed foods. Nearly all of the celery produced in the United States is grown in California, Michigan, and Florida. Michigan growers produce approximately 8% of the celery raised in the United States (92). The Florida acreage is not currently included in the USDA statistics because there is only one large celery operation in the state. Celery grown in Michigan is available for about a 4-month period (early July through early November), while California and Florida celery is available for 12- and 6-month periods, respectively.

Michigan has a long history of celery production dating back to the 1890s when approximately 350 growers farmed roughly 4,000 acres in Kalamazoo County (D. Frens, *personal communication*). In the 1980s, sixty growers raised celery on 3,400 acres. The majority of celery production in Michigan currently occurs in Allegan, Kent, Muskegon, Newaygo, Ottawa, and Van Buren counties, although there is limited production elsewhere in the state. In 2005, the celery crop destined for fresh market and processing was produced on 2,200 acres by 21 growers and was valued at nearly $18.2 million (92). Celery has a higher per acre value than several other important vegetable crops in Michigan. With an average value of $8,273/A, celery is more than eight times the value of fresh market and processing asparagus, six times the value of processing carrot, and three times the value of processing tomato (92). About one third of the celery grown in Michigan is processed for frozen food, soup, or juice. The value of celery for processing is slightly lower than the value of celery destined for the fresh market; however, higher

yields in processing celery (41 tons/A) typically result in similar returns when compared to fresh market production where yields are lower (32 tons/A) (D. Frens, *personal communication*).

All celery in Michigan is seeded into flats and raised in greenhouses for a period of six to eight weeks prior to transplanting in the field (97). This ensures uniform plant size and spacing in the field since celery seed does not uniformly germinate (3). Also, greenhouse transplants typically produce plants with greater root weight compared with plants originating from seed sown directly in the field (91). Greenhouse seedling flats usually contain 266 cells, and individual cells are approximately 0.5 inches in diameter. Pelletized seeds are planted with a precision seeder into flats containing a vermiculite/fine peat soil mix. Optimal seed germination occurs between 50 and 70°F, but alternating day and night temperatures of 70 and 60°F seem to improve the percentage and uniformity of germination (97). Flats are usually irrigated twice each day and fertilized at regular intervals during irrigation events. Once the seedlings are well established, they are mowed (clipped) to a height of three to four inches to facilitate ease of handling and to ensure uniform growth in the field. Mowing does not significantly reduce yield or increase the variation in plant size at harvest unless there is a high percentage of small, weak seedlings prior to mowing (94).

Almost all of the celery grown in Michigan is raised on muck soils with soil pH above 5.5 (97). These soils have high moisture holding capacity and high cation exchange capacity, which are well suited for celery growth. Transplanting begins in mid-April and continues almost daily until late-July (3). Transplants set in the field earlier are covered with plastic tunnels to avoid frost and promote early growth. A two- or four-

row, self-propelled transplanter is used to plant celery in the field (97). Despite the use of sprinkler irrigation just after transplanting, some growers loose 3% of the plants if they are not set properly (2).

Planting populations and the days to harvest differ based on the end use of the plants. Early-planted celery is normally planted at a high population and harvested for small celery hearts. A common cultivar used for celery hearts is 'Ventura'. Celery destined for the fresh market is harvested about 80 to 90 days after transplanting. Common cultivars used for fresh market production include 'Dutchess' and 'Green Bay'. Processing cultivars include 'Sabroso' and 'Dutchess' and may be harvested up to 95 days after transplanting to obtain high yield. Except for some celery hearts, nearly all of the celery produced in Michigan is mechanically harvested and transported to packing sheds (3). The plants are trimmed, washed, and packaged prior to shipping (3). Any diseased tissue on the plants must be manually removed. This is a time-consuming process that can reduce the size and quality grade of the plants.

In Michigan, three fungal diseases attack the marketable portion of celery plants every year and include late blight, early blight, and crater rot (3). When left untreated, these diseases have the potential to reduce yield (16,17,19) and additional trimming needed to remove diseased tissues may render the plants unmarketable. Bacterial leaf spot also occurs every year in Michigan (3) and is primarily a cosmetic disease of the leaves which seldom reduces yields (58). Consumers demand blemish-free celery, and growers are aware of the potential losses resulting from inadequate disease management. Therefore, celery growers rely on cultural disease management tactics and foliar

fungicides, which are applied shortly after transplanting and at frequent intervals throughout the season, to ensure a marketable crop.

Late Blight Epidemiology and Management

Late blight of celery is caused by the imperfect fungus *Septoria apiicola* Speg. and is considered the most important foliar disease of celery in Michigan (51). California (4,41,67) and Florida (9,47) celery production is also affected by late blight. The disease was first reported in the United States in 1891 (24). *S. apiicola* only infects celery and celeriac (*Apium graveolens* var. *rapaceum*) (25). In 1932, Cochran (25) reported distinct species of *Septoria* causing small-spot symptoms (*S. apii-graveolentis* Dorogin) and large-spot symptoms (*S. apii* Chester) of late blight. Later confirmation proved that one species, *S. apiicola*, is the cause of celery late blight (30,88). Attempts to discover the sexual (teleomorphic) stage of the fungus have been unsuccessful (25).

Late blight is identified by the appearance of small, tan to brown colored, irregularly shaped lesions on leaves and petioles (34,51). Lesions are initially detected on the older, outer leaves (26) which are sometimes surrounded by a diffuse chlorotic margin (30). Extensive blighting of the foliage occurs when lesions coalesce, and severely blighted tissues wither and senesce (24,26). Pycnidia of *S. apiicola* are black fruiting structures of the fungus that are embedded in nearly all infected tissues, either separate from one another or fused (30). They are 55 to 190 μm in diameter, generally globose, and have round to irregularly shaped ostioles that are less than half the diameter of the pycnidium (30). Pycnidia can be seen without the aid of magnification and resemble flecks of ground black pepper. Each pycnidium contains an average of 3,675

conidia, and an average of 56 pycnidia are observed in an individual lesion (55). Conidia of *S. apiicola* are hyline, 1.3 to 1.8 μm wide and 22 to 51 μm long, flexuous or straight, septate (typically ≥3 septa), and tapered at one end and blunt at the other (30). Conidia were sometimes referred to as "pycnidiospores" in earlier literature (88,89).

Donovan et al. (28) used scanning electron microscopy (SEM) to examine the infection process of *S. apiicola* on excised celery leaves. Conidia germinate under moist conditions, and germ tubes arise from one or several cells of each conidium. Hyphae do not grow directly toward stomata but branch and grow randomly across the leaf surface. Host penetration occurs either directly through the epidermis or via stomata at five to seven days after inoculation. Hyphal growth is confined to intercellular spaces 21 days after inoculation, and intracellular hyphal growth is observed 27 days after inoculation. At 27 days after inoculation, fungal colonization is extensive and leaves are necrotic (28). However, the fungus is not observed in phloem or xylem cells, and infection does not affect stomatal or epidermal cells until pycnidia are observed (29). Pycnidia develop just beneath the leaf surface and break through the leaf surface as they enlarge and near maturity (28). Conidia remain attached to the inner surface of the pycnidium until a wetting event occurs and they are extruded through the ostiole (28).

Conidia are disseminated by splashing water (9), including the movement of conidia-laden water droplets by farm laborers (56) and machinery. Berger (9) did not collect any *S. apiicola* conidia on spore trap slides when commercial fields with extensive late blight damage were monitored. *S. apiicola* conidia germinate on water agar after 8 hours of incubation at 21 or 25°C but do not germinate until 12 hours on celery leaves or in water (50). A higher percentage of conidia germinate on celery leaves at 25°C than at

21°C for the first 24 hours, but the percentages are similar for both temperatures at 36 hours after inoculation. After 36 hours of incubation at 21 or 25°C, the highest percent germination is observed on water agar (>95%), followed by celery leaves (80%) and water (40 to 60%). At 21°C, few lesions (<2) develop on leaves exposed to 24 hours of continuous or interrupted (12 hours dry) leaf wetness at 21 days after inoculation. Numerous lesions (>13) developed on leaves exposed to 36 hours of continuous leaf wetness or 48 hours of continuous or interrupted leaf wetness at 21 days after inoculation. No lesions developed on leaves exposed to <12 hours of leaf wetness, and only 0.3 lesions developed on leaves exposed to 12 hours of leaf wetness. At 25°C, lesions only developed after leaves were exposed to ≥24 hours of continuous or interrupted leaf wetness, and lesion numbers increased with longer periods of leaf wetness (50).

Mathieu and Kushalappa (59) investigated the infection of celery by *S. apiicola* at various temperatures and leaf wetness durations. Celery plants were inoculated and remained wet for periods of 12, 24, 36, 72, or 96 hours at temperatures of 10, 15, 20, 25, or 30°C. Successful infection occurred at all temperatures and leaf wetness durations tested, and lesions developed 12 to 24 days after inoculation. The greatest number of lesions was observed at 25°C when leaves remained wet for 72 hours after inoculation. Moderate infection occurred when plants were exposed to 12 hours of leaf wetness at 20 or 25°C, a leaf wetness and temperature scenario more likely to occur under field conditions (59).

Under field conditions, Sheridan (87) obtained successful infection when the mean relative humidity (RH) was 90% and mean temperature was 14°C on the two days following inoculation. Fifteen hours of consecutive rainfall were also recorded during

the periods of high humidity when infection was successful. No infection resulted during drier conditions when the mean RH was <90% and when no rainfall was recorded on the two days following inoculation (87).

Septoria apiicola is seed borne and can be the primary source of inoculum for late blight epidemics (5,9,37,46,60,61,86). Pycnidia are observed on the seed surface, and mycelium is observed in the pericarp and testa but not in the embryo or endosperm (86). Upon wetting, conidia are extruded from pycnidia on the seed coat which often adhere to expanding cotyledons (9,60). Several methods to eradicate *S. apiicola* from celery seed have been proposed including the use of aged seed which is two to three years old (46), hot water treatment (5,46), and fungicide treatment (60,61). Aging seed does not provide complete eradication since Berger (9) obtained infection from one lot of 3 year old seed. Hot water treatments at 50°C for 25 minutes may reduce seed germination in older seed lots (5,61) and may not entirely eradicate *S. apiicola* (61). Complete *S. apiicola* eradication is reportedly achieved when seeds are soaked in a fungicide suspension of 0.2% thiram for 24 hours at 30°C (60,61).

Berger (9) investigated the role of seed-borne inoculum and weather parameters in association with an epidemic of late blight in the Florida Everglades region in 1970. Diseased seedlings were observed in 4 out of 19 celery seed lots when examined under controlled conditions. Many of the infected seed lots were used in the 1970 growing season and provided the initial source of *S. apiicola* inoculum for the epidemic. Weather conditions were particularly favorable for the development of the epidemic due to record-setting rainfall amounts. Celery leaves remained wet for >24 hours on several occasions, providing conditions that were highly favorable for infection and spore dissemination (9).

Septoria apiicola is capable of persisting on infested celery debris in the soil and can be the primary source of inoculum for the subsequent celery crops (45) planted up to nine months after infested debris is incorporated into the soil (62). Infection does not occur in new plantings where infested celery debris was incorporated 21 months prior to planting. Maude (62) assumed that the lack of disease in the celery crop planted 21 months after the incorporation of infested debris was due to the rate of host tissue decaying in the soil. High numbers of viable spores were recovered when infested debris was left on the soil surface compared with the number of spores recovered from debris incorporated into the soil (62). Sheridan (86) found viable *S. apiicola* spores on four-month old infested leaf debris in the soil. Viable spores were also recovered from infested debris after 10 months of storage under ambient conditions in a laboratory (86). A 2-year crop rotation is recommended to avoid infection resulting from diseased celery debris in the soil (62).

The majority of Michigan celery growers do not practice crop rotation, although some use a 1-year rotation (48) with onion (*Allium cepa*), radish (*Raphanus sativus*), or lettuce (*Lactuca sativa*). Due to the limited availability of organic soil and the high value of celery, many Michigan growers are unable to follow the recommended 2-year crop rotation because planting lower-value rotational crops would reduce farm income.

Genetic resistance to *S. apiicola* is not currently available in commercial celery cultivars. All commercial celery cultivars tested by Edwards et al. (29) were classified as moderately to highly susceptible to *S. apiicola*. Parsley (*Petroselinum crispum*) and some wild celery lines are resistant, but crossing these plants with commercial celery cultivars has not provided a stable level of resistance (29). Lacy and Honma (52)

reported highly variable *S. apiicola* resistance among F2 progeny from celery plants originally crossed with parsley, although a later report indicated these plants were moderately to highly susceptible (29). The genes and mechanisms controlling resistance to *S. apiicola* in celery are not well understood (29).

In addition to the use of disease-free seed and adequate crop rotation, celery growers are advised to implement other cultural control measures to avoid late blight epidemics. If possible, growers should avoid the use of sprinkler irrigation to minimize the duration of leaf wetness and to reduce the risk of spreading the pathogen (41). In Michigan, the use of sprinkler irrigation is common, so growers should schedule irrigation late in the afternoon or at night to avoid prolonged periods of leaf wetness. Growers are advised to minimize field operations, such as the movement of people or machinery, when the leaves are wet to avoid dispersing the pathogen in the same field and to other fields (26,34,41,56). Proper fertilization is also recommended since it may reduce late blight severity (65). Most of the aforementioned cultural control tactics recommended for use in the field also applies, to some extent, in greenhouse transplant production, although sufficient research in this area is lacking. Celery seedlings should be irrigated at times that allow the leaves to dry quickly. Proper ventilation and air circulation are tactics used to lower RH and shorten the duration of leaf wetness. Mowing or any mechanical disturbance of the plants should be done when the leaves are dry to avoid spreading the pathogen.

Foliar fungicides are an important component in late blight management programs (53). A fungicide application is recommended prior to disease appearance since *S. apiicola* has a relatively long latent period (48). Benomyl, a systemic and curative (i.e.,

disease control after infection but before symptoms are visible) fungicide which is no longer registered for use on celery, applied at 14-day intervals was more effective than protectant fungicides applied at 7-day intervals when all fungicides were initially applied three days after disease symptoms (48). The yield of celery plants treated with protectant fungicides did not differ from the yield of celery plants left untreated. Although the benomyl treatment provided superior disease control and higher yields relative to protectant fungicide treatments, it resulted in disease symptoms on nearly 10% of the leaf area (48). Paulus et al. (72) obtained "satisfactory" control of *S. apiicola* with a 7-day application interval of protectant and systemic fungicides initially applied when disease symptoms were present on leaves and petioles, although the specific level of disease was not specified. The same fungicides applied at 14-day intervals did not provide adequate control when initiated at the same timing. In a separate study, benomyl provided significantly better disease control relative to chlorothalonil when both fungicides were initially applied when disease symptoms were first observed on leaves and reapplied at 14-day intervals (72). Although these studies did not directly compare preventive applications with post-symptom applications, they identify the potential risk associated with delaying the initial fungicide application until late blight symptoms are observed (48,72).

Mudita and Kushalappa (69) examined the effect of initial disease incidence levels on late blight progression and created a model to explain disease thresholds in relation to yield loss. Ultimately, they sought to determine a disease threshold that could be used to initiate fungicide treatment. Diseased transplants were randomly placed in experimental plots to obtain initial blight incidence levels of 0, 2, 4, 8, and 16% diseased

transplants per plot. All plots were treated with chlorothalonil every 7 to 10 days, starting three weeks after transplanting. Yield loss and disease incidence and severity increased with increasing initial blight incidence levels. Most plants in the 0% blight incidence treatment had lesions on the outer leaves, despite repeated fungicide applications and the apparent lack of initial inoculum in these plots. The model predicted yield loss at the 0% blight threshold, so it was not possible to determine an action threshold for initiating fungicide treatment. Despite their results, the authors recommend initiating fungicide treatment when late blight is first observed in commercial fields (69).

Michigan celery growers are advised to apply fungicides after transplanting and repeat every 7 to 10 days for the duration of the season (14). Five main active ingredients are currently registered for control of late blight in Michigan and include chlorothalonil (e.g., Bravo Ultrex 82.5WDG, Syngenta Crop Protection, Inc.), azoxystrobin (e.g., Quadris 2.08F, Syngenta Crop Protection, Inc.), trifloxystrobin (e.g., Flint 50WG, Bayer CropScience), propiconazole (e.g., Tilt 3.6EC, Syngenta Crop Protection, Inc.), and copper-based products (e.g., Kocide 2000 53.8DF, E. I. du Pont de Nemours and Company) (14).

Most growers use the protectant fungicide chlorothalonil to manage late blight because it is effective (19,48,72) and relatively inexpensive. Chlorothalonil disrupts multiple enzyme pathways in fungal cells (31) thereby inhibiting hyphal growth and/or spore germination. Attempts to improve the control of *S. apiicola* by mixing certain adjuvants with chlorothalonil have been unsuccessful (49). Adjuvants either provided positive or negative effects when applied with other (currently unregistered) fungicides for control of *S. apiicola* (1) which indicates adjuvant-fungicide combinations must be

tested on a case-by-case basis. Copper-based compounds are protectants which have activity against both fungi and bacteria. Coppers exhibit multi-site activity by inhibiting multiple enzyme pathways (27). These products are routinely applied in combination with other fungicides, but typically do not provide satisfactory control of *S. apiicola* when applied alone (20,33) unless disease pressure is extremely low (63).

Newer fungicide chemistries for use in celery include azoxystrobin, trifloxystrobin, and propiconazole. Azoxystrobin and trifloxystrobin are members of the strobilurin group of fungicides and are also classified as reduced risk products (6). Strobilurins inhibit mitochondrial respiration by binding at the Q_o site of cytochrome b. These reduced risk products exhibit very low toxicity to non-target organisms and have low environmental risk. Both fungicides have systemic and curative properties (6). Some growers choose to incorporate azoxystrobin into their spray program since it is effective against late blight (15,19,36,64,79). Trifloxystrobin is also effective against *S. apiicola* (36), but many Michigan celery growers use this fungicide less frequently than azoxystrobin. Propiconazole is a member of the demethylation-inhibiting (DMI) group of fungicides and has systemic and curative activity. DMIs inhibit strerol biosynthesis in fungal cells thereby preventing cell membrane formation (44). The fungicide may be applied up to eight days after inoculation without significantly compromising control of *S. apiicola* (95) but is generally more effective when applied earlier (96). Numerous studies document the effectiveness of propiconazole for late blight management (18,70,71,78,79,95,96). Some Michigan celery growers choose to use propiconazole in rotation with chlorothalonil for control of late blight (3). Both strobilurin and triazole fungicides act at highly specific yet distinct sites in fungal cells and must be rotated with

other fungicides that have different modes of action to prevent or delay the development of fungicide-resistant fungal populations. Resistance of *S. apiicola* to currently registered fungicides has not been observed in Michigan or documented elsewhere.

Early Blight Epidemiology and Management

Early blight, incited by the imperfect fungus *Cercospora apii* Fresen., is the most destructive fungal disease of celery in Florida (10) and often warrants 25 to 40 fungicide applications each season to produce a marketable crop (12). The disease was first reported on celery in Europe in 1863 (80,85). Early blight occurs wherever celery is grown (80,85) but occurs less frequently in California (42). The disease has become an annual problem for Michigan celery growers (3) since the early 1990s, although it apparently occurred less frequently in the past (51).

Symptoms of early blight initially appear on older, outer leaves and are characterized by light tan to gray colored circular lesions surround by a diffuse chlorotic halo (51,80). The lesions expand to $\geq$1 cm in diameter and turn dry and papery in texture (80). Lesions on petioles are generally elongate and lack a chlorotic halo. During periods of high relative humidity, the lesions may appear gray due to sporulation of the pathogen (51,80). Under favorable conditions, numerous lesions coalesce and infected tissues turn necrotic and die. Symptoms of early blight can be distinguished from those incited by *S. apiicola* due to the absence of pycnidia and the larger size of early blight lesions (80,85).

Cercospora apii hyphae are septate, brown, and 2 to 4 µm in diameter (80). Conidiophores are 4 to 4.5 µm wide and 55 to 100 µm long and arise from hyphal knots,

or pseudostromata, in substomatal spaces. Conidiophores are septate and emerge in clusters through stomata. Several hyline conidia are produced on each conidiophore, and each conidium is septate with 4 to 17 cells. Each conidium is straight or slightly curved, 3.5 to 5.5 μm wide and 40 to 200 μm long, and tapered at the apex (80). *Cercospora apii* requires temperatures of 15 to 30°C and RH near 100% for sporulation (7). Extensive sporulation occurs when leaf wetness durations exceed 10 hours (80). Conidia germinate and penetrate host tissues via stomata after ≥5 hours of leaf wetness (80). Lesions usually appear 10 to 12 days after infection (7). *C. apii* conidia can be carried on the clothing of farm laborers (56) although they are primarily disseminated by wind (7).

Berger (12) collected high numbers of spores on spore trapping slides following periods when temperatures were 15 to 30°C and RH was nearly 100% for ≥10 h per day. Early morning or late afternoon rains extended favorable RH periods and higher spore counts were recorded during subsequent spore liberation events. *Cercospora apii* conidia were found in rain droplets on leaf surfaces. Wind velocities did not affect the number of trapped spores, and nighttime winds dried the foliage and resulted in minimal spore release during the following day. The highest numbers of spores were trapped when the RH was <90%, and peaks in spore liberation were associated with bright, sunny mornings (0800 to 1000) with rapid decreases in RH. Morning cloud cover and fog impeded spore release until the weather cleared and RH decreased (12).

The number of trapped spores per day provided an estimate of future disease outbreaks: few lesions were found following spore counts of 0 to 25 spores/day; light infection (1 to 10 lesions/leaf) was observed after 25 to 100 spores/day were trapped; moderate infection (5 to 20 lesions/leaf) occurred following spore releases of 100 to 300

spores/day; and severe blight developed when spore counts were >300 spores/day (12). Symptoms were observed on routinely sprayed celery plants following very high spore liberation events (800 to 10,000 spores/day). The onset and progression of disease in fields where blight-free transplants were used was delayed compared with fields which were planted with 5 or 40%-blighted transplants (12).

The effect of plant spacing was investigated as a possible cultural tactic to reduce early blight on Florida celery. Berger (13) calculated higher *C. apii* infection rates during the middle to latter half of the growing season in celery planted at high densities compared with the infection rates calculated from low density plantings (13). Similarly, disease severity in high-density plantings was approximately double the severity observed in low-density plantings at eight weeks after transplanting, but these values did not differ at harvest (13). In contrast, Strandberg and White (90) reported no significant differences among infection rates, final disease levels, or leaf wetness durations in celery planted at different densities. Their results indicated that plant spacing or planting on raised beds did not improve air circulation and had no effect on early blight control (90). Increased plant spacing may not be a useful disease management tactic for growers since the small benefit observed by Berger (13) would likely be offset by yield losses resulting from reduced plant populations (13,90).

Cultural disease management tactics for early blight include methods to reduce initial inoculum and the use of tolerant cultivars. *Cercospora apii* reportedly survives as mycelium on infected seeds for >2 years and may provide a source of initial inoculum (80,85), although these assumptions has not been adequately documented (R. N. Raid, *personal communication*). Growers are instructed to plant pathogen-free seeds and limit

disease outbreaks on transplants in the greenhouse (80). Since infected celery debris left in the field after harvest serves as a source of inoculum for subsequent plantings (12), adequate crop rotation may reduce the risk of early blight epidemics (80). Early blight-tolerant cultivars include 'Flora-belle', 'June-bell', and 'Earlibelle' (80). Berger (10) reported a three week lag in disease incidence on a tolerant cultivar when compared with a susceptible cultivar, although season-long infection rates did not differ significantly between the cultivars. Despite the availability of semi-tolerant cultivars, fungicide sprays in the greenhouse and in the field are often required to protect the crop (80).

Florida celery growers are advised to apply the first fungicide spray immediately after transplanting (7,47). In 1969, subsequent applications were recommended at the following frequencies, depending on the number of blight favorable hours per day and the number of trapped spores per day: (i) spray once per week if there are 0 to 8 blight favorable hours and the number of trapped spores range from 1 to 100; (ii) spray twice per week if there are 8 to 12 blight favorable hours and the number of trapped spores range from 100 to 300; (iii) spray three times per week if there are 12 to 15 blight favorable hours and the number of trapped spores range from 300 to 500; (iv) spray three to seven times per week if there is 15 to 24 blight favorable hours and the number of trapped spores is >500 (7). Currently, the number of hours of blight-favorable weather are used to determine the frequency of applications but the use of spore trapping has apparently been discontinued (47,80). Fungicides may be applied as frequently as two to four times per week during blight-favorable periods (47). In some cases, cultural activities (i.e., field work and harvesting) are more important for determining spore potential than environmental monitoring (12). Ten-fold increases in spore counts were

recorded over 3-minute periods when field workers walked 5 to 7 m upwind though a blighted celery field. In addition, spore numbers peaked during harvest periods despite the lack of favorable spore liberation conditions (12). A fungicide application is currently recommended to celery fields located up to 0.5 miles downwind from harvesting operations (47). Berger (12) noted that since spore liberation is not always linked to blight favorable hours, spore trapping provides a more accurate measure of early blight risk than environmental data.

Most fungicides currently registered to control late blight also control early blight. In a fungicide efficacy study where both *S. apiicola* and *C. apii* were present, Hausbeck et al. (36) reported virtually equivalent control of both pathogens using alternating spray programs with registered fungicides. Miller and Hernandez (68) reported a higher level of early blight control when azoxystrobin was applied alone or in alternation with chlorothalonil compared with a standard chlorothalonil program. Raid and Dyce (81) found better early blight control was achieved in plots sprayed with azoxystrobin alternated with chlorothalonil compared with the disease control in plots treated with propiconazole alternated with chlorothalonil or chlorothalonil applied alone. However, early blight symptoms were detected on plants in the trial prior to initial fungicide treatments (81). Mixing copper hydroxide with chlorothalonil had a synergistic effect on early blight control since the mixture provided better control compared with either of the two fungicides applied independently (11). High and low rates of azoxystrobin were applied in two or three-way alternating spray schedules with chlorothalonil or propiconazole in a commercial celery field in Michigan (16). Yield loss in the untreated control was nearly 19% while fungicide treatments limited losses to <2% and provided

equivalent control of early blight (16). Significant differences in early blight control were not observed when azoxystrobin was applied at high vs. low rates which indicates no rate response was observed with this fungicide in these studies (16,35,68,81).

