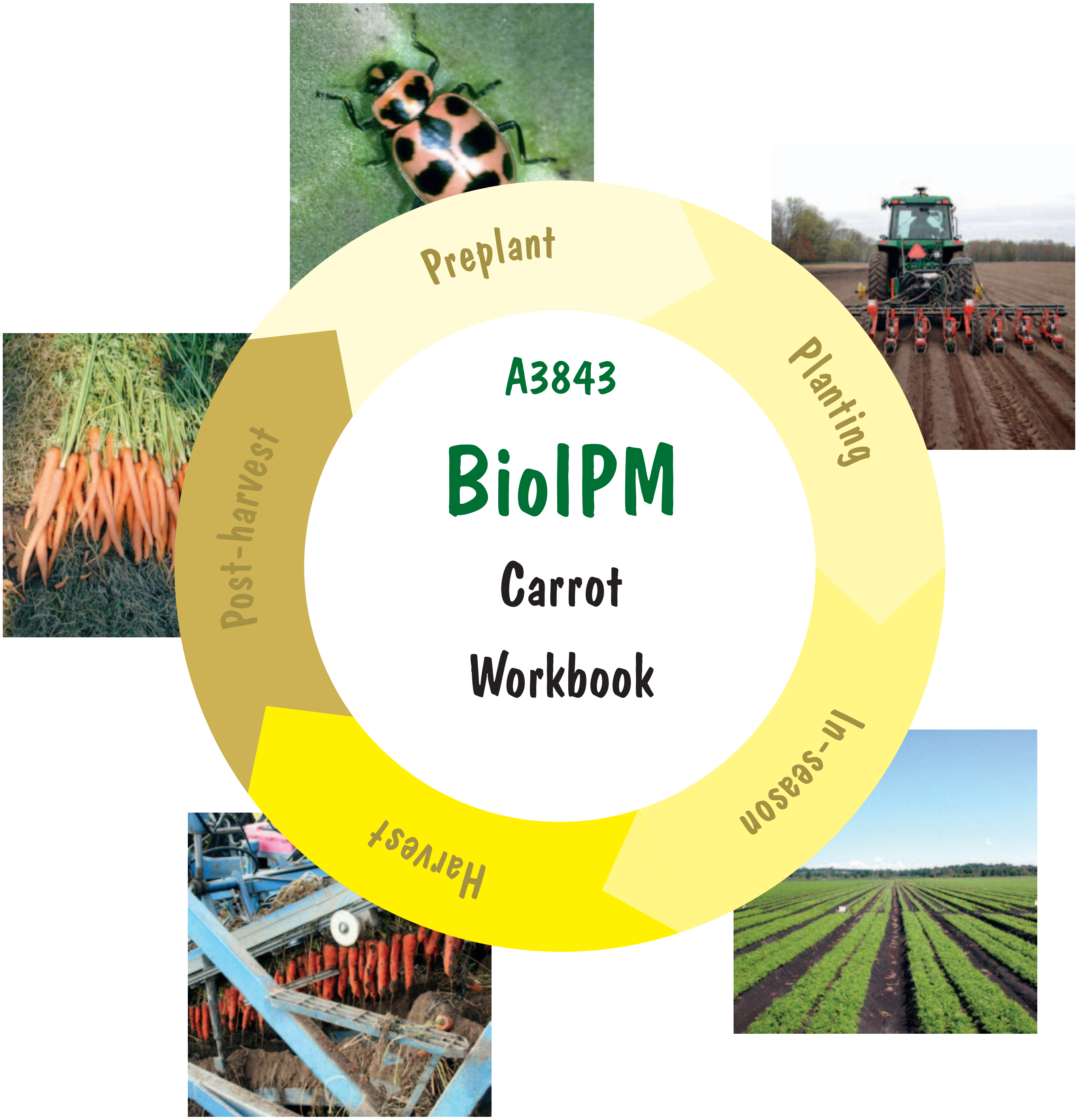

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BioIPM Carrot Workbook

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Introduction

This Carrot BioIPM Workbook is written for growers and the vegetable industry. It is organized seasonally to provide a comprehensive, year-round self-assessment tool and reference on pest management and cultural practices of the carrot production system. The workbook is organized into five chapters – preplant, planting, in-season, harvest, and post-harvest. Each chapter is further divided into pertinent topic sections with self-assessment statements followed by information on standard recommended practices as well as advancements to a biointensive production system.

This workbook is intended as a practical tool for growers' use throughout the entire production cycle. The workbook will help growers learn how to move toward a more biologically-based production system that is ecologically sound and economically profitable.

At the beginning of each topic, there is a set of statements about the farm's current production practices. This self-evaluation section is formatted on a scale, with Category A being the minimal practices that could be used, increasing to Category D, which describes advanced, sometimes experimental approaches. For most topics, the biointensive approach utilizes all categories — A through D. By checking all the statements that apply, growers can use the section to assess where their systems fall on various topics – such as managing leaf blight or selecting cultivars before planting. Growers can use the statements when making plans for the year ahead or to document practices or inputs used.

After each statement set, there is specific information expanding on the practices described in the categories A-D. Look to these paragraphs to learn how or why to implement specific activities and practices during various times of the year. The authors encourage growers to read about and consider the biologically based practices that may not currently be part of their carrot system.

When the Wisconsin state symbol is noted, the information is specific to Wisconsin soils.

All photographs were contributed by the authors and editing staff, unless otherwise noted.

Please visit the Nutrient and Pest Management program's website at ipcm.wisc.edu for more IPM and nutrient management publications.

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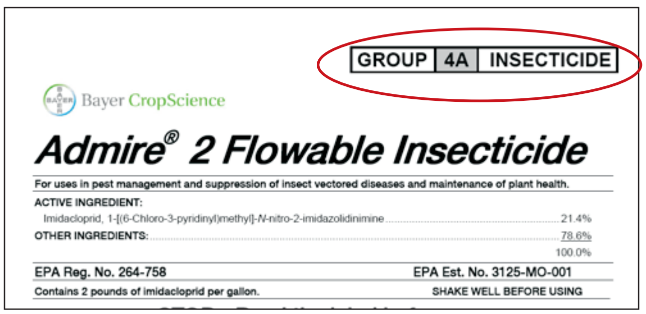
Pesticide Resistance Management in Rotational Years

Preplant

Resistance management is essential to maintain the efficacy of available pesticides in the vegetable system. Growers need to consider resistance management strategies in the rotational cropping years, both in fields and between the previous year's carrot crops. The goal is to avoid consecutive use of a product, or products with similar modes of action, against the same target pest.



GROUP 4A INSECTICIDE

Bayer CropScience

Admire® 2 Flowable Insecticide

For uses in pest management and suppression of insect vectored diseases and maintenance of plant health.

ACTIVE INGREDIENT:
Imidacloprid, 1-[(6-Chloro-3-pyridinyl)methyl]-N-nitro-2-imidazolidinimine 21.4%
OTHER INGREDIENTS: 78.6%
100.0%

EPA Reg. No. 264-758 EPA Est. No. 3125-MO-001

Contains 2 pounds of imidacloprid per gallon. SHAKE WELL BEFORE USING

Example of pesticide label with EPA Resistance Management Group information.

Read the following statements in order and check all that apply. Refer to the corresponding sections on the following pages for more information.

☐ **A.** ***Resistance is not considered when managing pests in rotational crops.***

☐ **B.** ***During rotational years, herbicides are chosen with a different chemical site of action from the primary carrot herbicides.***

☐ **C.** ***Insecticide and fungicide chemistries are alternated on an area-wide basis according to the EPA resistance management designations.***

☐ **D.** ***BioIPM strategies are implemented including cultural control methods to manage carrot pests in rotational crops.***

A. Resistance Management 101

Growers are aware that they should implement resistance management strategies during the current cropping season. Growers must also use resistance management strategies from cropping season to cropping season so that insects, plant pathogens, and weeds are not exposed to the same chemistries annually. Consecutive applications should be avoided whether the exposure takes place within or between years.

General resistance management strategies that should be used in rotational cropping years include:

- Only applying pesticides when pest levels are at or above threshold level, or when disease forecasting models determine that applications are appropriate.
- Alternating chemical classes between applications.
- Controlling known carrot pests in rotational years by using different pesticide chemistries labeled for rotational crops that may not be registered in carrots.
- Utilizing BioIPM strategies that decrease reliance on pesticide use.

Pests to Watch for Resistance Development

Insects: Carrot Weevil, Carrot Rust Fly

Diseases: Alternaria Leaf Blight, Cercospora Leaf Blight

Weeds: Marestail, pineappleweed, giant foxtail, green foxtail, velvetleaf, pigweed, large crabgrass, common lambsquarters, dodder, wild proso millet

B. Rotational Crop Resistance Management

HERBICIDES

Rotational resistance management strategies can be very effective to control weeds during the non-carrot years, since there are few herbicides available for carrots and it is essential to maintain the registered herbicides on carrots. Certain problem weeds, such as annual grasses, may be difficult to control in carrots because resistance to graminicides (grass herbicides) has been observed in several species worldwide. Resistant grasses and other weeds must be managed in rotational crops with herbicides with alternative modes of action. Limiting the weeds that are contributing to the seed bank will reduce populations in subsequent carrot crops. When using this strategy, chemical classes that are not available for the carrot crop should be used when possible, and chemical classes should be alternated between years.

Examples of rotational weed resistance management strategies for the carrot cropping system include:

- Using herbicide tank mixes of different chemical classes during the non-carrot year. However, remember that the chemical classes should not be ones that are used in the carrot year.
- Rotating herbicide chemistries each year to prevent resistant weed selection with repeated exposure to the same chemical class. For example, if Linuron is applied during the carrot crop year, do not apply herbicides that are in the same class in the rotational crop. The EPA resistance management designation codes for herbicides are found in the **In-Season Resistance Management** section.

C. Area Wide Resistance Management

INSECTICIDES

Insecticides with the same EPA resistance management designation code (see **In-Season Resistance Management** for codes) should not be used to control insects in consecutive sprays. For example, carrot weevils can be serious pests and over-winter in field debris or in field edges. Adults move into carrot fields in the spring and begin feeding. The most serious damage occurs from larval tunneling in roots. Therefore, growers must control adult weevils prior to egg laying and larval development. Adult weevils from the previous year overwinter and re-enter fields in the current year. Any adult weevil exposed to a specific insecticide class the previous fall should not be treated with the same class in the current season. This resistance management strategy should be employed for all pests that may persist or migrate short distances over cropping seasons.

In areas where the carrot rust fly is a problem, avoiding treatment of the larval population in successive years should also be practiced.

FUNGICIDES

Fungicide chemistries with single site modes of action have a high possibility of selecting resistance. Limiting pathogen exposure to these chemistries in the rotational years will delay the onset of resistance and maintain the compound's efficacy. Pathogens that are showing signs of reduced efficacy and increased disease pressure should be monitored for baseline levels of resistance. If populations are shown to be sensitive to resistance, continued exposure to the same chemistries will accentuate the concern.

The most serious concerns for resistance to fungicides are found with the newer, reduced-risk, single site chemistries such as the strobilurin fungicides (Group 11). To view the materials with a high probability of resistance development see the EPA designation code and relative risk of resistance development to fungicides in the table above. If sensitivity to Group 11 fungicides is seen in the previous years, carrot crops, steps should be taken to reduce disease pressure in the current cropping system while alternating fungicide classes to reduce exposures to sensitive materials.

For example, the Alternaria leaf blight and Cercospora leaf blight pathogens overwinter in plant refuse. Wind, rain, or insects can move the spores into fields during the current cropping season. Selecting fields that are farther away from the previous year's carrots would limit leaf blight infections. Carrots from the previous year that show signs of leaf blight insensitivity (building resistance) to strobilurin fungicides (Group 11) should use the Group 11 fungicides sparingly in the current cropping system. When fungicides are applied during the rotational year, consider alternating or tank mix-

Common Carrot Fungicides with a High Relative Risk of Developing Resistance

EPA Group 2:	Dicarboximide
	Rovral
	Iprodione
EPA Group 4:	Acylamines
	Ridomil Gold
	Mefenoxam
	Apron
	Metalaxyl
EPA Group 11:	Strobilurins
	Flint
	Trifloxystrobin
	Cabrio
	Pristine
	Pyraclostrobin
	Amistar
	Quadris
	Azoxystrobin

ing multi-site and single-site fungicides to limit leaf blight sensitivity. Do not apply strobilurin fungicides more than 3 times per season.

***ALTERNARIA* LEAF BLIGHT**

***CERCOSPORA* LEAF BLIGHT**

Resistance Concerns

If a grower has a concern that a weed, insect, or plant pathogen population is becoming resistant to a specific pesticide, an accurate sample and test should be done to confirm if resistance is the concern. Many university laboratories and private companies have testing procedures for evaluating the resistance of pest populations. Consult the individual labs for specific sampling protocols. Laboratory documentation would confirm if resistance is present, and would therefore allow growers to alter their management strategies.

D. BioIPM Techniques

The alternative bioIPM techniques for specific pests are discussed in the next topic section – **Pest Management in Rotational Crops**. General strategies include:

DISEASE

Use proper bioIPM strategies such as managing weed hosts and utilizing disease forecasting modules to schedule fungicide applications. Selecting resistant cultivars is an economically viable solution. Also, growers should consider long-term cropping systems with grains and other crops which are not susceptible to root knot nematodes to reduce pest populations in the soil.

INSECT

Incorporate bioIPM strategies such as cultivar selection, spot treatments, trap cropping, and biological controls whenever possible.

WEED

Use proper cultural, mechanical, and other bioIPM practices to limit weed populations.

Notes:

Pest Management in Rotational Crops

Preplant				

Cultural pest management strategies should be utilized in rotational years or in rotational crops to control pest numbers during the carrot cropping season.

Read the following statements in order and check all that apply. Refer to the corresponding sections on the following pages for more information.

- [ ] ***A. Carrot pests are managed in rotational crops.***
- [ ] ***B. Carrot trimmings and/or other plant residues are eliminated.***
- [ ] ***C. BioIPM techniques are used to manage crucial pest problems (such as carrot weevils, critical weeds, leaf blights) in rotational crops.***
- [ ] ***D. Field maps of pest population levels for insects, diseases, and weeds are maintained for long-term comparisons and evaluation of management strategies.***

A. Rotational Pest Management

Pest populations in the vegetable cropping season can be greatly limited if proper management strategies are utilized in the non-carrot years. Utilizing a variety of bioIPM strategies during the non-carrot crop will reduce in-season pest pressures. Proper planning and implementation of these various strategies will greatly enhance pest management programs during the carrot season, and could decrease pest populations and limit pesticide usage. Field maps should be maintained from year to year to target areas that have high pest pressures for management in the non-carrot years.

B. Destroy Trimmings and/or Plant Residues

To reduce inoculum sources for disease outbreaks, carrots should be completely plowed down within two weeks after harvest. Alternaria and Cercospora leaf blight inoculum overwinters in carrot residue. Eliminating inoculum sources can greatly reduce pathogen populations in the subsequent growing season. The pathogen can live on the plant debris for up to two years. Carrot weevils also overwinter on plant debris and plowing down plant residue will limit weevil overwintering sites.

Carrot debris remaining from harvest and processing, such as trimmings or culls, should be destroyed by soil incorporation as well. Cull piles and trimmings should be field spread on fields in the winter, subjecting them to multiple freeze and thaw cycles, then plowing them under prior to the growing season. If carrot remnants sprout, they should be killed using a herbicide or mechanical weed control method.

C. BioIPM Techniques

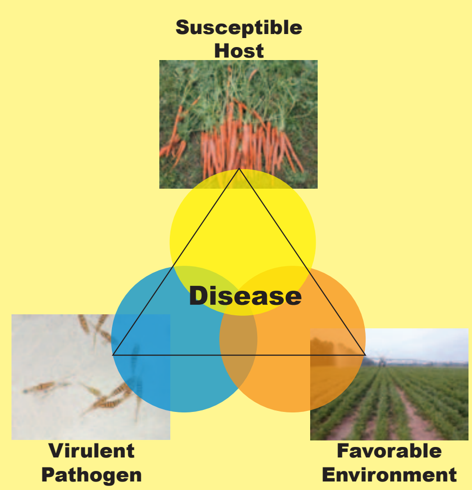
DISEASE

To help control root knot nematode in carrots, growers should utilize cover crops or rotational crops that are not hosts of root knot nematode. These crops include grain crops (such as corn, wheat, barley, and rye), Brassica species (such as oil seed, radish, and white mustards) and other crops such as forage pearl millet. More specifics on nematode management can be found in **In-Season Nematode Management** section.

Control volunteer carrots and host plants to limit spore formation and spread of leaf blight inoculum.

The Disease Triangle

All three components of the "disease triangle" must be present for diseases to develop. The three components of the disease triangle include sources of the pathogen, the planting of susceptible varieties, and a favorable environment. Limiting any of these components greatly reduces the risk of disease. Therefore, disease control strategies should revolve around managing any component of the disease triangle.



INSECTS:

Carrot weevils overwinter in field edges or in field debris. A complete plow down of carrot residues in fields and in sites adjacent to field edges will limit adult overwinter sites, limiting populations in the spring. Also, winter mortality of carrot weevil populations can occur when freezing occurs in areas where adults are overwintering.

Since carrot weevils and carrot fly are frequently localized populations, crop rotations that isolate the current crop from previous carrot crops effectively reduce current season infestations.

Carrot weevil life stages

WEEDS

Mechanical, physical, biological, or cultural practices should be utilized in the non-carrot years in and around the field to limit the number of weed seeds entering the seed bank. Tillage, burning, or other operations around field edges should occur before weeds flower to ensure minimal seeds are produced.

Growers should manage critical weeds of carrots in rotational crops (such as snap beans and sweet corn) to limit the seeds reaching the seed bank. Weeds such as pineappleweed, marestail, and wild carrots should be controlled in rotational crops since they can harbor insect and disease pests of carrots.

Spot spraying weed patches in and around fields, and mowing or tilling operations on field edges during the non-carrot years are effective weed management strategies if completed before seeds form.

Some herbicides can be biologically active at extremely low rates and residues may persist in the soil for a long time (such as some sulfonylurea and imidazolinone herbicides). There are various plant-back restrictions for these materials, so read the herbicide labels to ensure that they fit into the carrot system.

Crop rotation is an important part of any weed management program. Certain weeds naturally become associated with certain crops because of similar life cycles or similar growth requirements. If any one crop is grown continuously, weeds associated with that crop (such as wild proso millet in sweet corn) tend to dominate and proliferate year after year. A diverse crop rotation discourages domination by any one group of weed species and provides the opportunity to control troublesome species.

Pest Population Notes

Complete field notes and histories of pest populations should be kept on carrot fields. Careful notes should be kept on long-term soil diseases like cavity spot and nematode injury. Knowing the exact locations of these carrot problems will allow growers to 1) determine if carrots should be planted in the field or not, or 2) avoid “hot spot” locations in those fields; resulting in better production and pest management.

Notes:

D. Field Maps

Field maps designating areas where insect, disease and weed populations are found should be kept for long-term comparisons. Maps allow growers to become better managers by focusing on key concerns within fields, and by avoiding pests when possible.

Field maps show an overview of a particular farm. Field maps can be created on a computer or drawn by hand and should include areas that were infested by insects, weeds, or disease the previous years. Pesticide use, soil fertility, yield, or quality of previous crops can also be tracked.

Field maps should be used as a resource during field selection when planning crop rotations.

1) Draw an overview of the entire farm. This should include all of your fields.

2) Record what was planted in each field, including varieties.

3) Mark insect infestations from the previous year with X's or your choice of symbol. Be sure to differentiate between different pests.

4) Mark disease infestations from the previous year with your choice of symbol. Be sure to differentiate between different diseases.

5) Record what pesticides were used in each field and the rate of application.

6) Record weed patches, perennial weeds, or weed escapes on the map.

7) Record fertilizer programs.

8) Record production (quality & yield).

Global Positioning Systems (GPS) and Geographic Information Systems (GIS)

Global Positioning Systems (GPS) and Geographic Information Systems (GIS) technologies can be used for a geo-referenced spatial interpretation of data. In agricultural systems, these data can be used to quantify sub-field similarities and/or differences in crop yield, quality, pest populations, soil fertility, and pH, and can be used to apply agricultural inputs such as pesticides and fertilizer applications on a site specific basis.

How to get started with GPS unit and data logger and GIS based software:

GPS field boundaries can be taken at any time in the fall or early spring. They provide a general overview of the entire farm. Scouting points can be marked anytime from planting time to plant emergence. They provide specific information within each field for use during the entire growing season.

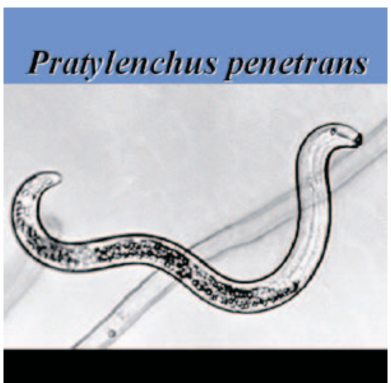
Procedure:

1. Mark individual field boundaries using a GPS unit.
2. Mark all scouting sites used for management information throughout the year.
3. Enter field boundaries and scouting sites into the GIS based software.
4. Organize farmview and fieldview in the database by crop year.
5. Create maps according to present and future farming needs.
6. Analyze data to obtain pest control information and evaluate cost effectiveness of control practices and possible effects of production practices on pest population distributions and dynamics.
7. Incorporate all crop year information into the database.

