Overview

Each year the commercial carrot crop in Wisconsin suffers losses from alternaria leaf blight, cercospora leaf spot, and aster yellows. The first two are diseases caused by fungi (* Alternaria dauci* and *Cercospora carotae*). The third is a disease caused by the aster yellows phytoplasma, a parasitic bacterium of carrot phloem tissue and also of the aster leafhopper (*Macrosteles quadrilineatus*) that spreads it from carrot plant to carrot plant as it feeds.

Warm weather, high humidity, and evening dew are common during summer months in Wisconsin, and these create ideal conditions for the fungi that cause alternaria leaf blight and cercospora leaf spot. When these fungi thrive, symptoms of foliar disease develop rapidly. Carrot leaves collapse and large portions of the field assume a burned or blighted appearance. Blighted leaves and petioles are often so weakened that they break off when gripped by a mechanical harvester, and carrots are left unharvested in the field.

When the aster leafhopper infects a carrot crop, the vascular tissue in roots and leaves is disrupted and a variety of results may follow, including unequal foliage branching, accumulation of red or purple anthocyanin pigments in leaves, witches’ broom, chlorosis, stunted root development, heavy growth of hairy secondary roots, root discoloration, bitter carrot flavors, and increased susceptibility to infection by other pathogens.

Disease cycle and epidemiology

*A. dauci* and *C. carotae* conidia (spores) and mycelia (the vegetative part of a fungus) may be spread into fields on contaminated carrot seed. Once introduced into a field, these fungi may persist in carrot debris for up to two years. The primary source of annual inoculum is spores, produced on crop debris, that are spread to new carrot crops by wind and splashing rain. These fungi can also infect wild carrot (Queen Anne’s lace) which may serve as a “green bridge” carrying them across seasons or between production regions.

*A. dauci* and *C. carotae* spores are easily spread by anything that moves—wind, water, and farm equipment. Spores germinate, penetrate and infect susceptible host tissue during periods of favorable conditions (leaf wetness, humidity and temperature), and symptoms become visible three to seven days later. Following colonization, conidia are repeatedly produced, perpetuating the spread of foliar disease throughout the growing season.

The aster yellows phytoplasma is vectored principally by the aster leafhopper, in a persistent, propagative manner. The leafhopper acquires the phytoplasma by feeding on infected plants and may carry and transmit the phytoplasma over great distances. After the insect feeds for an extended period (several hours) on vascular plant tissues (phloem), the phytoplasma circulates in its body and multi-
plies during a two- to three-week latent period. Once infectious (containing the phytoplasma), the leafhopper may transmit the phytoplasma to healthy plants during relatively short (several minutes) feeding bouts. Infected leafhoppers remain infected and may transmit the pathogen for the remainder of their adult lives, but they do not pass the phytoplasma along to progeny. The aster yellows phytoplasma is capable of colonizing and multiplying in a broad range of crop species (such as lettuce, potato, onion, celery, and carrot) and in over 300 annual and perennial weed species.

The first aster yellows phytoplasma to enter carrot fields in Wisconsin is vectored by adult female leafhoppers migrating from grain crops and weed hosts in the south-central U.S., including in Arkansas, Iowa, Kansas, Louisiana, and Missouri. Migrants begin to arrive in Wisconsin in April and May as carrot and small grain cover crops are germinating. The percentage of infected leafhoppers is initially low (0 to 1%). Insect numbers vary depending on spring weather patterns in the migration pathway. In addition to the long-distance migrants are the local leafhopper populations in Wisconsin. These will often overwinter as eggs in small grains (e.g. wheat, rye, barley) and in perennial weeds, and then will hatch and pass through five nymphal instars prior to adulthood. The first Wisconsin native adults enter carrot fields in mid June and are typically infected at much higher levels (2 to 5%) than migrants. The infestation of carrot fields by aster leafhoppers is thus initially low and sporadic in May, with aster yellows phytoplasma infectivity levels in dispersing insect populations averaging between 0 and 1%. As local aster leafhopper populations enter the picture in June, populations may increase sharply, accompanied by a two- to three-fold increase in the average percentage of insects infected with aster yellows, bringing average infectivity to 3 to 5% (see figure 1). Aster leafhopper numbers then fluctuate for the remainder of the season, depending upon control activities. Infectivity levels decline late in the season.