Disease Predictive Systems for *Septoria apiicola* and *Cercospora apii*

Disease predictive systems use easily obtained measurements of environmental conditions in the crop canopy and sometimes also rely on a spore trapping device to alert growers when disease-favorable conditions exist. In turn, growers are able to apply fungicides only when they are needed to manage diseases instead of applying fungicides on a calendar-based schedule. Disease predictors frequently require fewer fungicide applications compared with commonly used calendar-based schedules to achieve the same level of disease control. Applying fewer fungicide applications reduces disease management costs, the potential for fungicide residues on the crop, and the risk of pathogens developing resistance to fungicides. Disease predictors have been developed to manage foliar diseases incited by *S. apiicola* in Michigan (50) and *C. apii* in Florida (7,8). A third disease predictor controls *S. lycopersici* and other pathogens on tomato (76,77) and may be useful for managing *S. apiicola* on celery (33).

The disease predictor developed in Michigan was used for timing fungicide sprays to control late blight (50). Fungicides were applied when $\geq$12 h of continuous leaf wetness were recorded if no fungicides were applied in the previous seven days. The model was based on evidence that very few lesions developed on celery leaves exposed to 12 h of leaf wetness. The role of temperature was excluded from the predictive system since temperatures high enough to inhibit infection rarely occur during infection (leaf

wetness) periods in Michigan. In the 3-year study, the predictive model required two fewer applications relative to the weekly fungicide treatment without compromising disease control (50). Field studies in 2000 indicated that the *S. apiicola* predictor provides adequate disease control with two fewer applications when both *S. apiicola* and *C. apii* were present, but the yield from this treatment was significantly lower compared to some treatments where plants were treated every seven days (36). Hausbeck (33) reported that the *S. apiicola* predictor limited late blight and yield loss to levels similar to a 7-day fungicide schedule with three fewer applications. Despite substantial evidence for reducing the number of fungicide sprays without compromising disease control, the predictive system has not gained acceptance among Michigan celery growers.

A disease predictive system was developed to time fungicide sprays to manage *C. apii* on celery (7,8). The system used hourly measurements of RH and temperature in conjunction with a spore trap to identify sporulation periods. Fungicides were applied at different frequencies based on the number of *C. apii* conidia collected on spore trap slides and based on the number of hours of early blight-favorable weather. The use of this system in the 1968 winter growing season resulted in a savings of 5 to 15 fungicide applications without compromising disease control (8). Florida celery growers typically contract environmental monitoring and crop scouting activities to crop consultants because growers seldom have the time to operate disease predictive systems on their own (54). Also, the use of a spore trap requires expensive equipment and trained personnel to count conidia.

The *C. apii* predictor was tested in Michigan and Florida without the spore-trapping component. In Michigan, the predictor required four fewer applications and

provided equivalent control of both *C. apii* and *S. apiicola* compared with the standard weekly fungicide schedule in 2001 (M. K. Hausbeck, *unpublished data*). When only late blight was present in a 2002 study, the *C. apii* predictor limited disease and prompted six fewer applications compared to the 7-day fungicide treatment (33). In Florida, the *C. apii* predictor provided inconsistent control of early blight. Studies in 2002 and 2004 were conducted when environmental conditions were considered "conducive" and "moderately conductive", respectively, for early blight development and the *C. apii* predictor required five applications each season (82,84). The early blight control provided by the predictor was significantly lower compared to the weekly fungicide schedule which required 13 applications (82,84). In 2003, environmental conditions were considered "very conducive" for early blight development and the *C. apii* predictor required nine applications (83). Disease control and marketable yields were similar between plants treated according to the *C. apii* predictor and weekly application schedule (83).

The TOM-CAST disease predictor was originally developed to manage foliar diseases (incited by *Alternaria solani* and *Septoria lycopersici*) and anthracnose fruit rot (incited by *Colletotrichum coccodes*) on tomato (*Lycopersicon esculentum*) (76). For each 24-hour period (1100 to 1100), TOM-CAST uses the hours of leaf wetness and the average temperature during the wetness periods to calculate a disease severity value (DSV) ranging from 0 to 4, corresponding to environmental conditions unfavorable to highly favorable for disease development, respectively (76,77). A fungicide application is made when the cumulative DSV reaches a predetermined threshold. The predictor was recently validated for managing foliar pathogens on crops for which it was not originally developed to manage, including *Cercospora carotae* and *Alternaria dauci* on carrot

(*Daucus carota*) (23) and *Stemphylium vesicarium* on asparagus (*Asparagus officinalis*) (66). A preliminary study indicated that the TOM-CAST disease predictor may be appropriate for managing *S. apiicola* on celery, but only a single DSV threshold was tested (33).

Raid and Pernezny (82,83) and Raid et al. (84) tested the TOM-CAST 15-DSV program for control of *C. apii* in Florida. This program only required two to four fungicide sprays each season compared with the weekly application program which required 11 to 13 sprays. Fungicides applied according to the TOM-CAST 15-DSV program resulted in significantly less disease control each season and often resulted in lower marketable yields than the calendar-based fungicide program (82,83,84).

Since celery is successively planted over several months, the crop canopy and microclimate in the crop canopy varies from one field to the next depending on the age of the plants (12). Therefore, it is important to monitor environmental conditions separately in plantings of different maturities. Lacy et al. (54) lists environmental monitoring instruments that may be use to collect data for disease predictors, although newer instruments are often less expensive and are relatively less complicated.

Crater Rot Epidemiology and Management

Crater rot of celery is incited by the soil borne fungus *Rhizoctonia solani* Kuhn (teleomorph: *Thanatephorous cucumeris* (A.B. Frank) Donk.). Florida celery production has been affected by the disease since the early 1900s (85). The disease probably occurs wherever celery is grown (40). Initial symptoms are small, tan lesions located near the base of older petioles in contact with the soil (38). Lesions may develop as early as one

week after transplanting (74). Older lesions are sunken, red to dark brown, circular or oval, and up to one inch in diameter (38,93). Crater rot is difficult to detect in fields (93), as most of the damage is observed during harvesting and packing operations. Yield losses are incurred when diseased petioles are manually removed; a labor-intensive process resulting in reduced plant size (38). In Florida, yields are up to 28% lower when the disease is left uncontrolled (75). In Michigan, yield losses of 5 to 7% are reported (17,22).

The severity of the disease varies from year to year (38), presumably due to environmental changes in microclimate that have not been thoroughly identified. Pieczarka (74) observed significant increases in petiole infection following rain events, especially during the mid to latter half of the growing season. The disease is usually exacerbated by continuous celery culture (38), although *R. solani* incites disease on a wide variety of plants (40). *Rhizoctonia solani* isolates are classified by anastomosis groups (AGs), but isolates from celery have not been classified (40). *R. solani* isolates obtained from sugar beet and potato are pathogenic on celery (38), and isolates from celery incite disease on bean, cotton, and tomato (40).

Rhizoctonia solani produces relatively large (5 to 10 μm in diameter), tan to brown colored septate hyphae but does not produce spores (40). The fungus may produce sclerotia which are brown and variable in appearance. Both mycelium in infested crop debris and sclerotia can persist in the soil and serve as sources of initial inoculum for subsequent celery plantings or other crops (40).

The basidiomycete, *T. cucumeris*, may occur during periods of high humidity and cool temperatures, especially when the crop is nearing maturity (40). *T. cucumeris*

produces a white mat of superficial hyphae, basidia, and basidiospores (93) which resemble a light coating of talcum powder on the petiole. This growth does not cause disease symptoms, nor is there any evidence to support its role in crater rot epidemiology (40).

A disorder termed "celery petiole lesion" resembled crater rot damage and resulted in substantial losses to the California celery industry in the early 1990s (43). *Rhizoctonia solani* was not recovered from affected petioles, and other tests to detect pathogenic organisms were negative. Pesticides commonly used in celery production were tested for possible phytotoxic effects, and the insecticide naled (e.g., Dibrom, various manufacturers) was implicated with "celery petiole lesion" damage (43). Due to the similarity between symptoms of crater rot and symptoms of naled phytotoxicity, a laboratory analysis is recommended to distinguish between the problems (40). However, naled is no longer registered for use on celery.

Crater rot is minimized with a multitude of cultural control tactics and with effective fungicides. Celery growers are advised to avoid double cropping celery during the same season and to avoid planting celery to fields that have a large amount of undecomposed crop debris (40). Shallow planting or setting transplants on ridged rows reduces contact between petioles and infested soil or crop debris. If cultivation is used, soil should not be thrown at the base of plants to further reduce the chance of inoculum coming into contact with petioles. Rotation with non-host crops such as small grains may inhibit *R. solani* from reaching high populations (40). In California, the use of soil fumigants in rotational crops (e.g., strawberry) limits the *R. solani* population in the soil (4). Directing fungicide sprays toward the base of celery plants is recommended (40), but

may not always improve control compared with sprays applied over the top of the foliage (75).

Guzman et al. (32) recommend the practice of crop scouting at six weeks after transplanting to determine the percentage large (marketable) petioles with crater rot damage. A fungicide spray should be applied when 20% of plants show symptoms of crater rot, and subsequent sprays should be applied if the average number of infected petioles on each plant increases or if the percentage of infected plants increases. Lastly, they recommend one fungicide application just prior to the pre-harvest interval in the event that disease favorable weather persists until harvest (32).

In Florida, crater rot was reduced by modifying the planting depth and by applying the fungicide chlorothalonil (75). Untreated transplants with crowns set 1.3 cm below the soil surface on ridged rows had fewer infected petioles when compared to transplants set deeper (4.0 cm) on unridged rows. Chlorothalonil applications applied either one or six weeks after transplanting and reapplied weekly significantly reduced crater rot, regardless of planting depth or row configuration. Some spray programs were initiated at week six since most of the infected petioles during the first five weeks are not marketable. Fungicide sprays directed at the base of the plants did not improve disease control compared to sprays applied over the top of the foliage (75).

Fungicide efficacy studies were conducted in commercial celery fields with a history of crater rot in Michigan. Over 46% of untreated control plants had petiole lesions after plants were trimmed to fresh market specifications (17). All fungicide treatments limited disease incidence to <23%. Azoxystrobin alternated with chlorothalonil was the most effect treatment in reducing the incidence of crater rot and

minimizing yield loss (17). Both fungicides are currently registered for control of crater rot (14). In a separate commercial field, fungicides initially applied one or four weeks after transplanting provided complete control of crater rot and significantly reduced yield loss compared with the untreated control (22). Applying the first application on a preventive basis four weeks after transplanting reduced the number of applications and reduced fungicide costs by approximately $40/ha compared to the fungicide program initiated one week after transplanting (22).

Bacterial Leaf Spot Epidemiology and Management

Bacterial leaf spot is incited by *Pseudomonas syringae* pv. *apii* (Jagger) Young et al. The bacterium was first reported to infect celery in 1921 (39) and has since been reported to infect fennel (*Foeniculum vulgare*) and parsley (*Petroselinum crispum*) (58). The disease was previously known as northern bacterial blight to distinguish it from southern bacterial blight, incited by *P. cichorii*, which occurs on Florida-grown celery (85). Unlike the bacterial leaf spot pathogen, *P. cichorii* causes a petiole necrosis known as brown stem (73). Symptoms of bacterial leaf spot on celery leaves are initially small, water-soaked lesions which are circular to angular in shape (42,85). The lesions turn necrotic, coalesce, and produce a blighted appearance under favorable conditions. Lesions may appear as light tan necrotic spots and have a papery texture under dry conditions. Bacterial leaf spot lesions can be distinguished from those of late blight due to the absence of pycnidia (42,58). Similarly, lesions incited by *P. syringae* pv. *apii* are smaller, less circular in shape, and lack the gray color during periods of high humidity when compared with appearance of early blight lesions (42). Petioles are not typically

affected by the disease (42,58). Direct losses from the disease are reported to reach 5% due to the extra cost of removing infected foliage (58,85). Indirectly, the disease reduces the vigor and quality of transplants (42,57) and increases disease management costs in the greenhouse (42) and in the field.

Pseudomonas syringae pv. *apii* is a fluorescent bacterium which has the following biochemical and physiological characteristics when subjected to LOPAT tests: positive for levan production; negative for cytochrome oxidase; negative for potato rot; negative for arginine dihydrolase; and positive for tobacco hypersensitivity (42,57). An individual bacterium is 0.7 to 1.2 μm wide and 1.5 μm long and is motile by more than one polar flagella (58). The bacterium survives on celery seed for a period of two to three years, and infected seeds are considered the primary source of inoculum (58). The bacterium lives epiphytically on seedlings until favorable environmental conditions allow for populations to increase. *Pseudomonas syringae* pv. *apii* enters host tissue through wounds or stomata (57,58).

Environmental conditions and cultural practices associated with celery transplant production in greenhouses typically favor the development of bacterial leaf spot. Warm temperatures and frequent watering which are necessary for celery seedling establishment are also favorable conditions for *P. syringae* pv. *apii* (42,57). Close plant spacing allows the bacterium to spread between plants via splash dispersal during irrigation and via mechanical dispersal during mowing. High-pressure overhead irrigation and mowing also create wounds that allow the pathogen to easily infect seedlings (42,57). Although the disease may become established in the greenhouse, symptoms may not become evident until 7 to 10 days later (58) or until the transplants are set in the field. The use of

sprinkler irrigation in the field promotes disease development and spread of the bacterium (42).

Several cultural control tactics are recommended for managing bacterial leaf spot of celery, with an emphasis on reducing inoculum prior to transplanting. Growers should plant certified disease-free seed or treat the seed in a hot water at 50°C for 25 min (58). The hot water treatment drastically reduces *P. syringae* pv. *apii* from celery seed but does not provide completely eradicate the pathogen (57). This seed treatment may reduce seed germination especially if the seed is ≥2 years old. Celery flats and greenhouse benches should be disinfected between growing seasons. Growers should irrigate at times that allow leaves to dry quickly and avoid the use of high pressure irrigation (57). Proper greenhouse ventilation and air circulation can be used to reduce humidity and the duration of leaf wetness (54). Mowing should be conducted when the leaves are dry, and mowers should be disinfected at regular intervals (57). Vigilant sanitation of equipment and workers should be implemented to avoid contamination between greenhouses (57).

Celery growers in Michigan and California use copper hydroxide-based products in greenhouse transplant production and in the field to limit the disease, but these products only provide fair to good control (3,4). Bounds and Hausbeck (21) evaluated various products for bacterial leaf spot management at the request of Michigan celery growers (3). Weekly copper hydroxide (Kocide 2000 53.8DF at 1 and 1.5 lb/A) treatments that growers often use reduced bacterial leaf spot severity by >50% compared to the untreated control (21). Weekly applications copper hydroxide mixed with of an unregistered product classified as a plant defense activator, acibenzolar-S-methyl (Actigard 50WG, Syngenta Crop Protection, Inc.), resulted in the highest level of disease

control but did not differ significantly from the standard treatment of copper hydroxide applied alone. Other products were mixed with copper hydroxide and included the harpin protein biopesticide (Messenger STS 3WDG, Eden Bioscience Corporation) and the *Bacillus subtilis* biocontrol agent (Serenade Max 14.6WP, AgraQuest, Inc.). Although both of these products are registered for use on celery in the greenhouse and in the field, neither improved disease control relative to the standard copper hydroxide treatment. The severity of bacterial leaf spot in this study did not warrant additional trimming of diseased leaves or reduce yields even when plants were left untreated (21).

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CHAPTER I.

Comparing Disease Predictors and Fungicide Programs for Late Blight Management in Celery

ABSTRACT

Late blight, incited by the fungus *Septoria apiicola*, is the most important foliar disease of celery in Michigan and results in necrotic lesions on leaves and petioles that can reduce yields by up to 80%. Most celery growers apply the fungicide chlorothalonil as frequently as every seven days to protect the crop, but some of these applications may not be needed when environmental conditions do not favor disease development. The purpose of this study was to evaluate disease predictors using a standard (chlorothalonil) and a reduced-risk (azoxystrobin alternate chlorothalonil) fungicide program for managing late blight on 'Dutchess' celery in 2003 to 2005. Fungicides were initiated one week after transplanting and reapplied every seven days or according to the Septoria predictor, the Cercospora predictor, or TOM-CAST using intervals of 10, 15, and 20 disease severity values (DSV). In each year of this study, timing sprays according to the TOM-CAST 10-DSV predictor resulted in disease control comparable to the 7-day interval, but required up to five fewer sprays, and reduced fungicide costs ($\leq$\$215/ha) compared to the 7-day interval. The Septoria, Cercospora, and TOM-CAST 15-DSV predictors often provided control similar to the 7-day interval, but these predictors were somewhat inconsistent compared to TOM-CAST 10-DSV. The TOM-CAST 20-DSV predictor required the fewest number of sprays but unacceptable levels of disease resulted. The standard and reduced-risk fungicide programs frequently provided similar control, but azoxystrobin alternated with chlorothalonil was more effective than chlorothalonil alone when disease pressure was high.

INTRODUCTION

Late blight, incited by *Septoria apiicola* Speg., is an important foliar disease of celery (*Apium graveolens* L. var. *dulce* (Mill.) Pers.) in Michigan (1,16,27) and California (2,23,36). The disease also occurs in Florida (6) but has not been an annual problem in recent years (24). Late blight symptoms typically appear first on the older, outer leaves and are characterized by irregularly shaped, necrotic lesions (16) which are sometimes surrounded by a diffuse, chlorotic margin (17). The disease is easily distinguished from other common foliar diseases of celery in Michigan, such as early blight (incited by *Cercospora apii*) (29) and bacterial leaf spot (incited by *Pseudomonas syringae* pv. *apii*) (32), because black pycnidia are embedded in *S. apiicola* lesions (15). Each pycnidium is capable of releasing an average of 3,675 conidia (30). Conidial germination is highest in the presence of free moisture (53) and infection occurs when celery leaves remain wet for $\geq$12 h (26,33). Conidia are splash-dispersed by rainfall or overhead irrigation (6) and are moved by mechanical means in conidia-laden water droplets by farm laborers and machinery (31). Severely blighted tissues wither and senesce (16). Diseased petioles must be manually removed, a time consuming process which increases harvesting costs and reduces yields. Untreated plants can weigh 56 to 82% less after diseased petioles are removed (12,46); these plants are not marketable since only a few small, healthy petioles remain.

Foliar fungicides are often the primary tool for control of late blight (28) and can be applied as frequently as every seven days (8). The calendar-based management approach may result in excessive applications when environmental conditions do not favor disease development. Most growers use the protectant fungicide chlorothalonil,

which is classified as a B2 carcinogen, to manage late blight because it is effective (11,25,45,46) and relatively inexpensive. Azoxystrobin is a relatively new, reduced-risk fungicide labeled for use on celery that protects against *S. apiicola* (12,21,49). Azoxystrobin has systemic and curative properties and must be alternated with fungicides that have a different mode of action to prevent or delay the occurrence of fungicide-resistant strains of plant pathogens (3). The use of chlorothalonil in alternation with azoxystrobin is typically recommended since both products effectively limit late blight and they have different modes of action. Including azoxystrobin in a spray program to manage late blight may displace some of the applications of the B2 carcinogen, chlorothalonil.

Applying fungicides only when environmental conditions are favorable for *S. apiicola* may reduce the overall number of applications needed for effective disease control, reducing pesticide inputs to the environment. Two disease predictors have been developed to manage foliar diseases of celery. Lacy (26) developed a *S. apiicola* model (hereafter referred to as the Septoria predictor) which requires measurements of leaf wetness duration. Berger (4,5) developed a *C. apii* model (hereafter referred to as the Cercospora predictor) which requires measurements of relative humidity (RH) and temperature use in conjunction with a spore trap. Both disease predictors reduced the number of fungicide applications needed to obtain disease control comparable to calendar-based application schedules (5,26). A disease predictor that includes both leaf wetness duration and temperature may be appropriate for managing *S. apiicola* since both parameters are important for disease development (33).

The TOM-CAST disease predictor was originally developed to manage foliar diseases (incited by *Alternaria solani* and *Septoria lycopersici*) and anthracnose fruit rot (incited by *Colletotrichum coccodes*) on tomato (43,44). The system utilizes the duration of leaf wetness and average temperature during the wetness period to calculate a daily disease severity value (DSV). A fungicide is applied when the cumulative DSV reaches a predetermined threshold (43,44). Since its development for use on tomatoes, TOM-CAST has been validated for use in managing *Cercospora carotae* and *Alternaria dauci* on carrot (14,51) and *Stemphylium vesicarium* on asparagus (35).

Michigan celery growers are interested in reducing their reliance on the calendar-based fungicide regime and desire an alternative late blight management strategy in order to lower production costs while maximizing quality and yield (1). A preliminary study indicated that the TOM-CAST disease predictor may be appropriate for managing late blight of celery, but only a single DSV threshold was tested (20). The objective of this study was to compare disease predictors using a grower standard and a reduced-risk fungicide program to manage late blight on celery.

MATERIALS AND METHODS

Plot establishment and inoculation. The study was conducted at the Michigan State University Muck Soils Research Farm in Laingsburg, Michigan from 2003 to 2005. Seven- to eight-week old 'Dutchess' celery transplants were set 17.8 cm apart in rows spaced 0.8 m apart on 28 May 2003, 21 June 2004, and 25 May 2005 in Houghton muck soil, previously planted with potato (2003 and 2004) or carrot (2005). Each treatment plot consisted of one row 6.1 m long which included approximately 34 plants. Sections

of inoculated buffer row (0.8 to 1.5 m) bordered the ends of each plot, and two inoculated buffer rows separated adjacent treatment rows. Thirteen treatments which included one untreated control and 12 fungicide programs were arranged in a randomized complete block design in four blocks. Weed, insects, and fertilization requirements were managed according to standard production practices (8,59,60). Sprinkler irrigation was used to maintain the water requirements of the crop and to promote *S. apiicola* infection.

Inoculum was prepared and applied similar to the procedures described by Lacy et al. (28). Dried celery leaves infected with *S. apiicola* were soaked in tap water for 10 min, and the debris was removed by straining the spore suspension through two layers of cheesecloth. Spore concentration was determined using a hemacytometer, and the final spore suspension was adjusted to 1 x 10^6 conidia/ml with water just prior to inoculation. Plots were sprinkler-irrigated to wet the foliage for approximately 60 min prior to inoculation. Inoculum was applied at dusk with a hand-pump sprayer equipped with one hollow-cone or flat-fan nozzle delivering approximately 168 liters/ha. All buffer rows were inoculated (i.e., every plant except those in treatment plots); care was taken to avoid inoculating plants in treatment rows. This indirect inoculation approach was used to allow *S. apiicola* to spread under natural splash-dispersal conditions. Twelve or more hours of continuous leaf wetness were maintained by short intervals (10 to 15 min) of sprinkler irrigation in the morning after each inoculation. All buffer rows were inoculated twice each season at 42 and 49 days after planting (DAP) (2003 and 2005) and 39 and 51 DAP (2004).

Disease predictors and fungicide programs. The Septoria predictor requires a fungicide application when ≥12 h of consecutive leaf wetness occurs if no fungicides

were applied during the previous seven days (26). The Cercospora predictor used in this study was similar to the program developed in Florida (4), but without the spore-trapping component. The spore-trapping component of the predictor was omitted in an effort to test the system in a manner growers or crop consultants could operate without requiring excessive time or expensive equipment. A fungicide spray was applied if all of the following criteria were met: (i) no fungicides were applied during the previous seven days; (ii) $\geq$12 h of RH $\geq$90% were recorded the previous day (0700 yesterday to 0600 today); (iii) mean temperature was 15 to 30°C during previous day; (iv) temperatures three days ago were $\geq$12°C, or, if the temperature fell below 12°C, the mean night temperature (2200 to 0700) on each of the two succeeding nights was $\geq$15°C and had a mean RH $\geq$95%.

For each 24-h period (1100 to 1100), TOM-CAST uses the hours of leaf wetness and the average temperature during the wetness periods to calculate a DSV, ranging from 0 to 4, corresponding to environmental conditions unfavorable to highly favorable for disease development, respectively (44). Daily DSVs are summed and accumulated until a threshold value is reached, a fungicide spray is applied, and the DSV total is reset to zero. Unlike the Septoria or Cercospora predictors, the TOM-CAST program was not tested with a minimum fungicide reapplication interval since none was specified when the predictor was developed for tomato (43,44) or when the predictor was validated for use in asparagus (35) or carrot (14).

Hourly measurements of temperature and leaf wetness were obtained using a digital data recorder (WatchDog Leaf Wetness and Temperature Logger 3610TWD; Spectrum Technologies, Inc., Plainfield, IL) located in the upper 75% of the crop canopy

in an unsprayed row at a 45° angle facing north. A second digital data recorder (WatchDog Data Logger Model 450; Spectrum Technologies, Inc.) made hourly measurements of RH, temperature, and rainfall and was located in the upper 75% of the crop canopy. A tipping-bucket rain gauge (Model 3665R; Spectrum Technologies, Inc.) collected rainfall and sprinkler irrigation and was located 1.2 m above the soil surface. Data recorders were placed in the plots after transplanting and were set to record temperatures from 0 to 100°C and leaf wetness (i.e., wetness threshold set to 0) where applicable. Data were downloaded at least every other day to a laptop computer using a computer program (Specware 6.02; Spectrum Technologies, Inc.) equipped to calculate DSVs for the TOM-CAST predictor. Raw hourly data were examined to determine the number of hours of consecutive leaf wetness for the Septoria predictor. Similarly, raw hourly data were examined to determine the number of hours of RH $\geq$90 or $\geq$95% and to calculate average temperatures for the Cercospora predictor.