Soil Sampling

Preplant

Soil sampling is essential to ensure appropriate fertilizer recommendations. Accurate soil sampling results in more efficient fertilizer use, reduces costs, and reduces the potential for environmental contamination from excess fertilizer applications. Additionally, soil sampling ensures that disease and nematode population levels are known.



Read the following statements in order and check all that apply. Refer to the corresponding sections on the following pages for more information.

☐ **A.** ***One composite soil sample for each 5 acres of the field is taken to determine nutrient recommendations, pH, and organic matter levels.***

☐ **B.** ***Each field is sampled for root knot nematode levels before deciding to fumigate or plant carrots.***

☐ **C.** ***Soil organic matter is monitored and practices that increase organic matter are implemented.***

☐ **D.** ***Soil sampling determines other soil health characteristics and soil-borne disease levels.***

A. How to Sample Soils

Taking accurate soil samples is the first step in determining nutrient needs, pH, and organic matter levels. The following is detailed information on soil sampling.

NUMBER OF SAMPLES:

One composite sample should be taken for every 5 acres within the field. This will account for spatial variability across the field. Spatial variability across a field could have a great impact on liming practices, fertility programs, and carrot production potential.

FIELD AREA PER SAMPLE

Within each five acre area, collect a composite sample of 10 to 20 cores taken along a W-shaped pattern. Each sample area should have a similar crop and fertilizer history over the last two years as well as similar soil characteristics. Sample small areas within the field that differ topographically if they are large enough to warrant special treatment.

WHEN TO SAMPLE

Soil samples may be taken in the fall or the spring before the carrot crop is planted. Fall sampling ensures that the test results are ready prior to planting. Be aware of situations that may cause nutrients to leach beneath the root level between sampling and planting such as heavy rainfall or excessive pre-irrigation.

SAMPLING TOOLS

A stainless steel soil-sampling probe is recommended for obtaining soil samples. Tools must be clean and free from rust. Collect the sub-samples in a plastic or stainless steel container. **DO NOT USE** galvanized or brass equipment of any kind as they may contaminate the samples with micronutrients.

SAMPLING DEPTH

Sampling depth is based on tillage depth and is generally considered the top 6-8 inches of soil. Sampling depth should be maintained from year to year so soil test values can be more accurately compared. Sampling deeper than the tillage layer potentially results in underestimation of organic matter and available nutrients.

HANDLING AND MAILING

To obtain a composite soil sample, mix sub-samples thoroughly. From the mixed sample, put 1 to 2 cups into a clean paper bag. Take the sample to a local university extension office or fertilizer dealer for analysis.

Soil Test Results

Proper interpretation of the soil test results will allow growers to plan their fertility programs appropriately to ensure proper crop growth, production, and quality while limiting adverse environmental effects. Requirements for nitrogen, phosphorus, potassium, and liming needs can be derived directly from the soil test results. Results provide a current measurement of organic matter percentage and soil pH.

The soil analysis also provides secondary and micronutrient analysis (in ppm) including calcium, magnesium, boron, manganese, zinc, and sulfur if requested. Carrots sometimes require manganese, boron, and copper under Wisconsin production systems.

Using the test results from analysis and the corresponding fertility recommendations will provide adequate nutrition for the carrot crop.

B. Sampling to Inform Fumigation Decisions

Root knot nematodes can cause tremendous yield and quality loss to susceptible carrots. Since fumigation is expensive and destructive to soil biodiversity, it should only occur when root knot nematodes are found at or above recommended threshold levels (greater than 40 per 100 cubic centimeters of soil). Fumigation should occur in the fall prior to planting carrots the next spring.

Root Knot Thresholds

Fumigation should only occur if nematodes are found in the field to be greater than 40 per 100 cubic centimeters. Usually, fumigation for carrots is not economically viable, and it is better to avoid fields with high nematode populations. More details can be found in the **In-Season Nematode Management** section which also contains information on specific practices to reduce populations.

Notes:

C. Organic Matter

Organic matter quality and quantity is directly related to many key soil quality indicators. Small increases in organic matter content can have many beneficial effects on soil health, including providing carbon and energy sources for soil microbes, stabilizing soil particles, increasing soil nutrient availability, resisting compaction, and filtering environmental pollutants. Practices that may increase soil organic matter (such as cover crops, green manures, residue management, tillage systems, organic amendments) should be implemented when possible, and the changes in organic matter content should be tracked from year to year for long-term comparisons.

Certain soil types may vary in organic matter content. Organic matter content affects availability of nitrogen in soils. Decomposition and mineralization of soil organic matter leads to increased plant available nitrogen. As a result, increasing soil organic matter content leads to a general decrease in the amount of nitrogen fertilizer required to optimize crop productivity.

The soil quality production strategies relating to the changes in organic matter content are currently being researched. Specific recommendations will be included once field data have proven that the strategies are effective and economically feasible.

Quick note

The target soil pH level which optimizes carrot production on muck soils is 5.6; on mineral soils it is 5.8. Growers should track and manage pH over time.

D. Advanced Screens of Soil Characteristics

Soil quality is defined as the capacity to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality and promote plant and animal health. Healthy, biologically active soils enhance crop productivity, increase water and nutrient availability, decrease disease pressures, and filter environmental pollutants.

Laboratories can run a screen for various soil properties to track long-term changes in soil health. These properties include:

- Aggregate stability - ability of soil aggregates to resist disruption by outside forces (usually associated with tillage, water or wind). Soils with high aggregate stability are less susceptible to soil loss from water and wind erosion. Soils with high aggregate stability also provide better water and air infiltration and improved root growth.
- Water holding capacity - water that can be retained by soil. Increasing water holding capacity increases plant available water, decreasing the need for irrigation.
- Bulk density- measure of the weight of the soil per unit volume. It provides an indication of the degree of soil compaction.
- Total soil carbon - considered the "lifeblood" of the soil and is integrally linked to soil chemical, physical, and biological properties. Total soil carbon includes fractions that are very easily degraded (mineralized within 1 to 5 years) to fractions that are extremely resistant to breakdown or recalcitrant (turnover times from 50 to 1000's of years). Different soil carbon fractions perform different functions in the soil. For example, the active soil carbon fraction is the principal source of nutrients and energy for soil microbes. Active soil carbon is also responsible for disease suppression, nutrient cycling and formation of large (macro) aggregates. Stable or recalcitrant soil carbon contributes to the soil cation exchange capacity (CEC), soil water retention, and formation of smaller (micro) aggregates. Increasing soil carbon by incorporating organic materials like crop residues, green manures, and organic amendments (manure, compost, paper mill residuals, cannery wastes, etc.) can improve many soil properties including increased soil porosity, lower bulk density, higher water-holding capacity, greater aggregation, increased aggregate stability, lower erodibility, enhanced nutrient availability, and increased CEC.
- Soil compaction - impedes root growth limiting the amount of soil explored by roots for air, nutrients and water. The degree of soil compaction can be determined from bulk density measurements or by measuring penetration resistance (using a penetrometer).

Muck Soils and Flavor

Muck soils tend to reduce sweetness of fresh carrot and increase harsh flavors. Excessive nutrient levels, warm soil temperatures, and moisture stress may be factors influencing flavor on certain varieties on carrots grown on specific soil types.

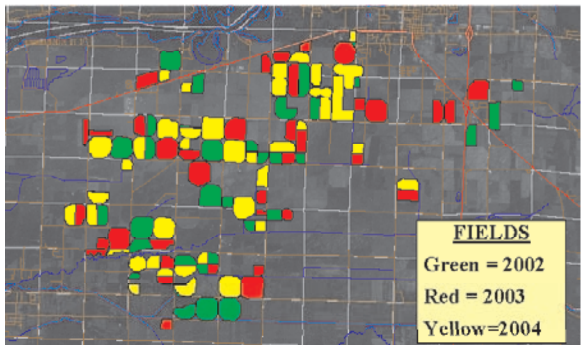
Quick Note

Growers can manage pH levels by liming or adding organic amendments to the soil during the rotational cropping system. The time required before pH is adjusted will depend on lime particle size. The smaller the particle size, the faster pH responds. Lime is usually applied 6 to 18 months before the target crop.

Field Selection

Preplant

Optimizing carrot health begins with selecting the appropriate planting site. Field placement and selection should be based on several pest and crop management considerations.



Example of Spatial Field Locations

Read the following statements in order and check all that apply. Refer to the corresponding sections on the following pages for more information.

- [ ] ***A. Carrots are rotated across fields on a three-year (or longer) schedule.***
- [ ] ***B. Crop rotations are planned to limit the buildup of disease, insect, weed, and nematode concerns.***
- [ ] ***C. Crops are rotated by at least ¼ of a mile to limit carrot weevil, cercospera, and alternaria leaf blight concerns.***
- [ ] ***D. Fields are mapped to monitor population levels.***

A. Temporal Rotation

Carrots should not be grown on fields where they were planted the previous year. Temporal (time in years) rotations should be increased for as long as possible. A rotation of at least 3 years is recommended. Longer rotations have benefits for disease and nematode suppression, insect control, weed management, soil quality characteristics, and soil biodiversity. Long-term rotations are among the most effective cultural control strategies for pest populations.

Different Types of Rotations

Temporal rotation – refers to the number of years since carrots were last planted. An example of a 3-year rotation is carrots, beans, onions, then carrots.

Spatial rotation – refers to the distance from the current carrot fields to last year's carrot fields.

B. Rotational Crops

Crops that are typically grown in rotation and are viable rotational options include snap beans or soybeans, onions, and field or sweet corn. These crops limit disease potential and root knot nematode populations. Crops that should not be grown in rotation with carrots include potato, pepper, eggplant, tomato, and strawberry due to root knot nematode, white mold, and bacterial soft rot concerns. Sod should be avoided in rotation because it harbors insect pests such as cutworms and wireworms.

Pest management and production practices are influenced by previous crops and rotational histories. Growers can be better managers by keeping field records of cropping history, pest populations, and management strategies. Field mapping systems should be used to designate possible rotational concerns.

Field maps provide an overview of a particular farm and can be created on a computer or drawn by hand. These maps should designate areas infested by insects, weeds, or plant pathogens in previous years. Field maps can help in decision-making in terms of identifiying future locations of fields. For example, if the field had soil-borne pest problems, rotate to a non-host crop to reduce the pest populations.

C. Spatial Rotation

The distance between the current and previous year's carrot crop can have an effect on the current pest pressures. A distance of at least ¼ mile (about 400 meters) between the previous year's carrots and the current year's field reduces and delays weevil infestations. Later planting dates can also delay and/or limit weevil infestations in the next year's carrot crop.

Diseases such as alternaria leaf blight and cercospera leaf blight can be limited by longer distances of rotations as well. Alternaria spores can move via air (wind) and water, and longer distances between the previous year's and current year's carrot crops can help in limiting infections.

D. Map Fields to Monitor Pest Populations Over Time

Pest management and production practices are influenced by previous crops and rotational histories. Growers can be better managers by keeping field records of cropping history, pest populations, and management strategies. Field mapping systems should be used to designate possible field concerns. For example, if the field had soil-borne pest problems, rotate to a non-host crop to reduce the pest populations. Information on field mapping practices can be found in the **Preplant – Pest Management in Rotational Crops** section.

Problem pests and concerns to record may include:

- Insects — wireworm, cutworms, and carrot weevil.
- Disease — cavity spot, root knot nematodes, cercospora leaf blight, and alternaria leaf blights.
- Weeds — pigweed, nightshades, foxtails, wild proso millet, marestail, smartweed, and common lambsquarters.
- Production information — yields, quality, and marketability.

Notes:

Seed Selection

Seed selection is important to assure vigorous crop growth and to ensure crop productivity for the intended market. Varieties are available for processing, cello-pack fresh market, bunching, and cut and peel. In addition, some carrot varieties have resistance to key pathogens.

Read the following statements in order and check all that apply. Refer to the corresponding sections on the following pages for more information.

☐ **A. *Quality, pathogen-free seed is purchased.***

☐ **B. *Seed is stored and properly handled.***

☐ **C. *Varieties are selected that are adapted to the production environment, for quality, and for marketing or processing attributes.***

☐ **D. *Varieties are selected for disease and insect resistance.***

A. Certified Seed

Planting only quality, pathogen-free seed is a crucial phase in the carrot BioIPM system, and is the foundation of any management program for a productive carrot crop. Locally grown seed may contain high levels of pathogens that may cause problems during the season.

Quality seed must meet phytosanitary standards established by the international seed trade industry. These standards reduce the possibility of introducing disease-causing micro-organisms on seeds. Qualtiy seed should carry a phytosanitary certificate.

Be sure to plant only weed-free carrot seed. Historically, crop seed has been a major source of new weed introductions in agriculture. Moreover, the weed seed found in crop seed often includes species that are difficult to manage and thus escape control in the seed crop.

Seed lots with less than threshold levels of a specific pathogen (colony forming units - CFU's) should be purchased. States vary in their CFU requirements, but in general, carrot seed should be less then 100 CFU's for bacterial blight when the disease is of concern. Consult with your state department of agriculture for specific CFU requirements.

B. Proper Seed Handling

Maintaining viable and healthy seed is key to optimizing crop growth and development and crop health. Seed should be stored in a cool dry location. Do not plant seed that is over 8 months old unless you have quantified seed viability and vigor. Set up planters and handle seed carefully to minimize potential damage.

Notes:

C. Planting Adapted Varieties

Varieties differ in their adaptation to given production schemes. Some varieties may perform better on muck versus mineral soils. In addition, the production environment may influence the relative health of the crop and varieties may differ in how they respond to different stress conditions. Planting multiple varieties can help reduce the risk of specific stress events limiting yields.

A key trait to evaluate in carrots is time to germination and germination uniformity. Carrots are small seeded and have variable germination rates. Emergence may vary by 7 to 14 days in some lots, and these differences are typically found in dry, poor soil. Uniform stands help promote canopy development and a healthier crop than variable stands, so uniform and timely germination is essential.

Quality factors among carrot varieties should be considered. Some varieties have better flavor under muck soils, making them more suitable for the fresh market. Carrot size, shape, resistance to cracking, resistance to bolting, flavor, and storability are quality factors to be considered.

Carrot variety resistant to foliar diseases.

Carrot variety highly susceptible to foliar diseases.

D. Resistant Varieties

Many varieties fulfill marketing requirements and provide resistance to common carrot pests. Resistant varieties are now available for leaf blights and aster yellows, and should be used when possible.

Cultivars and their resistance to foliar blights

Resistance level	Available Varieties
Resistant	Bolaro, Carson, Cheyenne, Calgary, Goliah, Canterbury, Halfback, Commanche, Sirocco
Moderately resistant	Canada, Prospector, 713087, Indiana, Nandrin, Danvers 126, SugarSnax 54, Enterprise, Nevis, Recoleta
Susceptible	Prodigy, 80494, Protégé, Yellowstone, Sunrise, PY-60, Gold King, Heritage, Early Gold, Lucky B, Fontana

Cultivars and their resistance to Aster Yellows

Resistance level	Available Varieties
Resistant	Prospector, Recoleta, Enterprise, Triple Play, PrimeCut 59, Nimrod, Sirocco, Bejo 2510, Bejo 2588, Spearhead, Growers Choice, Gold King
Tolerant	Cupar, Lucky B, Heritage, Prodigy, Noveno, Nagadir, Columbia, Interceptor, Morecuts, Prodigy, SugarSnax 54, Bradford, Nikki, Bolero, Bremen, Canada, Florida
Susceptible	Danvers 126, Early Gold, Bersky, Carson, Arrowhead

Using Resistant Varieties for Aster Yellows and Blight Control

- Varieties differ in disease progress, lesions/plant, and impact of disease on yield and quality.
- Useful levels of resistance are available.
- Grower awareness of disease susceptibility is crucial.
- Block and spray according to the disease susceptibility of the variety planted.
- Cultivar resistance = fewer fungicide and insecticide inputs.

Field Preparation

Planting

Fields should be prepared properly to maintain soil moisture and allow for root penetration and water infiltration. Field preparation includes tillage, proper soil moisture levels at planting, and the optional practice of incorporating green manures or other composted materials. Planning field preparation operations is improved by keeping good field records of the previous year's rotational crop and pest pressures.

Read the following statements in order and check all that apply. Refer to the corresponding sections on the following pages for more information.

☐ ***A. Preplant tillage is adequate for carrot planting and weed control and can be used to eliminate compaction.***

☐ ***B. Soil moisture levels are near field capacity at planting.***

☐ ***C. Raised beds are used for carrot production.***

☐ ***D. Equipment is calibrated prior to planting.***

A. Pre-plant Tillage

Pre-plant tillage is often an important part of carrot pest management. Tillage effectively controls emerged annual weeds and, when combined with herbicides, can manage perennial weeds and volunteer carrots. However, tillage can increase some perennial weed problems if underground storage organs are spread by tillage. Tillage can also interfere with herbicide uptake by weeds if herbicides are sprayed too soon after a tillage operation.

Water infiltration is influenced by crusting, organic matter, soil aggregation, and macro-pore formation (earth worm tunnels). Tillage can have both positive and negative effects on these factors. Tillage can improve water infiltration by disrupting surface seals or crusts. Deep tillage (greater than 8-10 inches) disrupts compacted areas formed by field traffic and natural hard pans. Tillage can also break up clods if done at the appropriate time, but may promote clod formation in excessively wet, heavy soils.

Generally, tillage negatively influences soil aggregation, macro-pore formation, and organic matter. Tillage is necessary, however, for loosening the soil prior to planting, managing plant residues, and warming the soil early in the season. Chisel plowing of corn stalks leaves residues that interfere with carrot planting. Avoid excessive tillage as it increases the cost of production and may increase the likelihood of wind erosion, loss of soil structure, potential for crusting, and soil compaction.

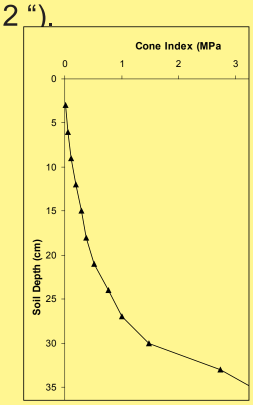
General guidelines for preplant tillage include the following:

- Clean tillage equipment of all soil and plant residue when moving from field to field to prevent the spread of weeds and pathogens between fields.
- Vary tillage depth from year to year to prevent the buildup of a plowpan at the lower tillage level. Occasionally, deep tillage operations (ripping to 18”) may be done ONLY if hardpans are a concern.
- When using heavy equipment, distribute the weight over multiple tires and axles to spread the load over as large an area as possible. Adjust speeds, ballast, and tire pressure to minimize tire slippage.

Subsurface Compaction Management

Subsurface compaction can limit carrot yield and quality and increase nematode damage.

This figure shows the compaction depth observed in Plainfield loamy sand in 2004. The Cone Index represents the force required to penetrate through soil. A Cone Index greater than 2 MPa can limit rooting and greater than 3 MPa impedes root penetration. Cultivated sand soils have developed compacted layers that limit rooting of carrot, potato, field corn, soybean, and most other crops. This commercial field would have prevented carrot rooting below 30 cm (12 “).



Precision ripping is an excellent method to manage compacted soil prior to planting carrots. Deep ripping has reduced the Cone Index to below 1.0 MPa in the furrow of the tillage shank. Rows are marked with fertilizer and bedded at the same time as the ripping operation. Precision ripping relies on GPS guidance systems to ensure crop rows are centered over the area traveled by the plow shank. Ripping and then planting on identical pattern with assistance of GPS guidance systems can ensure that the crop row is placed directly over soil loosened with deep ripping.

Manage subsurface compaction by:

a. Minimizing field traffic on wet soils

b. Precision ripping

c. Using flotation equipment such as wide tires or tracks

d. Planting deep rooted crops

B. Soil Moisture and Irrigation

Plant when the soil moisture is just below field capacity to minimize effects of wheel traffic on compaction but optimize soil conditions for germination and establishment. Planting in cool, wet soil can delay emergence and increase sensitivity to soil borne diseases such as rhizoctonia. If the soils are excessively dry, irrigate prior to planting.

Notes:

Feel Chart for Estimating Soil Moisture

(Soil Moisture %):

Optimum for carrot planting: 70-80

Sand or loamy sand soil texture

Below 20: No ball forms. Single grained soil flows through fingers with ease.

35-40: Forms weak brittle balls. Finger print outline not discernible. No soil sticks to hand.

50: Forms very weak ball. If soil is well broken up, it will form more than one ball upon squeezing. Fingerprint outline barely discernible. Soil grains will stick to hand.

60-65: Forms weak, brittle ball. Fingerprint outline not as distinct. Soil particles will stick to hand in a patchy pattern.

70-80: Forms weak ball. Distinct fingerprint outline on ball. Soil particles will stick to palm.