Queen Anne’s Lace (*Daucus carota*) is a host for *A. dauci* and *C. carotae* fungi and may serve as a green bridge across seasons or between production regions.
Traditional disease control practices

Alternaria leaf blight and cercospora leaf spot typically have been controlled in Wisconsin through repetitive applications of protectant fungicides. (Please check Commercial Vegetable Production in Wisconsin Guidelines, UW Extension publication A3422, for updated foliar registrations for use against these pathogens.) Fungicides are commonly applied on a seven- to ten-day calendar schedule, starting when plants are six to eight inches tall (July) and continuing through the growing season until two weeks prior to harvest (September or October). Foliar blights inflict the most significant damage during August, when a mature and dense carrot canopy creates a microclimate favorable for disease development. A dense carrot canopy also creates difficulty in providing adequate fungicide coverage to all leaves, especially those leaflets and petioles near the soil. Fungicide for a single application may cost $9 to $30 per acre, not including cost of application. The number and type of fungicide applications may fluctuate annually, depending upon the time of initial disease onset, plant growth stage, rate of disease progress, and duration of environmental conditions favorable for disease.

Aster yellows has been controlled by controlling the aster leafhopper. Synthetic pyrethroid insecticides approved for carrots constitute the backbone of the control options and include cyfluthrin, zeta-cypermethrin, and esfenvalerate, with esfenvalerate being the most widely used. Insecticide applications are made prescriptively during the period from June to August to reduce aster leafhopper populations and limit the transmission and spread of the aster yellows phytoplasma in the carrot crop. Initial applications are often made shortly after carrots emerge, when the first leafhoppers are observed in the field. Continued reapplication becomes very important as aster leafhopper populations increase later in the season. Leafhopper numbers then fluctuate for the remainder of the season, depending on control measures. Generally, insecticide sprays are necessary through August, until aster leafhopper populations decline.

Improved disease management using multiple IPM tools

A successful alternaria leaf blight, cercospora leaf spot, and aster yellows disease control program depends upon detailed understanding of the elements that directly affect disease development. Knowledge of the target organism and of the environmental influence on disease and host plant susceptibility are vital to timing and scheduling chemical applications. Using disease forecasting programs that target periods when plant protection is needed will improve timing of pesticide applications, improve product efficacy, and limit the number of sprays needed for adequate pest control. In addition, disease forecasting and insect monitoring greatly assist in timing the initiation of pesticide programs, and in reducing overall management costs. It is essential to understand the disease susceptibility of carrot cultivars, and then to plant, where available, resistant varieties that may require fewer inputs.

Disease monitoring techniques have shown promise in helping to better time the initiation of spray programs and to reduce unnecessary, early-season fungicide spraying. Field scouting of carrot foliage during the critical time period from late June through July provides a way to identify the first appearance of disease.
Timing the first application of fungicide at the critical stage of 0 to 5% foliar disease severity (this differs by variety) is an effective way to reduce chemical applications and to maximize their performance.

Briefly, fields should be scouted for disease symptoms weekly, as this is the backbone of all pest management programs. The goal of scouting is to give a complete, accurate, and unbiased assessment of pest populations. Scouting report forms are an excellent way to compile this information and must be comprehensive enough that control decisions can be made directly from the report form. These forms not only serve as a record of current pest populations but should be saved by the grower or consultant as part of the field history record. For efficiency, an M-shaped walking pattern is best used on square or rectangular fields. In irregularly shaped fields scouting must cover a representative area. Guidance on suggested field patterns can be obtained from UW Extension publication A3547, Crop Scouting Manual. At each of the five points along an M-shaped transect, severity of foliar disease symptoms should be noted in 25 randomly selected plants and appropriately recorded on the reporting forms.

Timing fungicide applications by use of the weather-based forecasting program TOM-CAST (Weather Innovations, Inc., Chatham, ON, Canada)—a program which generates disease severity values (DSVs) based on in-canopy temperature and leaf wetness—significantly reduces chemical inputs while providing effective control of alternaria leaf blight and cercospora leaf spot. It also allows yields comparable to those attained when prophylactic, weekly spray programs are used. TOM-CAST, a disease forecasting system originally developed for tomato plant protection in Ontario, Canada, has been validated for use on carrot. On-site environmental conditions are measured and recorded using a Watchdog Weather Station®. DSVs are calculated according to the duration of wetness periods and temperature within the canopy (see table 1). DSVs are totaled for each day and accumulated over several days until treatment thresholds of 15 or 20 DSVs are reached, at which point, depending upon the disease susceptibility of the cultivar, fungicide applications are recommended. After each fungicide application, DSVs are reset to zero.