The reduced-risk fungicide azoxystrobin (Quadris 2.08F at 0.17 kg a.i./ha, Syngenta Crop Protection, Inc., Greensboro, NC) and the fungicide chlorothalonil (Bravo Ultrex 82.5WDG at 1.7 kg a.i./ha, Syngenta Crop Protection, Inc.) were either applied in an alternating program (hereafter referred to as azoxystrobin/chlorothalonil), where azoxystrobin was applied at the initial application, or in a grower standard program where chlorothalonil was applied exclusively. The thirteen treatments included in this study were composed of an untreated control plus 12 fungicide treatments where both fungicide programs (azoxystrobin/chlorothalonil and chlorothalonil) were tested with each of the six application programs: (i) 7-day interval; (ii) Septoria predictor; (iii) Cercospora predictor; (iv) TOM-CAST 10-DSV; (v) TOM-CAST 15-DSV; (vi) TOM-CAST 20-

DSV. To allow for equal comparison among application programs, all fungicide treatments received an initial spray one week after transplanting. Applications were made with a CO_2 backpack boom sprayer (R & D Sprayers, Opelousas, LA) equipped with three Teejet XR8003VS flat-fan nozzles (Spraying Systems Co., Wheaton, IL) spaced 45.7 cm apart, operating at a boom pressure of 359 kPa, and delivering 467.6 liters/ha. The cost of fungicides applied for each treatment was calculated by multiplying the number of applications by estimated costs of azoxystrobin ($53/ha) or chlorothalonil ($28/ha) per application.

Disease assessment. Weekly visual evaluations of leaf blight severity were conducted on 20 plants from the middle of each treatment plot using a celery leaf blight assessment key developed by Strandberg (*unpublished*). According to the key, plots were assigned values of 0, 1, 5, 10, 15, 20, 25, 30, 35, 40, 45, or 50% leaf blight. The celery leaf blight assessment key was similar to the leaf blight assessment key developed for carrot (55). Plots were evaluated once prior to disease developing in treatment rows and three (2005) or four (2003 and 2004) times after disease symptoms were detected.

Ten plants were hand-harvested from each treatment plot and trimmed to fresh market specifications at 90 (2003), 95 (2004), and 85 DAP (2005). Disease severity was evaluated by visually estimating the percentage of symptomatic petiole tissue on all trimmed plants. Total yield was recorded, diseased petioles were removed, and plants were weighed again to obtain disease-free yield. The yield loss percentage was expressed as the weight of diseased petioles removed (total yield minus disease-free yield) divided by the total yield. The methods of disease assessment used in this study conform with the methods suggested by Kavanagh and Ryan (22).

Statistical analysis. Disease and yield data were analyzed using an analysis of variance (ANOVA) for a randomized complete block experiment with the Proc GLM procedure of the Statistical Analysis System (SAS Institute, Cary, NC). The equal variance assumption was examined using Levene's Robust test (39). All data were analyzed separately by year since the equal variance assumption between years was usually not met. Normality was examined using the residuals from each ANOVA and Proc Univariate procedure of SAS, and all data were square-root transformed to meet the normality assumption. The treatments in this experiment represent a two (fungicide program) by six (application program) factorial experiment with an additional untreated control treatment. Significant treatment differences were further examined using the following four linear contrasts to compare the treatments: (i) the difference between the untreated control and the average of fungicide treatments; (ii) differences among application programs across fungicide programs (main effect of application program); (iii) the difference between fungicide programs across application programs (main effect of fungicide program); (iv) the interaction between application program and fungicide program. Differences among means for any significant effect, giving priority to interaction effects, were examined using Tukey's Studentized Range test (54).

RESULTS

Environmental conditions were favorable for *S. apiicola* establishment and dissemination during each year of this study but were particularly favorable in 2003 when the rainfall and irrigation total was highest. Rainfall and irrigation totaled 21.9, 16.3, and 16.5 cm from the day after the first inoculation until harvest in 2003, 2004, and 2005,

respectively. During the same time period, the average leaf wetness was 12.7, 13.9, and 14.2 h/day and extended periods of leaf wetness (≥12 h) occurred on 62%, 78%, and 85% of the days in 2003, 2004, and 2005. Mean temperatures recorded in the crop canopy were similar in 2003 (19.3°C) and 2004 (19.1°C) but were slightly warmer in 2005 (22.2°C).

In each year of the study, late blight symptoms were observed on the leaves of inoculated plants 12 to 15 days after the buffer rows were first inoculated (DAFI). *S. apiicola* spread to treatment rows, and symptoms were detected 26 to 31 DAFI on untreated plants. Leaf blight severity on the untreated plants was ≤5% at 33 to 40 DAFI and was 35% (2004 and 2005) to 41% (2003) at the final evaluation (Fig. 1). Untreated plants trimmed to fresh market specifications had severe late blight symptoms on petioles (>38%) (Table 1), which required additional trimming and resulted in a yield loss of 54 to 69% (Table 2). Untreated plants were not marketable for fresh market use since fewer than four small, healthy petioles remained after blighted petioles were removed.

Fungicide-treated plants had significantly lower levels of disease and yield loss compared to untreated plants (Tables 1 and 2). Fungicide applications limited leaf blight severity to <22% (2003) or ≤5% (2004 and 2005) and petiole blight severity to <23% (2003) or ≤10% (2004 and 2005) (*data not shown*). When averaged across fungicide programs, similar control of petiole blight was provided by the following application programs during 2003: 7-day interval; Septoria predictor; Cercospora predictor; TOM-CAST 10-DSV predictor (Table 1). Only the 7-day interval and the Septoria predictor completely prevented yield loss (Table 2). The TOM-CAST 10-DSV and Cercospora predictors were comparable in limiting yield loss to <3%, but only the TOM-CAST 10-

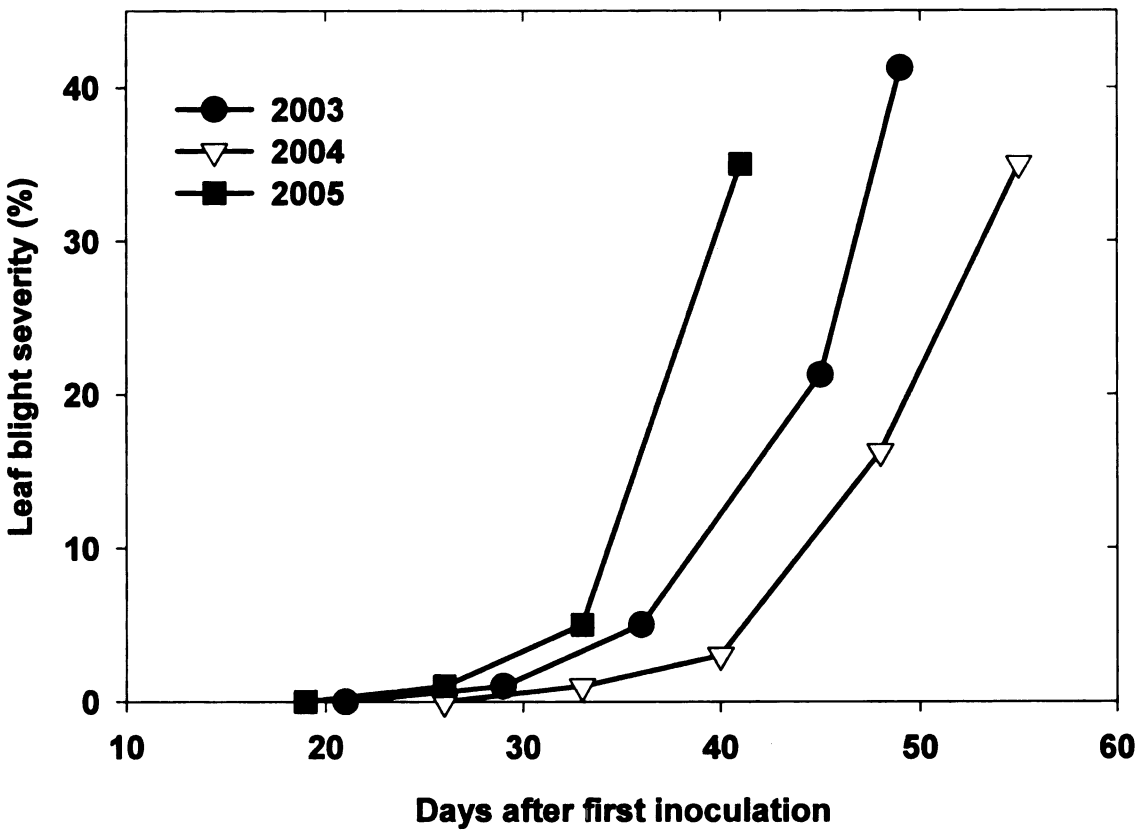

Fig. 1. Leaf blight severity of untreated 'Dutchess' celery plants when adjacent buffer row plants were inoculated with *Septoria apiicola* at approximately six and seven weeks after transplanting in 2003-2005.

Table 1. Effects of application programs and fungicides[v] on leaf and petiole blight severity resulting from *Septoria apiicola* on 'Dutchess' celery during 2003 to 2005

	Leaf blight severity (%)			Petiole blight severity (%)		
Treatment main effect	2003	2004	2005	2003	2004	2005
Untreated control[w]	41.3	35.0	35.0	51.3	42.5	38.8
Application program[x]						
7-day	0.5	0.2 a[y]	1.2 a	0.0 a	0.0 a	0.6 a
Septoria predictor	0.7	0.1 a	1.4 a	0.0 a	0.0 a	0.6 a
Cercospora predictor	2.2	0.3 a	0.9 a	0.7 a	0.0 a	0.5 a
TOM-CAST 10-DSV	1.0	0.6 a	0.6 a	0.5 a	0.3 ab	0.7 a
TOM-CAST 15-DSV	4.6	0.5 a	1.8 a	5.8 b	0.2 a	2.6 a
TOM-CAST 20-DSV	19.7	1.0 a	3.8 b	16.5 c	0.7 b	6.5 b
Fungicide program[z]						
chlorothalonil	3.9	0.5 a	1.7 a	3.3 b	0.3 a	1.7 a
azoxystrobin/chlorothalonil	3.0	0.4 a	1.4 a	1.9 a	0.1 a	1.5 a
Source	*P value*	*P value*	*P value*	*P value*	*P value*	*P value*
Treatment	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Untreated vs. avg. treated	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Application program	<0.0001	0.0503	<0.0001	<0.0001	0.0011	<0.0001
Fungicide program	0.0687	0.4431	0.3070	0.0270	0.2540	0.7733
Application-fungicide interaction	0.0008	0.5832	0.0643	0.0814	0.6802	0.0504

[v] Chlorothalonil (1.7 kg a.i./ha) was applied exclusively or in alternation with azoxystrobin (0.17 kg a.i./ha) where azoxystrobin was applied first. Both fungicide programs were tested with each application program.

[w] Untreated control data are shown for comparison purposes only and are not included in the statistical analyses for main effects or the interaction.

[x] Application program data (n = 8/mean) averaged across fungicide programs.

Table 1. Continued.

[y] Means within a column for each treatment main effect followed by the same letter are not significantly different according to Tukey's Studentized Range test ($P \leq 0.05$). Mean separation results are not presented for main effects when the application-fungicide interaction was significant.

[z] Fungicide program data (n = 24/mean) averaged across application programs.

Table 2. Effects of application programs and fungicides[v] on yield loss resulting from *Septoria apiicola* on 'Dutchess' celery during 2003 to 2005

	Yield loss (%)		
Treatment main effect	2003	2004	2005
Untreated control[w]	54.9	69.1	63.7
Application program[x]			
7-day	0.0 a[y]	0.0 a	1.0
Septoria predictor	0.0 a	0.0 a	2.6
Cercospora predictor	2.9 b	0.0 a	0.9
TOM-CAST 10-DSV	1.5 ab	0.6 a	0.8
TOM-CAST 15-DSV	8.4 c	0.3 a	7.0
TOM-CAST 20-DSV	32.5 d	2.5 b	15.6
Fungicide program[z]			
chlorothalonil	6.8 b	0.7 a	3.9
azoxystrobin/chlorothalonil	3.1 a	0.3 a	3.4
Source	*P value*	*P value*	*P value*
Treatment	<0.0001	<0.0001	<0.0001
Untreated vs. avg. treated	<0.0001	<0.0001	<0.0001
Application program	<0.0001	<0.0001	<0.0001
Fungicide program	0.0004	0.1215	0.5918
Application-fungicide interaction	0.0747	0.6516	0.0003

[v] Chlorothalonil (1.7 kg a.i./ha) was applied exclusively or in alternation with azoxystrobin (0.17 kg a.i./ha) where azoxystrobin was applied first. Both fungicide programs were tested with each application program.

[w] Untreated control data are shown for comparison purposes only and are not included in the statistical analyses for main effects or the interaction.

[x] Application program data (n = 8/mean) averaged across fungicide programs.

[y] Means within a column for each treatment main effect followed by the same letter are not significantly different according to Tukey's Studentized Range test ($P \leq 0.05$). Mean separation results are not presented for main effects when the application-fungicide interaction was significant.

[z] Fungicide program data (n = 24/mean) averaged across application programs.

DSV predictor was comparable to the 7-day interval. Applying fungicides according to the TOM-CAST 15- or 20-DSV predictors resulted in significantly higher yield loss when compared to all other application programs (Table 2).

Across application programs, azoxystrobin/chlorothalonil resulted in similar reductions in disease severity and yield loss compared with chlorothalonil (Tables 1 and 2). An exception was noted in 2003 when significant differences were detected under high disease pressure: azoxystrobin/chlorothalonil significantly reduced petiole blight severity (Table 1) and yield loss (Table 2) compared to chlorothalonil.

A significant interaction between application program and fungicide occurred for leaf blight severity in 2003, indicating the most effective program was dependent on the fungicide (Table 1). The 7-day interval, Septoria predictor, Cercospora predictor, and TOM-CAST 10-DSV predictor were equally effective in limiting leaf blight to <2% when chlorothalonil was applied (Table 3). While the TOM-CAST 15-DSV predictor was less effective than these programs, it resulted in significantly lower leaf blight than the TOM-CAST 20-DSV predictor. When azoxystrobin/chlorothalonil was used, the 7-day interval, Septoria predictor, and TOM-CAST 10-DSV predictor significantly reduced leaf blight ($\leq$1%) compared to the Cercospora predictor. The TOM-CAST 15-DSV predictor significantly reduced leaf blight compared to the TOM-CAST 20-DSV predictor and provided control similar to the Septoria, Cercospora, and TOM-CAST 10-DSV predictors when azoxystrobin/chlorothalonil was used (Table 3).

Under moderate disease pressure in 2004 and 2005, all disease predictors except TOM-CAST 20-DSV limited petiole blight to levels similar to the 7-day interval when averaged across fungicide programs (Table 1). In 2005, the TOM-CAST 20-DSV

Table 3. Interaction of application programs and fungicides on control of *Septoria apiicola* on 'Dutchess' celery in 2003 and 2005[y]

Disease assessment (year)	Fungicide program[z]	
Application program	Chlorothalonil	Azoxystrobin/chlorothalonil
Leaf blight severity (%) (2003)		
7-day	0.7 a B	0.2 a A
Septoria predictor	1.0 a B	0.5 ab A
Cercospora predictor	1.8 a A	2.7 c B
TOM-CAST 10-DSV	1.0 a A	1.0 ab A
TOM-CAST 15-DSV	8.3 b B	1.8 bc A
TOM-CAST 20-DSV	18.3 c A	21.2 d B
Yield loss (%) (2005)		
7-day	1.3 a A	0.8 a A
Septoria predictor	6.1 b B	0.3 a A
Cercospora predictor	0.2 a A	1.8 a B
TOM-CAST 10-DSV	0.9 a A	0.7 a A
TOM-CAST 15-DSV	12.6 b B	2.9 a A
TOM-CAST 20-DSV	8.1 b A	25.5 b B

[y] Means under each disease assessment-year combination in the same column (fungicide program) followed by the same lowercase letter and means in the same row (application program) followed by the same uppercase letter are not significantly different according to Tukey's Studentized Range test ($P \leq 0.05$).

[z] Chlorothalonil (1.7 kg a.i./ha) was applied exclusively or in alternation with azoxystrobin (0.17 kg a.i./ha) where azoxystrobin was applied first.

predictor had a significantly higher level of leaf blight than the 7-day interval (Table 1). Leaf blight severity did not differ significantly among application programs in 2004 (Table 1), but differences in yield loss occurred (Table 2). Yield loss was significantly higher when fungicides were applied according to the TOM-CAST 20-DSV predictor compared to all other application programs (Table 2).

In 2005, a significant interaction between the application program and fungicide was detected in the analysis of yield loss (Table 2). The Septoria, TOM-CAST 15-DSV, and TOM-CAST 20-DSV predictors resulted in yield losses that were statistically similar and significantly higher compared to the other application programs when chlorothalonil was applied exclusively (Table 3). All application programs were equally effective in limiting yield loss when azoxystrobin/chlorothalonil was used, with the exception of the TOM-CAST 20-DSV predictor (Table 3).

Significant interactions between application program and fungicide indicated that fungicides performed differently depending on the application program. Frequently, azoxystrobin/chlorothalonil outperformed chlorothalonil under high disease pressure in 2003, with two exceptions (Table 3). Chlorothalonil applied according to the Cercospora or TOM-CAST 20-DSV predictors was significantly more effective in limiting leaf blight compared to azoxystrobin/chlorothalonil (Table 3). Similar results were noted in the analysis of yield loss in 2005. When chlorothalonil or azoxystrobin/chlorothalonil was applied at 7-day intervals in 2005, there was no significant difference in yield losses. Fungicides did not differ significantly in leaf blight severity (2003) or yield loss (2005) when applied according to the TOM-CAST 10-DSV predictor (Table 3).

Overall, disease predictors increased the average number of days between sprays compared to the 7-day interval (Table 4). Fungicides were applied as frequently as every seven days for the Septoria and Cercospora predictors, which is the minimum interval specified by these programs. When environmental conditions did not favor disease, a maximum application interval of 17 days occurred for the Septoria and Cercospora predictors. The TOM-CAST 10-DSV predictor required a fungicide application as frequently as every four days or as infrequently as every 21 days. The TOM-CAST predictor prompted applications every 7 to 20 days (15-DSV) or every 11 to 28 days (20-DSV) (Table 4).

The Septoria and Cercospora predictors frequently provided equivalent disease control compared to the 7-day interval and required up to two and five fewer sprays, respectively (Table 5). The TOM-CAST 10-DSV predictor required either the same number or up to five fewer sprays compared to the 7-day program and always resulted in equivalent disease control regardless of fungicide. The TOM-CAST 15-DSV predictor required three to seven fewer sprays than the 7-day interval and often provided similar control under moderate disease levels in 2004 and 2005 but not when disease was severe in 2003. The TOM-CAST 20-DSV predictor required as many as nine fewer sprays compared to the 7-day interval, but equivalent disease control was not achieved regardless of fungicide. The 7-day interval was often the most costly since it required the most fungicide applications. Disease predictors which required two to seven fewer sprays than the 7-day interval reduced fungicides costs by $56 to $196/ha with chlorothalonil and $81 to $296 with azoxystrobin/chlorothalonil, respectively (Table 5).

Table 4. Frequency of applications as required by the 7-day interval and disease predictors for control of *Septoria apiicola* during 2003 to 2005

Application program	Average no. days between applications (minimum, maximum no. days between applications) 2003	2004	2005	Three-year ave. no. days between app.
7-day[z]	7.0 (6,9)	7.0 (6,8)	7.1 (7,8)	7.0
Septoria predictor	8.6 (7,12)	8.1 (7,15)	8.3 (7,11)	8.3
Cercospora predictor	11.7 (7,15)	8.8 (7,14)	9.0 (7,17)	9.6
TOM-CAST 10-DSV	10.9 (5,16)	10.6 (5,21)	7.2 (4,13)	9.3
TOM-CAST 15-DSV	16.3 (12,20)	14.8 (13,19)	10.6 (7,15)	13.3
TOM-CAST 20-DSV	21.7 (15,28)	21.0 (17,26)	14.2 (11,23)	18.1

[z] Forecasted or actual rain events either shortened or extended the days between applications for the 7-day interval.

Table 5. Number of fungicide applications and cost of fungicides applied according to different application programs for control of *Septoria apiicola* during 2003 to 2005

	No. fungicide sprays Cost of chlorothalonil--azoxystrobin alternate chlorothalonil ($/ha)[z]		
Application program	2003	2004	2005
7-day	12 336--486	13 364--539	11 308--458
Septoria predictor	10 280--405	11 308--458	10 280--405
Cercospora predictor	7 196--296	10 280--405	9 252--377
TOM-CAST 10-DSV	8 224--324	8 224--324	11 308--458
TOM-CAST 15-DSV	5 140--215	6 168--243	8 224--324
TOM-CAST 20-DSV	4 112--162	4 112--162	6 168--243

[z] The cost of fungicide applied was calculated using estimated costs of chlorothalonil ($28/ha) and azoxystrobin ($53/ha) per application.

DISCUSSION

Failure of a disease predictor to limit disease in celery has significant economic consequences since the crop value is relatively high and the plant parts affected by *S. apiicola* are the marketable portions of the crop. Consumers demand blemish-free celery, so an alternative disease management program that requires fewer fungicide applications than the standard program must not compromise disease control. In Michigan, the TOM-CAST system is predominantly used by producers of carrots and asparagus (38) that are valued at $3,424 and $2,420/ha, respectively. In contrast, the value of Michigan celery grown for processing and fresh market is six- to eight-fold higher at $20,431/ha (58). TOM-CAST is used to manage diseases of carrot and asparagus that occur on plant parts that are not usually marketed or consumed. In carrot, TOM-CAST is used to manage foliar blight on leaves and petioles (14,51), plant parts which supply photosynthetic energy to the edible root and must be healthy to withstand the pull of mechanical harvesters. In asparagus, TOM-CAST is used to manage purple spot on the fern after the edible spears are harvested (35). In our experiments with celery, management programs which allowed *S. apiicola* to affect the marketable portion of the crop were unacceptable.

The highest disease severity was observed in 2003 when the relatively high amount of rainfall and irrigation favored dissemination and infection by *S. apiicola* (6,52). Parker et al. (41) reported a linear relationship between rainfall, expressed as cumulative rainfall and cumulative hours with rain, and Septoria leaf spot severity (incited by *S. lycopersici*) on tomato foliage. In our trials, differences in disease severity among years likely impacted the efficacy of some of the fungicide treatments. For example, our 2003 results indicate that the TOM-CAST 15-DSV predictor was less

effective when compared with the 7-day interval when disease pressure was high. However, differences in disease control were not detected when TOM-CAST 15-DSV was tested under lower disease pressure in 2004 and 2005, especially when azoxystrobin was included in the spray program. Incorporating rainfall and irrigation parameters might be beneficial to the TOM-CAST predictor for managing diseases incited by *Septoria* spp. as others have recommended (19,40,41). Refining the TOM-CAST predictor to include these parameters could bolster the predictor for use in high risk crops, such as celery.

Our inoculated field plots may have had higher levels of *S. apiicola* inocula than the levels that typically occur in commercial celery fields. Even the 7-day interval did not entirely prevent disease development. Under conditions of naturally-occurring *S. lycopersici* inoculum, the TOM-CAST 20-DSV predictor provided equivalent disease control on tomato compared to the 7-day interval with five to six fewer applications (37). Perhaps the TOM-CAST 15-DSV predictor would be acceptable under natural conditions in commercial celery fields where the inoculum load is limited by cultural control measures. Most Michigan celery growers plant seed that is hot-water treated, which may not completely eradicate *S. apiicola* (34), and some growers use a one-year crop rotation (25) to reduce inoculum associated with infested celery debris in the soil. However, due to the uneven distribution of late blight under natural conditions, artificial inoculation is recommended when conducting fungicide efficacy studies with *S. apiicola* (28). When the Septoria predictor was first tested in the early 1990s, *S. apiicola* inoculum was applied once to the experimental plots (26). In our study, we followed the recommendation of Lacy et al. (28) and inoculated the buffer rows twice to ensure

adequate infection. The higher inoculum load in our experimental plots may explain why the Septoria predictor was less effective in limiting yield loss than the 7-day interval when chlorothalonil alone was applied in 2005.

In Florida, Raid and Pernezny (47,48) and Raid et al. (50) found that the TOM-CAST 15-DSV predictor resulted in significantly less *C. apii* control and often resulted in lower marketable yields than the weekly interval. However, the TOM-CAST 15-DSV predictor only required two to four fungicide sprays compared to the weekly interval which required 11 to 13 sprays (47,48,50). Under the environmental conditions in our study, the TOM-CAST 15-DSV predictor required a minimum of six sprays and provided control similar to the 7-day interval in 2004 and 2005. In Canada, Trueman et al. (57) recently evaluated the TOM-CAST 20-DSV predictor for controlling late blight of celery and determined that it was not as effective as the 7-day interval. Although our results with the TOM-CAST 20-DSV predictor agree with those of Trueman et al. (57), the fungicide programs used in our study differ greatly from those tested in Canada. Trueman et al. (57) applied copper hydroxide in alternation with either chlorothalonil or a new fungicide that is not currently registered for use on celery. Michigan celery growers often tank-mix copper hydroxide with chlorothalonil in their disease control programs because copper hydroxide limits bacterial leaf spot (13) and improves early blight control compared to chlorothalonil alone (7). Reports from Michigan (1,12,20) and California (2,42) indicate that copper-based fungicides provide little, if any, protection from *S. apiicola* when used alone. Although copper-based fungicides were not tested with disease predictors under the experimental conditions in our study, we are reluctant to

recommend copper-based fungicides for use with disease predictors in Michigan due to their limited efficacy against *S. apiicola.*

Overall, azoxystrobin/chlorothalonil was more effective than chlorothalonil in limiting petiole blight and yield loss under high disease pressure in 2003. Also, the alternating program was more effective than chlorothalonil alone when applied every seven days in 2003 or applied according to the Septoria or TOM-CAST 15 DSV predictors in 2003 and 2005. Raid (46) also obtained significantly better control of *S. apiicola* and higher yields when azoxystrobin was applied in alternation with chlorothalonil compared with chlorothalonil only. The benefit of including azoxystrobin in the spray program can likely be attributed to the systemic property, translaminar movement (3), and, perhaps the long residual activity, of this fungicide.