100: Upon squeezing, no free water appears on ball but wet outline of ball is left on hand. Ball has some stickiness and a sharp fingerprint outline is left on it.

Loam, silt loam, clay loam soil texture

Below 20: Powdery, dry, will not form a ball; if soil is crusted, easy to break into powdery condition.

35-40: A ball can be formed under pressure, but some soil will fall or flake away when hand is opened. The ball is very crumbly and hardly holds its shape.

50: Forms a ball readily, holds its shape. No moist feeling is left on hand nor will any soil fragments cling to palm. Ball is very brittle and breaks readily. Soil falls or crumbles into small granules when broken.

60-65: Forms firm ball; finger marks imprint on ball. Hand feels damp but not moist. Soil doesn't stick to hand. Ball is pliable. When broken, ball shatters or falls into medium-size fragments.

70-80: Damp and heavy; slightly sticky when squeezed. Forms tight plastic ball. Shatters with a burst into large particles when broken. Hand is moist.

100: Wet sticky, doughy, and slick. A very plastic ball is formed, handles like stiff bread dough or modeling clay; not muddy. Leaves water on hand. Ball will change shape and cracks will appear before breaking.

C. Raised Beds

Carrots should be planted with raised beds because this method can promote drainage, encourage quick emergence, increase depth to soil layers limiting root growth, and limit disease concerns by preventing standing water. Information on bed formation can be found in the **Planting Process** section.

Compaction Management

Soil compaction can reduce root development leading to shortened or malformed tap roots, limit or delay crop emergence, and reduce crop health. Prevent surface soil compaction by using these methods:

a. Do not till soils that are too wet.

b. Incorporate green manures, cover crops, or plant residues to improve soil organic matter and surface soil structure.

c. Plant companion crops to decrease soil crusting and prevent wind erosion.

d. Minimize wheel traffic over the crop row and on wet soils.

e. Minimize the number of tillage passes (excessive tillage degrades soil structure).

D. Calibrate Planting Equipment

Before planting begins, all planting equipment should be calibrated to ensure uniform and even planting of carrot seed. Planter types should be matched with the seed, whether it is pelleted or raw. Precision planters can be used to ensure uniform planting. Guidance systems can be used to make sure crop rows are placed directly on furrows from subsoil tillage.

GPS Guidance Systems

Guidance and automated steering systems rely on GPS technology to ensure that tractors and implements are traveling in the same pattern over the field. Global positioning systems (GPS) correct the path of the tractor by using signals from multiple satellites along with differential (known position of reckoning). Current correction on GPS guidance and automated steering systems allow accuracy of less than 2” (5 cm).

Using this system for ripping, row marking, banding fertilizers, and planting carrots ensures precision seed placement. This allows seed to be located over the non-compacted plow furrow and near nutrients important for crop growth.

Auto-steering allows for faster operational speed and less stress and fatigue on operators.

Multiple companies offer GPS guidance and automated steering systems. Examples of products available in 2007 include Trimble and GreenStar.

Planting Process

Planting

A good stand of carrots is essential to maximize crop productivity while minimizing the effect of weeds, plant pathogens, and insect pests. Environmental conditions at planting, accurate equipment, and careful planting processes all contribute to the health, quality, and emergence of the crop.

Read the following statements in order and check all that apply. Refer to the corresponding sections on the following pages for more information.

☐ ***A. Planting occurs at proper rates and at adequate temperatures.***

☐ ***B. Carrot seed is treated with a fungicide.***

☐ ***C. Carrots are planted in beds with a nurse crop.***

☐ ***D. Cultural pest management strategies are utilized during the planting process.***

A. Seed and Soil Conditions

Carrots germinate best at soil temperatures between 59 and 65 degrees F. Planting occurs from mid- to late April until the first week of July in Wisconsin. Planting should occur when air temperatures are between 60-70 degrees F. Carrot seedlings can tolerate frost upon emergence.

Carrot seed is small, and emerging seedlings are vulnerable to physical damage. Seed should be planted ½ to ¾" below the soil surface. Soil to seed contact is important for germination. Therefore, plant immediately after final tillage to ensure moist soil is available for germination. Poor soil to seed contact can lead to uneven emergence and poor crop stands.

Rows should be planted 16 to 18 inches apart and planted into beds on 40-60 inch centers. Carrots can be planted in double or triple row configuration (2 or 3 rows spaced 2 to 4 inches apart within a row), but configuration must consider harvest operations. Seeds can be planted at a rate of 7 to 12 per foot depending on target root size and row configuration.

Exact seeding rates and plant populations are specific for each variety and desired market. Processing carrots are exclusively grown in Wisconsin with slicer types planted at slightly higher populations than dicer carrots. Plant populations of dicer carrots typically range from 225,000 to 250,000 plants per acre. Slicer carrots are planted at much higher densities because longer, thinner carrots are desired—600,000 seeds per acre for early slicers and 700,000 seeds per acre for later season slicers. Seeding rate should be adjusted for germination percentage of certified seed. Higher populations are typically planted for fresh production because longer, thinner carrots are desired.

Proper plant populations promote plant growth while limiting leaf wetness. Denser canopies will help suppress weeds but will also increase leaf wetness. Conversely, more open canopies will promote weed growth, but decrease disease incidence.

B. Use Fungicide Seed Treatment

To limit disease concerns in the field, apply a fungicide seed treatment. This will help prevent damping off prior to emergence and will help ensure good emergence and a healthy stand of carrots. Obtain pre-treated seed from the seed supplier, and discuss the treatment and use of fungicide on the seed with the seed representative.

C. Plant Beds with Nurse Crops

Proper care at planting ensures good stand establishment, encourages early germination, and promotes a healthy crop which is better able to withstand minor pest pressures. Carrots are usually planted in raised beds to promote soil drainage, quick emergence, and disease suppression while reducing wind erosion and wind damage. Beds are typically six to ten inches high and range from sixty to seventy inches wide. The exact size of the bed is determined by the equipment used. There should be a one foot edge on all sides of the bed to allow for walking and other field traffic.

Carrots can be grown with nurse crops to reduce wind erosion and soil particle movement, which helps limit the loss of soil and/or the spread of plant pathogens and weed seeds from one field to the next. Nurse crops can be broadcast over the top or planted in strips. Oats, rye, and barley are the most common nurse crops. Plant densities of nurse crops are dependent on the cover crop; for example less barley is needed per unit area than oats. The nurse crops are killed with herbicides once carrots are large enough to be past the danger stage for damage by excessive winds.

D. Cultural Pest Management Strategies

A range of biologically based pest management strategies can be used at planting to limit pest populations later in the season. Some of these strategies include:

- Clean machinery from field to field to limit plant pathogen and weed spread. Dispersal usually occurs at the field entrance, and tillage then spreads pathogens and weed seed through the field. To clean machinery, remove all soil from the implement and tires (by pressure washing), and then spray all equipment parts coming in contact with the soil with a disinfectant. Disinfectant applications can be made with a simple hand sprayer before entering each field.
- Use a perimeter trap crop for carrot weevil control. The trap consists of early planted carrots to trap adult weevils before they infest the new crop. Once weevils enter the trap crop, it is subsequently destroyed.
- Use the stale seedbed method by preparing seedbeds about two weeks prior to planting. Control early-emerging weeds prior to planting with an appropriate non-residual herbicide, thus removing the first flush of weeds. The crop is then planted without additional tillage into a weed-free seedbed. Be sure to check the herbicide label for the required time between application and carrot planting.

Notes:

General IPM

In-season

Integrated Pest Management is a long-term approach to managing pests by combining biological, cultural, mechanical, physical, and chemical tools to combat pests in the most economically and environmentally effective manner.

Read the following statements in order and check all that apply. Refer to the corresponding sections on the following pages for more information.

- ☐ **A.** *Basic IPM approaches are understood.*
- ☐ **B.** *Fields are scouted. Economic thresholds, weather conditions, and resistance management are considered in chemical management decisions.*
- ☐ **C.** *Pest life cycles and ecology are known, and this understanding is used in management decisions.*
- ☐ **D.** *Biointensive IPM strategies are used that incorporate all available control methods, including cultural methods, biological controls, physical and mechanical controls, variety selection, and chemical controls. Pest management is considered in spatial (space) and temporal (time) contexts.*

A. IPM 101

Integrated Pest Management (IPM) involves various strategies to combat pests, including cultural, physical, mechanical, biological, host-plant resistance, and chemical control methods. Implementing a variety of these strategies is the basis for any biologically based pest management program (bioIPM). Resistance management strategies used to maintain efficacy of chemical classes are also an important component of IPM programs. The principal components of IPM programs are:

- Decision making tools, scouting and economic thresholds.
- Utilization of all available pest management strategies.
- Year round implementation of preventative pest measures.
- Looking at the cropping system as a whole, not just single pest species management.

This handbook section focuses on general IPM principles. Specific IPM strategies are also described in other sections for use throughout the production year.

Crop Health

Crop health should be maximized to optimize nutrient use, growth, and productivity while minimizing pest effects. Growers must be knowledgeable about resource requirements of the crop to maximize yield and quality, and must understand life history of pests and the vulnerable pest stages for optimal management.

B. Chemical Management Decisions

Chemical control measures are often an important component of an IPM program, but pesticides are not the only control option. IPM programs use economic threshold levels (at which pest damage exceeds the cost of control) to determine when chemical measures are warranted. Utilize IPM tools, such as disease forecasting, to provide adequate information on when to initiate fungicide spray programs.

When selecting chemical control measures, proper resistance management strategies are also needed. For more information, read the handbook's **Resistance Management** sections and look at the resistance management groups for insecticides, fungicides, and herbicides.

C. Pest Life Cycles and Ecology

Implementation of IPM programs require growers' knowledge of pest life cycles, IPM, control tactics, and general production practices. Advanced biointensive IPM (bioIPM) systems call for a more extensive understanding of pest life cycles and targeting control measures to specific times during each pest's vulnerable stages. A combination of control techniques including available biologically based pest management tools should be incorporated when possible.

On-line resources for Resistance Management Classifications

Fungicide Resistance Action Committee
http://www.frac.info/frac/index.htm

Insecticide Resistance Action Committee
http://www.irac-online.org/

Herbicide Resistance Action Committee
http://www.plantprotection.org/HRAC/

General pest life cycles for key pests in carrots are described below.

DISEASES

Alternaria leaf blight is a common foliar disease of carrots caused by a fungus that overwinters on crop debris in the soil. Alternaria spores are disseminated by wind, water, rain, and/or field equipment. Infection takes place during warm, moist weather conditions in the field. The fungus can live up to 2 years in the soil.

Bacterial leaf blight is a bacterial disease that is transmitted on seed or spread by rain, water, or insects. Wet, warm conditions favor bacterial blight development.

Cavity spot is caused by a fungal pathogen (*Pythium* spp.) that is favored by cool and moist soils. The fungus overwinters as oospores in the soil and can survive for many years.

Powdery mildew is caused by a fungal pathogen that overwinters on infected plant debris, or susceptible weed hosts. Disease development is favored by high temperatures, dry conditions, and high relative humidity levels specifically in the early morning or late evening hours.

Crater rot infection occurs when cool wet weather is encountered. The *Rhizoctonia carotae* fungus overwinters as sclerotia on plant debris and results in "damping off" of carrot seedlings. The seedlings wilt, turn brown and then eventually die, resulting in poor carrot stands. Infection of roots leads to blackened, disfiguring lesions.

Cercospora blight is a foliar disease of carrots, causing damage to foliage and weakening petioles. The fungus overwinters on plant debris and can survive on wild hosts, such as wild carrot. Spores are distributed by wind and water splash. The fungus infects the plant through stomata on the leaf, and lesions appear within 3-5 days of infection.

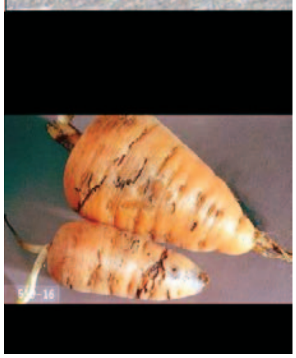
INSECTS

Aster leafhoppers are a serious pest of carrots since they are vectors of the phytoplasm-like organism causing aster yellows. The aster yellows, phytoplasma causes chlorosis and stunting of young leaves progressing to a dense growth of chlorotic shoots. Older leaves are yellow or bronze red, and roots have dense secondary root hair growth, harsh taste, and lighter yellow color. In the US, aster leafhoppers migrate northward each year from the Gulf States and are carried along southerly winds. Adults usually arrive in Wisconsin in May before locally overwintered populations reach adult stage in June. Adults then lay eggs on susceptible plants; nymphs hatch and mature in 20 to 30 days. Usually, 4 to 5 generations of aster leafhoppers can be found per year. The aster yellow phytoplasma is transmitted in a propagative fashion requiring several hours for acquisition and inoculation with a 2-3 week incubation period.

Carrot weevils over-winter as adults in field debris or in field edges. In the spring, adults move into fields and begin feeding. Eggs are laid, and larval development occurs. The most serious damage occurs from larval tunneling in roots. Second generation adults then feed, move to other plant sources, and overwinter.

Carrot weevil life stages

Carrot rust flies lay their eggs on the soil surface around plants. When maggots hatch a few days later, they begin feeding on plant roots, causing stunted growth and injury. Pupation occurs in the soil, and second generation adult flies emerge later in the summer to lay more eggs. The resulting maggots from the second generation cause the most damage. Carrot rust flies overwinter as pupae in the soil or as maggots on carrot roots and residues.



WEEDS:

Broadleaf weeds are dicots with broad leaves and 2 cotyledons, or seed leaves. Seed leaves or cotyledons are the first pair of leaves to appear as the plant emerges through the soil and generally have a different shape and appearance than true leaves.

One key that aids in the identification of broadleaf weeds is the arrangement of the leaves which vary by species. Some broadleaf weeds have leaves arranged alternately on the stem, some have leaves arranged opposite each other, and some have leaves arranged in a whorl about the stem.

Both annual and perennial broadleaf weeds affect carrot production. Annual species live for only a single year and reproduce by seed. They die naturally at the end of the season, after they have produced their seed crop. Perennial species live several years and reproduce by various types of vegetative structures in addition to seed. Perennials can regenerate shoots each year using food reserves stored in vegetative structures in the soil, and thus they are not dependent on seed germination for their survival. They can also re-sprout when their top growth has been removed mechanically or by other means, as long as the underground storage organ is intact.

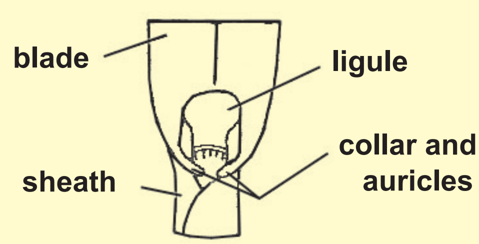
Problem Weeds in Carrots

Weeds of concern in carrot production include: pigweeds, nutsedge, dodder, marestail (horseweed), nightshades, common lambsquarters, smartweed, foxtails, and wild proso millet.

Grass weeds are typically monocots and most **annual grasses** have narrow leaves with parallel veins. To ensure proper control measures, it is important to correctly identify grass weeds. Seedling grasses are more difficult to identify than seedling broadleaf weeds, but as grasses grow, they develop distinguishing features that aid in proper identification. The five basic parts of the grass plant leaf that are commonly used for identification include:

- The **blade** is the flattened portion of the leaf.
- The **collar** is the junction between the blade and the sheath.
- The **sheath** is the portion of the leaf surrounding the stem.
- The **ligule** is a short tube that extends out of the collar. Not all grasses possess this structure.
- The **auricles** may or may not be present at the collar and clasp around the stem.

Monocot Anatomy



D. BioIPM Systems

Biologically based IPM (bioIPM) systems include numerous components based on the carrot system's ecology and incorporate more than field level IPM programs. Progress along the Integrated Pest Management (IPM) continuum toward biointensive IPM is made possible by greater reliance on pest management skills and practices that are inherently prevention-oriented. This will ultimately reduce the reliance on pesticides or practices that are primarily reactive and designed to kill pests when populations exceed prescribed thresholds.

Field data on crop status and pest population levels are the backbone of IPM systems. In making day-to-day operational decisions, the use of scouting data with knowledge of the pest life cycle, economic damage, other pest complexes, and beneficial species is critical to make informed decisions and properly design the pest management strategy. In general, as IPM systems become more complex and prevention-oriented, pest managers will need routine access to data with greater resolution in time and space. Several tactics that are commonly found in biologically based IPM programs include:

- Information management systems for long-term assessment of pest, crop, and production systems.
- Resistance management strategies to maintain efficacy of reduced-risk, low toxicity compounds in the production system.
- Area-wide pest and crop management strategies (multi-field and multi-grower pest control).
- Prevention based strategies using cultural, host plant resistance, physical, mechanical and other non-chemical strategies.
- Beneficial species management.

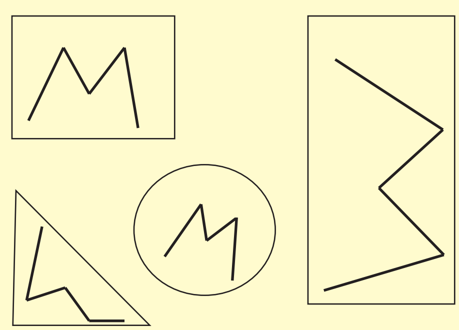
Notes:

Scouting

In-season

Effective scouting during the growing season will ensure that pests are controlled only when they reach economically damaging levels, will ensure efficacy of the applied control measure, and will provide information regarding pest population changes over time and space.

Suggested W Patterns for Scouting



Read the following statements in order and check all that apply. Refer to the corresponding sections on the following pages for more information.

☐ ***A. Fields are only occasionally scouted during the growing season.***

☐ ***B. Fields are scouted weekly for insects, diseases, and weeds starting at crop emergence and continuing until harvest.***

☐ ***C. Management strategies are monitored for their effect on target pests and non-target organisms. Written records are kept for long-term comparisons of pest pressures.***

☐ ***D. Field maps of pest "hot spots" are created to observe general patterns of changes in pest populations over time within a field.***

A. Crop Scouting 101

Crop scouting provides information on pest population dynamics that allows growers to exploit the pests' most vulnerable stages and to accurately time pesticide applications. Field scouting should occur at least weekly from crop emergence until harvest, and twice weekly when aster leafhoppers are present.

The number of scouting locations should be determined by field size. In large fields, one representative scouting site per 10 acres is recommended. On smaller fields at least 4 scouting sites per field should be used to obtain a representative average of pest infestation. To ensure that the entire field is represented in the scouting process, a W-shaped pattern should be followed across the field. If that is not feasible, the scout should make sure that a reasonable amount of the field is scouted, including the edges. Increasing the number of scouting locations provides better information to the crop manager for more informed management decisions.

Specific areas of the field should be scouted to look for certain pest concerns. For example, scout the field's edge for early season carrot weevils because they initially infest the field edges. Scouts and growers should completely inspect areas prone to disease development. These areas include locations near windbreaks, woodlots, low spots in the field, near irrigation pivots, or areas where fungicide applications are difficult to make, such as underneath power lines or utility poles and near highways or residential areas. Scout these disease-prone areas throughout the growing season until harvest is completed.

Individuals who are interested in becoming scouts should take the University of Wisconsin Vegetable Crop Scouting class. Crop scouts must be able to properly identify pests, scout using the proper techniques, and provide an accurate analysis of field pest concerns and overall crop health. Crop managers should employ certified crop scouts or IPM-trained farm employees to scout fields and provide accurate information for decision making.

B. Crop Scouting Methods

Implementing the University of Wisconsin recommended scouting procedures will help growers receive an accurate assessment of pest populations found in their fields. Complete and accurate field diagnosis also provides information to improve the timing of chemical treatments. Specific instructions for scouting the important carrot pests are provided below.

DISEASE

Scout at least weekly throughout the growing season until carrot harvest. Properly identify the disease found at each location in the field and note disease incidence (amount). Scouting should occur just before crop emergence in sites where overwintering inoculum may be present (such as near cull piles). Scout additional sites that could be prone to pathogen infections at least weekly. These include areas near windbreaks, woodlots, the irrigation pivot, or power or utility lines. Assess pathogen incidence based on the Horsfall-Barrett disease rating system.

INSECTS

Aster leafhopper adults are scouted using a sweep net by taking 25 sweeps per site. Count the total number of aster leafhoppers present per sweep. Scouting should begin in early spring when plants are newly sprouted and continue weekly until the end of July.

Carrot weevil adults should be scouted by counting the number of adults per 10 plants at each site. Field edges and margins should be scouted during the early season as these areas are where weevils first infest fields. Scouting these sites can also provide an early detection method for the populations of weevils. Baited traps can also be used to detect weevil populations before they

HORSFALL-BARRATT DISEASE RATING SYSTEM

Foliar disease severity can be monitored using the Horsfall-Barrett disease rating scale. This scale runs from 0 to 11 and accounts for proportion of the field that exhibits disease symptoms. The scale should be recorded on the scouting form.