Successful disease control and use of an integrated pest management approach to crop production requires thorough knowledge of the host and of the disease susceptibility of the variety being grown. This knowledge is a foundational building block of an integrated disease management program. Cultivars differ in disease resistance, and disease develops at different rates depending upon the level of resistance. The majority of the processing industry have accepted carrot

<table>
<thead>
<tr>
<th>Disease Severity Value</th>
<th>Mean temperature during period of leaf wetness</th>
<th>Leaf wetness period (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>55-63 °F</td>
<td>0-6</td>
</tr>
<tr>
<td></td>
<td>64-68 °F</td>
<td>0-3</td>
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<td>0-2</td>
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<tr>
<td></td>
<td>78-84 °F</td>
<td>0-3</td>
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</tbody>
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**Table 1.** Calculation of disease severity values (DSVs) for weather-based timing of foliar fungicide applications to control carrot foliar diseases.

**Glossary**

Adventitious roots: roots that arise or occur sporadically at unusual locations along the main carrot root—clusters of fine roots.

Chlorosis: a diseased condition in green plants marked by yellowing or blanching.

Conidia: asexual spores produced on a conidiophore of certain fungi.

Mycelium: the mass of interwoven filamentous hyphae that forms the vegetative portion of the fungus and is often submerged in another body, such as soil or organic matter or the tissues of a host; also: a similar mass of filaments formed by some bacteria.

Phloem: a complex tissue in the vascular system of higher plants that consists mainly of sieve tubes and elongated parenchyma cells usually with fibers and that functions in movement and storage of sugars as well as providing physical support to the plant.

Witches’ broom: a disease or deformity that changes the natural structure of a plant so that it often resembles the brush end of a broom.
cultivars that have been selected for quality traits but are susceptible to alternaria leaf blight and cercospora leaf spot. Many commercially available carrot cultivars and breeding lines have been evaluated in Wisconsin field trials. A few lines have been shown to have reduced levels of disease at harvest and fewer lesions per plant. Identification of these disease-tolerant lines, which have acceptable yields in the presence of both pathogens, indicates the potential for further commercial application of additional carrot lines. Understanding varietal susceptibility and incorporating disease-resistant carrot lines in commercial production offers the possibility of reducing fungicide applications and reducing costs of disease control.

Side-by-side evaluations in commercial fields of the calendar spray approach and the integrated pest management approach—including TOM-CAST combined with disease monitoring—have demonstrated that forecasting programs require fewer fungicide applications in most seasons (see table 2) and fewer chemical and monetary inputs. Fewer applications enable growers to cut costs of foliar disease management and reduce chemical inputs by 25 to 50%. Using an IPM program while growing disease-resistant carrot varieties (see table 4) has shown promise of reducing pesticide inputs a further 15 to 30% compared to what they would have been under the same regime growing standard susceptible varieties.

**Integrated pest management of aster yellows**

In order to manage the incidence of aster yellows in carrot fields efficiently, it is necessary to consider three key components of the disease cycle: the vector, the disease, and the crop.

**The vector**

To determine how many aster leafhoppers are infesting a field, use a standard 15-inch sweep net to sample. Specifically, take sets of 25 sweeps randomly across your field and count the total number of leafhoppers per 100 sweeps as an average for the field. Sweep-sample at least four sites per five acres of crop, and sweep at least weekly from emergence of the crop through July. Scouting should be conducted twice weekly during late July when aster leafhopper numbers typically fluctuate rapidly. It is important to accurately identify the pale green aster leafhopper, as it is the principal vector of the aster yellows pathogen and should not be confused with the potato leafhopper, which is similar in size but has a distinct bright green coloration. Potato leafhoppers are sometimes found in carrot fields but will not transmit the aster yellows pathogen.