An unexpected outcome in our study was that chlorothalonil resulted in significantly lower levels of leaf blight (2003) and yield loss (2005) than azoxystrobin/chlorothalonil when applied according to the Cercospora and TOM-CAST 20-DSV predictors. Potential factors that may have contributed to this outcome were our use of robust inoculum loads and lowest labeled fungicide rates. These factors may have selected for *S. apiicola* strains with reduced-sensitivity to azoxystrobin. Resistance in *S. tritici* to azoxystrobin is conferred by an amino acid substitution of glycine with alanine at position 143 on the cytochrome b gene (18) or by alternative respiration; however, the latter mechanism has no effect on disease control in vivo (61). Similar evidence has not been reported for *S. apiicola*, nor have baseline sensitivities of *S. apiicola* been established for strobilurin fungicides (including azoxystrobin and trifloxystrobin, which are both registered for use on celery in the United States). Whether a target site mutation

or alternative respiration occurred in *S. apiicola* in our study is unknown but appears unlikely since the inferior control provided by azoxystrobin/chlorothalonil was only evident in plots treated according to the Cercospora and TOM-CAST 20-DSV predictors. Further, spray programs that included azoxystrobin were among the most efficacious in fungicide efficacy trials simultaneously conducted and located adjacent to the experimental plots of the present study (9,10,11,12). Nevertheless, the Cercospora and TOM-CAST 20-DSV predictors provided inconsistent and unacceptable control, respectively, compared with the 7-day interval.

The TOM-CAST 10-DSV predictor was the only disease predictor that consistently provided disease control comparable to the 7-day interval when using either chlorothalonil or azoxystrobin/chlorothalonil. This program required up to five fewer applications than the 7-day program, while reducing fungicide costs up to $215/ha. The use of a 7-day minimum reapplication interval, that is required with other disease predictors (26,56), is a further adjustment to the TOM-CAST predictor that may improve the usefulness of this program for celery growers. For instance, the TOM-CAST 10-DSV predictor occasionally required applications at 4- to 5-day intervals, although this did not provide additional disease control benefits compared to the 7-day interval. Further, chlorothalonil cannot be used more frequently than every seven days. As new fungicides are developed for celery, these products should be tested in conjunction with disease predictors to verify their efficacy in management program that require fewer overall sprays. The environmental conditions in Michigan differ from those in other important celery-producing areas in the United States, such as California and Florida; further validation in other areas is needed. Implementation of disease predictors that reduce

fungicide inputs for late blight management in celery will likely benefit growers, consumers and the environment.

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CHAPTER II.

Evaluation of a Reduced-Risk Fungicide Program Applied According to Disease Thresholds for Late Blight Management in Celery

ABSTRACT

Late blight of celery, incited by *Septoria apiicola*, results in necrotic lesions on leaves and petioles and reduces yield when it occurs on marketable petioles. Michigan celery growers typically begin applying fungicides one to three weeks after transplanting and reapply fungicides at 7- to 10-day intervals to manage late blight. Delaying the initial fungicide application or using disease thresholds to prompt the first fungicide spray may reduce the number of applications needed for effective disease control. Weekly treatments of azoxystrobin alternated with chlorothalonil were initiated early (one week after transplanting), preventively (four weeks after transplanting), or when disease symptoms were detected at a trace, 5%, or 10% level on 'Dutchess' celery plants in 2003 and 2004. The early and preventive initiation programs were equally effective in preventing petiole blight and yield loss. The preventive disease management approach required three fewer applications, saving up to $134/ha, compared to the early fungicide program initiated one week after transplanting. Delaying the initial fungicide application until any level of disease developed subsequently resulted in high disease levels at harvest that were often similar to untreated control plants. Delaying the initial fungicide application until initial late blight symptoms are observed in the field is not recommended in Michigan due to the risk of extensive yield loss.

INTRODUCTION

Late blight, incited by *Septoria apiicola* Speg., is an important disease of celery (*Apium graveolens* L. var. *dulce* (Mill.) Pers.) worldwide (28) and is the most serious foliar disease of celery in Michigan (18). Symptoms of the disease are first observed on older, outer leaves (10) and consist of irregularly shaped, necrotic lesions which sometimes exhibit a faint chlorotic margin (12). An identifying sign of late blight is the presence of pycnidia, which are embedded in infected tissues (12) and resemble flecks of ground black pepper when observed without magnification. Severely blighted tissues wither and senesce (10). Diseased tissues must be manually removed which increases harvesting costs and reduces yield.

Celery growers are advised to use preventive disease control tactics such as planting disease-free seed (20) and implementing a two-year crop rotation (21) to avoid late blight epidemics. Most celery seed planted in Michigan is hot-water treated, which may not completely eradicate *S. apiicola* (20), and later pelleted for precise seeding into transplant trays. Pelleted seed may have a shorter shelf life compared to raw seed, so storing pelleted seed for the recommended two to three years to avoid seed-borne *S. apiicola* (10,16) may reduce germination. The majority of Michigan celery growers do not practice crop rotation, although some use a one-year rotation (17) with onion. Since genetic resistance to *S. apiicola* is not currently available in commercial celery cultivars (11), foliar fungicides are often relied on as the primary tool for disease control in the field (19).

Most growers use the protectant fungicide chlorothalonil to manage late blight because it is effective (7,17,25) and relatively inexpensive; however, chlorothalonil is

classified as a B2 carcinogen. Some Michigan growers incorporate azoxystrobin into their spray program since it is effective against late blight (6,7,8,14,27) and is more effective than chlorothalonil in some cases (23,26). Azoxystrobin is a newer fungicide registered for use on celery that has systemic and curative properties (4). It is considered to pose a low risk to non-target organisms and the environment, and has been registered as a reduced-risk fungicide by the United States Environmental Protection Agency (4). Including azoxystrobin in a spray program to manage late blight often displaces some applications of the B2 carcinogen, chlorothalonil.

Michigan celery growers typically begin applying fungicides one to three weeks after transplanting and reapply fungicides at 7- to 10-day intervals to manage late blight (5). Delaying the initial fungicide application until the level of disease reaches a critical threshold often reduces the total number of fungicide applications needed for effective disease control and has been successfully used in disease management programs for carrot (9,13) and onion (29). Similar programs have not been developed for celery. Mudita and Kushalappa (24) applied chlorothalonil three weeks after celery transplanting and every seven to ten days thereafter to plots containing 0 to 16% diseased transplants per plot. Due to the relatively low cost of fungicides in relation to the crop value and the occurrence of yield loss at low disease incidence thresholds, they were not able to establish an economical threshold for initiating fungicide treatment (24). Lacy (17) observed "fair to good" control of *S. apiicola* when benomyl, a systemic fungicide no longer registered for use on celery, was applied at 14-day intervals when the initial application was applied three days after lesions were detected on the leaves of inoculated plants. Nearly 10% of the foliage of benomyl-treated plants was blighted and was mostly

confined to the leaves, but this treatment was not directly compared with one that was initiated on preventive basis prior to disease symptom development (17). Since azoxystrobin is a relatively new fungicide and has a mode of action distinct from that of chlorothalonil or benomyl, an opportunity exists to test this fungicide in disease management programs where applications are withheld until low disease thresholds are reached. Delaying the initial fungicide application may reduce the number of applications without compromising control.

Consumers are concerned about pesticide residues on their food, and celery has been targeted as one of the most "contaminated" vegetables (2). Michigan celery growers are interested in alternative disease management practices for *S. apiicola* that reduce fungicide use without compromising disease control and yield (1). The purpose of this research was to incorporate a reduced-risk fungicide into late blight management programs and examine methods to reduce fungicide use in celery for the benefit of consumers, celery growers, and the environment. The objective of this study was to evaluate weekly, reduced-risk fungicide schedules initiated prior to disease development or according to disease thresholds for control of *S. apiicola* on celery.

MATERIALS AND METHODS

Plot establishment and inoculation. The study was conducted at the Michigan State University Muck Soils Research Farm in Laingsburg, Michigan in 2003 and 2004. Seven- to eight-week old 'Dutchess' celery transplants were set 17.8 cm apart in rows spaced 0.8 m apart on 28 May 2003 and 21 June 2004 in Houghton muck soil, previously planted with potato. Each treatment plot consisted of one row 6.1 m long which included

approximately 34 plants. Sections of inoculated buffer row (0.8 to 1.5 m) bordered the ends of each plot, and two inoculated buffer rows separated adjacent treatment rows. Six treatments which included one untreated control and five fungicide programs were arranged in a randomized complete block design in four blocks. Weed, insects, and fertilization requirements were managed according to standard production practices (5,33,34). Sprinkler irrigation was used to maintain the water requirements of the crop and to promote *S. apiicola* infection.

Inoculum was prepared and applied similar to the procedures described by Lacy et al. (19). Dried celery leaves infected with *S. apiicola* were soaked in tap water for 10 min, and the debris was removed by straining the spore suspension through two layers of cheesecloth. Spore concentration was determined using a hemacytometer, and the final spore suspension was adjusted to 1 x 10^6 conidia/ml with water just prior to inoculation. Plots were sprinkler irrigated to wet the foliage for approximately 60 min prior to inoculation. Inoculum was applied at dusk with a hand-pump sprayer equipped with one hollow-cone or flat-fan nozzle delivering approximately 168 liters/ha. All buffer rows were inoculated (i.e., every plant except those in treatment plots); care was taken to avoid inoculating plants in treatment rows. This indirect inoculation approach was used to allow *S. apiicola* to spread under natural splash-dispersal conditions. Twelve or more hours of continuous leaf wetness were maintained by short intervals (10 to 15 min) of sprinkler irrigation in the morning after each inoculation. All buffer rows were inoculated twice each season at 42 and 49 days after planting (DAP) in 2003 and 39 and 51 DAP in 2004.

Timings of initial fungicide applications. The six treatments tested in this study were (i) an untreated control, (ii) an early fungicide treatment initiated one week after transplanting (grower standard), (iii) a preventive fungicide treatment initiated four weeks after transplanting, (iv) a fungicide treatment initiated when a trace level of late blight was first detected in uninoculated treatment rows, (v) a fungicide treatment initiated when 5% leaf blight was observed in uninoculated treatment rows, and (vi) a fungicide treatment initiated when 10% leaf blight was observed in uninoculated treatment rows. Early treatments were applied on 5 June 2003 (8 DAP) and 28 June 2004 (7 DAP). Preventive treatments were applied on 27 June 2003 (30 DAP) and 19 July 2004 (28 DAP). Treatments made at a trace level of disease were applied on 7 August 2003 (71 DAP) and 30 August 2004 (70 DAP). Although symptoms of late blight were detected on 5 August 2003, rain occurred on 5 and 6 August and delayed the initial application by two days. A celery leaf blight assessment key developed by Strandberg (*unpublished*) was used to determine disease severity for the 5 and 10% thresholds. The 5% blight initiation treatments were applied on 14 August 2003 (78 DAP) and 13 September 2004 (84 DAP). The 10% blight initiation treatments were applied on 21 August 2003 (85 DAP) and 17 September 2004 (87 DAP). Subsequent fungicide applications were applied at 7-day intervals for all fungicide treatments until harvest.

The fungicides azoxystrobin (Quadris 2.08F at 0.17 kg a.i./ha, Syngenta Crop Protection, Inc., Greensboro, NC) and chlorothalonil (Bravo Ultrex 82.5WDG at 1.7 kg a.i./ha, Syngenta Crop Protection, Inc.) were applied in an alternating program where azoxystrobin was applied first. Applications were made with a CO_2 backpack boom sprayer (R & D Sprayers, Opelousas, LA) equipped with three Teejet XR8003VS flat-fan

nozzles (Spraying Systems Co., Wheaton, IL) spaced 45.7 cm apart, operating at a boom pressure of 359 kPa, and delivering 467.6 liters/ha. The cost of fungicides applied for each treatment was calculated by multiplying the number of applications by estimated costs of azoxystrobin ($53/ha) or chlorothalonil ($28/ha) per application.

Disease assessment and statistical analysis. Weekly visual evaluations of leaf blight severity were conducted on 20 plants from the middle of each treatment plot using a celery leaf blight assessment key developed by Strandberg (*unpublished*). According to the key, plots were assigned values of 0, 1, 5, 10, 15, 20, 25, 30, 35, 40, 45, or 50% leaf blight. The celery leaf blight assessment key was similar to the leaf blight assessment key developed for carrot (31). Plots were evaluated once prior to disease developing in treatment rows and four times after disease symptoms were detected.

Ten plants were hand-harvested from each treatment plot and trimmed to fresh market specifications at 90 DAP in 2003 and 95 DAP in 2004. Disease incidence was determined on trimmed plants by counting the number of plants with one or more lesions on the petioles. Disease severity was evaluated by visually estimating the percentage of symptomatic petiole tissue on all trimmed plants. Total yield was recorded, diseased petioles were removed, and plants were weighed again to obtain disease-free yield. The yield loss percentage was expressed as the weight of diseased petioles removed (total yield minus disease-free yield) divided by the total yield. The methods of disease assessment used in this study conform with the methods suggested by Kavanagh and Ryan (15).

Disease and yield data were analyzed using an analysis of variance (ANOVA) for a randomized complete block experiment with the Proc GLM procedure of the Statistical

Analysis System (SAS Institute, Cary, NC). Normality was examined using the residuals from each ANOVA and Proc Univariate procedure of SAS. Differences among means for any significant effect were examined using Tukey's Studentized Range test (30).

RESULTS

Late blight symptoms were observed on the leaves of inoculated plants in the buffer rows 15 to 16 days after the first inoculation (DAFI) each year. *S. apiicola* spread to uninoculated plants in treatment rows, and symptoms were detected 27 to 31 DAFI each year. At harvest, all untreated control plants had lesions on marketable petioles and when diseased petioles were removed, the yield loss was 50 (2003) and 74% (2004). None of the untreated control plants were marketable for fresh market use since only two to four small, healthy petioles remained after diseased petioles were removed.

In 2003, only the early and preventive treatments significantly reduced leaf and petiole blight (≤1%) compared to the untreated control (Table 1). Total yields recorded prior to the removal of diseased petioles were significantly different among treatments in 2003, where the early and preventive treatments resulted in the highest yields and the trace disease treatment resulted in the lowest yield (*data not shown*). The early and preventive treatments resulted in significantly higher disease-free yields compared to the untreated control and the trace, 5%, or 10% disease treatments (Table 1).

In 2004, both the early and preventive treatments produced healthy leaves and marketable petioles (Table 1). Applying the initial fungicide at 5 or 10% disease resulted in severe leaf and petiole blight similar to the untreated. When fungicides were initiated at trace disease, leaf and petiole blight were significantly reduced compared to the

Table 1. Late blight severity and yield of 'Dutchess' celery plants not treated or treated with fungicides[x] initiated at different timings for control of *Septoria apiicola* in 2004 and 2005

	Leaf blight severity (%)		Petiole blight severity (%)		Disease-free yield (kg)	
Treatment[y]	2003	2004	2003	2004	2003	2004
Untreated control	50.0 b[z]	38.8 c	42.5 bc	52.5 c	5.5 b	3.2 c
Early	0.8 a	0.0 a	0.0 a	0.0 a	11.9 a	13.1 a
Preventive	0.3 a	0.0 a	0.0 a	0.0 a	12.0 a	13.7 a
Trace threshold	50.0 b	27.5 b	47.5 c	27.5 b	4.8 b	5.8 b
5% blight threshold	50.0 b	38.8 c	36.3 bc	48.8 c	5.4 b	3.8 c
10% blight threshold	50.0 b	35.0 c	32.5 b	46.3 c	5.1 b	4.1 bc

[x] Azoxystrobin (0.17 kg a.i./ha) alternated with chlorothalonil (1.7 kg a.i./ha).

[y] Treatments were applied early (one week after transplanting), preventively (four weeks after transplanting), or when disease was detected in treatment rows at a trace, 5%, or 10% level. Subsequent sprays were applied every seven days.

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

untreated but this treatment was not as effective as the early and preventive treatments. Total yields did not differ significantly among treatments (*data not shown*), but differences among disease-free yields occurred (Table 1). The early and preventive treatments resulted in the highest disease-free yields. The yield of plants treated at trace disease was significantly higher compared to the untreated and those treated at 5% disease but was significantly lower compared to the early and preventive treatments (Table 1).

Three fewer fungicide sprays were made by initiating the first application four weeks after transplanting (preventive) compared with the early treatment initiated one week after transplanting. The preventive treatment reduced fungicide costs by $109/ha in 2003 and $134/ha in 2004 compared to the early treatment without compromising disease control (Table 2).

Table 2. Number of fungicide applications and cost of fungicides applied when initiated at different timings for control of *Septoria apiicola* in 2003 and 2004

	No. fungicide applications (fungicide cost [$/ha][y])	
Treatment[z]	2003	2004
Untreated control	0 (0)	0 (0)
Early	12 (486)	13 (539)
Preventive	9 (377)	10 (405)
Trace	3 (134)	4 (162)
5% blight threshold	2 (81)	2 (81)
10% blight threshold	1 (53)	1 (53)

[y] Azoxystrobin (0.17 kg a.i./ha) was alternated with chlorothalonil (1.7 kg a.i./ha). The cost of fungicide applied was calculated using estimated costs of azoxystrobin ($53/ha) and chlorothalonil ($28/ha) per application.

[z] Treatments were applied early (one week after transplanting), preventively (four weeks after transplanting), or when disease was detected in treatment rows at a trace, 5%, or 10% level. Subsequent sprays were applied every seven days.

DISCUSSION

Failure of a disease management program to limit late blight on celery has severe economic consequences. Since *S. apiicola* affects the petioles, which are the marketable portions of the crop, there is a zero tolerance for disease. Consumers demand blemish-free celery, yet desire reduced pesticide use. An integrated pest management (IPM) program which involves the use of disease thresholds to initiate fungicide treatment cannot compromise the value of the marketable product. Disease thresholds are currently used to initiate fungicide treatment for control of foliar blight of carrot (incited by *Cercospora carotae* and *Alternaria dauci*) (9) and are recommended for Botrytis leaf blight of onion (incited by *Botrytis squamosa*) (29). However, the value of celery grown for processing and fresh market is $20,431/ha in Michigan, which is substantially higher than the values of other important vegetable crops in Michigan such as processing carrot ($3,424/ha) and onion ($6,445/ha) (32). In carrot and onion, fewer sprays are typically applied since applications are withheld until specific disease thresholds are reached (9,29). These programs do not present a direct risk to the marketable portion of the crop since yields are not compromised (9,29) and disease symptoms do not occur on the marketable product. In our experiments with celery, delaying the initial spray until just a trace level of disease was observed allowed *S. apiicola* to become well established and subsequently destroyed the marketable portion of the crop.

Several studies have been conducted to examine the efficacy of fungicides applied after the appearance of late blight symptoms in inoculated field trials (3,17,22,25). In California, Paulus et al. (25) made weekly applications of chlorothalonil or benomyl and reported equivalent and "satisfactory" control of *S. apiicola* when the initial spray was

applied after disease symptoms were severe on leaves and petioles of inoculated plants. Both fungicide programs resulted in complete crop loss when the application interval was increased to 14 days (25). In a separate experiment, chlorothalonil or benomyl were initially applied when disease symptoms were first detected on the leaves of inoculated plants and fungicides provided adequate control when applied at 14-day intervals (25). In Michigan, Lacy (17) obtained "fair to good" control with benomyl when applied at a 14-day interval when the first application was applied three days after late blight lesions were detected on the leaves of inoculated plants. In England, Bambridge et al. (3) reported better control with benomyl than chlorothalonil when biweekly sprays were initiated after all plants were symptomatic, although the chlorothalonil rate was less than one-third of what is currently recommended. Under low disease pressure in Canada, McDonald et al. (22) controlled late blight with applications of chlorothalonil that were initiated after disease symptoms were present. These studies illustrate the variability in disease control based on geographic location, fungicides, and probably inocula levels since they were seldom specified. The fungicides used in the aforementioned studies act either on the surface of plant tissues to protect against infection (e.g., chlorothalonil) or act systemically to cure existing infections (e.g., benomyl). Although benomyl has both protectant and curative properties, it is no longer registered for use on celery in the United States. Our study was the first to examine the use of the reduced-risk fungicide azoxystrobin, which was labeled for use on celery in the United States in 2000, in situations where late blight symptoms were present on celery foliage prior to the first application. Although azoxystrobin has a unique biochemical mode of action (4) that differs from that of benomyl and chlorothalonil, it did not demonstrate eradicant activity

(i.e., disease control after disease symptoms are present) on *S. apiicola* under the conditions in our study. Our study illustrates the potential risk associated with delaying the initial fungicide application until disease symptoms were observed because *S. apiicola* was not controlled with weekly fungicide sprays once it was established in the celery crop.

Mudita and Kushalappa (24) suggest postponing the initial fungicide treatment until late blight symptoms are observed in commercial fields. In our study, waiting to apply the first fungicide treatment until any level of disease symptoms was observed resulted in complete crop loss during each year. Our results suggest a preventive disease management approach where fungicides are initially applied prior to disease symptom appearance. Perhaps our conclusion and that of Mudita and Kushalappa differ because the overall amount of *S. apiicola* inoculum in our experiment may have been higher than the inoculum level in their commercial fields. However, any damage to the marketable portion of the crop, resulting from any amount of *S. apiicola* inoculum, must be manually removed and thus increases harvesting costs and reduces yields. Since late blight damage is often unevenly distributed under natural (commercial field) conditions, artificial inoculation ensures uniform distribution of the pathogen (19) and allows for equal comparison among treatments. We used an indirect inoculation approach by applying inoculum to buffer rows only (rather than treatment rows) to allow *S. apiicola* to spread under natural, splash-dispersal conditions. The treatments that failed to provide adequate control were those that did not have fungicide active ingredient in place to provide protectant activity prior to the splash-dispersal of *S. apiicola* conidia to unprotected plants.

Disease risk factors such as environmental conditions and the levels of *S. apiicola* inoculum on transplants and on celery debris in the soil are important in the understanding of late blight epidemiology and management. In our study, the transplants were considered disease-free since no symptoms were detected prior to those resulting from inoculations. Also, the soil in which our plots were located had not been planted to celery for at least three years. Delaying the initial fungicide application until four weeks after transplanting may not result in acceptable disease control when sources of initial inoculum are not considered. Celery growers should continue their efforts to reduce or eliminate initial inoculum sources and apply fungicides preventively, as dictated by fungicide labels, to avoid late blight epidemics. Delaying the initial application until four weeks after transplanting did not reduce disease control or marketable yield. This preventive treatment required three fewer sprays, saving $109 to $134/ha, compared to the early treatment initiated one week after transplanting. Although fungicide costs account for only a small fraction of celery production inputs, the reduction in fungicide use is likely to have societal or environmental impacts that were not addressed in this study. The use of delayed initial fungicide applications could be used in conjunction with an effective disease predictive system to not only reduce the number of unnecessary early-season applications but also to reduce the number of fungicide applications needed for effective control of late blight for the duration of the growing season.

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CHAPTER III.

Coupling Delayed Initial Fungicide Applications and Disease Predictors for Late Blight, Early Blight, and Crater Rot Management in Michigan Celery Production

ABSTRACT

Michigan celery growers rely on foliar fungicides applied one to three weeks after transplanting and reapplied at weekly intervals to control *Septoria apiicola*, *Cercospora apii*, and *Rhizoctonia solani*, the fungi that incite late blight, early blight, and crater rot, respectively. Delaying the initial fungicide application and using disease predictors to time subsequent sprays may reduce the number of applications without compromising control. Field trials were established in 2004 and 2005 at a research farm where *S. apiicola* inoculum was applied and at a commercial field where early blight and crater rot developed from naturally-occurring inoculum. A reduced-risk fungicide program (chlorothalonil alternated with azoxystrobin) was initiated preventively (four to five weeks after transplanting) and reapplied weekly or according to the Septoria predictor or TOM-CAST 10-DSV and was compared with the standard, weekly application program initiated early (one to two weeks after transplanting). Combining the use of preventive initial applications with the Septoria predictor or TOM-CAST 10-DSV reduced the number of sprays by two to six while providing disease control that was comparable to the standard weekly fungicide program initiated early. These programs reduced fungicide expenditures by $71 to $213/ha compared to the weekly fungicide program initiated early.

INTRODUCTION

Michigan celery (*Apium graveolens* L. var. *dulce* (Mill.) Pers.) production is affected by three fungal pathogens that damage the marketable portion of plants every year. Diseased tissues must be manually removed which increases harvesting costs and reduces yield. Late blight, incited by *Septoria apiicola* Speg., is the most important foliar disease of celery in the state (26) and can result in yield losses near 80% (10,18). Early blight, incited by *Cercospora apii* Fresen., has become an annual problem for Michigan celery growers (1) since the early 1990s. Early blight can result in yield losses ranging from 19 to 58% in Michigan (5,20). Crater rot is incited by *Rhizoctonia solani* Kuhn and is reported to lower celery yields by 5 to 7% in Michigan (6,13).

The symptoms of each disease are distinct from one another, and an accurate diagnosis is usually conducted in the field by growers or experienced crop consultants. Late blight is identified by the appearance of small, tan to brown colored, irregularly shaped lesions on leaves and petioles (19,26). Lesions are initially detected on the older, outer leaves (16) which are sometimes surrounded by a diffuse chlorotic margin (17). The identifying feature of *S. apiicola* is the presence of pycnidia which are embedded in nearly all infected tissues and resemble flecks of ground black pepper without the aid of magnification (17). Symptoms of early blight also initially appear on older, outer leaves and are characterized by light tan to gray colored circular lesions surround by a diffuse chlorotic halo (26,37). The lesions expand to $\geq$1 cm in diameter and turn dry and papery in texture (37). Lesions on petioles are generally elongate and lack a chlorotic halo. During periods of high relative humidity, the lesions may appear gray due to sporulation of the pathogen (26,37). Symptoms of early blight can be distinguished from those

incited by *S. apiicola* due to the absence of pycnidia and the larger size of early blight lesions (37,42). Initial symptoms of crater rot are small, tan lesions located near the base of older petioles in contact with the soil (22). Mature lesions are sunken, red to dark brown, circular or oval, and up to 2.5 cm in diameter (22,46). Crater rot is difficult to detect in fields (46), as most of the damage is observed during harvesting and packing operations.