0= no infection

1=1-3% infection

2=3-6% infection

3=6-12% infection

4=12-25% infection

5=25-50% infection

6=50-75% infection

7=75-88% infection

8=88-94% infection

9=94-97% infection

10=97-100% infection

11=all foliage infected

become a problem in the entire carrot field. To bait, place whole carrot roots or slices on the ground under mesh screen or in jars. Females will be attracted to the carrots and lay eggs on the roots.

Carrot Rust Fly can be monitored using yellow sticky traps.

WEEDS

Begin scouting when the carrots emerge and continue until harvest.

1. At each sampling site, note any weed infestations.
2. Properly identify the weed species since this will dictate the control method.
3. Record the number of weed species present and their locations within the field.
4. If GPS is available, map weedy areas within a field by recording coordinates of the weed patch for long-term monitoring.

C. Information Gathering and Management

Field scouting has many advantages beyond the simple determination of pest species and numbers. Scouting can provide information on the effectiveness of current management programs (including cultural, biological, physical, mechanical, and chemical control methods) and can aid in future management decisions. By tracking scouting data with management information, growers can determine the most effective, economical, and environmentally sustainable control method. It is recommended that pest population numbers and control strategy information be kept for 10 years for long-term analysis. If data are discarded, the information cannot be used to guide better management strategies in the future.

D. Field Maps of "Hot Spots"

Long-term pest averages and numbers should be kept by the grower to watch the trends and changes in pest populations. Usually, there are areas within a field that are prone to pest infestations, especially with weeds and diseases such as cavity spot and nematodes. These areas of the field are known as "hot spots" and geo-reference mapping of such areas could provide valuable information from year to year. Mapping these areas using GPS systems can be done to assess the patterns and changes in these pest "hot spots" over time. Specifics on using GIS and GPS technologies can be found in the handbook's **Pest Management in Rotational Crops** section.

Disease Management

In-season

Utilize an integrated disease management program that incorporates cultural, physical, mechanical, biological, and chemical control strategies.

Read the following statements in order and check all that apply. Refer to the corresponding sections on the following pages for more information.

- [ ] *A. Fungicides are applied according to a calendar schedule.*
- [ ] *B. Timing of protectant fungicide applications occurs using the TOMCAST model.*
- [ ] *C. Information on cultivar differences in disease susceptibility are used for fungicide scheduling.*
- [ ] *D. Cultural control strategies are added to the carrot disease management system.*

A. Calendar Applied Fungicides

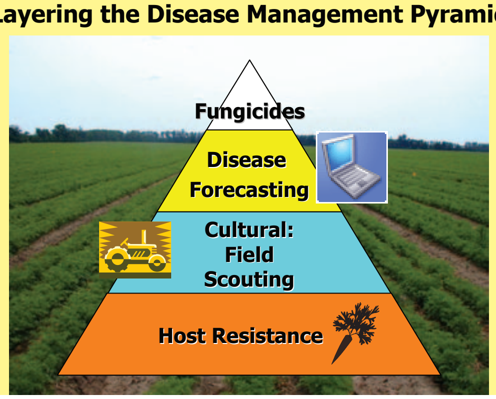
Traditionally fungicide applications for carrot disease control begin early in the growing season and continue at least weekly until harvest. Regular, frequent fungicide applications were the basis of many disease management programs. Today, new bioIPM techniques, including disease forecasting models and cultural, biological, and reduced-risk chemical options, have advanced disease management strategies. Using these new strategies will assure a more effective fungicide program with fewer well-timed spray applications. Some principles of carrot disease management include:

- New reduced-risk fungicide products that provide excellent disease control and high yields, while reducing total active ingredient applied and fungicide toxicity
- Fungicide programs containing azoxystrobin (Quadris®), pyraclostrobin (Cabrio®), boscalid (Endura®), and boscalid + pyraclostrobin (Pristine®) are effective alternatives to chlorothalonil (Bravo®, Echo®)
- Reduced risk fungicides provide control similar to chlorothalonil with substantially less active ingredient (alternating or tank mixing low-risk fungicides such as azoxystrobin, pyraclostrobin or boscalid + pyraclostrobin with chlorothalonil provide effective season-long control)

Disease Pyramid

Proper disease management strategy utilizes all the available tools to limit disease development. The disease pyramid gives a visual representation of the strategies to be employed.

Layering the Disease Management Pyramid



Fungicide Toxicity Values

Fungicide	Relative Toxicity Level
Azoxystrobin	Low
Chlorothalonil	Mid to high
Trifloxystrobin	Low
Pyraclostrobin	Low
Boscalid	Low
Copper hydroxide	Mid
Iprodione	Mid
Mefenoxam	Mid
Metalaxyl	Mid

B. Disease Forecasting Models

Disease forecasting models are useful tools to predict when disease incidence may occur as a result of weather and environmental conditions. The predictive models alert crop managers to start protectant fungicide applications. A disease forecasting model for carrots called TOMCAST is an integral part of the disease management programs for Wisconsin carrots (see sidebar on next page).

Fungicide sprays are initiated at 1% foliar disease (1% of foliage with symptoms) and subsequent sprays are applied at 15-20 DSV accumulations using the TOMCAST model depending on the carrot cultivar being grown.

Quick Note

Weather-based spray schedules with fewer well-timed applications reduce inputs and program costs without sacrificing disease control, yield, or quality.

TOMCAST Model

TOMCAST is a computer model that was developed to determine the number of Disease Severity Values (DSV's) that accumulate each day. DSV accumulation is used to decide the spray schedule needed for fungicides in carrot production. The DSV is determined by leaf wetness and temperature during the "leaf wetness" hours. As the number of leaf wetness hours and temperature increases, DSV's accumulate at a faster rate. A maximum of 3 DSV's can accumulate each day. Sprays for carrots need to be applied at between 15-20 DSV's in accordance with the varietial susceptibility.

TOMCAST - 15-20 DSV's to spray

	Disease Severity Value			
	0	**1**	**2**	**3**
Mean Temp. (° F)	**Leaf Wetness Period** (hrs)			
55-63	0-6	7-15	16-20	21+
64-68	0-3	4-8	9-15	16-22
69-77	0-2	3-5	6-12	13-20
78-84	0-3	4-8	9-15	16-22

C. Cultivar Susceptibility and Fungicides

Fungicide spray schedules for carrots are highly dependant on the variety grown. If a resistant variety is grown, sprays should be applied on a 20 DSV schedule. Varieties with moderate susceptibility should be sprayed on a 15 DSV schedule, while a susceptible variety should be sprayed weekly, or on a 10 to 15 DSV schedule. See the **Seed Selection** section for variety susceptability.

Quick Note

Combining host resistance + fungicides + scouting + reduced spray schedules may lead to sustantially fewer chemical inputs.

D. BioIPM Techniques for Disease Management

Alternate host species provide reproductive and overwintering sites for pathogen sources. Control strategies for alternate hosts should be employed during the growing season and include their direct control by cultivation or herbicide applications. Completely destroy any alternate hosts on field edges or in adjacent fields. Protectant fungicide applications for host crops should be used when the prediction models indicate that disease development is possible.

Other bioIPM strategies for disease control include:

- Foliage should be kept dry to limit the spread of disease. Work to maintain healthy plants with minimal stress and with proper irrigation that minimizes the duration of leaf wetness.
- Plant and harvest early to avoid Rhizoctonia crown rot problems.
- Use biocontrol antagonists when possible, such as *Ampelomyces quisqualis,* a parasite of powdery mildew, and *Coniothyrium minitans* for white mold (*Sclerotinia sclerotiorum*) control.

Advanced Disease IPM

✓ Pest resistant cultivars
✓ Soil testing for key pathogens
✓ Pest monitoring
✓ Prediction tools / weather monitoring
✓ Reduced-risk materials
✓ Monitor pesticide toxicity for all inputs
✓ Substitute less hazardous pesticides
✓ Reduce toxicity of season-long pest control
✓ Maintain or reduce program cost

Insect Management

In-season

Carrot weevil life stages

An Integrated Insect Management program that incorporates cultural, physical, mechanical, biological, and chemical control strategies should be utilized during the carrot growing season.

Read the following statements in order and check all that apply. Refer to the corresponding sections on the following pages for more information.

- ☐ **A.** *Insecticides are applied according to a calendar schedule.*
- ☐ **B.** *Insecticides are applied when populations reach economically damaging levels.*
- ☐ **C.** *Cultural control strategies such as spot treatments or targeted scouting are also used for insect management.*
- ☐ **D.** *Management decisions consider beneficial insects and beneficial species to be part of the pest control strategy.*

A. Calendar Spray Program

In traditional pest management systems, insecticides were the sole means of insect control and these chemicals were applied according to a calendar schedule. Field scouting was limited and the actual number or species of insects present was not taken into consideration.

Current insect management programs include both scouting and precise timing of insecticide sprays targeted at the vulnerable stages of the pest's life cycle. Using insect threshold levels assures more effective insecticidal sprays and less adverse environmental impact.

Insecticide Toxicity Values

Insecticide	Relative Toxicity Level
Azadirachtin	Low
Deltamethrin	Mid
Diazinon	High
Imidacloprid	Low
Malathion	High
Thiamethoxam	Low
Carbaryl	Mid
Cyfluthrin	Mid
Endosulfan	High
Methomyl	High
Oxamyl	High

B. Threshold Program

Control strategies should only be used when insect populations have reached or exceeded economic threshold levels. Threshold levels are set to limit yield loss from insect damage to the carrots. The control strategy employed is the manager's choice, and does not have to be a chemical application. Cultural, biological, physical, and chemical options are available to combat insect pests.

When the following insect thresholds are met, control strategies should be implemented.

Aster leafhopper adults need to be controlled when the AYI (aster yellows index) of 50 for susceptible varieties, 75 for intermediate varieties, and 100 for resistant varieties has been reached. Variety difference in aster yellow susceptibility (see **Seed Selection** section) determines the number of leafhoppers that can be in a field without resulting in economic damage. Aster yellow index is a combination of the number of leafhoppers and infectivity levels, derived from AYI levels via assays or default values.

Carrot weevil control should take place when eggs are found in fields. Spraying every 5 to 7 days for a two week period once eggs are found will control weevils.

Notes:

Aster Leafhopper (ALH)

General Aster leafhopper control:

- Monitor migration to predict arrival in Wisconsin
- Measure yellows infectivity
- Scout crop
- Treat at aster yellows index (AYI)

To determine the Aster Yellows Index (AYI), determine the initial values of the percentage of the population that is infected. This information can be obtained by UW-Extension, or, if you do not know, use 2.5% as the default value.

The AYI = number of leafhoppers/ 100 sweeps x % infectivity

The infectivity levels then applies to the treatment threshold for carrots. Note the differences due to variety. Threshold levels are 50 for susceptible, 75 for intermediate, 100 for resistant varieties.

AYI Values

Carrots (resistant)………100

Carrots (intermediate)………75

Carrots (susceptible)……… 50

See the **Seed Selection** section for information on carrot cultivars and relative resistance to Aster Yellows.

C. Cultural Management Strategies

Advances in bioIPM techniques for insects, including cultural, biological, mechanical, physical, and host plant resistance strategies, provide many ways to combat pests. Various cultural management strategies that limit or prevent pest levels should be included in the insect management program. Some of these strategies are described in the following paragraphs.

Spot treatments (only chemically treating the part of the field where pests are located) can be very effective for insect control. Spot treatments greatly reduce the amount of pesticide used. This limits the adverse affects of pesticides and preserves beneficial insect populations in non-treated areas. Spot treatments can be effective at preventing full field infestations. They are most effective for insects that are not greatly mobile. Unlike highly mobile or flying pests, insects that walk or are in worm stages are more likely to remain in the area where they were originally located. Spot treatments are effective for carrot weevil control along field edges.

Persistent transmission of Aster Yellows Phytoplasm –like-organism (PLO):

Aster leafhoppers propagate the aster yellows PLO after feeding occurs on diseased plants. ALH's can than spread the PLO after it circulates and multiplies in the insect body. The leafhoppers can spread the pathogen for 100 days or more after becoming infected. Acquistion of the PLO is a slow process that takes many hours or days of leafhopper feeding; therefore, controlling the leafhopper with insecticides effectively prevents transmission to other plants.

D. Beneficial Insects

Beneficial insect and fungal species within a field can greatly decrease pest populations. General insect predators may feed on pest species to reduce the populations. Biological control will not entirely suppress these populations, but may aid in an integrated control program.

Aphids are not normally a pest in carrots because they are often controlled by parasitic wasps. The wasps (which are microscopic and not easily seen by the human eye) lay their eggs in the aphid's body. The wasp's larva grows by feeding on the aphid, and after it is done feeding, it breaks away and leaves an aphid mummy. An aphid mummy looks like a petrified aphid body and is usually stuck to the underside of leaves. To determine if parasitic wasps are located in a field, scout and note the number of aphid mummies found in the field. If high numbers of aphid mummies are seen, insecticide applications may not be necessary, as wasps are controlling the aphid population.

To maintain both predatory and parasitic beneficial insect populations, use low toxicity insecticides that do not damage the beneficial species. Certain materials, such as the systemic neo-nicotinyl, spinosad, and Bt compounds are not detrimental to beneficial species. Their use allows beneficial populations to reproduce, increasing the overall number of predators in the field. Traditional chemistries, such as organophosphates, carbamates, and pyrethroids are detrimental to beneficial species. Maintaining habitat for beneficial populations is important so that predatory and parasitic insects have a place to survive when no prey is available. For specifics on beneficial releases and maintenance, see the **Biological Control Section** later in this chapter.

Quick Note

Preserve beneficial insects by using a pest specific insecticide that won't kill the beneficial insects. Using a broad spectrum foliar insecticide will kill the beneficial populations.

Notes:

Weed Management

An Integrated Weed Management program that incorporates cultural, mechanical, biological, and chemical control strategies should be utilized during the carrot growing season.

Read the following statements in order and check all that apply. Refer to the corresponding sections on the following pages for more information.

- [ ] ***A. Weeds are controlled solely by chemical means.***

- [ ] ***B. Weed species are accurately identified during the growing season. Postemergence herbicide applications are timed appropriately based on weed size.***

- [ ] ***C. Weeds that are difficult to manage in carrot crops are controlled in rotation crops.***

- [ ] ***D. Advanced cultural and mechanical control strategies are utilized when possible, including cultivation, weed control in areas surrounding production fields, and sanitation.***

A. Chemical Weed Control

Traditionally, weeds were controlled solely through the use of herbicides. With the advancement of bioIPM strategies, growers can now manage weeds in a more comprehensive, year-round program.

Both annual and perennial broadleaf weeds affect carrot production. Annual species live only a single year and reproduce by seed. They die at the end of the season after they have produced seed. Perennial species live several years and reproduce by various types of reproductive structures and sometimes also by seed. Perennials can regenerate shoots each year using food reserves stored in vegetative structures in the soil. Perennials can also re-sprout when the top growth has been removed as long as the storage organ is intact. Avoid planting into fields heavily infested with perennial weeds.

Chemical weed control options are very limited in carrot production, but adequate weed control can be achieved with proper herbicide selection and application timing. The key to season-long weed control is to manage weeds when they are very small. Carrots are not competitive with weeds, and weeds that escape early control will significantly impact crop yield.

Herbicide Toxicity Values

Herbicide	Relative Toxicity Level
Linuron	High
Trifluralin	High
Paraquat (non-selective)	High
Metribuzin	Mid
Glyphosate (non-selective)	Low
Clethodim	Low
Sethoxydim	Low
Fluazifop	Low

B. Accurately Identify Weed Species

Weed species in and around carrot production areas need to be accurately identified each growing season. Proper identification of weed species ensures proper selection of management approaches and flags potential problem areas. If growers are uncertain in identification of weed species, they should get the species accurately diagnosed by university specialists.

Optimal application timing is important in controlling weeds with foliar sprays. Herbicide efficacy varies with weed size. Larger annual broadleaves are generally more difficult to manage with the limited selective herbicides labeled in carrots. Larger broadleaves recover from herbicide injury and can survive a day or more after being uprooted by cultivation.

C. Control Weeds in Rotation Crops

Given that weed control options are limited in carrots, weeds must be controlled in the rotational crops that have more labeled herbicides. Prevent weed seed production and limit establishment of perennial weeds in rotation crops. Rotational crops that are competitive with weeds can reduce weed growth and seed production. Examples of crops more competitive with weeds than carrots and that have more weed control options include potatoes, soybeans, snap beans, and corn.

Consider mowing or tilling weeds that escape control after the crop season to ensure that they don’t produce seed. Weed seeds remain viable in soil for many years.

Quick Note

Many weed species can be a reservoir for aster yellows and can be a source of the problem. Controlling weeds in and around fields that host aster leafhoppers and aster yellows can help eliminate aster yellows concerns. Specific weed hosts include marestail and pineappleweed.

Notes:

D. Advanced Cultural and Mechanical Management

Use advanced cultural or mechanical methods when possible and when the situation dictates.

- Choose competitive carrot cultivars. Carrot cultivars vary greatly in the rate of early-season growth and canopy closure. In general, the cultivars that become established and close canopy the earliest will be most competitive with weeds.
- In-season cultivation in carrots is difficult because carrots are easily damaged by the cultivator and weeds often grow faster than the crop. Successful cultivation relies on a size differential where the crop is more established than the target weeds, and this rarely occurs in slow-growing carrots. In some cases, carrots can be "blind cultivated" with a flex-tine harrow prior to carrot emergence to improve crop safety and remove the first flush of weed seedlings.
- Use additional measures to control weeds adjacent to but not in the carrot crop. This prevents the spread of weed seeds and controls alternate plant hosts for disease and insect pests. Mow ditches and corners of pivots, and till headlands or any other bare soil where weeds are growing.
- Clean equipment when traveling from one field to another to prevent weed seed and vegetative tissue movement to new sites. The parasitic weed dodder, for example, is easily transported as vegetative tissue on equipment, including harvesters.
- After carrot harvest, be sure to control surviving weeds with tillage, mowing, or appropriate herbicides prior to seed production.

Herbicide Resistance in Weeds

The repeated use of herbicides with similar modes of action in the same field over a period of years has resulted in resistant weed biotypes. Weed resistance may be defined as those plants that grow normally after treatment with an herbicide dosage that usually kills the weed.

Characteristics of herbicides or herbicide families that contribute to the development of herbicide resistance are:

- Mode of action with a single target site.
- Effective in killing a wide range of weed species.
- Long soil residual activity.
- Frequent use in-season and from year to year without rotating, alternating, or tank mixing with other herbicide classes.

Prevention is important to avoid the development of herbicide-resistant weed populations. Preventative measures break the cycle of constant selection pressure for herbicide resistance.

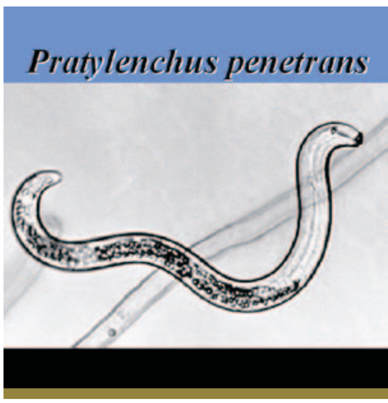
- Rotate herbicide modes of action across crops within the cropping sequence.
- Rotate herbicide mode of action between years.
- Plan 4 - 5 year crop rotation that addresses herbicide rotation.
- Avoid sequential applications of high risk herbicides (such as some ALS and ACCase herbicides).
- Use multiple modes of action.
- Choose herbicide families that pose a low risk of developing resistance.
- Follow all label instructions.
- Use mechanical weed control in rotational crops to reduce the reliance on herbicides.
- Eliminate weed escapes to prevent seed production of weeds with resistance to important herbicides.
- Tank mix herbicides with different modes of action.

Early detection of weed resistance and control of localized resistant populations can reduce the spread of herbicide resistance.

Notes:

Nematode Management

In-season



Root knot nematodes can cause serious problems in carrots if left un-checked. Growers should implement strategies to limit nematode populations and reduce the need for fumigation.

Read the following statements in order and check all that apply. Refer to the corresponding sections on the following pages for more information.

☐ ***A. Fields that have a history of root knot nematode damage are fumigated.***

☐ ***B. Fields are sampled prior to each carrot crop to assess the level of root knot nematodes.***

☐ ***C. Cover crops and non-host crop rotations are added to the carrot system.***

☐ ***D. BioIPM practices, such as carrot crown and foliage removal, are utilized.***

General Information

Nematode problems can cause yield and quality reduction in carrots. The root knot nematode is the most limiting issue in carrot production. The symptom of this problem is overall plant stress, stunted growth and a chlorosis of the leaves. Root symptoms include galls that form on the roots, causing malformed and stubby roots leading to eventual root decay. Root knot nematodes survive on susceptible crops; careful crop rotations should therefore be implemented to limit nematode populations.

A. Fumigation

Fumigants are non-specific, gaseous chemicals that are injected into the soil to control soil-borne pests. Fumigants are lethal to many soil pests, including weed seeds, and may also cause unintended side effects, such as the loss of beneficial soil fungi and nematodes. Fumigation should only occur if populations of root knot nematodes are found in the field at levels at or above 40 nematodes per 100 cubic centimeters of soil.