**The disease**

The aster leafhopper does not injure or cause yield reduction in carrots unless it inoculates the crop with aster yellows phytoplasma. For this reason, knowing the number of infectious leafhoppers is very important. A thousand aster leafhoppers per 100 sweeps can be ignored if they are free of aster yellows, but as few as 10 can be a problem if they are infected (see table 3 for example calculations—at various levels of insect infectivity and plant susceptibility—of the number of aster leafhoppers that indicates when spray treatment should begin).
Given that infectivity levels may vary, it is critical to have accurate current knowledge of the aster yellows infectivity of aster leafhoppers in a field. University of Wisconsin Extension Specialist Russell Groves (UW-Madison Entomology Department), and independent crop consultant Randy Van Haren of Pest Pros Inc. (Plainfield, Wisconsin), currently offer Wisconsin vegetable growers assay services that supply the information they need to accurately determine the number of aster leafhoppers carrying the aster yellows phytoplasma. In the past, infectivity was determined by a bioassay procedure in which leafhoppers from individual fields were caged on susceptible Chinese aster plants and symptoms were later recorded after a 21-day period. Current technology, however, allows us to eliminate the time lag and determine infectivity using a reverse transcriptase, polymerase chain reaction procedure. The infectivity level is then used in conjunction with the number of aster leafhoppers per 100 sweeps to rapidly and accurately compute the aster yellows index (AYI) for a given location at a specified time. The average number of aster leafhoppers per 100 sweeps, multiplied by the aster yellows phytoplasma infectivity, equals the aster yellows index, or AYI—and this is the index used to calculate the example danger levels illustrated in table 3.

It should be noted, however, that infectivity levels estimated by PCR can often be two to three times higher than estimates generated from the traditional bioassay methods. Ongoing research at the University of Wisconsin continues to resolve these differences and more accurately establish the relationships between these two methods.
The crop

The relative susceptibility of the carrot variety being grown is important to consider when determining the necessity of insecticide applications to limit aster yellows. Research over the past six years has demonstrated that carrot varieties differ considerably in their susceptibility to aster yellows (see table 5). For this reason, incorporating varietal susceptibility into the computation of the AYI further aids in determining when insecticide treatment thresholds have been exceeded and protection of the crop is necessary. To take advantage of varietal resistance, the following AYI action thresholds should be considered: treat susceptible varieties at 50 AYI, moderately resistant varieties at 75 AYI, and resistant varieties at 100 AYI.

IPM recommendations

Where available, incorporate pathogen-resistant varieties or, at a minimum, be aware of the presence of pathogens on your seed, and of the crop development stages, the optimum fertility requirements, and the susceptibility to major pests of the carrot variety you are growing. Invest in disease scouting or pest monitoring to provide accurate information on pest presence and disease in carrot fields. Use this information in conjunction with knowledge of the pathogen, the vector, and the conditions that favor disease development, in order to refine your action threshold for initiating pesticide applications. Once you start the program, incorporate specific weather data affecting pest or disease development (most notably temperature and leaf wetness data), and also aster leafhopper population numbers and infectivity data, in order to time subsequent sprays according to TOM-CAST and the AYI. Using reduced-risk fungicides such as azoxystrobin or boscalid tank-mixed and in rotation with broad-spectrum or multi-site fungicides.
cides, such as chlorothalonil, may reduce chemical inputs due to the extended interval of performance and systemic activity of these reduced-risk materials. All of these techniques may be used in an integrated management program for carrots to provide a variety-specific approach for controlling the major pests of carrots, including alternaria leaf blight, cercospora leaf spot, and aster yellows, while reducing reliance upon a calendar-based, pesticide application program.

IPM is not a technique or a recipe, but rather an approach for identifying and solving pest problems. Particular techniques for pest management may vary from field to field, year to year, crop to crop, and grower to grower, but the overall approach is always the same, using the essential components of an IPM program. It is important to point out that an IPM program is not a cookbook approach. It would be nice if we could tackle a set of pest problems the same way every time, but history has shown us that this will not work. As a result, we are unable to conceive of a static spray schedule for each of the carrot diseases described in this document. An IPM program is never complete and is a process of continuous improvement. The reason for this is that over time we learn more about our crop, our pests and their natural enemies, and refine our monitoring programs. We also improve our economic thresholds, and develop new control strategies. Furthermore, we periodically get new pests.

As we gain more knowledge, we need to use it to refine our IPM programs to make them more effective and to ensure they will work in the long term. This is the best way to minimize the economic impacts of pests in carrot fields and minimize the risks to human health and to the environment. It is very important to choose the right control technique based on the economic nature of the pest problem, the cost of the particular control technique, and the effects of this technique on the environment and human health.