Michigan celery growers typically begin applying the fungicide chlorothalonil one to three weeks after transplanting and reapply at weekly intervals to control all three diseases. Chlorothalonil is a broad-spectrum, protectant fungicide with activity against *S. apiicola* (7,9,10,18,36), *C. apii* (3,5), and *R. solani* (6,32), and is classified as a B2 carcinogen. Strategies to reduce the number of chlorothalonil applications have been implemented by producers of carrots for processing in Michigan (30). These strategies include the use of (i) a disease threshold to prompt the first fungicide spray, (ii) the TOM-CAST 15-DSV disease predictor to schedule subsequent sprays according to disease-favorable environmental conditions, and (iii) the reduced-risk fungicide azoxystrobin to displace some of the chlorothalonil applications (14). Azoxystrobin is a relatively new fungicide labeled for use on celery and is effective against *S. apiicola* (7,21,35), *C. apii* (20,29,38), and *R. solani* (6,13). Azoxystrobin has systemic and curative properties and must be alternated with fungicides that have a different mode of action to prevent or delay the occurrence of fungicide-resistant strains of plant pathogens (2). The use of chlorothalonil in alternation with azoxystrobin is typically recommended since both products effectively limit late blight and they have different modes of action.

Including azoxystrobin in a spray program to manage celery diseases may displace some of the applications of the B2 carcinogen, chlorothalonil.

By implementing some of the same disease control strategies used in carrot, Michigan celery growers may be able to reduce their dependence on chlorothalonil and apply fewer sprays to achieve the same level of disease control. Attempts to delay the initial fungicide application until late blight symptoms are detected on celery results in substantial yield loss (8). However, the initial fungicide spray can be applied on a preventive basis by delaying the first application until four and five weeks after transplanting without compromising control of crater rot (13) and late blight (12), respectively. The preventive fungicide program reduces the number of sprays by three while decreasing fungicide costs by approximately $100/ha compared to an early-initiation program started one to two weeks after transplanting (12,13). Disease predictors, such as the TOM-CAST 10-DSV program and the Septoria predictor, require up to four fewer sprays than the 7-day application program while providing comparable control of late blight (11). Disease predictors have not been tested in commercial celery fields in Michigan, nor have studies documented the efficacy of predictors in controlling diseases other than late blight, such as early blight and crater rot, that often occur in commercial celery fields.

Michigan celery growers are interested in reducing their reliance on early and repeated fungicide applications and desire an alternative disease management strategy in order to lower production costs while maximizing quality and yield (1). When implemented separately, delayed initial applications and disease predictors reduce the total number of fungicide applications without compromising disease control. Coupling

the use of delayed initial applications with a disease predictor may further reduce the number of fungicide applications needed to manage celery diseases. The objective of this study was to compare a standard fungicide application program with alternative disease management programs which utilized delayed initial applications and disease predictors.

MATERIALS AND METHODS

Plot establishment. Plots were established at the Michigan State University Muck Soils Research Farm in Laingsburg, Michigan and at a commercial celery field in Hudsonville, Michigan in 2004 and 2005. Seven-week old 'Dutchess' celery transplants were set 17.8 cm apart in rows spaced 0.8 m apart on 21 June 2004 and 25 May 2005 at the Muck Soils Research Farm (hereafter referred to as the research farm) in Houghton muck soil, previously planted with potato (2004) or carrot (2005). The study located in Hudsonville (hereafter referred to as the commercial field) was established with eight-week old 'Dutchess' celery transplants set 19.1 cm apart in rows spaced 0.5 m apart on 24 June 2004 and 16 June 2005 in Houghton muck soil, previously planted with onion. Each treatment plot consisted of a 6.1 m-long row which included approximately 34 and 32 plants at the research farm and commercial field, respectively. Sections of unsprayed buffer row (0.8 to 1.5 m) bordered the ends of each plot, and two unsprayed buffer rows separated adjacent treatment rows. Five treatments which included one untreated control and four fungicide programs were arranged in a randomized complete block design in four blocks. Weed, insects, and fertilization requirements were managed according to standard production practices (4,45,47). Sprinkler irrigation was used to maintain the water requirements of the crop.

At the research farm, *S. apiicola* inoculum was prepared and applied similar to the procedures described by Lacy et al. (27). Dried celery leaves infected with *S. apiicola* were soaked in tap water for 10 min, and the debris was removed by straining the spore suspension through two layers of cheesecloth. Spore concentration was determined using a hemacytometer, and the final spore suspension was adjusted to 1 x 10^6 conidia/ml with water just prior to inoculation. Plots were sprinkler irrigated to wet the foliage for approximately 60 min prior to inoculation. Inoculum was applied at dusk with a hand-pump sprayer equipped with one hollow-cone or flat-fan nozzle delivering approximately 168 liters/ha. All buffer rows were inoculated (i.e., every plant except those in treatment plots); care was taken to avoid inoculating plants in treatment rows. This indirect inoculation approach was used to allow *S. apiicola* to spread under natural splash-dispersal conditions. Twelve or more hours of continuous leaf wetness were maintained by short intervals (10 to 15 min) of sprinkler irrigation in the morning after each inoculation. All buffer rows were inoculated twice each season at 39 and 51 days after planting (DAP) in 2004 and at 42 and 49 DAP in 2005. Disease(s) developed from naturally-occurring inoculum at the commercial field.

Fungicide initiation and reapplication programs. The fungicide chlorothalonil (Bravo Ultrex 82.5WDG at 1.7 kg a.i./ha, Syngenta Crop Protection, Inc., Greensboro, NC) was applied in an alternating program with the reduced-risk fungicide azoxystrobin (Amistar 80WG at 0.17 kg a.i./ha, Syngenta Crop Protection, Inc.) where chlorothalonil was applied first. Applications were made with a CO_2 backpack boom sprayer (R & D Sprayers, Opelousas, LA). The spray boom used at the research farm was equipped with three Teejet XR8003VS flat-fan nozzles (Spraying Systems Co., Wheaton, IL) spaced

45.7 cm apart, operating at a boom pressure of 359 kPa, and delivering 467.6 liters/ha. The spray boom used at the commercial field was smaller in relation to the one used at the research farm since the row spacing was less at the commercial field. It was equipped with two Teejet XR8003VS flat-fan nozzles spaced 49.5 cm apart, operating at a boom pressure of 366 kPa, and delivering 467.6 liters/ha. The cost of fungicides applied for each treatment was calculated by multiplying the number of applications by estimated costs of chlorothalonil ($28/ha) and azoxystrobin ($43/ha) per application.

Initial fungicide treatments were either applied early according to the typical management practice at one (commercial field) to two (research farm) weeks after transplanting or applied preventively at four (commercial field) to five (research farm) weeks after transplanting. Early initiation sprays were reapplied at 7-day intervals. Preventive initiation sprays were reapplied every seven days or as required by the Septoria predictor or TOM-CAST using an interval of 10 DSVs.

The Septoria predictor requires a fungicide application when ≥12 h of consecutive leaf wetness occurs if no fungicides were applied during the previous seven days (25). For each 24-h period (1100 to 1100), TOM-CAST uses the hours of leaf wetness and the average temperature during the wetness periods to calculate a DSV, ranging from 0 to 4, corresponding to environmental conditions unfavorable to highly favorable for disease development, respectively (34). Daily DSVs are summed and accumulated until a threshold value is reached, a fungicide spray is applied, and the DSV total is reset to zero. Unlike the Septoria predictor, the TOM-CAST program was not tested with a minimum fungicide reapplication interval since none was specified when the forecaster was

developed for tomato (33,34) or when the forecaster was validated for use in asparagus (28) or carrot (15).

Hourly measurements of temperature and leaf wetness were obtained using digital data recorders (WatchDog Leaf Wetness and Temperature Logger 3610TWD; Spectrum Technologies, Inc., Plainfield, IL) located in the upper 75% of the crop canopy in an unsprayed row at a 45° angle facing north. Data recorders were placed in the plots after transplanting and were set to record temperatures from 0 to 100°C and leaf wetness (i.e., wetness threshold set to 0). Data were downloaded at least every three days to a laptop computer using a computer program (Specware 6.02; Spectrum Technologies, Inc.) equipped to calculate DSVs for the TOM-CAST system. Raw hourly data were examined to determine the number of hours of consecutive leaf wetness for the Septoria predictor. A tipping-bucket rain gauge (Model 3665R; Spectrum Technologies, Inc.) collected rainfall and sprinkler irrigation and was located 1.2 m above the soil surface at the research farm only.

Disease assessment and statistical analysis. Visual evaluations of leaf blight severity were conducted on 20 plants from the middle of each treatment plot using a celery leaf blight assessment key developed by Strandberg (*unpublished*). According to the key, plots were assigned values of 0, 1, 5, 10, 15, 20, 25, 30, 35, 40, 45, or 50% leaf blight. The celery leaf blight assessment key was similar to the leaf blight assessment key developed for carrot (44). Plots at the research farm were evaluated once prior to disease developing in treatment rows and three (2005) or four (2004) times at weekly intervals after disease symptoms were detected. Plots at the commercial field were evaluated once on the day of harvest.

Ten plants were hand-harvested from each treatment plot and trimmed to fresh market specifications at 92 and 85 DAP at the research farm and at 85 and 76 DAP at the commercial field in 2004 and 2005, respectively. At the research farm, late blight severity on petioles was evaluated by visually estimating the percentage of symptomatic petiole tissue on all trimmed plants. At the commercial field, crater rot incidence was determined by counting the number of trimmed plants with one or more lesions. Total yield was recorded, diseased petioles were removed, and plants were weighed again to obtain disease-free yield. The yield loss percentage was expressed as the weight of diseased petioles removed (total yield minus disease-free yield) divided by the total yield. The methods of disease assessment used in this study conform with the methods suggested by Kavanagh and Ryan (23).

Disease and yield data were analyzed using an analysis of variance (ANOVA) for a randomized complete block experiment with the Proc GLM procedure of the Statistical Analysis System (SAS Institute, Cary, NC). Normality was examined using the residuals from each ANOVA and Proc Univariate procedure of SAS. Differences among means for any significant effect were examined using Tukey's Studentized Range test (43).

RESULTS

Environmental conditions were considered favorable for disease development during each year of the study. The mean temperature recorded in the crop canopy at the research farm was 19.1 and 22.2°C in 2004 and 2005, respectively; similar mean temperatures were recorded at the commercial field. Combined rainfall and irrigation at the research farm totaled 16.3 (2004) and 16.5 cm (2005) from the day after the first

inoculation until harvest. At the commercial field, rainfall was recorded approximately 0.5 km from the experimental plots at a MAWN (Michigan Automated Weather Network) weather station and totaled 16.4 (2004) and 10.8 cm (2005).

Late blight symptoms were observed on the leaves on inoculated plants at the research farm 16 and 12 days after the buffer rows were first inoculated (DAFI) in 2004 and 2005, respectively. *S. apiicola* spread to uninoculated treatment rows, and symptoms were detected 31 (2004) and 26 (2005) DAFI on untreated plants. At harvest, all untreated plants trimmed to fresh market specifications had lesions on marketable petioles, and yield loss was >63% when diseased petioles were removed (Table 1). None of the untreated plants were marketable for fresh market use since only two to four small, healthy petioles remained after diseased petioles were removed. All fungicide treatments provided similar control and limited leaf blight severity to <1% each year (Table 1). All fungicide treatments prevented petiole blight, with one exception. In 2005, the preventive TOM-CAST 10-DSV management program resulted in a nominal amount of petiole blight and yield loss that did not differ significantly from the management programs that prevented petiole disease (Table 1).

At the commercial field, early blight symptoms were detected on the leaves of untreated plants 55 and 69 DAP in 2004 and 2005, respectively. At harvest, leaf blight severity was ≤1% on untreated plants, and the disease did not occur on petioles during either year (Table 2). All fungicide treatments significantly reduced leaf blight severity compared to the untreated control. Symptoms of crater rot were observed on 20% of untreated plants trimmed to fresh market specifications during the harvest in 2004, and symptoms were not found on fungicide-treated plants. Yield loss due to crater rot was

Table 1. Late blight severity and yield loss of 'Dutchess' celery plants not treated or treated with fungicides[x] for control of *Septoria apiicola* at the research farm in 2004 and 2005

	Leaf blight severity (%)		Petiole blight severity (%)		Yield loss (%)	
Management program[y]	2004	2005	2004	2005	2004	2005
Untreated control	33.8 b[z]	35.0 b	36.3 b	38.8 b	66.6 b	63.7 b
Early 7-day	0.3 a	0.5 a	0.0 a	0.0 a	0.0 a	0.0 a
Preventive 7-day	0.0 a	0.3 a	0.0 a	0.0 a	0.0 a	0.0 a
Preventive Septoria predictor	0.0 a	0.8 a	0.0 a	0.0 a	0.0 a	0.0 a
Preventive TOM-CAST 10-DSV	0.3 a	0.5 a	0.0 a	0.8 a	0.0 a	1.5 a

[x] Chlorothalonil (1.7 kg a.i./ha) alternated with azoxystrobin (0.17 kg a.i./ha).

[y] Early and preventive management programs were initiated two and five weeks after transplanting, respectively.

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

Table 2. Early blight severity and yield loss of 'Dutchess' celery plants not treated or treated with fungicides[x] for control of *Cercospora apii* and *Rhizoctonia solani* at the commercial field in 2004 and 2005

	Early blight (*C. apii*)				Crater rot (*R. solani*)	
	Leaf blight severity (%)		Petiole blight severity (%)		Yield loss (%)	
Management program[y]	2004	2005	2004	2005	2004	2005
Untreated control	1.0 b[z]	0.8 b	0.0	0.0	5.6 b	0.0
Early 7-day	0.0 a	0.0 a	0.0	0.0	0.0 a	0.0
Preventive 7-day	0.3 a	0.0 a	0.0	0.0	0.0 a	0.0
Preventive Septoria predictor	0.0 a	0.0 a	0.0	0.0	0.0 a	0.0
Preventive TOM-CAST 10-DSV	0.0 a	0.0 a	0.0	0.0	0.0 a	0.0

[x] Chlorothalonil (1.7 kg a.i./ha) alternated with azoxystrobin (0.17 kg a.i./ha).

[y] Early and preventive management programs were initiated one and four week(s) after transplanting, respectively.

[z] Means within a column followed by the same letter or no letter are not significantly different according to Tukey's Studentized Range test ($P \leq 0.05$).

>5% when diseased petioles were removed (Table 2).

Fungicides were applied as frequently as every seven days for the preventive Septoria predictor, which was the minimum interval dictated by this program, with one exception (Table 3). A single application was made six days after the previous application at the commercial field in 2005. A maximum of 10 days occurred between applications during periods when leaf wetness durations were <12 hours. The preventive TOM-CAST 10-DSV management program required fungicides as frequently as every four days or as infrequently as every 17 days depending on the weather. When averaged across both years and locations, the preventive Septoria predictor and TOM-CAST 10-DSV programs called for a fungicide every 7.7 to 8.2 days (Table 3).

Applying fungicides according to the standard management practice at one to two weeks after transplanting and at weekly intervals thereafter was the most costly management program because it required the most fungicide applications (Table 4). The preventive 7-day program did not compromise disease control and required three fewer applications, reducing fungicide costs by $99 to $114/ha, since it was initiated later in the season. The preventive Septoria predictor program often required the same number of applications compared to the preventive 7-day program, with one exception. In 2004, this management program required two fewer sprays than the preventive 7-day program at the commercial field. The preventive TOM-CAST 10-DSV program required two to six fewer applications, reducing fungicide costs by $71 to $213/ha, compared with the standard weekly fungicide program. When compared to the preventive 7-day program, the TOM-CAST 10-DSV program required three fewer sprays and one more spray in 2004 and 2005, respectively (Table 4).

Table 3. Frequency of fungicide applications required by different management programs for control of *Septoria apiicola* at the research farm and commercial field in 2004 and 2005[z]

Location	Ave. no. days between app. (min.,max. no. days between app.)		Two-year ave. no. days between app.
Management program	2004	2005	
Research farm			
Early 7-day	7.0 (6,8)	7.1 (7,8)	7.1
Preventive 7-day	7.0 (6,8)	7.2 (7,8)	7.1
Preventive Septoria predictor	7.6 (7,9)	7.8 (7,10)	7.7
Preventive TOM-CAST 10-DSV	11.5 (7,17)	6.3 (4,10)	8.2
Commercial field			
Early 7-day	6.9 (6,7)	7.1 (6,8)	7.0
Preventive 7-day	6.9 (6,7)	7.2 (6,8)	7.0
Preventive Septoria predictor*	8.2 (7,10)	7.2 (6,8)	7.7
Preventive TOM-CAST 10-DSV	9.8 (7,12)	6.1 (4,8)	7.7

[z] Forecasted or actual rain events either shortened or extended the days between applications for the 7-day interval at both locations each year. The interval was also shortened for the preventive Septoria predictor on one occasion at the commercial field in 2005.

Table 4. Number of fungicide applications and cost of fungicides applied according to different management programs for control of *Septoria apiicola* at the research farm and at the commercial field in 2004 and 2005

	No. fungicide applications (fungicide cost [$/ha][z])			
	Research farm		Commercial field	
Management program	2004	2005	2004	2005
Early 7-day	11 (383)	10 (355)	12 (426)	10 (355)
Preventive 7-day	8 (284)	7 (241)	9 (312)	7 (241)
Preventive Septoria predictor	8 (284)	7 (241)	7 (241)	7 (241)
Preventive TOM-CAST 10-DSV	5 (170)	8 (284)	6 (213)	8 (284)

[z] Chlorothalonil (1.7 kg a.i./ha) was alternated with azoxystrobin (0.17 kg a.i./ha). The cost of fungicide applied was calculated using estimated costs of chlorothalonil ($28/ha) and azoxystrobin ($43/ha) per application.

DISCUSSION

Combining the use of delayed initial applications with the Septoria predictor or TOM-CAST 10-DSV reduced the number of sprays by two to six while providing disease control that was comparable to the standard weekly fungicide program initiated early. These programs reduced fungicide expenditures by $71 to $213/ha compared to the weekly fungicide program initiated one to two weeks after transplanting. Our results were consistent under high disease pressure where *S. apiicola* inoculum was applied at the research farm and under conditions of naturally-occurring inoculum at the commercial field.

High levels of disease likely failed to develop at the commercial field due to low levels of inoculum. Some Michigan celery growers practice a one-year crop rotation (24) and plant celery seed which is hot-water treated to reduce initial inoculum, but foliar fungicides are often the primary means of disease control (27). The celery planted in the same field and surrounding fields were routinely sprayed with effective fungicides. We relied on natural inoculum to infect plants since it was desirable to evaluate the efficacy of the management programs in a commercial field situation. Differences among management programs may have become evident if the plots were artificially inoculated or if higher levels of inoculum were present in the growing area. Our results from the commercial field indicate that there is probably a lower risk for disease epidemics than growers realize. The use of cultural control measures, including the use of hot-water treated seed and limited crop rotation could account for the low level of inoculum and subsequent low disease risk. It is possible that Michigan celery growers underestimate the effectiveness of their efforts to reduce initial inoculum.

The preventive Septoria predictor required the same number of applications as the preventive 7-day interval during each year at the research farm and in 2005 at the commercial field. Leaf wetness durations of ≥12 hours frequently occur in celery crop canopies during the mid to latter portions of the celery growing season in Michigan. Thus, it was not surprising that the Septoria predictor prompted applications at regular 7- to 10-day intervals and often required the same number of sprays at the preventive 7-day program. Lacy (25) apparently applied the initial spray according to the Septoria predictor the first time that ≥12 hours of leaf wetness occurred after transplanting. This program resulted in a reduction of two sprays per season compared to a weekly spray schedule over a three year period (25), however, it was not clearly stated when initial sprays were applied for either management program. Our results, with regard to the frequent similarity in number of sprays applied according to the preventive 7-day spray schedule and the Septoria predictor, probably differ from those of Lacy (25) since we initiated both spray programs at the same time and Lacy (25) apparently did not.

Warmer temperatures in 2005 increased DSV accumulation, thereby prompting sprays as frequently as every four days according to TOM-CAST 10-DSV. This management program required one more spray at both locations than the weekly management program initiated at the same time, without any significant disease control benefit. Celery growers that exclusively apply chlorothalonil would not be permitted to follow this application program since the fungicide label dictates a minimum reapplication interval of seven days. A further adjustment to the TOM-CAST system should include a 7-day minimum reapplication interval, similar to the requirement for the Septoria predictor. This would allow growers to spray as frequently as every seven days

when the DSV total exceeds 10 and spray according to the TOM-CAST 10-DSV threshold when environmental conditions are less favorable for disease development. The use of a higher DSV threshold, such as TOM-CAST 15-DSV, may be appropriate but was not tested in conjunction with preventive initial applications or evaluated in commercial fields.

Raid and Pernezny (39,40) and Raid et al. (41) tested the TOM-CAST 15-DSV threshold for control of *C. apii* in Florida. This program only required two to four fungicide sprays each season compared with the weekly application schedule which required 11 to 13 applications. Sprays applied according to the TOM-CAST 15-DSV program resulted in significantly less disease control each season and often resulted in lower marketable yields compared to the calendar-based fungicide schedule (39,40,41). In Michigan, the TOM-CAST 15-DSV program required eight sprays and provided comparable control to the weekly application schedule (12 sprays) without compromising control of *S. apiicola* (11). Although the target pathogens differed between locations, the difference in efficacy of TOM-CAST 15-DSV between Florida and Michigan is likely due to the number of applications the predictor required.

With regard to crater rot, our results from the commercial field in 2004 agree with those of Pieczarka (31,32) who delayed initial fungicide applications until six weeks after transplanting and obtained equivalent control compared with applications initiated one week after transplanting. Some Michigan celery growers are especially concerned about crater rot when early-season sprays are not applied. However, most growers are reluctant to use azoxystrobin, a fungicide that is more expensive than chlorothalonil, early in the season. We applied chlorothalonil first in our study since celery growers prefer to apply

this fungicide as the first spray. Our results and those of Pieczarka (31,32) identify effective crater rot management strategies that lack early-season applications and reduce fungicide expenditures.

Our results indicate that Michigan celery growers who applied 10 to 12 applications in 2004 and 2005 probably applied more fungicide than was needed to manage disease. We managed *S. apiicola* under high disease pressure at the research farm with up to 55% fewer applications and managed *C. apii* and *R. solani* with up to 50% fewer applications under natural conditions at the commercial field. Future research could evaluate the use of a less conservative disease predictor, such as TOM-CAST 15-DSV, in an effort to further reduce unnecessary fungicide sprays.

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APPENDIX A.

Summary of Disease Predictor Data and Fungicide Application Dates in 2003-2005

Table A1. Summary of the effects of late blight on disease and yield assessments on 'Dutchess' celery plants not treated or treated every seven days or according to disease predictors with chlorothalonil (1.7 kg a.i./ha) or azoxystrobin (0.17 kg a.i./ha) alternated (alt.) with chlorothalonil for management of *Septoria apiicola* at the MSU Muck Soils Research Farm in 2003

Treatment	No. applications	Leaf blight severity (%)[v]	Petiole blight severity (%)[w]	Total yield (kg)[x]	Disease-free yield (kg)[y]	Yield loss (%)[z]
Untreated control	0	41.3	51.3	12.0	5.4	54.9
7-day						
Chlorothalonil	12	0.8	0.0	13.2	13.2	0.0
Azoxystrobin alt. chlorothalonil	12	0.3	0.0	12.3	12.3	0.0
Septoria predictor						
Chlorothalonil	10	1.0	0.0	11.3	11.3	0.0
Azoxystrobin alt. chlorothalonil	10	0.5	0.0	12.6	12.6	0.0
Cercospora predictor						
Chlorothalonil	7	2.0	0.5	12.3	11.4	6.5
Azoxystrobin alt. chlorothalonil	7	3.0	1.3	12.7	12.5	1.8
TOM-CAST 10-DSV						
Chlorothalonil	8	1.0	0.8	10.6	10.3	2.8
Azoxystrobin alt. chlorothalonil	8	1.0	0.3	12.5	12.3	1.1
TOM-CAST 15-DSV						
Chlorothalonil	5	8.8	8.8	11.7	10.1	13.3
Azoxystrobin alt. chlorothalonil	5	2.0	4.3	12.3	11.6	5.6
TOM-CAST 20-DSV						
Chlorothalonil	4	18.8	22.5	11.9	6.6	43.8
Azoxystrobin alt. chlorothalonil	4	21.3	12.5	11.4	8.6	23.9

[v] Evaluated using a leaf blight assessment key representing the percentage of diseased leaf area on the final rating date (25 August).

[w] Evaluated after 10 plants were trimmed to fresh market specifications as the percentage of petiole surface area with disease symptoms.

[x] Weight of 10 plants after plants were trimmed to fresh market specifications on 26 August.

[y] Weight of 10 plants after plants were trimmed to fresh market specifications and diseased petioles were removed.

[z] Percentage yield loss expressed as the weight of disease petioles removed (total yield minus disease-free yield) divided by the total yield.

Table A2. Summary of the effects of late blight on disease and yield assessments on 'Dutchess' celery plants not treated or treated every seven days or according to disease predictors with chlorothalonil (1.7 kg a.i./ha) or azoxystrobin (0.17 kg a.i./ha) alternated (alt.) with chlorothalonil for management of *Septoria apiicola* at the MSU Muck Soils Research Farm in 2004

Treatment	No. applications	Leaf blight severity (%)[v]	Petiole blight severity (%)[w]	Total yield (kg)[x]	Disease-free yield (kg)[y]	Yield loss (%)[z]
Untreated control	0	35.0	42.5	14.4	4.4	69.1
7-day						
Chlorothalonil	13	0.3	0.0	13.5	13.5	0.0
Azoxystrobin alt. chlorothalonil	13	0.3	0.0	13.9	13.9	0.0
Septoria predictor						
Chlorothalonil	11	0.3	0.0	14.7	14.7	0.0
Azoxystrobin alt. chlorothalonil	11	0.0	0.0	12.7	12.7	0.0
Cercospora predictor						
Chlorothalonil	10	0.3	0.0	14.2	14.2	0.0
Azoxystrobin alt. chlorothalonil	10	0.5	0.0	14.7	14.7	0.0
TOM-CAST 10-DSV						
Chlorothalonil	8	1.0	0.5	13.6	13.4	1.3
Azoxystrobin alt. chlorothalonil	8	0.3	0.3	14.0	14.0	0.2
TOM-CAST 15-DSV						
Chlorothalonil	6	0.5	0.3	13.6	13.6	0.7
Azoxystrobin alt. chlorothalonil	6	0.5	0.3	14.3	14.3	0.2
TOM-CAST 20-DSV						
Chlorothalonil	4	1.0	1.0	13.3	12.8	3.5
Azoxystrobin alt. chlorothalonil	4	1.0	0.5	13.4	13.1	2.2

[v] Evaluated using a leaf blight assessment key representing the percentage of diseased leaf area on the final rating date (23 September).