> *Quick note*
>
> The threshold to implement a management control program for the plant parasitic nematodes is greater than 40 nematodes per 100 cubic centimeters of soil.

If needed, fumigation is the most effective under the following conditions:

- The optimal soil temperature for fumigation is between 50-70º F. Do not fumigate when soil temperatures are below 45º F since the gas will not disperse properly in cold soils.
- For best results, fine-textured soils should contain 65-75% of available soil water, and coarse textured soils should contain a slightly higher moisture percentage.
- Fumigant should be injected more than 4 inches deep in the soil for nematode control. Make sure that the fumigant is being evenly distributed throughout the correct depths. Read the pesticide label for specific requirements.
- Because most fumigants are toxic to plants, a waiting period is required after application and before planting the crop. Usually two to three weeks between fumigation and planting allows time for the fumigant to dissipate.
- Fumigation is usually done after tillage, because good soil preparation and proper application procedures are important in order to achieve the desired results. Before injecting fumigant, the soil should be in good condition. Clods should be broken up and crop residues finely chopped and thoroughly incorporated, or target organisms may survive due to limited exposure to lethal fumigant levels.
- Fumigation of higher organic soils may require twice the fumigant rate used on mineral soils. Refer to the label for specific rate information.

B. Soil Sampling for Nematodes

Soil sampling to determine root knot nematode levels should be done before deciding if fumigation or other appropriate management is necessary. The best time to sample is late July or early August the year before planting carrots. Sampling may also coincide with sampling for soil fertility that usually occurs in the fall prior to carrots.

If nematode injury is observed in previous carrot or rotation crops, plant samples should be dug and analyzed for the presence of galls before planting carrots.

> *Quick note*
>
> Avoid planting carrots in fields with a high infestation of root knot nematodes. Avoidance is easily the best nematode control strategy.

C. Cover Crops and Crop Rotation

COVER CROPS

Cover crops have many benefits, such as increasing soil organic matter, improving soil structure, reducing soil erosion, providing weed management, and attracting beneficial insects. Some cover crops can be grown specifically as green manure crops to aid in control of the plant parasitic nematodes. Certain cover crops, such as rapeseed, release a chemical similar to that from conventional fumigants, providing a “biological fumigant” response. The cover crops also benefit the soil by adding organic matter, resulting in better overall soil quality. The improvements to the physical properties of the soil benefit the microbial community which exists in the soil. The activities of this microbial community have many benefits and may limit parasitic nematodes. Specific cover crops with nematicidal activity include marigolds and certain brassica species.

CROP ROTATION

One of the best cultural strategies to manage nematode in carrots is crop rotation. Choose rotational crops that are not hosts of the root knot nematode such as corn, rye, wheat, and small grains. A fallow year prior to carrot production will also be helpful.

Predatory Nematodes

There are some predatory nematode populations that attack root knot populations including *Steinernema* species and *Myrothecium verrucaria*. These nematode species feed on root-feeding nematodes. Samples can be assayed to determine the number and amount of predatory nematodes in your soil.

D. BioIPM Techniques

Avoidance strategies, such as mapping hot spots for specific treatments and/or simply not planting in highly infested fields is the easiest and most basic cultural control for nematode control. Keep track of nematode “hot spots” or concerns in cropping rotations to know if nematodes are present and if they are in high enough populations to be a concern. Avoiding these spots is a cost effective and simple control strategy.

Nematode Soil Sample Analysis

1) 20 core samples per 5 acres is recommended, although more intense sampling provides more accurate information.

2) Combine all core samples and mix well.

3) Remove 1 pint (2 cups) of soil from mix.

4) Place sample in a plastic bag.

5) Seal plastic bag to maintain soil moisture. **The sample should not dry out!**

6) Do not leave samples in the sun or hot areas.

7) Send samples to an appropriate testing service. The University of Wisconsin has the ability to test the soil. For UW analysis, send samples to:

UW-Madison Plant Pathology Dept. c/o Ann MacGuidwin, 1630 Linden Drive, Madison, WI 53706 Phone: (608) 263-6131 FAX: (608) 263-2626

Plant Nutrition

In-season

Fertility programs should follow research-based, University of Wisconsin recommendations. Inadequate nutrient applications can limit crop productivity and quality and compromise crop health. Excessive nutrient applications are economically and environmentally damaging. Crop health as influenced by fertility can influence crop susceptibility or tolerance to pests.

Read the following statements in order and check all that apply. Refer to the corresponding sections on the following pages for more information.

☐ **A.** ***Fertilizer applications are based on understanding of crop growth and nutrient need.***

☐ **B.** ***Fertilizer programs follow University of Wisconsin recommendations, and split applications are used where applicable.***

☐ **C.** ***Plant tissue sampling monitors crop fertility and allows for in-season adjustments.***

☐ **D.** ***Soil management practices such as green manures, soil amendments, and other practices are used to supply some crop nutrient needs.***

A. Crop Nutrient Needs

The growing season for carrots can vary widely from 120 to 140 days from planting to harvest in the Northern US. Carrots are unique in that they will continue to bulk until limited by light, space, or other resources. Fresh market carrots may have a shorter growing season than processing carrots. Cello-pack carrots may only grow for 60 days and cut and peel carrots possibly shorter still depending on timing of the production season. Research has shown that above-optimum levels of N, P, K, or Ca leads to lower sugar levels in carrots. However, flavor response to nutrients has been variable across soils, varieties, and other crop conditions. Crop nutrition does not appear to influence the harsh or bitter flavor sometimes associated with carrots.

Nitrogen is important in the promotion of crop growth as it influences protein synthesis and photosynthesis. Early-season nitrogen is required to support early crop growth and development of crop canopy. Carrots are slow to establish and take up little nitrogen for the first 4 to 6 weeks of growth. Excessive preplant nitrogen has caused forking in some carrot varieties under some soil and growing conditions. Crop demand for nitrogen increases once roots turn orange in color and root expansion begins. As the carrot root continues to bulk, nitrogen uptake continues to increase. Therefore, minimal nitrogen must be available to crops during vegetative growth with increased availability necessary during rapid bulking.

B. Nutrient Application Rates

Nutrient application rates should follow University of Wisconsin-Extension (UWEX) guidelines published in A2809 *Nutrient application guidelines for field, vegetable, and fruit crops in Wisconsin.* Nitrogen (N) rates are determined based on the amount of organic matter in the soil, where more N is needed on soils with low organic matter compared to soils with high organic matter. Higher organic matter soils can mineralize more N than can low organic matter soils. Phosphorus (P) and potassium (K) rates are based on soil test levels. Optimum soil test P and K levels vary depending on soil group. UWEX nutrient application guidelines have been developed to supply adequate levels of nutrients to maximize economic return. Additionally, UWEX nutrient guidelines are intended to prevent over-application of nutrients, which improves profitability and reduces the potential for environmental degradation.

Phosphorus and potassium application rate guidelines are provided in Tables 1 and 2. The soil test levels, in parts per million (ppm), for both P and K are placed in categories (Table 1). Soil test categories for P and K are defined differently based on soil group and are related to a soil's ability to supply nutrients to the crop. The amount of phosphate or potash fertilizer to apply is based on the soil test category (Table 2). Potassium and phosphorous fertilizer should be broadcast or banded adjacent to rows preplant or at planting. Banded applications maximize fertilizer availability to the crop and reduce nutrient availability to weeds relative to broadcast application.

Table 1. Soil test phosphorus and potassium categories for carrot

Soil Groups†	Soil test category					
	Very low	Low	Optimum	High	Very High	Excess. High
	ppm					
Phosphorus						
A – D	< 15	15 – 30	31 – 45	46 – 75	--	> 75
E & O	< 18	18 – 35	36 – 50	51 – 80	--	> 80
Potassium						
A & B	< 60	60 – 120	121 – 180	181 – 200	201 – 220	> 220
C	< 50	50 – 110	111 – 160	161 – 180	181 – 200	> 200
D	< 80	80 – 140	141 – 200	201 – 220	221 – 240	> 240
E & O	< 50	50 – 100	101 – 150	151 - 165	166 – 180	> 180

† Soil groups A – D are medium- and fine-textured. Soil group E is coarse-textured. Soil group O is organic. To determine the exact soil group for your soil series, see Table 4.1 in UWEX publication A2809.

Table 2. Phosphorus and potassium application rate guidelines for carrot

	Soil test category					
	Very Low	Low	Optimum	High	Very High	Excess.High
Nutrient	lb/a of P_2O_5 or K_2O to apply (includes starter fertilizer)					
Phosphorus	120	95	45	25	--	0
Potassium	340, 365 †	300, 325 †	240	120	60	0

† The lower rate is for soils in groups E and O. The higher rate is for soils in groups A-D.

Carrots have a much higher demand for P and K compared to grain, oilseed, and forage crops. P and K are relatively immobile in the soil. Therefore, P and K are primarily applied prior to planting. Fertilizer applications made prior to planting are generally applied broadcast or more commonly adjacent to rows during the bed forming operations or as a row marking operation. Fertilizer applications are less common at planting due to shallow planting and concerns with salt effects negatively affecting germination and emergence. Preplant applications are typically applied between crop rows spaced 10 to 12” apart. Guidance systems or row markers are essential for accurate placement of starter fertilizers so that crop rows are near enough to take advantage of fertilizers, but not on top of the fertilizer rows to minimize salt effects. Carrots are highly sensitive to saline conditions, which can cause poor emergence, lost yield, and quality reductions.

Nitrogen fertilizer application rate depends on soil organic matter content (Table 3). Both nitrate (NO_3^-) and ammonium (NH_4^+) forms of N can be used by plants. Nitrate is often the dominant form of inorganic N in soil. Because nitrate is negatively charged it does not bind to the cation exchange capacity (CEC) of the soil and therefore is susceptible to leaching, particularly in sandy soils. On organic soils, apply about 45% of the total recommended nitrogen rate preplant. Topdress the remaining 65% of the nitrogen 4 to 5 weeks after emergence. On mineral soils, incorporate 20% of the total recommended nitrogen rate prior to planting. Topdress 30, 30, and 20% of the remaining nitrogen at 4 to 5, 8 to 9, and 11 to 12 weeks after emergence, respectively. Specific varietal recommendations can be found in varietal profiles available through the seed dealer.

Plants only need very small amounts of micronutrients for maximum growth. When present in the soil at excessive concentrations, micronutrients can harm plants. Carrots have a medium relative micronutrient need for boron (B), copper (Cu), and manganese (Mn), and a low relative need for zinc (Zn) and molybdenum (Mo). Micronutrients should be applied when the soil test is low or when verified deficiency symptoms appear. Boron deficiency is most likely to occur on sandy soils. Copper deficiency is seen on very acid soils, particularly muck soils. Manganese deficiencies generally occur on soils with a pH greater than 6.8 and/or high organic matter content. Use plant analysis to confirm deficiency symptoms. If micronutrient deficiencies exist, consult UWEX publication A2809 for details regarding micronutrient application rates. Over application of B and Mn to carrot may result in nutrient toxicities and reduced yield.

Table 3. Nitrogen application rate guidelines for carrot

Organic matter content (%)	Nitrogen to apply (lb N/a)
< 2.0	120
2.0 – 9.9	100
10.0 – 20.0	80
> 20.0	40

C. Plant Tissue Analysis

Plant tissue analysis in carrots is important to assay current fertility programs to ensure optimum crop performance. Plant tissue analysis is typically done 60 days after planting in carrots. The most recent mature leaf is sampled to test current nutrient status in carrots. Tissue analysis is especially important for nitrogen and the micronutrients boron, copper, and manganese.

Carrot nutrient sufficiency ranges for most recently mature leaf sampled mid-season:

	Sufficiency range
	--%-----------------
nitrogen	2.1-3.5
phosphorous	0.2-0.49
potassium	2.5-4.9
calcium	1.5-3.0
magnesium	0.3-2.0
sulfur	0.23-0.35
	----ppm------------
iron	50-200
manganese	60-200
zinc	25-100
boron	30-80
copper	5.0-12

Quick Note

In Wisconsin, if you are required to have a nutrient management plan by state and/or federal agencies, then your nutrient applications rates can not exceed those in UWEX publication A2809. Please contact the appropriate agencies (WI-DATCP, WI-DNR and USDA-NRCS) for additional details.

D. Organic Sources of Nutrients and Other Soil Amendments

Animal manures and leguminous crops contain nutrients. When animal manures are applied to a field, N, P, and K fertilizer application rates should be reduced. When legumes, including green manures, are part of a crop rotation, N fertilizer (or manure) application rates should be reduced. Reducing fertilizer application rates to account for the nutrients supplied by manures and legumes is economically profitable, improves fertilizer use efficiency, and enhances water quality.

Animal manures: Application of animal manures can provide N, P, K, and other nutrients to the crop. The nutrient content of manures varies with animal species and storage. Nitrogen and P occur in both organic and inorganic forms in manure. The organic forms of these nutrients are slowly available. Thus, only a portion of the total nutrient content of manure is available in the first year after application. Additionally, N, P, K, and S may be available in the second and third growing seasons after manure application. Ideally, manure should be tested and the results of the test used to determine the amount of manure that may be applied so that the N needs of the crop and P needs of the rotation are not exceeded. If manure nutrients are not adequate to meet crop needs, then additional fertilizer may be applied. Manure must be applied at least 6 months prior to planting carrots to minimize potential contamination of the crop with bacteria or other human pathogens. In addition, carrots have been shown to be sensitive to animal manure application in part due to the salt effect created by large applications of manure.

LEGUMES

Legumes grown in rotation ahead of carrots can provide nitrogen credits to the crop. Nitrogen credits are the amount of fertilizer N that can be subtracted from the recommended N application rate.

Forage legumes: The nitrogen credits from forage legumes are dependent upon the legume species, soil texture, and amount of regrowth between the last cutting and killing the legume. Nitrogen credits are not affected by the time or method of killing (tillage or herbicide) the forage legume stand. Forage legume N credits can be confirmed with the pre-sidedress nitrate test (PSNT).

Field crop legumes: Field crop legumes include soybean, pea, and beans (dry, lima, or snap). These crops provide much smaller N credits compared to forage legumes and green manures. On sandy soils there is no N credit for field crop legumes. On non-sandy soils, there is a 40 lb N/a credit if soybean is the previous crop and a 20 lb N/a credit if leguminous vegetables are the previous crop.

Green manures: Green manures or cover crops can also provide crop nutrients. Forage legumes that are grown for only one growing season without forage harvest and then incorporated into the soil, such as alfalfa, red clover, sweet clover, and vetch, provide somewhat lower amounts of N than forage legumes grown for several seasons. Non-leguminous winter cover crops that are used to help reduce wind erosion, such as rye, will consume nutrients while they are actively growing in the fall, and thus reduce the potential for these nutrients to be lost via leaching or surface runoff. When winter cover crops are incorporated in the spring, they can supply some nutrients to the crop but often at very low rates. No nutrient credits should be taken for winter cover crops.

Compost: Application of compost also provides N, P, K, and other nutrients to the crop. Compost can be derived from a number of organic materials, including animal manures and plant residues. A benefit of compost is that it poses less human health risks, as high temperatures achieved during the composting process kills both human and plant pathogens. Compost can also be tested to determine total nutrient concentrations, though actual N, P, and K availability from compost is variable and not easily predicted at this time. The effects of compost application on carrots have not been studied and should be evaluated tentatively to minimize negative effects seen with manure on carrots.

Other soil amendments: A number of alternative soil amendments exist. For example, byproducts from paper production and waste drywall contain nutrients that improve plant growth. Use of these amendments should be approached cautiously, as some may contain elements that hinder crop growth. In addition, if amendments cause localized salinization in the soil, damage may occur. Make sure amendments are safe for the crop and analyzed for nutrient content to optimize use on carrots.

For additional detail on nutrient credits from manure and legumes see UWEX Publication A2809 *Nutrient application guidelines for field, vegetable, and fruit crops in Wisconsin*.

Quick Note

Carrots that have nitrogen deficiencies are most susceptible to Alternaria leaf blights. Proper nitrogen rates should be applied to prevent stress on plants and possible disease development.

Notes:

Irrigation

In-season

Irrigation management strategies should provide adequate water to ensure proper growth without over-watering to prevent nutrient loss due to leaching. High organic soils may require irrigation in the spring to reduce wind erosion.

Read the following statements in order and check all that apply. Refer to the corresponding sections on the following pages for more information.

- [ ] ***A. Irrigation is applied according to crop knowledge and past experience.***
- [ ] ***B. Scheduling determines irrigation timing and amount.***
- [ ] ***C. Soils are monitored to ensure adequate moisture levels.***
- [ ] ***D. Irrigation systems are used to maximize water use efficiency.***

A. Irrigation

The goal of water management is to maintain adequate soil moisture throughout the growth of the crop, while avoiding extremes and excessive fluctuations. For carrots, the soil moisture status becomes critical when water levels reach 50 to 60% of plant available water. Stomata begin to close, reducing O_2 and CO_2 exchange and reducing plant growth when 40 to 50% of plant available water is depleted from the rooting zone of the plant. Fluctuations in soil moisture content can lead to splitting of carrot roots. Even watering is the best method to prevent root cracking and splitting.

Excessive soil moisture can also cause stress on carrots as well as leach nutrients. Excess moisture can fade or bleach carrots leading to non-uniform color. It can promote rough surfaces and deformations or branching. Excess moisture can also promote development of carrot diseases.

Carrots are most sensitive to drought stress during emergence and stand establishment, initiation of root bulking, and active root bulking. Carrot seed are small and are planted shallowly. Therefore large fluctuations in soil moisture in the seed zone shortly after planting due to evaporation, or uneven soil moisture can lead to poor germination and uneven stands. In addition, soil wetting and drying can lead to crusting that will inhibit carrot emergence.

Drought stress at initiation of root bulking can limit the growth of carrot roots as well as weaken cells on the surface of the carrot root. Resumption of growth with irrigation or rain can lead to the rupturing of weakened cells, resulting in cracks or splits in carrot roots. Initiation of root bulking occurs when carrots turn orange about 8 weeks after planting.

Drought stress during active root bulking results in reduced photosynthesis and loss in root growth and yield. Average root bulking is greater during active growth than any other time of carrot growth, and limitation due to water can lead to yield reductions.

Excess moisture is most detrimental to carrots during root elongation. In fact, slight drought stress after crop establishment and prior to initiation of root bulking can improve carrot rooting depth. Excess moisture can result in reduced root elongation, limiting the depth of rooting and potentially resulting in forked carrots.

In Season: Evapotranspiration (ET)

Irrigation schedules are based on an estimation of the amount of water the plants require each day. Crop water use is referred to as evapotranspiration. This is the sum of two forms of water loss - evaporation from the soil surface and transpiration from the plants.

Evapotranspiration is affected by several climatic factors and plant characteristics. It increases as sunlight, temperature, wind, and the size of the plant canopy increase. Evapotranspiration decreases as the relative humidity increases and as stomata on the leaves close in response to water stress.

Various methods have been developed for estimating daily ET. Estimate of ET for production areas in Wisconsin and Minnesota can be viewed by accessing the WI-MN cooperative extension agricultural weather page at www.soils.wisc.edu/wimnext/et/wimnext.html

Moisture Availability

Moisture availability to plants depends on the energy related to the adhesion of water to soil particles. Water moves in the direction of lower energy potential. Field capacity is equal to -18 kPa (adhesion energy equal to force of gravity). Stomata begin to close at -36 kPa, the critical point where crop growth becomes limited.

B. Irrigation Scheduling Tools

Irrigation scheduling can balance crop use with irrigation and rainfall regardless of the type of irrigation system. The simplest tool to use is a checkbook method to track water use and irrigation needs. In this approach, crop water use is calculated using estimates of evapotranspiration. When calculations show that the allowable depletion is reached, irrigation is applied to bring the available soil water back to field capacity. An irrigation scheduling spreadsheet that uses the checkbook method can be accessed at: http://www.soils.wisc.edu/wimnext/water.html.

The amount of available soil water can be derived from the WISDOM computer irrigation scheduling tools, which are based on the Wisconsin Irrigation Scheduling Program (WISP). The irrigation-scheduling module requires the input of the following parameters for successful and effective operations:

- Allowable depletion value for the soil.
- Allowable depletion balance at initiation of irrigation scheduling.
- Amount of rainfall and irrigation applied to the field.
- Daily evapotranspiration estimate.
- Percent canopy cover to adjust the ET when the crop is less than full cover.

These inputs are used in a simple checkbook-like accounting format in which water deposits and water withdrawals are used to derive the allowable depletion balance. The allowable depletion balance reflects the current amount of soil water storage and can be used to determine irrigation frequency and amounts.

Drip Irrigation

Effective drip irrigation systems reduce over watering while providing adequate moisture to plants in the root zone. The high equipment cost and the labor required to lay drip tubes prohibits this technology's use on larger commercial fields.

Available Plant Water and the WISDOM module

The plant available water (PAW) is the difference between a soil's field capacity (total amount of water that can be held by a soil) and the permanent wilting point (point at which plants die). Yield and quality losses can occur in carrots before plants show symptoms of drought stress, such as leaf wilting. The critical point is the water content that leads to closure of stomata and reductions in photosynthesis and plant growth. The difference between field capacity and the critical point is called the allowable depletion. The maximum allowable depletion for carrot is 40 to 50% of PAW. If the field is allowed to go below the allowable depletion (AD), significant stress will occur, and yield and quality will suffer. Allowable depletion is influenced by soil texture class and rooting depth of carrot. Effective rooting depth of carrot is 3 feet.