[w] Evaluated after 10 plants were trimmed to fresh market specifications as the percentage of petiole surface area with disease symptoms.

[x] Weight of 10 plants after plants were trimmed to fresh market specifications on 24 September.

[y] Weight of 10 plants after plants were trimmed to fresh market specifications and diseased petioles were removed.

[z] Percentage yield loss expressed as the weight of disease petioles removed (total yield minus disease-free yield) divided by the total yield.

Table A3. Summary of the effects of late blight on disease and yield assessments on 'Dutchess' celery plants not treated or treated every seven days or according to disease predictors with chlorothalonil (1.7 kg a.i./ha) or azoxystrobin (0.17 kg a.i./ha) alternated (alt.) with chlorothalonil for management of *Septoria apiicola* at the MSU Muck Soils Research Farm in 2005

Treatment	No. applications	Leaf blight severity (%)[v]	Petiole blight severity (%)[w]	Total yield (kg)[x]	Disease-free yield (kg)[y]	Yield loss (%)[z]
Untreated control	0	35.0	38.8	10.2	3.7	63.7
7-day						
Chlorothalonil	11	2.0	0.8	10.8	10.7	1.3
Azoxystrobin alt. chlorothalonil	11	0.8	0.5	10.5	10.4	1.0
Septoria predictor						
Chlorothalonil	10	2.0	1.0	9.8	9.2	6.6
Azoxystrobin alt. chlorothalonil	10	1.0	0.3	10.9	10.8	0.4
Cercospora predictor						
Chlorothalonil	9	0.8	0.3	10.3	10.3	0.2
Azoxystrobin alt. chlorothalonil	9	1.0	0.8	10.7	10.5	2.0
TOM-CAST 10-DSV						
Chlorothalonil	11	0.8	1.0	10.5	10.4	1.0
Azoxystrobin alt. chlorothalonil	11	0.5	0.5	10.3	10.2	0.9
TOM-CAST 15-DSV						
Chlorothalonil	8	3.0	5.5	10.2	8.8	14.2
Azoxystrobin alt. chlorothalonil	8	1.0	1.0	11.4	11.3	3.6
TOM-CAST 20-DSV						
Chlorothalonil	6	3.0	5.8	10.1	9.0	10.4
Azoxystrobin alt. chlorothalonil	6	5.0	10.0	10.8	8.0	25.8

[v] Evaluated using a leaf blight assessment key representing the percentage of diseased leaf area on the final rating date (16 August).

[w] Evaluated after 10 plants were trimmed to fresh market specifications as the percentage of petiole surface area with disease symptoms.

[x] Weight of 10 plants after plants were trimmed to fresh market specifications on 18 August.

[y] Weight of 10 plants after plants were trimmed to fresh market specifications and diseased petioles were removed.

[z] Percentage yield loss expressed as the weight of disease petioles removed (total yield minus disease-free yield) divided by the total yield.

Table A4. Dates of fungicide applications when applied weekly or according to disease predictors to manage *Septoria apiicola* on 'Dutchess' celery at the MSU Muck Soils Research Farm in 2003

Treatment	Application dates												Total no. applications
Untreated control	--	--	--	--	--	--	--	--	--	--	--	--	0
7-day	5 Jun	13 Jun	20 Jun	27 Jun	3 Jul	12 Jul	18 Jul	24 Jul	30 Jul	7 Aug	14 Aug	21 Aug	12
Septoria predictor	5 Jun	15 Jun	23 Jun	2 Jul	14 Jul	21 Jul	29 Jul	7 Aug	14 Aug	21 Aug			10
Cercospora predictor	5 Jun	15 Jun	30 Jun	11 Jul	24 Jul	7 Aug	14 Aug						7
TOM-CAST 10-DSV	5 Jun	19 Jun	3 Jul	8 Jul	18 Jul	3 Aug	11 Aug	20 Aug					8
TOM-CAST 15-DSV	5 Jun	25 Jun	7 Jul	22 Jul	9 Aug								5
TOM-CAST 20-DSV	5 Jun	3 Jul	18 Jul	9 Aug									4

Table A5. Dates of fungicide applications when applied weekly or according to disease predictors to manage *Septoria apiicola* on 'Dutchess' celery at the MSU Muck Soils Research Farm in 2004

Treatment	Application dates													Total no. applications
Untreated control	--	--	--	--	--	--	--	--	--	--	--	--	--	0
7-day	28 Jun	5 Jul	12 Jul	19 Jul	26 Jul	2 Aug	8 Aug	15 Aug	22 Aug	30 Aug	6 Sep	13 Sep	20 Sep	13
Septoria predictor	28 Jun	13 Jul	20 Jul	28 Jul	5 Aug	13 Aug	20 Aug	27 Aug	3 Sep	10 Sep	17 Sep			11
Cercospora predictor	28 Jun	5 Jul	13 Jul	20 Jul	29 Jul	5 Aug	13 Aug	27 Aug	6 Sep	15 Sep				10
TOM-CAST 10-DSV	28 Jun	8 Jul	18 Jul	28 Jul	4 Aug	25 Aug	30 Aug	10 Sep						8
TOM-CAST 15-DSV	28 Jun	12 Jul	26 Jul	8 Aug	27 Aug	10 Sep								6
TOM-CAST 20-DSV	28 Jun	18 Jul	4 Aug	30 Aug										4

Table A6. Dates of fungicide applications when applied weekly or according to disease predictors to manage *Septoria apiicola* on 'Dutchess' celery at the MSU Muck Soils Research Farm in 2005

Treatment	Application dates											Total no. applications
Untreated control	--	--	--	--	--	--	--	--	--	--	--	0
7-day	1 Jun	8 Jun	15 Jun	22 Jun	29 Jun	5 Jul	13 Jul	20 Jul	27 Jul	3 Aug	11 Aug	11
Septoria predictor	1 Jun	8 Jun	16 Jun	27 Jun	5 Jul	12 Jul	19 Jul	28 Jul	7 Aug	15 Aug		10
Cercospora predictor	1 Jun	10 Jun	27 Jun	5 Jul	14 Jul	21 Jul	28 Jul	5 Aug	12 Aug			9
TOM-CAST 10-DSV	1 Jun	8 Jun	14 Jun	27 Jun	7 Jul	14 Jul	18 Jul	22 Jul	1 Aug	8 Aug	12 Aug	11
TOM-CAST 15-DSV	1 Jun	11 Jun	26 Jun	11 Jul	18 Jul	25 Jul	7 Aug	14 Aug				8
TOM-CAST 20-DSV	1 Jun	14 Jun	7 Jul	18 Jul	1 Aug	12 Aug						6

Table A7. Dates of fungicide applications when applied early (2 weeks after transplanting) and reapplied weekly or applied preventively (5 weeks after transplanting) and reapplied weekly or according to disease predictors to manage *Septoria apiicola* on 'Dutchess' celery at the MSU Muck Soils Research Farm in 2004 and 2005

Year Treatment	Application dates											Total no. applications
2004												
Untreated control	--	--	--	--	--	--	--	--	--	--	--	0
Early 7-day	5 Jul	12 Jul	19 Jul	26 Jul	2 Aug	8 Aug	15 Aug	22 Aug	30 Aug	6 Sep	13 Sep	11
Preventive 7-day	26 Jul	2 Aug	8 Aug	15 Aug	22 Aug	30 Aug	6 Sep	13 Sep				8
Preventive Septoria predictor	26 Jul	2 Aug	9 Aug	17 Aug	26 Aug	2 Sep	10 Sep	17 Sep				8
Preventive TOM-CAST 10-DSV	26 Jul	2 Aug	13 Aug	30 Aug	10 Sep							5
2005												
Untreated control	--	--	--	--	--	--	--	--	--	--		0
Early 7-day	8 Jun	15 Jun	22 Jun	29 Jun	6 Jul	13 Jul	20 Jul	27 Jul	3 Aug	11 Aug		10
Preventive 7-day	29 Jun	6 Jul	13 Jul	20 Jul	27 Jul	3 Aug	11 Aug					7
Preventive Septoria predictor	29 Jun	7 Jul	14 Jul	21 Jul	28 Jul	7 Aug	15 Aug					7
Preventive TOM-CAST 10-DSV	29 Jun	8 Jul	14 Jul	18 Jul	22 Jul	1 Aug	8 Aug	12 Aug				8

Table A8. Dates of fungicide applications when applied early (1 week after transplanting) and reapplied weekly or applied preventively (4 weeks after transplanting) and reapplied weekly or according to disease predictors to manage *Septoria apiicola* on 'Dutchess' celery at the commercial field in 2004 and 2005

Year Treatment	Application dates												Total no. applications
2004													
Untreated control	--	--	--	--	--	--	--	--	--	--	--	--	0
Early 7-day	1 Jul	8 Jul	15 Jul	22 Jul	29 Jul	5 Aug	12 Aug	19 Aug	26 Aug	2 Sep	9 Sep	15 Sep	12
Preventive 7-day	22 Jul	29 Jul	5 Aug	12 Aug	19 Aug	26 Aug	2 Sep	9 Sep	15 Sep				9
Preventive Septoria predictor	22 Jul	29 Jul	7 Aug	15 Aug	22 Aug	30 Aug	9 Sep						7
Preventive TOM-CAST 10-DSV	22 Jul	3 Aug	15 Aug	26 Aug	2 Sep	9 Sep							6
2005													
Untreated control	--	--	--	--	--	--	--	--	--	--			0
Early 7-day	23 Jun	1 Jul	7 Jul	14 Jul	22 Jul	29 Jul	5 Aug	13 Aug	19 Aug	26 Aug			10
Preventive 7-day	14 Jul	22 Jul	29 Jul	5 Aug	13 Aug	19 Aug	26 Aug						7
Preventive Septoria predictor	14 Jul	22 Jul	29 Jul	5 Aug	13 Aug	19 Aug	26 Aug						7
Preventive TOM-CAST 10-DSV	14 Jul	19 Jul	24 Jul	1 Aug	9 Aug	13 Aug	19 Aug	26 Aug					8

APPENDIX B.

Summary of Field Experiments Conducted to Evaluate Fungicide Efficacy, Disease Predictors, and/or Delayed Initial Applications for Managing Late Blight, Early Blight, Crater Rot, and/or Bacterial Leaf Spot in Michigan Celery Production in 2003-2005

CELERY (*Apium graveolens* 'Dutchess')
Late blight; *Septoria apiicola*

R.S. Bounds and M.K. Hausbeck
Michigan State University
Department of Plant Pathology
East Lansing, MI 48824

Evaluation of fungicides and biopesticides for managing late blight of celery, 2003.

This study was conducted at the Michigan State University Muck Soils Research Farm in Laingsburg, MI on a Houghton muck field previously planted to potato. Seven-week old celery 'Dutchess' transplants were planted 7 in. apart in rows spaced 32 in. apart on 29 May. Treatment plots consisted of one row 22.5 ft long with 5 ft of unsprayed buffer between plots in the same row. Two buffer rows were left unsprayed between each treatment row. Ten treatments were replicated four times in a randomized complete block design. The field was fertilized with applications of 8-21-29 (400 lb/A on 22 May) plus micronutrients (0.5% Cu, 1% Mn, and 0.5% Zn), 0-0-62 (400 lb/A on 22 May), 46-0-0 (100 lb/A on 23 Jun), Techmangan (4 lb/A on 2 Jul), and calcium nitrate (10 lb/A on 14 Jul). Insects were controlled with applications of Sevin XLR Plus (0.5 qt/A on 2 Jul), Sevin 80S (1.5 lb/A on 14 Jul), Vydate C-LV (4 pt/A on 19 Jul), and Lannate LV (3 pt/A on 9 Aug). Weeds were controlled with applications of Lorox 50DF (2 lb/A on 16 Jun) and Caparol 4L (1 qt/A on 8 Jul); supplemental hand weeding was performed as needed. *Septoria* inoculum (2.9×10^7 spores/fl oz) was prepared by soaking dried infected celery leaves for 10 min in water and straining through two layers of cheesecloth. Unsprayed buffer rows were inoculated 30 Jul, and all rows were inoculated on 8 Aug. Inoculum was applied with a hand-pump backpack sprayer using one hollow cone nozzle that delivered 12 gal/A. Fungicides were applied with a CO_2 backpack sprayer equipped with three XR8003 flat fan nozzles spaced 18 in. apart and calibrated to deliver 50 gal/A at a nozzle pressure of 52 psi. Ten applications were made at weekly intervals on 3, 12, 18, 25 and 30 Jul; 8, 15, 22, and 29 Aug; and 5 Sep. Leaf blight severity was evaluated and ten plants from the middle of each treatment row were hand-harvested and trimmed to fresh market specifications (14 in. length) on 11 Sep. Petiole disease incidence and severity were assessed, diseased petioles were removed from the plants, and yields were recorded. Average minimum and maximum air temperatures (F) were 41.2 and 64.7, 48.2 and 76.4, 54.6 and 81.4, 53.6 and 82.0, and 44.1 and 72.3 for May, Jun, Jul, Aug, and Sep, respectively. Rainfall totals (in.) were 3.8, 1.6, 1.0, 1.4, and 2.1 for the same respective months.

Disease symptoms appeared in inoculated buffer rows on 15 Aug. At harvest, petioles of untreated plants were severely diseased which resulted in extensive trimming and low yield. Applications of Quadris 2.08F alternated with Tilt 3.6EC, Bravo Ultrex 82.5WDG applied alone or applied in alternation with Pristine 38WG or Quadris 2.08F were highly effective in controlling disease and resulted in no disease symptoms on leaves or petioles. Plots treated with Endura 70WG or Bravo Ultrex 82.5WDG alternated with Cabrio 20WG, Serenade 10WP, or Messenger 3WDG resulted in limited amounts of leaf blight (0.3 – 13.0%) and were not significantly different from treatments where disease was absent. Plants treated with 710-145f 0.14% w/v were severely diseased and

similar to the untreated plants for all parameters measured. No phytotoxicity occurred on any of the plants.

Treatment and rate/A (application sequence[z])	Petiole blight		Leaf blight (%)[w]	Trimmed yield (lb)[v]
	Incidence (%)[y]	Severity[x]		
Untreated	100.0 b[u]	5.8 b	47.5 b	13.2 b
Cabrio 20WG 1 lb (1,3,5,7,9) Bravo Ultrex 82.5WDG 1.8 lb (2,4,6,8,10)	0.0 a	1.0 a	0.3 a	30.8 a
Pristine 38WG 0.66 lb (1,3,5,7,9) Bravo Ultrex 82.5WDG 1.8 lb (2,4,6,8,10)	0.0 a	1.0 a	0.0 a	38.4 a
Quadris 2.08F 14.9 fl oz (1,3,5,7,9) Bravo Ultrex 82.5WDG 1.8 lb (2,4,6,8,10)	0.0 a	1.0 a	0.0 a	32.3 a
Quadris 2.08F 14.9 fl oz (1,3,5,7,9) Tilt 3.6EC 4 fl oz (2,4,6,8,10)	0.0 a	1.0 a	0.0 a	35.6 a
Endura 70WG 0.7 lb (1-10)	0.0 a	1.0 a	2.8 a	33.8 a
Bravo Ultrex 82.5WDG 1.8 lb (1-10)	0.0 a	1.0 a	0.0 a	33.1 a
Serenade 10WP 6 lb (1,3,5,7,9) Bravo Ultrex 82.5WDG 1.8 lb (2,4,6,8,10)	0.0 a	1.0 a	1.8 a	33.5 a
Messenger 3WDG 0.6 lb (1,3,5,7,9) Bravo Ultrex 82.5WDG 1.8 lb (2,4,6,8,10)	15.0 a	2.0 a	13.0 a	31.4 a
710-145f 0.14% w/v 5.7 pt (1-10)	100.0 b	6.3 b	48.8 b	9.3 b

[z] Application sequence: 1 = 3 Jul; 2 = 12 Jul; 3 = 18 Jul; 4 = 25 Jul; 5 = 30 Jul; 6 = 8 Aug; 7 = 15 Aug; 8 = 22 Aug; 9 = 29 Aug; 10 = 5 Sep.

[y] Percentage of trimmed plants with one or more petiole lesions. Variable could not be normalized.

[x] Severity of petiole blight evaluated using a 1-10 scale where 1 = no disease to 10 = all petioles severely blighted. Variable could not be normalized.

[w] Evaluated using a leaf blight assessment key representing the percentage of diseased leaf area. Variable could not be normalized.

[v] Ten plants from the center of each plot were hand-harvested, trimmed to 14 in. length, and stripped of diseased petioles prior to weighing.

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

CELERY (*Apium graveolens* 'Dutchess')
Late blight; *Septoria apiicola*

R.S. Bounds and M.K. Hausbeck
Michigan State University
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Evaluation of a biopesticide and fungicides for managing late blight of celery, 2003.

This study was conducted at the Michigan State University Muck Soils Research Farm in Laingsburg, MI on a Houghton muck field previously planted to potato. Seven-week old celery 'Dutchess' transplants were planted 7 in. apart in rows spaced 32 in. apart on 29 May. Treatment plots consisted of one row 22.5 ft long with 5 ft of unsprayed buffer between plots in the same row. Two buffer rows were left unsprayed between each treatment row. Nine treatments were replicated four times in a randomized complete block design. The field was fertilized with applications of 8-21-29 (400 lb/A on 22 May) plus micronutrients (0.5% Cu, 1% Mn, and 0.5% Zn), 0-0-62 (400 lb/A on 22 May), 46-0-0 (100 lb/A on 23 Jun), Techmangan (4 lb/A on 2 Jul), and calcium nitrate (10 lb/A on 14 Jul). Insects were controlled with applications of Sevin XLR Plus (0.5 qt/A on 2 Jul), Sevin 80S (1.5 lb/A on 14 Jul), Vydate C-LV (4 pt/A on 19 Jul), and Lannate LV (3 pt/A on 9 Aug). Weeds were controlled with applications of Lorox 50DF (2 lb/A on 16 Jun) and Caparol 4L (1 qt/A on 8 Jul); supplemental hand weeding was performed as needed. *Septoria* inoculum (2.9×10^7 spores/fl oz) was prepared by soaking dried infected celery leaves for 10 min in water and straining through two layers of cheesecloth. Unsprayed buffer rows were inoculated 30 Jul, and all rows except the untreated uninoculated plots were inoculated on 8 Aug. Inoculum was applied with a hand-pump backpack sprayer using one hollow cone nozzle that delivered 12 gal/A. Fungicides were applied with a CO_2 backpack sprayer equipped with three XR8003 flat fan nozzles spaced 18 in. apart and calibrated to deliver 50 gal/A at a nozzle pressure of 52 psi. Seven applications were made on 18 and 30 Jul; 8, 15, 22, and 29 Aug; and 5 Sep. Leaf blight severity was evaluated and ten plants from the middle of each treatment row were hand-harvested and trimmed to fresh market specifications (14 in. length) on 11 Sep. Petiole disease incidence and severity were assessed, diseased petioles were removed from the plants, and yields were recorded. Average minimum and maximum air temperatures (F) were 41.2 and 64.7, 48.2 and 76.4, 54.6 and 81.4, 53.6 and 82.0, and 44.1 and 72.3 for May, Jun, Jul, Aug, and Sep, respectively. Rainfall totals (in.) were 3.8, 1.6, 1.0, 1.4, and 2.1 for the same respective months.

Disease symptoms appeared in inoculated buffer rows on 15 Aug. Leaf blight severity of the uninoculated untreated plants at harvest was 35%, indicating substantial disease spread. The incidence of petiole blight in both the untreated and 710-145f 0.14% w/v only treatments was 100%. All treatments with Bravo Ultrex 82.5WDG or Quadris 2.08F provided excellent disease control and significantly reduced disease on petioles and leaves and increased marketable yield when compared with the untreated or 710-145f 0.14% w/v only treatments. No phytotoxicity occurred on any of the plants.

Treatment and rate/A (application sequence[z])	Petiole blight		Leaf blight (%)[w]	Trimmed yield (lb)[v]
	Incidence (%)[y]	Severity[x]		
Untreated uninoculated	100.0 b[u]	4.8 b	35.0 b	20.7 b
Untreated inoculated	100.0 b	7.3 c	41.3 c	16.3 b
Bravo Ultrex 82.5WDG 1.8 lb (1-7)	0.0 a	1.0 a	0.0 a	41.6 a
Quadris 2.08F 14.9 fl oz (1-7)	0.0 a	1.0 a	0.0 a	37.3 a
710-145f 0.14% w/v 2.8 pt (1-7)	100.0 b	7.5 c	43.8 c	12.3 b
710-145f 0.14% w/v 5.7 pt (1-7)	100.0 b	7.5 c	43.8 c	14.3 b
Bravo Ultrex 82.5WDG 1.8 lb (1,3,5,7) 710-145f 0.14% w/v 5.7 pt (2,4,6)	0.0 a	1.0 a	3.0 a	36.8 a
Quadris 2.08F 14.9 fl oz (1,3,5,7) 710-145f 0.14% w/v 5.7 pt (2,4,6)	0.0 a	1.0 a	3.0 a	35.4 a
Bravo Ultrex 82.5WDG 1.8 lb (1,4,7) 710-145f 0.14% w/v 5.7 pt (2,5) Quadris 2.08F 14.9 fl oz (3,6)	0.5 a	1.3 a	0.5 a	34.4 a

[z] Application sequence: 1 = 18 Jul; 2 = 30 Jul; 3 = 8 Aug; 4 = 15 Aug; 5 = 22 Aug; 6 = 29 Aug; 7 = 5 Sep.

[y] Percentage of trimmed plants with one or more petiole lesions. Variable could not be normalized.

[x] Severity of petiole blight evaluated using a 1-10 scale where 1 = no disease to 10 = all petioles severely blighted.

[w] Evaluated using a leaf blight assessment key representing the percentage of diseased leaf area.

[v] Ten plants from the center of each plot were hand-harvested, trimmed to 14 in. length, and stripped of diseased petioles prior to weighing.

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

CELERY (*Apium graveolens* 'Sabroso')
Early blight; *Cercospora apii*

R.S. Bounds and M.K. Hausbeck
Michigan State University
Department of Plant Pathology
East Lansing, MI 48824

Evaluation of fungicides for managing early blight of celery and impact on yield, 2003.

This study was conducted at cooperator's farm in Kent County, MI on a Houghton muck field previously planted to onion. Seven-week old celery 'Sabroso' transplants were planted 6.75 in. apart in rows staggered 32-28-32 in. apart on 17 Jun. Treatment plots were 20 ft long with 5 ft of unsprayed buffer between plots in the same row and consisted of two rows spaced 28 in. apart. Two buffer rows were left unsprayed between each treatment plot. Eight treatments were replicated four times in a randomized complete block design. Weeds, insects, and fertilization were managed according to standard production practices. The field was irrigated with drip irrigation tape placed 3 in. beneath the soil surface between rows spaced 28 in. apart. Fungicides were applied with a CO_2 backpack sprayer equipped with three XR8003 flat fan nozzles spaced 18 in. apart and calibrated to deliver 50 gal/A at a nozzle pressure of 52 psi. Eight applications were made at weekly intervals on 23 and 29 Jul; 6, 12, 20, and 27 Aug; and 4 and 10 Sep. Leaf blight severity was evaluated weekly from 12 Aug to 15 Sep. Petiole blight was assessed and yields were recorded on 15 Sep. Average minimum and maximum air temperatures (F) were 52.2 and 77.3, 58.2 and 81.3, 59.9 and 83.6, and 49.9 and 72.6 for Jun, Jul, Aug, and Sep, respectively. Rainfall totals (in.) were 0.9, 2.7, 1.9, and 2.5 for the same respective months.

Disease symptoms appeared in several localized areas throughout the field on 12 Aug. Leaf blight severity on untreated plants was moderate (26.3%) at the time of harvest, while all fungicide treatments limited leaf blight to $\leq$ 2.0%. All fungicide treatments significantly reduced disease and yield loss when compared to the untreated. Treatments of Bravo Ultrex 82.5WDG applied alone or in alternation with Quadris 2.08F (15.4 fl oz/A) were highly effective in controlling early blight and resulted in no petiole blight or yield reduction. The three-way alternation program of Quadris 2.08F (9.2 fl oz/A), Bravo Ultrex 82.5WDG, and Tilt 3.6EC was the least effective of the fungicide treatments in limiting petiole blight and reducing yield loss; however, it did not differ when compared to treatments that prevented petiole disease. The treatments did not have a significant effect on total yield, indicating the fungicides did not adversely affect plant growth. No phytotoxicity occurred on any of the plants.

Treatment and rate/A (application sequence)[z]	Leaf blight[y]		Petiole blight (%)		Yield	
	AUDPC[x]	At harvest (%)	Incidence[w]	Severity[v]	Total (lb)[u]	Loss (%)[t]
Untreated	391.0 b[s]	26.3 b	77.5 b	11.8 b	21.7	18.7 b
Bravo Ultrex 82.5WDG 1.8 lb (1-8)	18.8 a	1.0 a	0.0 a	0.0 a	21.1	0.0 a
Quadris 2.08F 9.2 fl oz (1,3,5,7) Bravo Ultrex 82.5WDG 1.8 lb (2,4,6,8)	22.5 a	1.0 a	5.0 a	0.3 a	21.5	0.2 a
Quadris 2.08F 15.4 fl oz (1,3,5,7) Bravo Ultrex 82.5WDG 1.8 lb (2,4,6,8)	30.5 a	2.0 a	0.0 a	0.0 a	19.9	0.0 a
Quadris 2.08F 9.2 fl oz (1,4,7) Bravo Ultrex 82.5WDG 1.8 lb (2,5,8) Tilt 3.6EC 4 fl oz (3,6)	47.9 a	2.0 a	25.0 a	1.0 a	21.8	1.9 a
Quadris 2.08F 15.4 fl oz (1,4,7) Bravo Ultrex 82.5WDG 1.8 lb (2,5,8) Tilt 3.6EC 4 fl oz (3,6)	30.5 a	2.0 a	7.5 a	0.6 a	22.0	0.7 a
Bravo Ultrex 82.5WDG 1.8 lb (1-3,7) Quadris 2.08F 9.2 fl oz (4-6,8)	20.6 a	1.0 a	15.0 a	0.3 a	20.7	0.7 a
Bravo Ultrex 82.5WDG 1.8 lb (1-3,7) Quadris 2.08F 15.4 fl oz (4-6,8)	33.9 a	2.0 a	7.5 a	0.6 a	22.0	0.5 a

[z] Kocide 2000 53.8DF 1.5 lb/A was added to each fungicide treatment to limit bacterial blight. Application sequence: 1 = 23 Jul; 2 = 29 Jul; 3 = 6 Aug; 4 = 12 Aug; 5 = 20 Aug; 6 = 27 Aug; 7 = 4 Sep; 8 = 10 Sep.

[y] Evaluated using a leaf blight assessment key representing the percentage of diseased foliage. Variables could not be normalized.

[x] Area under the disease progress curve.

[w] Percentage of trimmed plants with one or more petiole lesions.

[v] Severity of petiole blight assessed as the percentage of petiole area with disease symptoms. Data were transformed using square root (Y) to stabilize the variance. The table shows back-transformed data.

[u] Ten plants from the center of one row per plot were hand-harvested, trimmed to 14 in. length, and weighed on 15 Sep.

[t] Harvested plants were stripped of disease petioles and re-weighed. Yield loss was calculated as a percentage of stripped weight divided by the total yield. Data were transformed using square root (Y) to stabilize the variance. The table shows back-transformed data.

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

CELERY (*Apium graveolens* 'Dutchess')
Crater rot; *Rhizoctonia solani*

R.S. Bounds and M.K. Hausbeck
Michigan State University
Department of Plant Pathology
East Lansing, MI 48824

Evaluation of fungicides for managing crater rot of celery, 2003.

This study was conducted at cooperator's farm in Allegan County, MI on a Houghton muck field previously planted to celery. Seven-week old celery 'Dutchess' transplants were planted 8 in. apart in rows staggered 26-14-26 in. apart on 15 May. Treatment plots were 20 ft long with 5 ft of unsprayed buffer between plots in the same row and consisted of two rows spaced 14 in apart. Two buffer rows were left unsprayed between each treatment plot. Six treatments were replicated four times in a randomized complete block design. Weeds, insects, and fertilization were managed according to standard production practices. The field was irrigated with a high-volume hard hose traveling irrigation unit that generated extensive soil splashing onto petioles. Fungicides were applied with a CO_2 backpack sprayer equipped with three XR8003 flat fan nozzles spaced 19 in. apart and calibrated to deliver 50 gal/A at a nozzle pressure of 52 psi. Nine applications were made at weekly intervals on 3, 11, 18, and 25 Jun; 2, 9, 16, 23, and 29 Jul. A directed spray pattern with three XR8002 nozzles was used for the last four applications by replacing the outer nozzles with 6 in. drop nozzles directed at 45-degree angles inward. The incidence of crater rot was assessed and yields were recorded on 6 Aug. Average minimum and maximum air temperatures (F) were 45.0 and 66.3, 52.2 and 77.3, 58.2 and 81.3, and 59.9 and 83.6 for May, Jun, Jul, and Aug, respectively. Rainfall totals (in.) were 4.5, 0.9, 2.7, and 1.9 for the same respective months.

Disease pressure was moderately low when compared to previous seasons with warmer and more humid weather during Jul. Crater rot symptoms were observed only during harvest and not during random destructive sampling of plants in untreated buffer rows in the latter part of the season. Over 45% of untreated plants had petiole lesions while all fungicide treatments limited disease to $\leq$ 22.1%. Only the alternation of Quadris 2.08F and Bravo Ultrex 82.5WDG significantly limited the incidence of crater rot when compared to the untreated. Total yield and marketable yield were not affected by treatments. Yield loss from plants treated with Bravo Ultrex 82.5WDG alone or Tilt 3.6EC alternated with Bravo Ultrex 82.5WDG did not differ from the untreated. Applications of Quadris 2.08F, Topsin M 70WP, or Scholar 50WP alternated with Bravo Ultrex 82.5WDG were effective in limiting yield loss when compared to the untreated. No phytotoxicity occurred on any of the plants.

Treatment and rate/A (application sequence)[z]	Crater rot incidence[y]	Yield		
		Total (lb)[x]	Marketable (lb)[w]	Loss (%)[v]
Untreated	46.3 b[u]	44.6	41.6	6.7 c
Bravo Ultrex 82.5WDG 1.8 lb (1-9)	17.9 ab	48.7	47.0	2.7 bc
Quadris 2.08F 9.2 fl oz (1,3,5,7,9) Bravo Ultrex 82.5WDG 1.8 lb (2,4,6,8)	1.0 a	50.4	50.3	0.1 a
Tilt 3.6EC 4 fl oz (1,3,5,7,9) Bravo Ultrex 82.5WDG 1.8 lb (2,4,6,8)	22.1 ab	49.2	47.9	2.3 bc
Topsin M 70WP 0.5 lb (1,3,5,7,9) Bravo Ultrex 82.5WDG 1.8 lb (2,4,6,8)	19.6 ab	46.8	45.9	1.7 ab
Scholar 50WP 0.44 lb (1,3,5,7,9) Bravo Ultrex 82.5WDG 1.8 lb (2,4,6,8)	16.1 ab	46.2	45.3	1.8 ab

[z] Kocide 2000 53.8DF 1.5 lb/A was added to each fungicide treatment to limit bacterial blight. Application sequence: 1 = 3 Jun; 2 = 11 Jun; 3 = 18 Jun; 4 = 25 Jun; 5 = 2 Jul; 6 = 9 Jul; 7 = 16 Jul; 8 = 23 Jul; 9 = 29 Jul.

[y] Crater rot incidence was assessed by counting the number of plants with one or more petiole lesions out of the total number of consecutive plants from 15 ft. of one row.

[x] Plants from 15 ft. of one row were hand-harvested, trimmed to 14 in. length, and weighed.

[w] Harvested plants were stripped of disease petioles and weighed again.

[v] Yield loss was calculated as a percentage of stripped weight divided by the total yield. Data were transformed using log (Y+1) to stabilize the variance. The table shows back-transformed data.

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

CELERY (*Apium graveolens* var. *dulce* 'Dutchess')
Late blight; *Septoria apiicola*

R.S. Bounds and M.K. Hausbeck
Michigan State University
Department of Plant Pathology
East Lansing, MI 48824

Evaluation of two spray initiation timings, two application intervals, and seven fungicide programs for managing late blight of celery, 2003.

This study was conducted at the Michigan State University Muck Soils Research Farm in Laingsburg, MI on a Houghton muck field previously planted to potato. Seven-week old celery 'Dutchess' transplants were planted 7 in. apart in rows spaced 32 in. apart on 28 May. Treatment plots consisted of one row 20 ft long with 5 ft of unsprayed buffer between plots in the same row. Two buffer rows were left unsprayed between each treatment row. Twenty-nine treatments were replicated four times in a randomized complete block design. *Septoria* inoculum (2.9×10^7 spores/fl oz) was prepared by soaking dried infected celery leaves for 10 min in water and straining through two layers of cheesecloth. Unsprayed buffer rows were inoculated on 16 Jul. Inoculum was applied with a hand-pump backpack sprayer using one hollow cone nozzle that delivered approximately 12 gal/A. The initial fungicide application was applied either (i) one week after transplanting on 5 Jun (preventive)or (ii) when disease symptoms were observed in uninoculated treatment rows on 22 Jul (disease detection). Fungicides were reapplied either (i) weekly or (ii) according to the TOM-CAST disease forecaster using a threshold of 15 disease severity values (DSV). Seven fungicide programs tested: (i) Kocide 2000 53.8DF; (ii) Bravo Ultrex 82.5WDG; (iii) Quadris 2.08F; (iv) Bravo Ultrex 82.5WDG alternated with Kocide 2000 53.8DF; (v) Quadris 2.08F alternated with Kocide 2000 53.8DF; (vi) Quadris 2.08F alternated with Bravo Ultrex 82.5WDG; and (vii) Quadris 2.08F alternated with Kocide 2000 53.8DF alternated with Bravo Ultrex 82.5WDG. Fungicides were applied with a CO_2 backpack sprayer equipped with three XR8003 flat fan nozzles spaced 18 in. apart and calibrated to deliver 50 gal/A at a boom pressure of 52 psi. Ten plants from each treatment row were hand-harvested, trimmed to 14 in. length, and weighed on 26 Aug. Trimmed plants were evaluated for disease, stripped of diseased petioles, and weighed again.

Disease symptoms appeared on inoculated plants in untreated buffer rows and on a few uninoculated plants in treatment rows which were not previously treated on 22 Jul. The infection of uninoculated plants was not the result of the manual inoculation, but rather from natural infection of transplants. Since disease symptoms did not develop uniformly in uninoculated treatment rows, this factor likely confounded the experiment. Due to significant three-way interactions among the factors (initiation timing, application interval, and fungicide program), the data were analyzed for differences between the combined effects of application interval and initiation timing within each fungicide program. All fungicide programs, except Kocide 2000 53.8DF applied alone, were effective in limiting disease and yield loss to low levels when applied one week after transplanting and reapplied every seven days. The preventive 7-day interval was often significantly more effective in limiting disease and yield loss than the TOM-CAST intervals initiated either preventively or at disease detection. The Quadris 2.08F

alternated with Bravo Ultrex and Bravo Ultrex applied alone fungicide programs often provided the highest level of control. No phytotoxicity occurred on any of the plants.

Treatment and rate/A Application interval / initiation timing[z]	No. of sprays	Disease severity (%) Leaves[y]	 Petioles[x]	Yield loss (%)[w]
Untreated control	0	27.5	23.8	39.5
Kocide 2000 53.8DF 1.5 lb				
7-day / preventive	12	19.3 a[v]	14.8 a	31.6 a
7-day / disease detection	5	23.4 a	21.5 a	33.0 a
TOM-CAST 15 DSV / preventive	5	33.4 a	24.2 a	36.9 a
TOM-CAST 15 DSV / disease detection	2	25.1 a	20.0 a	35.0 a
Bravo Ultrex 82.5WDG 1.8 lb				
7-day / preventive	12	0.0 a	0.0 a	0.0 a
7-day / disease detection	5	1.0 ab	0.0 a	0.0 a
TOM-CAST 15 DSV / preventive	5	2.6 b	3.0 b	8.9 a
TOM-CAST 15 DSV / disease detection	2	5.1 b	3.4 b	11.9 a
Quadris 2.08F 9.2 fl oz				
7-day / preventive	12	0.1 a	0.0 a	0.0 a
7-day / disease detection	5	1.7 ab	0.6 a	2.6 a
TOM-CAST 15 DSV / preventive	5	5.0 bc	0.7 a	1.8 a
TOM-CAST 15 DSV / disease detection	2	13.4 c	9.3 b	18.0 b
Bravo Ultrex 82.5WDG 1.8 lb alt. Kocide 2000 53.8DF 1.5 lb				
7-day / preventive	12	0.3 a	0.1 a	0.3 a
7-day / disease detection	5	5.5 b	3.7 b	13.1 b
TOM-CAST 15 DSV / preventive	5	13.0 b	15.8 c	25.7 c
TOM-CAST 15 DSV / disease detection	2	4.7 b	1.7 ab	12.3 ab
Quadris 2.08F 9.2 fl oz alt. Kocide 2000 53.8DF 1.5 lb				
7-day / preventive	12	0.6 a	0.1 a	0.5 a
7-day / disease detection	5	2.6 ab	3.2 ab	13.7 b
TOM-CAST 15 DSV / preventive	5	8.3 bc	5.7 b	16.2 b
TOM-CAST 15 DSV / disease detection	2	14.6 c	8.3 b	21.7 b
Quadris 2.08F 9.2 fl oz alt. Bravo Ultrex 82.5WDG 1.8 lb				
7-day / preventive	12	0.1 a	0.1 a	0.1 a
7-day / disease detection	5	0.3 a	0.0 a	0.0 a
TOM-CAST 15 DSV / preventive	5	1.0 a	0.6 a	4.8 a
TOM-CAST 15 DSV / disease detection	2	10.8 b	7.3 b	10.2 a
Quadris 2.08F 9.2 fl oz alt. Kocide 2000 53.8DF 1.5 lb alt. Bravo Ultrex 82.5WDG 1.8 lb				
7-day / preventive	12	0.0 a	0.0 a	0.0 a
7-day / disease detection	5	2.4 b	1.1 ab	7.5 a
TOM-CAST 15 DSV / preventive	5	8.3 bc	7.7 c	9.4 a
TOM-CAST 15 DSV / disease detection	2	11.8 c	2.6 bc	10.7 a

[z] Preventive sprays were initially applied one week after transplanting; disease detection sprays were applied when disease symptoms were observed in treatment rows.

[y] Percentage of petiole area with disease symptoms. Data were transformed using square root (Y) to stabilize the variance. The table shows back-transformed data.

[x] Evaluated using a leaf blight assessment key representing the percentage of diseased leaf area. Data were transformed using square root (Y) to stabilize the variance. The table shows back-transformed data.

[w] Harvested plants were stripped of disease petioles and weighed again. Yield loss was calculated as a percentage of stripped weight divided by the total yield.

[v] Means within each fungicide program in a column followed by the same letter are not significantly different according to Tukey's Studentized Range Test (P=0.05).

CELERY (*Apium graveolens* L. var. *dulce* 'Dutchess')
Late blight; *Septoria apiicola*

R.S. Bounds and M.K. Hausbeck
Michigan State University
Department of Plant Pathology
East Lansing, MI 48824

Evaluation of fungicides for managing late blight of celery, 2004.

This study was conducted at the Michigan State University Muck Soils Research Farm in Laingsburg, MI on a Houghton muck field previously planted to potato. Eight-week old celery 'Dutchess' transplants were planted 7 in. apart in rows spaced 32 in. apart on 21 Jun. Treatment plots consisted of one row 20 ft long with 5 ft of unsprayed buffer between plots in the same row. Two buffer rows were left unsprayed between each treatment row. Eleven treatments were replicated four times in a randomized complete block design. *Septoria* inoculum (2.9×10^7 spores/fl oz) was prepared by soaking dried infected celery leaves for 10 min in water and straining through two layers of cheesecloth. Inoculum was applied with a hand-pump backpack sprayer to all plants in the trial on 30 Jul using one hollow cone nozzle that delivered 12 gal/A. Fungicides were applied with a CO_2 backpack sprayer equipped with three XR8003 flat fan nozzles spaced 18 in. apart and calibrated to deliver 50 gal/A at a nozzle pressure of 52 psi. Nine applications were made at weekly intervals on 19 and 26 Jul; 2, 9, 17, 23, and 30 Aug; and 6 and 14 Sep. Leaf blight severity was evaluated on 8 and 20 Sep, and ten plants from the middle of each treatment row were hand-harvested and trimmed to fresh market specifications (14 in. length) on 21 Sep. Petiole disease incidence and severity were assessed, diseased petioles were removed from the plants, and yields were recorded. Data were analyzed using the general linear models procedure in SAS, and differences among treatments were examined using the Waller-Duncan Bayesian k-ratio t-test. Average monthly minimum and maximum air temperatures (°F) were: Jun (52.0 and 74.8); Jul (55.9 and 79.1); Aug (52.3 and 75.7); and Sep (46.9 and 77.4). Rainfall totals (in.) were 4.2, 3.7, 1.8, and 0.9 for the same respective months.

Disease symptoms appeared throughout the plot on 11 Aug. Untreated plants were severely diseased on leaves (50%) and petioles (71%) at harvest which resulted in extensive trimming and low yield. Three fungicide programs provided season-long disease prevention on leaves and petioles and included Endorse 2.5WP alternated with Bravo Ultrex 82.5WDG, Amistar 80WG alternated with Tilt 3.6EC, and Amistar 80WG alternated with Bravo Ultrex 82.5WDG. Applications of Pristine 38WG alternated with Bravo Ultrex 82.5WDG or Bravo Ultrex 82.5WDG (1.8 lb/A) applied alone were also effective programs. Applications of Endura 70WG resulted in a lower trimmed yield than programs that prevented disease. Mixing EXP 1 with a reduced rate of Bravo Ultrex 82.5 (0.6 lb/A) provided no disease control benefit when compared to the reduced rate Bravo Ultrex 82.5WDG (0.6 lb/A) treatment. Disease control and yield of the Serenade Max 20WP alternated with Bravo Ultrex 82.5WDG treatment and the reduced rate Bravo Ultrex 82.5WDG (0.6 lb/A) treatment did not differ. Applications of Switch 62.5WG were ineffective and resulted in a low yield similar to the untreated control. No phytotoxicity was observed.

Treatment and rate/A (application sequence[z])	Leaf blight (%)[y]		Petiole blight		Trimmed yield (lb)[v]
	8 Sep	20 Sep	Incidence (%)[x]	Severity[w]	
Untreated control	39.9 d[u]	50.0 e	100.0 e	71.3 d	2.7 d
Endura 70WG 4.6 oz (1-10)	1.0 b	6.3 c	72.5 d	7.8 b	23.1 c
Pristine 38WG 10.5 oz (1,3,5,7,9) Bravo Ultrex 82.5WDG 1.8 lb (2,4,6,8,10)	0.0 a	0.0 a	2.5 ab	0.3 a	29.8 a
Endorse 2.5WP 2.2 lb (1,3,5,7,9) Bravo Ultrex 82.5WDG 1.8 lb (2,4,6,8,10)	0.0 a	0.0 a	0.0 a	0.0 a	28.5 ab
Amistar 80WG 5 oz (1,3,5,7,9) Tilt 3.6EC 4 fl oz (2,4,6,8,10)	0.0 a	0.0 a	0.0 a	0.0 a	28.0 ab
Amistar 80WG 5 oz (1,3,5,7,9) Bravo Ultrex 82.5WDG 1.8 lb (2,4,6,8,10)	0.0 a	0.0 a	0.0 a	0.0 a	28.4 ab
Switch 62.5WG 11 oz (1-10)	32.5 c	46.3 d	100.0 e	55.0 c	6.6 d
EXP 1 12.8 fl oz + Bravo Ultrex 82.5WDG 0.6 lb (1-10)	1.0 b	3.0 b	42.5 c	3.3 a	25.0 bc
Bravo Ultrex 82.5WDG 0.6 lb (1-10)	0.6 b	3.0 b	25.0 bc	1.8 a	27.5 ab
Bravo Ultrex 82.5WDG 1.8 lb (1-10)	0.1 a	0.3 a	0.0 a	0.0 a	28.8 ab
Serenade Max 20WP 2 lb (1,3,5,7,9) Bravo Ultrex 82.5WDG 1.8 lb (2,4,6,8,10)	0.6 b	3.0 b	10.0 ab	2.5 a	27.8 ab

[z] Application sequence: 1 = 19 Jul; 2 = 26 Jul; 3 = 2 Aug; 4 = 9 Aug; 5 = 17 Aug; 6 = 23 Aug; 7 = 30 Aug; 8 = 6 Sep; 9 = 14 Sep.

[y] Evaluated using a leaf blight assessment key representing the percentage of diseased leaf area. Data from 8 Sep were transformed using square root (Y) to stabilize the variance; the table shows back-transformed data. Data from 20 Sep could not be normalized.

[x] Percentage of trimmed plants with one or more petiole lesions. Variable could not be normalized.

[w] Percentage of petiole area with disease symptoms.

[v] Ten plants from the center of each plot were hand-harvested, trimmed to 14 in. length, and stripped of diseased petioles prior to weighing.

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

CELERY (*Apium graveolens* var. *dulce* 'Dutchess')
Late blight; *Septoria apiicola*

R.S. Bounds and M.K. Hausbeck
Michigan State University
Dept. of Plant Pathology
East Lansing, MI 48824

Evaluation of fungicide programs and disease predictors for managing late blight of celery, 2004.

This study was conducted at the Michigan State University Muck Soils Research Farm in Laingsburg, MI on a Houghton muck field previously planted to potato. Seven-week old celery transplants were planted 7 in. apart in rows spaced 32 in. apart on 21 Jun. Each plot consisted of a 20 ft-long row with 5 ft of unsprayed row between adjacent plots in the same row. Two unsprayed buffer rows separated adjacent treatment rows. Treatments were replicated four times in a randomized complete block design. Weeds, insects, and fertilization were managed according to standard production practices. *Septoria apiicola* inoculum (2.9×10^7 spores/fl oz) was prepared by soaking dried infected celery leaves for 10 min in water and straining the spore suspension through two layers of cheesecloth. Inoculum was applied to the buffer rows on 30 Jul and 11 Aug using a hand-pump backpack sprayer with one hollow cone nozzle that delivered approximately 12 gal/A. Fungicides were applied with a CO_2 backpack boom sprayer equipped with three XR8003 flat fan nozzles spaced 18 in. apart and calibrated to deliver 50 gal/A at a boom pressure of 52 psi. Fungicides were initially applied one week after transplanting and were reapplied every seven days or according to the Septoria or TOM-CAST 10 DSV disease predictors. The 7-day interval required 12 applications, the Septoria predictor required 11 applications, and the TOM-CAST 10-DSV predictor required 8 applications. Ten plants from the middle of each plot were hand-harvested, trimmed to fresh market specifications (14 in. length), and weighed on 22 Sep. Trimmed plants were evaluated for late blight, stripped of diseased petioles, and weighed again. Data were analyzed using the general linear models procedure in SAS. Average monthly minimum and maximum air temperatures (°F) were 52.0 and 74.8 in Jun, 55.9 and 79.1 in Jul, 52.3 and 75.7 in Aug, and 46.9 and 77.4 in Sep. Rainfall totaled 4.2, 3.7, 1.8, and 0.9 in. for the same respective months.

Disease symptoms were detected in inoculated buffer rows on 15 Aug and were observed on all uninoculated untreated plants by 2 Sep. At harvest, all untreated plants were severely diseased, with 70% yield loss recorded when diseased petioles were removed. Nominal amounts of leaf blight (0.3 to 1.0%) were observed for 10 of the 15 fungicide spray programs. All fungicide programs, regardless of application interval, were equally effective in preventing petiole blight and significantly reduced leaf blight severity compared to the untreated control plants. Likewise, all application intervals were equally effective against late blight. However, the Septoria and TOM-CAST 10-DSV predictors required 1 and 4 fewer applications, respectively, relative to the weekly schedule. This study identified effective fungicide spray programs that can be used in conjunction with the Septoria and TOM-CAST 10-DSV predictors while reducing the number of applications needed to achieve equivalent disease control. Symptoms of phytotoxicity were not observed.

Treatment and rate/A (application sequence[z]) Application interval	No. of sprays	Petiole blight (%)[y] Incidence	Petiole blight (%)[y] Severity	Leaf blight (%)[x]	Yield loss (%)[w]
Untreated control	0	100.0 b[v]	42.5 b	38.8 b	70.0 b
Bravo Ultrex 82.5WDG 1.8 lb (1-12)					
7-day	12	0.0 a	0.0 a	0.0 a	0.0 a
Septoria predictor	11	0.0 a	0.0 a	0.0 a	0.0 a
TOM-CAST 10-DSV	8	0.0 a	0.0 a	0.5 a	0.0 a
Bravo Ultrex 82.5WDG 1.8 lb (1,2,4,5,7,8,10,11) Tilt 3.6EC 4 fl oz (3,6,9,12)					
7-day	12	0.0 a	0.0 a	0.0 a	0.0 a
Septoria predictor	11	0.0 a	0.0 a	0.3 a	0.0 a
TOM-CAST 10-DSV	8	0.0 a	0.0 a	0.3 a	0.0 a
Bravo Ultrex 82.5WDG 1.8 lb (1,2,4,5,7,8,10,11) Amistar 80WG 3 oz (3,6,9,12)					
7-day	12	0.0 a	0.0 a	0.3 a	0.0 a
Septoria predictor	11	0.0 a	0.0 a	0.0 a	0.0 a
TOM-CAST 10-DSV	8	0.0 a	0.0 a	0.3 a	0.0 a
Bravo Ultrex 82.5WDG 1.8 lb (1,3,5,7,9,11) Amistar 80WG 3 oz (2,6,10) Tilt 3.6EC 4 fl oz (4,8,12)					
7-day	12	0.0 a	0.0 a	0.3 a	0.0 a
Septoria predictor	11	0.0 a	0.0 a	0.3 a	0.0 a
TOM-CAST 10-DSV	8	0.0 a	0.0 a	1.0 a	0.0 a
Bravo Ultrex 82.5WDG 1.8 lb (1,4,7,10) Amistar 80WG 3 oz (2,5,8,11) Tilt 3.6EC 4 fl oz (3,6,9,12)					
7-day	12	0.0 a	0.0 a	0.0 a	0.0 a
Septoria predictor	11	0.0 a	0.0 a	0.5 a	0.0 a
TOM-CAST 10-DSV	8	0.0 a	0.0 a	0.3 a	0.0 a

[z] Application sequence indicates the order in which fungicides were applied. For the 7-day interval, fungicides were applied on: 1 = 28 Jun; 2 = 5 Jul; 3 = 12 Jul; 4 = 19 Jul; 5 = 26 Jul; 6 = 2 Aug; 7 = 8 Aug; 8 = 15 Aug; 9 = 22 Aug; 10 = 30 Aug; 11 = 6 Sep; 12 = 13 Sep. For the Septoria predictor, fungicides were applied on: 1 = 28 Jun; 2 = 13 Jul; 3 = 20 Jul; 4 = 28 Jul; 5 = 5 Aug; 6 = 13 Aug; 7 = 20 Aug; 8 = 27 Aug; 9 = 3 Sep; 10 = 10 Sep; 11 = 17 Sep. For the TOM-CAST 10-DSV predictor, fungicides were applied on: 1 = 28 Jun; 2 = 8 Jul; 3 = 18 Jul; 4 = 28 Jul; 5 = 4 Aug; 6 = 25 Aug; 7 = 30 Aug; 8 = 10 Sep.