Allowable Depletion by Soil Type

		Carrot rooting depth (in)		
Soil type	AD/foot	12”	24”	36”
Sand, loamy sand	0.5	0.5	1	1.5
Sandy loam	1	1	2	3
Clay, Silty Clay, Sandy Clay Loam Silt Loam, Loam, Silty Clay Loam, Clay Loam	1.5	1.5	3	4.5
Muck	2	2	3	4

Be aware of food safety issues with water. Use of surface water contaminated by manures may cause food safety problems.

Quick Note

To limit disease concerns, avoid prolonged periods of leaf wetness during the growing season.

C. Soil Moisture Monitoring

Carrot sensitivity to drought stress and over-watering requires precise management of soil moisture content. Under- or over-watering can result in stressed crops that are more susceptible to pest damage. Several different methods can be used to estimate soil moisture content, including the feel method, TDR probes, or watermark sensors.

The feel method involves excavating soil and balling it within your hand as a means to estimate volumetric soil moisture content. See the **Field Preparation** section for a description of how to use the feel method to estimate soil moisture content.

TDR probes can be used to estimate volumetric soil moisture content. Current technology allows for automatic or remote downloads from sensing equipment to allow for realtime estimation of soil moisture content. Field capacity of Plainfield loamy sand soils is 14% volumetric moisture content while critical point is at 10 to 11% volumetric soil moisture content.

Multiple technologies can be used to estimate soil water potential. A current technology that is commonly used is the Watermark sensor, which accurately estimates soil water potential and is easy to install. With this technology, yield capacity is -18 kPa and the critical point is -36 kPa.

Soil Types and Irrigation

Irrigation systems vary with soil type. Irrigation systems in the Midwest are typically center pivot and use ground water as the water source. In the western US, irrigation systems are center pivot or flood irrigation. Muck soils have center pivot irrigation or utilize subsurface irrigation. Water tables in muck soils can be raised by blocking drainage ditches, resulting in raising the water table to the bottom of the rooting zone.

D. Water Use Efficiency

Several practices can improve water use efficiency, especially irrigation efficiency. Practices to promote deep rooting will decrease the frequency of irrigation and increase the ability of the crop to capture water and nutrient resources.

Muck soils are ideal for carrot production because they are deep, friable or loose, fertile and have a large water holding capacity. Deep and loose soils will promote the deep rooting of carrots and improve crop water use as well as nutrient uptake. In addition, the large water-holding capacity of muck soils decreases the likelihood of drought stress and the need for irrigation. Irrigation can be achieved without wetting the canopy through subsoil irrigation.

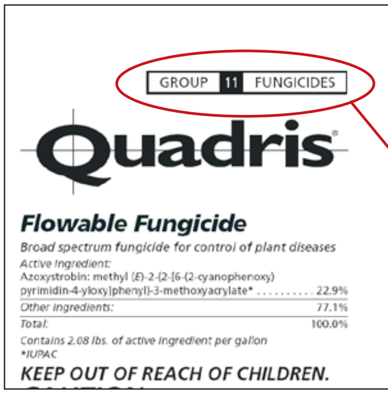
Carrot Flavor

Volatile terpenoids and sugar contribute to harsh flavor and sweetness in carrot, respectively. Bitterness can also influence carrot flavor, though it is not typically affected by field conditions but rather by storage conditions. Soil temperature and moisture conditions influence harsh and sweet flavor in carrot. Temperatures of 65 to 70 degrees F increase carrot sweetness, but warmer temperatures also increase bulking and harsh flavors. Optimal conditions for bulking and flavor are warm days (75 to 80 degrees F) and cool nights.

Irrigation plays an important role. Evaporative cooling can lower soil temperatures during warm, sunny days. Conversely, drought stress can lead to increased soil temperatures. Other management factors that influence temperature conditions are planting date, harvest date, crop maturity, and the cultivar being grown. Muck soils tend to decrease sweet and increase harsh flavors compared to sand soils. Production regions and growing season environments can also influence flavor.

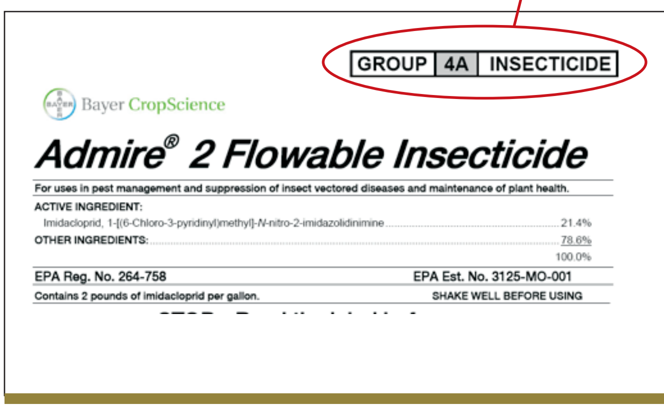
Resistance Management

In-season



Resistance of pest populations to pesticides is an increasing problem in carrot production. Proper resistance management strategies should be used to maintain the efficacy of available pesticide chemistries in the carrot production system.

Examples of pesticide labels with EPA Resistance Management Group information.



Read the following statements in order and check all that apply. Refer to the corresponding sections on the following pages for more information.

☐ **A. Pest management decisions consider pesticide modes of actions and classes.**

☐ **B. Similar pesticide modes of action are not used consecutively within the growing season.**

☐ **C. Fungicides with single-site of action are not used in consecutive applications.**

☐ **D. Disease, insect and weed populations are monitored for resistance development.**

A. Pesticide Modes of Action

Pesticides all have a specific way in which they control pests. This is known as the pesticide's mode of action, or target action site. Growers need to know these modes of action so they can implement proper resistance management strategies. Ultimately, applying these strategies will minimize the likelihood that resistance to the various chemistries will develop, and thus growers will maintain more options for carrot pest management.

The Environmental Protection Agency (EPA) and the Fungicide, Insecticide, and Herbicide Resistance Action Committees (FRAC, IRAC, HRAC) have developed a voluntary pesticide labeling proposal that groups pesticides with similar modes of action and designates them with a number. Look at the tables in this section for the EPA resistance management groups for insecticides, fungicides, and herbicides.

Pesticide resistance develops in a variety of ways. In general, the pest species become resistant through selection of biotypes of disease, insects, and weeds exposed to a particular group of pesticides over a period of years. These pests have the genetic potential to pass along the resistance trait during reproduction. Many times the resistance traits are irreversible in the populations, and once resistance occurs, the pesticide will never work in the system again. Occasionally resistance is reversed in new populations when the pesticide is not used for a length of time. For example, certain fungal populations may exhibit a form of "resistance" in one growing season, but are susceptible to the same fungicide group in the following years.

B. Resistance Management Recommendations

Resistance management programs should incorporate bioIPM approaches that limit pest infestations, limit the number of applications needed, time the products appropriately, and target the vulnerable life stages.

Growers should consider the following resistance management strategies and evaluate all chemical applications (fungicides, insecticides, and herbicides) as part of a comprehensive IPM program.

FUNGICIDES

- For the strobilurin Group 11 fungicides, always alternate Group 11 compounds with another mode of action, specifically a multisite compound group. Do not apply Group 11 compounds twice in a row, even if they are tank mixed with combinations of other fungicide classes. Do not exceed six applications of strobilurin fungicides per crop per acre per year.
- Use disease forecasting programs and IPM approaches to target fungicide applications to when control is most needed.
- Integrate lower risk fungicides into a season-long, seed to market disease management program. Use bioIPM strategies that limit inoculum sources and disease potential whenever possible.

Fungicide Resistance Codes

Fungicide	Resistance Code	Risk Level
Azoxystrobin	11	High
Chlorotholanil	M5	Low
Trifloxystrobin	11	High
Pyraclostrobin	11	High
Boscalid	7	Mid
Copper hydroxide	M1	Low
Iprodione	2	High
Mefenoxam	4	High
Metalaxyl	4	High

INSECTICIDES:

- Rotate crops and select field locations to avoid high, early season pest pressure.
- Scout pests accurately.
- Treat only at economic thresholds.
- Time application to target the most vulnerable life stage.
- Obtain good spray coverage.
- Spot treat when feasible.
- Take all pests into consideration to maximize sprays.
- Preserve natural controls by using selective insecticides and by choosing specific materials (timings, rates).
- Use cultural control to reduce populations.
- Use a trap crop on field edges in spring and fall.

HERBICIDES

- Rotate crops.
- Rotate herbicides with different modes of action.
- Use herbicide mixtures with different modes of action if allowed by the herbicide labels.
- Control weedy escapes and practice good sanitation to prevent the spread of resistant weeds.
- Integrate cultural, mechanical, and chemical weed control methods.

Insecticide Codes

Insecticide	Resistance Code
Azadirachtin	26
Deltamethrin	3
Diazinon	1B
Imidacloprid	4A
Malathion	1B
Thiamethoxam	4A
Carbaryl	1A
Cyfluthrin	3
Endosulfan	2A
Methomyl	1A
Oxamyl	1A

Herbicide Resistance Codes

Herbicide	Resistance Code
Linuron	7
Trifluralin	3
Fluazifop	1
Clethodim	1
Sethoxydim	1
Metribuzin	5

C. Single-site fungicide use

Single-site fungicides may be prone to the development of resistance by plant pathogens, including the new, reduced-risk Group 11 strobilurin fungicides. Recommendations for Group 11 fungicides are to avoid consecutive sprays of any Group 11 fungicide. This includes pre-mix products that include a Group 11 or Group 7 material, or if the applications are tank-mixed with other, non-Group 11 materials.

D. Monitoring for resistance

If a grower has a concern that a population is becoming resistant, an accurate sample and test should be done to confirm resistance. Many university laboratories and private companies have testing procedures for resistant populations. Consult the individual labs for specific sampling protocols. Laboratory documentation would confirm if resistance is found, and would therefore allow the grower to alter pest management strategies.

Notes:

Biological Control

In-season

Strategies that promote beneficial species should be utilized whenever possible. Maintenance and augmentative releases of beneficial species may have an effect on limiting pest populations within the field.

Read the following statements in order and check all that apply. Refer to the corresponding sections on the following pages for more information.

- [ ] ***A. Beneficial insects and biological controls are considered part of the carrot production system.***
- [ ] ***B. Insecticides that are safe to beneficial insects are used when possible.***
- [ ] ***C. Beneficial habitat is maintained and beneficial insects, and/or fungi are occasionally released.***
- [ ] ***D. The potential for pest control by beneficial insects is known and considered in management decisions***

A. Biological Control of Insects

Biological control uses naturally occurring organisms to control pests. Using biological control methods as part of a comprehensive IPM program can reduce the adverse environmental and public safety hazards of pesticides.

Beneficial organisms, also called "natural enemies" fall into three categories: general predatory insects, parasitic insects, and insect pathogens (fungi, bacteria, or nematodes). Identify beneficial populations, and determine if biological control is a feasible option for the field and crop prior to implementing biocontrol strategies. For beneficial management to be effective, adequate prey (food) for the insect needs to be present at all times. If pest populations are too low, the beneficial insects may starve or migrate. If pest populations are too high, the natural enemies may be unable to act quickly enough to protect the crop. Maintenance of suitable habitat in or around the field may increase beneficial species and may aid in biological control. Maintained areas may include non-agriculture areas in and around fields that are ecologically diverse and planted with multiple species with a variety of colors. These areas attract beneficial species and also serve as areas in which they can reside when little prey (food) is available in the field.

B. Pesticide Selection

The choice of pesticides may have a large effect on beneficial populations. Broad spectrum insecticides and fungicides kill or eliminate pest species, as well as potential biological control agents. Carefully select pesticides to protect biological control organisms. New, reduced-risk pesticides make targeted applications possible and with little adverse affect to beneficial populations. Review the in-season disease, insect, and weed sections to determine the reduced-risk options that do not adversely affect beneficial species.

Scouts must properly identify and count beneficial populations. If few to no beneficials are found, biocontrol will not be effective. However, if many beneficial species are detected, only pesticides that do not harm beneficials should be chosen.

Common Beneficial Species

Common natural enemies of carrot insect pests include:

Predaceous stink bugs

- Shield-shape and distinctive odor.
- Preys on larvae.

Tachnid flies

- Adult species are robust, dark and look like houseflies, except tachnids have stout bristles at the tip of their abdomens.
- Internal parasites of larvae - lay eggs on larvae.

Ten-spotted ladybird beetle

- Dome shape with distinctive color patterns.
- Generalist predators that attack larvae.

Parasitic wasps

- Microscopic predators.
- Feed on aphids and leave a characteristic mummy on the underside of leaves.

C. Beneficial Insect Habitat

If beneficial populations are found, growers can maintain them by protecting or enhancing their habitats. To keep beneficial species in and around fields, maintain the overwintering areas and field edges for natural enemies. To improve habitats, plant a variety of plant species that attract both beneficial organisms and non-pest hosts of the beneficial insects. Providing a variety of floral colors and plant types aids in survival of beneficials.

Augmentative releases of biological control agents may be utilized. Biocontrol companies routinely sell predatory insects, such as lady bugs and lacewings, that can be released in the field. These agents may be effective if released in large quantities at life stages conducive to feeding on pests.

D. Biocontrol Potential

When insecticides are used that do not adversely affect beneficial species, many microscopic parasitic wasps are able to survive. These parasitic wasps feed extensively on aphid populations, and these natural enemies contribute to aphid control. Broad spectrum insecticides kill the parasitic wasp populations, but targeted insecticides will not harm the wasps. To determine if natural enemies are attacking aphids, look for aphid mummies stuck to the leaf undersides. Parasitic wasps feeding on aphids result in the mummies. If a high number of aphid mummies are seen, insecticide applications may not be necessary.

Notes:

Quick Note

When selecting pesticides, choose insecticides that preserve natural enemies. Pesticides that are pest specific help to maintain beneficial populations, whereas broad-spectrum pesticides eliminate both pests and beneficial insects. See the label listing to verify.

Harvest Decisions and Environmental Conditions

Conditions during the harvest operations can have a great impact on carrot storability and quality. Quality parameters of concern include pliability, turgor, color, and flavor. A proper bioIPM program needs to be maintained throughout the harvest season.

Read the following statements in order and check all that apply. Refer to the corresponding sections on the following pages for more information.

- ☐ ***A. Carrots are harvested at the optimal time for the variety and markets.***
- ☐ ***B. Carrots are harvested at the correct temperature and soil moisture with clean equipment set up to minimize mechanical damage.***
- ☐ ***C. Carrots are stored under optimal conditions.***
- ☐ ***D. BioIPM techniques are utilized during the harvest and loading into storage.***

A. Monitor Harvest Conditions

Harvest is a busy time of year, yet proper harvesting decisions can prevent damage to the crop. Root length, diameter, and tip fill are the best indicators of harvest timing depending on variety and marketability. Carrots for fresh market are typically harvested immature whereas processing carrots are allowed to mature. Carrots can be harvested through multiple mechanisms. Some carrots are topped and then lifted, while others are lifted by their tops and then the tops are cut off during the mechanical harvesting process.

Harvesting normally occurs 60-70 days after planting for fresh market carrots and 100 days or more after planting for processing carrots. Storage carrots should be harvested when roots reach core temperatures similar to optimal storage conditions of 32 degrees F.

B. Air and Soil Temperatures

Harvesting a healthy crop is a crucial step in marketing a high quality carrot. Carrot harvest timing should also be adjusted for crop growing conditions to optimize quality and storability. If carrots are going directly for processing from the field, core temperatures of roots will not affect quality. Irrigation management prior to harvest may influence carrot rigidity or firmness, so prevent soils from becoming too dry to minimize potential damage during harvest or handling.

If carrots are going to be stored even for short times, the core temperature should be near optimal storage temperatures of 32 degrees F. This will minimize refrigeration and time needed to cool the carrots to the optimal storage temperature.

Carrots being placed into storage need to be free of debris and unnecessary crop residues. Carrots should be run over grading tables to remove as much debris as possible. Cull broken, damaged, rotted roots or defective carrots before placing them in short- or long-term storage as they are a source of future problems.

Carrot shattering, bruise, or tip breakage can occur during harvest operations. Make sure harvesting equipment is in top working order and free of crop and soil residues when harvesting carrots. This should prevent damage to carrots and minimize potential contamination of roots.

Carrot storage facilities, handling equipment, and containers, if used, should be sanitized prior to carrot harvest. This will decrease the pathogen load from one carrot harvest to the next and reduce the residual effects of previous carrot disease issues.

C. Storage Management

Nearly all fresh market carrots are stored for some period of time before reaching the table. Carrots can begin to lose quality within 12 to 24 hours of being harvested, so optimal storage management is necessary to maximize crop value. Storage parameters that are critical for managing carrots are crop condition, temperature, humidity, and air quality.

The optimal storage temperature for carrots is 32 degrees F, and stored carrots can tolerate temperatures as low as 29.5 degrees F before freezing injury occurs. A general rule is that 7/8 of the field heat should be removed from the carrot root within 1 to 2 days after harvest. Carrots placed in the storage at 55 degrees F need to be cooled to 34 degrees F within 24 to 48 hours to minimize quality losses. Allowable core temperature of carrots at harvest will depend to some extent on the cooling capacities within the storage facility.

Storage life of different carrot types at 32 degrees F (0 degrees C) is typically:

Bunched: 10-14 days

Fresh-cut: 3-4 weeks

Immature roots: 4-6 weeks

Mature roots: 7-9 months

Storage life of bunching carrots is limited due to the presence of the tops and the associated higher water loss and respiration.

Optimal humidification for carrot storage is suggested to be 98 to 100%. At the same time free water can rapidly lead to quality losses and development of pathogens on carrot roots. Humidification is important to prevent water loss from carrot roots leading to weight loss and loss in crispness of the carrot root.

Water loss is more important for fresh market carrots, so humidity should remain closer to 100% to optimize quality. Processing carrots may be able to tolerate more water loss, so humidity should be maintained at 95% or higher. The longer the storage duration, the more important humidification will become. An accumulation of free water at 98% relative humidity is more likely than at 95%.

Air quality also influences carrots. Ethylene rapidly increases the bitterness of carrots. In addition, carbon dioxide levels in excess of 5% or oxygen levels less than 3% have detrimental effects on carrot quality. Air exchange may be necessary if refrigeration is used to cool carrots.

Storage Concerns

Bitterness may be caused by preharvest stress (improper irrigation scheduling) or exposure to ethylene from ripening rooms or mixing with commodities such as apples.

Freezing injury will likely result at temperatures of 29.5 degrees F (-1.2 degress C) or lower. Frozen carrots generally exhibit an outer ring of water-soaked tissue, viewed in cross section, that blackens in 2-3 days. In the field, carrots appear to tolerate temperatures well below 29.5 degrees F, but the quantification of the impact on storability and subsequent sensitivity to pathogens is limited.

Washing carrots. Carrots stored with soil still attached have better quality characteristics out of storage than when washed carrots are stored. Most carrots that are stored in several regions of the US , however, are washed prior to storage to remove disease inoculum found in soil. In part, washing can help lower core temperatures of harvested carrots. Free water resulting from washing carrots needs to be removed quickly to prevent disease development in storage.

Quick Note

Harvest at the first sign of maturity when possible. This prevents the induction of cavity spot since older carrots are more susceptible to the disease than younger carrots. Harvesting immature carrots can lead to damage as well. Mature carrots are less sensitive to oxidative browning on their surface than immature carrots.

D. BioIPM Practices

Pest management needs change throughout the growing season, and growers must maintain their season long bioIPM program. Many times, there is no economic benefit to controlling insects late in the growing season. However, season-long control of diseases is useful. Some bioIPM strategies that should be employed at harvest include:

- There should be no insecticide applications within 3 weeks of harvest.
- Culls and carrot trimmings should be properly disposed of quickly.
- Field maps of hot spots should be developed for use in future years.
- Post harvest tillage can be used to limit field debris and weed seed bank development.
- Machinery should be properly cleaned between fields to prevent weed and disease dispersal.

Quick Note

Sprouting will continue as carrot roots develop new shoots after harvest. This is one reason low temperature postharvest management is critical. Common associated disorders include wilting, shriveling, or flaccid tissue due to dehydration.

Pest Management Decisions for Storage

Post-harvest

BioIPM should be used after harvest to minimize pest population survival for the following season.

Read the following statements in order and check all that apply. Refer to the corresponding sections on the following pages for more information.

☐ ***A. Cover crops are planted for weed and disease management and erosion control.***

☐ ***B. Plant debris is turned under quickly after harvest.***

☐ ***C. An adequate storage program is utilized.***

☐ ***D. BioIPM strategies are used over the winter.***

A. Cover Crops

Cover crops (rye, wheat, barley, oats) should be planted in the fall after harvest to promote establishment before winter begins. Cover crops provide many benefits, including improving crop and soil productivity, reducing disease potential, adding organic matter, reducing soil erosion, and providing competitive weed control. Many carrot fields have delayed harvest, making fall establishment of cover crops a challenge. If possible, strips of cover crops should be planted to allow for ground cover through part of the field to minimize erosion.