[y] Incidence = % of trimmed plants with one or more petiole lesions; severity = % of petiole surface area with symptoms.

[x] Evaluated prior to harvest using a leaf blight assessment key of the % of diseased leaf area on 22 Sep.

[w] Yield loss was calculated as the % of total yield lost due to late blight.

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

CELERY (*Apium graveolens* var. *dulce* 'Dutchess')
Late blight; *Septoria apiicola*

R.S. Bounds and M.K. Hausbeck
Michigan State University
Dept. of Plant Pathology
East Lansing, MI 48824

Evaluation of fungicide initiation timing for managing late blight of celery, 2004.

This study was conducted at the Michigan State University Muck Soils Research Farm in Laingsburg, MI on a Houghton muck field previously planted to potato. Seven-week old celery transplants were planted 7 in. apart in rows spaced 32 in. apart on 21 Jun. Each plot consisted of a 20 ft-long row with 5 ft of unsprayed row between adjacent plots in the same row. Two unsprayed buffer rows separated adjacent treatment rows. Treatments were replicated four times in a randomized complete block design. Weeds, insects, and fertilization were managed according to standard production practices. *Septoria apiicola* inoculum (2.9×10^7 spores/fl oz) was prepared by soaking dried infected celery leaves for 10 min in water and straining the spore suspension through two layers of cheesecloth. Inoculum was applied to all plants in the trial on 30 Jul and 11 Aug with a hand-pump backpack sprayer using one hollow cone nozzle that delivered approximately 12 gal/A. Fungicides were applied with a CO_2 backpack boom sprayer equipped with three XR8003 flat fan nozzles spaced 18 in. apart and calibrated to deliver 50 gal/A at a boom pressure of 52 psi. Fungicide spray programs were initiated two (early) or five (preventive) weeks after transplanting. Ten applications were made at weekly intervals for the early fungicide program which commenced on 5 Jul. Seven applications were made at weekly intervals for the preventive fungicide program which commenced on 26 Jul. Ten plants from the middle of each treatment row were hand-harvested, trimmed to fresh market specifications (14 in. length), and weighed on 21 Sep. Trimmed plants were evaluated for late blight, stripped of diseased petioles, and weighed again. Data were analyzed using the general linear models procedure in SAS. Average monthly minimum and maximum air temperatures (°F) were 52.0 and 74.8 in Jun, 55.9 and 79.1 in Jul, 52.3 and 75.7 in Aug, and 46.9 and 77.4 in Sep. Rainfall totaled 4.2, 3.7, 1.8, and 0.9 in. for the same respective months.

Late blight lesions were first detected on 15 Aug, and disease progressed rapidly until harvest. Leaving plants untreated resulted in a significant yield loss of 80%. The early and preventive fungicide programs were equally effective at preventing petiole blight and yield loss. Three fewer fungicide applications were made by initiating the first application five weeks after transplanting compared with the early program initiated two weeks after transplanting. The preventive fungicide program reduced fungicide costs by approximately $40/A compared to the early fungicide program. Symptoms of phytotoxicity were not observed.

Treatment and rate/A (application sequence[z])	Initial application	Petiole blight (%)[y]		Leaf blight (%)[x]	Yield loss (%)[w]
		Incidence	Severity		
Untreated control	--	100.0 b[v]	70.0 b	48.4 b	80.8 b
Bravo Ultrex 82.5WDG 1.8 lb (1,3,5,7,9) Amistar 80WG 3 oz (2,6,10) Tilt 3.6EC 4 fl oz (4,8)	early	0.0 a	0.0 a	0.5 a	0.0 a
Bravo Ultrex 82.5WDG 1.8 lb (4,6,8,10) Amistar 80WG 3 oz (5,9) Tilt 3.6EC 4 fl oz (7)	preventive	0.0 a	0.0 a	0.3 a	0.0 a

[z] Application sequence: 1 = 5 Jul; 2 = 12 Jul; 3 = 19 Jul; 4 = 26 Jul; 5 = 8 Aug; 6 = 15 Aug; 7 = 22 Aug; 8 = 30 Aug; 9 = 6 Sep; 10 = 13 Sep.

[y] Incidence = % of trimmed plants with one or more petiole lesions; severity = % of petiole surface area with symptoms.

[x] Evaluated prior to harvest using a leaf blight assessment key representing the % of diseased leaf area on 21 Sep.

[w] Yield loss was calculated as the % of total yield lost due to late blight.

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

CELERY (*Apium graveolens* var. *dulce* 'Dutchess')
Crater rot; *Rhizoctonia solani*

R.S. Bounds and M.K. Hausbeck
Michigan State University
Dept. of Plant Pathology
East Lansing, MI 48824

Evaluation of fungicide initiation timing for managing crater rot of celery, 2004.

This study was conducted at a cooperator's farm in Ottawa County, MI on a Houghton muck field previously planted to celery. Eight-week old celery transplants were planted 6 in. apart in rows spaced 28 in. apart on 24 Jun. Each plot consisted of a row 20 ft-long row with 5 ft of unsprayed row between adjacent plots in the same row. Two unsprayed buffer rows separated adjacent treatment rows. Treatments were replicated four times in a randomized complete block design. Weeds, insects, and fertilization were managed according to standard production practices. Cultivation was not implemented for weed control. Fungicides were applied with a CO_2 backpack boom sprayer equipped with two XR8003 flat fan nozzles spaced 19.5 in. apart and calibrated to deliver 50 gal/A at a boom pressure of 53 psi. Fungicide spray programs were initiated one (early) or four (preventive) weeks after transplanting. Ten applications were made at weekly intervals for the early fungicide program which commenced on 1 Jul. Seven applications were made at weekly intervals for the preventive fungicide program which commenced on 22 Jul. Ten plants from the middle of each treatment row were hand-harvested, trimmed to fresh market specifications (14 in. length), and weighed on 9 Sep. The incidence of crater rot symptoms on the petioles was assessed on trimmed plants, diseased petioles were counted and removed from the plants, and marketable yields were weighed. Data were analyzed using the general linear models procedure in SAS. Average monthly minimum and maximum air temperatures (°F) were 55.1 and 74.9 in Jun, 59.0 and 79.7 in Jul, 54.3 and 76.4 in Aug, and 50.5 and 79.4 in Sep. Rainfall totaled 2.4, 2.6, 3.0, and 0.3 in. for the same respective months.

This trial was originally designed to evaluate early and preventive fungicide applications for managing foliar blights of celery. A few early blight lesions (caused by *Cercospora apii*) were detected on 18 Aug in an unsprayed buffer row, but the disease did not spread to treatment plots. Symptoms of crater rot were observed on petioles during harvest. Over 22% of untreated plants had crater rot lesions after trimming, and a significant yield loss of 5.2% resulted when diseased petioles were removed. The early and preventive fungicide programs were equally effective at preventing crater rot, but three fewer fungicide applications were made by initiating the first application four weeks after transplanting compared with the early program initiated one week after transplanting. The preventive fungicide program reduced fungicide costs by approximately $40/A compared to the early fungicide program. Symptoms of phytotoxicity were not observed.

Treatment and rate/A (application sequence[z])	Initial application	Crater rot		Yield loss (%)[y]
		Incidence (%)	No. infected petioles	
Untreated control	--	22.5 b[x]	6.3 b	5.2 b
Bravo Ultrex 82.5WDG 1.8 lb (1,3,5,7,9) Amistar 80WG 3 oz (2,6,10) Tilt 3.6EC 4 fl oz (4,8)	early	0.0 a	0.0 a	0.0 a
Bravo Ultrex 82.5WDG 1.8 lb (4,6,8,10) Amistar 80WG 3 oz (5,9) Tilt 3.6EC 4 fl oz (7)	preventive	0.0 a	0.0 a	0.0 a

[z] Application sequence: 1 = 1 Jul; 2 = 8 Jul; 3 = 15 Jul; 4 = 22 Jul; 5 = 29 Jul; 6 = 5 Aug; 7 = 12 Aug; 8 = 19 Aug; 9 = 26 Aug; 10 = 2 Sep. Kocide 2000 53.8DF (1.5 lb/A) was added to each fungicide treatment to limit the development of bacterial leaf spot (*Pseudomonas syringae* pv. *apii*).

[y] Yield loss was calculated as the % of total yield lost due to crater rot.

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

CELERY (*Apium graveolens* 'Dutchess')
Crater rot; *Rhizoctonia solani*

R.S. Bounds and M.K. Hausbeck
Michigan State University
Department of Plant Pathology
East Lansing, MI 48824

Evaluation of fungicides for managing crater rot of celery, 2004.

This study was conducted at cooperator's farm in Allegan County, MI on a Houghton muck field previously planted to celery. Eight-week old celery 'Dutchess' transplants were planted 8 in. apart in rows staggered 26-14-26 in. apart on 26 May. Treatment plots were 20 ft long with 5 ft of unsprayed buffer between plots in the same row and consisted of two rows spaced 14 in. apart. Two buffer rows were left unsprayed between each treatment plot. Six treatments were replicated four times in a randomized complete block design. Weeds, insects, and fertilization were managed according to standard production practices. Fungicides were applied with a CO_2 backpack sprayer equipped with three XR8003 flat fan nozzles spaced 19 in. apart and calibrated to deliver 50 gal/A at a nozzle pressure of 52 psi. Ten applications were made at weekly intervals on 15, 23, and 29 Jun; 7, 13, 20, and 29 Jul; and 3, 10, and 18 Aug. A directed spray pattern with three XR8002 nozzles was used for the last four applications by replacing the outer nozzles with 6 in. drop nozzles directed at 45-degree angles inward. The incidence of crater rot was assessed and yields were recorded on 24 Aug. Average monthly minimum and maximum air temperatures (°F) were: May (48.7 and 69.4); Jun (55.1 and 74.9); Jul (59.0 and 79.7); and Aug (54.3 and 76.4). Rainfall totals (in.) were 6.8, 2.4, 2.6, and 3.0 for the same respective months.

Few crater rot symptoms were detected during random destructive sampling of plants in untreated buffer rows in the latter part of the season. Overall, disease pressure was low and no disease symptoms were found in treatment rows at harvest. There was no significant yield difference among treatments. Early blight (caused by *Cercospora apii*) lesions were detected on 29 Jul in one localized area of an untreated buffer row, but cool weather kept the disease from spreading. No phytotoxicity was observed.

Treatment and rate/A (application sequence)*	Yield per 10 trimmed plants (lb)
Untreated	22.6 **
Bravo Ultrex 82.5WDG 1.8 lb (1-10)	23.3
Amistar 80WG 3 oz (1,3,5,7,9) Bravo Ultrex 82.5WDG 1.8 lb (2,4,6,8,10)	23.3
Cabrio 20WG 12 oz (1,3,5,7,9) Bravo Ultrex 82.5WDG 1.8 lb (2,4,6,8,10)	23.1
Scholar 50WP 7 oz (1,3,5,7,9) Bravo Ultrex 82.5WDG 1.8 lb (2,4,6,8,10)	21.6
Moncut 70DF 11.4 oz + Bravo Ultrex 82.5WDG 1.8 lb (1,3,5,7,9) Bravo Ultrex 82.5WDG 1.8 lb (2,4,6,8,10)	22.3

* Kocide 2000 53.8DF (1.5 lb/A) was added to each fungicide treatment to limit bacterial blight. Application sequence: 1 = 15 Jun; 2 = 23 Jun; 3 = 29 Jun; 4 = 7 Jul; 5 = 13 Jul; 6 = 20 Jul; 7 = 29 Jul; 8 = 3 Aug; 9 = 10 Aug; 10 = 18 Aug.

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

CELERY (*Apium graveolens* var. *dulce* 'Dutchess')
Late blight; *Septoria apiicola*

R.S. Bounds and M.K. Hausbeck
Michigan State University
Dept. of Plant Pathology
East Lansing, MI 48824

Evaluation of fungicides for managing late blight of celery, 2005.

This study was conducted at the Michigan State University Muck Soils Research Farm in Laingsburg, MI on a Houghton muck field previously planted to carrot. Seven-week old celery transplants were planted 7 in. apart in rows spaced 32 in. apart on 25 May. Each plot consisted of a 20 ft-long row with 5 ft of unsprayed row between adjacent plots in the same row. Two unsprayed buffer rows separated adjacent treatment rows. Treatments were replicated four times in a randomized complete block design. Weeds, insects, and fertilization were managed according to standard production practices. *Septoria apiicola* inoculum (2.9×10^7 spores/fl oz) was prepared by soaking dried infected celery leaves for 10 min in water and straining the spore suspension through two layers of cheesecloth. Inoculum was applied to all plants in the trial, several hours after fungicide treatments were applied on 6 and 13 Jul, using a hand-pump backpack sprayer with one hollow cone nozzle that delivered approximately 12 gal/A. Fungicides were applied with a CO_2 backpack boom sprayer equipped with three XR8003 flat fan nozzles spaced 18 in. apart and calibrated to deliver 50 gal/A at a boom pressure of 52 psi. Six applications were made at weekly intervals, except for plots treated biweekly with Bravo Ultrex 82.5WDG, which received three applications on alternate dates. Leaf blight severity was evaluated on 11 and 16 Aug, and ten plants from the middle of each treatment row were hand-harvested and trimmed to fresh market specifications (14 in. length) on 17 Aug. Petiole disease incidence and severity were assessed at harvest, diseased petioles were removed from the plants, and yields were recorded. Data were analyzed using the general linear models procedure in SAS. Average monthly minimum and maximum air temperatures (°F) were 39.3 and 65.3 in May, 57.5 and 82.7 in Jun, 58.4 and 84.4 in Jul, and 56.5 and 81.9 in Aug. Rainfall totaled 1.2, 2.3, 2.8, and 3.2 in. for the same respective months.

Disease symptoms were first observed on leaves throughout the control plots on 18 Jul. Untreated control plants were severely diseased at harvest, which necessitated extensive trimming and resulted in low yield. Four fungicide programs provided season-long disease prevention on petioles, including Amistar 80WG alternated with Tilt 3.6EC, Amistar 80WG alternated with Bravo Ultrex 82.5WDG, Pristine 38WG alternated with Bravo Ultrex 82.5WDG, and Bravo Ultrex 82.5WDG applied weekly. Trimmed yields of plants treated with TM 473 4F alternated with Bravo Ultrex 82.5WDG, and those treated biweekly with Bravo Ultrex 82.5WDG, did not differ significantly from yields of plants treated with fungicide programs that prevented petiole infection. Treatments that included Endura 70WG or Endorse 11.3DF offered limited protection and were generally inferior to the standard Bravo Ultrex 82.5WDG weekly treatment. Applications of Serenade Max 14.6WP alternated with Bravo Ultrex 82.5WDG, Kocide 2000 53.8DF, and Botran 75-W were ineffective at limiting late blight and resulted in disease levels and

yields similar to the untreated control plants. Symptoms of phytotoxicity were not observed.

Treatment and rate/A (application sequence[z])	Leaf blight (%)[y]		Petiole blight (%)[x]		Trimmed yield (lb)
	11 Aug	16 Aug	Incidence	Severity	
Untreated control	40.0 d[w]	51.3 de	100.0 c	72.5 cd	3.9 d
Amistar 80WG 5 oz (1,3,5) Tilt 3.6EC 4 fl oz (2,4,6)	0.0 a	0.8 a	0.0 a	0.0 a	21.9 a
Amistar 80WG 5 oz (1,3,5) Bravo Ultrex 82.5WDG 1.8 lb (2,4,6)	0.0 a	0.5 a	0.0 a	0.0 a	20.7 a
Bravo Ultrex 82.5WDG 1.8 lb (1-6)	0.8 a	1.0 a	0.0 a	0.0 a	19.7 a
Pristine 38WG 10.5 oz (1,3,5) Bravo Ultrex 82.5WDG 1.8 lb (2,4,6)	0.5 a	0.8 a	0.0 a	0.0 a	18.1 ab
TM 473 4F 2.9 fl oz (1,3,5) Bravo Weather Stik 6SC 1.5 pt (2,4,6)	1.0 a	2.0 a	50.0 b	1.0 a	18.1 ab
Bravo Ultrex 82.5WDG 1.8 lb (1,3,5)	2.0 a	7.5 a	75.0 bc	8.0 ab	17.4 ab
Endura 70WG 4.6 oz (1-6)	7.5 b	17.5 b	100.0 c	11.3 ab	13.2 bc
Endorse 11.3DF 7 oz (1,3,5) Bravo Ultrex 82.5WDG 1.8 lb (2,4,6)	13.8 c	27.5 c	100.0 c	23.8 b	8.8 cd
Serenade Max 14.6WP 2 lb (1,3,5) Bravo Ultrex 82.5WDG 1.8 lb (2,4,6)	36.3 d	43.8 d	100.0 c	56.3 c	6.3 d
Kocide 2000 53.8DF 1.5 lb (1-6)	38.8 d	48.8 de	100.0 c	68.8 cd	5.2 d
Botran 75-W 2 lb (1-6)	40.0 d	55.0 e	100.0 c	75.0 d	4.7 d

[z] Application sequence: 1 = 6 Jul; 2 = 13 Jul; 3 = 21 Jul; 4 = 27 Jul; 5 = 3 Aug; 6 = 11 Aug.

[y] Evaluated using a leaf blight assessment key representing the % of diseased leaf area.

[x] Incidence = % of trimmed plants with one or more petiole lesions; severity = % of petiole surface area with symptoms.

[w] Means within a column followed by the same letter are not significantly different according to Tukey's Studentized Range Test ($P \leq 0.05$).

CELERY (*Apium graveolens* var. *dulce* 'Dutchess')
Bacterial leaf spot; *Pseudomonas syringae* pv. *apii*

R.S. Bounds and M.K. Hausbeck
Michigan State University
Dept. of Plant Pathology
East Lansing, MI 48824

Evaluation of products for managing bacterial leaf spot of celery, 2005.

This study was conducted at the Michigan State University Muck Soils Research Farm in Laingsburg, MI on a Houghton muck field previously planted to carrot. Seven-week old celery transplants were planted 7 in. apart in rows spaced 32 in. apart on 25 May. Each plot consisted of a 20 ft-long row with 5 ft of unsprayed row between adjacent plots in the same row. Two unsprayed buffer rows separated adjacent treatment rows. Treatments were replicated four times in a randomized complete block design. Weeds, insects, and fertilization were managed according to standard production practices. Products were applied with a CO_2 backpack boom sprayer equipped with three XR8003 flat fan nozzles spaced 18 in. apart and calibrated to deliver 50 gal/A at a boom pressure of 52 psi. Eleven applications were made at weekly intervals starting on 1 Jun. Disease developed from natural infection of the transplants. Ten plants from the middle of each treatment row were hand-harvested, trimmed to fresh market specifications (outer petioles removed and plants cut to 14-in. length), and weighed on 17 Aug. Since little difference in disease was detected among treatments on 17 Aug (*data not shown*), four additional plants were hand-harvested from each treatment row and evaluated for disease on 30 Aug. Outer petioles were removed but not the upper foliage. Terminal leaves were removed from all marketable petioles (petioles on which the first node was $\geq$ 9 in. above the base of the plant), and leaf spot severity was visually assessed on the detached leaves by estimating the percentage of leaf area with bacterial leaf spot symptoms. Similarly, disease severity was assessed for 10 whole plants that were not harvested/plot. Disease incidence was determined by the total number of marketable petioles and the number of marketable petioles with leaf spot symptoms on the leaves. Data were analyzed using the general linear models procedure in SAS. Average monthly minimum and maximum air temperatures (°F) were 39.3 and 65.3 in May, 57.5 and 82.7 in Jun, 58.4 and 84.4 in Jul, and 56.5 and 81.9 in Aug. Rainfall totaled 1.2, 2.3, 2.8, and 3.2 in. for the same respective months.

Disease symptoms were first observed on newly expanded leaves on 8 Jun. The causal agent was confirmed as *Pseudomonas syringae* pv. *apii* by BIOLOG analysis conducted by Diagnostic Services at Michigan State University. Disease levels were moderate at the time of final evaluation but not high enough to warrant additional trimming of diseased leaves. All treatments, except those that included Serenade Max 14.6WP or Citraplex 20% Copper, reduced leaf spot severity relative to the untreated control. Applications of Actigard 50WG + Kocide 2000 53.8DF resulted in the lowest leaf spot severity but did not differ significantly from the standard treatment of Kocide 2000 53.8DF (1.5 lb/A) applied alone. No significant rate response was observed with Kocide 2000 53.8DF applied at 1 vs. 1.5 lb/A. Leaf spot severity evaluations on terminal leaves and whole plants yielded similar results, but the latter required less time for evaluation. Only Serenade Max 14.6WP + Kocide 2000 53.8DF significantly reduced

the incidence of marketable petioles with diseased leaves relative to the untreated control, yet this control was not statistically superior compared to that achieved with the other treatments. Future studies could quantify *P. syringae* pv. *apii* populations on leaves of the treatments included in this study. Symptoms of phytotoxicity were not observed.

Treatment and rate/A (application sequence*)	Leaf spot severity (%)		Incidence of petioles with diseased leaves (%)	Trimmed yield (lb)
	Terminal leaves	Whole plants		
Untreated control	26.3 c**	28.8 c	67.6 b	19.5
Actigard 50WG 0.5 oz + Kocide 2000 53.8DF 1.5 lb (1-11)	4.0 a	6.5 a	50.3 ab	19.8
Tanos 50DF 8 oz + Kocide 2000 53.8DF 1.5 lb (1,3,5,7,9,11) Kocide 2000 53.8DF 1.5 lb (2,4,6,8,10)	11.3 ab	11.3 a	51.8 ab	20.3
Kocide 2000 53.8DF 1.5 lb (1-11)	10.0 ab	12.5 ab	57.5 ab	20.3
Kocide 2000 53.8DF 1 lb (1-11)	13.8 ab	13.8 ab	51.6 ab	19.2
Messenger STS 3WDG 6 oz + Kocide 2000 53.8DF 1.5 lb (1-11)	13.8 ab	15.0 ab	55.3 ab	19.3
Serenade Max 14.6WP 3 lb + Kocide 2000 53.8DF 1.5 lb (1-11)	16.3 bc	17.5 abc	47.2 a	20.1
Citraplex 20% Copper 8 oz (1-11)	26.3 c	25.0 bc	57.2 ab	18.8

* Application sequence: 1 = 1 Jun; 2 = 8 Jun; 3 = 16 Jun; 4 = 22 Jun; 5 = 29 Jun; 6 = 6 Jul; 7 = 13 Jul; 8 = 21 Jul; 9 = 27 Jul; 10 = 3 Aug; 11 = 11 Aug.

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

CELERY (*Apium graveolens* 'Dutchess')
Early blight; *Cercospora apii*

R.S. Bounds and M.K. Hausbeck
Michigan State University
Department of Plant Pathology
East Lansing, MI 48824

Evaluation of calendar-based schedules and TOM-CAST DSV thresholds for timing the initial fungicide treatment to manage early blight of celery, 2005.

This study was conducted at a cooperator's farm in Ottawa County, MI on a Houghton muck field previously planted to onion. Eight-week old celery 'Dutchess' transplants were planted 7.5 in. apart in rows spaced 20 in. apart on 16 Jun. Temperature and leaf wetness sensors were placed in the field at the time of transplanting to monitor TOM-CAST DSV accumulation throughout the growing period. Treatment plots consisted of one row 20 ft long with 5 ft of unsprayed buffer between plots in the same row. Two buffer rows were left unsprayed between each treatment row. Seven treatments were replicated four times in a randomized complete block design. Weeds, insects, and fertilization were managed according to standard production practices. Fungicides were applied with a CO_2 backpack sprayer equipped with two XR8003 flat fan nozzles spaced 19.5 in. apart and calibrated to deliver 50 gal/A at a boom pressure of 53 psi. Sprays were initially applied to the early initiation and preventive treatments on 23 Jun and 15 Jul, respectively, representing 1 and 4 weeks after transplanting. Sprays for the remaining treatments were initially applied when 10, 20, 30, and 40 TOM-CAST DSVs had accumulated since transplanting and occurred on 27 Jun, 1 Jul, 11 Jul, and 17 Jul, respectively. Subsequent applications were made to all fungicide treatments according to TOM-CAST 10-DSV. Leaf blight severity was evaluated and ten plants from the middle of each treatment row were hand-harvested on 31 Aug. Plants were trimmed to fresh market specifications (14 in. length) and weighed.

Early blight lesions were detected on 24 Aug in unsprayed buffer and untreated control rows. At harvest, untreated plants had very few early blight lesions on the leaves (covering <1% of the total leaf area) and none on the petioles. There were no yield differences since the disease did not occur on the petioles. No phytotoxicity was observed.

Treatment and rate/A Timing of first application[z] (no. sprays)	Leaf blight severity (%)[y]	Total yield (lb)[x]
Untreated control	0.8	17.7
Bravo Ultrex 82.5WDG 1.8 lb applied at TOM-CAST 10-DSV intervals		
Early (10)	0.0	17.8
Preventive (8)	0.0	21.3
TOM-CAST 10-DSV (10)	0.0	19.2
TOM-CAST 20-DSV (9)	0.3	18.5
TOM-CAST 30-DSV (8)	0.0	17.2
TOM-CAST 40-DSV (7)	0.0	20.5

[z] The first fungicide application for the early and preventive programs were made 1 and 4 weeks after transplanting, respectively, and sprays were applied thereafter according to the TOM-CAST 10-DSV interval. The first fungicide application for the remaining treatments was applied after 10, 20, 30, or 40 DSVs had accumulated after transplanting; subsequent sprays were applied thereafter according to the TOM-CAST 10-DSV interval.

[y] Evaluated using a leaf blight assessment key representing the percentage of diseased leaf area.

[x] Ten plants per plot were trimmed to fresh market specification (14 in. length) and weighed on 31 Aug.