Rye will grow during any warm period during the fall, winter, or early spring. Cereal grains including barley, oat, wheat, and rye, are most suitable for establishment due to the limited growing season remaining after carrot harvest. Spring or winter annual cereals should be selected based on timing of harvest and subsequent crop.

Summer annual cover crops such as barley or oat could be planted after carrot harvest if the subsequent crop will be planted in early to mid April (i.e. onion or potato). Spring annual cereals will develop 2-3 leaves and be 2" high by killing frost if planted between September 30th and October 15th in Wisconsin. Barley or oat should provide protection from wind erosion, but will die over the winter, minimizing their effect on early spring planting.

Winter annual cover crops such as rye and wheat could be planted after carrot harvest if spring growth is desirable prior to later planted crops such as corn, soybean, or snap bean. Rye is likely preferable due to lower cost for seed. Winter rye may be more suitable if harvest is delayed as seed and seedlings can survive winter and will germinate or re-initiate growth under cool conditions early in the spring if insufficient heat units are available for fall establishment.

Quick Note

Do not mix carrots with produce that generates ethylene. Carrots that are exposed to low levels of ethylene will become bitter.

Cover Crop Basics

Cover crops may be non-legumes, legumes, or a combination grown together. Most of the commonly used non-legume cover crops are grasses. These include:

- Annual cereals (rye, wheat, barley, oats)
- Annual or perennial forage grasses such as ryegrass
- Warm-season grasses like sorghum-sudangrass (limited utility unless seeded during the summer)

Commonly used legume cover crops include:

- Winter annuals such as crimson clover, field peas, subterranean clover and many others
- Perennials like red clover, white clover and some medics
- Biennials such as sweetclover
- Summer annuals (in colder climates, the winter annuals are often grown in the summer)

Growers should determine which cover crop works best in their production system. To find a suitable cover crop or mix of covers, consider these steps:

- Clarify the primary needs of the carrot system.
- Identify the best time and place for a cover crop in the system.
- Test a few options.
- Evaluate effects on the crop, ease of handling residues, and on pest response.
- Determine the cost of cover crops and economics of the system, but also estimate the cost benefit they may provide (such as fertility benefits, soil conservation, and reduced pest management costs).

B. Incorporate Plant Debris

An effective leaf blight management strategy is burial of carrot residues within two weeks after harvest. Carrot residues provide over-wintering sites for pathogens causing Alternaria and Cercospera leaf blight. Leaving crop residues on the soil surface can result in release of inoculum that can infect neighboring carrot fields in subsequent crop years.

Leaving carrot residues on the soil surface, however, can facilitate freezing of carrot crowns and meristematic tissues, decreasing the potential for survival of volunteer plants. Fall plowing may require 1 to 2 additional tillage passes in order to prepare for the subsequent crop. Burial of carrot residues will result in little ground cover, increasing the vulnerability of the soils to wind erosion until a suitable cover crop can be established.

Carrot fields should be direct seeded to cover crops of choice depending on timing of harvest and intended rotation crop. Carrot residues must be incorporated prior to carrot planting during the subsequent season. Carrot residues that are not incorporated can increase inoculum loads of the pathogens Alternaria and Cercospera leaf blight. High inoculum levels earlier in the year will lead to earlier establishment of leaf blight in new carrot fields and earlier and more applications of fungicides for leaf blight management.

Quick Note

Deep plowing and incorporation of plant residues may be needed to hasten decomposition of carrots. This should be done immediately after harvest.

C. Storage Program

Proper storage conditions will allow for maintenance of carrots after harvest. The entire storage facility should be washed and disinfected prior to handling carrots. Storages should have adequate air movement with a temperature of 32 degrees F, and relative humidity levels at 95% or more. Depending on variety and market use, carrots can be stored at these temperatures for up to 6 months. Bunched carrots should only be stored for up to 14 days, and fresh cut carrots should only be stored for 3-4 weeks.

IPM strategies, especially for disease management, should continue until carrots are sold and off the farm. Implementation of IPM strategies in storage will greatly aid in storage disease management strategies. To maintain healthy carrots in storage:

- Inspect, repair, and sanitize the storage facility and storage equipment before putting carrots in storage.
- Properly dispose of waste carrots. Do not put cull piles near the storage facility.
- Ensure bruise-free carrots by not dropping the roots from heights of more than 4 feet (1.2 meters) on storage and packing lines.
- Isolate damaged or diseased carrots in separate bins for immediate grading, marketing, or processing.
- Sanitize storage and storage containers after emptying the storage and prior to refilling with the next crop.

D. Utilize BioIPM Strategies

BioIPM strategies should be used after the season to prepare for the upcoming production season. Some strategies that should be considered during this time include:

- Mapping insect overwintering sites (e.g. carrot weevils)
- Mapping disease and nematode problem areas in the field

PEST PROFILES

Aster Yellows of Carrot

April	May	June	July	August	September	October
	peak activity	peak activity	peak activity			

Aster yellows is a chronic, systemic disease that is spread by the aster leafhopper. Symptoms of aster yellows are virus-like, but the disease is actually caused by the aster yellows phytoplasma, an organism related to bacteria. Aster leafhoppers acquire the pathogen by feeding on infected plants. The incidence of aster yellow varies greatly from year to year because of the fluctuation in the populations and flight patterns of leafhoppers and the fluctuations in the number of infected reservoir plants. Aster yellows is a difficult disease to control, in part because of the extensive host range of both the insect and the pathogen that includes vegetables, grains, forages, field crops, flowers, and weeds. Of the vegetable hosts, carrots, lettuce, celery, onion, and potatoes are of the most concern.

Carrots infected with aster yellows are usually malformed, with numerous hairy secondary roots. These roots may have a bitter taste, woodiness, and a pale, rather than deep orange, color. The crowns of diseased plants are predisposed to soft-rot bacteria in moist weather and can be difficult to harvest mechanically. The younger the plant at the time of infection, the more severe the damage from aster yellows.

Above-ground symptoms of aster yellows are yellowing and vein clearing of young leaves at the center of the crown. Dormant buds in the crown grow into yellow shoots which give a short, bunchy, "witches' broom" appearance to the top. Old leaves become twisted and reddened or bronzed and eventually break off. Symptoms of aster yellows are often mistaken for herbicide damage.

The aster yellows phytoplasma must live in plant cells or the aster yellows leafhopper to survive. The pathogen overwinters in infected perennial plant, or is brought to the north with leafhopper migration from southern states in the spring. Leafhoppers spread the phyotplasma from plant to plant when they feed. When a leafhopper feeds on and acquires the pathogen from an infected plant, a 3-week incubation period is required for the pathogen to multiply inside the leafhopper before it is capable of transmitting it to another plant.

Aster yellows is caused by the aster yellows phytoplasma, a bacterium-like organism that lives in the phloem tissue of plants. The aster leafhopper moves the aster yellows phytoplasma from plant to plant.

Scouting: The incidence of aster yellows in a carrot crop will be directly related to the size of the leafhopper population carrying the pathogen. Begin scouting for aster leafhoppers in early spring when plants are newly sprouted, and continue scouting weekly through the end of July. Yellow or orange sticky traps may be placed in the field to determine when the first migrants arrive. Place the cards just above the crop, a few rows in from the outer field edge. Be sure to check the cards daily so that rapid changes in the leafhopper population can be detected

Once leafhoppers appear, estimate the size of the population by sweeping the area with a net. Sweep nets work best when wind speeds are low and the foliage is dry. Take 25 sweeps in 4 locations per field and record the total number of leafhoppers present. One sweep equals one pass over the foliage.

Threshold: Large numbers of leafhoppers does not necessarily predict more aster yellows, nor does a small population mean that no aster yellows will occur, because the most important factor is the number of leafhoppers in the population that are carrying the pathogen (infectivity rate). To find out how much of the current leafhopper population is infective, contact your county Extension office or call the UW-Madison Entomology department at 608-262-6510. If you are not able to do this, assume 2.5%.

The Aster Yellows Index is calculated by multiplying the infectivity rate of the leafhopper population by the number of leafhoppers collected in 100 sweeps. The treatment threshold depends on the crop and resistance level of the variety planted.

- Aster Yellow Index = (Current infectivity rate of leafhoppers) x (the number of leafhoppers per 100 sweeps)

For example, if the current leafhopper infectivity rate is 2.5%, and 20 leafhoppers were found in 100 sweeps with a sweep net, then:

2.5 (infectivity rate) **x 20** (number caught per 100 sweeps)

= 50 (aster yellows index)

Continued on next page...

Treatment thresholds for resistant and susceptible varieties and crops are based on the index as follows:

Crop	Aster Yellows Index
Carrots	
Resistant varieties	100
Intermediate varieties	75
Susceptible varieties	50
Celery	35
Lettuce	25

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Aster yellows is rarely lethal. Thus, infected perennials can serve as source of the aster yellows phytoplasma for many years.

Symptoms of aster yellows resemble a virus.

Management Strategies

Cultural control

- Leafhoppers migrate from grain fields, so plant susceptible vegetables as far away from grains as possible.
- Plant a resistant variety if possible. For a listing of currently-available resistant cultivars, see Extension publication *Commercial Vegetable Production in Wisconsin* (A3422), or contact your county Extension agent or seed supplier.
- Sowing seed at higher densities has been shown to reduce incidence of yellows.
- Floating row covers may be used in small acreages to cover susceptible plants early in the season.
- When possible, remove plants suspected of having aster yellows so that the plant will not become a reservoir for further spread.
- Eradicating perennial weedy hosts may be helpful to reduce overwintering sites. Common weed hosts for aster yellows include thistle, fleabane, wild lettuce, sow thistle, chicory, wild carrot, galinsoga, dandelion, plantain, cinquefoil, and others.
- Crop debris should be plowed under as soon as possible after harvest.

Biological control

- Natural enemies may help to control aster leafhopper populations. However, they are not likely to affect transmission of aster yellows.

Chemical control

- Insecticides may be used to control aster yellow leafhoppers, but are difficult to control, especially on young plants with little surface area. Timing of insecticide applications is critical. Scout consistently. Refer to A3422 *Commercial Vegetable Production in Wisconsin* for currently-labeled products.
- Because disease symptoms take a month to develop on carrot, treatment should be discontinued 30 days before harvest.
- Note that insecticides used for leafhopper control will affect the natural enemies of aphids, and aphid populations may increase with repeated leafhopper treatments.

Cavity Spot of Carrot *Pythium violae* & other *Pythium* sp.

PEST PROFILES

peak activity occurs in wet, cool conditions, but symptoms not seen until carrots reach maturity

April	May	June	July	August	September	October

Cavity spot is a common root disease of carrots. The fungus *Pythium* that causes cavity rot is endemic to many soils, especially muck soils. High soil moisture from rainfall, poor drainage, or over-irrigation encourages the development of cavity rot. The pathogen has a wide host range that includes alfalfa and other legumes, cucurbits, brassicas, wheat, and celery. Management of *Pythium* diseases is difficult if the growing season is wet.

Cavity spot does not tend to reduce yield, but it does affect the appearance and the marketability of the carrot. The fungus causes dark-colored, sunken, horizontal lesions along the tap root, mostly on the upper third of the root. Lesions begin as tiny, sunken spots that form into larger decayed areas if invaded by other fungi or bacteria.

Pythium fungi overwinter in soil as thick-walled spores or as resting mycelium (the vegetative part of the fungus). Fungal growth and disease development are favored by wet soil conditions and cool temperatures. Root infection can occur any time during crop development, but symptoms may not be apparent until carrots are approaching maturity. The amount of disease that occurs is determined mainly by soil moisture and the amount of *Pythium* in the soil.

▶ Fungal pathogens may develop resistance to fungicides. Do not use products with the same mode of action in consecutive applications. Rotate with pesticides with different Resistance Group numbers.

Mature carrots are more susceptible to infection from Cavity spot.

Scouting: Cavity spot often shows up near harvest. Look for horizontal lesions of varying size on the tap root. *Pythium* root dieback, another root disease caused by a *Pythium* fungus, may also be found and is characterized by rusty-brown lateral roots, forking, and stunting. These symptoms can be easily confused with damage from nematodes, soil compaction, or too wet soils.

Threshold: No thresholds have been established.

Management Strategies

Cultural control

▶ Select well-drained fields with light-textured soils. Avoid planting low spots. Improve field drainage where needed. Consider planting on raised ridges or beds. Break compacted zones when needed.

▶ Avoid problem fields with a history of cavity rot, if possible.

▶ Practice 3-year crop rotations with crops other than alfalfa or carrots. Non-hosts include onions, tomato, and potato.

▶ Plant vigorous, disease-free seed. Varieties differ in their tolerance to *Pythium.* Check with your seed supplier.

▶ Some cover crops, such as Sudangrass, rapeseed, and mustard, have been reported to suppress *Pythium*. Cover crops need to be incorporated well before the crop is planted, and when soils are thoroughly warm and have adequate moisture to encourage rapid breakdown. The biofumigant effect of cover crops can vary by season, cover crop variety, maturity at incorporation, and soil microbiology.

▶ Harvest carrots promptly when mature because older carrots are more susceptible to infection.

Chemical control

▶ Soil-applied fungicides or seed treatments for management of cavity spot may be helpful, but if soil moisture conditions and disease pressure levels are highly favorable for disease, they may not be effective. Refer to A3422 *Commercial Vegetable Production in Wisconsin* for currently labeled products.

Leaf Blights of Carrot *Alternaria dauci, Cercospora carotae, Xanthomonas carotae*

April	May	June	July	August	September	October
		peak activity	peak activity			

Two fungal pathogens, *Alternaria* or *Cercospora*, commonly cause leaf spot or blight diseases on carrot. A bacterial pathogen, *Xanthomonas*, can also cause leaf blights in Wisconsin. All three pathogens are capable of producing severe leaf blights on carrot leaves and petioles during prolonged periods of wet weather. They sometimes occur together, and the strategies used to manage them are similar.

Leaf spot or blight diseases can develop rapidly when conditions are favorable. Blights begin as small lesions on the leaves that join into larger ones until the leaflets die. The foliage can have a scorched or burnt appearance. *Cercospora* leaf blight generally appears earlier in the season than *Alternaria* and can be severe on young leaves. *Alternaria* can cause damping-off of carrot seedlings, but tends to be more severe later in the season as plants approach maturity. Carrot leaf blights rarely affect growth of carrot roots unless infection occurs early and remains severe. However, petioles of leaves weakened by foliar blights become brittle and often break off during harvest, resulting in harvesting loss.

The fungal pathogens that cause foliar blight are introduced in or on contaminated seed or may over-winter in diseased crop debris in the soil. Spores produced on this debris are carried by wind or water to young carrots. The fungi enter the plant through stomata. Lesions appear in 3-5 days, and new spores are produced soon after, causing numerous cycles of the disease when conditions are favorable. The spores become airborne and are spread mainly by wind, as well as, splashing rain and field equipment. Moisture is essential for infection because the fungal spores require surface moisture to germinate. The bacterial leaf blight pathogen *Xanthomonas* is mainly introduced in or on contaminated seed. Bacteria require warm (>75 degrees) temperatures to infect plants and reproduce and are spread mainly by splashing water.

Alternaria (left)and Cercospora (right) leaf blights are important foliage diseases of carrot, but they do not affect the edible carrot root.

Scouting: Regular field scouting and attention to weather conditions and variety planted is key to leaf blight management. A minimum of 50 to 100 mid-age leaves should be sampled twice weekly starting in mid-late June and examined for the presence of carrot leaf diseases. Look for small, dark brown to black spots on leaves and elongated lesions on petioles. A leaf is counted as infected if one or more leaf blight lesions are found on the leaflets or petiole.

If conditions are favorable, small lesions coalesce into large necrotic areas until the whole leaflet dies. Symptoms often resemble frost injury or herbicide damage. Leaf spots caused by the bacterial pathogen may have an irregular, yellow halo and appear water-soaked. A sticky amber-colored bacterial exudate, which is a diagnostic sign of bacterial blight, may be present on leaves or petioles.

Infection by all leaf blight pathogens takes place rather slowly unless a favorable environment is present. Initially, leaf blights occur in irregular small patches within a field but may become uniform and widespread throughout the field when disease is severe. Alternaria leaf spot can spread rapidly on the older leaves of a maturing crop after the rows have closed. This is due in part to poor air circulation among the older lower leaves in the canopy, the moisture-holding capacity of the dense foliage, and the cooler weather in the late season.

Threshold: If fungicides are considered, begin treatment when 25% of the leaves sampled are infected, which is approximately 1–2% of the crop. Be sure to make note of the variety planted. The time of the season when blight reaches 1-2% varies considerably from year to year and between varieties. No threshold has been established for bacterial blights.

Use the TOMCAST disease forecasting model for specific spray timings and intervals.

Continued on next page...

Management Strategies

Cultural control

- Crop rotation is a very important management tool for fungal and bacterial leaf blights. A minimum rotation of 2 to 3 years out of carrots is effective against the three diseases.

- Select well-drained sites when planting new fields. Improve air flow within the field by widening row spacings. Do not plant new fields upwind of existing fields with blight symptoms.

- Planting resistant or tolerant varieties is very effective. Leaf blights appear later in the season on tolerant varieties and spread more slowly, resulting in less need for fungicide use.

- Plant only vigorous, disease-free seed from a reputable seed supplier.

- Hot water treatment is the best control of bacterial leaf blight. Use a hot water treatment of 122 degrees F for 15 minutes. Some reduction in viability will probably occur.

- If irrigation is used, irrigate early in the day to allow foliage to dry thoroughly. Use drip irrigation if possible.

- Promote healthy, vigorous growth throughout the season with balanced fertility and good growing practices. Poorly growing plants or plants with nitrogen deficiency tend to be more susceptible to blights.

- Plow plant debris immediately after harvest.

Chemical

- Protectant fungicides, starting at the first sign of infection, are effective in controlling leaf blights. For current recommendations, refer to A3422 *Commercial Vegetable Production in Wisconsin*. Note that fungicides will not control blights caused by bacteria.

- Base fungicide applications on regular and consistent monitoring using established thresholds. The application of fungicides can be delayed or eliminated if crop scouting and weather conditions indicate that blight infection is unlikely. Early carrots rarely need to be treated if they are harvested within 100 days and not close to late fields.

- It's important to apply fungicides at high pressure and in sufficient water to reach the lower leaves in a dense canopy. Good coverage of the lower leaves in the canopy is critical because, once infected, these leaves become sources of spores for infection of healthy younger leaves.

- Do not apply fungicides in rainy weather because canopy penetration will be poor.

- Fungicide seed treatments may reduce *Alternaria dauci*.

- Fungal blight pathogens may develop resistance to some systemic fungicides. Do not use products with the same mode of action in consecutive applications. Rotate with pesticides with different Resistance Group numbers.

Symptoms of leaf blights begin with small, dark brown to black spots with yellow borders along leaf margins. As the blight progresses, the entire leaflet shrivels and dies, causing the foliage to appear burned.

PEST PROFILES

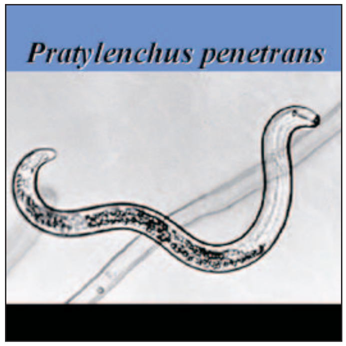
Root Knot Nematode *Meloidogyne hapla*

	peak activity					
April	May	June	July	August	September	October

The root-knot nematode is a microscopic, plant-parasitic roundworm that lives in soil and plant tissues. It is particularly common in muck soils in Wisconsin. The nematode feeds on plants by puncturing cell walls and sucking the cell contents with a needlelike mouthpart called a stylet. Carrots in particular, can be severely damaged by nematodes as they feed on the root tip and rootlets. The root-knot nematode has a wide host range, including carrots and many other vegetable and forage crops such as onion, lettuce, potato, alfalfa, soybean, and clover. Grain crops such as corn, wheat, barley, and oat are non-hosts, and rotation with these crops is an effective way to reduce root knot nematode populations.

Root knot nematodes can cause substantial damage to crops and are of major concern where they occur. Carrots are one of the most sensitive crops to this nematode with a damage threshold density of less than 1 egg/cc soil. When carrots are infected early in the season, they can become severely forked and galled on the main root as well as on the fine fibrous roots. Severely infected carrots are unmarketable. Infection later in the season is often restricted to the fine fibrous roots. Note that forking can also be caused by other soil-borne pathogens such as *Pythium*, which prune the root tips during the seedling stage, but in these cases no galls will be present on the main taproot or fine fibrous roots. Nematode-infected root systems are not efficient in the uptake of water and nutrients, and plants may be stunted and wilt easily.

Severe yield losses can result from reduced marketability of carrots infected with nematodes.



Adult root knot nematodes and their egg masses are visible at 10X magnification.

Most nematodes in soil feed on bacteria, fungi, or other soil microorganisms, but the root knot nematode is a plant pathogen.

Scouting: It is important to know whether or not this nematode is present in the field in order to develop long-term crop rotations and cropping sequences that either reduce populations in heavily infested fields or prevent their increase in fields that have low infestation levels or no nematodes. Use a soil bioassay with lettuce to assess soil root-knot nematode levels, or submit soil samples for nematode analysis at a public or private soil testing lab.

To sample soil, take representative, composite samples of the field as described in the soil sampling section of this workbook. Because nematodes are associated with plants, take the samples from near the root zone. Nematodes are found in irregular patches in the field, so cover the field well in a W-shaped pattern. The more subsamples taken, the more representative the sample will be. Keep the samples cool, but do not freeze. Transport the samples as soon as possible to the soil testing laboratory. Contact your county extension agent or other farm advisor to locate laboratories that analyze nematode samples, and for information on how to interpret sample results.

In addition to soil testing, roots of susceptible crops should be examined directly in the field for the presence of galls or thickenings. Nematodes and their egg masses are visible at 10X magnification on galled tissue. The highest amount of infections on roots and numbers in soil will be found close to harvest.

Keep field records and maps of the occurrence, location, and severity of root-knot nematodes.

Threshold: The damage threshold for carrots is less than one egg per cubic centimeter (cc) of soil. If a previous crop was a host for root knot nematodes, the population may be high enough to cause damage to a carrot crop that follows.

Continued on next page...

Management Strategies

Cultural control

- Crop rotation out of carrots into sweet corn, field corn, oats, or sod for 3 years, if economically possible, is highly effective in reducing numbers of nematodes in an infested field.

- The use of cover crops grown between the main crops may provide an alternative management strategy. Ryegrain, barley, oats, sudangrass, tall fescue, annual ryegrass, and wheat are not hosts to root knot nematode.

- Keep fields free from host weeds common to muck soils such as dandelion, purslane, mallow, and plantain.

- Plant breeders are finding good sources of resistance to root knot nematode damage (forking and galling). New resistant carrot cultivars are likely to be available soon. Check with your seed supplier.

- Avoid moving soil from infested fields to uninfested fields on equipment and vehicles. Wash machinery and equipment after use in infested fields. Avoid surface water run-off from infested fields.

- Soil solarization can reduce nematodes in the upper 12 inches of soil. It requires a 4-to 6-week treatment during the hottest time of the year.

Chemical control

- Soil fumigation is effective but expensive, especially on muck soils. Apply soil fumigants in the fall when the soil temperature is at least 50 degrees F. Refer to A3422 *Commercial Vegetable Production in Wisconsin* for currently labeled products.

Nematode Life Cycle

The root knot nematode life cycle has three major stages: egg, juvenile, and adult. When temperature and moisture levels are favorable in the spring, worm-shaped juveniles hatch from eggs in the soil. These juveniles are the only life stage of the nematode that can infect roots. The juveniles penetrate host roots just behind the root tip region and establish their special permanent feeding sites (giant cells) in the vascular tissues of the root. The giant cells provide nutrients for the nematodes, which continue to feed, enlarge, and molt three times. Root cells around the feeding sites are also induced to enlarge and form galls (knots), often extensive secondary root formation, and branching of the main root. Adult females produce an egg mass just outside the root or just beneath the root surface. Under favorable conditions, root-knot nematode eggs can survive for at least one year in the soil. The life cycle can be completed in 3 to 4 weeks under optimum conditions.

The nematode moves into new areas mainly by surface water drainage, blowing soil, and movement of soil by equipment and machinery.

PEST PROFILES

Black Cutworm *Agrotis ipsilon*

peak activity	peak activity					
April	May	June	July	August	September	October

Cutworms are the larvae (caterpillars) of several species of night-flying moths. The larvae are called cutworms because they cut down young plants as they feed on stems at or below the soil surface. Cutworms feed on many common vegetable and field crops, including asparagus, bean, cabbage and other crucifers, carrot, celery, corn, lettuce, pea, pepper, potato, and tomato. The black cutworm is a particular problem because it is present earlier in the season when plants are most susceptible to damage.

Cutworms feed on young seedlings, most actively at night or on cloudy days. Some cutworms, such as the black, bronzed, and army cutworms, can be very injurious, cutting many new plants in an evening. During the day, they remain hidden in debris on or just under the soil surface. Although cutworms are active throughout the summer, they are rarely a problem after spring. Populations can vary greatly from year to year.

Overwintering black cutworms in Wisconsin are rarely abundant enough to cause significant damage. Moths that appear in late May have migrated into Wisconsin from other states. Adult moths are gray with a series of distinctive dark markings on their forewings. Female moths lay hundreds of eggs, either singly or in clusters, on emerging weeds or plant residue. Generally, black cutworm moths will not lay eggs in fields that have already been planted. Young larvae feed on the foliage or small roots until they are about ½ inch in length. At this stage, they begin feeding on seedling stems, either cutting through them or burrowing into them. There are three generations per year in the upper Midwest.

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Mature cutworm larvae are dark greasy worms about 1 ½" long that curl up into a tight C-shape when disturbed.
The first generation of cutworms that are active during seedling establishment in May and June cause the most damage.

Scouting: Cutworm damage is most critical at seedling emergence, when feeding can reduce stands. Look for plants cut off near the ground or plants that are noticeably wilting (when cutworms chew on the stems but do not sever the plant). Check in the late afternoon and evening when cutworms are more active, or in the morning when damage is fresh and easier to see. You may also detect droppings on the ground. To verify cutworms are present, run your hand over the soil, rolling over soil clumps and other potential hiding places within a one foot square area of the damage. When disturbed, cutworms curl into a C-shaped ball.

Although pheromone traps are useful for monitoring moth activity, they do not predict if cutworm damage will occur, or when or where damage might be expected.

Threshold: Timely detection is critical if insecticide treatment is considered. Spot treat when numbers exceed two larvae per row foot.

Management Strategies

Cultural Control

- Thorough soil preparation in advance of planting helps in cutworm control by exposing and killing over-wintering larvae. Till in green manure several weeks before planting.
- Remove weeds, especially grasses, and plant residue to reduce egg-laying sites and seedling weeds that attract small cutworms.
- Avoid planting susceptible crops in low wet areas or in rotations following sod.
- Plow in crop residue after harvest.

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Biological Control

- A number of braconid parasites and predaceous ground beetles help keep cutworm numbers down.
- Cutworms are attractive to birds.
- Flooding may force larvae to the soil surface during the day where they are attacked by parasites or predators.

Chemical Control

- Spot treatment of cutworms can be effective when threshold is reached. Refer to A3422 *Commercial Vegetable Production in Wisconsin* for currently labeled products.
- Caterpillars hide under the soil surface adjacent to the plant stem during the day and feed on the stems after dark. For best results, make application between midnight and dawn while cutworms are feeding above ground.

Aster Leafhopper *Macrosteles quadrilineatus*

April	May	June	July	August	September	October
		peak activity	peak activity	peak activity		

The aster leafhopper is an annual pest in the upper Midwest because of its ability to spread a damaging systemic disease called aster yellows. Aster yellows is a chronic disease with virus-like symptoms but is actually caused by the aster yellows phytoplasma, an organism related to bacteria. Leafhoppers prefer small grains, lettuce, carrots, celery, and small grains for feeding and breeding, while other crops such as potatoes and onions provide a temporary source of food and refuge for adults.

Aster leafhoppers use their piercing-sucking mouthparts to suck plant juices from green parts of plants, often giving leaves a whitened, mottled appearance. While this damage is disfiguring, the real problem occurs when the insect transmits the aster yellows pathogen. On carrots, symptoms of aster yellow infection begin as a yellowing and twisting of new foliage. Later they produce a dense growth of yellow or reddish shoots. Carrot roots become covered with root hairs and develop a bitter taste and poor color, making them unmarketable. Infection also leaves the roots vulnerable to soft rots. The younger the plant at the time of infection, the more severe the damage from aster yellows. Aster yellows disease is untreatable; the only solution is to remove infected plants.

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Adult aster leafhoppers are tiny, active, olive-green, wedge-shaped insects. They're also called six-spotted leafhoppers because of the three pairs of spots on the tops of their heads.

The aster leafhopper spreads a virus-like organism called a phytoplasma which causes aster yellows disease in plants.

Scouting: Begin scouting for aster leafhoppers in early spring when plants are newly sprouted, and continue scouting weekly through the end of July. Yellow or orange sticky traps may be placed in the field to determine when the first migrants arrive. Place the cards just above the crop, a few rows in from the outer field edge. Be sure to check the cards daily so that rapid changes in the leafhopper population can be detected

Once leafhoppers appear, estimate the size of the population by sweeping the area with a net. Sweep nets work best when wind speeds are low and the foliage is dry. Take 25 sweeps in 4 locations per field and record the total number of leafhoppers present. One sweep equals one pass over the foliage.

Threshold: University of Wisconsin entomologists have developed an Aster Yellows Index (AYI) to guide leafhopper treatment thresholds. The AYI estimates the relative threat of aster yellows and is calculated by multiplying the number of leafhoppers found in 100 sweeps by the percent of local leafhoppers that carry the disease. Only a small percentage of leafhoppers carry the aster yellows pathogen, and that percentage can change throughout the season. To find out how much of the current leafhopper population is infective, contact your county Extension office or call the UW-Madison Entomology department at 608-262-6510. If you are not able to do this,assume 2.5%.

Then compute the index using the following formula:

- ▶(Current infectivity rate of leafhoppers) x (the number of leafhoppers per 100 sweeps) = Aster Yellow Index

For example, if the current leafhopper infectivity rate is 2.5%, and 20 leafhoppers were found in 100 sweeps with a sweep net, then:

2.5 (infectivity rate) **x 20** (number caught per 100 sweeps)

= 50 (aster yellows index)

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Treatment thresholds for resistant and susceptible varieties and crops are based on the index as follows:

Crop	Aster Yellows Index
Carrots	
Resistant varieties	100
Intermediate varieties	75
Susceptible varieties	50
Celery	35
Lettuce	25

Management Strategies

Cultural control

- Leafhoppers migrate from grain fields, so plant as far away from grains as possible.
- Plant a resistant or tolerant cultivar. For a listing of currently available resistant cultivars, see Extension publication *A3422 Commercial Vegetable Production in Wisconsin* or contact your county Extension agent or seed supplier.
- Sowing seed at higher densities can reduce overall damage by aster yellows.
- Eradicate perennial weeds that commonly serve as overwintering hosts of aster yellows, including thistles, plantains, wild carrot, wild chicory, dandelion, fleabanes, wild lettuce, daisies, black-eyed Susan, rough cinquefoil, and many others.
- Floating row covers may be used in small acreages to protect susceptible plants from leafhopper feeding.
- Plow under crop debris soon after harvest.

Biological control

- Aphid generalists such as parasitic wasps, *Orius* species, and damsel bugs may help to control aster leafhopper populations, but they will probably not affect transmission of aster yellows.

Chemical control

- Leafhoppers are difficult to control with insecticides, especially on young plants with little surface area. Refer to A3422 *Commercial Vegetable Production in Wisconsin* for currently labeled products. Chemicals with low residual activity, such as synthetic pyrethroids need to be applied 2 to 3 times weekly when leafhopper influxes and rains are frequent.
- Note that insecticides used for leafhopper control will affect the natural enemies of aphids, and aphid populations may increase with repeated leafhopper treatments.
- Because aster yellow symptoms take a month to develop in carrots, treatment should be discontinued 3 to 4 weeks before harvest.
- Follow proper resistance management strategies - do not spray the same product or products with a similar mode of action in consecutive applications.

Aster Leafhopper Life Cycle

There are two distinct leafhopper populations each year in the north: migrant and native. The first aster leafhoppers that appear each spring result from migratory adults which overwinter as eggs on southern grain fields in Louisiana and Missouri and subsequently migrate northward on warm southerly winds in May and June. This population of leafhoppers is significant because some of the migrants acquire the aster yellows organism in their overwintering area and may be able to transmit the pathogen by the time they reach Wisconsin. Young plants in the field at this time would be susceptible to infection when the migrant leafhoppers feed.

The native aster leafhopper populations arise from overwintered eggs deposited the previous fall on winter grains and weeds. Young leafhoppers, or nymphs, hatch from the eggs in June and early July. They resemble the adults, but are cream colored or dark and lack fully-developed wings. Nymphs are less active but crawl rapidly when disturbed, often settling in the lower leaves. There are normally two to three generations per year in the upper Midwest. The native leafhoppers are probably less important in aster yellows transmission.

To acquire and transmit the aster yellow pathogen, the aster leafhopper must feed for a prolonged period on an infected host (either locally or in a southern state). The pathogen must then incubate within the leafhopper for about 3 weeks before it can be transmitted to another plant.

PEST PROFILES

Carrot Rust Fly *Psila rosae*

	peak activity			peak activity		
April	May	June	July	August	September	October

The carrot rust fly is an occasional pest of carrots in the upper Midwest. The adult fly does not injure plants, but the maggot larvae feed and tunnel into carrot roots, reducing yield and quality and exposing the carrots to rot. A rust-colored material develops in the tunnels, giving the insect its name. Other hosts of carrot rust fly are parsnips, celery, celeriac, and parsley.

The carrot rust fly maggot damages plants by eating the small fibrous roots and by tunneling in larger roots. Usually the plant tops continue to look healthy. Larvae may kill young plants. Damage generally increases the longer the carrots are left in the ground. Maggots often continue to feed in stored carrots.

The carrot rust fly overwinters as pupae in the soil or as maggots in overwintering roots. The adult fly lays eggs in May and June on the soil surface around host plants. The eggs hatch into white or yellow-white maggots that feed on and in the roots for several weeks until they pupate. The brown pupae rest in the soil near the roots until August when the next generation of adult flies emerge. The maggots from this August-September generation generally cause the most damage.

Adults are small, dark, shiny flies with straw-yellow legs and heads and large red eyes. Carrot rust fly larvae cause surface tunnels in roots. Tunnels are filled with a rusty mush and the stiff white maggots.

Scouting: Adult flies can be monitored using yellow sticky traps. Traps should be placed just above the carrot canopy and within the first couple of rows along the field edges. Damage is often most prevalent along field edges. There should be an average of 2.5 to 5 sticky traps per acre. Traps should be monitored 1 to 2 times per week.

Threshold: Insecticide treatment is generally not recommended for carrot rust fly.

Management Strategies

Cultural control

- Adults are weak flyers. Plant carrots in open fields where wind protects them from adult flights. Avoid fields surrounded by brush or woods.
- Avoid fields with a history of rust fly infestations.
- Crop rotation is effective in keeping populations from building. Do not include related plants such as parsley or celery in the rotation. If land is available, locate the new carrot field at least ½ mile from the old field.
- Delay planting until after mid-May to avoid peak egg-laying.
- In small plantings and seedbeds, row covers are effective in excluding the pest insect from feeding or laying eggs on the crop.
- Cover crops and interplanted crops have been shown to reduce damage by carrot rust fly. However, in some cases this can reduce carrot yield.
- Harvest carrots as soon as possible. Do not store carrots in ground to avoid late season maggot infestation.
- Plow crop debris deeply after harvest.

Biological control

- Little is known about the effect of natural enemies on carrot rust flies.

Chemical control

- Insecticides have limited effectiveness against carrot rust fly, mainly because the adult spends most of its time in the periphery of the fields.

Carrot Weevil *Listronotus oregonensis*

April	May	June	July	August	September	October
	peak activity	peak activity				

The carrot weevil adult is a small, dark-brown snout beetle that overwinters in debris in the vicinity of previous host crops. The larvae hatch from eggs laid in the spring and feed on the upper third of carrot roots, causing serious, localized damage when populations build up. Most feeding activity occurs from late May until mid-June. Parsley, celery, and parsnips are also hosts of carrot weevil.

The adult beetle feeds on carrot foliage, but the damage is rarely serious. Most of the damage from the carrot weevil is from the feeding activity of the larvae as they burrow into the carrots. Infested roots can be riddled with tunnels which provide entry points for pathogens that cause secondary rots.

The adult carrot weevil beetle overwinters in debris or about one inch below the soil surface. In spring, the beetles become active and mate after a few warm days. Adult females chew small cavities in the crown or petioles of carrots and deposit two to three eggs in each, sealing the cavity with a black exudate. Eggs hatch after one to two weeks into typical white, legless, C-shaped larvae with a brown head. The young larvae tunnel down into the root to feed, or leave the stalk and enter the roots from the soil. They feed for about two weeks. There is one generation in the northern Midwest. At the end of August, a new population of adult weevils is present in the field, but this weevil population does not cause damage to the current-year crop. The weevil adults overwinter and reproduce in the following crop season.

The carrot weevil adult is a dark-brown snout beetle about ¼ inch long. It overwinters in debris in the vicinity of previous host crops. Damage to crops is from feeding by the white, legless, C-shaped larvae.

Scouting: Carrot weevil infestations can be detected by examining plants for egg-laying scars, which is easier than sampling for adults. To check a suspected scar, rub off the dark spot and check for a puncture beneath. If a puncture is found, a weevil has deposited eggs in it.

Egg-laying occurs around 400 – 450 degree days and can be monitored by placing five or six baited traps along the field margin near overwintering sites. Use whole carrot roots or slices under screens or in jars with good access for the adult beetles. Examine the traps every 3-4 days for eggs.

Threshold: No thresholds have been established

Management Strategies

Cultural control

- Crop rotation is very effective in preventing weevil damage by keeping populations from building. Do not include celery, parsnip, or parsley in the rotation.
- Plant new fields some distance away from previous carrot fields.
- Time planting to occur after the peak egg-laying period (400-450 degree days).
- Plow in crop debris after harvest to remove overwintering sites.

Biological control

- Parasitism by an egg parasitoid, *Anaphes* sp., is a significant control factor and should be encouraged by maintaining border areas that offer habitat and pollen for the parasitoid.
- Research into biological control by application of entomopathogenic nematodes shows promise for the future.

Chemical control

- Insecticides can be used to kill weevils in May when all of the adults have become active. Depending on the level of weevil activity, a single well-timed application, or a spray regimen of every 5-7 days for 2 weeks once eggs are found can provide good control. Refer to A3422 *Commercial Vegetable Production in Wisconsin* for currently labeled products.

PEST PROFILES

Wireworm *Agriotus spp., Melanotus spp. and others*

	peak activity					
April	May	June	July	August	September	October

Wireworms are the larvae of several species of click beetles (beetles that flip into the air with an audible click when turned upside down). Wireworms feed primarily on grasses, including corn and small grains, but they have a wide host range that includes beans, beets, cabbage, carrots, lettuce, onions, peas, potatoes, radishes, and other row crops. Asters, phlox, gladioli, and dahlias are some of the herbaceous ornamentals that can become infested by wireworms.

Wireworms feed on the seed, the developing seed leaves, and the young seedling, which results in reduced germination, snakehead seedlings, and wilted or stunted plants. Wireworms feed on the developing carrots directly, causing yield loss, and provide entry points for pathogens that cause secondary rots.

Wireworms have an extended life cycle, taking from 1 to 6 years to complete one generation. They overwinter as either adults or larvae. Adult females may live 10 to 12 months, spending most of this time in the soil where they might lay up to 100 eggs in sod and grassy weeds in row crops. Eggs hatch into tiny larvae that feed on the roots of grasses, weeds, and other crops. The larvae of some species will feed for two to three years before pupating. Because of the long egg-laying period, overlapping generations and larvae of different sizes are generally present.

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Wireworms are thin, shiny, jointed, hard-bodied, yellow to reddish-brown, wormlike larvae. They range in length from ¼ to 1 ½ inches.

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Adult wireworms are hard-shelled, brown or black beetles that right themselves from an overturned position with a clicking sound. Adults prefer to lay eggs in grassy areas, including grain crop fields, mixed pastures, old fields, and sometimes potatoe fields.

Scouting: Dead spots or wilted plants scattered throughout a planting may indicate wireworm activity. If you suspect wireworm damage, dig up ungerminated seeds or damaged plants along with a core of surrounding soil. Check for wireworms and signs of feeding in and around the roots, or in the underground portion of stems.

Bait stations are another way to check for wireworm larvae. A station is a hole, approximately 6 inches deep, in which a cupful of wheat and corn is placed and then covered. To determine if wireworms are present before planting, place 4 to 5 bait stations in the field 4 to 5 weeks before planting. Dig up the bait station after a few weeks and check for the presence of wireworm larvae.

Threshold: No thresholds have been established for wireworms.

Management Strategies

Cultural control

- If possible, avoid areas with a history of wireworm problems.
- Rotate crops.
- Avoid poorly drained fields.
- Plant when the soil is warm.
- Clean summer fallowing of infested fields can reduce populations.
- Plow in crop debris after harvest.

Biological control

- Several natural enemies have been described, but their effect on wireworm populations is not known.

Chemical control

- Insecticides registered for wireworm control are rarely recommended since outbreaks are infrequent. If treatment is necessary or if an area has a history of soil insect problems (wireworms, mole crickets, cutworms) apply an insecticide at the time of planting. Refer to A3422 *Commercial Vegetable Production in Wisconsin* for currently labeled products.

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